FINAL

Roanoke River PCB TMDL Development (Virginia)

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Prepared by:

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for impaired waterbodies. A TMDL establishes the amount of a pollutant that a waterbody can assimilate without exceeding its water quality standard for that pollutant. TMDLs provide the scientific basis for a state to establish water quality-based controls to reduce pollution from both point sources and nonpoint sources to restore and maintain the quality of the state's water resources.

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. The TMDL components are illustrated using the following equation:

$$\text{TMDL} = \sum WLAs + \sum LAs + MOS$$

The objective of the Roanoke River PCB TMDL study is to identify the sources of Polychlorinated Biphenyl (PCB) contamination in the watershed and determine the reductions in pollutant loadings necessary to achieve the applicable water quality standards. The TMDL study drainage area is approximately 2,379 square miles and includes two sections of the Roanoke River watershed—from its headwaters downstream to Niagra Dam (upper Roanoke) and from Leesville Dam downstream to its confluence with the Dan River [lower Roanoke (Staunton)]. The mainstem lengths of the upper and lower sections of the river are approximately 29 and 96 miles, respectively, and run through several Virginia counties, including Montgomery, Roanoke, Bedford, Franklin, Campbell, Pittsylvania, Charlotte, and Halifax.

The impairment listings for stream and reservoir segments in the study area are based on the historical fish tissue and sediment monitoring data record. This TMDL study was designed to address select PCB impairments included on Virginia's 1998 303(d) list. More recent monitoring studies have resulted in the listing of additional PCB-impaired stream and reservoir segments in the watershed, including updates on Virginia's 2008 303(d) list (Table ES-1) and a forthcoming violation listing (2010) of the public water supply use. The framework developed for these TMDLs does not include allocations for impaired segments outside of the study watersheds described above. It does include allocations for all stream segments in the study area, however, and if no other significant sources of PCBs are found, it can be assumed that these TMDLs will significantly improve the more recent PCB impairment listings, as well.

Table ES-1. 2008 303(d) PCB impaired segments

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID
Roanoke River	Near Dixie Caverns – Mason Creek confluence	Roanoke, City of Salem, City of Roanoke	12.88 miles	2002	L12L-01-PCB
Roanoke River	Mason Creek confluence – Back Creek mouth	City of Salem, City of Roanoke	15.47 miles	1996	
Peters Creek	Peters Creek headwaters – Roanoke River confluence	Roanoke, City of Roanoke	7.17 miles	2004	
Tinker Creek	Deer Branch confluence – Roanoke River confluence	Roanoke, City of Roanoke	5.35 miles	2006	
Smith Mountain Lake[a]	Back Creek mouth – Smith Mountain Lake Dam (includes Blackwater arm up to Rt. 122 bridge)	Bedford, Franklin	17,157 acres	2002	

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID
Blackwater River[a]	Maggodee Creek confluence – Blackwater River arm of Smith Mountain Lake	Franklin	11.43 miles	2006	
Staunton (Roanoke) River	Leesville Dam – Pipeline crossing 5.4 miles downstream of Rt. 360 bridge	Charlotte, Halifax, Campbell, Pittsylvania	83.9 miles	1998	L19R-01-PCB
Staunton (Roanoke) River	Pipeline crossing 5.4 miles downstream of Rt. 360 bridge – Kerr Reservoir	Halifax, Charlotte	4.49 miles	1998	
Cub Creek	Rough Creek Rd. – Roanoke River confluence	Charlotte	14.25 miles	2008	
Little Otter River	West of Rt. 680 at Cobbs Mountain – mouth of the Little Otter River on the Big Otter River	Bedford	14.36 miles	2002	L26R-01-PCB

a. These segments are not included in the TMDL study area
b. Source: http://www.deq.state.va.us/wqa/ir2008.html

TMDL reductions were calculated on the basis of meeting water quality targets in the upper and lower sections of the Roanoke (Staunton). Water quality targets were derived from Bioaccumulation Factors (BAF) and the Virginia Department of Environmental Quality (VADEQ) fish tissue criterion for total PCBs (tPCBs). BAFs allow for the back-calculation of a water concentration equivalent from a fish tissue concentration, in this case a threshold level of 54 parts per billion (ppb). Two endpoints were developed corresponding to the upper [390 picograms per liter (pg/L)] and lower (140 pg/L) sections of the Roanoke (Staunton) River basin on the basis of the available water quality and fish tissue monitoring data. The decision to evaluate the upper and lower sections separately was made because of the large reservoirs that separate them and the differences in the magnitude and composition of PCB contamination.

The TMDL endpoints have been developed to be protective of fish for human consumption and are more stringent than the 1,700 pg/L state criterion for human health. The human health criterion applies to waterbodies used for public water supply, in addition to all other surface waters. The TMDL endpoints, therefore, are more than adequate to protect the water supply use and address the forth coming violation listing (2010) of the public water supply use in the Roanoke River watershed.

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements was developed, calibrated, and validated for the Roanoke River study watershed. LSPC is a dynamic watershed model that generates precipitation-driven simulation of time-variable flow and water quality. The LSPC model was configured to simulate PCBs in both the dissolved- and sediment-associated states. Sediment-associated PCB loading and in-stream transport, deposition, burial and resuspension processes, along with partitioning of PCBs in the water and sediment layer were incorporated into the model simulations. A summary of the TMDLs, LAs, and WLAs developed for streams in the Roanoke River watershed is presented in Table ES-2. Streams listed as impaired for PCBs on Virginia's 2008 303(d) list are identified by their associated list ID. A summary of the TMDLs, LAs, and WLAs by source category is presented in Table ES-3.

Table ES-2. Average annual tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	4,923.2	28.2	630.3	34.7	693.2	85.9
South Fork Roanoke River	Not listed	3,532.2	230.2	788.6	53.6	1,072.5	69.6
Masons Creek	Not listed	1,777.5	9.1	193.2	10.6	212.9	88.0

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Peters Creek	L12L-01-PCB	1,742.6	65.4	31.2	5.1	101.7	94.2
Tinker Creek	L12L-01-PCB	16,593.6	103.9	3,414.2	185.2	3,703.2	77.7
Wolf Creek	Not listed	1,078.4	10.0	20.3	1.6	31.9	97.0
Unnamed Trib to Roanoke River	Not listed	59.4	0.5	1.3	0.1	1.9	96.8
Roanoke River	L12L-01-PCB	133,207.2	28,157.7	3,455.7	1,663.9	33,277.3	75.0
Upper Total		**162,914.1**	**28,605.0**	**8,534.8**	**1,954.7**	**39,094.5**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	5,400.9	0.1	1,812.4	95.4	1,907.9	64.7
Sycamore Creek	Not listed	93,226.4	1.4	186.3	9.9	197.6	99.8
Lynch Creek	Not listed	7,670.6	0.1	17.8	0.9	18.8	99.8
Reed Creek	Not listed	253.4	0.0	75.9	4.0	79.9	68.5
X-trib	Not listed	215,127.2	0.1	1.3	0.1	1.5	100.0
Unnamed Trib to Roanoke River	Not listed	12,848.6	0.1	19.1	1.0	20.2	99.8
Little Otter River	L26R-01-PCB	3,934.3	0.0	596.2	31.4	627.6	84.0
Big Otter River	Not listed	7,630.9	0.0	2,462.8	129.6	2,592.4	66.0
Straightstone Creek	Not listed	464.8	0.0	279.0	14.7	293.7	36.8
Seneca Creek	Not listed	692.9	0.0	400.8	21.1	421.9	39.1
Whipping Creek	Not listed	398.4	0.0	157.7	8.3	166.0	58.3
Falling River	Not listed	4,135.2	0.0	1,746.5	91.9	1,838.4	55.5
Childrey Creek	Not listed	390.2	0.0	201.3	10.6	211.9	45.7
Catawba Creek	Not listed	168.8	0.0	94.8	5.0	99.8	40.9
Turnip Creek	Not listed	376.2	0.0	272.6	14.3	286.9	23.7
Hunting Creek	Not listed	86.6	0.0	65.2	3.4	68.6	20.7
Cub Creek	L19R-01-PCB	1,376.7	0.0	997.4	52.5	1,049.9	23.7
Black Walnut Creek	Not listed	181.9	0.8	46.5	2.5	49.7	72.7
Roanoke Creek	Not listed	2,446.8	0.0	1,429.6	75.2	1,504.8	38.5
Difficult Creek	Not listed	823.2	0.0	462.1	24.3	486.5	40.9
Roanoke River	L19R-01-PCB	239,207.9	1,931.8	11,961.7	731.2	14,624.8	93.9
Lower Total		**596,841.9**	**1,934.3**	**23,287.0**	**1,327.4**	**26,548.8**	**95.6**

Table ES-3. Average annual tPCBs TMDLs for Roanoke River source categories

Source Category	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	% Reduction[a]
Upper Roanoke River				
VPDES Dischargers	17,665.8	28,267.1		-60.0
Individual Industrial/General Permits	6,827.4	5.3		99.9
MS4	109,622.4	332.7		99.7
Contaminated Sites	7,853.5		1.0	100.0
Urban background (unknown sites)	12,082.4		114.4	99.1
Atmospheric Deposition	8,862.5		8,419.4	5.0
Total	**162,914.1**	**28,605.0**	**8,534.8**	**77.2**
Lower Roanoke (Staunton) River				
VPDES Dischargers	78,305.9	1,926.7		97.5

Source Category	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	% Reduction[a]
Individual Industrial/General Permits	388,012.2	7.5		100.0
MS4	11.7	0.1		99.3
Contaminated Sites	83,901.8		1.2	100.0
Urban background (unknown sites)	22,244.9		138.7	99.4
Atmospheric Deposition	24,365.4		23,147.2	5.0
Total	**596,841.9**	**1,934.3**	**23,287.0**	**95.8**

a. WLA and LA percent reductions differ from TMDL percent reductions because they do not include an MOS load

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TABLES

FIGURES

1. INTRODUCTION AND BACKGROUND

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not supporting their designated uses even if pollutant sources have implemented technology-based controls. A TMDL establishes the maximum allowable pollutant load that a waterbody is able to assimilate and still achieve its designated use(s). The maximum allowable load is determined on the basis of the relationship between pollutant sources and in-stream water quality. A TMDL provides the scientific basis for a state to establish water quality-based controls to reduce pollution from both point sources and nonpoint sources to restore and maintain the quality of the state's water resources (USEPA 1991). The development of TMDLs requires an assessment of the waterbody's assimilative capacity, critical conditions, and other considerations.

Virginia's 2008 section 303(d) list classifies several waterbodies in the Roanoke River basin as impaired for Polychlorinated Biphenyls (PCB) from elevated PCB concentrations found in fish tissue and sediment samples. The Virginia Department of Environmental Quality (VADEQ) first collected monitoring data on PCB contamination in the basin in 1971. Regular fish tissue and sediment sampling for PCBs began in 1993, and a rotating basin monitoring schedule is ongoing as part of the Statewide Fish Tissue and Sediment monitoring program. The Virginia Department of Health (VDH) has issued fish consumption advisories for several sections of the Roanoke River and tributaries since 1998 on the basis of the fish tissue data collected by VADEQ.

Section 303(d) of the Clean Water Act requires states to develop TMDLs for waters that do not meet water quality standards. The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination in the watershed and to determine the reductions required to achieve water quality standards for PCB impaired segments.

PCBs are a group of synthetic chemicals that consist of 209 individual compounds (known as congeners). Physically, they are either oily liquids or solids and are colorless to light yellow in color with no known smell or taste. PCBs made in the United States were marketed under the trade name Aroclor and most are identified by a four-digit numbering code in which the first two digits indicate that the parent molecule is a biphenyl. Each of the 209 possible PCB compounds consists of two sigma bonded, chlorine substituted phenyl groups. Individual PCB congeners differ in the number and position of the chlorine substituents. PCBs possess excellent dielectric and flame-resistant properties derived from their stable molecular structure. These same properties cause PCBs to accumulate in the fatty tissue of biota and bioaccumulate in the food chain (http://www.epa.gov/ttn/atw/hlthef/polychlo.html).

Although it is now illegal to manufacture, distribute, or use PCBs, before 1974 they were used in numerous products including, capacitors, transformers, plasticizers, surface coatings, inks, adhesives, pesticide extenders, paints, carbonless duplicating paper, etc. After 1974, PCB use was restricted to producing capacitors and transformers, and in 1979 the manufacture and use of PCBs was completely banned. Historically, PCBs had been introduced into the environment through discharges from point sources and through spills and releases. Although point source contributions are now controlled, facilities could be unknowingly discharging PCB loads as a result of historical contamination. Sites with PCB-contaminated soils can also act as precipitation-driven nonpoint sources. In addition, the widespread use of PCBs before their ban coupled with their stable molecular structure has caused a generalized distribution of the pollutant in air, soil, and water at background concentrations. Once in a waterbody, PCBs become associated with sediment particles. PCBs are very resistant to breakdown and thus remain in river and lake sediments for many years.

PCB concentrations in environmental media tend be very small, particularly in water due to its hydrophobic properties. Throughout the remainder of this document the units presented in Table 1-1 are used to describe PCB concentrations in fish tissue, sediments, and water.

Table 1-1. Common PCB concentration units and abbreviations

Media	Unit	Unit abbreviation	Parts-per description	Part-per abbreviation
Fish tissue, sediment	micrograms per kilogram	µg/kg	parts per billion	ppb
Water	micrograms per liter	µg/L	parts per billion	ppb
	picograms per liter	pg/L	parts per quadrillion	ppq

1.1. Watershed Description

The Roanoke River watershed drains a largely rural area of the coastal plain from the eastern edge of the Appalachian Mountains in southern Virginia, southeast across the Piedmont to the Albemarle Sound in northeastern North Carolina. The drainage area of the Roanoke River from its headwaters to the Dan River confluence is approximately 3,343 square miles with a length of approximately 227 miles, spanning three physiographic provinces along its course.

Moving southeast from the headwaters, these include the Valley and Ridge, Blue Ridge, and Piedmont. The river also crosses through several Virginia counties—including Montgomery, Roanoke, Franklin, Bedford, Pittsylvania, Campbell, Halifax, and Charlotte—in addition to two reservoirs, Smith Mountain Lake and Leesville Lake. The major tributaries to the Roanoke River, in downstream order, are the North and South Fork Roanoke River, Mason Creek, Peters Creek, Tinker Creek, Back Creek, Falling Creek, Blackwater River, Pigg River, Goose Creek, Sycamore Creek, Lynch Creek, Big Otter River, Seneca Creek, Falling River, Catawba Creek, Turnip Creek, Cub Creek, Roanoke Creek, and Difficult Creek.

The TMDL study area includes two sections of the Virginia portion of the watershed beginning at the river headwaters in the Blue Ridge Mountains downstream to Niagra Dam about 1.5 miles east of the city of Roanoke (upper Roanoke) and from Leesville Dam downstream to its confluence with the Dan River at approximately river mile 46 [lower Roanoke (Staunton)] (Figure 1-1). For the remainder of this document when the Roanoke River watershed/basin is discussed, it is in reference to the TMDL study portion of the watershed. Figure 1-2 presents the general location and major streams and lakes of the Roanoke River watershed and the TMDL study area.

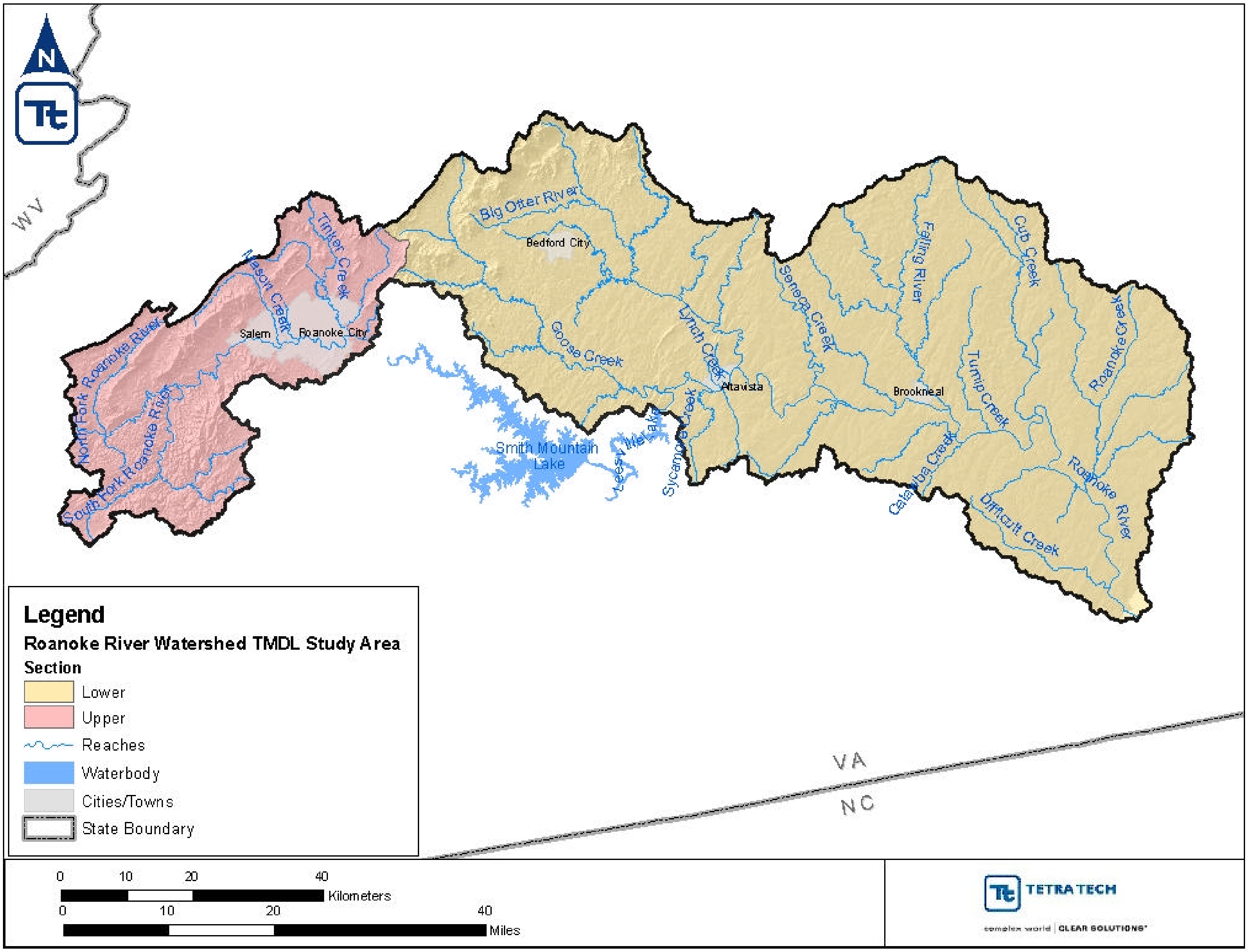

Figure 1-1. Roanoke River basin sections.

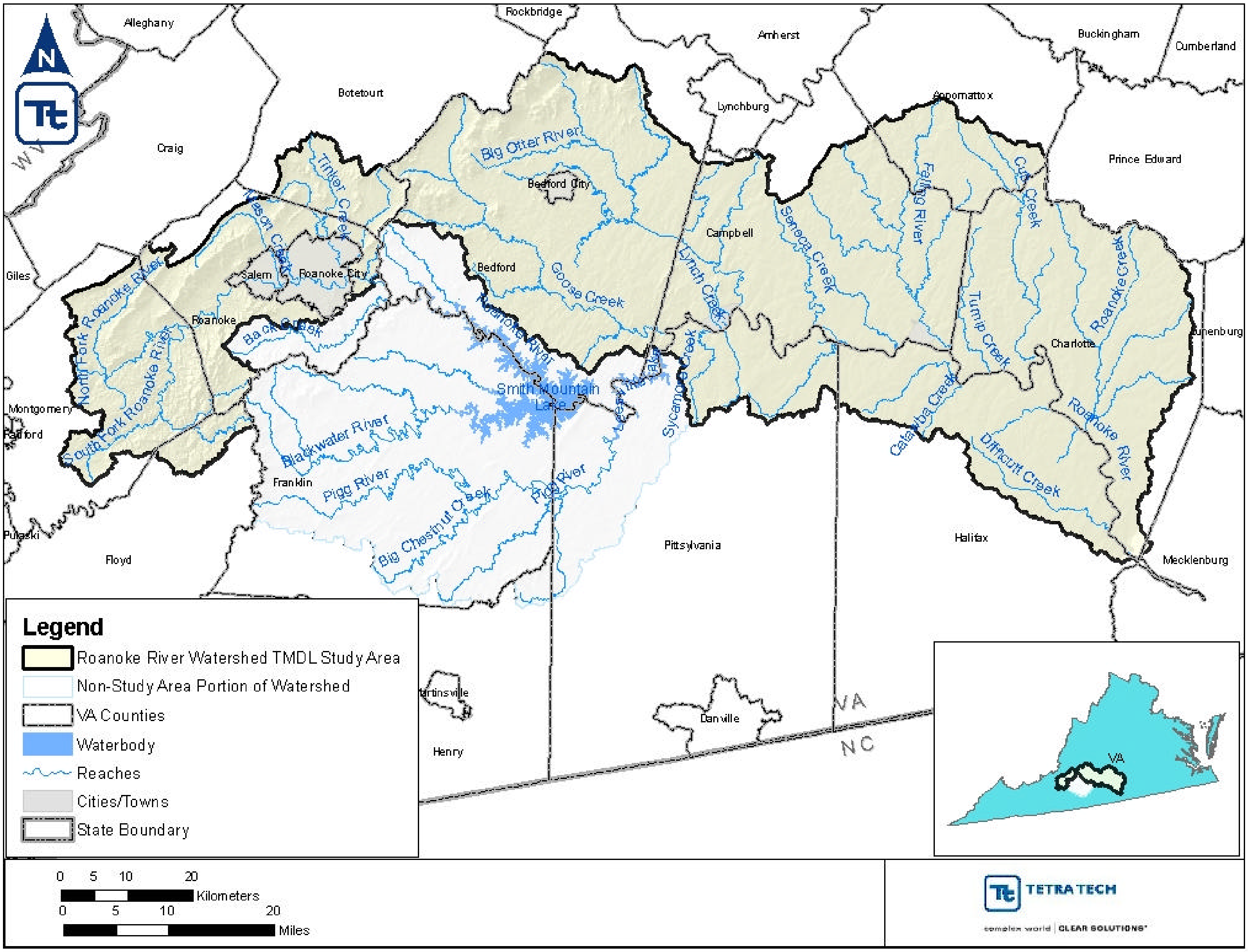

Figure 1-2. Location and major waterbodies of the Roanoke River basin.

1.2. Impaired Waterbodies

Impairment listings for stream and reservoir segments in the Roanoke basin are based on the historical monitoring data record. Investigation of PCB contamination in the watershed began in 1971 and continues today.

In 1971 the Virginia State Water Control Board (SWCB) conducted a study to determine the extent of pesticide contamination in Virginia waterbodies. As part of the study, elevated PCB concentrations were found in fish tissue samples collected from the Roanoke and Dan Rivers. These results were published in a 1973 report, *The Occurrence of Polychlorinated Biphenyls (PCBs) in the Roanoke and Dan Rivers, A Preliminary Report* (Wallmeyer 1973).

Between 1979 and 1991, the SWCB and EPA continued to monitor state waters, including fish tissue monitoring in the Roanoke River watershed. Fish samples collected in several segments of the river indicated a persistent presence of PCBs. In late 1992, the Virginia Department of Health (VDH) recommended collecting additional fish in the Roanoke basin to better characterize the extent of the contamination. SWCB conducted an extensive fish tissue study from February to August 1993 and issued a final report in June 1996 that concluded the occurrence of PCBs in resident fish species was widespread.

Under a Memorandum of Understanding between VADEQ and VDH, all fish tissue data generated by the Virginia Fish Tissue and Sediment Contaminants Monitoring Program are provided to VDH. VDH reviews the data and provides recommendations to VADEQ regarding the need for follow-up tissue studies and whether there is a potential unacceptable risk to human consumers. VDH uses a fish tissue contaminant screening level to determine potential risk. If fish tissue sample contaminant concentrations exceed the screening level, a fish consumption advisory is issued for the affected waterbodies. Where VDH issues a fishing ban or advisory, limiting consumption, the waterbody is designated as either partially or not supporting for fish consumption use based on the severity of the advisory. An advisory limiting fish consumption is considered partially supporting and an advisory prohibiting consumption is considered not supporting the fish consumption use (VADEQ n.d.).

The first PCB fish consumption advisory for basin waters was issued on July 24, 1998, for a segment of the Roanoke (Staunton) River beginning 29 miles below Leesville Dam and extending downstream to the Kerr Reservoir. The health advisory was issued on the basis of monitoring results from a 1998–1999 study that showed fish tissue PCB concentrations in the advisory area to be greater than the formerly applicable screening level of 600 parts per billion (ppb). On December 2, 1999, the fish consumption advisory was expanded to include the 29-mile segment upstream to the Leesville Dam.

On the basis of results of sampling studies conducted in 2000 and 2002, consumption advisories for the basin were expanded again on October 29, 2003 to include the segment of the Roanoke River from the Niagara Dam downstream to Smith Mountain Lake (Smith Mountain Lake segment). The most recent modifications (August 31, 2007) to the spatial extent of fish consumption advisories for the Roanoke River basin were a result of VDH adopting tiered screening levels that specify a *do not eat* PCB concentration threshold of 500 ppb and a limited consumption (fewer than two 8 ounce meals a month) PCB concentration range between 50 and 500 ppb and additional monitoring efforts by the state. Stream segments in the basin under fish consumption advisories include the following:

- Roanoke River (upper section): From the confluence of the North and South Forks of the Roanoke River (near the Lafayette gaging station) downstream to the Niagara dam, including tributaries Peters Creek upstream to the Route 460 bridge crossing, and Tinker Creek upstream to the confluence with Deer Branch (near Route 115).
- Roanoke River/Smith Mountain Lake: From the Niagara dam downstream to Smith Mountain Dam, including the Blackwater River arm of Smith Mountain Lake upstream to the Route 122 bridge.
- Roanoke (Staunton) River: From below Leesville Dam downstream to the confluence with Dan River including Cub Creek up to Rough Creek Road (State Route 695).

This TMDL study was designed to address select PCB impairments included on Virginia's 1998 303(d) list. The collection of additional fish tissue and sediment data since 1993 has resulted in a growing list of river and lake segments that are considered impaired for human health and aquatic life concerns, including updates on Virginia's 2008 303(d) list and a forthcoming violation listing (2010) of the public water supply use in the watershed. Table 1-2 and Figure 1-3 show the VADEQ 1998 and 2008 303(d) PCB impaired segments and the current VDH fish consumption advisory segments (as of August 31, 2007)

Table 1-2. 2008 303(d) PCB impaired segments and associated VDH fish consumption advisories

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID	VDH advisory[c]
Roanoke River	Near Dixie Caverns – Mason Creek confluence	Roanoke, City of Salem, City of Roanoke	12.88 miles	2002	L12L-01-PCB	Roanoke River (upper section)
Roanoke River	Mason Creek confluence – Back Creek mouth	City of Salem, City of Roanoke	15.47 miles	1996	L12L-01-PCB	Roanoke River (upper section)
Peters Creek	Peters Creek headwaters – Roanoke River confluence	Roanoke, City of Roanoke	7.17 miles	2004	L12L-01-PCB	Roanoke River (upper section)
Tinker Creek	Deer Branch confluence – Roanoke River confluence	Roanoke, City of Roanoke	5.35 miles	2006	L12L-01-PCB	Roanoke River (upper section)
Smith Mountain Lake[a]	Back Creek mouth – Smith Mountain Lake Dam (includes Blackwater arm up to Rt. 122 bridge)	Bedford, Franklin	17,157 acres	2002	L12L-01-PCB	Roanoke River/Smith Mountain Lake
Blackwater River[a]	Maggodee Creek confluence – Blackwater River arm of Smith Mountain Lake	Franklin	11.43 miles	2006	L12L-01-PCB	Roanoke River/Smith Mountain Lake
Staunton (Roanoke) River	Leesville Dam – Pipeline crossing 5.4 miles downstream of Rt. 360 bridge	Charlotte, Halifax, Campbell, Pittsylvania	83.9 miles	1998	L19R-01-PCB	Roanoke (Staunton) River
Staunton (Roanoke) River	Pipeline crossing 5.4 miles downstream of Rt. 360 bridge – Kerr Reservoir	Halifax, Charlotte	4.49 miles	1998	L19R-01-PCB	Roanoke (Staunton) River
Cub Creek	Rough Creek Rd. – Roanoke River confluence	Charlotte	14.25 miles	2008	L19R-01-PCB	Roanoke (Staunton) River
Little Otter River	West of Rt. 680 at Cobbs Mountain – mouth of the Little Otter River on the Big Otter River	Bedford	14.36 miles	2002	L26R-01-PCB	None

a. These segments are not included in the TMDL study area
b. Source: http://www.deq.state.va.us/wqa/ir2008.html
c. Source: http://www.vdh.state.va.us/epidemiology/DEE/publichealthtoxicology/advisories/RoanokeRiver.htm

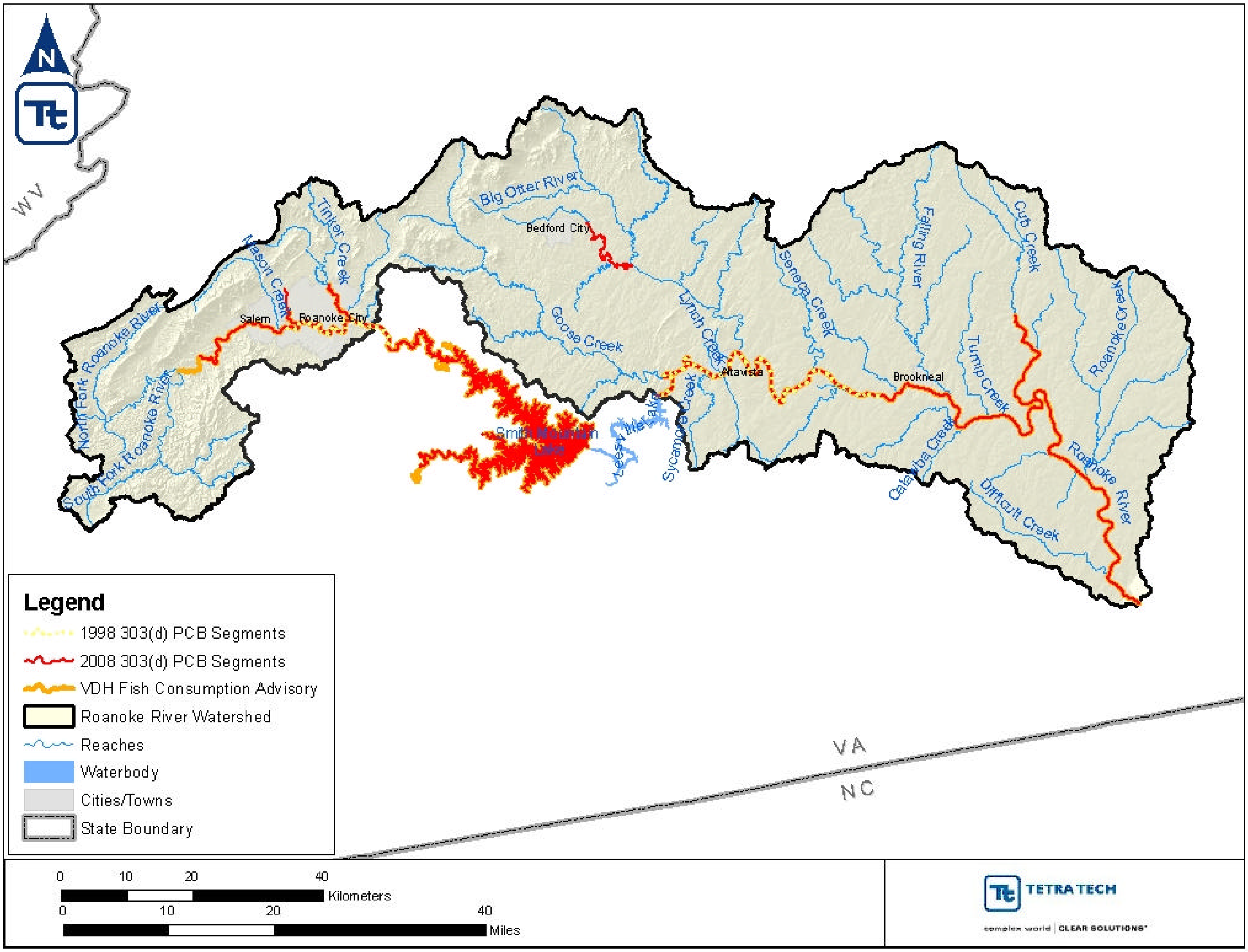

Figure 1-3. 1998 and 2008 303(d) PCB impaired segments and current fish consumption advisories.

1.3. Endangered Species Concerns

In addition to the human health concerns, there are concerns about the effects of PCB pollution on biota in the Roanoke River basin. The resident bald eagle population and the endangered Roanoke Logperch (*Percina rex*) have been identified by the Virginia Branch of the U.S. Fish and Wildlife Service (USFWS) as species that are potentially at risk from the effects of PCB contamination. The Roanoke Logperch is a federally endangered species that occurs only in the upper Roanoke drainage, Pigg River, Smith River, and larger tributaries. The Orangefin Madtom (*Nocturus gilberti*) is also found only locally and is listed as threatened in Virginia and as a species of special concern nationally.

1.4. Applicable Water Quality Standards

All surface waters in Virginia have the designated uses of contact recreation, propagation of fish and game, and production of edible and marketable natural resources (9 VAC 25-260-10). Virginia's water quality standards for the maintenance of designated uses include numeric Aroclor PCBs criteria for the protection of aquatic life and a total PCBs (tPCBs) criterion for the protection of human health (9 VAC-25-260-140.B). The state criteria are based on criteria developed by EPA as issued in its 1999 Final Rule: *Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance—Revision of Polychlorinated Biphenyls (PCBs) Criteria* (USEPA 1999).

The 1999 final rule is an update to the human health criterion and a restatement of the aquatic life criteria both established as part of the National Toxics Rule (NTR) issued in 1992. The reassessment used revised PCB cancer study results and information on environmental processes, representative classes of environmental PCB mixtures, and different exposure pathways to develop a range of cancer slope factors—0.07 per milligram per kilogram per day (mg/kg-d) (lowest risk and persistence) to 2.0 per mg/kg-d (high risk and persistence)—that indicate the potency of a cancer-causing chemical. EPA determined that the major pathway of human exposure to PCBs is fish consumption and that bioaccumulated PCBs are the most toxic. As a result, the upper-bound cancer slope factor (2.0 per mg/kg-d) was selected to develop the 1999 human health criterion. The EPA criterion incorporates a bioconcentration factor (BCF) to account for the uptake and accumulation of PCBs in fish tissues from contaminated waters.

VADEQ has also developed a numeric criterion for tPCBs concentrations in fish tissue [54 micrograms per kilogram (µg/kg)]. Called a screening value (SV), it was developed using the same toxicological, exposure, and risk data used to develop the human health PCB criterion. The SV represents the fish tissue concentration that the Virginia water quality criterion is designed to protect and is considered by VADEQ to be its fish tissue concentration equivalent (VADEQ n.d.).

The hydrophobic properties of PCBs make them difficult to detect in water quality samples. As a result, VADEQ uses fish tissue monitoring data as a surrogate to determine whether a waterbody is attaining the human health PCB criterion. If a fish tissue composite sample exceeds the SV, the water is classified as threatened for fish consumption. Fish containing a contaminant at or below the screening value concentration are considered to pose minimal risk to the average consumer. Related VDH fish consumption advisory guidelines specify a *do not eat* PCB concentration threshold of 500 ppb and a limited consumption (not more than 2 meals a month) PCB concentration range between 50 and 500 ppb. Advisories limiting and prohibiting fish consumption define waters as not supporting the fish consumption use (VADEQ, 2008.).

VADEQ uses sediment PCB contamination data to assess the likelihood of an observed effect on aquatic life. Sediment monitoring data are compared to the Probable Effects Concentration (PEC) SV for sediment (MacDonald et al. 2000). This SV is considered to be protective of aquatic organisms exposed to PCBs in the sediment.

PCBs also have the potential to affect non-aquatic wildlife that consume contaminated fish. The USFWS conducted a study in the summer of 2003 to determine the acceptable concentration of PCBs in bald eagle eggs and forage fish (Kane 2004). The reported No Observed Adverse Effect Level (NOAEL) for bald eagles eggs was a tPCBs concentration of 40.0 µg/kg (wet weight). The World Health Organization (WHO) defines NOAEL "as the greatest concentration or amount of a chemical found by experiment or observation that causes no detectable adverse alteration of morphology, functional capacity, growth, development, or life span of the target." Considering potential bioaccumulation in the food chain, the acceptable tPCBs concentration in forage fish was calculated to be 4.52 µg/kg. This value represents the Total Dietary Concentration of PCBs in forage fish that would meet the above NOAEL. All PCB criteria and guidelines developed and adopted by regulatory agencies considered for use as the TMDL target are presented in Table 1-3.

Table 1-3. Applicable water quality, fish tissue, and sediment criteria/guidelines for PCBs

Agency	Criteria description	Pollutant	Aquatic life (ppb)	Human health (ppb)
			Chronic	
Water Column				
Virginia Department of Environmental Quality (VADEQ)	State water quality criteria[a]	PCB-1260	0.014	
		PCB-1254	0.014	
		PCB-1248	0.014	
		PCB-1242	0.014	
		PCB-1232	0.014	
		PCB-1221	0.014	
		PCB-1016	0.014	
		tPCBs		0.0017
Fish Tissue				
VADEQ	State screening value[b]	tPCBs		54
Virginia Department of Health (VDH)	Limited consumption threshold[b]	tPCBs		50–500
	Do not eat threshold[b]	tPCBs		> 500
U.S. Fish and Wildlife Service (USFWS)	No Observed Adverse Effects Level (NOAEL)[c]	tPCBs	4.5	
Sediment				
VADEQ	State screening value based on Probable Effects Concentration[d]	tPCBs	676	

a. Source: Virginia State Code 9 VAC-25-260-140.B
b. Source: (VADEQ n.d)
c. Source: (Kane 2004)
d. Source: (MacDonald et al. 2000)

1.5. Targeted Water Quality Goal

VADEQ assesses stream segments for PCB impairments through its fish tissue monitoring program. PCBs are hydrophobic and are thus difficult to detect in water quality samples. As a result, VADEQ uses fish tissue monitoring data as a surrogate to evaluate PCB water quality. The threshold fish tissue PCB concentration for designating a waterbody as impaired is based on toxicological, exposure, and risk data used to develop the numeric water column human health PCB criterion. The human health criterion includes a BCF component that takes into account the uptake and accumulation of PCBs in fish tissues from contaminated waters.

Development of the applicable human health criterion relied on guidance issued by EPA in 1980 (45 *Federal Register* [FR] 79347, November 28, 1980). However, in 1998 EPA proposed revisions to the methodology it uses to derive water quality criteria for human health (63 FR 43755, August 14, 1998) and issued revised guidance in a 2003 technical support document (USEPA 2003a). The revised methodology recommends the use of bioaccumulation factors (BAFs) in place of BCFs. Bioaccumulation considers multiple pathways of exposure to a contaminant (i.e., uptake from water, food, and sediments) as opposed to bioconcentration, which considers uptake from water only. This approach was also used in the development of PCB TMDLs for the tidal Potomac River (ICPRB, 2007).

The methods recommended by EPA were used to develop TMDL endpoints for the protection of human health specific to conditions in the Roanoke River basin employing analysis of the relationships between water column PCB concentrations and fish tissue concentrations. Water concentrations were related to fish tissue concentrations by calculating BAFs. BAFs allow for the back-calculation of a water concentration equivalent from a fish tissue concentration, in this case a threshold level of 54 ppb. BAFs were calculated for fish species for which requisite supporting data were available. A target species was selected from this group taking into account species of special concern to the basin stakeholders and relative BAF values with greater importance given to species with higher BAFs. A higher BAF results in a lower water concentration; therefore, the target species should be protective of all fish species with lower BAFs.

Watershed-section-specific BAF converted fish tissue concentrations are recommended for the TMDL target water quality criteria. Two endpoints were developed corresponding to the upper [390 picograms per liter (pg/L)] and lower (140 pg/L) sections of the Roanoke (Staunton) River basin on the basis of the available water quality and fish tissue monitoring data. The decision to evaluate the upper and lower sections separately was made because of the large reservoirs that separate them and the differences in the magnitude and composition of PCB contamination. The TMDL endpoints are more protective than the 1,700 pg/L state criterion for human health. The human health criterion applies to waterbodies used for public water supply, in addition to all other surface waters. The TMDL endpoints, therefore, are more than adequate to protect the water supply use and address the forth coming violation listing (2010) of the public water supply use in the Roanoke River watershed. The species used to derive the endpoints for the upper and lower sections of the Roanoke (Staunton) were carp and striped bass, respectively. The methods and results for calculating BAFs are described in Appendix A.

2. DATA INVENTORY AND ANALYSIS

TMDL development requires a complete review of existing data to characterize the extent of pollutant contamination and sources in the watershed. Data from numerous sources were used to characterize the watershed and water quality conditions, identify pollutant sources, and support the calculation of PCB TMDLs for the Roanoke River watershed. The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and on-going source investigation whereby sources of PCB contamination are continuously being reviewed and updated based on the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of these TMDLs, rather than a complete and final characterization.

2.1. General Data Inventory

The following inventories include physical and monitoring data used to characterize general conditions in the Roanoke River watershed as they relate to the development of PCB TMDLs within the framework of the technical approach. For discussion of the context in which each is incorporated into the technical approach, see Section 5.0 and Appendix G.

2.1.1. Land Use

Land use information for the Roanoke River basin is shown in Table 2-1 and Figure 2-1. Estimates of land use areas in the watershed were derived from the 2001 Multi-Resolution Land Characteristics (MRLC 2001) Consortium's National Land Cover Dataset (NLCD) developed by the U.S. Geological Survey (USGS). The NLCD was derived from satellite imagery taken circa 2001 and is the most current, detailed land use data available for the study area. Each 30-meter by 30-meter pixel in the satellite image is classified according to its reflective characteristics.

Both sections of the Roanoke (Staunton) watershed are predominantly forested with 64 and 63 percent of land area for the upper and lower classified as such, respectively. The cities of Salem and Roanoke are the largest population centers in the watershed and are in the upper segment. Consequently, though it has the smaller land area, the upper Roanoke has a larger area of urban land uses (49,431 acres). Further downstream, the watershed becomes largely pastoral with land cover in the lower segment 24 percent pasture or grassland compared with 11 percent in the upper segment. Cultivated crops and wetlands make up a small portion of the upper and lower watershed area at less than 2 percent each in both sections.

Table 2-1. 2001 NLCD land use distribution in the Roanoke River basin

Detailed land use description	Group land use description	Upper land use area (acre)			Lower land use area (acre)		
		Detailed	Grouped	Grouped %	Detailed	Grouped	Grouped %
Open Water	Water/Wetland	1,100			6,051		
Woody Wetlands		27			21,005		
Herbaceous Wetlands		60	1,187	0.3	487	27,543	1.9
Pasture/Hay	Pasture	36,823			308,084		
Grassland		15	36,838	11.3	26,726	334,810	24.4
Row Crops	Cropland	2,048	2,048	0.6	14,125	14,125	1.1
Deciduous Forest	Forest	189,706			523,242		
Evergreen Forest		14,318			149,118		
Mixed Forest		5,199			51,915		
Shrub/Scrub		26	209,250	64.1	25,246	749,521	63.0
Barren Land	Other	99			2,932		
Developed, Open Space		27,482	27,582	8.5	49,233	52,165	5.2
Developed, Low Intensity	Developed	34,303			15,263		
Developed, Medium Intensity		11,050			2,146		
Developed, High Intensity		4,078	49,431	15.1	731	18,140	4.4
Total		**326,336**		**100.0**	**1,196,304**		**100.0**

Source: (MRLC 2001)

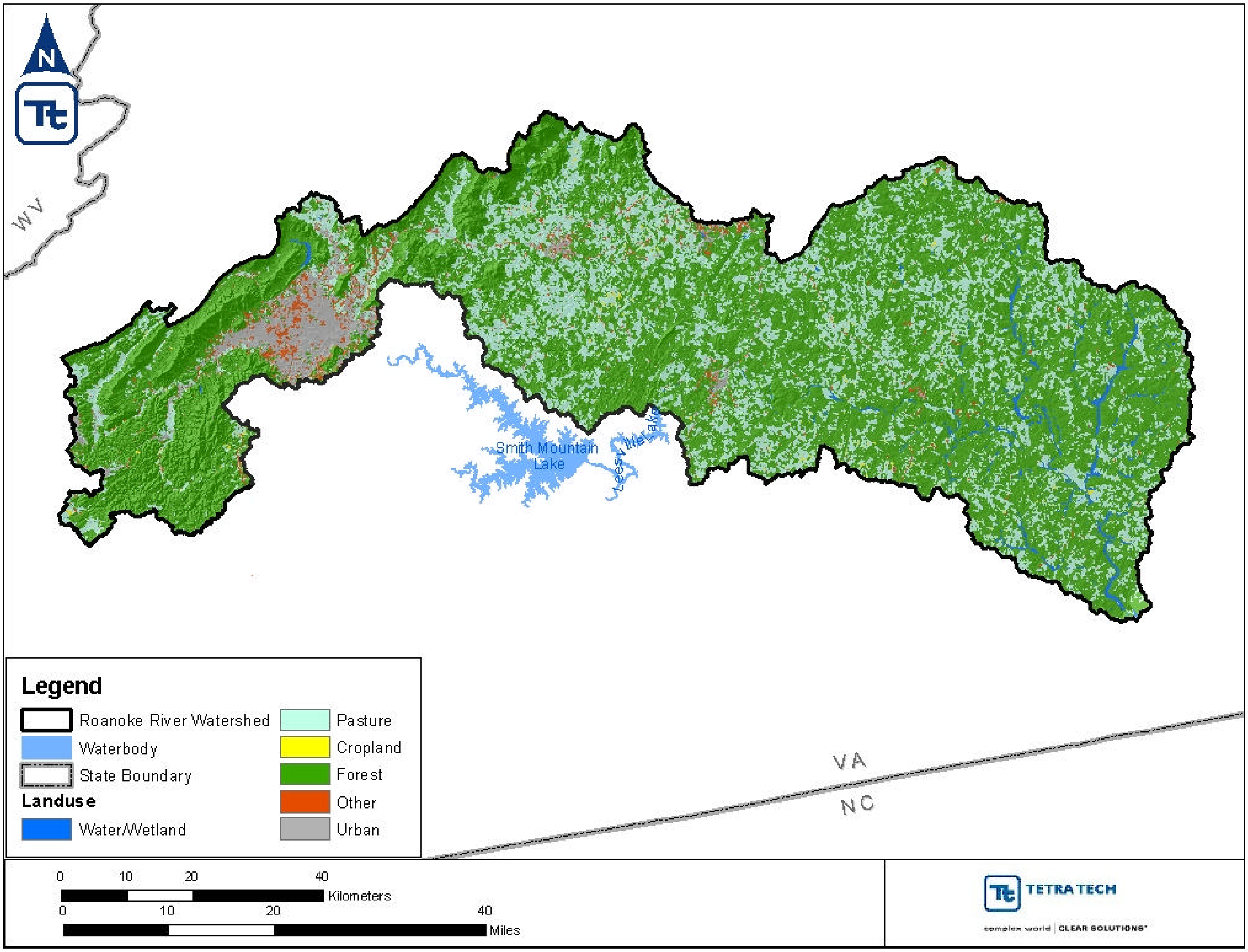

Figure 2-1. Land use in the Roanoke River basin (MRLC 2001).

2.1.2. Soils

Soils data developed by the Natural Resources Conservation Service (NRCS) were used to characterize soils in the Roanoke River basin. General soils data are available as map unit delineations for the United States provided as part of the State Soil Geographic (STATSGO) database. The geographic information system (GIS) data coverages provide accurate locations for the soil map units at a scale of 1:250,000 (USDA 1995). A map unit is composed of several soil series having similar properties. Identification fields in the GIS coverage can be linked to a database that provides information on chemical and physical soil characteristics. Because multiple soil series characterize each soil map unit, a weighted sum of soil series parameters was calculated to describe the general properties of interest for each soil map unit.

Hydrologic Soil Group

Hydrologic soil classifications group soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS has defined four hydrologic groups for soils (Table 2-2) (USDA 1993). Figure 2-2 shows the distribution of hydrologic soil groups in the Roanoke River basin.

Table 2-2. NRCS hydrologic soil groups

Hydrologic soils group	Description
A	Soils with high infiltration rates. Usually deep, well drained sands or gravels. Little runoff
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Source: (USDA 1993)

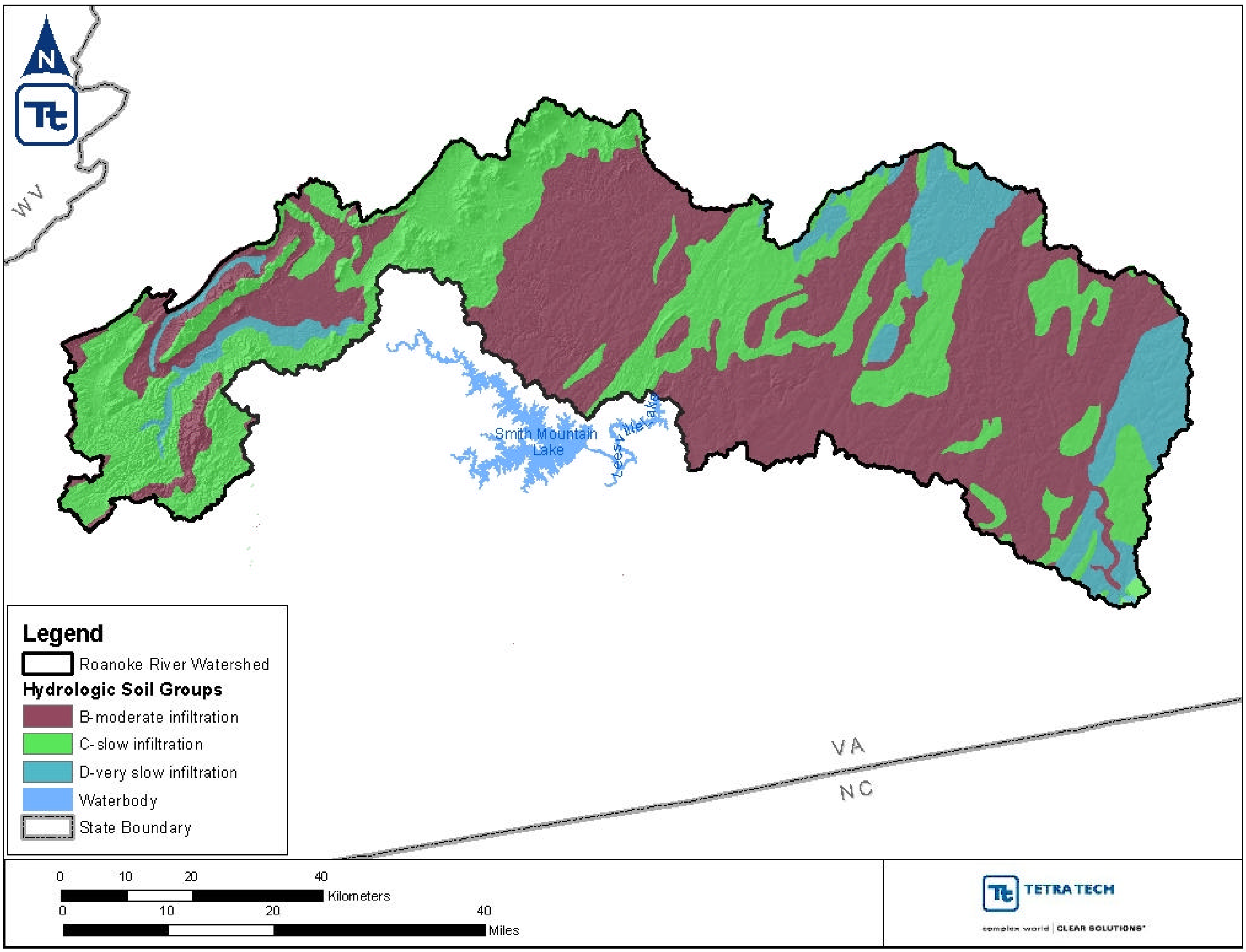

Figure 2-2. Hydrologic soil groups in the Roanoke River basin (USDA 1995).

2.1.3. Topography

Stream types, precipitation, and soil types can vary dramatically by elevation. The National Elevation Dataset (NED), developed by the USGS, was used to characterize the topography in the Roanoke River basin (USGS 2009). The NED consists of 30-meter grid resolution elevation data for the conterminous United States. Topography in the basin varies from the steep slopes and valleys in the Valley and Ridge Province to gently sloping terrain in the Piedmont Province. Figure 2-3 shows the elevation distribution in the watershed. Elevation ranges from 1,282 meters (4,206 feet) above mean sea level (AMSL) in the headwaters of Big Otter River to 85 meters (80 feet) AMSL at the Dan River confluence.

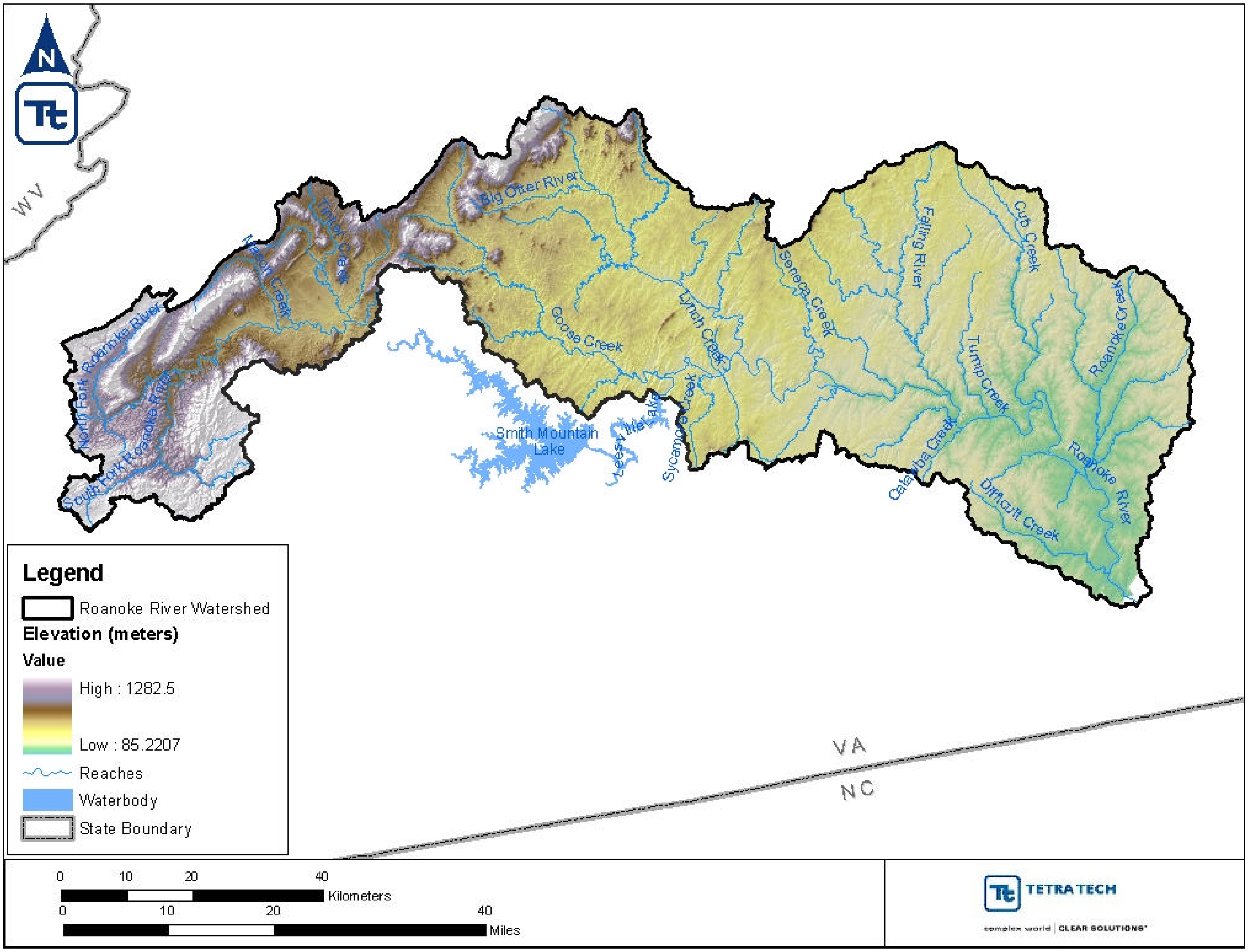

Figure 2-3. Elevation in the Roanoke River basin (USGS 2009).

2.1.4. USGS Stream Flow Gages

USGS flow gage data were compiled to characterize the hydrology of the Roanoke River and its major tributaries. Data of interest included daily average continuous stream flow data, which were obtained through the USGS National Water Information System. Stream gages with data available for the watershed are presented in Table 2-3 with associated statistics for period of record and percent completeness. Figure 2-3 presents the locations of gages in the watershed.

Table 2-3. USGS continuous stream flow gages in the Roanoke River basin

Site ID	Station name	Drainage area (square miles)	Period of record	% Complete
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1980-9/9/2006	100.0%
02054500	Roanoke River at Lafayette, VA	254	1/1/1980–9/9/2006	100.0%
02054510	Roanoke River near Wabun, VA	270	1/1/1995–9/9/1999	100.0%
02054530	Roanoke River at Glenvar, VA	281	1/1/1992–9/9/2006	99.9%
02055000	Roanoke River at Roanoke, VA	384	1/1/1980–9/9/2006	100.0%
02055100	Tinker Creek near Daleville, VA	11.7	1/1/1980–9/9/2006	99.9%
02056000	Roanoke River at Niagra, VA	509	1/1/1980–9/9/2006	100.0%
02059500	Goose Creek near Huddleston, VA	188	1/1/1980–9/9/2006	99.9%
02060500	Roanoke River at Altavista, VA	1,782	1/1/1980–9/9/2006	100.0%
02061500	Big Otter River near Evington, VA	315	1/1/1980–9/9/2006	99.9%
02062500	Roanoke (Staunton) River at Brookneal, VA	2,404	1/1/1980–9/9/2006	99.3%
02064000	Falling River near Naruna, VA	165	1/1/1980–9/9/2006	100.0%
02065500	Cub Creek at Phenix, VA	97.6	1/1/1980–9/9/2006	100.0%
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1980–9/9/2006	99.9%

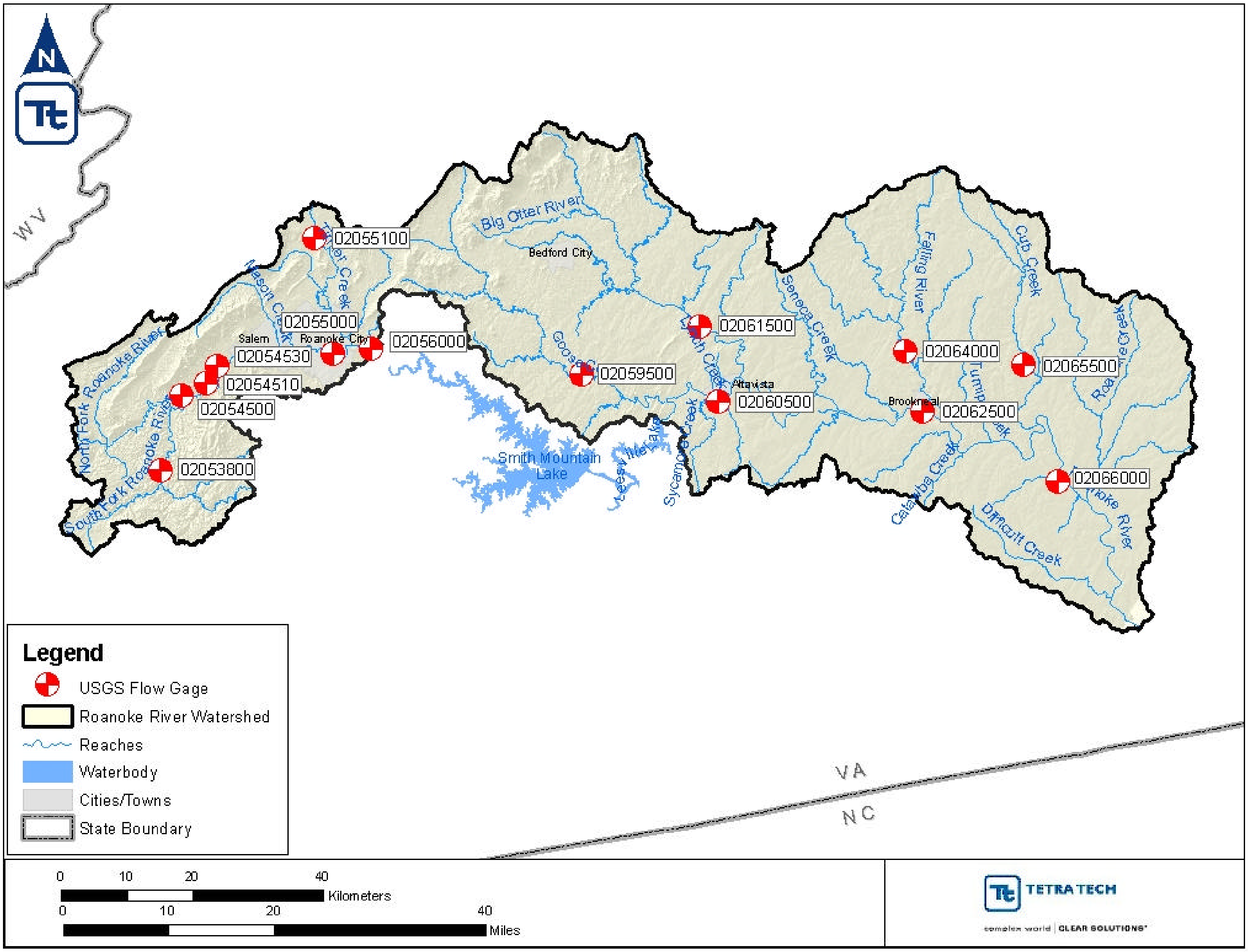

Figure 2-4. USGS continuous stream flow gages in the Roanoke River basin.

2.1.5. TSS Monitoring

VADEQ conducted total suspended solids (TSS) monitoring for waters in the Roanoke River watershed as part of VADEQ's Ambient Water Quality Monitoring Program (AWQMP) and various special studies. The primary function of the AWQMP is to provide data for the National Water Quality Inventory Report on the quality of state waters as required by section 305(b) of the Clean Water Act. From 1990 to 2008, 64 water quality stations were sampled for TSS in the Roanoke River basin (Figure 2-5). For a complete list of these stations and associated location descriptions and statistics, see Table B-4 in Appendix B. Note that the monitoring station IDs in Figure 2-5 follow a standard format. The first three letters identify the stream on which the station is located, followed by five digits specifying the river mile. A river mile identifies the station's distance from the mouth of the river measured along the route of the river.

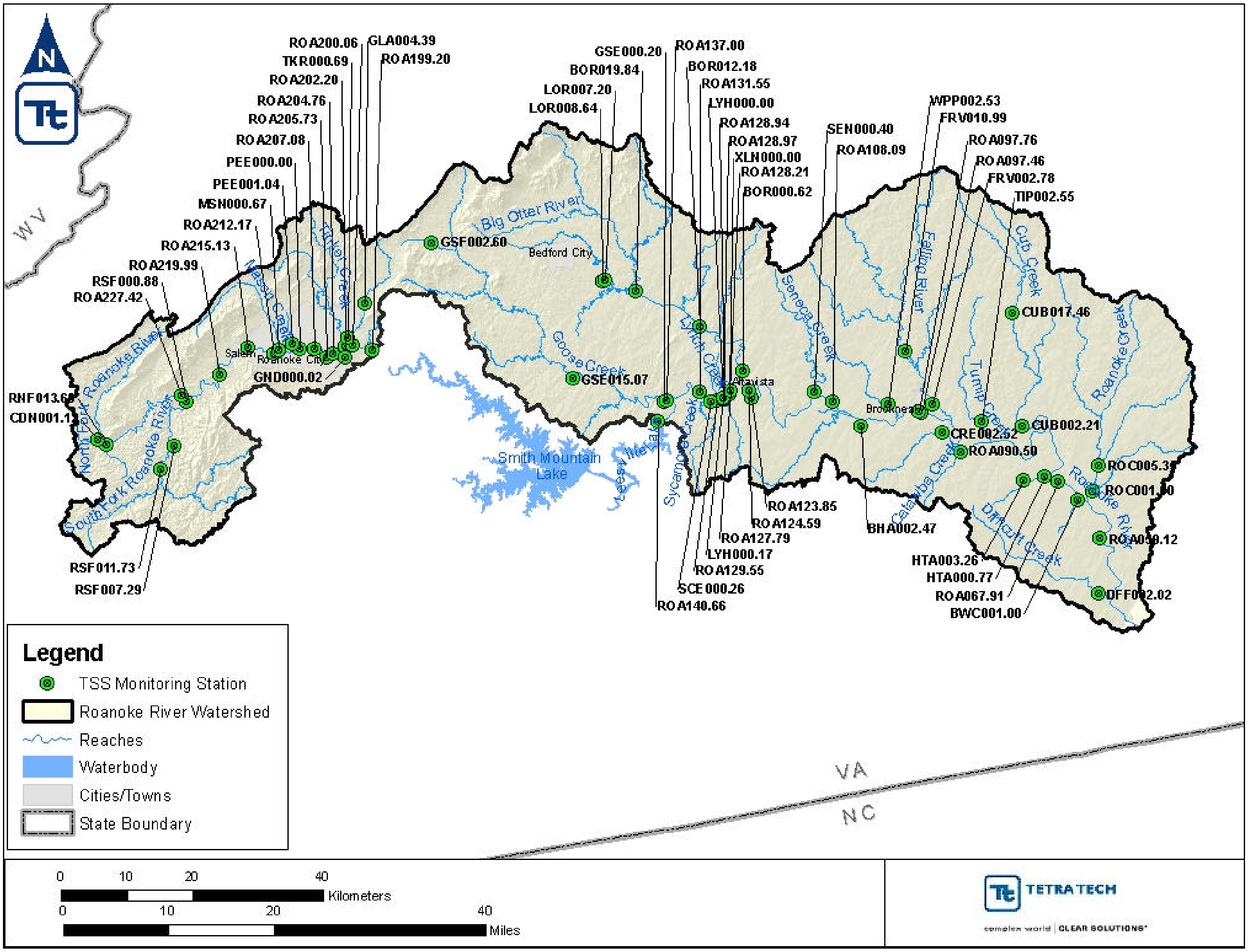

Figure 2-5. TSS monitoring stations in the Roanoke River basin.

2.2. PCB Monitoring Data Inventory

The following PCB data summary was developed on the basis of the fish tissue, sediment, and water quality monitoring data reviewed as part of TMDL development. Fish tissue PCB data collected in 1971 and presented in the 1973 report, *The Occurrence of Polychlorinated Biphenyls in the Roanoke and Dan Rivers—A Preliminary Report* (Wallmeyer 1973), are not included because of significant advances in analytical detection sensitivity since the 1970s. Ambient water quality monitoring conducted before 2006, though discussed, has also been excluded from the proceeding analysis because of concerns of background contamination and unknown analytical methods. Table 2-4 presents the available sources of PCB monitoring data for the Roanoke River basin.

To support TMDL development, additional PCB data were collected in fall 2005 through spring 2008 at selected monitoring locations in the watershed. Sampling included the use of semi-permeable membrane devices (SPMDs) and a high-resolution, low-detection level analysis method (1668A) to assess water column PCB concentrations, as well as effluent concentrations at selected facility outfalls. Details of the development of the 2005 special study are presented in the October 2005 *Sampling and Analysis Plan, Roanoke River Basin PCB TMDL Development (Virginia)* (Tetra Tech 2005).

Note that the monitoring station IDs in Figures 2-6 through 2-8 presented in Section 2.2.1 follow a standard format. The first three letters identify the stream on which the station is located, followed by five digits specifying the river mile. A river mile identifies the station's distance from the mouth of the river measured along the route of the river.

Table 2-4. PCB data sources for the Roanoke River basin

Data set	VADEQ data source	Period of record	Sample count
PCB water column data	Parameter specific data set submitted by VADEQ	1978–1996	40
PCB fish tissue data	Online data post	1993–2006	678
PCB sediment data	Online data post	1996–2008	127
Semi-permeable Membrane Devices	TMDL special study	2006	21
High Resolution Low Detection Level Analysis Method (1668a)	TMDL special study	2005–2008	59 water column, 12 effluent samples

2.2.1. PCB Monitoring Locations

VADEQ collects fish tissue and sediment samples as part of the Virginia Fish Tissue and Sediment Contaminants Monitoring Program. Under the program, data are collected to assess the human health risks for individuals who might consume fish from state waters and to identify impaired aquatic ecosystems. The sampling program is charged with monitoring every major watershed in Virginia at least once within a 2–3 year cycling period. In addition to *routine* samples taken as a part of the standard cycling period, monitoring at study sites can take place as part of the special Virginia Environmental Emergency Response Fund or in the case of a special request approved by VADEQ (VADEQ 2004).

From 1993 to 2008, 40 fish tissue and 108 sediment stations were sampled in the Roanoke River basin. Of these, 24 fish tissue and 56 sediment stations are on the Roanoke River mainstem (including the North and South Forks) with the remainder on tributaries. Fish tissue station locations are presented in Figure 2-6. Sediment station locations are presented in Figure 2-7a and 2-7b. Appendix B presents a summary of available fish tissue and sediment data, as well as station descriptions.

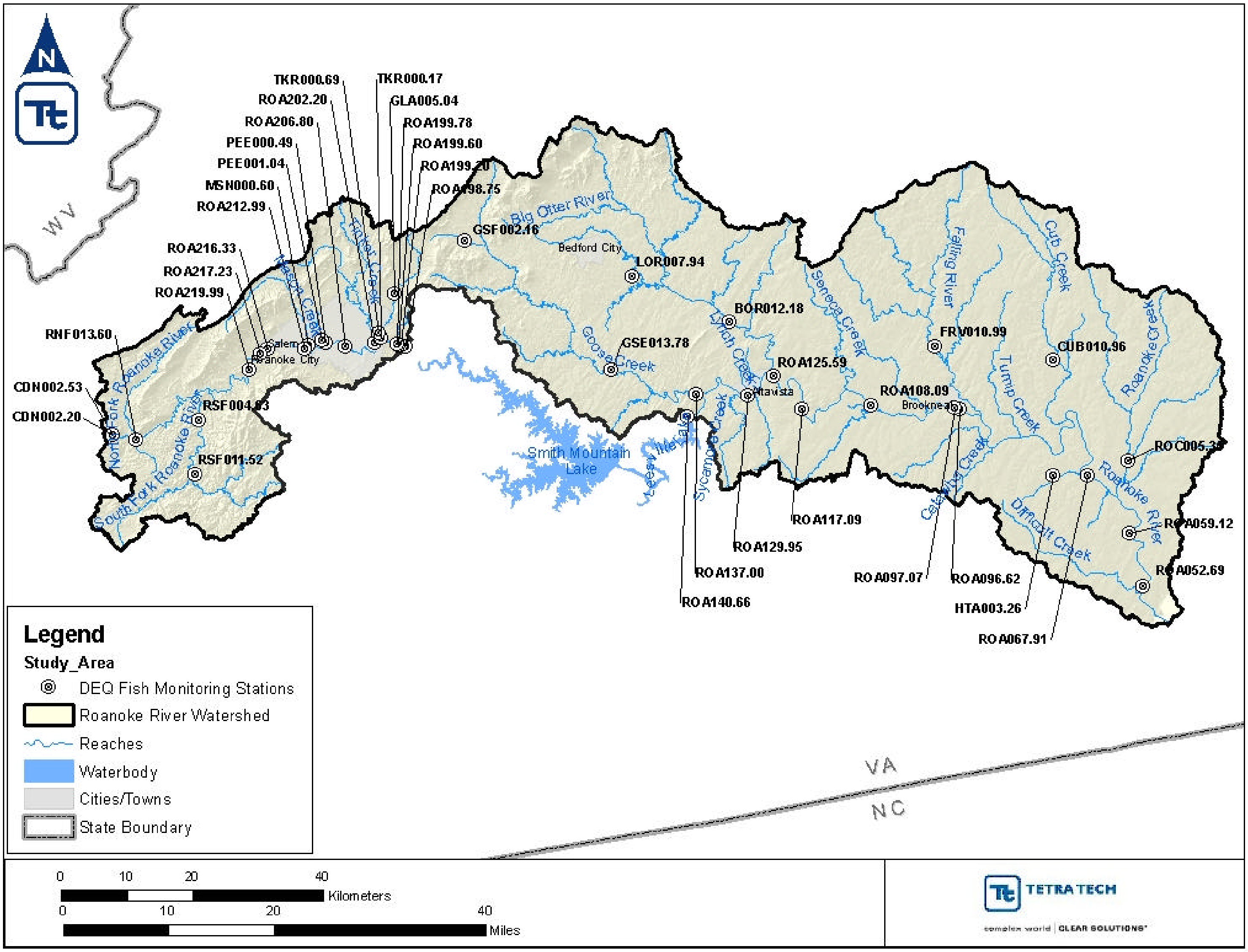

Figure 2-6. VADEQ fish tissue monitoring stations.

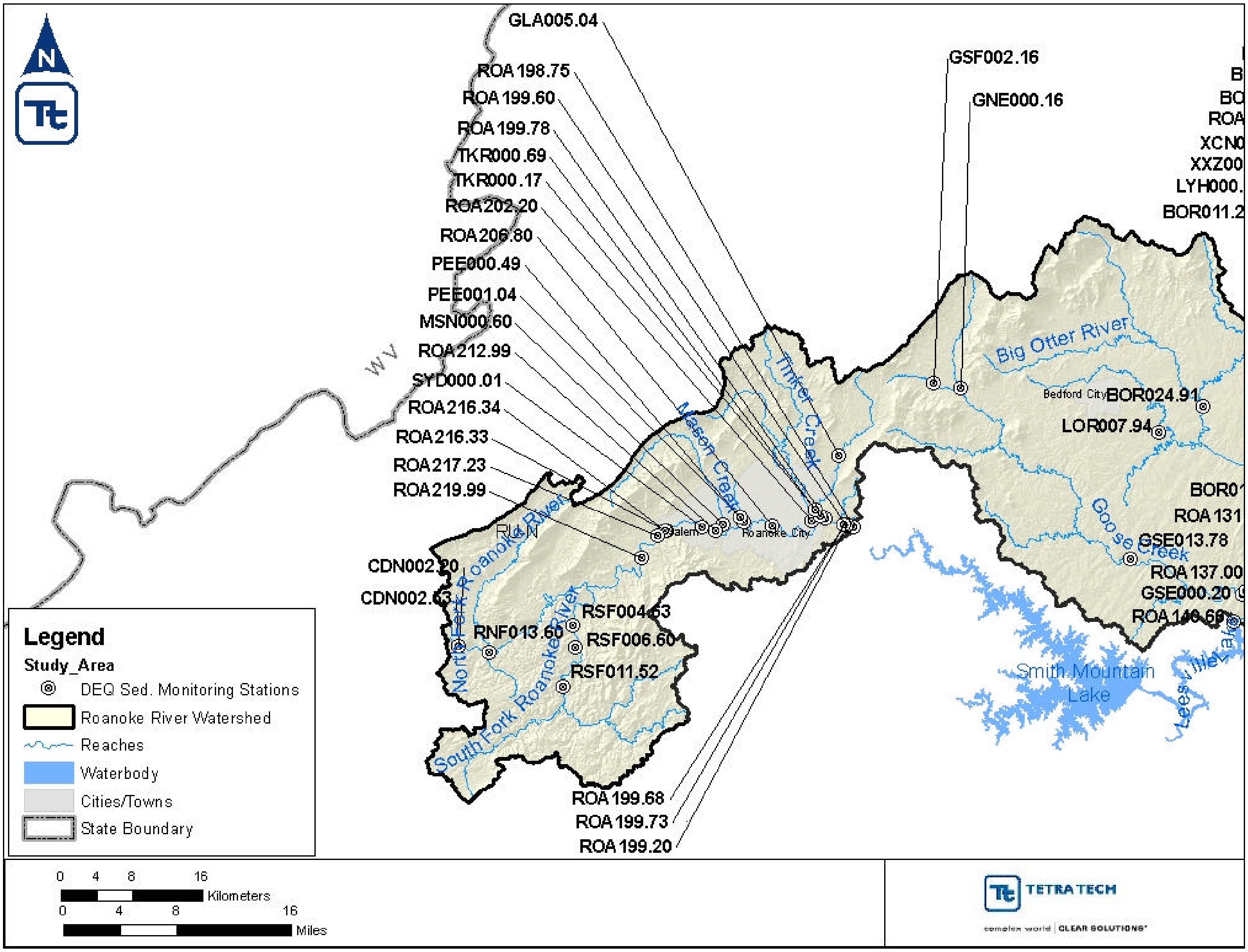

Figure 2-7a. VADEQ sediment monitoring stations-upper Roanoke.

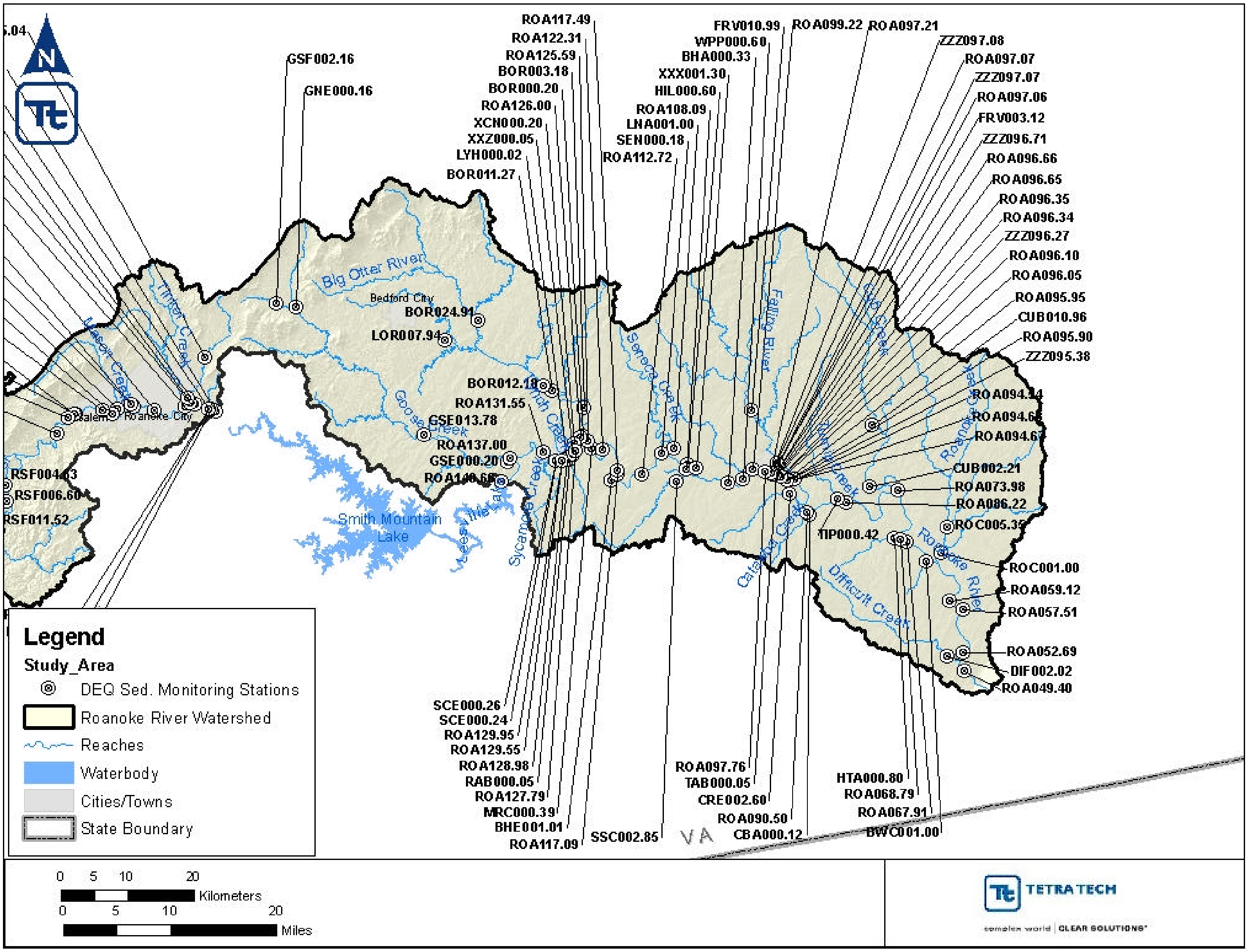

Figure 2-7b. VADEQ sediment monitoring stations-lower Roanoke (Staunton).

VADEQ collects water column samples as part of its AWQMP. The primary function of the AWQMP is to provide data for the National Water Quality Inventory Report on the quality of state waters as required by section 305(b) of the Clean Water Act. From 1978 to 1996, 21 water quality stations were sampled for PCBs in the Roanoke River basin. The analytical methods used to process samples during this period routinely failed to detect measurable concentrations of PCBs in contaminated waters because of their hydrophobic properties. A single record from the data set reported PCB concentrations above the detection limit. Because of the age and uncertainty associated with these data, they have been excluded from the analysis that follows.

A special study was conducted by VADEQ in the Roanoke River basin in fall 2005 through spring 2008 that included water column PCB monitoring. The special study was designed, in part, to augment the existing water quality record in support of TMDL development. Water quality samples were collected at low-flow and high-flow conditions at 29 monitoring locations throughout the watershed. The special study results were processed using a high-resolution, low-detection level analysis method (1668A) specifically to account for the hydrophobic properties of PCBs. The special study water quality station locations are shown in Figure 2-8, and the data summary and station descriptions are provided in Table B-3 in Appendix B.

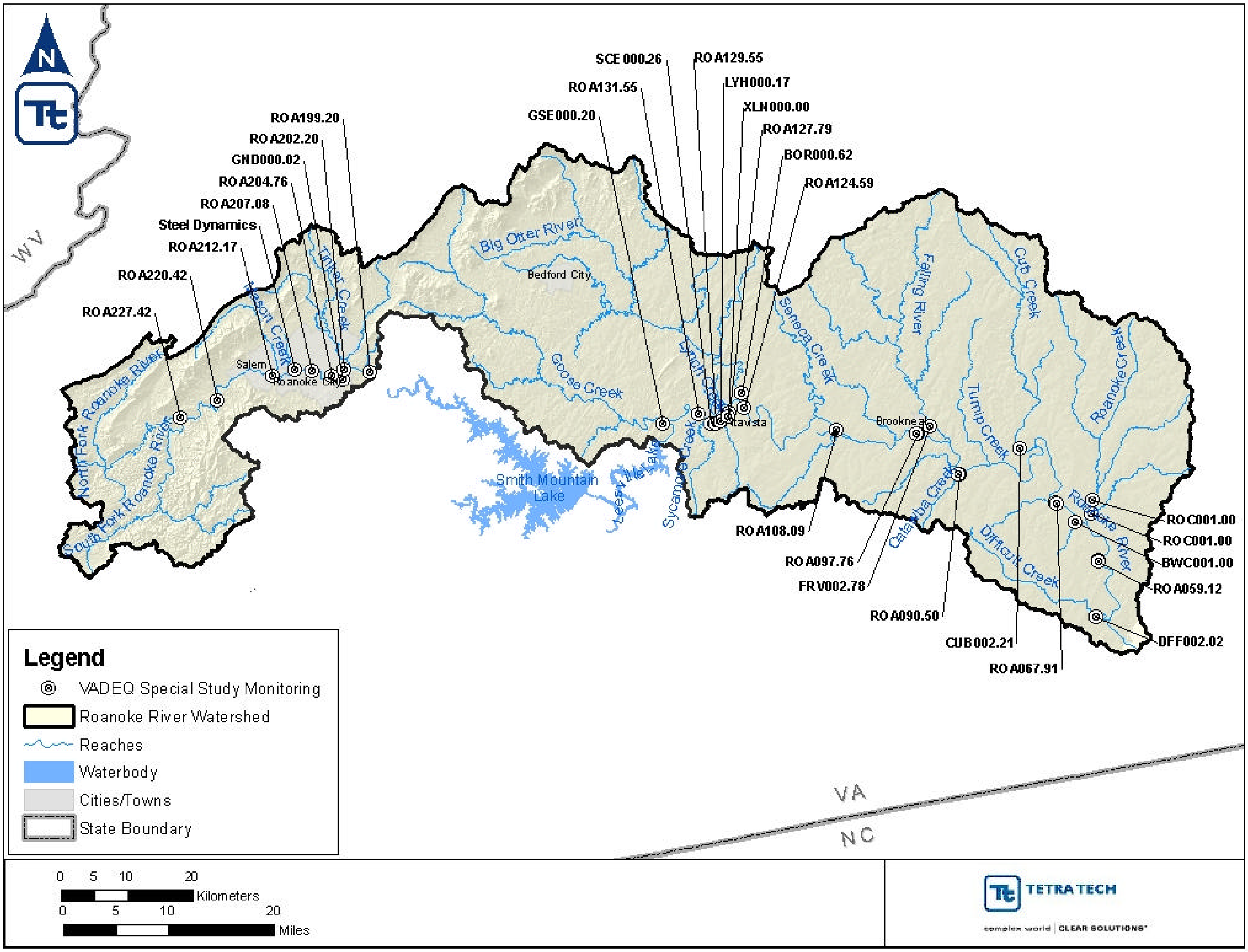

Figure 2-8. Special study water quality monitoring stations.

2.2.2. Fish Tissue and Sediment PCB Results

VADEQ collects and analyzes fish tissue and sediment samples under the Fish Tissue and Sediment Monitoring Program. Data collected in the Roanoke River basin were compiled and summarized to help identify spatial trends and help identify potential PCBs sources in the watershed. Note that the mobility and seasonal migration patterns of various fish species can limit the conclusions that can be drawn from analyzing the spatial distribution of PCB concentrations in fish tissue samples. The location of dams, tributaries, and other physical characteristics can influence the PCB signature in fish tissue samples. These and other factors are also considered in the analysis of sediment PCB data.

PCBs typically adsorb to sediment particles, which are transported into streams and rivers through erosion, stormwater runoff, and other processes. Although the in-stream transport of sediment can cause uncertainty as to the source of contamination, its movement is relatively predictable, and the presence of PCBs can be assumed to be an indicator of an upstream source (active or legacy). In lieu of reliable water column monitoring results, areas with high fish tissue and sediment concentrations provide the strongest evidence of local PCB contamination problems. The Roanoke River basin was divided into upper and lower sections for data analysis purposes as described in Section 1.1 and presented in Figure 1-2. Data analysis observations are noted at the end of this section.

Fish Tissue PCB Results

Figures 2-9 through 2-12 present the 25th–75th percentile, range, average, and median tPCBs concentrations of fish species collected at fish tissue monitoring stations summarized for the entire period of record (fish species abbreviations are presented in Table 2-5). The VADEQ fish tissue screening value (54 µg/L) is also provided to give a point of comparison between the figures. Monitoring results are grouped by watershed section and have been broken out into mainstem (North and South Fork Roanoke and Roanoke rivers) and tributary stations. Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river-mile code. Data summaries and location descriptions for fish tissue monitoring stations are presented in Appendix B.

Station IDs have been condensed for Figures 2-9 through 2-12 for the purpose of presentation. Station IDs differ from those presented in the map of fish tissue monitoring station locations (Figure 2-6) as follows:

- River miles are expressed at the highest significant digit, not as a standard five digits (eg. 56.1 vs. 056.10).
- With the exception of stations on the North and South Forks of the Roanoke (NF and SF), mainstem Roanoke monitoring stations are presented as the river mile only. The North and South Fork stations IDs begin with an NF and SF, respectively, followed by the river mile.
- Tributary monitoring stations are presented as the river mile first, followed by the three letter code for the waterbody on which the station is located. Waterbody codes and associated waterbody names are presented in Table 2-6.

Table 2-5. Fish species abbreviations

Fish abbreviation	Fish name	Fish abbreviation	Fish name
BC	black crappie	RES	redear sunfish
BJS	black jumprock sucker	RHS	redhorse sucker
BLC	blue catfish	RWD	riverweed darter
BGS	bluegill sunfish	RB	roanoke bass
BHC	bluehead chub	RD	roanoke darter
C	carp	RHG	roanoke hogsucker
CC	channel catfish	RB	rock bass
CHB	chub	SRS	shorthead redhorse sucker
FD	fantail darter	SMB	smallmouth bass
FHC	flathead catfish	SPB	spotted bass
GS	gizzard shad	STB	striped bass
GRS	golden redhorse sucker	SF	sunfish
GSF	green sunfish	WE	walleye
LMB	largemouth bass	WB	white bass
MM	margined madtom	WC	white crappie
MS	mixed sunfish species	WP	white perch
NHS	northern hogsucker	WS	white sucker
QCS	quillback carpsucker	YP	yellow perch
RBS	redbreast sunfish		

Table 2-6. Monitoring station waterbody ID codes

Station waterbody code	Waterbody name
BHA	Buffalo Creek
BHE	Beechtree Creek
BOR	Big Otter River
BWC	Black Walnut Creek
CBA	Catawba Creek
CDN	Cedar Run
CRE	Childrey Creek
CUB	Cub Creek
DIF	Difficult Creek
FRV	Falling River
GLA	Glade Creek
GNE	North Fork Goose Creek
GSE	Goose Creek
GSF	South Fork Goose Creek
HIL	Hill Creek
HTA	Hunting Creek
LNA	Long Branch
LOR	Little Otter River
LYH	Lynch Creek
MRC	Mill Creek

Station waterbody code	Stream name
MSN	Mason Creek
PEE	Peters Creek
RAB	Reed Creek
RNF	North Fork
ROA	Roanoke River
ROC	Roanoke Creek
RSF	South Fork Roanoke River
SCE	Sycamore Creek
SEN	Seneca Creek
SSC	Straightstone Creek
SYD	Snyders Branch
TAB	Tanyard Branch
TIP	Turnip Creek
TKR	Tinker Creek
WPP	Whipping Creek
XCN	Unnamed Tributary to Roanoke River
XXX	Unnamed Tributary to Roanoke River
XXZ	Unnamed Tributary to Roanoke River
ZZZ	Unnamed Tributary to Roanoke River

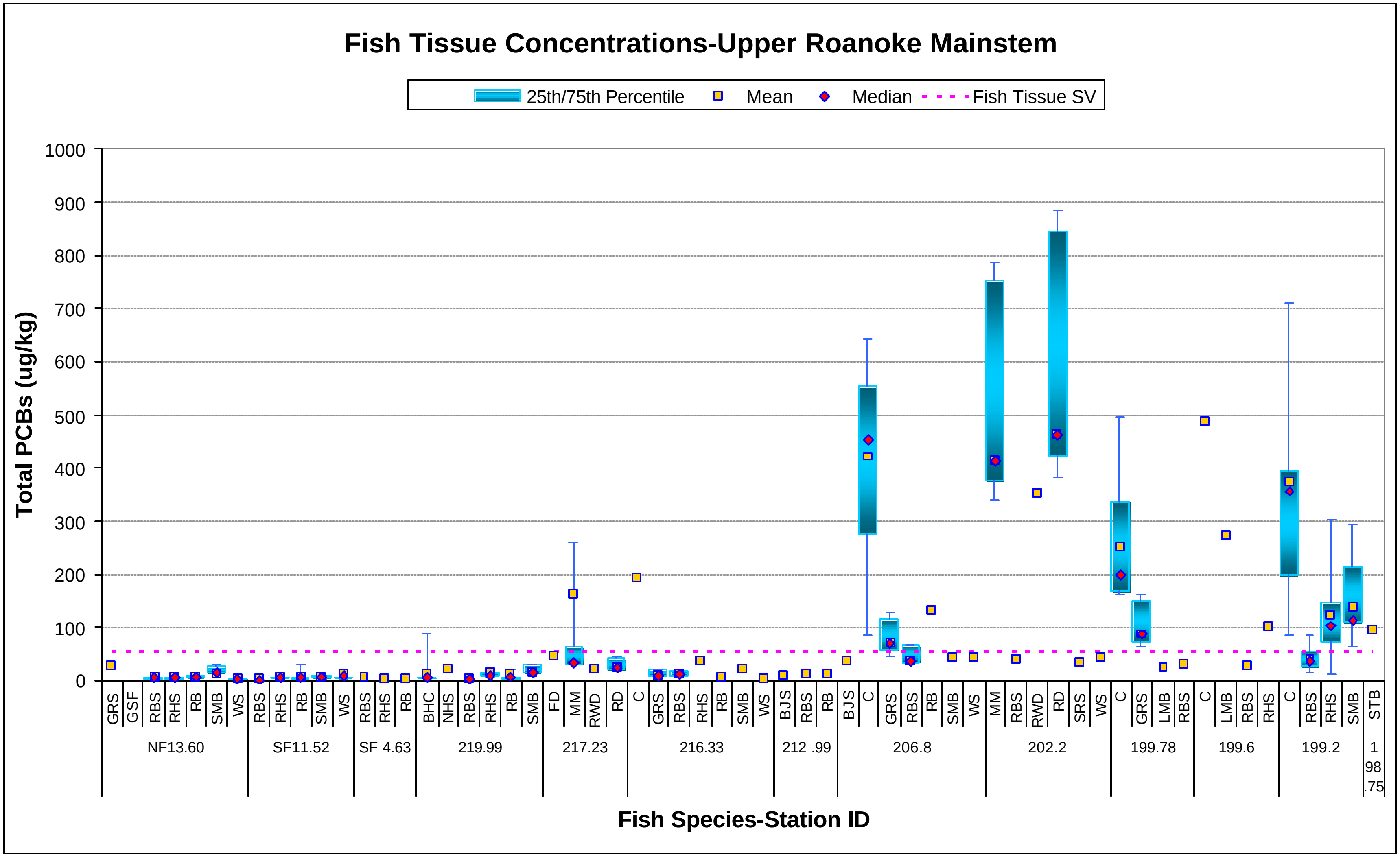

Figure 2-9. Fish tissue monitoring results for upper Roanoke River mainstem.

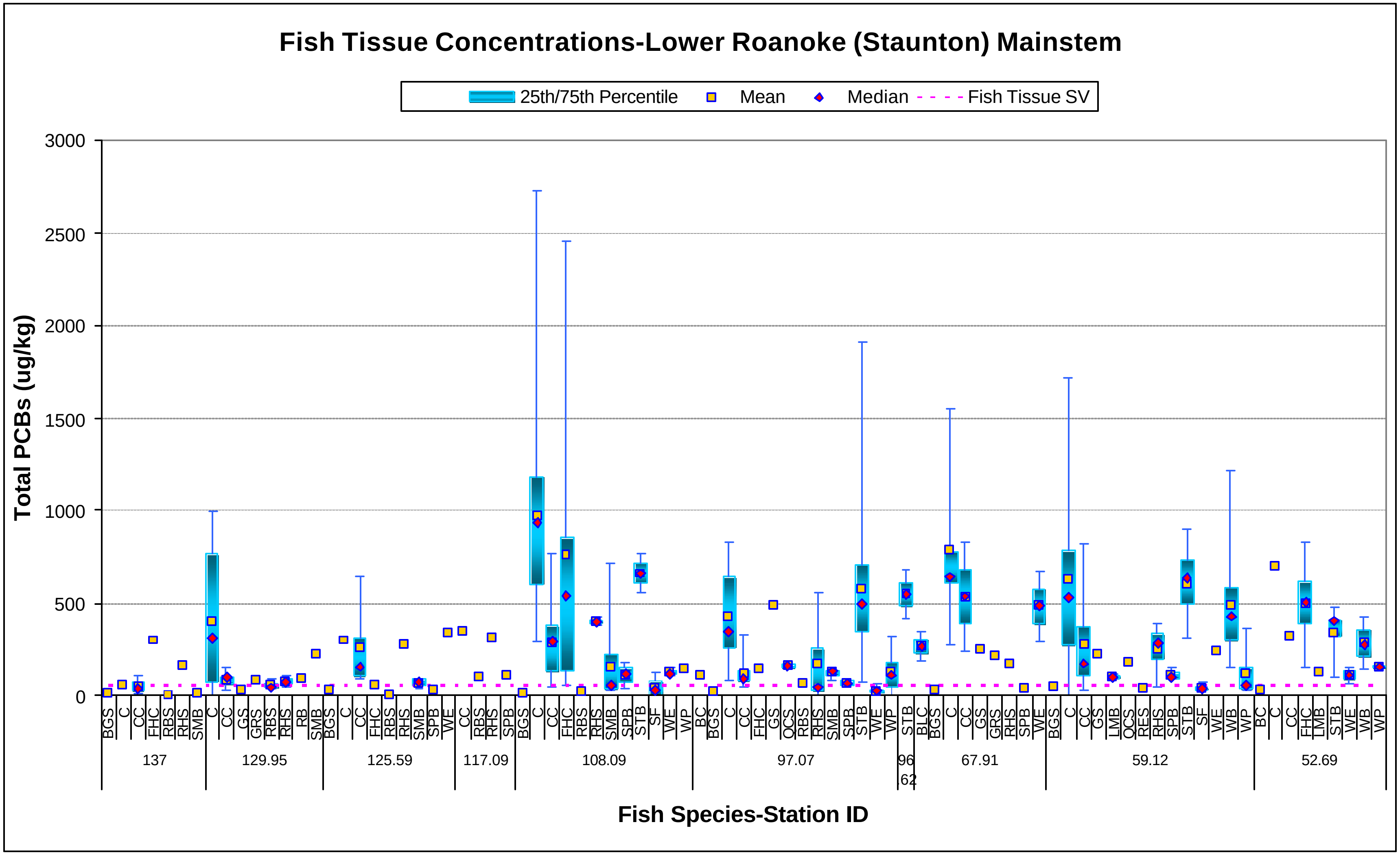

Figure 2-10. Fish tissue monitoring results for lower Roanoke (Staunton) River mainstem.

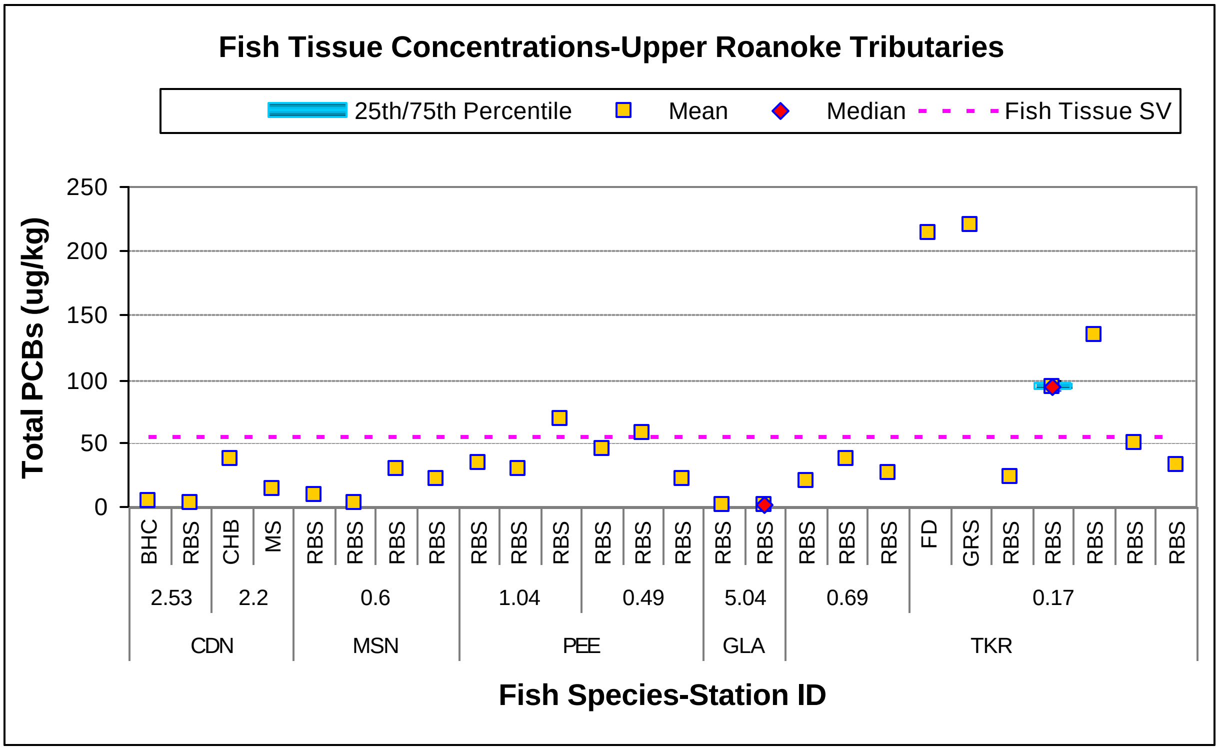

Figure 2-11. Fish tissue monitoring results for upper Roanoke River tributaries.

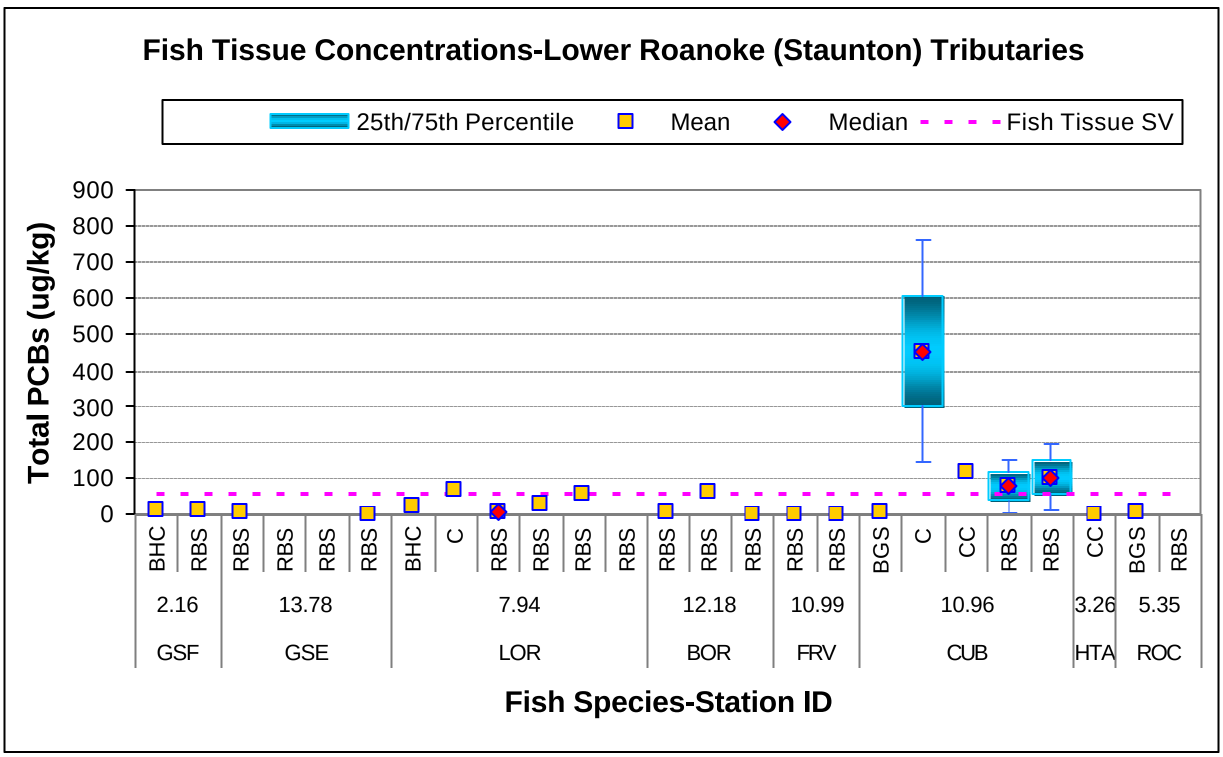

Figure 2-12. Fish tissue monitoring results for lower Roanoke (Staunton) River tributaries.

Sediment PCB Results

Figures 2-13 and 2-14 present the 25th–75th percentile, range, average, and median of tPCBs concentrations recorded at sediment monitoring stations summarized for the entire period of record. To maintain a reasonable scale, outliers in the dataset are represented as text boxes that give the average tPCBs concentration at a monitoring station. Monitoring results are grouped by watershed section and have been broken out into mainstem (Figure 2-13) and tributary stations (Figure 2-14). Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river-mile code. Station IDs are given as presented in Figures 2-7a and 2-7b, which show the locations of sediment monitoring stations (see Section 2.2.1). Station ID waterbody codes and associated waterbody names are given in Table 2-6. Data summaries and location descriptions for sediment monitoring stations are presented in Appendix B.

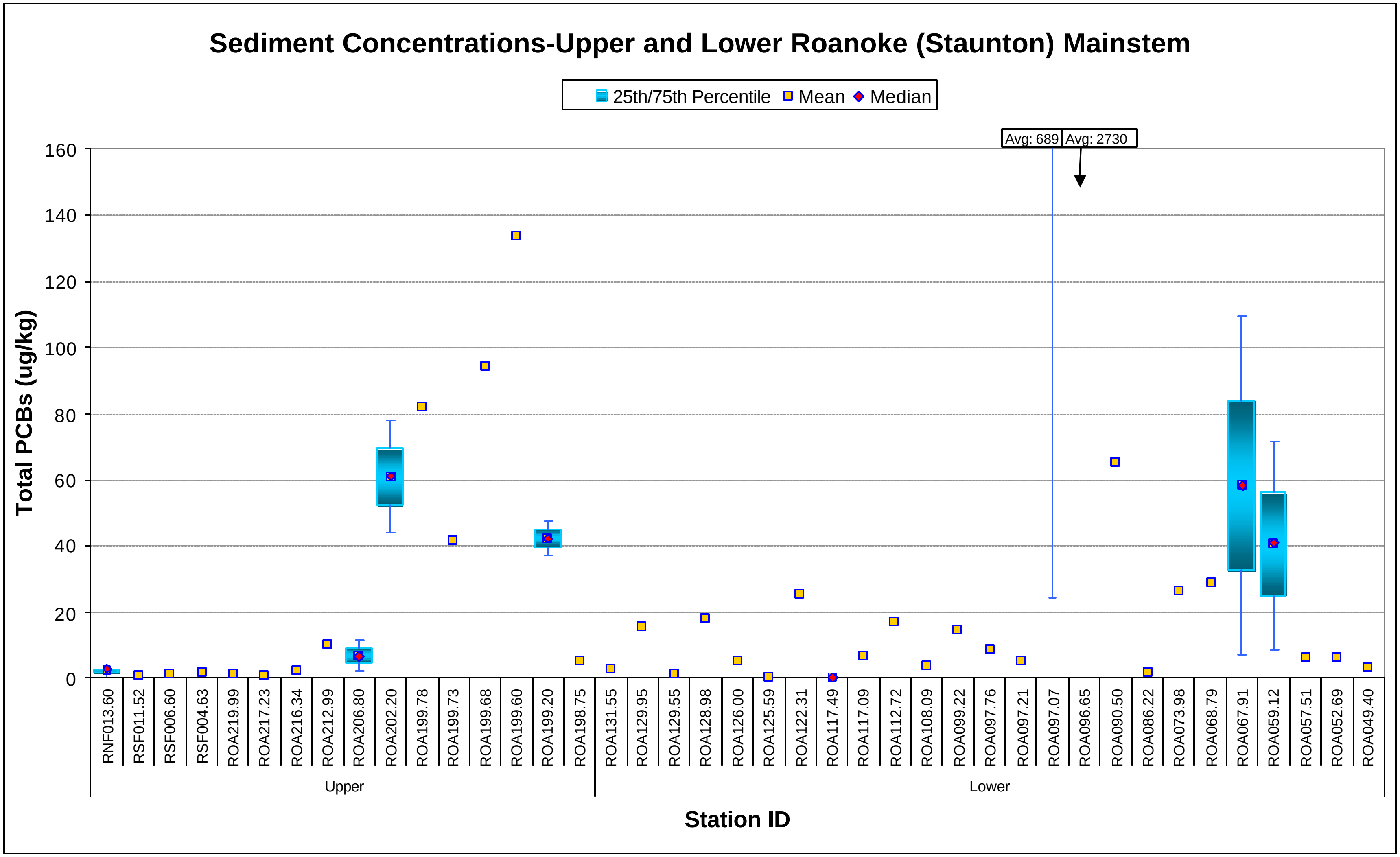

Figure 2-13. Sediment monitoring results for upper and lower Roanoke (Staunton) River mainstem.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

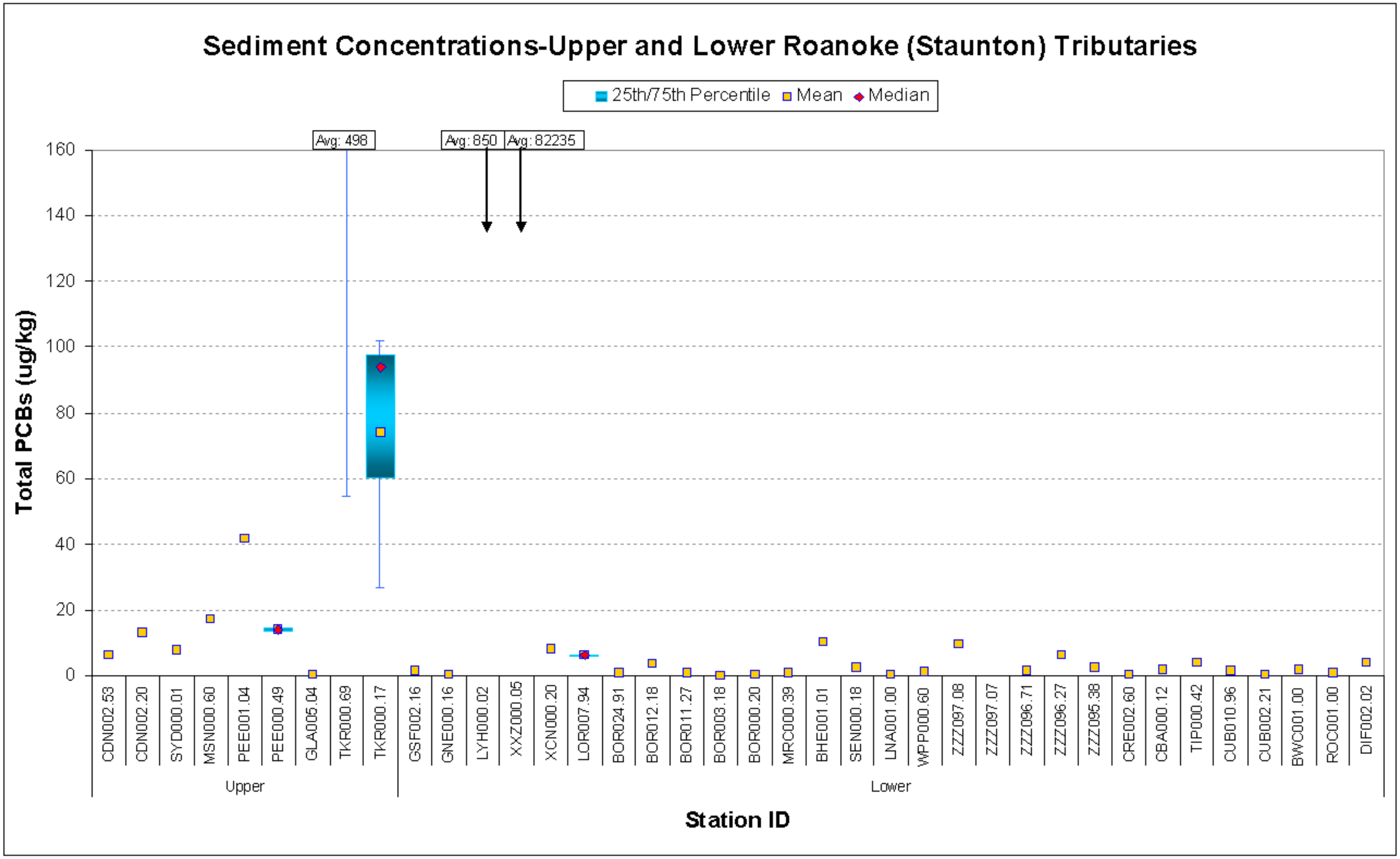

Figure 2-14. Sediment monitoring results for upper and lower Roanoke (Staunton) River tributaries.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

2.2.3. Fish Tissue and Sediment Data Analysis Summary

Upper Roanoke Segment (headwaters to Roanoke arm of Smith Mountain Lake):

- Flathead catfish, margined madtom, and carp had the highest average PCB concentrations.
- The highest average fish tissue concentration was observed at station ROA202.20 (Roanoke River near the 13th St. Bridge).
- In general, average fish tissue PCB concentration levels are higher at stations farther downstream. PCB concentrations are observed in fish species collected along the entire VADEQ impaired segment but become > 500 ppb downstream of Peters Creek at station ROA206.80 (Roanoke River near Wasena Park at Route 11 bridge). Peters Creek coincides with the city limits of Roanoke.
- Higher PCB levels were noted downstream of Roanoke River mile 206.80 for all species that were collected both above and below this location.
- Average PCB concentrations exceeded the VADEQ impairment threshold (54 ppb) for at least one species at all stations downstream of Roanoke River mile 206.80.
- Tinker Creek—station TKR000.17 (Tinker Creek near Route 24)—recorded the highest average fish tissue PCB concentrations for a tributary.
- An increasing trend in average sediment PCB concentration is also observed downstream of Peters Creek. Concentrations reach a maximum at station ROA199.60 (Roanoke River above Niagra Dam). The dam is likely an area of suspended solids deposition.
- The only location of high sediment PCB concentrations in a tributary is observed at the mouth of Tinker Creek. High fish tissue and sediment PCB concentrations on and directly downstream of Tinker Creek suggest the possibility of PCB source(s) in this general location.

Lower Roanoke (Staunton) Segment (Leesville Dam downstream to Kerr Reservoir):

- The highest average PCB concentrations in the Roanoke River Basin were noted for lower Roanoke (Staunton) stations.
- The majority of fish species had average concentrations greater than the VADEQ impairment threshold. For fish species with more than 10 samples, sunfish had the lowest concentrations overall.
- Carp, striped bass, and flathead catfish had the highest average PCB concentrations.
- Downstream of Seneca Creek, station ROA108.09 (Roanoke River near Long Island) recorded the highest fish tissue PCB concentrations.
- In general, average fish tissue PCB concentrations are higher downstream of station ROA108.09 between the towns of Altavista and Brookneal.
- Average fish tissue concentrations seem to decrease between mainstem stations ROA108.09 and 97.07, near the town of Brookneal, before increasing again downstream at river mile 67.91, near Route 746, and generally decreasing thereafter.
- Exceedances of the VADEQ fish tissue threshold PCB concentration were observed on three tributaries, Little and Big Otter rivers and Cub Creek. The Little Otter River is a tributary to the Big Otter and flows through the city of Bedford. Sediment data collected at stations on the Big Otter River and its tributaries showed a maximum concentration of 5 ppb.
- Cub Creek recorded the highest average fish tissue PCB concentrations of any tributary stream segment, although the only sediment sample collected in the area was found to have concentration of less than 2 ppb.
- The only sediment monitoring stations on tributaries to record exceedances of the VADEQ SV were on Lynch Creek near Altavista Park (LYH000.02), an unnamed tributary located just west of the

Altavista STP that flows through the known PCB contaminated site BGF Industries (XXZ000.05), and an unnamed tributary near the town of Brookneal at Route 501 (ZZZ097.07).

- Two sediment monitoring stations on the Roanoke River mainstem recorded concentrations exceeding the VADEQ SV (ROA097.07 and 96.65). Both of these are near the town of Brookneal.
- Sediment and fish tissue monitoring data suggest that PCB sources might be in the towns of Altavista and Brookneal.

2.3. Water Column PCB Results

VADEQ conducted a special study in the Roanoke River basin in fall 2005 through spring 2008. The study was designed, in part, to augment the existing water quality record in support of TMDL development. Water quality samples were collected during low-flow and high-flow conditions at 29 monitoring locations throughout the watershed. Because of the hydrophobic properties of PCBs, earlier analytical methods used to process samples collected for prior monitoring studies routinely failed to detect measurable concentrations of PCBs. The special study results were processed using a high-resolution, low-detection level analysis method (1668A) specifically to account for PCBs' hydrophobic properties.

Figures 2-15 and 2-16 present the 25th–75th percentile, range, average, and median of tPCBs concentrations recorded during high- and low-flow conditions at the special study water quality monitoring stations for the upper and lower Roanoke (Staunton). Where measured PCB concentrations at a station were significantly higher than at other stations located in the same section, the average concentration is given in a text box to maintain the scale of the figure. The TMDL water quality targets for the upper and lower sections are also included for points of reference. Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river mile code and tributary point of confluence with the Roanoke River mainstem. Note that data collected in fall 2005 have been excluded from the analysis because of concerns of sample contamination. Data summaries for the special study water quality monitoring stations are presented in Appendix B.

Station IDs have been condensed for Figures 2-15 and 2-16 for the purpose of presentation where monitoring was done for only high- or low-flow conditions. Station IDs differ from those presented in the map of water column monitoring station locations (Figure 2-8) in that river miles are expressed as the highest significant digit, not as a standard five digits (eg. 56.1 vs. 056.10). Station ID waterbody codes and associated waterbody names are given in Table 2-6.

Trends in the water quality monitoring data are very similar to those observed in the fish tissue and sediment monitoring record. In the upper section of the Roanoke, a significant increase in tPCBs concentrations occurs between river mile 207.08 and 204.76. Along this length of the mainstem, the surrounding urban land use becomes progressively denser as one moves toward the city center of Roanoke. Many of the suspected contaminated sites in the upper section are also in this area, as discussed in Section 3.1. Upstream of river mile 207.08, all monitoring data is below the water quality target. High- and low-flow PCB concentrations peak at river mile 202.20 just upstream of the Tinker Creek confluence. High-flow concentrations decrease at river mile 199.20 at Niagra Dam, which could be due to the backwater effect of the dam and the reduction of flow turbulence and the resuspension of contaminated sediments. In addition, at all monitoring locations, low-flow tPCBs concentrations are lower than high-flow concentrations. This gives strong evidence of increased loading during storm events, which cause stormwater runoff and streambed sediment resuspension.

In the lower section of the Roanoke (Staunton), increases in water column tPCBs concentrations also correspond to the locations of suspected contaminated sites. At river mile 129.55, along the town of Altavista, a noticeable increase in tPCBs concentrations is seen. This increase becomes significant as one moves downstream to river mile 124.59 where high-flow concentrations exceeded 4,000 picograms per liter (pg/L). Very high water concentrations were recorded on two tributaries to the mainstem above this point at the mouth of Lynch Creek (LYH000.17) and an unnamed tributary (XLN000.00) that drains industrial sites in Altavista.

Water column concentrations remain elevated moving downstream to river mile 97.76, adjacent to the town of Brookneal, where the measured high-flow concentration also exceeded 4,000 pg/L. Downstream of Brookneal high-flow concentrations monitored on the Roanoke mainstem decrease, but remain well above the water quality target. Interestingly, below river mile ROA90.50 as the river approaches the Kerr Reservoir and the water starts to slacken, low-flow PCB concentrations begin to exceed high-flow concentrations. This could be because the reservoir is causing contaminated sediment to settle out and accumulate in these areas, which then contributes PCBs to the water column at a steady rate that is more apparent during low-flow conditions. Sediment monitoring data seem to generally support this conclusion, with an increase in PCB concentration noticeable downstream of river mile 97.07 (see Figure 2-13). Monitoring results for tributaries in the lower section are generally below the water quality target, with the exception of the two that run through the town of Altavista and the Big Otter River (BOR000.62), which exceeded criteria during high-flow conditions.

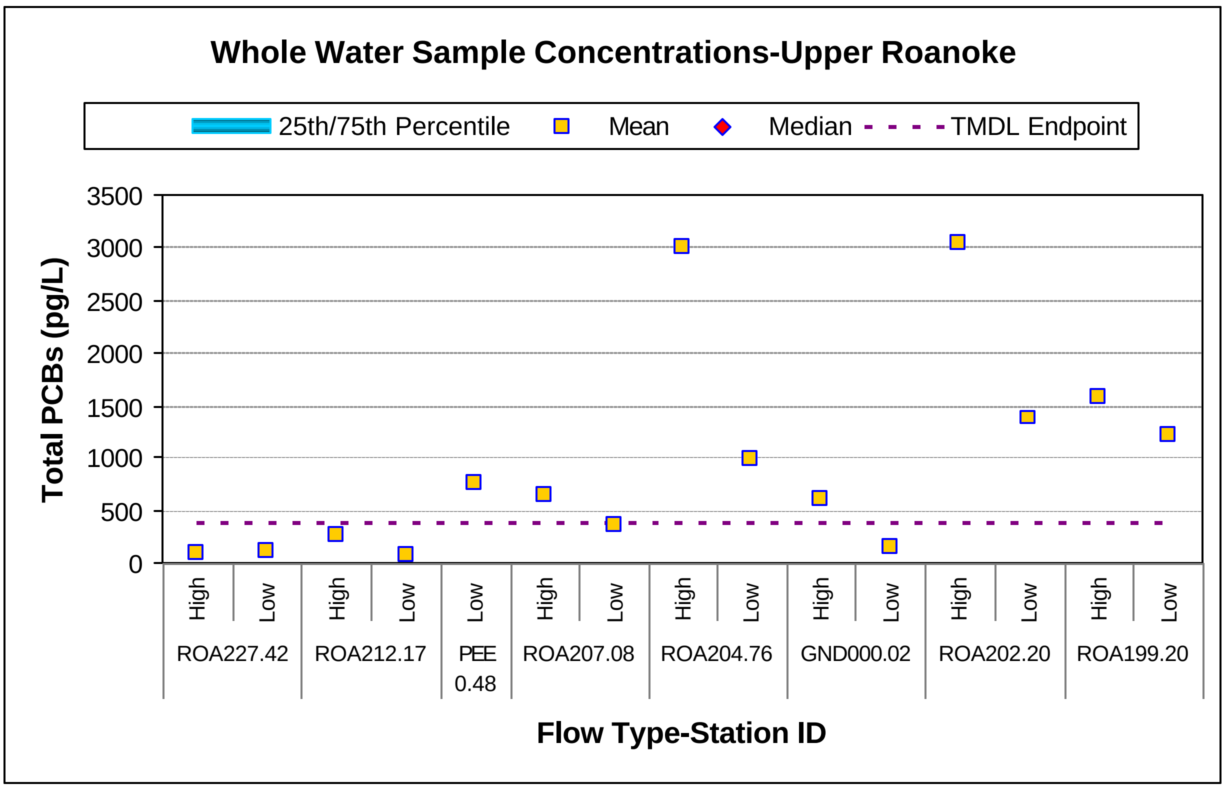

Figure 2-15. Special study water column monitoring results for the upper Roanoke River.

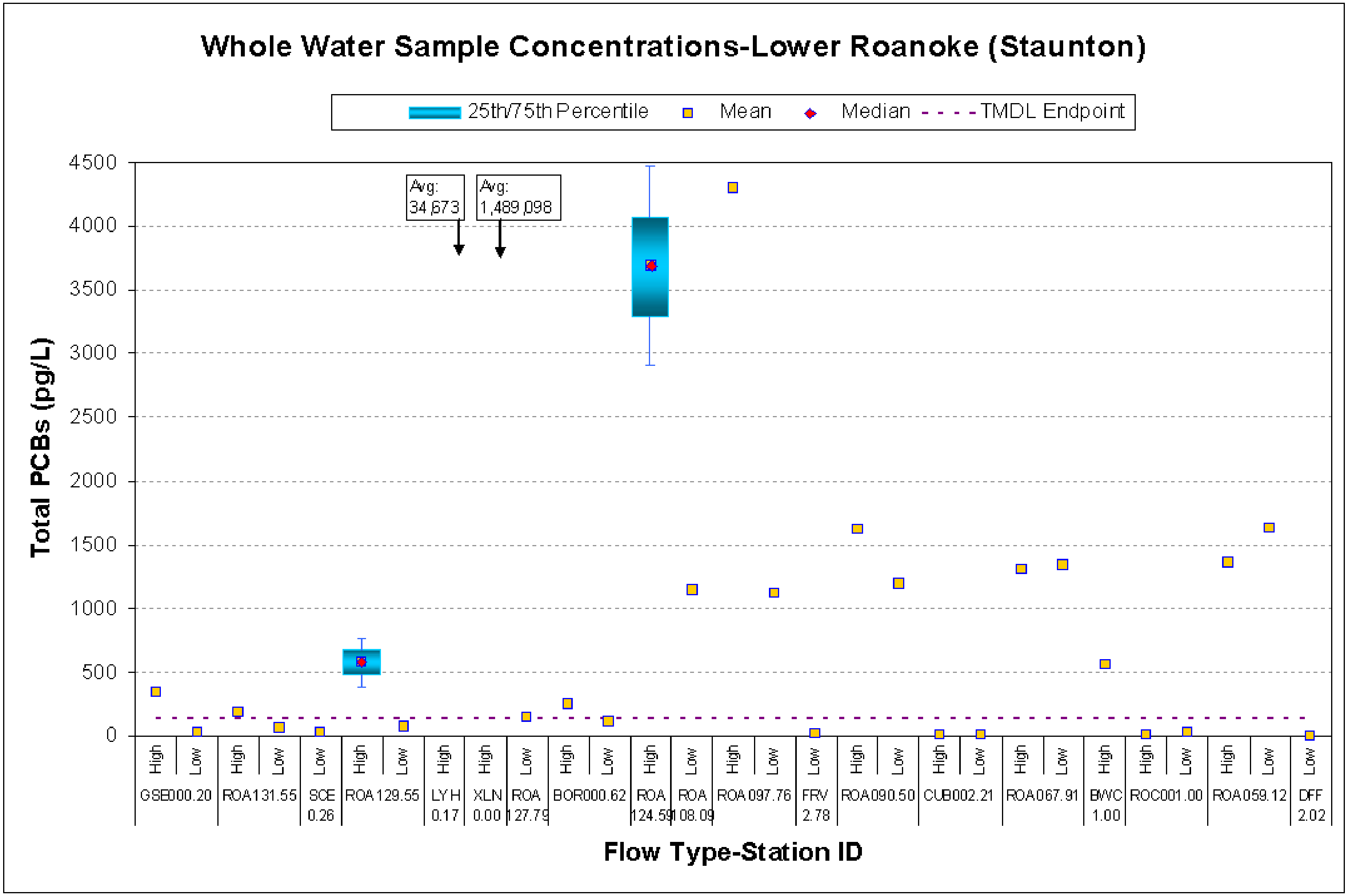

Figure 2-16. Special study water column monitoring results for the lower Roanoke (Staunton) River.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

3. SOURCE ASSESSMENT

This section presents the information collected to date on point and nonpoint sources of PCBs in the Roanoke River basin. The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and on-going source investigation whereby sources of PCB contamination are continuously being reviewed and updated based on the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of these TMDLs, rather than a complete and final characterization. The discussion that follows is limited to identifying the sources represented in the TMDL. Discussion of the representation of sources within the TMDL model framework is presented in Section 5.0 and Appendix G.

For the purposes of this TMDL, sources of PCB loadings to a waterbody are defined as either current or legacy. Current sources generate PCB loads that have a defined, disruptable pathway to a waterbody. Such sources, in theory, can be controlled without eliminating the source of PCBs by blocking the pathway. Examples of current sources include PCB-contaminated soils that wash off from upland areas, leachate from landfills and industrial disposal areas, leaking transformers and storage containers, discharges of PCB-contaminated effluent, local deposition of atmospheric PCBs accumulated from off-gassing contaminated sites, and a variety of other sources.

Legacy sources generate PCB loads to a waterbody that cannot be easily controlled because there is no disruptable pathway from the source to the affected waterbody. Control of the source requires its direct removal. In all cases, the source exists at an interface with the waterbody where there is continuous exchange of material. Examples of legacy sources include in-stream contaminated sediments, stream bank soils that are not part of a contaminated site, biota, and background atmospheric deposition to surface waters.

Both current and legacy sources are represented in the TMDL model framework. For discussion of the methodology used to define source loads, see Section 5.0 and Appendix G.

3.1. Source Inventory/Current Sources

VADEQ has conducted several site investigations and special studies in recent years to assess the spatial extent of PCB contamination in the Roanoke basin and to identify current sources generating PCB loads in the watershed. An inventory was created to organize all existing data related to efforts to identify and characterize facilities/sites where PCBs may have been used, stored, or disposed of.

The information compiled includes various memos and other correspondence, public meeting records, site investigations, VADEQ monitoring data and special studies, pollution complaint records, solid waste facility information, VPDES facility information, Toxic Substance Control Act (TSCA) data, Comprehensive Environmental Response Compensation and Liability Act (CERCLA) records, Resource Conservation and Recovery Act (RCRA) database records, and other available information. Such records were examined in conjunction with the available PCB fish tissue and sediment monitoring data to identify possible sources of PCBs in the Roanoke River watershed. In the early stages of the TMDL study, a PCB source database was created to inventory historical PCB monitoring data at facilities in the upper Roanoke watershed.

After a review of the collected records and monitoring data, the conclusions that were drawn were used to design a 2005 special study that included monitoring effluent at selected facilities, collecting water column samples, and deploying SPMDs at various locations throughout the watershed. This special study was ultimately expanded into the fall 2005 through spring 2008 special study, which included three rounds of sampling conducted October 13, 2005–January 31, 2006, August 7, 2007–September 10, 2007, and July 1, 2007–May 9, 2008. Monitoring for the expanded study included the media originally planned to be sampled in 2005, as well as sediment and facility sludge monitoring.

3.1.1. Point Sources

Thirteen point sources are represented as current PCB sources in the TMDL. Three sites (Dan River, Inc.; Burlington Industries; and the town of Altavista Sewage Treatment Plant) are also represented as nonpoint sources (see Section 3.1.2). Table 3-1 lists the sites represented as point sources and Figure 3-1 shows their locations.

Facility outfalls were represented as PCB point sources if results from the 2005–2008 VADEQ special study found the facility has contributed a PCB load. VADEQ also requested that applicable facilities be included as determined using their PCB point source monitoring guidance (VADEQ, 2009).

Table 3-1. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Design flow (MGD)	Receiving stream
Upper Roanoke River					
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.035	NF Roanoke River
Montgomery County PSA - Shawsville STP	Sewerage systems	VA0024031	001	0.2	SF Roanoke River
Montgomery County PSA - Elliston Lafayette WWTP	Sewerage systems	VA0062219	001	0.25	SF Roanoke River
Steel Dynamics	Steel works	VA0001589	005	0.067	Peters Creek
Norfolk Southern Railway Co – Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.07	Peters Creek
WVWA Roanoke Regional Water Pollution Control Plant	Sewerage systems	VA0025020	001	55	Roanoke River
Lower Roanoke (Staunton) River					
ITG Burlington Industries LLC Hurt Plant	Fabrics finishing	VA0001678	001	3.42	Roanoke (Staunton) River
Old Dominion Pittsylvania Power Station	Electric services	VA0083399	001	0.192	Roanoke (Staunton) River
Altavista - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	3.6	Roanoke River
Old Dominion Altavista Power Station	Electric services	VA0083402	001	0.117	Roanoke (Staunton) River
Dan River, Inc - Brookneal	Fabrics finishing	VA0001538	001	1.326	Roanoke (Staunton) River
Brookneal - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.078	Roanoke (Staunton) River
Old Dominion Clover Power Station	Electric services	VA0083097	001	1.735	Roanoke (Staunton) River

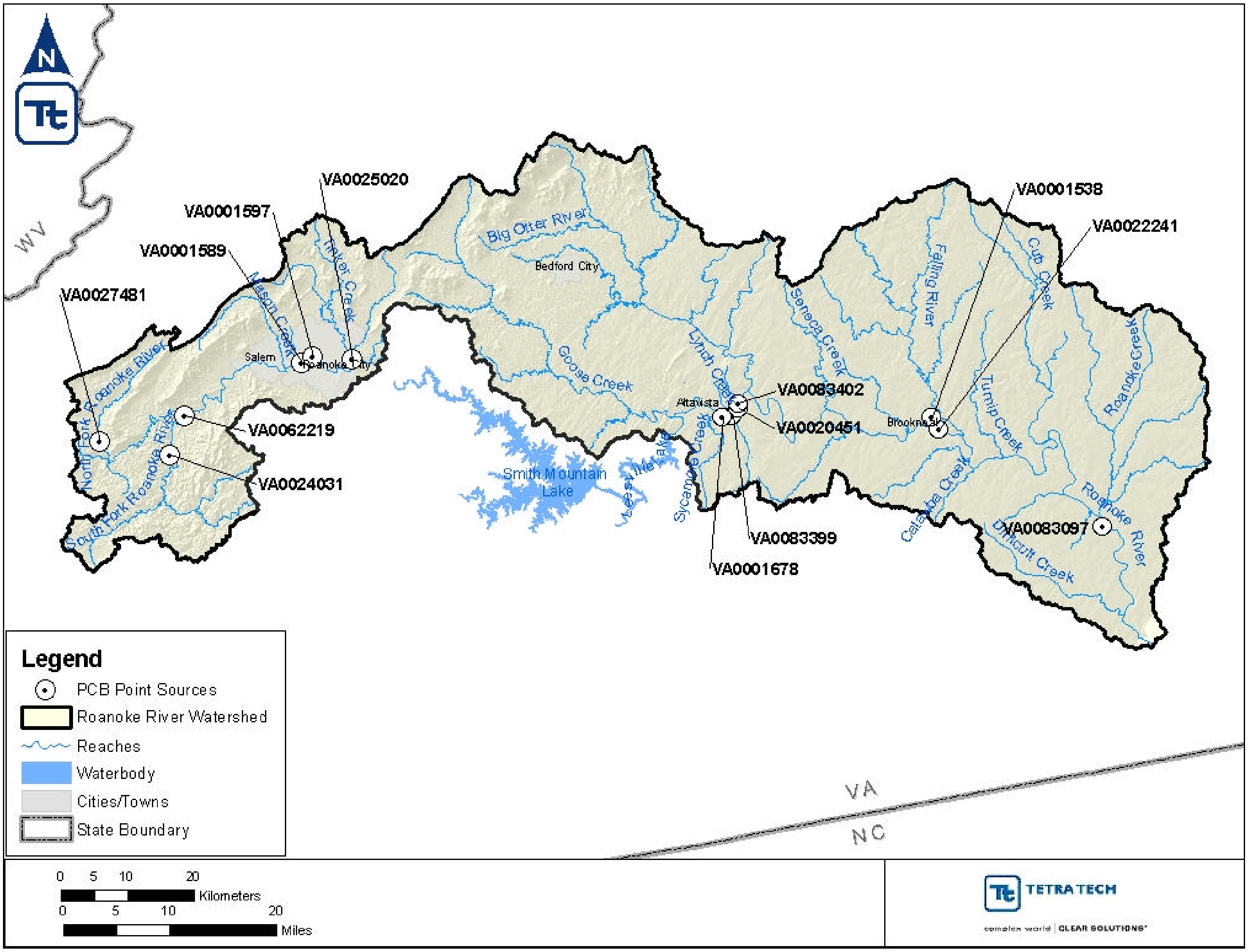

Figure 3-1. Model PCB point sources.

3.1.2. Nonpoint Sources

Twenty-one nonpoint sources are represented as current PCB sources in the TMDL. Three sites (Dan River, Inc.; Burlington Industries; and the town of Altavista Sewage Treatment Plant) are both point and nonpoint sources (see Section 3.1.1). Table 3-2 lists the sites represented as nonpoint sources and Figures 3-2 through 3-4 present their locations.

Areas represented as nonpoint sources include sites where analysis of on-site soil samples found measurable concentrations of PCBs. Available results for on-site soil sampling were obtained from four sources: *PCB Source Investigation: Altavista and Hurt* (VADEQ 1999), *Analysis of Brownfield Cleanup Alternatives Former Virginia Scrap Iron & Metal Company, Inc. Property* (City of Roanoke 2008), a *Site File Review for PCBs in the Roanoke River Watershed* that was completed as part of a CERCLA preliminary assessment (USEPA 1999a), and the VADEQ PCB source survey database.

Not all TMDL-represented nonpoint sources have available soil sampling results confirming PCB contamination. The Altavista east- and west-town dumps and Dan River, Inc., are characterized as contaminated sites because of the following considerations:

- The Altavista east- and west-town dumps were included as sampling sites in the *Altavista/Hurt PCB Source Investigation* (VADEQ 1999) but were ultimately not sampled because of concerns of safety risks. Numerous facilities adjacent to the dumps are known contaminated sites, however, and the dumps are known to be historical disposal areas for local industry.
- Dan River, Inc., is a fabrics finishing plant similar to the known contaminated site BGF industries. Effluent monitoring results also show that the facility has contributed a PCB load.

Research has also shown that off-gassing from PCB-contaminated sites can cause local deposition of atmospheric PCBs and contribute loads to a waterbody (Totten et al. 2004). Although no data exists to represent this process for the Roanoke River watershed, it could be considered in future TMDL studies if data become available. Background atmospheric deposition of PCBs represented as a legacy source is represented in the TMDL. For further information, see the discussion of legacy sources.

Table 3-2. Model PCB contaminated sites

Site name	NPDES ID	Site/facility description	County/city	Receiving stream
Upper Roanoke River				
Dixie Caverns Landfill	VAD980552095[b]	Landfill	Roanoke	Roanoke River
Roanoke River Floodway Bench Cuts		Areas along the Roanoke River mainstem where the floodplain has been expanded	Roanoke	Roanoke River
Norfolk Southern 12		Railroads, line-haul operating	Roanoke City	Roanoke River
Evans Paint	VASFN0305570[b]	Former chemical manufacturing plant (Evans Chemical)	Roanoke City	Roanoke River
Virginia Scrap Iron Co.	VRP00408[c]	Site of an old metal scrap yard	Roanoke City	Roanoke River
Norfolk Southern 1		Railroads, line-haul operating	Roanoke City	Roanoke River
Tinker-American Electric Power (AEP) property		Electric Services	Roanoke City	Roanoke River
Riverdale Development (formerly American Viscose Co.)	VRP00394[c]	Fabrics finishing plant	Roanoke City	Roanoke River
Appalachian Power Co. (APCO) Yard		Electric Services	Roanoke City	Roanoke River
Jacob Webb		Personal residence (unknown location)	Roanoke City	Roanoke River
Lower Roanoke (Staunton) River				
Burlington Industries-Altavista Hurt[a]	VA0001678	Fabrics finishing plant	Pittsylvania	Sycamore Creek
English Construction		Landfill	Pittsylvania	Roanoke (Staunton) River
West town dump-Altavista		Landfill	Campbell	Lynch Creek
Oil distributors-Altavista		Current location of three adjacent oil distributors and common *wet* area	Campbell	Lynch Creek
Lane Furniture Co.		Site of old furniture manufacturing plant	Campbell	Roanoke (Staunton) River
BGF Industries[a]		Fabrics finishing plant	Campbell	Roanoke (Staunton) River, UT
East town Dump-Altavista		Landfill	Campbell	Roanoke (Staunton) River
Altavista STP	VA0020451	Sewerage system	Campbell	Roanoke (Staunton) River
A. O. Smith		Electric motor manufacturing	Campbell	Roanoke (Staunton) River, UT
Schrader Bridgeport[a]		Metal plating and rubber valve manufacturing	Campbell	Roanoke (Staunton) River, UT

Site name	NPDES ID	Site/facility description	County/city	Receiving stream
Dan River, Inc.	VA0001538	Fabrics finishing plant	Campbell	Roanoke (Staunton) River

a. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (See Section 3.1.3)
b. EPA Superfund ID#
c. Virginia Voluntary Remediation Program (VRP) site#

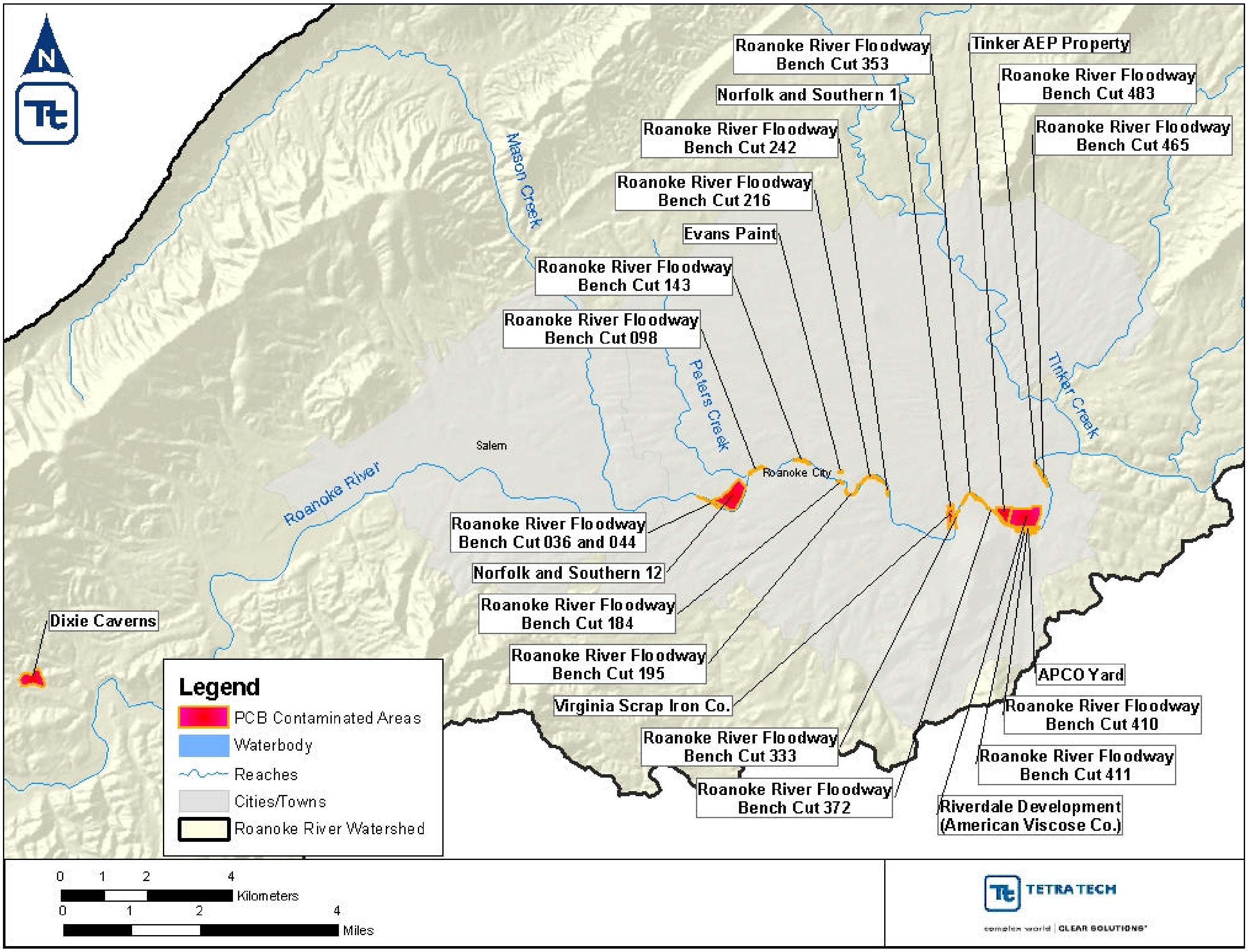

Figure 3-2. Model nonpoint source areas—Roanoke.

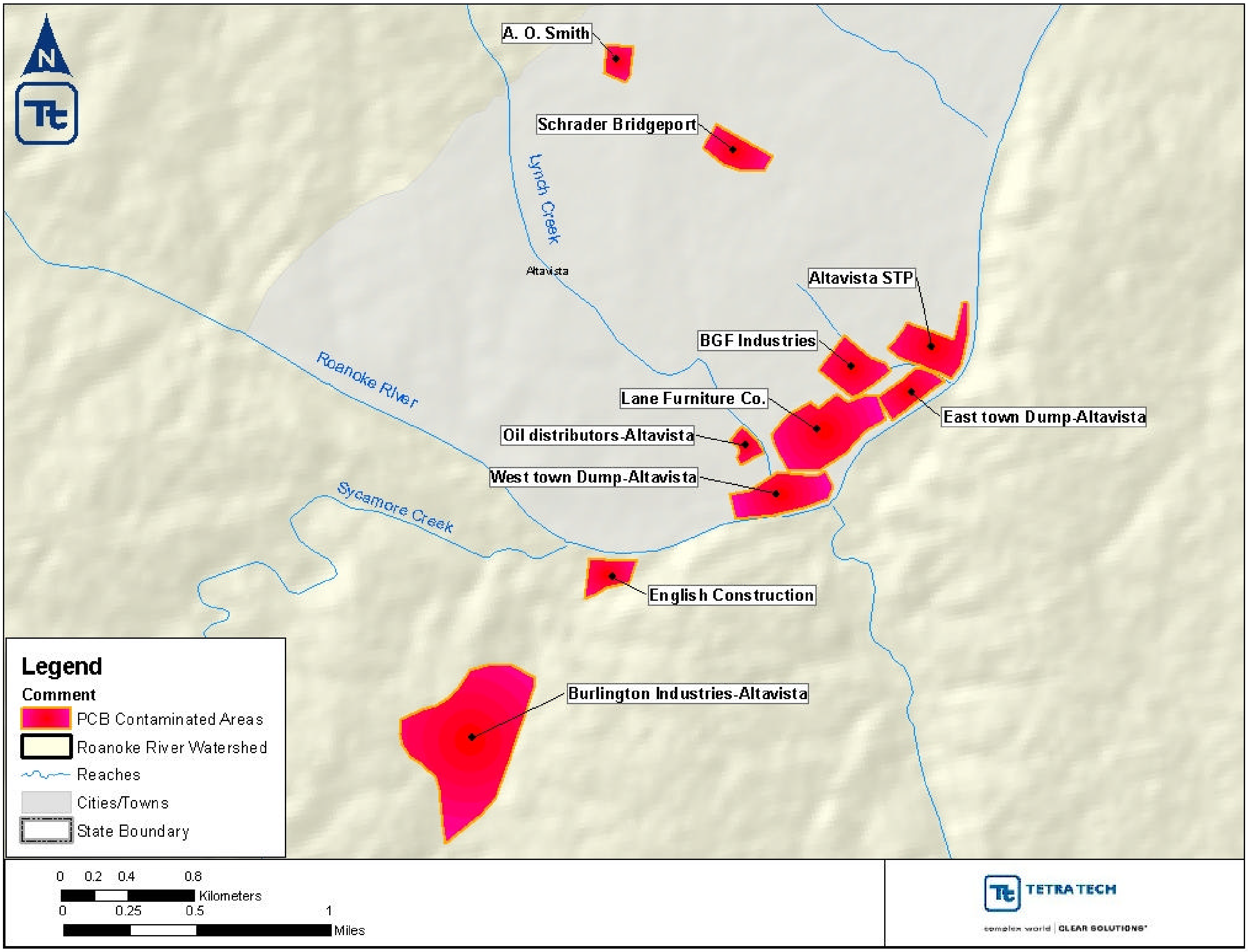

Figure 3-3. Model nonpoint source areas—Altavista.

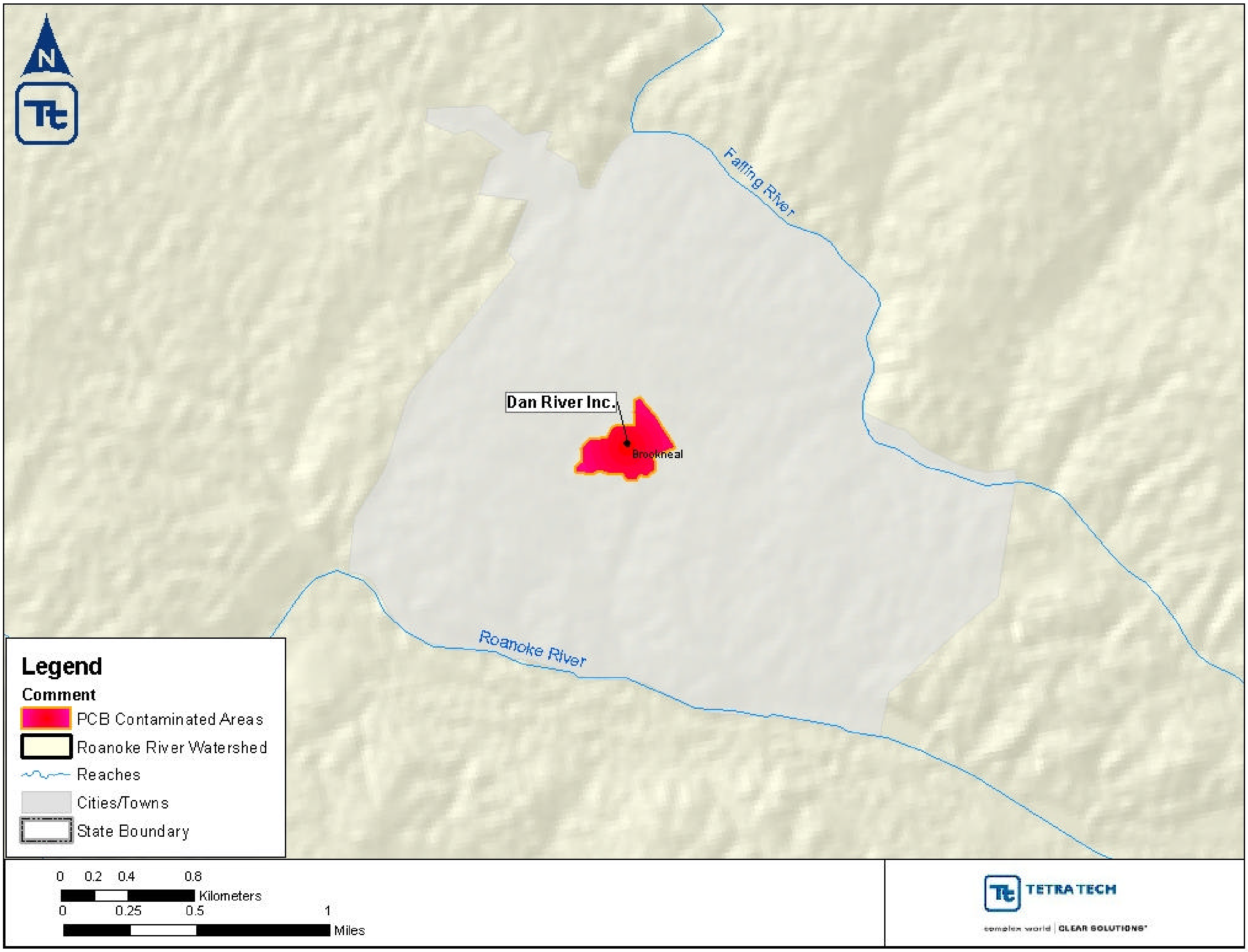

Figure 3-4. Model nonpoint source areas—Brookneal.

3.1.3. MS4s/Stormwater Permits

On November 22, 2002, EPA's Office of Wetlands, Oceans and Watersheds and Office of Wastewater Management issued a memorandum, *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs* (USEPA 2002), that updated previous regulation and finalized requirements under which municipal separate storm sewer systems (MS4s) are treated as point sources when calculating TMDLs. As a result, pollutant loadings from MS4s and facilities and sites issued general stormwater permits must be explicitly accounted for when calculating TMDLs.

MS4s in the Roanoke River basin are listed in Table 3-3 and presented in Figure 3-5. A list of active stormwater permits issued to facilities and sites in the basin is provided in Appendix C. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit. Section 5.0 and Appendix G discuss the representation of loads generated by nonpoint source contaminated sites.

Table 3-3. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613
Town of Christiansburg	VAR040025	1,193

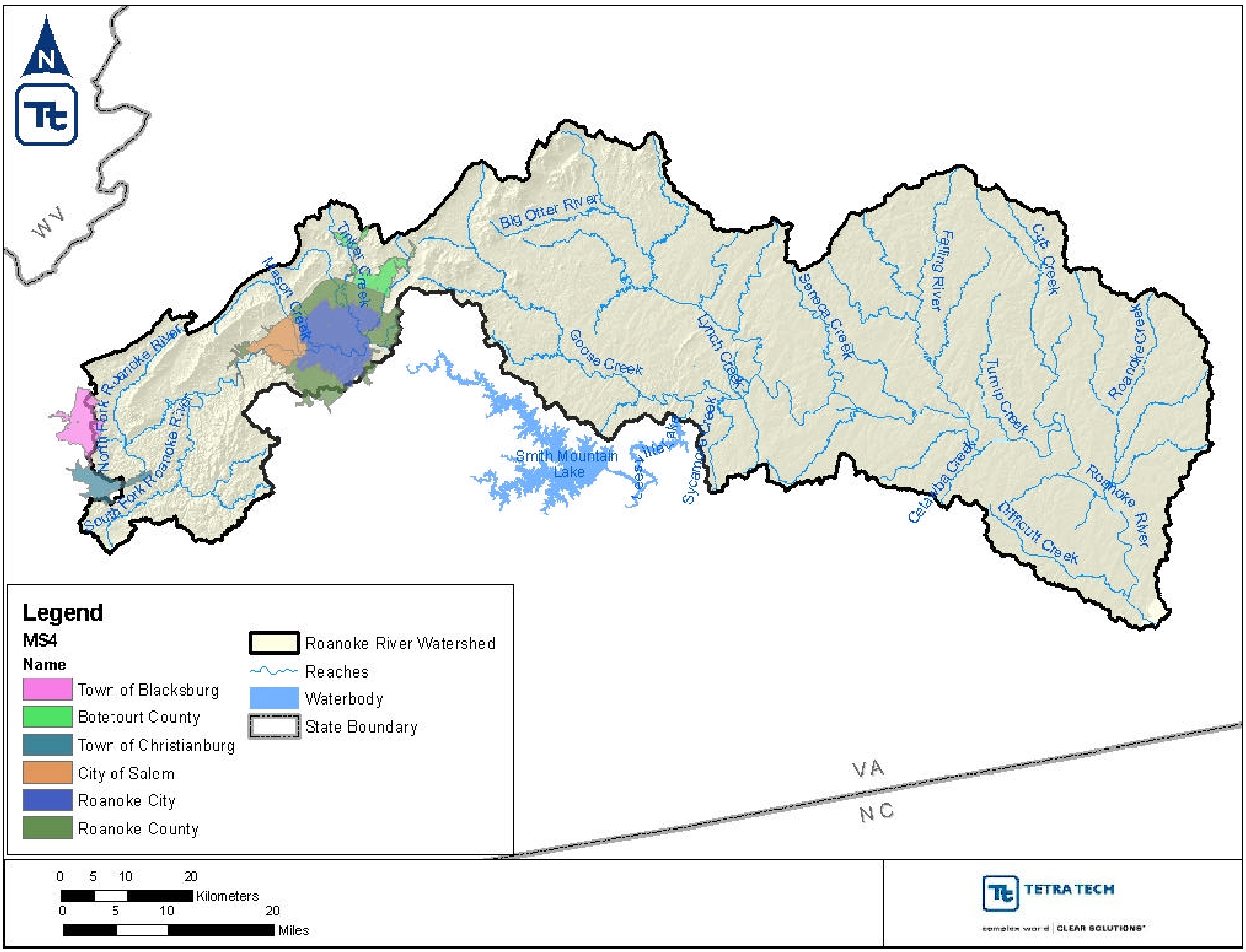

Figure 3-5. Model MS4 areas.

3.2. Legacy Sources

Legacy sources represented in the TMDL include loadings of PCBs from contaminated streambed and background atmospheric deposition of PCBs to surface waters. These sources exist at an interface with the affected waterbody and do not have a loading pathway that can be easily controlled.

3.2.1. Atmospheric Deposition

The wide-spread use of PCBs before their ban in the 1970s coupled with their stable molecular structure has caused a generalized distribution of the pollutant in air, soil, and water at background concentrations. The net flux of gaseous PCBs between the atmosphere and the surface of a waterbody is a function of the dynamic concentration gradient between the two. Atmospheric deposition has been shown to be a significant pathway of PCB cycling in freshwater systems (PADEP 2001).

3.2.2. Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical or current loadings or both. These PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers.

The movement and accumulation of streambed sediments are governed by in-stream processes. Contaminated streambed sediments are available for consumption by aquatic biota, are transported downstream, and can be buried under additional sediments. Downstream transport can result in sediments being flushed out of the system or being trapped behind downstream dams. Existing PCB projects, such as the Hudson River project in New York and the Housatonic River project in Massachusetts, have found that historical discharges have resulted in contaminated sediments, which tend to collect in slow river stretches or reservoirs. The contaminated sediments tend to remain in such depositional areas until they are dredged or dislodged by storms.

4. TMDL TECHNICAL APPROACH

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions necessary to meet water quality standards. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions.

The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination and to determine the reductions required to achieve water quality criteria for PCB impaired segments. This section presents an overview of the modeling approach for developing PCB TMDLs for the Roanoke River basin. For a more detailed discussion of the TMDL technical approach see Appendix G.

4.1. Critical Considerations

The pollutant of concern for the current modeling application is tPCBs. PCBs are a hydrophobic nonpolar organic chemical species that tend to associate with fine sediments. PCBs associate with sediments by the process of adsorption. Adsorption describes the tendency of PCBs to accumulate on the surface of sediments in an aqueous environment as a function of energetic favorability, where the strength of the PCB-sediment association is proportional to the availability of adsorption surfaces (TSS concentration), sediment organic content, and the PCB species degree of chlorination.

Land use in the Roanoke River basin includes extensive areas of largely undeveloped forest and pastoral lands and relatively small areas of concentrated development. Each land use affects the hydrology and sediment loads of the basin in a different way. Available monitoring data, as described in Section 2.2, suggests that potential sources of PCBs are often associated with developed land uses.

4.2. Modeling Framework

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements, was used to develop PCB TMDLs for the Roanoke River basin. A watershed model is a series of algorithms that integrate meteorological forcing data and watershed characteristics to simulate upland and tributary routing processes, including hydrology and pollutant transport. Once a model has been adequately set up and calibrated and the dominant unit processes are deemed representative on the basis of comparison with available monitored conditions, it becomes a useful tool to quantify existing flows and loads from tributaries without gages and from diffuse overland flow sources.

4.2.1. Loading Simulation Program C++ (LSPC)

EPA-approved LSPC (http://www.epa.gov/athens/wwqtsc/html/lspc.html) was selected for Roanoke River watershed modeling. LSPC is a watershed modeling system that includes Hydrologic Simulation Program–FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. During the past several years it has been used to develop hundreds of EPA-approved TMDLs, and it is generally considered the most advanced hydrologic and watershed loading model available.

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970s. The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley 1966), which was one of the pioneering watershed models. The HSPF framework is composed of modules with components that can be assembled in different ways, depending on the objectives of the project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes

All three modules include many submodules that calculate the various hydrologic, sediment, and water quality processes in the watershed. Table 4-1 lists the modules from HSPF that are used in LSPC.

Table 4-1. HSPF modules included in LSPC

Receiving water modules (RCHRES)	HYDR	Simulates in-stream hydraulic behavior
	ADCALC	Simulates in-stream advection of dissolved or entrained constituents
	CONS	Simulates in-stream conservative constituents
	HTRCH	Simulates in-stream heat exchange
	SEDTRN	Simulates in-stream behavior of inorganic sediment
	GQUAL	Simulates in-stream behavior of a generalized quality constituent
Watershed modules PERLND/IMPLND	SNOW	Simulates snow fall, accumulation, and melting
	PWATER/IWATER	Simulates water budget for a pervious/impervious land segment
	SEDMNT/SOLIDS	Simulates production and removal of sediment for a pervious/impervious land segment
	PSTEMP	Simulates soil layer temperatures
	PWTGAS/IWTGAS	Estimates water temperature and dissolved gas concentrations in the outflows from pervious/impervious land segments
	PQUAL/IQUAL	Simulates water quality in the outflows from pervious/impervious land segments

Source: (Bicknell et al. 1997)

Spatially, the watershed is divided into a series of subbasins or subwatersheds representing the drainage areas that contribute to each of the stream reaches. These subwatersheds are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and subsurface flow contributions from each of the land segments and subwatersheds and routes them through the waterbodies using storage-routing techniques. The stream network is constructed to represent all the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Important routines for water quality simulation include the QUAL and SED modules, both of which have PERLND/IMPLND and RCHRES components that define the upland and in-stream characteristics of each. Together, these routines provide the basic framework for simulating pollutant loading and transport in a watershed.

5. MODEL SETUP

An LSPC model was configured for the areas contributing to TMDL impaired streams (see Section 1.2) in the Roanoke River basin as a series of hydrologically connected subwatersheds. Configuration of the model involved subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for the units using meteorological, land use, soils, stream, and water quality data. Developing and applying the watershed model to address the project objectives involved the following major steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Representation of Watershed Sources
4. Model Calibration and Validation

The model configuration steps are presented briefly in the discussion that follows. For a more detailed explanation of each, see Appendix G.

5.1. Watershed Segmentation

Watershed segmentation refers to subdividing the entire watershed into small, discrete subwatersheds for modeling and analysis. Subwatersheds represent hydrologically connected modeling units and capture the drainage areas of their associated stream segments. The delineated subbasins represent the scale at which model simulations take place.

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from its headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam downstream to its confluence with the Dan River. These large segments were further subdivided into subbasins primarily using the watershed stream network, locations of PCB sources, and topographic variability, and secondarily using the locations of available water quality, fish tissue, and sediment PCB monitoring stations; the locations of USGS continuous stream flow gages; and existing watershed boundaries [Virginia subwatersheds (VAWATBOD) developed by VADEQ]. Delineating the Roanoke River watershed resulted in 45 and 107 model subwatersheds for the upper and lower Roanoke (Staunton) segments, respectively (Figures 5-1 and 5-2).

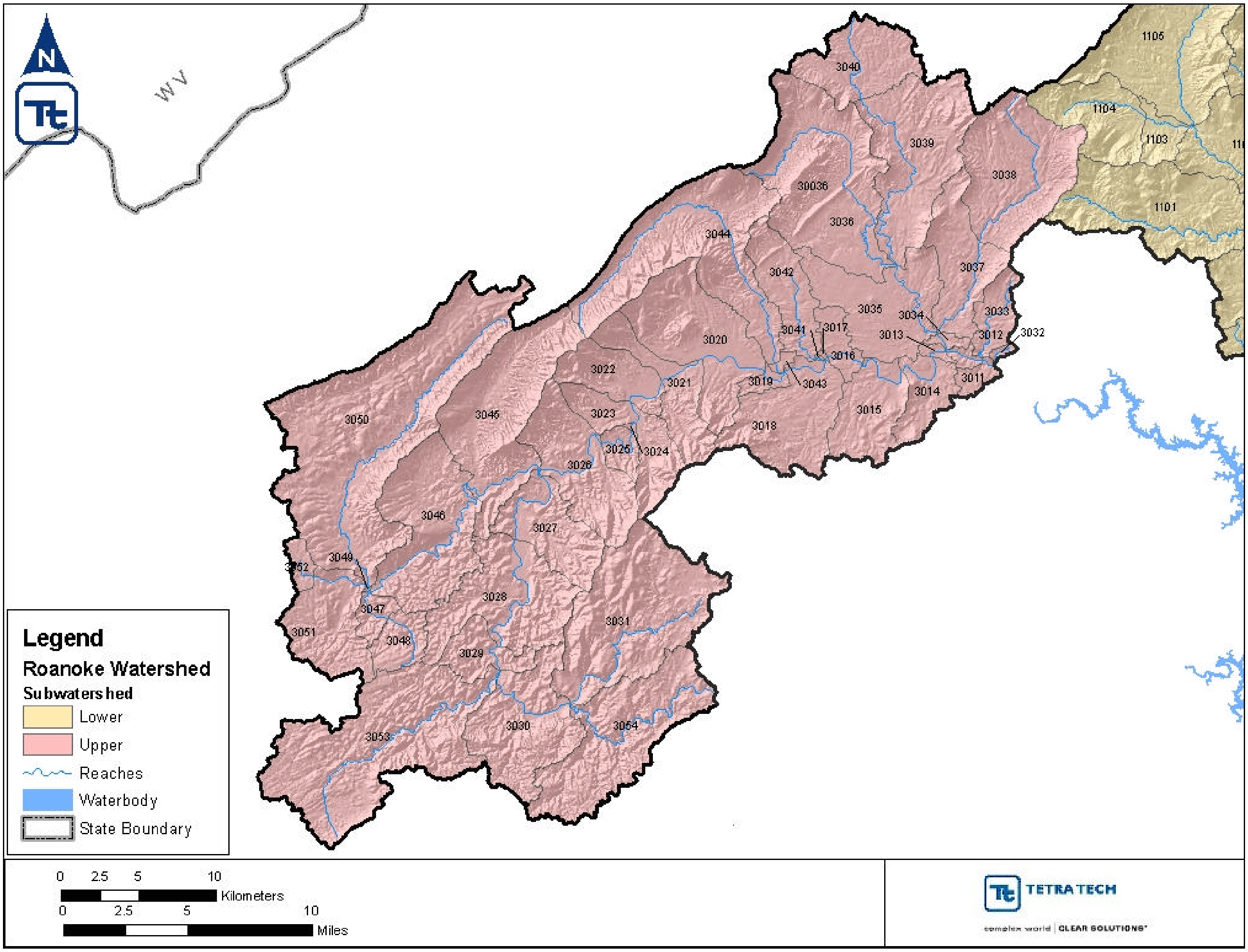

Figure 5-1. Subwatershed divisions of the upper Roanoke.

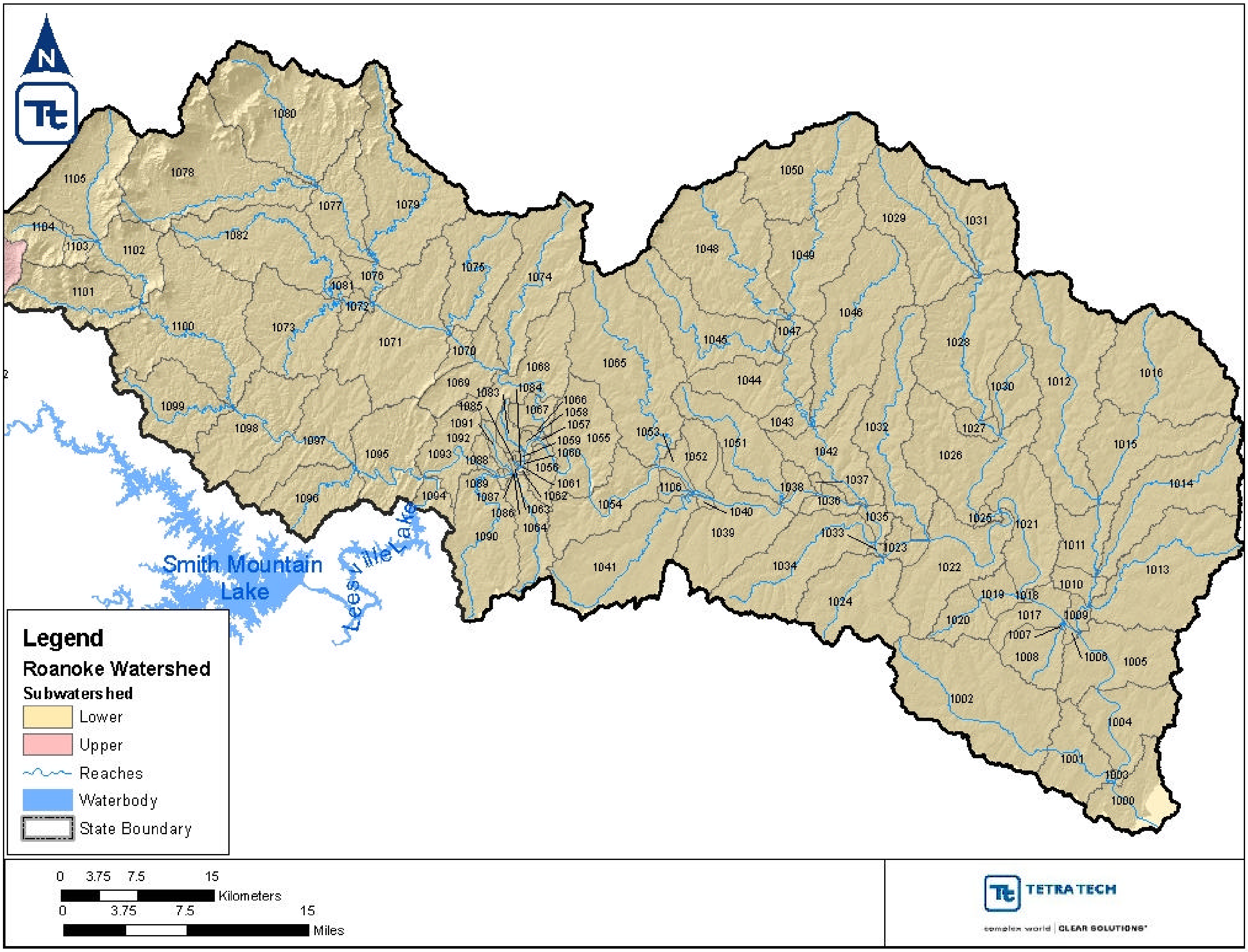

Figure 5-2. Subwatershed divisions of the lower Roanoke (Staunton).

5.2. Configuration of Key Model Components

Configuring the model involved considering three major components, all of which provide the basis for the model's ability to estimate stream flow:

- Meteorological data, which drives the watershed model
- Land use representation, which provides the basis for distributing soils and pollutant loading characteristics throughout the basin
- Watershed physical attributes, which provide the basis for estimating stream channel geometry

5.2.1. Meteorology

Hydrologic processes depend on changes in environmental conditions, particularly weather. As a result, meteorological data are a critical component of the watershed model. These data are the driver of LSPC algorithms simulating watershed hydrology and water quality; thus, accurately representing climactic conditions is required to develop a valid modeling system.

Key meteorological data were accessed from NOAA's National Climatic Data Center (NCDC) to develop a representative data set for the study area covering the modeling period. NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States. COOP stations record hourly or daily rainfall data, while airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover.

5.2.2. Land Use and Soils Data

LSPC requires a basis for distributing hydrologic parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by land use and soils GIS data coverages for the watershed.

General land use/land cover data sets for the Roanoke River watershed were extracted from the NLCD database (MRLC 2001) (see Section 2.1.1). The land use/land cover data were overlain with the hydrologic soil group data described in Section 2.1.1 to create a composite data layer that describes both land cover and soil group distribution in the watershed (Figure 5-3). The composite layer was used as the model land use allowing for the accurate representation of hydrologic variability at the subbasin level by taking into account both land surface and subsurface characteristics.

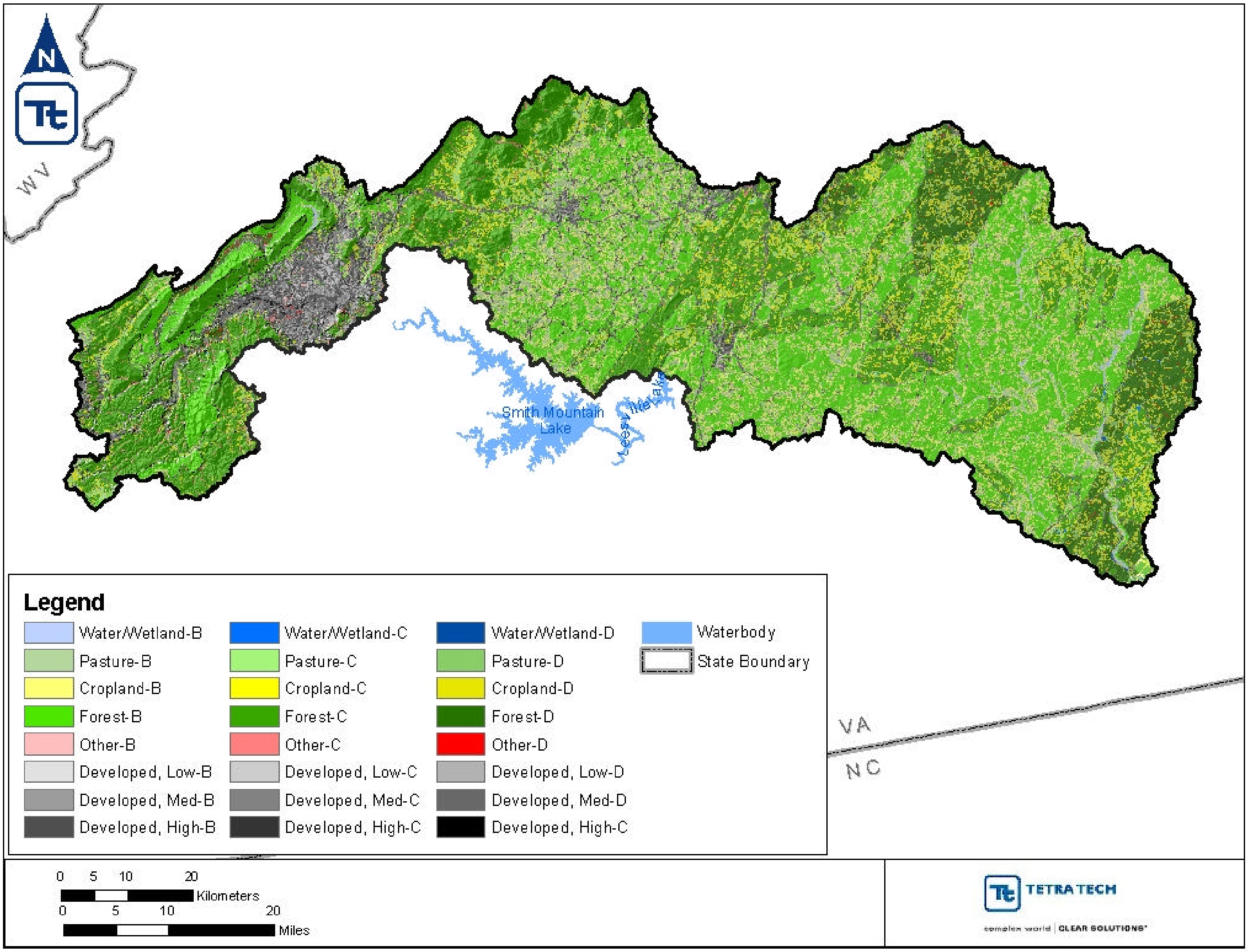

Figure 5-3. Composite model land use.

5.2.3. Elevation Data/Stream Characteristics

LSPC requires a representative stream reach for each subwatershed to route flow throughout the subwatershed network. The stream network connects all the subwatersheds represented in the watershed model. Watershed elevation data derived from the NED (see Section 2.1.3) was used to estimate stream channel slope (USGS 2009).

LSPC requires that each subwatershed-representative stream reach be assigned to a stream class. A stream class defines the model parameters related to the simulation of in-stream pollutant transport and fate processes. A single stream class can be used to define these parameters for all representative stream reaches, or multiple stream classes can be defined in the model allowing parameter variability between stream reaches. For the Roanoke River LSPC model, an individual stream class was defined for each representative stream reach. This approach allowed a unique set of parameters to be assigned to each of the 152 reaches, 107 in the lower and 45 in the upper, corresponding to each model subwatershed.

5.3. Source Representation

The Roanoke River PCB TMDL model considers TSS and PCB sources. Sources of TSS include nonpoint sources associated with the erosion and upland soils washoff and point source discharges from facilities. TSS sources are included in the model setup because the representation of TSS point sources is required to accurately represent watershed hydrology, and nonpoint sediment loadings are the vehicle for sediment-associated PCB loadings.

PCB sources are defined as either current or legacy as described in Section 3.0. Both current and legacy sources are considered by the LSPC model representation of the Roanoke River basin. Current sources are point source dischargers, contaminated sites, urban background including unidentified contaminated sites, and areas covered by general stormwater permits and MS4s. All legacy sources are nonpoint and include in-stream contaminated sediments and atmospheric deposition to surface waters. Available data were plotted in GIS and, as appropriate, assigned to the defined model subbasins, segments, and land uses.

The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and ongoing source investigation whereby sources of PCB contamination are continuously being reviewed and updated on the basis of the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of the TMDLs, rather than a complete and final characterization.

5.3.1. TSS Sources

An inventory of discharge monitoring reports (DMRs) for facilities permitted for point source discharges of TSS in the Roanoke River watershed was provided by VADEQ. In the Roanoke River watershed, 52 facilities representing 55 outfalls are permitted for discharging TSS loads. Effluent from such facilities is represented at the rate and concentrations presented in the DMRs, where available, or at design flow and concentration limits where records were unavailable. Tables 5-1 and 5-2 present the National Pollutant Discharge Elimination System (NPDES) IDs, names, receiving water, design flow, and average concentration limit for facilities in the upper and lower model segments, respectively.

Table 5-1. Model TSS point sources—Upper Roanoke model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
WVWA Falling Creek Water Treatment Plant	VA0001465	001	0	Falling Creek	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	001	0	Carvins Creek, unnamed tributary 1	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	002	0	Carvin Creek unnamed tributary 2	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	003	0	Carvin Creek unnamed tributary 2	30
Steel Dynamics	VA0001589	005	0.039	Peters Creek	No limit
Norfolk Southern Railway Co - Shaffers Crossing	VA0001597	002	0	Lick Run unnamed tributary	30
Shawsville Town - Sewage Treatment Plant	VA0024031	001	0.2	South Fork Roanoke River	30
WVWA Roanoke Regional Water Pollution Control Plant	VA0025020	001	55	Roanoke River	2.5
Blacksburg Country Club Sewage Treatment Plant	VA0027481	001	0.035	North Fork Roanoke River	30
Montgomery County PSA - Elliston-Lafayette Waste Water Treatment Plant	VA0062219	001	0.25	South Fork Roanoke River	30
Oak Ridge MHP Sewage Treatment Plant	VA0072389	001	0.015	Falling Creek unnamed tributary	30
Roanoke Moose Lodge	VA0077895	001	0.0047	Mason Creek	30
WVWA Crystal Spring Water Filtration Plant	VA0091065	001	0.092	Roanoke River	30

Table 5-2. Model TSS point sources—Lower Roanoke (Staunton) model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Motiva Enterprises LLC - Montvale	VA0001490	001	0.065	South Fork Goose Creek	No limit
Bedford City - Water Treatment Plant	VA0001503	001	0.038	Little Otter River unnamed tributary	30
Dan River, Inc – Brookneal	VA0001538	001	1.326	Roanoke (Staunton) River	No limit
ITG Burlington Industries, LLC, Hurt Plant	VA0001678	001	3.275	Roanoke (Staunton) River	No limit
Appomattox Trickling Filter Plant	VA0020249	001	0.17	Caldwells Creek	30
Altavista - Wastewater Treatment Plant	VA0020451	001	3.6	Roanoke (Staunton) River	30
Bedford County Schools - Liberty High School	VA0020796	001	0.024	Little Otter River unnamed tributary	30
Bedford County Schools - Body Camp Elem. School	VA0020818	001	0.005	Wells Creek unnamed tributary	30
Bedford Co - New London Academy	VA0020826	001	0.006	Buffalo Creek unnamed tributary	30
Bedford Co - Otter River Elem. School	VA0020851	001	0.005	Big Otter River unnamed tributary	30
Bedford County Schools - Thaxton Elem. School	VA0020869	001	0.004	Wolf Creek unnamed tributary	30
Brookneal - Staunton River Lagoon	VA0022241	001	0.078	Roanoke (Staunton) River	45
Brookneal - Falling River Lagoon	VA0022250	001	0.082	Falling River	30
Bedford City - Sewage Treatment Plant	VA0022390	001	2	Little Otter River	30
Halifax County Schools Clays Mill Elem. School	VA0022748	001	0.0072	Mill Branch unnamed tributary	30
DOC Rustburg Correctional Unit 9	VA0023396	001	0.028	Button Creek unnamed tributary	30
Moneta Adult Detention Facility	VA0023515	001	0.021	Mattox Creek unnamed tributary	30
Campbell Co Util and Serv Auth - Rustburg	VA0023965	001	0.2	Molley Creek	30
Keysville Waste Water Treatment Plant	VA0024058	001	0.5	Ash Camp Creek	30
Charlotte County Schools Bacon District Elem. School	VA0029319	001	0.006	Little Horsepen Creek unnamed tributary	30
Charlotte County Schools Phenix Elem. School	VA0029335	001	0.006	Terrys Creek unnamed tributary	30
Briarwood Village Mobile Home Park Sewage Treatment Plant	VA0031194	001	0.024	Smith Branch unnamed tributary	30
BP Products North America Incorporated	VA0054577	001	0	South Fork Goose Creek	No limit
BP Products North America Incorporated	VA0054577	003	0	South Fork Goose Creek unnamed tributary	No limit
Magellan Terminals Holdings LP - Montvale Terminal	VA0055328	001	0.008	South Fork Goose Creek unnamed tributary	No limit
Camp Virginia Jaycees Sewage Treatment Plant	VA0060909	001	0.015	Day Creek unnamed tributary	30
Charlotte County Schools Jeffress Elem. School	VA0063118	001	0.004	Sandy Creek unnamed tributary	30
Southern Mobile Home Park	VA0063568	001	0.0096	Piney Creek unnamed tributary	30
Bedford County Schools - Staunton River High School	VA0063738	001	0.026	Shoulder Run unnamed tributary	30
Thousand Trails Lynchburg Preserve	VA0068543	001	0.0396	Mollys Creek	30
Clover Waste Water Treatment Plant	VA0073733	001	0.035	Clover Creek	30
Woodhaven Nursing Home - Montvale	VA0074870	001	0.005	South Fork Goose Creek unnamed tributary	30
Campbell Co Utility and Service Authority - Otter River Water Filtration Plant	VA0078646	001	0.0428	Big Otter River	30

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Alum Springs Shopping Center	VA0078999	001	0.04	Buffalo Creek	30
Old Dominion Clover Power Station	VA0083097	001	1.735	Roanoke (Staunton) River	30
Old Dominion Pittsylvania Power Station	VA0083399	001	0.192	Roanoke (Staunton) River	30
Old Dominion Altavista Power Station	VA0083402	001	0.117	Roanoke (Staunton) River	30
Brookneal Town Water Treatment Plant	VA0084034	001	0.0006	Phelps Creek	30
Drakes Branch Waste Water Treatment Plant	VA0084433	001	0.08	Twitty's Creek	30
Montvale Wastewater Treatment Plant	VA0087238	001	0.05	South Fork Goose Creek	30
Dillons Trailer Park - Sewage Treatment Plant	VA0087840	001	0.018	Poorhouse Creek	55
Cedar Rock Waste Water Treatment Plant	VA0091553	001	0.015	Elk Creek unnamed tributary	30
Moneta Regional Waste Water Treatment Plant	VA0091669	001	0.5	Hunting Creek	30

5.3.2. PCB Sources

Current Sources

The 13 point and 21 nonpoint sources described in Section 3.0 are represented as current PCB sources in the model. In addition to the known current sources, urban land areas throughout the model watershed have been assigned a level of contamination on the basis of available sediment monitoring data to account for unidentified contaminated sites. Such areas are referred to as *urban background/unidentified* sources for the purposes of this TMDL.

Nonpoint Sources

The LSPC model was set up to represent nonpoint source loading of PCBs as a sediment-associated process. For the representation of known contaminated sites, a PCB-contaminated land use was created. Using estimates of site footprints and locations, PCB land use areas were assigned to model subbasins. The areas of PCB land uses are shown in Figures 3-2 through 3-4.

Sites known to have PCB-contaminated soils were delineated into parcels as depicted in available aerial photography and USGS topoquads to estimate the contamination footprint. General model land use areas within the footprint were converted to corresponding PCB land uses and assigned a soils tPCBs concentration, or *potency factor*, on the basis of available monitoring data. The soils monitoring data from the literature sources listed in Section 3.1 were used to estimate potency factors for known contaminated sites. A potency factor calculated from available sediment monitoring data was also assigned to the remaining land areas in the watershed to capture loadings from urban background/unidentified contaminated sites. Table 5-3 lists the model-represented known contaminated sites, associated land area, and contamination level. For a discussion of contaminated site contamination levels (or potency factors), see Appendix G (Section G2.3.2).

Table 5-3. Model PCB-contaminated sites[a]

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
Upper Roanoke River					
Dixie Caverns Landfill	VAD980552095[c]	Roanoke	Roanoke River	38.7	Moderate
Roanoke River Floodway Bench Cuts		Roanoke	Roanoke River	47.4	Moderate
Norfolk Southern 12		Roanoke City	Roanoke River	64.3	Moderate
Evans Paint	VASFN0305570[c]	Roanoke City	Roanoke River	1.7	Moderate
Virginia Scrap Iron Co.	VRP00408[d]	Roanoke City	Roanoke River	7	Moderate
				0.17	High

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
Norfolk Southern 1		Roanoke City	Roanoke River	2.5	Moderate
Tinker-American Electric Power (AEP) property		Roanoke City	Roanoke River	23	Moderate
Riverdale Development (formerly American Viscose Co.)	VRP00394[d]	Roanoke City	Roanoke River	81.1	Moderate
Appalachian Power Co. (APCO) Yard		Roanoke City	Roanoke River	0.8	Moderate
Jacob Webb		Roanoke City	Roanoke River	5.5	Moderate
Lower Roanoke (Staunton) River					
Burlington Industries-Altavista[b]	VA0001678	Pittsylvania	Sycamore Creek	116.3	Moderate
English Construction		Pittsylvania	Roanoke (Staunton) River	12	Moderate
West town dump-Altavista		Campbell	Lynch Creek	28	Moderate
Oil distributors-Altavista		Campbell	Lynch Creek	5.7	Moderate
Lane Furniture Co.		Campbell	Roanoke (Staunton) River	49.6	Moderate
BGF Industries[b]		Campbell	Roanoke (Staunton) River unnamed tributary	20.6	High
East town Dump-Altavista		Campbell	Roanoke (Staunton) River	14.5	Moderate
Altavista STP	VA0020451	Campbell	Roanoke (Staunton) River	25.6	Moderate
A. O. Smith		Campbell	Roanoke (Staunton) River unnamed tributary	7.7	Moderate
Schrader Bridgeport[b]		Campbell	Roanoke (Staunton) River unnamed tributary	16	Moderate
Dan River, Inc.	VA0001538	Campbell	Roanoke (Staunton) River	37.7	Moderate

a. The site acreage and contamination levels are those used in the model. It should be noted that these data are based on best available information during the PCB Source investigation. Both acreage and contamination levels are estimated <u>with emphasis on the boldfaced sites</u>.
b. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (see *Point Sources* in Section 5.3.2)
c. EPA Superfund ID#
d. Virginia Voluntary Remediation Program (VRP) site#

Point Sources

PCB point sources for the TMDLs are traditional facility effluent, MS4s, and sites permitted for stormwater discharges. An inventory of the three types of point sources was provided by VADEQ to be included in the Roanoke River watershed model.

Facilities found to be discharging PCB contaminated effluent as part of the 2005–2008 Special Study monitoring are represented as PCB point sources in the model. In addition, several additional facilities were included as PCB point sources at the request of VADEQ. Facilities represented as PCB point sources and associated information including NPDES ID, mean monthly flow, and model represented effluent PCB concentration are presented in Table 5-4.

Table 5-4. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Mean monthly flow (mgd)	Mean PCB conc. (pg/L)
Upper Roanoke River					
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.02	390
Montgomery County PSA - Shawsville Sewage Treatment Plant	Sewerage systems	VA0024031	001	0.06	390
Montgomery County PSA - Elliston Lafayette Waste Water Treatment Plant	Sewerage systems	VA0062219	001	0.07	390

NPDES facility name	Facility type	NPDES ID	Outfall	Mean monthly flow (mgd)	Mean PCB conc. (pg/L)
Steel Dynamics	Steel works	VA0001589	005	0.06	1,090
Norfolk Southern Railway Co - Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.009	390
WVWA Roanoke Regional Water Pollution Control Plant	Sewerage systems	VA0025020	001	37.35	340
Lower Roanoke (Staunton) River					
ITG Burlington Industries, LLC - Hurt Plant	Fabrics finishing	VA0001678	001	2.13	19,150
Old Dominion Pittsylvania Power Station	Electric Services	VA0083399	001	0.11	140
Altavista Town - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	1.54	10,000
Old Dominion Altavista Power Station	Electric Services	VA0083402	001	0.117	140
Dan River, Inc. - Brookneal	Fabrics finishing	VA0001538	001	0.68	500
Brookneal Town - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.04	140
Old Dominion Clover Power Station	Electric Services	VA0083097	001	0.75	190

VADEQ provided an inventory of MS4s and sites and facilities that were issued general permits for stormwater discharges in the Roanoke River basin. Such facilities are not subject to numerical criteria, but have responsibilities related to minimizing stormwater runoff and pollutant loads, and may be subject to monitoring requirements. These areas are not represented explicitly in the model but are assigned PCB WLAs in the TMDL. PCB loads for these areas are estimated as an area-weighted fraction of nonpoint source, land-use contributions.

Modeled land uses were overlain with GIS coverages of MS4s and sites covered by general stormwater permits to characterize the land use distributions of those areas. PCB loads for the permitted areas were calculated as the load generated by their respective land areas. Table 5-5 lists MS4s in the Roanoke River basin. Appendix C provides a list of sites and facilities covered by general stormwater permits. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit.

Table 5-5. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613
Town of Christiansburg	VAR040025	1,193

Legacy Sources

Legacy sources represented in the model are PCB contributions from contaminated streambed sediments and background atmospheric deposition of PCBs to surface waters. Those sources exist at an interface with the affected waterbody and can be characterized as nonpoint sources.

Contaminated Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical loadings, current loadings, or both. The PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers.

The mass of PCBs in streambed sediments available for loading at the beginning of the simulation period is set as an initial condition in the LSPC model setup. It is defined by a sediment tPCBs concentration and streambed depth, density, and porosity assigned to each model-represented stream class. The Roanoke River basin model includes an individual stream class for each model subbasin-representative stream reach, as discussed in Section 5.2.3. Stream classes define critical in-stream parameters including initial sediment pollutant concentration, streambed depth, density, and porosity. Assigning individual stream classes to each subwatershed stream reach allows model parameters to be specific to each reach.

Background Atmospheric Deposition

The net exchange of gas-phase molecules between the atmosphere and a waterbody (dry atmospheric deposition) is a function of the relative concentrations of the chemical in each. There are no available data to characterize the atmospheric and water column concentrations of gaseous PCBs in the Roanoke River watershed. The Chesapeake Bay Program Atmospheric Deposition Study (Chesapeake Bay Program 1999) has estimated net dry atmospheric tPCBs deposition rates for urban and regional (nonurban) areas in the Chesapeake Bay watershed as 16.3 and 1.6 $\mu g/m^2/yr$, respectively (ICPRB 2007). The regional atmospheric deposition rate was applied to the entire Roanoke River watershed as an estimate of local conditions. If local data become available, they will be incorporated into future TMDL studies.

5.4. Model Boundary Condition

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from the River headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam to its confluence with the Dan River. Because there is no dynamic link between the two, to accurately represent the lower watershed, discharge data for the Leesville Dam, which represents all upstream flows to that point on the river, were incorporated as a model boundary condition.

To account for the PCB loadings from sources in the upper and middle Roanoke, a boundary condition PCB water concentration was assigned to the model-represented Leesville Dam discharge. The boundary water column concentration was estimated from available fish tissue data collected at monitoring station ROA140.66—which is the only monitoring station in Leesville Reservoir—using calculated BAFs for resident fish species. A BAF-converted fish tissue PCB concentration is an estimate of the ambient water quality that captures all upstream source contributions and associated watershed and in-stream processes.

Four fish tissue records were converted into equivalent water column concentrations, giving a concentration range of 40.0–120.0 pg/L and a median concentration of 79.0 pg/L. The median value was assigned as the model boundary condition. That value is significantly lower than the applicable state human health water quality criterion for PCBs (1,700 pg/L) and is indicative of Leesville Reservoir's status as unimpaired for PCBs. Discussion of the methodology for developing and applicability of BAFs is presented in Appendix A.

5.5. Existing Conditions/Model Calibration and Validation

The model was developed in a step-wise manner, beginning with basic watershed processes and building on them to ultimately represent PCB loading and transport. The foundation of the model is simulated hydrology. On the basis of the calibrated hydrology, sediment loading and transport were simulated and calibrated. Watershed hydrology and sediment simulations provide the framework for PCB loadings and transport modeling. The sections that follow discuss briefly the development of each aspect of the watershed model. For a more detailed explanation of each, see Appendix G.

5.5.1. Selecting a Representative Modeling Period

Selecting a representative modeling period was done using the availability of stream flow and water, fish tissue, and sediment monitoring data collected in the Roanoke River watershed that cover varying wet and dry periods. VADEQ has collected water, fish tissue, and sediment monitoring data for the Roanoke River since 1973, but the period of 1990–2008 was selected for modeling purposes. This period includes monitoring results in step with modern analytical methods and includes varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area.

5.5.2. Hydrology

Hydrology and water quality calibration are performed in sequence, because water quality modeling is dependent on an accurate hydrology simulation. The driver of model hydrology is climatological data, described in Section 5.2.1 and Appendix G. Such data are used as input to simulate the watershed water balance within the LSPC model framework that describes the watershed subbasin network, topology, land use, soils, and reach characteristics.

Hydrology Calibration/Validation

Land use-specific hydrology parameters are used to calibrate modeled hydrology. Calibration involves comparing the modeled and observed flow rates at locations in the watershed where observed data are available. Appendix D presents LSPC Hydrology parameters and the range of values used for the Roanoke River watershed model.

STATSGO served as a starting point for designating infiltration and groundwater flow parameters. Starting values were refined through the hydrologic calibration process. As discussed in Section 5.2.2, a custom land use data layer was developed that accounted for the variability of hydrologic characteristics throughout the watershed. To account for topography variability in the upper and lower Roanoke (Staunton), two groups of land use parameters were configured in the model. This allowed for designating separate hydrology parameter values for the upper and lower segments. Assigning appropriate parameter values was dependent on the composite hydrologic soil group/land cover distribution of each subwatershed.

Average daily flow discharge data were available for eight and seven USGS gages in the upper and lower Roanoke (Staunton) River, respectively (Figure 5-4). The upper Roanoke watershed model was calibrated using daily stream flow data from USGS gages 02056000 and 02053800, while the lower Roanoke (Staunton) was calibrated using gages 02066000 and 02061500. USGS gages 02056000 and 02066000 were selected as calibration points because they represent the farthest downstream locations in the upper and lower sections and capture the distribution of land uses and soil groups in each. An accurate model calibration at these points would capture the overall water budget for the upper and lower Roanoke (Staunton) and reflect the cumulative range of flows for their entire stream networks.

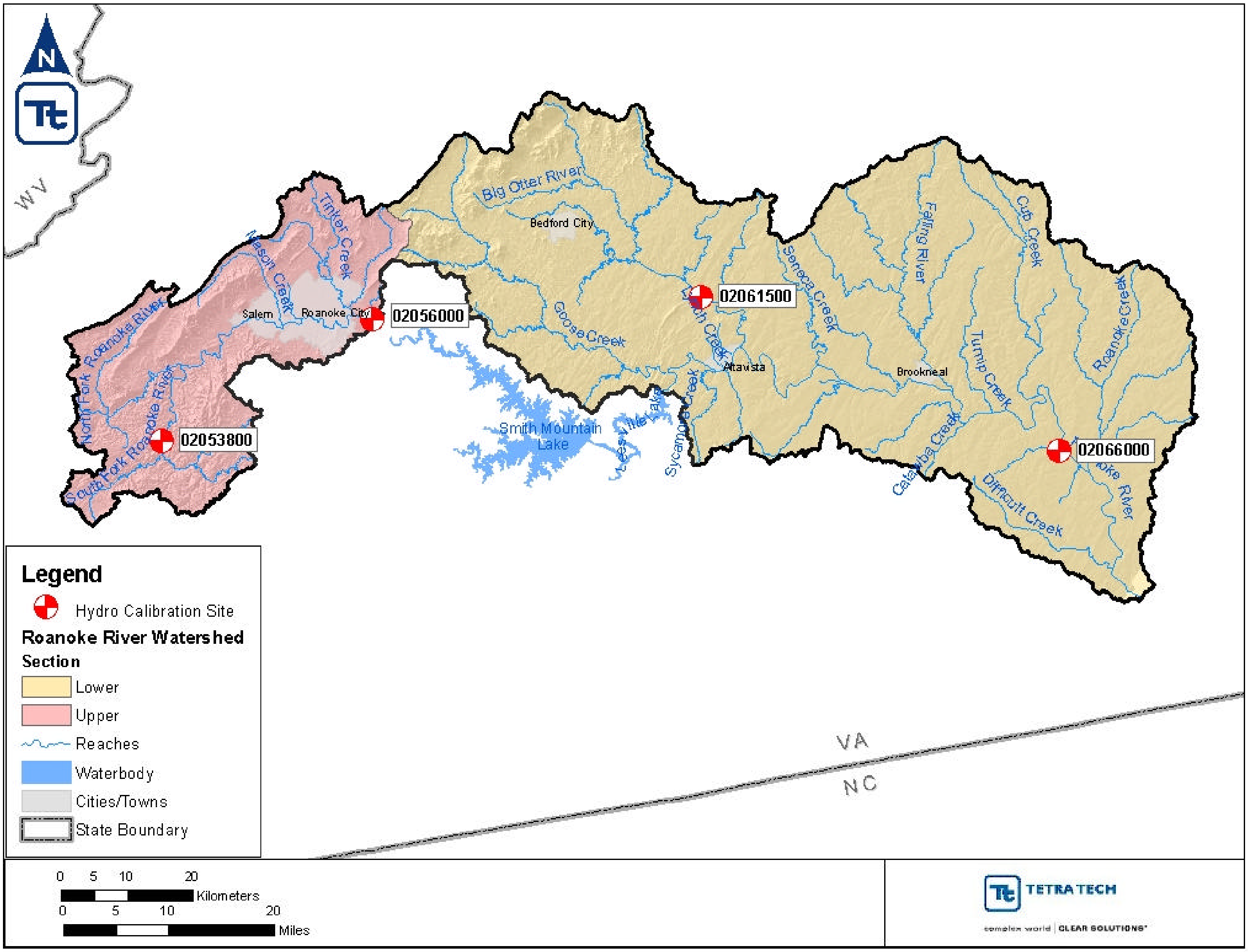

Figure 5-4. Locations of hydrology calibration USGS gages.

USGS gages 02053800 and 02061500 are on tributaries to the upper and lower Roanoke (Staunton)—South Fork Roanoke River and Big Otter River, respectively—and were used as calibration points to verify the applicability of the calibration to smaller areas within watersheds. Agreement between simulated and observed flows at both mainstem and tributary points would suggest an accurate hydrologic system representation of the upper and lower Roanoke (Staunton) watersheds. The USGS gages used for calibration are listed in Table 5-6.

Table 5-6. USGS continuous daily discharge gages used for hydrology calibration

Site ID	Station name	Drainage area (square miles)	Period of record
Upper Roanoke River			
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1990–5/31/2008
02056000	Roanoke River at Niagra, VA	509	1/1/1990–5/31/2008
Lower Roanoke (Staunton) River			

Site ID	Station name	Drainage area (square miles)	Period of record
02061500	Big Otter River near Evington, VA	315	1/1/1990–5/31/2008
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1990–5/31/2008

Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period
2. Representation of low-flow, average-flow, and high-flow water years
3. Consistency of selected period with key model inputs (i.e., land use coverage)
4. Quality of initial modeled versus observed data correlation

After a review of the data for those four selection criteria, the years 2004 and 1996 were chosen as calibration periods for the upper and lower Roanoke (Staunton), respectively. The NLCD land use coverage used in the model was developed in 2001; therefore, the selected calibration periods are consistent with that key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a period of 18.5 years (January 1, 1991, through May 31, 2008) for both the upper and lower watersheds.

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved adjusting infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results are presented in Appendix E. It is important to note that although the included log plots allow for comparative visualization of flows that span several orders of magnitude, that type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows.

Overall, the calibrated model predicted the watershed water budget well. All model validations showed the modeled water budget to be within 9 percent of observed conditions. Predicted seasonal volumes were also within recommended ranges at every location. Predicted storm volumes and storm peaks also closely matched observed data. Because the runoff and resulting stream flow are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorological and gage stations.

5.5.3. Sediment

In-stream sediment concentrations are modeled as a function of discrete processes including erosion of soil particles from land areas; transport of eroded sediments to streams; and in-stream transport, scour, and deposition of sediments. Sediment loadings are dependent on hydrologic conditions, particularly the amount and timing of surface runoff, while in-stream processes are dependent on the unique hydraulics of each reach.

Sediment Calibration

Land use and stream class-specific sediment parameters are used to calibrate modeled sediment loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed sediment loads and TSS concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC sediment parameters and the range of values used for the Roanoke River watershed model.

Sediment land use parameters are closely related to the factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), which served as a starting point for designating related soil detachment and washoff parameters. Appropriate values were assigned to the composite land use on the basis of the land cover description and hydrologic soil group. Starting values were refined through the sediment calibration process. Event mean concentrations were also defined to represent background concentrations not captured by the discrete erosive processes simulated by the model, particularly for low-flow conditions. All sediments and soils represented in the model are assigned particle class fractions (e.g. % sand, silt, clay). Analysis of the distribution of STATSGO soil groups in the watershed was used to estimate the particle class fractions of eroded upland soils.

In-stream sediment parameters are based primarily on the physical properties of the particle class fractions including particle diameter, fall velocity, and density. Such properties were estimated from the range of literature values presented in *EPA BASINS Technical Note 8, Sediment Parameter and Calibration Guidance for HSPF* (USEPA 2006).

Observed TSS data are available for 21 and 43 monitoring stations in the upper and lower Roanoke (Staunton), respectively. On the basis of the number of data records and co-location with USGS continuous flow gages, the Roanoke River watershed model was calibrated for sediment using TSS monitoring stations ROA227.42, ROA204.76, ROA97.46, and ROA67.91 (Figure 5-5). Stations at river mile 227.42 and 204.76 are in the upper Roanoke model segment, while stations at river mile 97.46 and 67.91 are in the lower Roanoke (Staunton) model segment. General descriptions of these monitoring locations are presented in Table 5-7.

Table 5-7. TSS monitoring station used for TSS calibration

Station ID	Station description	Period of record	Associated flow gage
Upper Roanoke River			
4AROA227.42	Rt. 773 at gaging station in Lafayette, VA	1/10/1990–5/9/2007	USGS 02054500
4AROA204.76	Roanoke River at Roanoke City, VA	10/13/2005–11/22/2005	USGS 02055000
Lower Roanoke (Staunton) River			
4AROA097.46	Roanoke River at Brookneal gage, Rt. 50	1/24/1990–5/1/2007	USGS 02062500
4AROA067.91	Rt.746 bridge (Watkina Bridge) near Randolph, VA	2/1/1990–9/10/2007	USGS 02066000

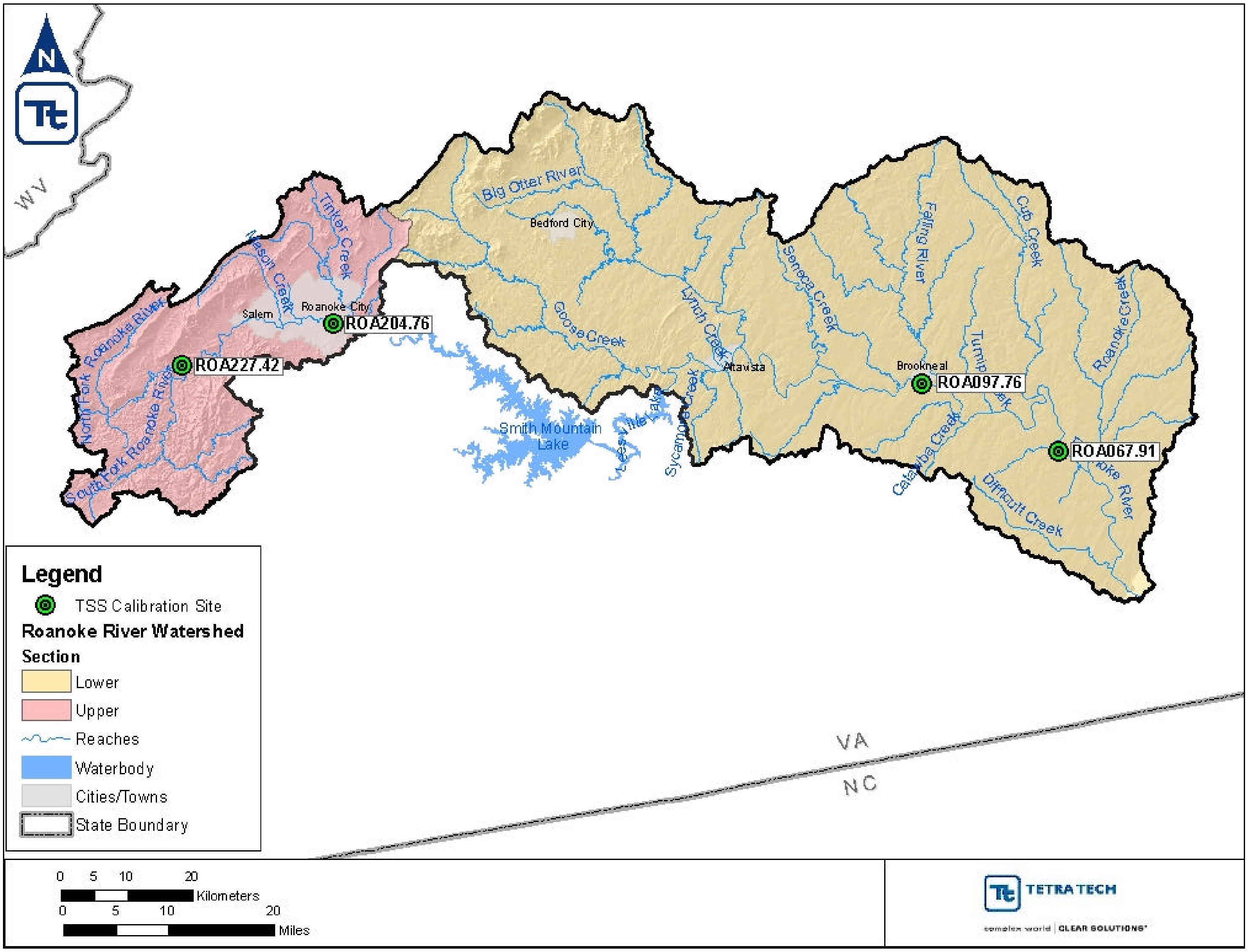

Figure 5-5. Locations of TSS monitoring calibration stations.

Sediment simulations were run for the model time series as described in Section 5.5.1. Antilog plots of flow versus sediment loads for observed and modeled data are presented for the selected calibration locations in Appendix F. In general, the magnitude of sediment loadings for observed and modeled data increase at a similar rate and are within the same range for the gradient of flow conditions. Observed loadings are, generally, more variable in relation to flow conditions than in modeled scenarios. Log plots comparing model output to observed TSS concentrations at the selected locations are also presented in Appendix F. Note that observed concentrations reported as detection limits have been assigned a concentration of 3 mg/L.

5.5.4. PCBs

LSPC was configured to simulate tPCBs in both the dissolved- and sediment-associated states to characterize water quality conditions in the Roanoke River watershed. The simulation of loadings and in-stream behavior of tPCBs as a sediment-associated pollutant is dependent on the hydrologic and TSS calibrations that serve as its foundations.

The model was set up to represent a unique stream class for each subwatershed stream reach as discussed in Section 5.2.3. Each model stream class defines critical in-stream parameters, including the conditions related to the mass balance of tPCBs for the sediment-water system in each stream reach. tPCBs are partitioned into dissolved and particulate fractions in both the water (PCB with suspended sediment interaction) and sediment layers (PCB with bed sediment interaction). LSPC simulates deposition (settling) and scour (resuspension) of PCBs with sediment in addition to sorption/desorption and in-stream losses.

PCB Calibration

Land use and stream class-specific PCB parameters are used to calibrate modeled tPCB loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed tPCB concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC PCB parameters and the range of values used for the Roanoke River watershed model.

Monitoring data collected by VADEQ were used to define the model's design and representation of critical parameters required for simulating tPCBs in each stream class. Such parameters include the following:

- Particle class fractions of upland soils and streambed sediments
- The initial tPCBs concentration of particle class fractions
- Partition coefficients as a function of the fraction of the organic carbon content in stream sediments and homolog composition of PCB contamination
- Adsorption/desorption rates as a function of the homolog composition of PCB-contaminated suspended sediments

Observed water column tPCB data are available for 29 monitoring stations throughout Roanoke River watershed. These stations were sampled as part of the 2005–2008 PCB monitoring special study conducted by VADEQ (see Section 2.3). On the basis of the confidence in the analytical results of the sampling data, the Roanoke River watershed model was calibrated at the 24 PCB monitoring stations shown in Figures 5-6 and 5-7. General descriptions of the monitoring locations are presented in Table 5-8.

Table 5-8. PCB monitoring stations used for PCB calibration

Monitoring station	Station description	Sample dates
Upper Roanoke River		
4AROA227.42	Rt. 773 at gaging station in Lafayette	3/3/08, 4/7/08
4AROA212.17	419 Bridge near Lewis Gale	3/3/08, 4/7/08
4AROA207.08	Roanoke River at Memorial Bridge	3/3/08, 4/7/08
4AROA204.76	Roanoke River at Walnut Ave. in Roanoke City	3/3/08, 4/7/08
4AROA199.20	Roanoke River below Niagara Dam	3/3/08, 4/7/08
Lower Roanoke (Staunton) River		
4AGSE000.20	Goose Creek	9/10/07, 10/26/07
4AROA131.55	Rt. 29 Bridge bypass, Altavista	8/8/07, 5/9/08
4ALYH000.17	Lynch Creek at Riverside Park	5/9/2008
4ASCE000.26	Sycamore Creek near Pocket Road	8/27/2007
4AROA129.55	Roanoke River near business Rt. 29 bridge at USGS gage	8/8/07, 10/26/07, 5/9/08
4AXLN000.00	Unnamed trib on BGF property	12/1/2007
4ABOR000.62	Big Otter River at Rt. 712	8/21/07, 10/26/07
4AROA127.79	Roanoke River downstream of Altavista STP	8/9/2007
4AROA124.59	Roanoke River downstream Altavista	3/10/08, 5/9/08

Monitoring station	Station description	Sample dates
4AROA108.09	Roanoke River near Long Island	9/10/2007
4AFRV002.78	Falling River downstream of lagoon outfall	9/10/2007
4AROA097.76	Roanoke River upstream of Brookneal	8/8/07, 3/6/08
4AROA090.50	Roanoke River at Rt. 620 South of Brookneal	8/8/07, 10/26/07
4ACUB002.21	Cub Creek at Rt. 649 (Coles Ferry Road)	8/28/07, 10/26/07
4AROA067.91	Roanoke River near Rt. 746	9/10/07, 10/26/07
4AROC001.00	Roanoke Creek near Saxe	8/28/07, 10/26/07
4ABWC001.00	Black Walnut Creek	10/26/2007
4AROA059.12	Roanoke River near Rt. 360 - Clover	9/10/07, 10/26/07
4ADFF002.02	Difficult Creek at Rt. 716	8/28/2007

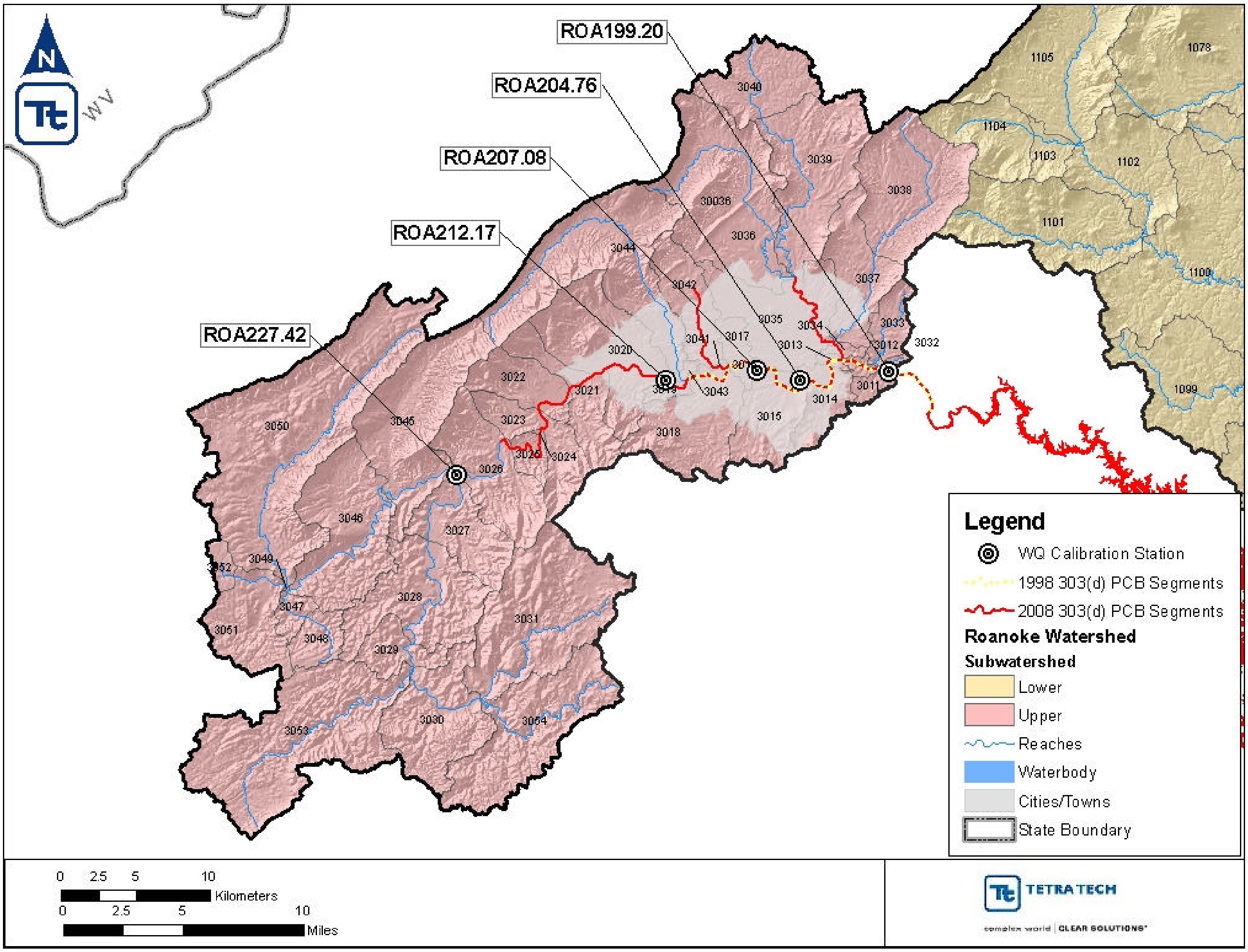

Figure 5-6. Locations of upper Roanoke tPCB-monitoring calibration stations.

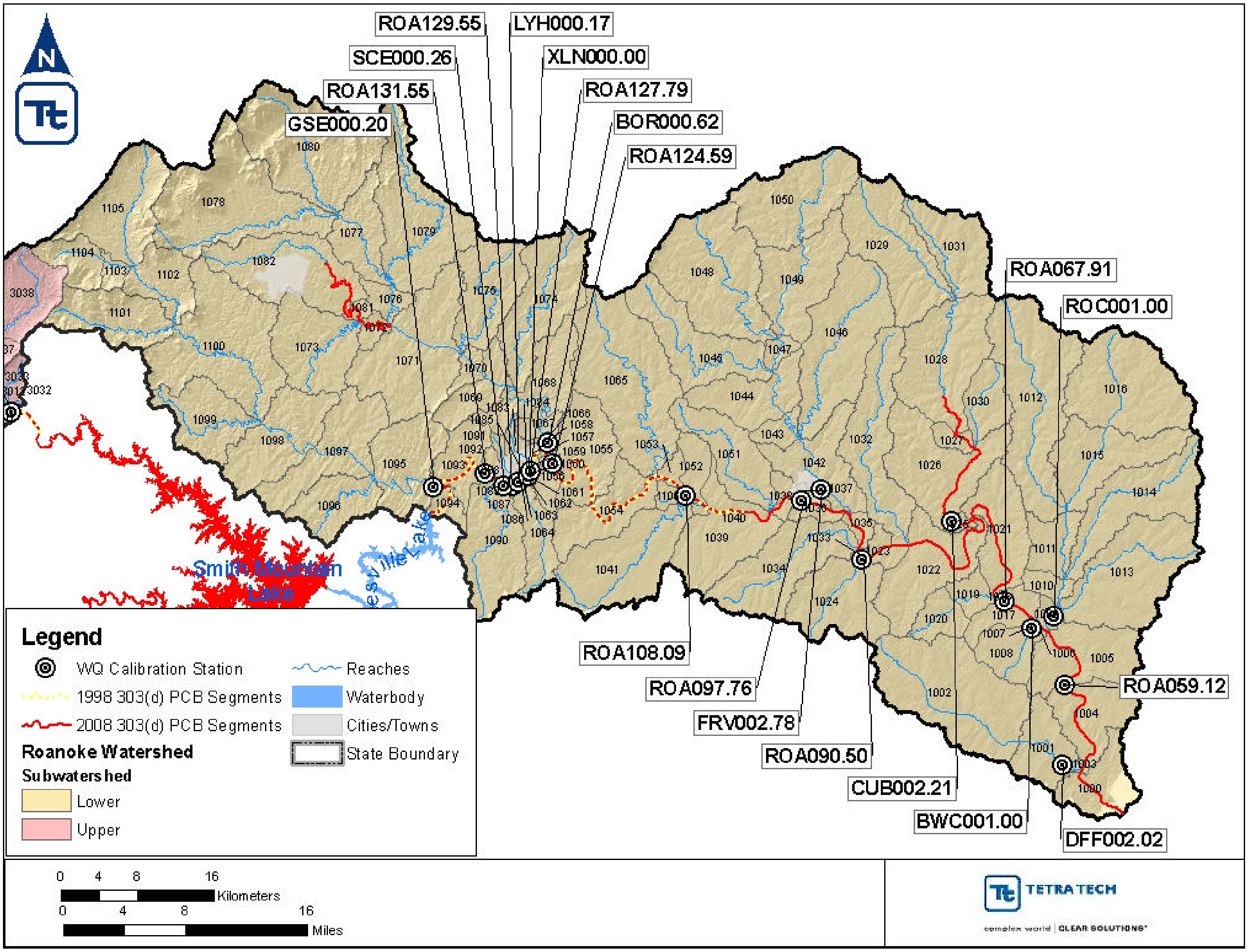

Figure 5-7. Locations of lower Roanoke (Staunton) tPCB-monitoring calibration stations.

PCB simulations were run for the model time series as described in Section 5.5.1. Log plots for observed and modeled tPCBs are presented at the selected calibration locations in Appendix F. In general, the model captures the trends and magnitude of contamination observed in the monitoring data.

At locations with significant upstream contaminated sources and high in-stream shear stresses, storm events cause in-stream concentration spikes as contaminated soils are transported to streams and contaminated streambed sediments are resuspended, releasing associated PCBs. In areas where there are few or no contaminated sites or streambed sediments, storm events cause in-stream tPCBs concentrations to decrease as clean inflows dilute the PCB concentrations directly fluxing from streambed sediments and atmospheric deposition. Finally, in areas where there are highly contaminated streambed sediments and relatively low in-stream shear stresses, the direct flux of PCBs from streambed sediments dominate water column concentrations, whereby storm events cause in-stream tPCBs concentrations to decrease even though there could be significant areas of upstream contaminated soil.

In addition, the magnitude of modeled low-flow and high-flow tPCBs concentrations are generally within the same magnitude as the observed data. This suggests that upland soils contamination areas and PCB concentrations, initial streambed sediment PCB concentrations, and water column-streambed sediment dynamics are being represented appropriately.

6. TMDL ALLOCATION ANALYSIS

A TMDL is the total amount of pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards or goals. It is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for both nonpoint sources and background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is represented by the following equation:

$$\text{TMDL} = \Sigma WLAs + \Sigma LAs + MOS$$

In TMDL development, allowable loadings from pollutant sources are established and when summed, are equivalent to the TMDL which forms the basis for the requirement of water quality-based controls. TMDLs can be expressed on a mass loading basis (e.g., grams of pollutant per day) or as a concentration in accordance with 40 CFR 130.2(l).

The goal of the model application was to determine allowable source contributions that meet the targeted tPCBs water quality TMDL endpoints specific to the upper and lower sections of the watershed. Boundary conditions and source inputs were adjusted to achieve in-stream whole water column tPCBs concentrations that meet the TMDL targets of 390 and 140 pg/L for the upper and lower sections, respectively. Baseline loads represent the existing condition where no load reductions have been applied to the source categories. WLAs and LAs were assigned on the basis of meeting the assimilative capacity of each subwatershed drainage area delineated for the Roanoke River watershed.

Sources were reduced to meet the TMDL endpoints in the worst case scenario subwatersheds in each watershed section. The worst case scenario subwatersheds were 3013 and 1000, both representing the Roanoke River mainstem in the upper and lower Roanoke (Staunton) sections, respectively (See Figures 5-1 and 5-2). Source reductions started with the current sources (point sources and contaminated sites) that can be reasonably reduced, followed by reductions to legacy sources where eliminating current sources was not sufficient to meet the TMDL. The WLAs, LAs, and TMDLs that follow are presented by stream/river segments in the watershed. The model subbasins associated with watershed streams are presented in Table D-8 in Appendix D.

Tables 6-1 and 6-2 present a summary of the WLAs, LAs, and TMDLs, developed for streams in the upper and lower watershed sections on an average annual and daily basis, respectively. As tPCBs bioaccumulate in fish tissue over time, it is more appropriate to express the loads on an annual basis. WLAs and LAs were assigned on the basis of the assimilative capacity of the Roanoke River watershed. Source load allocations for this TMDL scenario are presented in the following sections. Source loads are calculated as the average annual load produced by a source category as simulated in the LSPC model (see Chapter 5 and Appendix G). Average daily loads were calculated as the average annual load divided by 365.

Loadings from contaminated streambed sediments have been excluded from the TMDLs. The rationale for this exclusion is due to the dynamic relationship between the sediment and water column tPCB processes where the flux from sediments is a function of tPCBs concentrations in the stream water-sediment system as a whole (see Appendix G). Rather than a direct loading, the flux of tPCBs to-and-from streambed sediments can be characterized as an internal model mechanism. For this reason the loadings are not comparable to the direct loads contributed by the other sources. Table D-7 in Appendix D presents the initial streambed sediment concentration reductions applied to meet the TMDL condition in the upper and lower Roanoke (Staunton) subwatersheds.

Table 6-1. Average annual tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	4,923.2	28.2	630.3	34.7	693.2	85.9
South Fork Roanoke River	Not listed	3,532.2	230.2	788.6	53.6	1,072.5	69.6
Masons Creek	Not listed	1,777.5	9.1	193.2	10.6	212.9	88.0
Peters Creek	L12L-01-PCB	1,742.6	65.4	31.2	5.1	101.7	94.2
Tinker Creek	L12L-01-PCB	16,593.6	103.9	3,414.2	185.2	3,703.2	77.7
Wolf Creek	Not listed	1,078.4	10.0	20.3	1.6	31.9	97.0
Unnamed Trib to Roanoke River	Not listed	59.4	0.5	1.3	0.1	1.9	96.8
Roanoke River	L12L-01-PCB	133,207.2	28,157.7	3,455.7	1,663.9	33,277.3	75.0
Upper Total		**162,914.1**	**28,605.0**	**8,534.8**	**1,954.7**	**39,094.5**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	5,400.9	0.1	1,812.4	95.4	1,907.9	64.7
Sycamore Creek	Not listed	93,226.4	1.4	186.3	9.9	197.6	99.8
Lynch Creek	Not listed	7,670.6	0.1	17.8	0.9	18.8	99.8
Reed Creek	Not listed	253.4	0.0	75.9	4.0	79.9	68.5
X-trib	Not listed	215,127.2	0.1	1.3	0.1	1.5	100.0
Unnamed Trib to Roanoke River	Not listed	12,848.6	0.1	19.1	1.0	20.2	99.8
Little Otter River	L26R-01-PCB	3,934.3	0.0	596.2	31.4	627.6	84.0
Big Otter River	Not listed	7,630.9	0.0	2,462.8	129.6	2,592.4	66.0
Straightstone Creek	Not listed	464.8	0.0	279.0	14.7	293.7	36.8
Seneca Creek	Not listed	692.9	0.0	400.8	21.1	421.9	39.1
Whipping Creek	Not listed	398.4	0.0	157.7	8.3	166.0	58.3
Falling River	Not listed	4,135.2	0.0	1,746.5	91.9	1,838.4	55.5
Childrey Creek	Not listed	390.2	0.0	201.3	10.6	211.9	45.7
Catawba Creek	Not listed	168.8	0.0	94.8	5.0	99.8	40.9
Turnip Creek	Not listed	376.2	0.0	272.6	14.3	286.9	23.7
Hunting Creek	Not listed	86.6	0.0	65.2	3.4	68.6	20.7
Cub Creek	L19R-01-PCB	1,376.7	0.0	997.4	52.5	1,049.9	23.7
Black Walnut Creek	Not listed	181.9	0.8	46.5	2.5	49.7	72.7
Roanoke Creek	Not listed	2,446.8	0.0	1,429.6	75.2	1,504.8	38.5
Difficult Creek	Not listed	823.2	0.0	462.1	24.3	486.5	40.9
Roanoke River	L19R-01-PCB	239,207.9	1,931.8	11,961.7	731.2	14,624.8	93.9
Lower Total		**596,841.9**	**1,934.3**	**23,287.0**	**1,327.4**	**26,548.8**	**95.6**

Table 6-2. Average daily tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/d)	WLA (mg/d)	LA (mg/d)	MOS (mg/d)	TMDL (mg/d)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	13.488	0.077	1.727	0.095	1.899	85.9
South Fork Roanoke River	Not listed	9.677	0.631	2.161	0.147	2.938	69.6
Masons Creek	Not listed	4.870	0.025	0.529	0.029	0.583	88.0
Peters Creek	L12L-01-PCB	4.774	0.179	0.086	0.014	0.279	94.2
Tinker Creek	L12L-01-PCB	45.462	0.285	9.354	0.507	10.146	77.7
Wolf Creek	Not listed	2.955	0.027	0.056	0.004	0.087	97.0
Unnamed Trib to Roanoke River	Not listed	0.163	0.001	0.004	0.000	0.005	96.8
Roanoke River	L12L-01-PCB	364.951	77.144	9.468	4.559	91.171	75.0
Upper Total		**446.340**	**78.370**	**23.383**	**5.355**	**107.108**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	14.797	0.000	4.966	0.261	5.227	64.7
Sycamore Creek	Not listed	255.415	0.004	0.510	0.027	0.541	99.8
Lynch Creek	Not listed	21.015	0.000	0.049	0.003	0.051	99.8
Reed Creek	Not listed	0.694	0.000	0.208	0.011	0.219	68.5
X-trib	Not listed	589.389	0.000	0.004	0.000	0.004	100.0
Unnamed Trib to Roanoke River	Not listed	35.202	0.000	0.052	0.003	0.055	99.8
Little Otter River	L26R-01-PCB	10.779	0.000	1.633	0.086	1.719	84.0
Big Otter River	Not listed	20.906	0.000	6.747	0.355	7.102	66.0
Straightstone Creek	Not listed	1.273	0.000	0.764	0.040	0.805	36.8
Seneca Creek	Not listed	1.898	0.000	1.098	0.058	1.156	39.1
Whipping Creek	Not listed	1.092	0.000	0.432	0.023	0.455	58.3
Falling River	Not listed	11.329	0.000	4.785	0.252	5.037	55.5
Childrey Creek	Not listed	1.069	0.000	0.552	0.029	0.581	45.7
Catawba Creek	Not listed	0.463	0.000	0.260	0.014	0.273	40.9
Turnip Creek	Not listed	1.031	0.000	0.747	0.039	0.786	23.7
Hunting Creek	Not listed	0.237	0.000	0.179	0.009	0.188	20.7
Cub Creek	L19R-01-PCB	3.772	0.000	2.733	0.144	2.876	23.7
Black Walnut Creek	Not listed	0.498	0.002	0.127	0.007	0.136	72.7
Roanoke Creek	Not listed	6.704	0.000	3.917	0.206	4.123	38.5
Difficult Creek	Not listed	2.255	0.000	1.266	0.067	1.333	40.9
Roanoke River	L19R-01-PCB	655.364	5.293	32.772	2.003	40.068	93.9
Lower Total		**1,635.183**	**5.299**	**63.800**	**3.637**	**72.736**	**95.6**

6.1. Wasteload Allocations

Federal regulations (40 CFR 130.7) require TMDLs to include individual WLAs for each point source. WLAs contain the allowable loadings from existing and future point sources. The WLA portion of the TMDL includes the traditional point source discharges, individually permitted stormwater dischargers, and MS4s. WLAs for point source categories in Roanoke River watershed streams grouped by watershed section are presented in Table 6-3. WLA's for individual point sources, permitted stormwater dischargers, and MS4s are presented in Tables 6-4 through 6-6. Note that the loads calculated for all WLA sources are estimates. Loads assigned to traditional point sources were derived from one or two samples of effluent tPCBs concentrations and loads attributed to stormwater dischargers and MS4s are based on estimates of upland soil tPCBs concentrations (see Appendix G). In all cases additional PCB monitoring will have to be performed.

For this TMDL, the VADEQ agreed to apply a consistent approach to all traditional point sources for determining WLAs. The allocations are derived as facility design flow multiplied by the applicable watershed section water column target. In some cases, because current flows are less than facility design flows, this approach results in a TMDL WLA that is larger than the estimated baseline load, which is indicated by negative reduction values in Table 6-4. In addition, for one point source, VA0025020 Western Virginia Water Authority, the existing concentration at which it is discharging is lower than the applicable water quality target. This also contributed to its negative reduction value.

Table 6-3. Average annual tPCBs WLAs for Roanoke River watershed streams

Stream	Point sources			Stormwater dischargers[a]			MS4s		
	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]
Upper Roanoke River									
North Fork Roanoke River	10.7	17.8	-66.3	105.5	1.0	99.1	990.5	9.4	99.1
South Fork Roanoke River	68.4	228.6	-234.0	0.0	0.0	0.0	177.4	1.7	99.1
Masons Creek	0.0	0.0	0.0	5.9	0.1	99.1	950.6	9.0	99.1
Peters Creek[c]	90.7	50.8	44.0	1.4	0.0	99.1	1,542.2	14.6	99.1
Tinker Creek[c]	0.0	0.0	0.0	135.6	1.3	99.1	10,799.4	102.6	99.1
Wolf Creek	0.0	0.0	0.0	0.0	0.0	0.0	1,053.7	10.0	99.1
Unnamed Trib to Roanoke River	0.0	0.0	0.0	0.0	0.0	0.0	52.8	0.5	99.1
Roanoke River[c]	17,495.9	27,969.9	-59.9	6,579.0	3.0	100.0	94,055.7	184.8	99.8
Upper Total	**17,665.8**	**28,267.1**	**-60.0**	**6,827.4**	**5.3**	**99.9**	**109,622.4**	**332.7**	**99.7**
Lower Roanoke (Staunton) River									
Goose Creek	0.0	0.0	0.0	0.0	0.0	0.0	11.7	0.1	99.3
Sycamore Creek	0.0	0.0	0.0	92,387.5	1.4	100.0	0.0	0.0	0.0
Lynch Creek	0.0	0.0	0.0	8.2	0.1	99.3	0.0	0.0	0.0
Reed Creek	0.0	0.0	0.0	1.8	0.0	99.3	0.0	0.0	0.0
X-trib	0.0	0.0	0.0	208,892.4	0.1	100.0	0.0	0.0	0.0
Unnamed Trib to Roanoke River	0.0	0.0	0.0	3,885.9	0.1	100.0	0.0	0.0	0.0
Little Otter River[d]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Big Otter River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Straightstone Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seneca Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whipping Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Falling River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Childrey Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catawba Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turnip Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hunting Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cub Creek[e]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Walnut Creek	0.0	0.0	0.0	112.1	0.8	99.3	0.0	0.0	0.0
Roanoke Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Difficult Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream	Point sources			Stormwater dischargers[a]			MS4s		
	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[b]
Roanoke River[e]	78,305.9	1,926.7	97.5	82,724.2	5.1	100.0	0.0	0.0	0.0
Lower Total	**78,305.9**	**1,926.7**	**97.5**	**388,012.2**	**7.5**	**100.0**	**11.7**	**0.1**	**99.3**

a. Stormwater loads were assigned to streams based on the spatial orientation of the permitted area within the subbasin network
b. WLA percent reductions differ from TMDL percent reductions because they do not include an MOS load
c. 2008 303(d) segment L12L-01-PCB
d. 2008 303(d) segment L26R-01-PCB
e. 2008 303(d) segment L19R-01-PCB

Table 6-4. Point source tPCBs WLAs

Stream	NPDES ID	Facility	Pipe	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[a]
Upper Roanoke River						
North Fork Roanoke River	VA0027481	Blacksburg Country Club	1	10.7	17.8	-66.3
North Fork Roanoke River Total				**10.7**	**17.8**	**-66.3**
South Fork Roanoke River	VA0062219	Montgomery County PSA - Elliston Lafayette WWTP	1	38.5	127.0	-229.6
South Fork Roanoke River	VA0024031	Montgomery County PSA - Shawsville STP	1	29.9	101.6	-239.6
South Fork Roanoke River Total				**68.4**	**228.6**	**-234.0**
Peters Creek	VA0001589	Steel Dynamics	5	90.7	50.8	44.0
Peters Creek Total[b]				**90.7**	**50.8**	**44.0**
Roanoke River	VA0025020	WVWA Roanoke Regional Water Pollution Control Plant	1	17,491.1	27,934.4	-59.7
Roanoke River	VA0001597	Norfolk Southern Railway Co - Shaffers Crossing	2	4.8	35.6	-642.0
Roanoke River Total[b]				**17,495.9**	**27,969.9**	**-59.9**
Upper Total				***17,665.8***	***28,267.1***	***-60.0***
Lower Roanoke (Staunton) River						
Roanoke River	VA0083097	Old Dominion Clover Power Station	1	197.4	319.3	-61.8
Roanoke River	VA0022241	Brookneal Town - Staunton River Lagoon	1	8.2	14.4	-74.2
Roanoke River	VA0001538	Dan River, Inc - Brookneal	1	474.8	244.1	48.6
Roanoke River	VA0083402	Old Dominion Altavista Power Station	1	22.7	21.5	5.0
Roanoke River	VA0020451	Town of Altavista-STP	1	21,311.1	662.6	96.9
Roanoke River	VA0083399	Old Dominion Pittsylvania Power Station	1	21.3	35.3	-66.0
Roanoke River	VA0001678	ITG Burlington Ind. LLC Hurt Plant	1	56,270.5	629.5	98.9
Roanoke River Total[c]				**78,305.9**	**1,926.7**	**97.5**
Lower Total				***78,305.9***	***1,926.7***	***97.5***

a. WLA percent reductions differ from TMDL percent reductions because they do not include an MOS load
b. 2008 303(d) segment L12L-01-PCB
c. 2008 303(d) segment L19R-01-PCB

Table 6-5. Permitted stormwater dischargers tPCBs WLAs[a]

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[c]
Upper Roanoke River					
North Fork Roanoke River	VAR050204	Wolverine Advanced Materials	12.70	0.12	99.050
North Fork Roanoke River	VAR051352	MRSWA Solid Waste Transfer Station MRF	54.91	0.52	99.050

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[c]
North Fork Roanoke River	VAR050251	Federal Mogul Corp - Blacksburg	30.12	0.29	99.050
North Fork Roanoke River	VAR050340	Wolverine Advanced Materials - Blacksburg	7.78	0.07	99.050
North Fork Roanoke River Total			**105.50**	**1.00**	**99.050**
Masons Creek	VAR050174	Carbone of America Corporation	4.09	0.04	99.050
Masons Creek	VAR050762	Novozymes Biologicals, Inc.	1.76	0.02	99.050
Masons Creek Total			**5.85**	**0.06**	**99.050**
Peters Creek	VA0001589	Steel Dynamics	1.44	0.01	99.050
Peters Creek Total[d]			**1.44**	**0.01**	**99.050**
Tinker Creek	VAR050027	Auto Salvage and Sales Incorporated	0.78	0.01	99.050
Tinker Creek	VAR050275	Old Dominion Auto Salvage	3.12	0.03	99.050
Tinker Creek	VAR050436	Norfolk Southern Corp - Roadway Material Yard	0.68	0.01	99.050
Tinker Creek	VAR050520	O'Neal Steel Inc	16.12	0.15	99.050
Tinker Creek	VAR050530	Shenandoah Auto Parts	0.88	0.01	99.050
Tinker Creek	VAR050747	Parts Unlimited	3.43	0.03	99.050
Tinker Creek	VAR051262	Shorewood Packaging Corporation - Roanoke	2.18	0.02	99.050
Tinker Creek	VAR051315	A D Weddle Company Inc	4.04	0.04	99.050
Tinker Creek	VAR051460	Dynax America Corp USA	6.74	0.06	99.050
Tinker Creek	VAR051478	Precision Steel	2.07	0.02	99.050
Tinker Creek	VAR051492	Virginia Transformer Corp	4.49	0.04	99.050
Tinker Creek	VAR051518	East End Shops	41.49	0.39	99.050
Tinker Creek	VAR051570	Altec Industries Inc	13.60	0.13	99.050
Tinker Creek	VAR520005	Vishay Vitramon Inc	15.19	0.14	99.050
Tinker Creek	VAR520156	Freightcar America	12.40	0.12	99.050
Tinker Creek		Advanced Metal Finishing	0.42	0.00	99.050
Tinker Creek		NSW	3.75	0.04	99.050
Tinker Creek		Packaging Corp. of America	3.11	0.03	99.050
Tinker Creek		The Roanoke Times	1.15	0.01	99.050
Tinker Creek Total[d]			**135.62**	**1.29**	**99.050**
Roanoke River	VAR050135	Virginia Scrap Iron & Metal Company Inc	4,896.27	0.23	99.995
Roanoke River	VAR050150	Graham White Manufacturing Company	19.75	0.19	99.050
Roanoke River	VAR050176	John W Hancock Jr LLC dba New Millennium Bldg Syst	1.75	0.02	99.050
Roanoke River	VAR050208	Walker Machine and Foundry Corp	6.82	0.06	99.050
Roanoke River	VAR050273	Ralph Smith Inc	2.77	0.03	99.050
Roanoke River	VAR050515	Yokohama Tire Corp	50.20	0.48	99.050
Roanoke River	VAR050522	Progress Rail Services Corp - Roanoke	6.08	0.06	99.050
Roanoke River	VAR050526	RR Donnelley and Sons Company - Roanoke	94.87	0.90	99.050
Roanoke River	VAR050717	Cycle Systems Incorporated	3.97	0.04	99.050
Roanoke River	VAR050741	Medeco Security Locks Inc	17.64	0.17	99.050
Roanoke River	VAR050775	Star City Auto Parts Inc	0.49	0.00	99.050
Roanoke River	VAR520200	Hancock Rack Syst dba New Millenium Building Syst	3.14	0.03	99.050
Roanoke River		Accellent Cardiology, Inc.-Main Bldg	4.52	0.04	99.050
Roanoke River		Accellent Cardiology, Inc.-West Bldg	3.31	0.03	99.050
Roanoke River		Allied Tool & Machine Co., of Virginia	0.61	0.01	99.050
Roanoke River		Fabricated Metals Ind., Inc.	2.89	0.03	99.050
Roanoke River		Packaging Corp. of America	1,415.49	0.19	99.987

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[c]
Roanoke River		Patterson Avenue CDD Landfill - Norfolk Southern Railway	14.44	0.14	99.050
Roanoke River		Roanoke Regional Landfill	0.53	0.01	99.050
Roanoke River		Sanitary Landfill at Mowles Spring Park (closed)	10.70	0.10	99.050
Roanoke River	VA0001589	Steel Dynamics	6.84	0.07	99.050
Roanoke River		Tecton Products, Roanoke VA	15.06	0.14	99.050
Roanoke River		Wise Recycling, LLC	0.86	0.01	99.050
Roanoke River Total[d]			**6,578.99**	**2.95**	**99.955**
Upper Total			***6,827.41***	***5.31***	***99.922***
Lower Roanoke (Staunton) River					
Sycamore Creek	VA0001678	Burlington Industries - Hurt	92,387.54	1.40	99.998
Sycamore Creek Total			**92,387.54**	**1.40**	**99.998**
Lynch Creek	VAR051341	Graham Packaging Plastic Products, Inc.	8.22	0.06	99.326
Lynch Creek Total			**8.22**	**0.06**	**99.326**
Reed Creek	VA0083399	Old Dominion Pittsylvania Power Station	1.82	0.01	99.326
Reed Creek Total			**1.82**	**0.01**	**99.326**
X-trib		BGF Industries	208,892.36	0.12	100.000
X-trib Total			**208,892.36**	**0.12**	**100.000**
Unnamed Trib to Roanoke River	VAR050529	Schrader Bridgeport	3,885.88	0.06	99.999
Unnamed Trib to Roanoke River Total			**3,885.88**	**0.06**	**99.999**
Black Walnut Creek	VA0083097	Old Dominion Clover Power Station	112.13	0.76	99.326
Black Walnut Creek Total			**112.13**	**0.76**	**99.326**
Roanoke River	VAR050525	Abbott Labs	15.37	0.10	99.325
Roanoke River		BGF Industries	81,933.90	0.05	100.000
Roanoke River	VA0083402	Old Dominion Altavista Power Station	7.66	0.05	99.325
Roanoke River	VA0083097	Old Dominion Clover Power Station	725.61	4.89	99.326
Roanoke River	VA0083399	Old Dominion Pittsylvania Power Station	3.21	0.02	99.325
Roanoke River	VAR050529	Schrader Bridgeport	38.47	0.00	99.999
Roanoke River Total[e]			**82,724.24**	**5.12**	**99.994**
Lower Total			***388,012.19***	***7.51***	***99.998***

a. Stormwater loads were assigned to streams based on the spatial orientation of the permitted area within the subbasin network
b. General stormwater permit NPDES IDs were not available for no-exposure sites and other select facilities
c. WLA percent reductions differ from TMDL percent reductions because they do not include an MOS load
d. 2008 303(d) segment L12L-01-PCB
e. 2008 303(d) segment L19R-01-PCB

Table 6-6. MS4 tPCBs WLAs

Stream	MS4	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[a]
Upper Roanoke River				
North Fork Roanoke River	Blacksburg	823.7	7.8	99.050
North Fork Roanoke River	Christianburg	166.8	1.6	99.050
North Fork Roanoke River Total		**990.5**	**9.4**	**99.050**
South Fork Roanoke River	Christianburg	177.4	1.7	99.050
South Fork Roanoke River Total		**177.4**	**1.7**	**99.050**
Masons Creek	City of Salem	923.7	8.8	99.050
Masons Creek	Roanoke City	14.6	0.1	99.050
Masons Creek	Roanoke County	12.4	0.1	99.050
Masons Creek Total		**950.6**	**9.0**	**99.050**

Stream	MS4	Baseline (mg/yr)	WLA (mg/yr)	% Reduction[a]
Peters Creek	City of Salem	18.6	0.2	99.050
Peters Creek	Roanoke City	1,033.7	9.8	99.054
Peters Creek	Roanoke County	490.0	4.7	99.050
Peters Creek Total[b]		**1,542.2**	**14.6**	**99.053**
Tinker Creek	Botetourt County	1,672.7	15.9	99.050
Tinker Creek	Roanoke City	5,081.3	48.3	99.050
Tinker Creek	Roanoke County	4,045.4	38.4	99.050
Tinker Creek Total[b]		**10,799.4**	**102.6**	**99.050**
Wolf Creek	Roanoke City	0.5	0.0	99.050
Wolf Creek	Roanoke County	1,053.2	10.0	99.050
Wolf Creek Total		**1,053.7**	**10.0**	**99.050**
Unnamed Trib to Roanoke River	Roanoke County	52.8	0.5	99.050
Unnamed Trib to Roanoke River Total		**52.8**	**0.5**	**99.050**
Roanoke River	City of Salem	4,451.6	42.3	99.050
Roanoke River	Roanoke City	84,565.4	94.7	99.888
Roanoke River	Roanoke County	5,038.7	47.9	99.050
Roanoke River Total[b]		**94,055.7**	**184.8**	**99.804**
Upper Total		***109,622.4***	***332.7***	***99.697***
Lower Roanoke (Staunton) River				
Goose Creek	Botetourt County	11.7	0.1	99.325
Goose Creek Total		**11.7**	**0.1**	**99.325**
Lower Total		***11.7***	***0.1***	***99.325***

a. WLA percent reductions differ from TMDL percent reductions because they do not include an MOS load
b. 2008 303(d) segment L12L-01-PCB

6.2. Load Allocations

Generally, the LA is the amount of a pollutant contributed to the waterbody by nonpoint sources. For the purposes of this TMDL, nonpoint sources have been grouped into current and legacy sources. Current nonpoint sources include contributions of PCBs to the Roanoke River watershed from runoff of contaminated sites not within the spatial extent of MS4s or areas permitted for stormwater discharges. Contaminated sites have been categorized as known contaminated sites and urban background including unidentified contaminated sites. Legacy nonpoint sources include atmospheric deposition to surface waters and historically contaminated streambed sediment in the river.

Loadings from contaminated streambed sediments have been excluded from the TMDLs. The rationale for this exclusion is due to the dynamic relationship between the sediment and water column tPCB processes where the flux from sediments is a function of tPCBs concentrations in the stream water-sediment system as a whole (see Appendix G). Rather than a direct loading, the flux of tPCBs to-and-from streambed sediments can be characterized as an internal model mechanism. For this reason the loadings are not comparable to the direct loads contributed by the other sources. Table D-7 in Appendix D presents the initial streambed sediment concentration reductions applied to meet the TMDL condition in the upper and lower Roanoke (Staunton) subwatersheds.

LAs for nonpoint source categories in Roanoke River watershed streams grouped by watershed section are presented in Table 6-7. LAs for individual known contaminated sites not covered by MS4 or stormwater permits are presented in Table 6-8. Note that the loads calculated for all LA sources are estimates. Loads assigned to contaminated sites are based on estimates of upland soil PCB concentrations, while loads attributed to atmospheric deposition are based on literature sources (see Appendix G). In both cases additional PCB monitoring will have to be performed.

Table 6-7. Average annual tPCBs LAs for Roanoke River watershed streams

Stream	Known contaminated sites			Urban background/unidentified contaminated sites			Atmospheric deposition		
	Baseline (mg/yr)	LA (mg/yr)	% Reduction[a]	Baseline (mg/yr)	LA (mg/yr)	% Reduction[a]	Baseline (mg/yr)	LA (mg/yr)	% Reduction[a]
Upper Roanoke River									
North Fork Roanoke River	0.0	0.0	0.0	3,184.8	30.3	99.1	631.6	600.1	5.0
South Fork Roanoke River	0.0	0.0	0.0	2,481.1	23.6	99.1	805.3	765.0	5.0
Masons Creek	0.0	0.0	0.0	623.9	5.9	99.1	197.1	187.3	5.0
Peters Creek[b]	0.0	0.0	0.0	76.1	0.7	99.1	32.1	30.5	5.0
Tinker Creek[b]	0.0	0.0	0.0	2,085.6	19.8	99.1	3,573.0	3,394.4	5.0
Wolf Creek	0.0	0.0	0.0	3.4	0.0	99.1	21.3	20.2	5.0
Unnamed Trib to Roanoke River	0.0	0.0	0.0	5.2	0.0	99.1	1.3	1.3	5.0
Roanoke River[b]	7,853.5	1.0	100.0	3,622.4	34.0	99.1	3,600.7	3,420.7	5.0
Upper Total	**7,853.5**	**1.0**	**100.0**	**12,082.4**	**114.4**	**99.1**	**8,862.5**	**8,419.4**	**5.0**
Lower Roanoke (Staunton) River									
Goose Creek	0.0	0.0	0.0	3,506.3	23.6	99.3	1,882.9	1,788.8	5.0
Sycamore Creek	0.0	0.0	0.0	647.3	4.4	99.3	191.5	181.9	5.0
Lynch Creek	7,034.0	0.1	100.0	612.8	2.9	99.5	15.5	14.7	5.0
Reed Creek	0.0	0.0	0.0	172.8	1.2	99.3	78.7	74.8	5.0
X-trib	6,065.5	0.1	100.0	168.4	0.4	99.7	0.9	0.8	5.0
Unnamed Trib to Roanoke River	8,349.1	0.1	100.0	595.8	2.1	99.6	17.8	16.9	5.0
Little Otter River[c]	0.0	0.0	0.0	3,330.4	22.5	99.3	603.9	573.7	5.0
Big Otter River	0.0	0.0	0.0	5,074.5	34.2	99.3	2,556.4	2,428.6	5.0
Straightstone Creek	0.0	0.0	0.0	172.3	1.2	99.3	292.5	277.9	5.0
Seneca Creek	0.0	0.0	0.0	272.9	1.8	99.3	420.0	399.0	5.0
Whipping Creek	0.0	0.0	0.0	234.1	1.6	99.3	164.3	156.1	5.0
Falling River	0.0	0.0	0.0	2,313.2	15.6	99.3	1,822.0	1,730.9	5.0
Childrey Creek	0.0	0.0	0.0	179.5	1.2	99.3	210.6	200.1	5.0
Catawba Creek	0.0	0.0	0.0	69.5	0.5	99.3	99.3	94.4	5.0
Turnip Creek	0.0	0.0	0.0	90.0	0.6	99.3	286.3	272.0	5.0
Hunting Creek	0.0	0.0	0.0	18.1	0.1	99.3	68.5	65.1	5.0
Cub Creek[d]	0.0	0.0	0.0	329.2	2.2	99.3	1,047.5	995.2	5.0
Black Walnut Creek	0.0	0.0	0.0	21.0	0.1	99.3	48.8	46.3	5.0
Roanoke Creek	0.0	0.0	0.0	948.8	6.4	99.3	1,498.1	1,423.2	5.0
Difficult Creek	0.0	0.0	0.0	339.2	2.3	99.3	484.0	459.8	5.0
Roanoke River[d]	62,453.1	0.9	100.0	3,148.7	13.6	99.6	12,576.0	11,947.2	5.0
Lower Total	**83,901.8**	**1.2**	**100.0**	**22,244.9**	**138.7**	**99.4**	**24,365.4**	**23,147.2**	**5.0**

a. LA percent reductions differ from TMDL percent reductions because they do not include an MOS load
b. 2008 303(d) segment L12L-01-PCB
c. 2008 303(d) segment L26R-01-PCB
d. 2008 303(d) segment L19R-01-PCB

Table 6-8. Known contaminated site tPCBs LAs

Stream	Contaminated site	Baseline (mg/yr)	LA (mg/yr)	% Reduction[a]
Upper Roanoke River				
Roanoke River	Dixie Caverns	7,853.517	1.046	99.987
Roanoke River Total[b]		**7,853.517**	**1.046**	**99.987**
Upper Total		***7,853.517***	***1.046***	***99.987***
Lower Roanoke (Staunton) River				
Lynch Creek	Lane Furniture Co.	1,654.530	0.024	99.999
Lynch Creek	Oil distributors-Altavista	1,846.731	0.027	99.999
Lynch Creek	West town Dump-Altavista	3,532.784	0.050	99.999
Lynch Creek Total		**7,034.044**	**0.101**	**99.999**
X-trib	Altavista STP	3,977.088	0.057	99.999
X-trib	East town Dump-Altavista	1,991.809	0.028	99.999
X-trib	Lane Furniture Co.	96.643	0.001	99.999
X-trib Total		**6,065.540**	**0.087**	**99.999**
Unnamed Trib to Roanoke River	A. O. Smith	3,760.673	0.055	99.999
Unnamed Trib to Roanoke River	Schrader Bridgeport[d]	4,588.422	0.065	99.999
Unnamed Trib to Roanoke River Total		**8,349.095**	**0.120**	**99.999**
Roanoke River	Altavista STP	8,750.517	0.125	99.999
Roanoke River	Dan River Inc.	28,703.655	0.411	99.999
Roanoke River	East town Dump-Altavista	3,256.645	0.046	99.999
Roanoke River	English Construction	3,930.367	0.058	99.999
Roanoke River	Lane Furniture Co.	10,990.042	0.158	99.999
Roanoke River	Schrader Bridgeport	186.755	0.003	99.998
Roanoke River	West town Dump-Altavista	6,635.100	0.096	99.999
Roanoke River Total[c]		**62,453.079**	**0.897**	**99.999**
Lower Total		***83,901.758***	***1.205***	***99.999***

a. LA percent reductions differ from TMDL percent reductions because they do not include an MOS load
b. 2008 303(d) segment L12L-01-PCB
c. 2008 303(d) segment L19R-01-PCB
d. Schrader Bridgeport is characterized as a contaminated site and stormwater site because the contaminated area extends beyond the area permitted for stormwater discharges

6.3. Margin of Safety

The MOS is the portion of the pollutant loading reserved to account for any uncertainty in the data. There are two ways to incorporate the MOS: (1) implicitly incorporate the MOS by using conservative model assumptions to develop allocations or (2) explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations. A 5 percent explicit MOS was applied to account for uncertainty in this TMDL. LAs and WLAs were reduced by 5 percent to offset the loading attributed to MOS. In addition, other implicit MOS factors were inherently included in the modeling analysis because of the requirements of the models and input data properties, including not simulating the decay of PCBs.

6.4. Critical Conditions and Seasonal Variation

TMDLs must be developed with consideration of critical conditions and seasonal variation. The critical condition is the set of environmental conditions, which, if met, will ensure the attainment of objectives for all other conditions. The critical conditions for PCB loading to the Roanoke River watershed include both storm magnitude precipitation, which causes uplands soil erosion and streambed scour, and low-flow conditions, which cause water quality target exceedances at locations where highly contaminated sediments have accumulated. The LSPC model simulates precipitation variability throughout the watershed as represented by the weather time-series used to drive the model. Thus, the model inherently covers the range of hydrologic conditions that occur in the watershed, including storm-flow and low-flow conditions. Seasonal variation is also captured in the time variable simulation, which represents seasonal precipitation on a year-to-year basis.

7. REASONABLE ASSURANCE

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point sources and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved. While neither the Clean Water Act nor current EPA regulations direct states to develop a detailed implementation plan as part of the TMDL development and approval process, reasonable assurance for implementing the allocated loadings is required as part of the TMDL process. The TMDL IP is a requirement of Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act or WQMIRA (§62.1-44.19:4 through 19:8 of the Code of Virginia). Adaptive Implementation, TMDL WLA implementation through VPDES permitting and conventional Implementation Plan development are all strategies discussed in this chapter to achieve reasonable assurance.

7.1. Adaptive Implementation Strategy

VADEQ intends to implement this TMDL using an adaptive implementation strategy. As described by Wong (2006), adaptive implementation is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The focus of this approach is oriented towards increasingly efficient management and restoration and is not generally anticipated to lead to a re-opening of the TMDL. However, the TMDL and allocation scenarios can be changed if warranted by new data and information.

Adaptive implementation will be particularly useful for the Roanoke River PCB TMDL because of the complexities and uncertainties involved in understanding the fate and transport of PCBs. New data and information will be used to direct control strategies aimed to mitigate PCB loadings to the watershed. Additional information will also help to better understand and characterize PCB loadings from key sources, many of which are still unknown or unconfirmed in the upper Roanoke River watershed. Ultimately, this strategy allows responsiveness to new information while providing the flexibility in implementing the TMDL.

7.2. Implementation of Waste Load Allocations

To implement the WLA component of the TMDL, Virginia utilizes the National Pollutant Discharge Elimination System (NPDES) program administered by the Commonwealth (known as Virginia Pollution Discharge Elimination System, or VPDES) under the authority delegated by EPA. Federal regulations require that all new or revised NPDES permits be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). These regulations allow permits to use best management practices (BMPs) in lieu of numeric effluent limitations under certain conditions (40 CFR 122.44(k)). The regulation, in subsections 3 and 4, states that BMP-based water quality based effluent limits (WQBELs) can be used where "Numeric effluent limitations are infeasible; or [t]he practices are reasonably necessary to achieve effluent limitations and standards or to carry out the purposes and intent of the CWA."

In circumstances where final effluent PCB data do not exist or additional characterization is necessary to determine attainment of the WLA, special conditions shall be incorporated into VPDES permits (including municipalities, industrial wastewater, industrial stormwater under individual or general permits) either during modification or re-issuance. To ensure the PCB monitoring requirements are consistently applied, VADEQ has developed PCB point source monitoring guidance (VADEQ, 2009). The document provides guidelines on selecting applicable facilities, final effluent sample collection, PCB analysis using a low-level PCB method (EPA Method 1668), monitoring frequency, and data reporting requirements. This requirement shall also apply to MS4 systems as WLAs have been included in the TMDL.

As mentioned previously, non-numeric WQBELs (BMPs) will be used to comply with the WLA provisions of the Roanoke River PCB TMDL. Where warranted, non numeric BMPs shall be implemented and will focus on PCB source tracking and elimination at the site of contamination, rather than end-of-pipe controls. These BMPs, also referred to as Pollutant Minimization Plans (PMP) would be submitted by the permittee for review and approval. The permittee would be required to execute and periodically update the plan until monitoring and/or compliance with approved BMPs demonstrate that the assigned WLA is consistently met. Essential components of a PMP are as follows:

- Dischargers provide a framework for tracking sources of PCBs within their system. An important component includes the review of historical activities on properties under their control for past presence or known spills of PCBs.
- PMPs must contain specific actions, timetables, and assessment of the effectiveness of the actions. An example of action(s) can include steps needed to locate and control unknown PCB sources.
- Measurement and demonstration of progress in reducing PCBs.

7.3. Implementation of Load Allocations

LAs are assigned to nonpoint sources, including known contaminated sites, urban background and unidentified contaminated sites, and atmospheric contamination. Contaminated streambed sediments can also be considered within this category but are not expressed within this TMDL as a direct (or external) source. Under the adaptive implementation approach, the Commonwealth intends to use existing programs in order to attain water quality goals. Available programmatic options include a combination of regulatory authorities, such as the NPDES (WLA component) and Toxics Substances Control Act (TSCA), as well as state programs including the Voluntary Remediation Program (VRP), *Toxics Contamination Source Assessment Policy*, and the Virginia Environmental Emergency Response Fund (VEERF). The *PCB Strategy for the Commonwealth of Virginia*, published in October 2004, establishes the general strategy and outlines the regulatory framework and state initiatives that Virginia will use to address PCB impaired waterbodies. This document is available at: www.deq.virginia.gov/fishtissue/pcbstrategy.html.

Atmospheric deposition sources of PCBs can be numerous and difficult to quantify. PCBs enter the air through a variety of pathways, and the deposition of PCBs from the atmosphere to the land surface and the volatilization of PCBs from the land to the atmosphere are not well understood. Atmospheric deposition studies will help identify these pathways, and efforts to remediate contaminated sites will help reduce possible atmospheric contributions.

tPCBs in streambed sediments are contributing to the system through the dynamic relationship between the sediment and waster processes. This occurs through sediment resuspension and/or partitioning from sediment through desorption. PCB desorption was especially evident during low river flows where water quality target violations occurred within the water column. To address contaminated bed sediments where hot spots exist, mechanical or vacuum dredging could be explored as an option to permanently remove PCBs from the system.

7.3.1. Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19.7. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State

Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards (US EPA 1999).

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ and Virginia Department of Conservation and Recreation (VADCR) TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, the Virginia Department of Game and Inland Fisheries and other cooperating agencies are technical resources to assist in this endeavor. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

7.4. Follow-up monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the PCB impaired waterbodies in accordance with the fish tissue, sediment, and special study monitoring programs. The objectives are twofold: 1) to assess progress made toward achieving the Roanoke River PCB TMDL, and 2) with the Statewide Fish Tissue and Sediment Monitoring Program to systematically assess and evaluate, using a multi-tier screening, waterbodies in Virginia in order to identify toxic contaminant(s) accumulation that may adversely affect human users of the resource. As funding is available, it is also suggested that monitoring of water column and streambed sediment PCB concentrations be continued by VADEQ through special studies.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be in similar locations as the listing stations. At a minimum, the monitoring stations should be representative of the original impaired segments. The details of the follow-up monitoring will be outlined in the annual Fish Tissue and Sediment Monitoring Plan prepared by VADEQ's Water and Biological Monitoring Program. Other agency personnel, watershed stakeholders, etc. may provide input on the annual water monitoring plan.

The long term monitoring of fish tissue, sediment and, as resources allow, ambient water concentrations for PCBs will be used to evaluate trends in PCB concentrations in different environmental media, better characterize PCB loadings into the watershed and identify potential PCB hotspots for remedial activity. New information will be considered in light of the TMDL reduction goals. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

7.4.1. On-going efforts to characterize and reduce PCB loadings

In 2006, the General Assembly passed legislation requiring the Secretary of Natural Resources to develop a plan for the cleanup of the Chesapeake Bay and Virginia's waters (HB 1150). This plan was completed in 2007 (Commonwealth of Virginia 2007). The plan addresses both point and non-point sources of pollution and includes measurable and attainable objectives for water cleanup, attainable strategies, a specified timeline, funding sources, and mitigation strategies. Additionally, challenges to meeting the clean up plan goals (i.e. lack of program funding, staffing needs, monitoring needs) are identified. Information regarding Virginia's Water Clean-Up Plan can be found at http://www.naturalresources.virginia.gov/Initiatives/WaterCleanupPlan/.

Reductions in sediment from construction sites and development areas will also be of benefit for reducing PCBs. The Virginia Erosion and Sediment Control and Virginia Stormwater Management Programs—administered by the Department of Conservation and Recreation and delegated to local jurisdictions—provide the framework for implementing sediment reduction BMPs throughout localities. More information regarding these programs can be found at http://www.dcr.virginia.gov/soil_&_water/e&s.shtml.

8. PUBLIC PARTICIPATION

It is the policy of the Commonwealth of Virginia and EPA to require public participation as part of the TMDL development process. The public comment period for this TMDL begins on July 29, 2009 and ends August 27, 2009. A public notice was published in the *Virginia Register* on July 20, 2009. Two separate public meetings will be held for presentation and discussion of the PCB TMDL development. The upper Roanoke River meeting is scheduled for Wednesday, July 29, at 7 p.m. at the DEQ Blue Ridge Regional Office conference room located at 3019 Peters Creek Road in Roanoke. The lower Roanoke (Staunton) River meeting is scheduled for Thursday, July 30, at 7 p.m. at the Brookneal Elementary School gymnasium located at 1330 Charlotte St. in Brookneal.

Following the final public meetings, comments from interested parties and the general public were submitted to DEQ's Roanoke and Lynchburg Regional Offices by August 27th, 2009. Comments with responses are attached to this TMDL.

9. References

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., A.S. Donigian, Jr., and R.C. Johanson. 1997. Hydrological Simulation Program—FORTRAN, User's manual for version 11. EPA/600/R-97/080. U.S. Environmental Protection Agency, Athens, GA.

CBP (Chesapeake Bay Program). 1999. *Chesapeake Bay Basin Toxics Loading and Release Inventory.* EPA 903-R99-006. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

City of Roanoke. 2008. *Analysis of Brownfield Cleanup Alternatives Former Virginia Scrap Iron & Metal Company, Inc. Property.* City of Roanoke, Roanoke, VA.

Crawford, N.H., and R.K. Linsley. 1966. *Digital Simulation in Hydrology: Stanford Watershed Model IV*. Technical Report 39. Stanford University, Department of Civil Engineering, Palo Alto, CA.

ICPRB (Interstate Commission on the Potomac River). 2007. *Total Maximum Daily Loads of Polychlorinated Biphenyls (PCBs) for Tidal Portions of the Potomac and Anacostia Rivers in the District of Columbia, Maryland, and Virginia (Draft)*. Prepared for District of Columbia Department of the Environment, Maryland Department of the Environment, and Virginia Department of Environmental Quality. September 28, 2007.

Kane, C. 2004, September 1. FW: PCBs, Eagles, Logperch and Roanoke River. E-mail to Clint Boschen (clint.boschen@tetratech.com).

MacDonald, D. D., C. G. Ingersoll, T. A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. *Arch. Environ. Contam. Toxical.* 36:20-31.

MRLC (Multi-Resolution Land Characteristics Consortium). 2001. *National Land Cover Dataset*. Multi-Resolution Land Characteristics Consortium, Washington, DC. <http://www.mrlc.gov/nlcd_multizone_map.php>. Accessed March 1, 2006.

PADEP (Pennsylvania Department of Environmental Protection). 2001. *Total Maximum Daily Load PCB Levittown Lake*. Pennsylvania Department of Environmental Protection, Harrisburg, PA

Tetra Tech. 2005. *Sampling and Analysis Plan Roanoke River Basin PCB TMDL Development (Virginia)*. Prepared for U.S. Environmental Protection Agency Region 3, Virginia Department of Environmental Quality, and U.S. Fish and Wildlife Service by Tetra Tech, Inc., Fairfax, VA.

Totten, L.A., C.L. Gigliotti, and D.A. Vanryl. 2004. Atmospheric Concentrations and Deposition of Polychlorinated Biphenyls to the Hudson River Estuary. *Environmental Science and Technology* 38:2568–73.

USDA (U.S. Department of Agriculture). 1993. *Soil Survey Manual*. U.S. Department of Agriculture Handbook 18. U.S. Department of Agriculture, Soil Conservation Service. Soil Survey Division Staff, Natural Resources Conservation Service, Washington, DC.

———. 1995. *U.S General Soil Map (STATSGO) for state of Virginia*. U. S. Department of Agriculture, Soil Survey Division Staff, Natural Resources Conservation Service, Washington, DC. <http://soildatamart.nrcs.usda.gov>. Accessed 15 October 2004.

USEPA (U.S. Environmental Protection Agency). 1991. *Guidance for Water Quality-Based Decisions: The TMDL Process*. EPA 440/-4-91-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

———. 1996. *National Sediment Quality Survey: A Report to Congress on the Extent and Severity of Sediment Contamination in Surface Waters of the United States*. EPA-823D96002. U. S. Environmental Protection Agency, Office of Water, Washington, DC.

———. 1999. *Water Quality Standards Establishment of Numeric Criteria for Priority Toxic Pollutants States' Compliance--Revision of Polychlorinated Biphenyls (PCBs) Criteria*. Federal Register Vol. 64 No. 216: 61181-61196.

———. 1999a. *Site File Review Roanoke River PCB Site Roanoke River Watershed, Virginia*. EPA-9902-10. Prepared by Weston Consultants for EPA Region 3, Philadelphia, PA.

———.2002. *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs.* U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds and Office of Wastewater Management, Washington, DC.

———. 2003. *Water Quality Standards Establishment of Numeric Criteria for Priority Toxic Pollutants States' Compliance--Revision of Polychlorinated Biphenyls (PCBs) Criteria*. Federal Register Vol. 64 No. 216: 61181-61196.

———. 2003a. *Methodology for deriving ambient water quality criteria for the protection of human health (2000)*. EPA-822-R-03-030. Technical support document volume 2: development of national bioaccumulation factors. Office of Water, Washington, DC.

———. 2006. *Basins Technical Note 8 Sediment Parameter and Calibration Guidance for HSPF*. EPA-67-C-0-037. U. S. Environmental Protection Agency, Office of Water, Washington, DC.

USGS (U.S. Geological Survey). 2009. *National Elevation Dataset.* Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD. <http://ned.usgs.gov/>. Accessed March 3, 2006.

VADEQ (Virginia Department of Environmental Quality). 1999. *Quality Assurance Project Plan For Site Specific PCB Source Investigation at Altavista Area.* Commonwealth of Virginia Department of Environmental Quality, Water Quality Assessment. Richmond, VA.

———. 2004. *2004 Fish Tissue and Sediment Monitoring Plan Water Quality Standards and Biological Programs*. Commonwealth of Virginia Department of Environmental Quality, Richmond, VA.

———. 2007. 2008 Water Quality Assessment Guidance Manual, Guidance Memo No. 07-2010. Commonwealth of Virginia Department of Environmental Quality, Water Quality Assessment. Richmond, VA. http://www.deq.state.va.us/waterguidance/wqam.html .

———. 2009. Guidance for monitoring of point sources for TMDL development using low-level PCB method 1668, TMDL Guidance Memo No. 09-2001. Commonwealth of Virginia Department of Environmental Quality. http://www.deq.state.va.us/tmdl/pcb.html.

Wallmeyer, Jerry. 1973. *The Occurrence of Polychlorinated Biphenyls (PCBs) in the Roanoke and Dan Rivers, A Preliminary Report*. Virginia State Water Control Board, Richmond, VA.

Wischmeier, W.H., and D.D. Smith. 1978. *Predicting rainfall erosion losses – a guide to conservation planning*. The USDA Agricultural Handbook No. 537. U.S. Department of Agriculture, Washington, DC.

Wong, B.B. 2006 Clarification Regarding "Phased" Total Maximum Daily Loads. U.S. Environmental Protection Agency, Washington D.C. Available on-line at: http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.html.

Appendix A: Development of BAFs and Water Quality Targets for the Roanoke River PCB TMDL Study

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A1. INTRODUCTION

This document describes how species bioaccumulation factors (BAF) are computed from observed PCB concentrations in fish tissue samples and nearby water column samples. Results are presented for both individual species and trophic levels (planktivore, benthivore-generalist, and predator), similar to the approach used in the Potomac PCB draft TMDL report (ICPRB 2007) which used the guidelines outlined in the USEPA 2003 technical support document for development of bioaccumulation factors. Water column targets for allowable PCB concentrations can be derived by dividing the state's fish tissue criterion or screening threshold by some factor that represents the fish's ability to absorb and retain PCBs.

The revised EPA guidelines (USEPA 2003) recommend using BAF instead of bio-concentration factors (as was done in the 1980 EPA guidelines) for persistent, hydrophobic chemicals such as PCBs. The "total" BAF is also the ratio of the PCB concentration in an organism's wet tissue to its concentration in water. However, it is measured in situations where both the organism and its food and environment are exposed to PCBs.

Baseline BAFs (total BAFs normalized to freely dissolved PCBs in the water and lipid content of the fish tissue), were calculated to identify those species most susceptible to accumulating and maintaining PCBs. These normalized BAFs were used to derive total BAFs adjusted to a common condition for comparison purposes. Finally, these computed BAFs were used to establish water quality targets for the Roanoke model that achieve allowable PCB concentrations in the consumable tissue of fish.

A2. TOTAL BAFS

Calculation of a BAF requires information on total concentration of PCB in the fish and total concentration of PCB in the ambient water. Total PCB water column data were available only from the recent whole water analysis (n = 20 samples) conducted during the TMDL special study in 2007–2008 (August to May). Adjusted total PCB data were used for the analysis (Richards 2007). All historical total PCB data in the water column were at detection limits and, therefore, could not be used. Fish tissue data corresponding to these twenty water quality sampling stations were available for a similar time period (2006).

The fish tissue data included 16 different fish species. Only four of the 16 species had a sample size of greater than 5, with Carp having the most samples (n=36), the other species being Striped Bass (n=31), Cannel Catfish (n=18), and Redhorse Sucker (n=7). Each fish tissue sampling station was associated with a corresponding water column and assigned a corresponding whole water total PCB concentration. The paired fish tissue-water column data was then split into two groups, those located above Niagra Dam (upper) and those located below Leesville Dam (lower). This was done because of three major dams separating the two areas (Niagra Dam, Smith Mtn. Dam, and Leesville Dam) and the available water column monitoring data suggests that levels and types of PCB contamination differ between the two sections (upper and lower) (Tetra Tech 2009). Table 2-1 shows the water column station and associated fish tissue station. Figure 2-1 shows the stations located spatially along the Roanoke River.

Table A2-1. Water column station and associated fish tissue station used in BAF analysis

Water column station ID	Associated fish tissue station
4ACUB002.21	4ACUB010.96
4AROA059.12	4AROA059.12
4AROA067.91	4AROA067.91
4AROA097.76	4AROA097.07
4AROA127.79	4AROA129.95
4AROA129.55	4AROA129.95
4AROA131.55	4AROA129.95
4AROA199.20	4AROA199.20
4AROA204.76	4AROA206.80
4AROA207.08	4AROA206.80

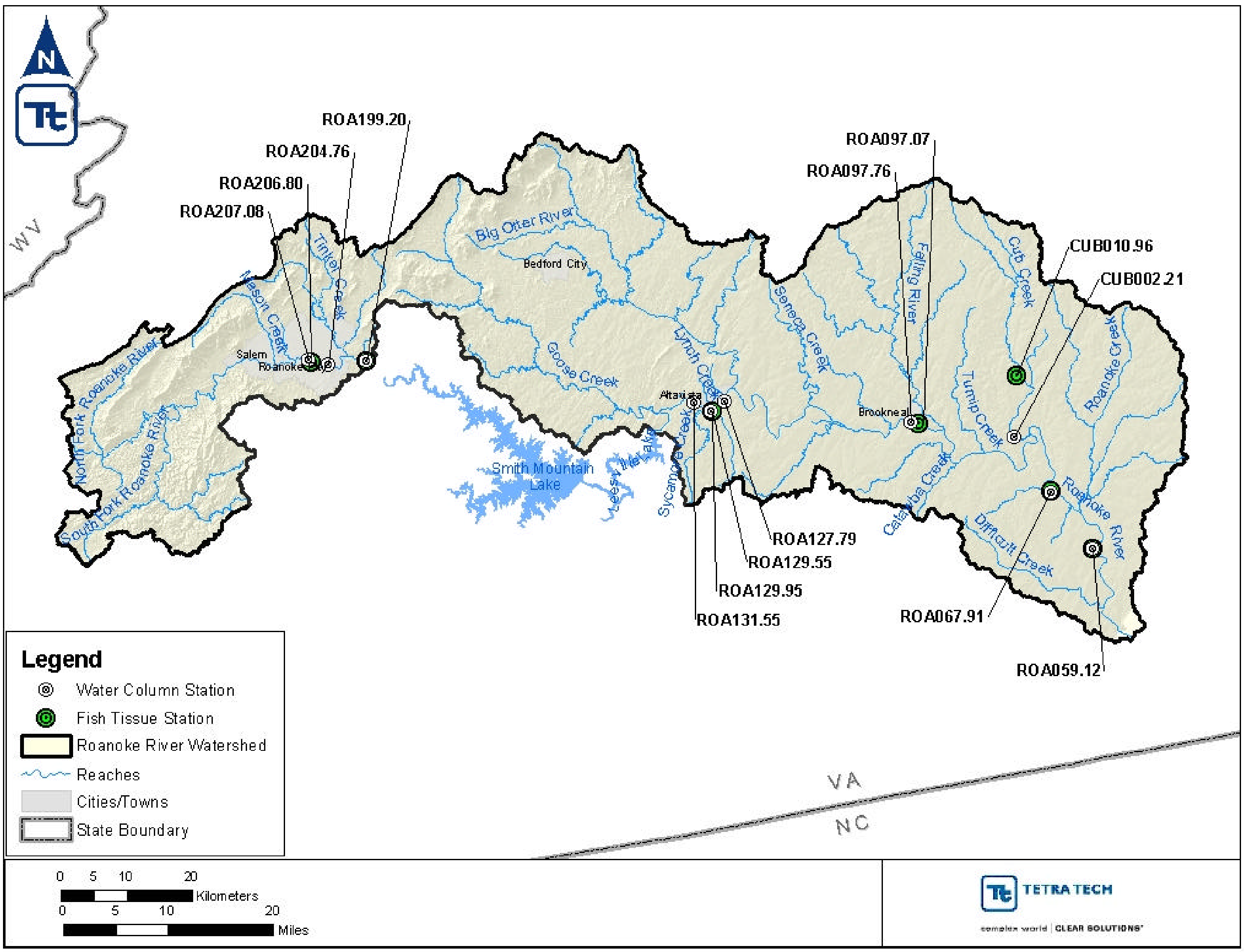

Figure A2-1 BAF monitoring station locations in the Roanoke River watershed.

Total BAFs or field measured BAFs were calculated using the equation given below (EPA 2000, 2003):

$$totalBAF = \frac{[tPCB]_{tissue}}{[tPCB]_{water}} \qquad \text{[Eq 1.]}$$

where $[tPCB]_{tissue}$ = concentration of tPCB in wet fish tissue (µg/kg)

$[tPCB]_{water}$ = concentration of tPCB in water (µg/liter)

Species-specific total BAFs derived from the observed Roanoke River fish and water column total PCB concentrations are highly variable, with BAF values for a species ranging as much as three orders of magnitude. This variability within species is to be expected given day-to-day fluctuations in PCB loadings to the water column. Median total BAF values for the lower section of the watershed range from 26,226 L/kg (Redear Sunfish) to 1,354,560 L/kg (Smallmouth Bass). Median total BAF values for the upper section of the watershed range from 55,741 L/kg (White Sucker) to 231,159 L/kg (Carp). In general, the total BAFs were always higher than the default bio-concentration value (31,200) recommended in the 1980 EPA guidelines for 304(a) PCB criteria. Out of the species with greater than ten samples, the highest median total BAFs computed were for Carp and Smallmouth Bass in the upper and lower Roanoke, respectively.

Median total BAF values for each species grouped by watershed section as well as for the three trophic levels are shown in Tables 2-2 and 2-3 respectively. Trophic level BAFs were determined by pooling the species samples by trophic level and calculating the geometric means of all the samples, regardless of species (USEPA 2003).

Table A2-2. Median total BAF values by species

Section	Trophic level	Fish species name	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	Carp	8	231,158.8
Upper	Benthivore / Generalist	Redhorse Sucker	1	132,670.4
Upper	Benthivore / Generalist	Golden Redhorse Sucker	1	123,093.4
Upper	Benthivore / Generalist	White Sucker	1	55,740.5
Lower	Predator	Smallmouth Bass	1	1,354,599.9
Lower	Predator	Rock Bass	1	571,527.5
Lower	Benthivore / Generalist	Carp	28	493,262.8
Lower	Predator	Striped Bass	31	373,096.7
Lower	Predator	Walleye	2	362,022.8
Lower	Benthivore / Generalist	Redbreast Sunfish	3	300,603.6
Lower	Benthivore / Generalist	Redhorse Sucker	7	243,858.3
Lower	Predator	Blue Catfish	2	201,165.0
Lower	Planktivore	Gizzard Shad	2	185,970.7
Lower	Benthivore / Generalist	Channel Catfish	18	181,403.6
Lower	Benthivore / Generalist	Golden Redhorse Sucker	1	160,037.6
Lower	Predator	White Bass	2	145,140.2
Lower	Benthivore / Generalist	Black Crappie	1	61,496.6
Lower	Predator	Largemouth Bass	1	56,886.4
Lower	Benthivore / Generalist	Redear Sunfish	1	26,226.1

Table A2-3. Trophic Level total BAF values (geometric mean)

Section	Trophic level	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	11	166,163.6
Lower	Benthivore / Generalist	59	355,623.3
Lower	Predator	40	292,288.7
Lower	Planktivore	2	173,072.3

A3. BASELINE BAFS

Total BAFs for PCBs vary depending on the food habits and lipid concentrations of each fish species and on the concentration of freely-dissolved PCBs in the water column. EPA recommends calculating a "baseline" BAF for the purpose of extrapolating between different species and bodies of water (USEPA 2003). These BAFs are also useful in identifying the species most susceptible to accumulating and retaining PCBs. The baseline BAF is the total BAF normalized to the fish tissue lipid content and the freely-dissolved PCB concentration in the water (USEPA 2003, ICPRB 2007)

$$baselineBAF = \left[\frac{totalBAF}{F_d} - 1\right] \cdot \frac{1}{\%lipid} \qquad \text{[Eq 2.]}$$

where totalBAF = Total BAF of PCB calculated using Eq. 1.
F_d = fraction of total PCB in water that is freely dissolved
$\%lipid$ = fraction of tissue that is lipid

The freely-dissolved PCB concentration is a function of dissolved and particulate organic carbon concentrations in the water column. However, this analysis was simplified to a suspended solids basis due to the lack of readily available dissolved and particulate carbon (DOC and POC) data. The dissolved fraction (F_d) of total PCB in water was calculated using [Eq.3 or Eq.4] given below:

$$F_d = \frac{1}{1 + m \cdot K_d} \qquad \text{[Eq 3.]}$$

where m = suspended solids concentration (mg/L)
K_d = partitioning coefficient for PCB

Suspended solids concentration from five stations were assigned to the matched fish tissue-water column PCB data and used to calculate baseline BAFs (2007–2008). Only data points where water column PCB and TSS concentrations were collected during the same sampling event were used. Table 3-1 shows the mean suspended solids concentration.

Table A3-1 Mean total suspended solids concentrations at analysis monitoring stations

Station ID	Count (n)	Mean TSS (mg/L)
4ACUB002.21	2	20.5

Station ID	Count (n)	Mean TSS (mg/L)
4AROA059.12	2	15.5
4AROA067.91	2	34
4AROA097.76	2	35
4AROA127.79	1	4
4AROA129.55	3	80.7
4AROA131.55	2	37
4AROA199.20	2	52.5
4AROA204.76	2	21.5
4AROA207.08	2	25.5

The partitioning coefficient for PCB can be approximated to the following equation given below from Thomann and Mueller (1987):

$$K_d = 1\times10^{-6} \cdot \mathrm{f_{oc}} \cdot \mathrm{K_{ow}}$$

where : $\mathrm{f_{oc}}$ = weight fraction of the total carbon in the solid matter (gC/g) and can be computed from the relationship $POC = \mathrm{f_{oc}} \cdot m$ and

$\mathrm{K_{ow}}$ = octanol-water PCB partition coefficient

Substituting this approximation into [Eq.3] we get:

$$F_d = \frac{1}{1 + (1\times10^{-6} \cdot \mathrm{K_{ow}}) \cdot \mathrm{f_{oc}} \cdot m} \qquad \text{[Eq 4.]}$$

Partition coefficients of PCB (K_{ow}) congeners range over four orders of magnitude. A weighted homolog was calculated for each water column concentration data point and used to estimate the associated K_{ow} for the BAF calculation. Homolog specific partitioning coefficients for PCBs are presented below in Table 3-2.

Table A3-2 Homolog specific partitioning coefficients

Homolog	Middle log Kow
Kow_mono+di	4.675
Kow_tri	5.425
Kow_tetra	6.005
Kow_penta	6.525
Kow_hexa	6.73
Kow_hepta	7.235
Kow_octa	7.6
Kow_nona	7.915
Kow_deca	8.18

Source: ICPRB, 2007

The $\mathrm{f_{oc}}$ value was calculated using the following relationship $POC = \mathrm{f_{oc}} \cdot m$.

POC data were extrapolated from measured TOC values (TOC data collected in conjunction with the TSS data). POC was estimated from observed TOC data using the ratio of DOC to TOC that was estimated based on the TMDL special study dataset (WCRO data – from Richards M., 8/10/07). A ratio of POC/TOC = 0.10 was used to estimate the POC (calculated based on samples where DOC < TOC). Based on National default values of POC and DOC given in USEPA, 2003 the POC to TOC ratio is 0.17. This computed POC, along with the suspended solids concentration, was used to estimate the fraction of organic carbon f_{oc} for each station. Suspended solids values for each station were multiplied by 0.10 to estimate the POC at each station.

For individual fish samples, the total PCB concentration in the fish tissue was normalized to that sample's measured lipid fraction, and then divided by the concentration of freely-dissolved total PCB as shown in [Eq. 2]. The highest median baseline BAFs (i.e. which most readily absorb and maintain total PCBs) were for Carp in both the upper and lower watershed sections (Table 3-4).

Table A3-4. Median baseline BAF values by species and watershed section

Section	Trophic level	Fish species name	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	Carp	8	1,691,732.6
Upper	Benthivore / Generalist	Golden Redhorse Sucker	1	1,351,113.7
Upper	Benthivore / Generalist	Redhorse Sucker	1	1,222,709.4
Upper	Benthivore / Generalist	White Sucker	1	673,166.7
Lower	Predator	Smallmouth Bass	1	63,021,024.6
Lower	Predator	Rock Bass	1	22,802,020.7
Lower	Benthivore / Generalist	Redbreast Sunfish	3	16,990,173.2
Lower	Benthivore / Generalist	Carp	28	7,394,544.6
Lower	Predator	Walleye	2	5,424,439.8
Lower	Benthivore / Generalist	Redhorse Sucker	7	4,843,871.5
Lower	Benthivore / Generalist	Golden Redhorse Sucker	1	3,544,944.5
Lower	Predator	Largemouth Bass	1	3,120,453.4
Lower	Predator	Blue Catfish	2	3,007,903.7
Lower	Benthivore / Generalist	Channel Catfish	18	2,144,105.3
Lower	Predator	White Bass	2	1,924,718.3
Lower	Predator	Striped Bass	31	1,336,420.6
Lower	Benthivore / Generalist	Redear Sunfish	1	1,117,173.5
Lower	Planktivore	Gizzard Shad	2	889,057.3
Lower	Benthivore / Generalist	Black Crappie	1	774,068.5

A4. ADJUSTED TOTAL BAFS

A species' baseline BAF can be standardized to a common condition by normalizing based on the median lipid content of that species and a single freely-dissolved PCB concentration representative of the ecosystem (the median dissolved concentration across all stations grouped by watershed section was used in the analysis). This calculation results in adjusted total BAFs for each species with no variability attributable to differences in fish lipid content or freely-dissolved PCB concentrations in the water column:

$$AdjustedTotalBAF = [(baselineBAF \cdot median\%lipid) + 1] \cdot medianF_d \qquad \text{[Eq 5.]}$$

The adjusted total BAF [Eq.5] is the species' baseline BAFs adjusted to the species' median % lipid and the overall median % freely-dissolved total PCBs. Table 4-1 shows the adjusted total BAF values by species.

The VADEQ fish tissue screening threshold for total PCBs was then divided by the median adjusted total BAF to derive a water column total PCB target for the entire Roanoke River. The fish tissue PCB threshold in Virginia is currently 54 ng/g. The mean adjusted total BAF for each species and the associated water column PCB targets for each species are shown in Table 4-1.

Table A4-1. Adjusted total BAFs and associated VA water column total PCB targets

Model Section	Trophic Level	Fish species name	Median Adjusted Total BAF (L/kg)	Count (n)	WC Target (ng/L)
Upper	Benthivore / Generalist	Carp	139,520	8	0.387
Upper	Benthivore / Generalist	Golden Redhorse Sucker	124,929	1	0.432
Upper	Benthivore / Generalist	Redhorse Sucker	74,307	1	0.727
Upper	Benthivore / Generalist	White Sucker	56,572	1	0.955
Lower	Predator	Smallmouth Bass	1,546,278	1	0.035
Lower	Benthivore / Generalist	Carp	680,218	28	0.079
Lower	Predator	Rock Bass	652,399	1	0.083
Lower	Benthivore / Generalist	Redbreast Sunfish	504,013	3	0.107
Lower	Predator	Walleye	390,034	2	0.138
Lower	Predator	Striped Bass	385,038	31	0.140
Lower	Benthivore / Generalist	Golden Redhorse Sucker	365,606	1	0.148
Lower	Benthivore / Generalist	Redhorse Sucker	328,347	7	0.164
Lower	Planktivore	Gizzard Shad	315,748	2	0.171
Lower	Benthivore / Generalist	Channel Catfish	228,087	18	0.237
Lower	Predator	Blue Catfish	222,532	2	0.243
Lower	Predator	White Bass	165,524	2	0.326
Lower	Predator	Largemouth Bass	64,721	1	0.834
Lower	Benthivore / Generalist	Black Crappie	60,673	1	0.890
Lower	Benthivore / Generalist	Redear Sunfish	29,838	1	1.810

A higher adjusted total BAF will result in a lower target water concentration, which should be protective of all fish species with lower BAFs. Based on the BAF analysis (Table 4-1) several fish species have a water column target value of an order of magnitude lower than the current VA water column target for human health of 1.7 ng/L (i.e. more stringent then the current criteria). It is suggested that the target be based on the Carp BAF of 139,520 for the upper section and Striped Bass BAF of 385,038 for the lower section. Based on the VADEQ fish tissue threshold, these BAFs equate to water quality targets of 0.387 and 0.140 ng/L, for the upper and lower sections, respectively. Carp is suggested as the target species for the upper section of the Roanoke because it is the only species with an adequate sample size (n=8) and is protective of water quality. Striped Bass is suggested as the target species for the lower section of the Roanoke because of its robust sample size (n=31) and stakeholder concern about the protection of sporting fish species. Smallmouth and Rock Bass, two other sport species with lower water quality targets, had inadequate sample sizes (n=6).

A5. REFERENCES

ICPRB (Interstate Commission on the Potomac River Basin). 2007. *Total Maximum Daily Loads of Polychlorinated Biphenyls (PCBs) for Tidal Portions of the Potomac and Anacostia Rivers in the District of Columbia, Maryland, and Virginia (Draft).* Prepared by The Interstate Commission on the Potomac River Basin (ICPRB). July 17, 2007.

Richards M. 2007. *Roanoke (Staunton) River PCBs: Ambient Grab and Effluent Preliminary Results*. May 4, 2007.

Thomann, R. V., and Mueller, J.A. (1987). *Principals of surface water quality modeling and control.* Harper & Row Publishing Co.

Tetra Tech. 2009. *Roanoke River PCB TMDL Development.* Prepared for U.S. Environmental Protection Agency Region 3, Philadelphia, PA.

USEPA (U. S. Environmental Protection Agency). 2003. *Methodology for deriving ambient water quality criteria for the protection of human health (2000).* EPA-822-R-03-030. Technical support document volume 2: development of national bioaccumulation factors. Office of Water, Washington, DC.

Appendix B:
Roanoke River PCB TMDL Water Quality Monitoring Summary

LIST OF TABLES

Table B-1. Fish tissue PCB monitoring data summary—upper Roanoke River

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ACDN002.53	Cedar Run near Rt. 603	5/28/2002	1	Redbreast Sunfish	3.2	3.2	3.2	1
4ACDN002.53	Cedar Run near Rt. 603	5/28/2002	1	Bluehead Chub	5.1	5.1	5.1	1
4ACDN002.20	Cedar Run near Rt. 603	10/14/1999	1	Mixed Sunfish species	14.2	14.2	14.2	1
4ACDN002.20	Cedar Run near Rt. 603	10/14/1999	1	Chub	37	37	37	1
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-5/28/2002	10	White Sucker	0.9	3.4	1.7	8
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	5	Smallmouth Bass	5.5	18	13.4	5
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	11	Rock Bass	1.7	14.8	7.3	11
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	11	Redhorse Sucker	0.3	15.7	6.7	9
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-5/28/2002	11	Redbreast Sunfish	0.3	11.8	4.8	11
4ARNF013.60	North Fork Roanoke River near Rt. 603	10/14/1999	1	Green Sunfish				0
4ARNF013.60	North Fork Roanoke River near Rt. 603	5/28/2002	1	Golden Redhorse Sucker	26.6	26.6	26.6	1
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	White Sucker	1.7	26.7	11.5	9
4ARSF011.52	South Fork Roanoke River	7/14/1993	3	Smallmouth Bass	2.7	7.6	5.3	3
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	Rock Bass	1.6	32.7	7	10
4ARSF011.52	South Fork Roanoke River	7/14/1993	5	Redhorse Sucker	0.9	8	4.4	5
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	Redbreast Sunfish	0.3	3.8	1.3	7
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Rock Bass	2.9	2.9	2.9	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Redhorse Sucker	3	3	3	1
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Redbreast Sunfish	3.8	3.8	3.8	1
4AROA219.99	Roanoke River near Glenvar	6/16/1993-6/17/1993	5	Smallmouth Bass	8.6	17.7	14.2	5
4AROA219.99	Roanoke River near Glenvar	6/16/1993-5/29/2002	11	Rock Bass	0.4	33	11.2	11
4AROA219.99	Roanoke River near Glenvar	6/16/1993	5	Redhorse Sucker	4.2	32	16	5
4AROA219.99	Roanoke River near Glenvar	6/16/1993-5/29/2002	11	Redbreast Sunfish	0.4	6.6	2.7	11
4AROA219.99	Roanoke River near Glenvar	5/29/2002	1	Northern Hogsucker	20.3	20.3	20.3	1
4AROA219.99	Roanoke River near Glenvar	6/17/1993	9	Bluehead Chub		1	87.9	14
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	2	Roanoke Darter	17.5	29.6	23.6	2
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	1	Riverweed Darter	18.9	18.9	18.9	1
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	3	Margined Madtom	29.9	424.3	162.3	3
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	1	Fantail Darter	44.7	44.7	44.7	1
4AROA216.33	Roanoke River below Koppers, Salem	7/23/2002	1	White Sucker	2.1	2.1	2.1	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Smallmouth Bass	21.5	21.5	21.5	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Rock Bass	4.4	4.4	4.4	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Redhorse Sucker	34.7	34.7	34.7	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999-7/23/2002	2	Redbreast Sunfish	5.8	16.7	11.3	2
4AROA216.33	Roanoke River below Koppers, Salem	7/23/2002	2	Golden Redhorse Sucker	9.6	9.8	9.7	2
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Carp	192.3	192.3	192.3	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Rock Bass	13.1	13.1	13.1	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Redbreast Sunfish	9.9	9.9	9.9	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Black Jumprock Sucker	9.7	9.7	9.7	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Smallmouth Bass	22.2	22.2	22.2	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Rock Bass	30	30	30	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Redhorse Sucker	2.5	2.5	2.5	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Redbreast Sunfish	8.7	8.7	8.7	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Rock Bass	68.2	68.2	68.2	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Redhorse Sucker	29.3	29.3	29.3	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Redbreast Sunfish	33.5	33.5	33.5	1
4APEE000.49	Peters Creek	5/29/2002	1	White Sucker	21.4	21.4	21.4	1
4APEE000.49	Peters Creek	5/29/2002	1	Rock Bass	57	57	57	1
4APEE000.49	Peters Creek	5/29/2002	1	Redbreast Sunfish	44.8	44.8	44.8	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/19/2006	1	White Sucker	43.4	43.4	43.4	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	8/22/2002	1	Smallmouth Bass	43.3	43.3	43.3	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999	1	Rock Bass	130.5	130.5	130.5	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999-8/22/2002	2	Redbreast Sunfish	30.3	38.7	34.5	2
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/22/2002-7/19/2006	2	Golden Redhorse Sucker	44.7	95.7	70.2	2
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	8/22/2002-7/19/2006	5	Carp	85	688.2	420.4	4
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999	1	Black Jumprock Sucker	35.3	35.3	35.3	1
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	White Sucker	44.1	44.1	44.1	1
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	Shorthead Redhorse Sucker	32.7	32.7	32.7	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004-9/16/2004	2	Roanoke Darter	382.1	543.7	462.9	2
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004-9/16/2004	2	Riverweed Darter	350.4	350.4	350.4	1
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	Redbreast Sunfish	38.7	38.7	38.7	1
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004	2	Margined Madtom	340.1	483.6	411.9	2
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/24/2002	2	White Sucker	0.4	2	1.2	2
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/24/2002	1	Roanoke Bass	1.4	1.4	1.4	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Rock Bass	26.3	26.3	26.3	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Redhorse Sucker	37.3	37.3	37.3	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Redbreast Sunfish	20.3	20.3	20.3	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	White Sucker	32.2	32.2	32.2	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Rock Bass	49.4	49.4	49.4	1
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	1	Roanoke Darter	134.4	134.4	134.4	1
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	2	Riverweed Darter	91	99.6	95.3	2
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Redbreast Sunfish	23.2	23.2	23.2	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Golden Redhorse Sucker	221.1	221.1	221.1	1
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	1	Fantail Darter	214	214	214	1
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	1	Redbreast Sunfish	31	31	31	1
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	1	Largemouth Bass	23.7	23.7	23.7	1
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	2	Golden Redhorse Sucker	63.1	109.9	86.5	2
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	4	Carp	163.1	438.9	249.3	4
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Redhorse Sucker	100.5	100.5	100.5	1
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Redbreast Sunfish	26.5	26.5	26.5	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Largemouth Bass	271.9	271.9	271.9	1
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Carp	488.9	488.9	488.9	1
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993	5	Smallmouth Bass	62.3	237	135.9	5
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993-7/19/2006	11	Redhorse Sucker	11.7	317.7	120.7	11
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993	20	Redbreast Sunfish	13.9	80.1	39	20
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993-7/19/2006	11	Carp	84.2	832.2	373	11
4AROA198.75	Smith Mountain Lake - Back Creek	4/27/2004	1	Striped Bass	94.1	94.1	94.1	1

Table B-2. Fish tissue PCB monitoring data summary—lower Roanoke (Staunton) River

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	White Bass	40	40	40	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	Walleye	4.8	4.8	4.8	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-12/10/1998	2	Striped Bass	25.9	52.1	39	2
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-7/20/2006	3	Largemouth Bass	1.9	9.5	4.5	3
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-9/24/1999	2	Gizzard Shad	6.9	12.7	9.8	2
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	Channel Catfish	45	45	45	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	9/24/1999-7/20/2006	4	Carp	5.9	17.4	11.3	4
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	9/24/1999	1	Bluegill Sunfish	1.5	1.5	1.5	1
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	5/30/2002	1	White Sucker	12.8	12.8	12.8	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	5/30/2002	1	Bluehead Chub	10	10	10	1
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Smallmouth Bass	0.2	0.2	0.2	1
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Rock Bass				0
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Roanoke Hogsucker				0
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Redbreast Sunfish	4.2	4.2	4.2	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Smallmouth Bass	14.4	14.4	14.4	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Redhorse Sucker	160.5	160.5	160.5	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Redbreast Sunfish	1.4	1.4	1.4	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Flathead Catfish	299.9	299.9	299.9	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	3	Channel Catfish	12.3	107.1	51.9	3
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Carp	56.1	56.1	56.1	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Bluegill Sunfish		14.4	14.4	14.4
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Smallmouth Bass	223.5	223.5	223.5	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Rock Bass	94.3	94.3	94.3	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	2	Redhorse Sucker	47.5	105.5	76.5	2
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	3	Redbreast Sunfish	37.7	84.2	55.1	3
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002	1	Golden Redhorse Sucker	83.1	83.1	83.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Gizzard Shad	30.4	30.4	30.4	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	5	Channel Catfish	25	149.9	87.6	5
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	9	Carp	7	995.8	397.6	9
4ALOR007.94	Little Otter River near Rt.784, below Bedford	5/30/2002	1	White Sucker				0
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Smallmouth Bass	54.8	54.8	54.8	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Redhorse Sucker	28.5	28.5	28.5	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999-5/30/2002	2	Redbreast Sunfish	3.1	8.2	5.7	2
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Carp	68.3	68.3	68.3	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	5/30/2002	1	Bluehead Chub	21.3	21.3	21.3	1
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Roanoke Hogsucker	0.6	0.6	0.6	1
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Redhorse Sucker	60.6	60.6	60.6	1
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Redbreast Sunfish	4.1	4.1	4.1	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Walleye	336.5	336.5	336.5	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Spotted Bass	30.8	30.8	30.8	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	3	Smallmouth Bass	38.5	95.8	70	3
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Redhorse Sucker	275.6	275.6	275.6	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Redbreast Sunfish	8.3	8.3	8.3	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Flathead Catfish	58.1	58.1	58.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	4	Channel Catfish	95.2	647.2	262.6	4
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Carp	300.6	300.6	300.6	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Bluegill Sunfish	31.5	31.5	31.5	1
4AROA117.09	Roanoke River near Taber	10/20/1999	1	Spotted Bass	106.5	106.5	106.5	1
4AROA117.09	Roanoke River near Taber	10/27/1999	1	Redhorse Sucker	307.9	307.9	307.9	1
4AROA117.09	Roanoke River near Taber	10/20/1999	1	Redbreast Sunfish	99.5	99.5	99.5	1
4AROA117.09	Roanoke River near Taber	10/27/1999	1	Channel Catfish	345	345	345	1
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	White Perch	144.3	144.3	144.3	1
4AROA108.09	Roanoke River near Long Island	2/9/1993	3	Walleye	111.6	157.1	129.2	3
4AROA108.09	Roanoke River near Long Island	2/9/1993-5/12/1993	10	Sunfish	1.5	125.9	46.3	10
4AROA108.09	Roanoke River near Long Island	5/5/1993	2	Striped Bass	550.2	772.4	661.3	2
4AROA108.09	Roanoke River near Long Island	2/9/1993-10/20/1998	5	Spotted Bass	37.1	177.8	112.2	5
4AROA108.09	Roanoke River near Long Island	5/5/1993-4/19/2006	12	Smallmouth Bass	27.4	716.6	155.5	12
4AROA108.09	Roanoke River near Long Island	10/20/1998-4/19/2006	3	Redhorse Sucker	381.2	419.3	399.1	3
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	Redbreast Sunfish	23.1	23.1	23.1	1
4AROA108.09	Roanoke River near Long Island	10/20/1998-10/21/1998	6	Flathead Catfish	57.3	2451.6	757.7	6
4AROA108.09	Roanoke River near Long Island	2/9/1993-4/19/2006	17	Channel Catfish	45.5	761.4	285.3	17
4AROA108.09	Roanoke River near Long Island	2/9/1993-4/19/2006	20	Carp	294.7	2724.5	968	20
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	Bluegill Sunfish	12.9	12.9	12.9	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/24/2002	11	White Perch	7.5	323.8	127.1	11
4AROA097.07	Roanoke River near Brookneal	2/9/1993	6	Walleye	4.5	62.5	27.6	5
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/21/2006	30	Striped Bass	75.8	1906	568.8	29
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	4	Spotted Bass	50.9	91.2	68.2	4
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	4	Smallmouth Bass	79.5	156.1	123.2	4
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/18/2006	13	Redhorse Sucker	4.6	560	165.7	11
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Redbreast Sunfish	64.1	64.1	64.1	1
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	2	Quillback Carpsucker	144.5	174.2	159.4	2
4AROA097.07	Roanoke River near Brookneal	4/24/2002	1	Gizzard Shad	491	491	491	1
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Flathead Catfish	144.7	144.7	144.7	1
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/18/2006	11	Channel Catfish	51.6	331.9	121	11
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/18/2006	11	Carp	82.7	834.9	431.1	11
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Bluegill Sunfish	19.6	19.6	19.6	1
4AROA097.07	Roanoke River near Brookneal	4/18/2006	1	Black Crappie	109.2	109.2	109.2	1
4AROA096.62	Roanoke River near Brookneal (site #74)	5/9/2000	2	Striped Bass	416.7	675.9	546.3	2
4AFRV010.99	Falling River near Rt. 643 gaging station	8/26/1999	1	Redhorse Sucker	0.2	0.2	0.2	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AFRV010.99	Falling River near Rt. 643 gaging station	8/26/1999	1	Redbreast Sunfish	0.2	0.2	0.2	1
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999-6/21/2006	2	Redhorse Sucker	8.4	195.5	101.9	2
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999-6/21/2006	2	Redbreast Sunfish	3.8	151.1	77.4	2
4ACUB010.96	Cub Creek near Rt.40 gaging station	6/21/2006	1	Channel Catfish	113.7	113.7	113.7	1
4ACUB010.96	Cub Creek near Rt.40 gaging station	6/21/2006	2	Carp	145	763.4	454.2	2
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999	1	Bluegill Sunfish	8.3	8.3	8.3	1
4AHTA003.26	Hunting Creek (Conner Lake)	6/21/2006	1	Channel Catfish	0	0	0	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	2	Walleye	291.9	671	481.5	2
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Spotted Bass	38.8	38.8	38.8	1
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Redhorse Sucker	171.2	171.2	171.2	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	1	Golden Redhorse Sucker	211.8	211.8	211.8	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	1	Gizzard Shad	246.1	246.1	246.1	1
4AROA067.91	Roanoke River near Rt. 746	8/5/1999-9/25/2006	2	Channel Catfish	240.1	833.6	536.8	2
4AROA067.91	Roanoke River near Rt. 746	8/5/1999-9/25/2006	9	Carp	275.2	1553.3	782.9	9
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Bluegill Sunfish	28	28	28	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	2	Blue Catfish	189.1	345.3	267.2	2
4AROC005.35	Roanoke Creek near Saxe	8/27/1999	1	Redbreast Sunfish				0
4AROC005.35	Roanoke Creek near Saxe	8/27/1999	1	Bluegill Sunfish	4.5	4.5	4.5	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993	9	White Perch	26.7	369.4	120.1	9

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	12	White Bass	149.8	1209.2	484.8	12
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/2/2002	1	Walleye	241.9	241.9	241.9	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/13/1993	9	Sunfish	8.8	75.4	39.3	9
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/2/2002-4/17/2006	16	Striped Bass	308.3	898.9	602	16
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998	3	Spotted Bass	89.8	152.9	113.7	3
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998-4/17/2006	4	Redhorse Sucker	44.8	388.2	250.5	4
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2006	1	Redear Sunfish	38.9	38.9	38.9	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002	1	Quillback Carpsucker	179	179	179	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002-4/17/2006	2	Largemouth Bass	84.4	119.3	101.8	2
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002	1	Gizzard Shad	224.5	224.5	224.5	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	20	Channel Catfish	32.3	820.7	271.7	20
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	21	Carp	9.3	1711.8	626.1	21
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998	1	Bluegill Sunfish	51.5	51.5	51.5	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	3	White Perch	148.5	166.3	156.2	3
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	3	White Bass	144.9	428.3	282.6	3
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	2	Walleye	67.6	150.8	109.2	2
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	5	Striped Bass	98.7	480.3	343.6	5
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Largemouth Bass	132.8	132.8	132.8	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	4	Flathead Catfish	149.3	831.3	497.1	4
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Channel Catfish	318.1	318.1	318.1	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Carp	699	699	699	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Black Crappie	32	32	32	1

Table B-3. Sediment PCB monitoring data summary—upper Roanoke River

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4ACDN002.53	Cedar Run near Rt. 603	8/26/1999	1	6.14	6.14	6.14	1
4ACDN002.20	Cedar Run near Rt. 603	10/23/1998	1	12.83	12.83	12.83	1
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/23/1999	3	0.29	3.11	2.06	3
4ARSF011.52	South Fork Roanoke River	10/22/1998	1	0.66	0.66	0.66	1
4ARSF006.60	South Fork Roanoke River	7/13/1996	1	1	1	1	1
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/22/1998	1	1.57	1.57	1.57	1
4AROA219.99	Roanoke River near Glenvar	8/8/2007	1	1.53	1.53	1.53	1
4AROA217.23	Roanoke River near Green Hill Park	7/31/1997	1	0.55	0.55	0.55	1
4AROA216.34	Roanoke River	7/23/1996	1	2.19	2.19	2.19	1
4AROA216.33	Roanoke River, Salem below Koppers	6/19/1996	1				0
4ASYD000.01	Snyders Branch	8/17/1999-5/30/2002	1	7.57	7.57	7.57	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/15/1997	1	9.98	9.98	9.98	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	6/19/1996	1	17.06	17.06	17.06	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave bridge	7/17/1997	1	41.74	41.74	41.74	1
4APEE000.49	Peters Creek	8/6/1997	2	13.47	14.85	14.16	2
4AROA206.80	Roanoke River at Wasena Park near Rt. 11 bridge	6/2/1999	2	1.94	11.65	6.79	2
4AROA202.20	Roanoke River at 13th Street bridge	8/6/1999	2	43.83	77.84	60.83	2
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/30/1999	1	0.34	0.34	0.34	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line (A) -- !!!	7/15/1997	2	54.52	940.76	497.64	2
4ATKR000.17	Tinker Creek near Rt. 24	8/5/1999-9/10/2007	3	26.45	101.9	74.03	3
4AROA199.78	Roanoke River just above Niagara Dam	6/2/1999	1	81.87	81.87	81.87	1
4AROA199.73	Roanoke River above Niagara Dam	7/26/1999	1	41.5	41.5	41.5	1
4AROA199.68	Roanoke River above Niagara Dam	7/29/1999	1	94.6	94.6	94.6	1
4AROA199.60	Roanoke River above Niagara Dam	5/29/2002	1	133.37	133.37	133.37	1
4AROA199.20	Roanoke River just upstream Niagara Dam	6/19/1996	2	37.23	47.35	42.29	2
4AROA198.75	Roanoke River upstream Back Creek	7/23/1999	1	5.34	5.34	5.34	1

Table B-4. Sediment PCB monitoring data summary—lower Roanoke (Staunton) River

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4AROA140.66	Roanoke River (Leesville Lake-Lower Lake site)	7/7/1999	1				0
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	7/30/1999	1	1.39	1.39	1.39	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4AGNE000.16	North Fork Goose Creek near Road Rt. 751	7/22/1999	1	0.27	0.27	0.27	1
4AGSE013.78	Goose Creek near Rt. 732 gaging station	7/27/1999	1				0
4AGSE000.20	Goose Creek	7/30/1999	1				0
4AROA137.00	Roanoke River near Leesville Tail Race	8/3/2004	1				0
4AROA131.55	Roanoke River	7/29/1999	1	2.93	2.93	2.93	1
4ASCE000.26	Sycamore Creek	7/30/1999	1				0
4ASCE000.24	Sycamore Creek near Pocket Road	8/3/2004	1				0
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	8/21/2002	1	15.62	15.62	15.62	1
4AROA129.55	Roanoke River at Altavista	2/5/2008	1	1.29	1.29	1.29	1
4ALYH000.02	Lynch Creek near Altavista Park	8/6/1997	1	849.9	849.9	849.9	1
4AROA128.98	Roanoke River at Rt. 668 near Altavista Park	6/10/2002	1	17.95	17.95	17.95	1
4ARAB000.05	Reed Creek at Rt. 668 near Altavista	8/5/2004	1				0
4AXXZ000.05	Unnamed Tributary, just west of Altavista STP -- !!!	7/8/1999-7/22/2002	1	82235.37	82235.37	82235.37	1
4AROA127.79	Roanoke River	10/18/1999	1				0
4AXCN000.20	Unnamed Tributary at Rt. 29 Substation Altavista	2/5/2008	1	7.95	7.95	7.95	1
4AROA126.00	Roanoke River upstream of Big Otter River	7/13/1996	1	4.71	4.71	4.71	1
4ALOR007.94	Little Otter River near Rt. 784, below Bedford	8/3/2004	2	5.46	6.8	6.13	2
4ABOR024.91	Big Otter River near Road off Rt. 297	7/1/1999	1	0.58	0.58	0.58	1
4ABOR012.18	Big Otter River near Rt. 682	6/3/1999	1	3.46	3.46	3.46	1
4ABOR011.27	Big Otter River	6/3/1999	1	0.87	0.87	0.87	1
4ABOR003.18	Big Otter River	6/2/1999	1	0.13	0.13	0.13	1
4ABOR000.20	Big Otter River	6/2/1999	1	0.2	0.2	0.2	1
4AROA125.59	Roanoke River downstream Altavista	8/3/2004	1	0.29	0.29	0.29	1
4AMRC000.39	Mill Creek near Rt. 640	8/19/1999	1	0.67	0.67	0.67	1
4AROA122.31	Roanoke River	8/6/1997	1	25.09	25.09	25.09	1
4AROA117.49	Roanoke River	7/30/1999	2	0	0	0	2
4AROA117.09	Roanoke River near Taber	8/2/2004	1	6.69	6.69	6.69	1
4ABHE001.01	Beechtree Creek near Rt. 631	6/2/1999	1	10.16	10.16	10.16	1
4AROA112.72	Roanoke River	8/7/1996	1	16.61	16.61	16.61	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4ASEN000.18	Seneca Creek near Rt. 704	8/8/2007	1	2.48	2.48	2.48	1
4ALNA001.00	Long Branch at Rt. 633	8/3/1999	1	0.2	0.2	0.2	1
4AROA108.09	Roanoke River near Long Island	8/3/2004	1	3.44	3.44	3.44	1
4AHIL000.60	Hill Creek at Rt. 633	8/4/2004	1				0
4ASSC002.85	Straightstone Creek near Rt. 761	8/8/2007	1				0
4AXXX001.30	Unnamed Tributary at Rt. 633 Green Hill	7/22/2002-8/17/2004	1				0
4ABHA000.33	Buffalo Creek at Rt. 639	8/9/2007	1				0
4AWPP000.60	Whipping Creek near Road off Rt. 614	9/15/1999-8/21/2002	1	0.88	0.88	0.88	1
4AROA099.22	Roanoke River	8/4/2004	1	14.72	14.72	14.72	1
4AROA097.76	Roanoke River near Brookneal	8/4/2004	1	8.45	8.45	8.45	1
4AROA097.21	Roanoke River	7/23/1996	1	4.92	4.92	4.92	1
4AZZZ097.08	Unnamed trib near Rt. 501,north side	10/27/1998-9/10/2007	1	9.45	9.45	9.45	1
4AROA097.07	Roanoke River near Brookneal	2/5/2008	4	24.44	1050.95	689.08	3
4AZZZ097.07	Unnamed trib near Rt. 501,south side	9/14/1999-8/4/2004	1	174.89	174.89	174.89	1
4AROA097.06	Middle Roanoke River at Rt. 501	6/2/1999	2				0
4AZZZ096.71	Unnamed trib across from Tanyard Branch,south side	10/26/1998-4/24/2002	1	1.5	1.5	1.5	1
4AROA096.66	Downstream of lagoon outfall	8/28/2007	1				0
4ATAB000.05	Tanyard Branch, downstream of lagoon	5/29/2002	1				0
4AROA096.65	Downstream of Tanyard Branch	8/5/2004	1	2730	2730	2730	1
4AROA096.35	Downstream of Hatchery Water Intake	7/30/1999	1				0
4AROA096.34	Directly across from site of sample # 10	8/3/2004	1				0
4AZZZ096.27	Unnamed tributary across from Hatchery	5/29/2002-8/18/2004	1	6.23	6.23	6.23	1
4AROA096.10	South bank, upstream of Hatchery culvert	5/30/2002	1				0
4AROA096.05	North bank, upstream of rusty culvert	7/30/1999	1				0
4AROA095.95	North bank, downstream of last set of Hatchery Ponds	6/3/1999	1				0
4AROA095.90	South bank,across from sample #16 of Roanoke River	7/22/1999	1				0
4AZZZ095.38	Unnamed tributary downstream of sample # 17	6/30/1999-5/28/2002	1	2.6	2.6	2.6	1
4AROA094.68	Middle, just downstream of RR Bridge trestle	7/24/2002	1				0
4AROA094.67	North bank, dowrstream of Railroad (RR) Bridge	7/27/1999	1				0
4AROA094.54	Downstream of RR Bridge,south side of sandy island	8/8/2007	1				0
4AFRV010.99	Falling River near Rt. 643 gaging station	8/3/1999	1				0
4AFRV003.12	Falling River, downstream of lagoon	8/27/1999	1				0

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
	outfall						
4ACRE002.60	Childrey Creek at Rt. 632	8/3/1999	1	0.33	0.33	0.33	1
4AROA090.50	Roanoke River	6/2/1999	1	65.27	65.27	65.27	1
4ACBA000.12	Catawba Creek at Rt. 626	8/18/1999	1	1.83	1.83	1.83	1
4ATIP000.42	Turnip Creek near Road off Rt. 649	8/18/1999	1	3.7	3.7	3.7	1
4AROA086.22	Roanoke River	8/5/2004	1	1.62	1.62	1.62	1
4ACUB010.96	Cub Creek near Rt. 40 gaging station (A)	6/2/1999	2	1.52	1.52	1.52	1
4ACUB002.21	Cub Creek	6/3/1999	1	0.42	0.42	0.42	1
4AROA073.98	Roanoke River	7/22/1999	1	26.18	26.18	26.18	1
4AHTA000.80	Hunting Creek at Rt. 617	7/16/1999	1				0
4AROA068.79	Roanoke River	8/4/1999-9/13/1999	1	28.43	28.43	28.43	1
4AROA067.91	Roanoke River near Rt. 746 bridge	8/28/2007	2	6.81	109.55	58.18	2
4ABWC001.00	Black Walnut Creek	7/30/1999	1	1.74	1.74	1.74	1
4AROC005.35	Roanoke Creek near Saxe	10/20/1999	1				0
4AROC001.00	Roanoke Creek	7/15/1997	1	0.56	0.56	0.56	1
4AROA059.12	Roanoke River near Clover	7/23/1999	3	8.67	71.34	40.27	3
4AROA057.51	Roanoke River	7/26/1999	1	5.95	5.95	5.95	1
4AROA052.69	Roanoke River, upstream Kerr Reservoir	5/28/2002	1	6.4	6.4	6.4	1
4ADIF002.02	Difficult Creek at Rt. 716	8/3/1999	1	3.74	3.74	3.74	1
4AROA049.40	Roanoke River	6/30/1999	1	3.04	3.04	3.04	1

Table B-5. Water column PCB monitoring data summary—upper Roanoke River

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
Steel Dynamics	3/3/2008	Low	750.9	750.9	750.9	1
4AROA227.42	11/22/2005-4/7/2008	High	95.3	95.3	95.3	1
4AROA227.42	10/13/2005-3/3/2008	Low	57	106.6	81.8	2
4AROA212.17	4/7/2008	High	255.9	255.9	255.9	1
4AROA212.17	3/3/2008	Low	80.1	80.1	80.1	1
4AROA207.08	4/7/2008	High	641.8	641.8	641.8	1
4AROA207.08	3/3/2008	Low	363.4	363.4	363.4	1
4AROA204.00	10/14/2005	Low	0	0	0	1
4AGND000.02	4/7/2008	High	613.2	613.2	613.2	1

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
4AGND000.02	3/3/2008	Low	155.3	155.3	155.3	1
4AROA204.76	11/22/2005-4/7/2008	High	863	3013.9	1938.45	2
4AROA204.76	3/3/2008	Low	986.9	986.9	986.9	1
4AROA202.20	4/7/2008	High	3043.9	3043.9	3043.9	1
4AROA202.20	3/3/2008	Low	1376.4	1376.4	1376.4	1
4AROA199.20	11/22/2005-4/7/2008	High	466	1588.1	1027.05	2
4AROA199.20	10/14/2005-3/3/2008	Low	53	1212.7	632.85	2

Table B-6. Water column PCB monitoring data summary—lower Roanoke (Staunton) River

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
4AGSE000.20	10/26/2007	High	343	343	343	1
4AGSE000.20	9/10/2007	Low	34.8	34.8	34.8	1
4AROA131.55	5/9/2008	High	186.9	186.9	186.9	1
4AROA131.55	8/8/2007	Low	57.4	57.4	57.4	1
4ALYH000.17	5/9/2008	High	34672.5	34672.5	34672.5	1
4ASCE000.26	8/27/2007	Low	28.6	28.6	28.6	1
4AROA129.55	10/26/2007-5/9/2008	High	388.2	766.3	577.25	2
4AROA129.55	8/8/2007	Low	72	72	72	1
4AXLN000.00	12/1/2007	High	1489097.7	1489097.7	1489097.7	1
4ABOR000.62	10/26/2007	High	252.5	252.5	252.5	1
4ABOR000.62	8/21/2007	Low	115.4	115.4	115.4	1
4AROA127.79	8/9/2007	Low	147.7	147.7	147.7	1
4AROA124.59	3/10/2008-5/9/2008	High	2908.8	4466.4	3687.6	2
4AROA108.09	9/10/2007	Low	1146.8	1146.8	1146.8	1
4AFRV002.78	9/10/2007	Low	17.8	17.8	17.8	1
4AROA097.76	3/6/2008	High	4304.2	4304.2	4304.2	1
4AROA097.76	8/8/2007	Low	1118.1	1118.1	1118.1	1
4AROA090.50	10/26/2007	High	1624.8	1624.8	1624.8	1
4AROA090.50	8/8/2007	Low	1192.2	1192.2	1192.2	1
4ACUB002.21	10/26/2007	High	12.9	12.9	12.9	1
4ACUB002.21	8/28/2007	Low	12.4	12.4	12.4	1
4AROA067.91	12/1/2005-10/26/2007	High	991	1307	1149	2
4AROA067.91	10/21/2005-9/10/2007	Low	58	1340.1	699.05	2
4AROC001.00	10/26/2007	High	5.2	5.2	5.2	1
4AROC001.00	8/28/2007	Low	26.2	26.2	26.2	1
4ABWC001.00	10/26/2007	High	559.2	559.2	559.2	1

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
4AROA059.12	12/1/2005-10/26/2007	High	1317	1359	1338	2
4AROA059.12	10/21/2005-9/10/2007	Low	262	1627	944.5	2
4ADFF002.02	8/28/2007	Low	3.8	3.8	3.8	1

Table B-7. TSS monitoring data summary—upper Roanoke River

Station ID	Station Description	Period of Record	Date Count	Min. TSS (mg/L)	Max. TSS (mg/L)	Avg. TSS (mg/L)	Sample Count
4ACDN001.12	Rt. 723 bridge	1/0/1900-1/0/1900	13	3	5	3.2	13
4ARNF013.66	Rt. 603 bridge near Ellett - Montgomery	7/16/2003-5/9/2007	24	3	10	3.7	24
4ARSF011.73	Rt. 637 bridge at gage	7/22/1999-11/27/2006	22	3	29	4.6	22
4ARSF007.29	Upstream of US 11/460 in Shawsville	4/28/2005-4/28/2005	2	3	3	3	1
4ARSF000.88	Rt. 460/11 bridge below Green Hill, Inc.	7/7/2005-11/27/2006	9	3	17	5	9
4AROA227.42	Rt. 773 at gaging station in Lafayette	1/10/1990-4/7/2008	195	1	366	13.5	186
4AROA219.99	Rt. 612 bridge above Salem at Wabun	10/13/2005	1	14	14	14	1
4AROA215.13	Mill Lane Bridge, Salem, VA	7/15/2003-10/13/2005	13	3	108	11.5	13
4AROA212.17	Rt. 11 bridge below Eaton, Inc.	4/16/1990-4/7/2008	144	2	776	18.4	134
4AMSN000.67	Roanoke Boulevard bridge	7/15/2003-11/7/2006	22	3	38	4.8	22
4APEE001.04	Shenandoah Avenue bridge	7/26/1994-11/7/2006	55	3	30	7	41
4APEE000.00	10 yards above confluence	8/26/1992-10/13/2005	2	14	14	14	1
4AROA207.08	Little Otter River below Bedford	10/13/2005-4/7/2008	3	5	46	19.3	3
4AROA205.73	Franklin Road bridge, Roanoke, VA	7/21/2003-11/7/2006	21	3	10	4.8	21
4AROA204.76	Roanoke River at Roanoke City	10/13/2005-4/7/2008	4	3	40	18.3	3
4AROA202.20	13th St. bridge above Roanoke STP	1/10/1990-4/7/2008	199	1	744	19.4	187
4AGLA004.39	Layman Rd. (Rt. 606)	8/8/2001-5/4/2005	24	3	65	8.5	24
4AGND000.02	Below Riverland Road	3/3/2008-4/7/2008	2	3	13	8	2
4ATKR000.69	Rt. 24 bridge above Town of Vinton	2/5/1990-5/9/2007	181	3	325	12.8	167
4AROA200.06	Roanoke River downstream of Tinker Creek	10/13/2005	1	7	7	7	1
4AROA199.20	Blue Ridge Parkway bridge below Roanoke	7/12/2005-4/7/2008	13	3	93	14.4	12

Table B-8. TSS monitoring data summary—lower Roanoke (Staunton) River

Station ID	Station Description	Period of Record	Date Count	Min. TSS (mg/L)	Max. TSS (mg/L)	Avg. TSS (mg/L)	Sample Count
4AROA140.66	Leesville Lake #1A-Top #1B-Middle #1C-Bot	4/16/1990-6/12/2003	105	3	46	6.6	90
4AGSF002.60	Rt. 897 Bridge	6/25/2002	1	3	3	3	1
4AGSE015.07	Goose Creek	4/10/2006	1	9	9	9	1
4AGSE000.20	Rt. 630 bridge at Leesville	3/15/1990-10/26/2007	58	3	340	27.1	25
4AROA137.00	Roanoke River near Leesville Tail Race	10/20/2005	1	3	3	3	1
4AROA131.55	Rt. 29 bridge bypass, Altavista	8/8/2007-5/9/2008	3	5	69	30	3
4ASCE000.26	Rt. 924 bridge – Pittsylvania County	3/15/1990-8/27/2007	67	3	41	7.7	35
4AROA129.55	Rt. 29 bridge at gage - Pittsylvania	2/1/1990-5/9/2008	116	3	208	14.1	71
4ALYH000.00	Lynch Creek	10/20/2005	1	8	8	8	1
4ALYH000.17	Lynch Creek above last bridge @ boat ramp	5/20/2008	1	3	3	3	1
4AROA128.97	Alta Vista Water Intake	10/20/2005	1	5	5	5	1
4AROA128.94	Roanoke River near Lane West Landfill	10/20/2005	1	4	4	4	1
4AROA127.79	Roanoke River power line crossing 1.15 miles NE Rt.	8/9/2007	1	4	4	4	1
4AXLN000.00	X-Trib of Roanoke (BGF)	10/20/2005	1	12	12	12	1
4AROA128.21	Roanoke River near Lane East Landfill	10/20/2005	1	4	4	4	1
4ALOR008.64	Rt. 784 bridge, Bedford Co.	7/17/1996-6/6/2007	81	3	559	31.9	77
4ALOR007.20	Little Otter River below Bedford	4/23/2007	1	10	10	10	1
4ABOR019.84	Upstream of Cobbs Creek Mouth	4/6/2004	1	5	5	5	1
4ABOR012.18	Station #8 Rt.644 bridge (Bedford County)	8/19/1992-8/9/1993	2				0
4ABOR000.62	Rt. 712 bridge, near confluence with River	3/15/1990-10/26/2007	157	3	417	30.1	136
4AROA124.59	Rt. 640 bridge - Campbell County	8/19/1999-5/9/2008	13	3	157	24.8	13
4AROA123.85	Old Mansion Bridge	10/21/2005	1	8	8	8	1
4ASEN000.40	Rt. 704 bridge, above Long Island	3/15/1990-5/1/2007	69	3	104	7	35
4AROA108.09	Rt. 761 bridge – main channel of Roanoke	2/23/1993-5/1/2007	34	3	124	18.8	34
4ABHA002.47	Rt. 639 (Rockbarn Road)	8/12/2003-6/30/2005	12	3	58	10.4	12
4AWPP002.53	Whipping Creek, Rt. 633	8/12/2003-6/30/2005	12	3	20	5.1	12

4AROA097.76	Roanoke (Staunton) River	10/21/2005-3/6/2008	4	4	66	23	4
4AROA097.46	Roanoke River at Brookneal gage, Rt. 50	1/24/1990-5/1/2007	182	3	239	23.8	174
4ACRE002.52	Childrey Creek Rt. 632 bridge	9/19/1990-2/26/2001	52	1	496	27.9	48
4AFRV010.99	Narana gage Rt. 643	7/12/2001-5/1/2007	36	3	45	5.6	36
4AFRV002.78	Off Rt. 600 Below Brookneal STP	3/5/1990-9/10/2007	67	3	202	12.2	33
4AROA090.50	Rt. 620 south of Brookneal	2/1/1990-10/26/2007	20	5	20	10	3
4ATIP002.55	Turnip Creek, Rt. 619 bridge	9/29/1994-6/10/2003	47	3	338	19.1	45
4ACUB017.46	Red House Rd.	8/4/2003-6/27/2005	17	3	45	8.9	17
4ACUB002.21	Rt. 649 (Coles Ferry Road)	8/28/2007-10/26/2007	2	10	31	20.5	2
4AHTA003.26	Station 1 - Conner Lake	8/3/1993-8/3/1993	2				0
4AHTA000.77	Hunting Creek @ Rt. 617	8/4/2003-6/27/2005	12	3	20	8.6	12
4AROA067.91	Rt.746 bridge (Watkins Bridge) near Rand	2/1/1990-10/26/2007	110	2	266	26.1	89
4ABWC001.00	Rt. 600	8/29/2007	1				0
4AROC005.35	Roanoke Creek at the confluence with TWI	8/28/2001-6/14/2007	15	3	8	4.7	15
4AROC001.00	Roanoke Cr. @ Roanoke Station Rd.	8/28/2007-10/26/2007	2	4	11	7.5	2
4AROA059.12	Rt. 360 bridge, east of Clover	1/8/1990-10/26/2007	197	1	408	29	168
4ADFF002.02	Rt. 716 bridge	7/2/1990-8/28/2007	70	1	253	10.1	65

Appendix C:
Roanoke River PCB TMDL Stormwater Sites

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Table C-1. Sites represented as stormwater discharges—upper Roanoke River

Permit ID	Facility Name	Area (acres)
VAR051315	A D Weddle Company Inc	7.31
	Accellent Cardiology, Inc.-Main Bldg	3.97
	Accellent Cardiology, Inc.-West Bldg	3.00
	Advanced Metal Finishing	0.92
	Allied Tool & Machine Co., of Virginia	1.26
VAR051570	Altec Industries Inc	40.56
VAR050027	Auto Salvage and Sales Incorporated	1.67
VAR050174	Carbone of America Corporation	7.71
VAR050717	Cycle Systems Incorporated	5.52
VAR051460	Dynax America Corp USA	16.05
VAR051518	East End Shops	85.76
	Fabricated Metals Ind., Inc.	5.97
VAR050251	Federal Mogul Corp - Blacksburg	38.14
VAR520156	Freightcar America	25.23
VAR050150	Graham White Manufacturing Company	22.49
VAR520200	Hancock Rack Syst dba New Millenium Building Syst	2.58
VAR050176	John W Hancock Jr LLC dba New Millennium Bldg Syst	2.78
VAR050741	Medeco Security Locks Inc	16.26
VAR051352	MRSWA Solid Waste Transfer Station MRF	137.42
VAR050436	Norfolk Southern Corp - Roadway Material Yard	1.50
VAR050762	Novozymes Biologicals, Inc	1.72
VAR050762	Novozymes Biologicals, Inc.	1.90
	NSW	7.01
VAR050275	Old Dominion Auto Salvage	10.49
VAR050520	O'Neal Steel Inc	19.87
	Packaging Corp. of America	3.00
	Packaging Corp. of America	3.71
VAR050747	Parts Unlimited	5.23
	Patterson Avenue CDD Landfill - Norfolk Southern Railway	19.84
VAR051478	Precision Steel	5.23
VAR050522	Progress Rail Services Corp - Roanoke	12.08
VAR050273	Ralph Smith Inc	2.03
	Roanoke Regional Landfill	104.15
VAR050526	RR Donnelley and Sons Company - Roanoke	133.66
	Sanitary Landfill at Mowles Spring Park (closed)	36.98
VAR050530	Shenandoah Auto Parts	1.87
VAR051262	Shorewood Packaging Corporation - Roanoke	4.07
VAR050775	Star City Auto Parts Inc	1.05
VA0001589	Steel Dynamics	16.61
	Tecton Products, Roanoke VA	19.96
	The Roanoke Times	2.51
VAR050135	Virginia Scrap Iron & Metal Company Inc	8.33
VAR051492	Virginia Transformer Corp	8.95
VAR520005	Vishay Vitramon Inc	21.57
VAR050208	Walker Machine and Foundry Corp	7.27
	Wise Recycling, LLC	0.74
VAR050204	Wolverine Advanced Materials	13.48
VAR050340	Wolverine Advanced Materials - Blacksburg	12.70
VAR050515	Yokohama Tire Corp	56.12

Table C-2. Sites represented as stormwater discharges—lower Roanoke River

Permit ID	Facility Name	Area (acres)
VAR050525	Abbott Labs	36.35
	BGF Industries	28.07
VA0001678	Burlington Industries - Hurt	138.41
VA0083402	Old Dominion Altavista Power Station	8.81
VA0083097	Old Dominion Clover Power Station	934.02
VA0083399	Old Dominion Pittsylvania Power Station	8.77
VAR051341	Graham Packaging Plastic Products, Inc.	18.97
VAR050529	Schrader Bridgeport	9.73

Appendix D:
Roanoke River PCB TMDL Model Parameters

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Table D-1. Roanoke River watershed model hydrologic parameters and ranges

Model Parameter	Parameter description	Value range
LZSN	lower zone nominal soil moisture storage (in)	5.0–5.4
INFILT	index to the infiltration capacity of the soil (in/hr)	0.022–0.250
KVARY	variable groundwater recession (1/in)	0.2–0.3
AGWRC	base groundwater recession (none)	0.986–0.990
PETMAX	air temperature below which evapotranspiration is reduced (deg F)	40
PETMIN	air temperature below which evapotranspiration is set to 0 (deg F)	35
INFEXP	exponent in the infiltration equation (none)	2
INFILD	ration between the maximum and mean infiltration capacities (none)	2
DEEPFR	fraction of groundwater inflow that will enter deep groundwater (none)	0.12–0.16
BASETP	fraction of remaining potential evapotranspiration that can be satisfied from baseflow (none)	0.03–0.04
AGWETP	fraction of remaining potential evapotranspiration that can be satisfied from active groundwater (none)	0
CEPSC	interception storage capacity (in)	0.08–0.22
UZSN	upper zpne nominal storage (in)	0.50–0.65
NSUR	Manning's n for the assumed overland flow plane (none)	0.25
INTFW	interflow parameter (none)	1.0–2.0
IRC	interflow recession parameter (none)	0.37–0.55
LZETP	lower zone evapotranspiration parameter (none)	0.20–0.65

Table D-2. Roanoke River watershed model land sediment parameters and ranges

Model Parameter	Parameter Description	Value range
SMPF	Supporting management practice factor (P factor)	0.2–0.75
KRER	Coefficient in the soil detachment equation	0.29–0.32
JRER	Exponent in the soil detachment equation	2
AFFIX	Fraction by which detached sediment storage decreases each day as a result of soil compaction	0.04
COVER	Fraction of land surface that is shielded from rainfall erosion	0.15–0.88
NVSI	Rate at which sediment enters detached storage from the atmosphere	0
KSER	Coefficient in the detached sediment washoff equation	0.5–4.5
JSER	Exponent in the detached sediment washoff equation	2
KGER	Coefficient in the matrix soil scour equation	0
JGER	Exponent in the matrix soil scour equation	2.5
ACCSDP	Rate at which solids accumulate on the land surface	0.07
REMSDP	Fraction of solids storage that is removed each day when there is no runoff	0.066
SED-SURO	Background concentration associated with surface flow (mg/L)	20
SED-IFWO	Background concentration associated with interflow outflow (mg/L)	3
SED-AGWO	Background concentration asscciated with groundwater outflow (mg/L)	3
SED_1	Fraction of total sediment from land that is sediment class sand	0.04
SED_2	Fraction of total sediment from land that is sediment class silt	0.616–0.706
SED_3	Fraction of total sediment from land that is sediment class clay	0.254–0.344

Table D-3. Roanoke River watershed model stream sediment parameters and ranges

Model Parameter	Parameter Description	Particle class	Value range
SEDFRAC	Initial sediment particle class fractions (by weight) in bed material	Sand	0.1–0.977
		Silt	0.009–0.45
		Clay	0.013–0.45
DB50/D	Median/effective diameter of the sediment particle class	Sand	0.00492
		Silt	0.00028
		Clay	0.00002
W	Particle fall velocity in still water (in/s)	Sand	0.0866
		Silt	0.000118
		Clay	0.000002
RHO	Particle density (gm/cm3)	Sand	2.6
		Silt	2.3
		Clay	2
KSAND	Coefficient in sandload power function		0.01
EXPSND	Exponent in sandload power function		1
TAUCD	Critical bed shear stress for deposition (lb/ft2)		0.01
TAUCS	Critical bed shear stress for scour (lb/ft2)		0.0002–4.08
M	Erodibility coefficient of the cohesive particles (lb/ft2/day)		0.01

Table D-4. Roanoke River watershed stream physical parameter values

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1000	74.4	2.5	0.45
1001	16	2.5	0.45
1002	14.3	1	0.45
1003	73.6	2	0.45
1004	73.6	2	0.45
1005	73.4	2.5	0.45
1006	71.2	2	0.45
1007	7.8	2.5	0.45
1008	7.7	1.5	0.45
1009	25	2.5	0.45
1010	22.8	2	0.45
1011	20.6	2.5	0.45
1012	14.3	1.5	0.45
1013	13.1	2	0.45
1014	11.8	2	0.45
1015	15.9	2.5	0.45
1016	13	1	0.45
1017	71	2	0.45
1018	70.9	2	0.45
1019	8.5	2.5	0.45
1020	6.9	1.5	0.45
1021	70.8	2.5	0.45
1022	69.1	2.5	0.45
1023	68.5	2	0.45
1024	10.9	1	0.45
1025	21.5	2.5	0.45
1026	21.4	2	0.45
1027	18.4	2.5	0.45
1028	18.1	2	0.45
1029	12.3	1	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1030	7.8	1.5	0.45
1031	10	1.5	0.45
1032	11.9	1.5	0.45
1033	68.1	2	0.45
1034	11.8	1.5	0.45
1035	67.8	2	0.45
1036	65.3	2.5	0.45
1037	65.2	2	0.45
1038	65.2	0.5	0.45
1039	64.9	0.5	0.45
1040	12.7	2	0.45
1041	12.3	1	0.45
1042	25.8	1.5	0.45
1043	22.6	2	0.45
1044	22.3	2.5	0.45
1045	11.3	1.5	0.45
1046	13.2	2	0.45
1047	19.3	2.5	0.45
1048	13.6	1	0.45
1049	15.2	2	0.45
1050	11.9	1	0.45
1051	10	1.5	0.45
1052	64.2	0.5	0.45
1053	64.1	0.5	0.45
1054	63.4	1	0.45
1055	63.2	2	0.45
1056	62.9	1.5	0.45
1057	62.9	2	0.45
1058	58.1	2.5	0.45
1059	58.1	2.5	0.45
1060	58.1	2.5	0.45
1061	58.1	2	0.45
1062	58.1	2.5	0.45
1063	58.1	0.5	0.45
1064	8.1	1	0.45
1065	14.4	1	0.45
1066	31.4	2	0.45
1067	31.4	2	0.45
1068	31.2	2	0.45
1069	29.4	2.5	0.45
1070	28.9	2	0.45
1071	27.8	1.5	0.45
1072	15.8	2	0.45
1073	11	1.5	0.45
1074	11.9	1	0.45
1075	10.5	1.5	0.45
1076	22.7	2	0.45
1077	19.8	2	0.45
1078	14.3	0.5	0.45
1079	13.1	1	0.45
1080	13.9	0.5	0.45
1081	12.4	2	0.45
1082	12.1	1	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1083	4.6	1.5	0.45
1084	1.4	2.5	0.45
1085	1.3	2	0.45
1086	57.9	0.5	0.45
1087	57.9	0.5	0.45
1088	57.9	0.5	0.45
1089	57.9	0.5	0.45
1090	11.2	1.5	0.45
1091	4.1	1.5	0.45
1092	57.5	2	0.45
1093	57.4	2.5	0.45
1094	53.7	1	0.45
1095	26.7	2.5	0.45
1096	9.1	1.5	0.45
1097	24.9	2.5	0.45
1098	23.5	1.5	0.45
1099	10	1	0.45
1100	20.7	1.5	0.45
1101	10.1	0.5	0.45
1102	15	1.5	0.45
1103	8.3	2	0.45
1104	7.5	0.5	0.45
1105	11.5	0.5	0.45
1106	4.1	2	0.45
3011	35.1	2.5	0.45
3012	34.9	1.5	0.45
3013	31.5	2.5	0.45
3014	31.5	1.5	0.45
3015	31.3	2	0.45
3016	31	1	0.45
3017	30.9	0.5	0.45
3018	30.6	1	0.45
3019	29	2.5	0.45
3020	29	1	0.45
3021	28.3	1	0.45
3022	27.9	0.5	0.45
3023	27.6	1	0.45
3024	27.3	0.5	0.45
3025	27.3	1	0.45
3026	27.2	1	0.45
3027	20.8	1	0.45
3028	20.2	1	0.45
3029	19	1.5	0.45
3030	15.7	1	0.45
3031	11	0.5	0.45
3032	2.1	1	0.45
3033	5.3	1	0.45
3034	19.1	2.5	0.45
3035	16.6	1.5	0.45
3036	11.1	2	0.45
3037	11.7	2	0.45
3038	9.8	0.5	0.45
3039	11.8	1.5	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
3040	7.7	1	0.45
3041	7	1.5	0.45
3042	6.9	1.5	0.45
3043	11.2	2.5	0.45
3044	11.1	0.5	0.45
3045	19.4	1.5	0.45
3046	17.7	1	0.45
3047	6.2	1	0.45
3048	5.2	0.5	0.45
3049	15.3	1.5	0.45
3050	14	1	0.45
3051	8.1	0.5	0.45
3052	3.6	1	0.45
3053	12.1	0.5	0.45
3054	10.2	0.5	0.45
30036	11.1	2.5	0.45

Table D-5. Roanoke River watershed model PCB parameters and ranges

Model Parameter	Parameter Description	Value range
POTFW	Washoff potency factor (lb/ton-sediment)	0.00001–0.204
POTFC	Background concentration potency factor (lb/ton-sediment)	0.00001–0.204
ADDC	Atmospheric dry deposition flux (lb/acre/day)	3.91E-08
ADPM1	Partition coefficent with suspended sand (L/mg)	0
ADPM2	Partition coefficent with suspended silt (L/mg)	0.078–0.1139
ADPM3	Partition coefficent with suspended clay (L/mg)	0.078–0.1139
ADPM4	Partition coefficent with bed sand (L/mg)	0
ADPM5	Partition coefficent with bed silt (L/mg)	0.085–5.28
ADPM6	Partition coefficent with bed clay (L/mg)	0.085–5.28
ADPM1	Adorption/desorption rate with suspended sand (L/mg)	2.87
ADPM2	Adorption/desorption rate with suspended silt (L/mg)	2.87
ADPM3	Adorption/desorption rate with suspended clay (L/mg)	2.87
ADPM4	Adorption/desorption rate with bed sand (L/mg)	1.00E-06
ADPM5	Adorption/desorption rate with bed silt (L/mg)	1.00E-06
ADPM6	Adorption/desorption rate with bed clay (L/mg)	1.00E-06

Table D-6. Roanoke River watershed initial streambed sediment PCB concentrations

Reach ID	Total PCBs (mg/mg)
1000	9.77E-09
1001	2.97E-08
1002	2.97E-08
1003	8.57E-08
1004	8.57E-08
1005	8.57E-08
1006	1.89E-07
1007	4.32E-09
1008	4.32E-09
1009	3.82E-09
1010	3.82E-09
1011	3.82E-09
1012	3.82E-09
1013	3.82E-09

Reach ID	Total PCBs (mg/mg)
1014	3.82E-09
1015	3.82E-09
1016	3.82E-09
1017	1.89E-07
1018	8.89E-08
1019	1.86E-08
1020	1.86E-08
1021	8.89E-08
1022	7.06E-09
1023	2.84E-07
1024	9.83E-09
1025	1.91E-09
1026	1.91E-09
1027	6.90E-09
1028	6.90E-09
1029	6.90E-09
1030	6.90E-09
1031	6.90E-09
1032	6.82E-08
1033	2.84E-07
1034	2.20E-09
1035	2.00E-06
1036	2.00E-06
1037	2.00E-06
1038	3.60E-08
1039	3.60E-08
1040	1.86E-08
1041	1.86E-08
1042	6.27E-08
1043	6.27E-08
1044	6.27E-08
1045	6.27E-08
1046	6.27E-08
1047	6.27E-08
1048	6.27E-08
1049	6.27E-08
1050	6.27E-08
1051	4.71E-09
1052	5.65E-09
1053	1.14E-08
1054	6.99E-08
1055	5.24E-08
1056	3.00E-09
1057	2.95E-08
1058	2.95E-08
1059	2.95E-08
1060	8.20E-05
1061	8.20E-05
1062	8.20E-05
1063	8.20E-05
1064	1.86E-08
1065	1.09E-07
1066	2.17E-09

Reach ID	Total PCBs (mg/mg)
1067	1.46E-09
1068	1.46E-09
1069	1.20E-08
1070	1.20E-08
1071	1.20E-08
1072	3.40E-08
1073	3.40E-08
1074	2.37E-08
1075	1.20E-08
1076	3.19E-09
1077	3.19E-09
1078	3.19E-09
1079	3.19E-09
1080	3.19E-09
1081	3.40E-08
1082	3.40E-08
1083	4.28E-08
1084	2.06E-04
1085	2.06E-04
1086	5.98E-07
1087	1.80E-07
1088	8.41E-08
1089	1.95E-09
1090	8.47E-09
1091	5.00E-06
1092	1.96E-08
1093	3.30E-08
1094	3.30E-08
1095	5.34E-09
1096	5.34E-09
1097	5.34E-09
1098	5.34E-09
1099	5.34E-09
1100	5.34E-09
1101	5.34E-09
1102	5.34E-09
1103	5.34E-09
1104	5.34E-09
1105	1.05E-09
1106	1.86E-08
3011	7.18E-07
3012	1.85E-07
3013	3.00E-06
3014	2.00E-06
3015	2.00E-06
3016	3.00E-06
3017	3.00E-06
3018	3.00E-06
3019	7.41E-07
3020	7.41E-07
3021	1.07E-08
3022	1.07E-08
3023	2.54E-08

Reach ID	Total PCBs (mg/mg)
3024	2.54E-08
3025	1.33E-08
3026	1.33E-08
3027	6.92E-09
3028	2.78E-09
3029	3.55E-09
3030	3.55E-09
3031	3.55E-09
3032	1.15E-07
3033	1.86E-08
3034	8.00E-06
3035	8.00E-06
3036	8.00E-06
3037	1.13E-08
3038	1.13E-08
3039	1.13E-08
3040	1.13E-08
3041	2.34E-07
3042	1.26E-07
3043	7.75E-08
3044	7.75E-08
3045	1.11E-08
3046	1.11E-08
3047	1.11E-08
3048	1.11E-08
3049	1.11E-08
3050	1.11E-08
3051	5.11E-08
3052	5.11E-08
3053	3.55E-09
3054	3.55E-09
30036	3.83E-09

Table D-7. Roanoke River watershed baseline and TMDL initial streambed sediment PCB concentrations

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1000	9.77E-09	9.77E-09	0.000
1001	2.97E-08	1.00E-08	0.664
1002	2.97E-08	1.00E-08	0.664
1003	8.57E-08	1.00E-08	0.883
1004	8.57E-08	1.00E-08	0.883
1005	8.57E-08	1.00E-08	0.883
1006	1.89E-07	1.00E-08	0.947
1007	4.32E-09	4.32E-09	0.000
1008	4.32E-09	4.32E-09	0.000
1009	3.82E-09	3.82E-09	0.000
1010	3.82E-09	3.82E-09	0.000
1011	3.82E-09	3.82E-09	0.000
1012	3.82E-09	3.82E-09	0.000
1013	3.82E-09	3.82E-09	0.000

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1014	3.82E-09	3.82E-09	0.000
1015	3.82E-09	3.82E-09	0.000
1016	3.82E-09	3.82E-09	0.000
1017	1.89E-07	1.00E-08	0.947
1018	8.89E-08	1.00E-08	0.887
1019	1.86E-08	1.00E-08	0.461
1020	1.86E-08	1.00E-08	0.461
1021	8.89E-08	1.00E-08	0.887
1022	7.06E-09	7.06E-09	0.000
1023	2.84E-07	1.00E-08	0.965
1024	9.83E-09	9.83E-09	0.000
1025	1.91E-09	1.91E-09	0.000
1026	1.91E-09	1.91E-09	0.000
1027	6.90E-09	6.90E-09	0.000
1028	6.90E-09	6.90E-09	0.000
1029	6.90E-09	6.90E-09	0.000
1030	6.90E-09	6.90E-09	0.000
1031	6.90E-09	6.90E-09	0.000
1032	6.82E-08	1.00E-08	0.853
1033	2.84E-07	1.00E-08	0.965
1034	2.20E-09	2.20E-09	0.000
1035	2.00E-06	1.00E-08	0.995
1036	2.00E-06	1.00E-08	0.995
1037	2.00E-06	1.00E-08	0.995
1038	3.60E-08	1.00E-08	0.722
1039	3.60E-08	1.00E-08	0.722
1040	1.86E-08	1.00E-08	0.461
1041	1.86E-08	1.00E-08	0.461
1042	6.27E-08	1.00E-08	0.840
1043	6.27E-08	1.00E-08	0.840
1044	6.27E-08	1.00E-08	0.840
1045	6.27E-08	1.00E-08	0.840
1046	6.27E-08	1.00E-08	0.840
1047	6.27E-08	1.00E-08	0.840
1048	6.27E-08	1.00E-08	0.840
1049	6.27E-08	1.00E-08	0.840
1050	6.27E-08	1.00E-08	0.840
1051	4.71E-09	4.71E-09	0.000
1052	5.65E-09	5.65E-09	0.000
1053	1.14E-08	1.00E-08	0.123
1054	6.99E-08	1.00E-08	0.857
1055	5.24E-08	1.00E-08	0.809
1056	3.00E-09	3.00E-09	0.000
1057	2.95E-08	1.00E-08	0.661
1058	2.95E-08	1.00E-08	0.661
1059	2.95E-08	1.00E-08	0.661
1060	8.20E-05	1.00E-08	1.000

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1061	8.20E-05	1.00E-08	1.000
1062	8.20E-05	1.00E-08	1.000
1063	8.20E-05	1.00E-08	1.000
1064	1.86E-08	1.00E-08	0.461
1065	1.09E-07	1.00E-08	0.909
1066	2.17E-09	2.17E-09	0.000
1067	1.46E-09	1.46E-09	0.000
1068	1.46E-09	1.46E-09	0.000
1069	1.20E-08	1.00E-08	0.167
1070	1.20E-08	1.00E-08	0.167
1071	1.20E-08	1.00E-08	0.167
1072	3.40E-08	1.00E-08	0.706
1073	3.40E-08	1.00E-08	0.706
1074	2.37E-08	1.00E-08	0.578
1075	1.20E-08	1.00E-08	0.167
1076	3.19E-09	3.19E-09	0.000
1077	3.19E-09	3.19E-09	0.000
1078	3.19E-09	3.19E-09	0.000
1079	3.19E-09	3.19E-09	0.000
1080	3.19E-09	3.19E-09	0.000
1081	3.40E-08	1.00E-08	0.706
1082	3.40E-08	1.00E-08	0.706
1083	4.28E-08	1.00E-08	0.766
1084	2.06E-04	1.00E-08	1.000
1085	2.06E-04	1.00E-08	1.000
1086	5.98E-07	1.00E-08	0.983
1087	1.80E-07	1.00E-08	0.944
1088	8.41E-08	1.00E-08	0.881
1089	1.95E-09	1.95E-09	0.000
1090	8.47E-09	8.47E-09	0.000
1091	5.00E-06	1.00E-08	0.998
1092	1.96E-08	1.00E-08	0.489
1093	3.30E-08	1.00E-08	0.697
1094	3.30E-08	1.00E-08	0.697
1095	5.34E-09	5.34E-09	0.000
1096	5.34E-09	5.34E-09	0.000
1097	5.34E-09	5.34E-09	0.000
1098	5.34E-09	5.34E-09	0.000
1099	5.34E-09	5.34E-09	0.000
1100	5.34E-09	5.34E-09	0.000
1101	5.34E-09	5.34E-09	0.000
1102	5.34E-09	5.34E-09	0.000
1103	5.34E-09	5.34E-09	0.000
1104	5.34E-09	5.34E-09	0.000
1105	1.05E-09	1.05E-09	0.000
1106	1.86E-08	1.00E-08	0.461
3011	7.18E-07	1.50E-08	0.979

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
3012	1.85E-07	1.50E-08	0.919
3013	3.00E-06	1.50E-08	0.995
3014	2.00E-06	1.50E-08	0.993
3015	2.00E-06	1.50E-08	0.993
3016	3.00E-06	1.50E-08	0.995
3017	3.00E-06	1.50E-08	0.995
3018	3.00E-06	1.50E-08	0.995
3019	7.41E-07	1.50E-08	0.980
3020	7.41E-07	1.50E-08	0.980
3021	1.07E-08	1.07E-08	0.000
3022	1.07E-08	1.07E-08	0.000
3023	2.54E-08	1.50E-08	0.410
3024	2.54E-08	1.50E-08	0.410
3025	1.33E-08	1.33E-08	0.000
3026	1.33E-08	1.33E-08	0.000
3027	6.92E-09	6.92E-09	0.000
3028	2.78E-09	2.78E-09	0.000
3029	3.55E-09	3.55E-09	0.000
3030	3.55E-09	3.55E-09	0.000
3031	3.55E-09	3.55E-09	0.000
3032	1.15E-07	1.50E-08	0.870
3033	1.86E-08	1.50E-08	0.192
3034	8.00E-06	1.50E-08	0.998
3035	8.00E-06	1.50E-08	0.998
3036	8.00E-06	1.50E-08	0.998
3037	1.13E-08	1.13E-08	0.000
3038	1.13E-08	1.13E-08	0.000
3039	1.13E-08	1.13E-08	0.000
3040	1.13E-08	1.13E-08	0.000
3041	2.34E-07	1.50E-08	0.936
3042	1.26E-07	1.50E-08	0.881
3043	7.75E-08	1.50E-08	0.807
3044	7.75E-08	1.50E-08	0.807
3045	1.11E-08	1.11E-08	0.000
3046	1.11E-08	1.11E-08	0.000
3047	1.11E-08	1.11E-08	0.000
3048	1.11E-08	1.11E-08	0.000
3049	1.11E-08	1.11E-08	0.000
3050	1.11E-08	1.11E-08	0.000
3051	5.11E-08	1.50E-08	0.706
3052	5.11E-08	1.50E-08	0.706
3053	3.55E-09	3.55E-09	0.000
3054	3.55E-09	3.55E-09	0.000
30036	3.83E-09	3.83E-09	0.000

Table D-8. Stream and river segments associated with model subbasins

Watershed Section	Model subbasin	Stream name
Upper	3043	Masons Creek
Upper	3044	Masons Creek
Upper	3045	North Fork Roanoke River
Upper	3046	North Fork Roanoke River
Upper	3047	North Fork Roanoke River
Upper	3048	North Fork Roanoke River
Upper	3049	North Fork Roanoke River
Upper	3050	North Fork Roanoke River
Upper	3051	North Fork Roanoke River
Upper	3052	North Fork Roanoke River
Upper	3041	Peters Creek
Upper	3042	Peters Creek
Upper	3010	Roanoke River
Upper	3011	Roanoke River
Upper	3012	Roanoke River
Upper	3013	Roanoke River
Upper	3014	Roanoke River
Upper	3015	Roanoke River
Upper	3016	Roanoke River
Upper	3017	Roanoke River
Upper	3018	Roanoke River
Upper	3019	Roanoke River
Upper	3020	Roanoke River
Upper	3021	Roanoke River
Upper	3022	Roanoke River
Upper	3023	Roanoke River
Upper	3024	Roanoke River
Upper	3025	Roanoke River
Upper	3026	Roanoke River
Upper	3027	South Fork Roanoke River
Upper	3028	South Fork Roanoke River
Upper	3029	South Fork Roanoke River
Upper	3030	South Fork Roanoke River
Upper	3031	South Fork Roanoke River
Upper	3053	South Fork Roanoke River
Upper	3054	South Fork Roanoke River
Upper	3034	Tinker Creek
Upper	3035	Tinker Creek
Upper	3036	Tinker Creek
Upper	3037	Tinker Creek
Upper	3038	Tinker Creek
Upper	3039	Tinker Creek
Upper	3040	Tinker Creek
Upper	30036	Tinker Creek
Upper	3032	Unnamed Trib to Roanoke River
Upper	3033	Wolf Creek
Lower	1066	Big Otter River
Lower	1067	Big Otter River
Lower	1068	Big Otter River

Watershed Section	Model subbasin	Stream name
Lower	1069	Big Otter River
Lower	1070	Big Otter River
Lower	1071	Big Otter River
Lower	1074	Big Otter River
Lower	1075	Big Otter River
Lower	1076	Big Otter River
Lower	1077	Big Otter River
Lower	1078	Big Otter River
Lower	1079	Big Otter River
Lower	1080	Big Otter River
Lower	1007	Black Walnut Creek
Lower	1008	Black Walnut Creek
Lower	1024	Catawba Creek
Lower	1034	Childrey Creek
Lower	1025	Cub Creek
Lower	1026	Cub Creek
Lower	1027	Cub Creek
Lower	1028	Cub Creek
Lower	1029	Cub Creek
Lower	1030	Cub Creek
Lower	1031	Cub Creek
Lower	1001	Difficult Creek
Lower	1002	Difficult Creek
Lower	1042	Falling River
Lower	1043	Falling River
Lower	1044	Falling River
Lower	1045	Falling River
Lower	1046	Falling River
Lower	1047	Falling River
Lower	1048	Falling River
Lower	1049	Falling River
Lower	1050	Falling River
Lower	1095	Goose Creek
Lower	1096	Goose Creek
Lower	1097	Goose Creek
Lower	1098	Goose Creek
Lower	1099	Goose Creek
Lower	1100	Goose Creek
Lower	1101	Goose Creek
Lower	1102	Goose Creek
Lower	1103	Goose Creek
Lower	1104	Goose Creek
Lower	1105	Goose Creek
Lower	1019	Hunting Creek
Lower	1020	Hunting Creek
Lower	1072	Little Otter River
Lower	1073	Little Otter River
Lower	1081	Little Otter River
Lower	1082	Little Otter River
Lower	1091	Lynch Creek
Lower	1064	Reed Creek
Lower	1009	Roanoke Creek

Watershed Section	Model subbasin	Stream name
Lower	1010	Roanoke Creek
Lower	1011	Roanoke Creek
Lower	1012	Roanoke Creek
Lower	1013	Roanoke Creek
Lower	1014	Roanoke Creek
Lower	1015	Roanoke Creek
Lower	1016	Roanoke Creek
Lower	1000	Roanoke River
Lower	1003	Roanoke River
Lower	1004	Roanoke River
Lower	1005	Roanoke River
Lower	1006	Roanoke River
Lower	1017	Roanoke River
Lower	1018	Roanoke River
Lower	1021	Roanoke River
Lower	1022	Roanoke River
Lower	1023	Roanoke River
Lower	1033	Roanoke River
Lower	1035	Roanoke River
Lower	1036	Roanoke River
Lower	1037	Roanoke River
Lower	1038	Roanoke River
Lower	1039	Roanoke River
Lower	1052	Roanoke River
Lower	1053	Roanoke River
Lower	1054	Roanoke River
Lower	1055	Roanoke River
Lower	1056	Roanoke River
Lower	1057	Roanoke River
Lower	1058	Roanoke River
Lower	1059	Roanoke River
Lower	1060	Roanoke River
Lower	1061	Roanoke River
Lower	1062	Roanoke River
Lower	1063	Roanoke River
Lower	1086	Roanoke River
Lower	1087	Roanoke River
Lower	1088	Roanoke River
Lower	1089	Roanoke River
Lower	1092	Roanoke River
Lower	1093	Roanoke River
Lower	1094	Roanoke River
Lower	1065	Seneca Creek
Lower	1040	Straightstone Creek
Lower	1041	Straightstone Creek
Lower	1106	Straightstone Creek
Lower	1090	Sycamore Creek
Lower	1032	Turnip Creek
Lower	1083	Unnamed Trib to Roanoke River
Lower	1051	Whipping Creek
Lower	1084	X-trib

Watershed Section	Model subbasin	Stream name
Lower	1085	X-trib

Table D-9. Leesville Dam average daily discharge time series

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
1/1/1990	7220	8/10/1994	470	3/19/1999	1290	10/26/2003	608
1/2/1990	7120	8/11/1994	467	3/20/1999	1150	10/27/2003	574
1/3/1990	2990	8/12/1994	491	3/21/1999	1180	10/28/2003	956
1/4/1990	1400	8/13/1994	559	3/22/1999	1710	10/29/2003	1010
1/5/1990	992	8/14/1994	518	3/23/1999	1590	10/30/2003	1050
1/6/1990	1210	8/15/1994	440	3/24/1999	1240	10/31/2003	1060
1/7/1990	1600	8/16/1994	3320	3/25/1999	836	11/1/2003	1070
1/8/1990	2080	8/17/1994	7400	3/26/1999	664	11/2/2003	973
1/9/1990	3540	8/18/1994	4860	3/27/1999	537	11/3/2003	652
1/10/1990	3810	8/19/1994	302	3/28/1999	522	11/4/2003	569
1/11/1990	2300	8/20/1994	329	3/29/1999	471	11/5/2003	579
1/12/1990	1660	8/21/1994	1040	3/30/1999	496	11/6/2003	630
1/13/1990	1220	8/22/1994	916	3/31/1999	497	11/7/2003	2490
1/14/1990	1200	8/23/1994	446	4/1/1999	475	11/8/2003	3550
1/15/1990	941	8/24/1994	449	4/2/1999	735	11/9/2003	1950
1/16/1990	684	8/25/1994	456	4/3/1999	990	11/10/2003	1080
1/17/1990	708	8/26/1994	462	4/4/1999	1020	11/11/2003	874
1/18/1990	872	8/27/1994	473	4/5/1999	916	11/12/2003	731
1/19/1990	945	8/28/1994	437	4/6/1999	496	11/13/2003	642
1/20/1990	1010	8/29/1994	431	4/7/1999	469	11/14/2003	707
1/21/1990	966	8/30/1994	444	4/8/1999	450	11/15/2003	676
1/22/1990	1030	8/31/1994	480	4/9/1999	490	11/16/2003	625
1/23/1990	1080	9/1/1994	650	4/10/1999	502	11/17/2003	605
1/24/1990	1010	9/2/1994	653	4/11/1999	600	11/18/2003	834
1/25/1990	1490	9/3/1994	575	4/12/1999	1830	11/19/2003	3060
1/26/1990	2310	9/4/1994	493	4/13/1999	2630	11/20/2003	3180
1/27/1990	2170	9/5/1994	494	4/14/1999	2260	11/21/2003	3720
1/28/1990	1810	9/6/1994	476	4/15/1999	1320	11/22/2003	3840
1/29/1990	1210	9/7/1994	479	4/16/1999	861	11/23/2003	2580
1/30/1990	1140	9/8/1994	490	4/17/1999	800	11/24/2003	912
1/31/1990	2460	9/9/1994	498	4/18/1999	628	11/25/2003	1030
2/1/1990	1820	9/10/1994	544	4/19/1999	467	11/26/2003	1070
2/2/1990	1470	9/11/1994	534	4/20/1999	453	11/27/2003	1100
2/3/1990	1290	9/12/1994	535	4/21/1999	472	11/28/2003	1040
2/4/1990	1710	9/13/1994	515	4/22/1999	465	11/29/2003	1020
2/5/1990	3370	9/14/1994	518	4/23/1999	480	11/30/2003	1140
2/6/1990	1980	9/15/1994	535	4/24/1999	471	12/1/2003	1090
2/7/1990	1460	9/16/1994	543	4/25/1999	528	12/2/2003	1140
2/8/1990	1410	9/17/1994	565	4/26/1999	1260	12/3/2003	1160
2/9/1990	1300	9/18/1994	535	4/27/1999	1230	12/4/2003	1160
2/10/1990	2250	9/19/1994	504	4/28/1999	1070	12/5/2003	1180
2/11/1990	4490	9/20/1994	534	4/29/1999	981	12/6/2003	1460
2/12/1990	1960	9/21/1994	547	4/30/1999	897	12/7/2003	1590
2/13/1990	1980	9/22/1994	543	5/1/1999	907	12/8/2003	1710
2/14/1990	1460	9/23/1994	526	5/2/1999	981	12/9/2003	1670
2/15/1990	1460	9/24/1994	528	5/3/1999	1020	12/10/2003	1170

Date	Flow (cfs)
2/16/1990	2410
2/17/1990	2580
2/18/1990	1440
2/19/1990	807
2/20/1990	1310
2/21/1990	1910
2/22/1990	1940
2/23/1990	2160
2/24/1990	2270
2/25/1990	1850
2/26/1990	285
2/27/1990	363
2/28/1990	664
3/1/1990	1170
3/2/1990	1370
3/3/1990	1240
3/4/1990	2130
3/5/1990	1520
3/6/1990	1030
3/7/1990	884
3/8/1990	857
3/9/1990	896
3/10/1990	1020
3/11/1990	975
3/12/1990	982
3/13/1990	1080
3/14/1990	1010
3/15/1990	985
3/16/1990	2700
3/17/1990	4150
3/18/1990	6240
3/19/1990	5460
3/20/1990	977
3/21/1990	565
3/22/1990	748
3/23/1990	898
3/24/1990	1210
3/25/1990	1220
3/26/1990	1310
3/27/1990	1250
3/28/1990	1290
3/29/1990	1490
3/30/1990	1940
3/31/1990	2800
4/1/1990	2840
4/2/1990	3560
4/3/1990	4310
4/4/1990	2170
4/5/1990	1490
4/6/1990	1230
4/7/1990	2910
4/8/1990	2850

Date	Flow (cfs)
9/25/1994	529
9/26/1994	541
9/27/1994	147
9/28/1994	492
9/29/1994	537
9/30/1994	561
10/1/1994	536
10/2/1994	582
10/3/1994	542
10/4/1994	548
10/5/1994	564
10/6/1994	583
10/7/1994	591
10/8/1994	578
10/9/1994	553
10/10/1994	538
10/11/1994	558
10/12/1994	580
10/13/1994	577
10/14/1994	547
10/15/1994	468
10/16/1994	510
10/17/1994	740
10/18/1994	549
10/19/1994	574
10/20/1994	558
10/21/1994	527
10/22/1994	549
10/23/1994	530
10/24/1994	445
10/25/1994	526
10/26/1994	542
10/27/1994	520
10/28/1994	530
10/29/1994	528
10/30/1994	512
10/31/1994	536
11/1/1994	490
11/2/1994	492
11/3/1994	503
11/4/1994	571
11/5/1994	525
11/6/1994	529
11/7/1994	566
11/8/1994	547
11/9/1994	536
11/10/1994	528
11/11/1994	472
11/12/1994	488
11/13/1994	522
11/14/1994	512
11/15/1994	517

Date	Flow (cfs)
5/4/1999	1150
5/5/1999	1070
5/6/1999	1010
5/7/1999	1090
5/8/1999	946
5/9/1999	1020
5/10/1999	1070
5/11/1999	1090
5/12/1999	1030
5/13/1999	980
5/14/1999	1120
5/15/1999	802
5/16/1999	831
5/17/1999	986
5/18/1999	984
5/19/1999	945
5/20/1999	944
5/21/1999	990
5/22/1999	1040
5/23/1999	1040
5/24/1999	1040
5/25/1999	891
5/26/1999	542
5/27/1999	540
5/28/1999	525
5/29/1999	501
5/30/1999	504
5/31/1999	528
6/1/1999	552
6/2/1999	562
6/3/1999	548
6/4/1999	564
6/5/1999	575
6/6/1999	553
6/7/1999	558
6/8/1999	576
6/9/1999	581
6/10/1999	574
6/11/1999	588
6/12/1999	587
6/13/1999	588
6/14/1999	585
6/15/1999	576
6/16/1999	577
6/17/1999	515
6/18/1999	358
6/19/1999	477
6/20/1999	476
6/21/1999	351
6/22/1999	341
6/23/1999	345
6/24/1999	353

Date	Flow (cfs)
12/11/2003	3560
12/12/2003	7020
12/13/2003	4650
12/14/2003	2200
12/15/2003	2080
12/16/2003	1900
12/17/2003	1720
12/18/2003	2880
12/19/2003	2540
12/20/2003	1970
12/21/2003	1590
12/22/2003	1320
12/23/2003	1320
12/24/2003	1270
12/25/2003	1180
12/26/2003	1070
12/27/2003	895
12/28/2003	729
12/29/2003	605
12/30/2003	737
12/31/2003	941
1/1/2004	930
1/2/2004	921
1/3/2004	944
1/4/2004	933
1/5/2004	1050
1/6/2004	1450
1/7/2004	1570
1/8/2004	1430
1/9/2004	1310
1/10/2004	1340
1/11/2004	1210
1/12/2004	1010
1/13/2004	1030
1/14/2004	1040
1/15/2004	1030
1/16/2004	1060
1/17/2004	972
1/18/2004	839
1/19/2004	946
1/20/2004	1050
1/21/2004	979
1/22/2004	902
1/23/2004	937
1/24/2004	908
1/25/2004	949
1/26/2004	1230
1/27/2004	1670
1/28/2004	1650
1/29/2004	1440
1/30/2004	1040
1/31/2004	1010

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
4/9/1990	2340	11/16/1994	524	6/25/1999	480	2/1/2004	828
4/10/1990	1760	11/17/1994	538	6/26/1999	542	2/2/2004	831
4/11/1990	1600	11/18/1994	546	6/27/1999	405	2/3/2004	692
4/12/1990	1670	11/19/1994	538	6/28/1999	350	2/4/2004	2690
4/13/1990	1510	11/20/1994	502	6/29/1999	331	2/5/2004	3850
4/14/1990	1550	11/21/1994	455	6/30/1999	367	2/6/2004	2410
4/15/1990	2120	11/22/1994	333	7/1/1999	362	2/7/2004	2980
4/16/1990	3160	11/23/1994	420	7/2/1999	388	2/8/2004	3590
4/17/1990	1400	11/24/1994	478	7/3/1999	457	2/9/2004	3820
4/18/1990	1100	11/25/1994	525	7/4/1999	473	2/10/2004	3360
4/19/1990	1170	11/26/1994	521	7/5/1999	422	2/11/2004	2780
4/20/1990	1180	11/27/1994	523	7/6/1999	389	2/12/2004	2600
4/21/1990	1140	11/28/1994	443	7/7/1999	386	2/13/2004	2080
4/22/1990	1010	11/29/1994	485	7/8/1999	230	2/14/2004	1980
4/23/1990	1180	11/30/1994	459	7/9/1999	413	2/15/2004	1790
4/24/1990	1410	12/1/1994	480	7/10/1999	527	2/16/2004	1730
4/25/1990	1260	12/2/1994	506	7/11/1999	403	2/17/2004	1840
4/26/1990	1100	12/3/1994	512	7/12/1999	329	2/18/2004	1880
4/27/1990	1090	12/4/1994	499	7/13/1999	214	2/19/2004	1710
4/28/1990	1090	12/5/1994	219	7/14/1999	242	2/20/2004	1390
4/29/1990	1010	12/6/1994	260	7/15/1999	277	2/21/2004	1120
4/30/1990	934	12/7/1994	390	7/16/1999	372	2/22/2004	1110
5/1/1990	1050	12/8/1994	425	7/17/1999	447	2/23/2004	1100
5/2/1990	1120	12/9/1994	462	7/18/1999	396	2/24/2004	1120
5/3/1990	1160	12/10/1994	464	7/19/1999	363	2/25/2004	1140
5/4/1990	1140	12/11/1994	282	7/20/1999	369	2/26/2004	1130
5/5/1990	1210	12/12/1994	317	7/21/1999	357	2/27/2004	1120
5/6/1990	1520	12/13/1994	478	7/22/1999	0	2/28/2004	1010
5/7/1990	1210	12/14/1994	403	7/23/1999	183	2/29/2004	973
5/8/1990	1140	12/15/1994	404	7/24/1999	402	3/1/2004	900
5/9/1990	1000	12/16/1994	426	7/25/1999	396	3/2/2004	805
5/10/1990	639	12/17/1994	438	7/26/1999	360	3/3/2004	818
5/11/1990	3610	12/18/1994	413	7/27/1999	374	3/4/2004	917
5/12/1990	1480	12/19/1994	454	7/28/1999	369	3/5/2004	1060
5/13/1990	955	12/20/1994	481	7/29/1999	289	3/6/2004	1140
5/14/1990	967	12/21/1994	489	7/30/1999	353	3/7/2004	1380
5/15/1990	990	12/22/1994	475	7/31/1999	445	3/8/2004	1370
5/16/1990	914	12/23/1994	481	8/1/1999	413	3/9/2004	1230
5/17/1990	806	12/24/1994	475	8/2/1999	366	3/10/2004	1110
5/18/1990	846	12/25/1994	493	8/3/1999	375	3/11/2004	899
5/19/1990	850	12/26/1994	514	8/4/1999	388	3/12/2004	753
5/20/1990	803	12/27/1994	519	8/5/1999	390	3/13/2004	672
5/21/1990	795	12/28/1994	509	8/6/1999	446	3/14/2004	568
5/22/1990	2720	12/29/1994	523	8/7/1999	501	3/15/2004	526
5/23/1990	3980	12/30/1994	517	8/8/1999	452	3/16/2004	764
5/24/1990	1710	12/31/1994	498	8/9/1999	397	3/17/2004	1170
5/25/1990	1360	1/1/1995	380	8/10/1999	393	3/18/2004	1550
5/26/1990	1260	1/2/1995	456	8/11/1999	399	3/19/2004	1600
5/27/1990	1140	1/3/1995	513	8/12/1999	411	3/20/2004	1600
5/28/1990	5550	1/4/1995	533	8/13/1999	468	3/21/2004	1360
5/29/1990	7060	1/5/1995	510	8/14/1999	512	3/22/2004	1130
5/30/1990	7490	1/6/1995	317	8/15/1999	463	3/23/2004	850

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
5/31/1990	2370	1/7/1995	75	8/16/1999	406	3/24/2004	795
6/1/1990	1400	1/8/1995	223	8/17/1999	406	3/25/2004	792
6/2/1990	1210	1/9/1995	440	8/18/1999	415	3/26/2004	795
6/3/1990	1300	1/10/1995	409	8/19/1999	418	3/27/2004	794
6/4/1990	1220	1/11/1995	421	8/20/1999	441	3/28/2004	780
6/5/1990	1080	1/12/1995	418	8/21/1999	479	3/29/2004	851
6/6/1990	808	1/13/1995	399	8/22/1999	433	3/30/2004	983
6/7/1990	648	1/14/1995	498	8/23/1999	388	3/31/2004	1200
6/8/1990	558	1/15/1995	4590	8/24/1999	392	4/1/2004	1320
6/9/1990	432	1/16/1995	7710	8/25/1999	299	4/2/2004	1250
6/10/1990	436	1/17/1995	9850	8/26/1999	129	4/3/2004	1160
6/11/1990	1110	1/18/1995	6580	8/27/1999	256	4/4/2004	1070
6/12/1990	1080	1/19/1995	956	8/28/1999	454	4/5/2004	831
6/13/1990	861	1/20/1995	3310	8/29/1999	429	4/6/2004	683
6/14/1990	704	1/21/1995	2810	8/30/1999	394	4/7/2004	642
6/15/1990	680	1/22/1995	1410	8/31/1999	414	4/8/2004	536
6/16/1990	609	1/23/1995	294	9/1/1999	408	4/9/2004	508
6/17/1990	622	1/24/1995	408	9/2/1999	396	4/10/2004	776
6/18/1990	665	1/25/1995	1060	9/3/1999	458	4/11/2004	861
6/19/1990	558	1/26/1995	1130	9/4/1999	510	4/12/2004	862
6/20/1990	615	1/27/1995	1000	9/5/1999	77	4/13/2004	4210
6/21/1990	606	1/28/1995	850	9/6/1999	0	4/14/2004	6060
6/22/1990	539	1/29/1995	1210	9/7/1999	0	4/15/2004	7110
6/23/1990	491	1/30/1995	984	9/8/1999	145	4/16/2004	7580
6/24/1990	636	1/31/1995	895	9/9/1999	269	4/17/2004	4090
6/25/1990	468	2/1/1995	769	9/10/1999	277	4/18/2004	1710
6/26/1990	839	2/2/1995	650	9/11/1999	330	4/19/2004	1190
6/27/1990	919	2/3/1995	916	9/12/1999	353	4/20/2004	1240
6/28/1990	375	2/4/1995	1890	9/13/1999	323	4/21/2004	1420
6/29/1990	659	2/5/1995	1470	9/14/1999	331	4/22/2004	1390
6/30/1990	685	2/6/1995	493	9/15/1999	340	4/23/2004	1170
7/1/1990	683	2/7/1995	902	9/16/1999	184	4/24/2004	962
7/2/1990	677	2/8/1995	1250	9/17/1999	236	4/25/2004	968
7/3/1990	595	2/9/1995	963	9/18/1999	362	4/26/2004	1040
7/4/1990	593	2/10/1995	614	9/19/1999	373	4/27/2004	1490
7/5/1990	589	2/11/1995	501	9/20/1999	323	4/28/2004	1410
7/6/1990	575	2/12/1995	395	9/21/1999	307	4/29/2004	1140
7/7/1990	582	2/13/1995	480	9/22/1999	273	4/30/2004	1060
7/8/1990	575	2/14/1995	600	9/23/1999	319	5/1/2004	1040
7/9/1990	563	2/15/1995	1380	9/24/1999	387	5/2/2004	1150
7/10/1990	617	2/16/1995	3270	9/25/1999	438	5/3/2004	1360
7/11/1990	568	2/17/1995	3880	9/26/1999	397	5/4/2004	1160
7/12/1990	399	2/18/1995	4010	9/27/1999	345	5/5/2004	981
7/13/1990	447	2/19/1995	2340	9/28/1999	0	5/6/2004	886
7/14/1990	6710	2/20/1995	1260	9/29/1999	0	5/7/2004	839
7/15/1990	4980	2/21/1995	1110	9/30/1999	76	5/8/2004	859
7/16/1990	8500	2/22/1995	1130	10/1/1999	2310	5/9/2004	954
7/17/1990	3150	2/23/1995	1180	10/2/1999	357	5/10/2004	1670
7/18/1990	440	2/24/1995	929	10/3/1999	421	5/11/2004	1240
7/19/1990	851	2/25/1995	848	10/4/1999	467	5/12/2004	965
7/20/1990	950	2/26/1995	811	10/5/1999	468	5/13/2004	956
7/21/1990	812	2/27/1995	635	10/6/1999	500	5/14/2004	965

Date	Flow (cfs)
7/22/1990	687
7/23/1990	547
7/24/1990	663
7/25/1990	652
7/26/1990	493
7/27/1990	454
7/28/1990	465
7/29/1990	457
7/30/1990	448
7/31/1990	456
8/1/1990	476
8/2/1990	480
8/3/1990	437
8/4/1990	421
8/5/1990	396
8/6/1990	1760
8/7/1990	1640
8/8/1990	778
8/9/1990	740
8/10/1990	622
8/11/1990	493
8/12/1990	485
8/13/1990	511
8/14/1990	539
8/15/1990	410
8/16/1990	453
8/17/1990	308
8/18/1990	519
8/19/1990	539
8/20/1990	512
8/21/1990	1740
8/22/1990	1350
8/23/1990	426
8/24/1990	593
8/25/1990	1150
8/26/1990	1200
8/27/1990	897
8/28/1990	558
8/29/1990	539
8/30/1990	524
8/31/1990	530
9/1/1990	543
9/2/1990	551
9/3/1990	547
9/4/1990	543
9/5/1990	538
9/6/1990	524
9/7/1990	513
9/8/1990	530
9/9/1990	504
9/10/1990	461
9/11/1990	497

Date	Flow (cfs)
2/28/1995	1130
3/1/1995	1680
3/2/1995	1500
3/3/1995	1340
3/4/1995	1120
3/5/1995	1020
3/6/1995	754
3/7/1995	667
3/8/1995	3020
3/9/1995	3130
3/10/1995	1520
3/11/1995	1450
3/12/1995	1120
3/13/1995	988
3/14/1995	437
3/15/1995	429
3/16/1995	420
3/17/1995	452
3/18/1995	593
3/19/1995	587
3/20/1995	682
3/21/1995	650
3/22/1995	702
3/23/1995	647
3/24/1995	566
3/25/1995	538
3/26/1995	544
3/27/1995	533
3/28/1995	460
3/29/1995	450
3/30/1995	434
3/31/1995	438
4/1/1995	457
4/2/1995	452
4/3/1995	472
4/4/1995	482
4/5/1995	489
4/6/1995	493
4/7/1995	477
4/8/1995	478
4/9/1995	482
4/10/1995	464
4/11/1995	449
4/12/1995	433
4/13/1995	374
4/14/1995	417
4/15/1995	479
4/16/1995	1210
4/17/1995	1940
4/18/1995	1500
4/19/1995	1070
4/20/1995	920

Date	Flow (cfs)
10/7/1999	522
10/8/1999	540
10/9/1999	540
10/10/1999	512
10/11/1999	484
10/12/1999	519
10/13/1999	546
10/14/1999	555
10/15/1999	561
10/16/1999	563
10/17/1999	561
10/18/1999	561
10/19/1999	569
10/20/1999	550
10/21/1999	468
10/22/1999	510
10/23/1999	539
10/24/1999	555
10/25/1999	561
10/26/1999	760
10/27/1999	562
10/28/1999	529
10/29/1999	534
10/30/1999	535
10/31/1999	538
11/1/1999	505
11/2/1999	473
11/3/1999	320
11/4/1999	364
11/5/1999	441
11/6/1999	436
11/7/1999	437
11/8/1999	442
11/9/1999	443
11/10/1999	446
11/11/1999	450
11/12/1999	458
11/13/1999	454
11/14/1999	455
11/15/1999	459
11/16/1999	469
11/17/1999	486
11/18/1999	481
11/19/1999	469
11/20/1999	462
11/21/1999	463
11/22/1999	420
11/23/1999	369
11/24/1999	427
11/25/1999	449
11/26/1999	437
11/27/1999	362

Date	Flow (cfs)
5/15/2004	965
5/16/2004	1120
5/17/2004	1230
5/18/2004	868
5/19/2004	673
5/20/2004	524
5/21/2004	613
5/22/2004	541
5/23/2004	746
5/24/2004	699
5/25/2004	655
5/26/2004	619
5/27/2004	898
5/28/2004	1260
5/29/2004	1030
5/30/2004	844
5/31/2004	520
6/1/2004	630
6/2/2004	676
6/3/2004	632
6/4/2004	728
6/5/2004	2720
6/6/2004	2840
6/7/2004	1130
6/8/2004	795
6/9/2004	661
6/10/2004	589
6/11/2004	720
6/12/2004	824
6/13/2004	830
6/14/2004	721
6/15/2004	530
6/16/2004	831
6/17/2004	1590
6/18/2004	1260
6/19/2004	880
6/20/2004	867
6/21/2004	651
6/22/2004	496
6/23/2004	457
6/24/2004	405
6/25/2004	548
6/26/2004	1470
6/27/2004	2050
6/28/2004	1240
6/29/2004	944
6/30/2004	672
7/1/2004	586
7/2/2004	566
7/3/2004	526
7/4/2004	530
7/5/2004	520

Date	Flow (cfs)
9/12/1990	506
9/13/1990	503
9/14/1990	103
9/15/1990	458
9/16/1990	482
9/17/1990	534
9/18/1990	568
9/19/1990	518
9/20/1990	508
9/21/1990	706
9/22/1990	890
9/23/1990	508
9/24/1990	518
9/25/1990	527
9/26/1990	528
9/27/1990	534
9/28/1990	574
9/29/1990	575
9/30/1990	558
10/1/1990	553
10/2/1990	503
10/3/1990	458
10/4/1990	519
10/5/1990	568
10/6/1990	596
10/7/1990	605
10/8/1990	502
10/9/1990	696
10/10/1990	609
10/11/1990	4390
10/12/1990	6640
10/13/1990	4670
10/14/1990	7770
10/15/1990	2360
10/16/1990	688
10/17/1990	334
10/18/1990	791
10/19/1990	3590
10/20/1990	3510
10/21/1990	1400
10/22/1990	0
10/23/1990	3410
10/24/1990	14700
10/25/1990	10200
10/26/1990	3470
10/27/1990	3730
10/28/1990	3580
10/29/1990	969
10/30/1990	551
10/31/1990	501
11/1/1990	611
11/2/1990	612

Date	Flow (cfs)
4/21/1995	877
4/22/1995	869
4/23/1995	1130
4/24/1995	1420
4/25/1995	1030
4/26/1995	860
4/27/1995	874
4/28/1995	895
4/29/1995	908
4/30/1995	1250
5/1/1995	1480
5/2/1995	861
5/3/1995	703
5/4/1995	782
5/5/1995	778
5/6/1995	832
5/7/1995	850
5/8/1995	873
5/9/1995	893
5/10/1995	605
5/11/1995	562
5/12/1995	718
5/13/1995	816
5/14/1995	856
5/15/1995	857
5/16/1995	851
5/17/1995	869
5/18/1995	890
5/19/1995	826
5/20/1995	797
5/21/1995	865
5/22/1995	896
5/23/1995	917
5/24/1995	513
5/25/1995	506
5/26/1995	487
5/27/1995	433
5/28/1995	316
5/29/1995	352
5/30/1995	440
5/31/1995	506
6/1/1995	527
6/2/1995	488
6/3/1995	359
6/4/1995	286
6/5/1995	405
6/6/1995	489
6/7/1995	411
6/8/1995	428
6/9/1995	424
6/10/1995	516
6/11/1995	0

Date	Flow (cfs)
11/28/1999	380
11/29/1999	412
11/30/1999	443
12/1/1999	455
12/2/1999	447
12/3/1999	459
12/4/1999	455
12/5/1999	451
12/6/1999	436
12/7/1999	425
12/8/1999	444
12/9/1999	449
12/10/1999	434
12/11/1999	388
12/12/1999	424
12/13/1999	429
12/14/1999	0
12/15/1999	0
12/16/1999	170
12/17/1999	322
12/18/1999	463
12/19/1999	500
12/20/1999	587
12/21/1999	726
12/22/1999	709
12/23/1999	626
12/24/1999	569
12/25/1999	577
12/26/1999	556
12/27/1999	544
12/28/1999	545
12/29/1999	537
12/30/1999	548
12/31/1999	497
1/1/2000	434
1/2/2000	436
1/3/2000	428
1/4/2000	428
1/5/2000	372
1/6/2000	418
1/7/2000	420
1/8/2000	426
1/9/2000	416
1/10/2000	0
1/11/2000	587
1/12/2000	2750
1/13/2000	996
1/14/2000	527
1/15/2000	411
1/16/2000	407
1/17/2000	421
1/18/2000	435

Date	Flow (cfs)
7/6/2004	541
7/7/2004	535
7/8/2004	464
7/9/2004	449
7/10/2004	469
7/11/2004	180
7/12/2004	295
7/13/2004	250
7/14/2004	396
7/15/2004	420
7/16/2004	408
7/17/2004	497
7/18/2004	447
7/19/2004	443
7/20/2004	439
7/21/2004	453
7/22/2004	463
7/23/2004	466
7/24/2004	566
7/25/2004	683
7/26/2004	570
7/27/2004	464
7/28/2004	598
7/29/2004	633
7/30/2004	654
7/31/2004	843
8/1/2004	868
8/2/2004	0
8/3/2004	1150
8/4/2004	1550
8/5/2004	1640
8/6/2004	1490
8/7/2004	1280
8/8/2004	1100
8/9/2004	510
8/10/2004	526
8/11/2004	527
8/12/2004	484
8/13/2004	2110
8/14/2004	1680
8/15/2004	511
8/16/2004	506
8/17/2004	548
8/18/2004	423
8/19/2004	473
8/20/2004	497
8/21/2004	518
8/22/2004	462
8/23/2004	505
8/24/2004	548
8/25/2004	535
8/26/2004	539

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
11/3/1990	567	6/12/1995	224	1/19/2000	432	8/27/2004	546
11/4/1990	596	6/13/1995	824	1/20/2000	421	8/28/2004	557
11/5/1990	753	6/14/1995	972	1/21/2000	448	8/29/2004	522
11/6/1990	874	6/15/1995	528	1/22/2000	447	8/30/2004	528
11/7/1990	972	6/16/1995	421	1/23/2000	481	8/31/2004	541
11/8/1990	805	6/17/1995	334	1/24/2000	454	9/1/2004	560
11/9/1990	1590	6/18/1995	421	1/25/2000	465	9/2/2004	566
11/10/1990	2750	6/19/1995	466	1/26/2000	441	9/3/2004	568
11/11/1990	1640	6/20/1995	531	1/27/2000	450	9/4/2004	575
11/12/1990	612	6/21/1995	507	1/28/2000	448	9/5/2004	570
11/13/1990	372	6/22/1995	855	1/29/2000	448	9/6/2004	562
11/14/1990	351	6/23/1995	21600	1/30/2000	486	9/7/2004	2330
11/15/1990	437	6/24/1995	9330	1/31/2000	469	9/8/2004	4770
11/16/1990	540	6/25/1995	8020	2/1/2000	525	9/9/2004	3180
11/17/1990	689	6/26/1995	3640	2/2/2000	519	9/10/2004	7570
11/18/1990	721	6/27/1995	5290	2/3/2000	574	9/11/2004	6090
11/19/1990	720	6/28/1995	0	2/4/2000	576	9/12/2004	1880
11/20/1990	738	6/29/1995	0	2/5/2000	569	9/13/2004	980
11/21/1990	721	6/30/1995	17700	2/6/2000	559	9/14/2004	1120
11/22/1990	670	7/1/1995	15300	2/7/2000	565	9/15/2004	3580
11/23/1990	667	7/2/1995	6110	2/8/2000	555	9/16/2004	6330
11/24/1990	680	7/3/1995	1860	2/9/2000	567	9/17/2004	3630
11/25/1990	693	7/4/1995	1520	2/10/2000	578	9/18/2004	0
11/26/1990	630	7/5/1995	1320	2/11/2000	577	9/19/2004	314
11/27/1990	514	7/6/1995	1000	2/12/2000	564	9/20/2004	478
11/28/1990	547	7/7/1995	1250	2/13/2000	835	9/21/2004	523
11/29/1990	557	7/8/1995	1650	2/14/2000	1060	9/22/2004	532
11/30/1990	649	7/9/1995	1360	2/15/2000	1290	9/23/2004	509
12/1/1990	661	7/10/1995	1030	2/16/2000	940	9/24/2004	519
12/2/1990	659	7/11/1995	604	2/17/2000	633	9/25/2004	530
12/3/1990	497	7/12/1995	476	2/18/2000	353	9/26/2004	515
12/4/1990	2000	7/13/1995	481	2/19/2000	2670	9/27/2004	523
12/5/1990	3620	7/14/1995	497	2/20/2000	3280	9/28/2004	0
12/6/1990	1240	7/15/1995	634	2/21/2000	1350	9/29/2004	7840
12/7/1990	760	7/16/1995	490	2/22/2000	1240	9/30/2004	12700
12/8/1990	808	7/17/1995	473	2/23/2000	979	10/1/2004	13300
12/9/1990	837	7/18/1995	353	2/24/2000	714	10/2/2004	8770
12/10/1990	824	7/19/1995	527	2/25/2000	514	10/3/2004	2980
12/11/1990	845	7/20/1995	614	2/26/2000	485	10/4/2004	1740
12/12/1990	871	7/21/1995	461	2/27/2000	547	10/5/2004	1620
12/13/1990	821	7/22/1995	379	2/28/2000	644	10/6/2004	1290
12/14/1990	753	7/23/1995	497	2/29/2000	653	10/7/2004	914
12/15/1990	737	7/24/1995	409	3/1/2000	746	10/8/2004	844
12/16/1990	742	7/25/1995	313	3/2/2000	753	10/9/2004	713
12/17/1990	764	7/26/1995	1390	3/3/2000	735	10/10/2004	689
12/18/1990	781	7/27/1995	2050	3/4/2000	588	10/11/2004	687
12/19/1990	781	7/28/1995	2070	3/5/2000	522	10/12/2004	714
12/20/1990	867	7/29/1995	804	3/6/2000	517	10/13/2004	802
12/21/1990	806	7/30/1995	460	3/7/2000	513	10/14/2004	2090
12/22/1990	798	7/31/1995	443	3/8/2000	489	10/15/2004	2070
12/23/1990	856	8/1/1995	484	3/9/2000	489	10/16/2004	1320
12/24/1990	2610	8/2/1995	493	3/10/2000	493	10/17/2004	882

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
12/25/1990	3900	8/3/1995	504	3/11/2000	491	10/18/2004	526
12/26/1990	1980	8/4/1995	520	3/12/2000	715	10/19/2004	504
12/27/1990	1420	8/5/1995	544	3/13/2000	1130	10/20/2004	483
12/28/1990	855	8/6/1995	515	3/14/2000	651	10/21/2004	601
12/29/1990	2400	8/7/1995	568	3/15/2000	469	10/22/2004	771
12/30/1990	3350	8/8/1995	517	3/16/2000	469	10/23/2004	797
12/31/1990	2490	8/9/1995	493	3/17/2000	468	10/24/2004	763
1/1/1991	2900	8/10/1995	497	3/18/2000	627	10/25/2004	759
1/2/1991	1630	8/11/1995	489	3/19/2000	673	10/26/2004	891
1/3/1991	1360	8/12/1995	513	3/20/2000	824	10/27/2004	909
1/4/1991	1040	8/13/1995	551	3/21/2000	5990	10/28/2004	904
1/5/1991	851	8/14/1995	529	3/22/2000	3360	10/29/2004	914
1/6/1991	842	8/15/1995	2200	3/23/2000	2310	10/30/2004	911
1/7/1991	1060	8/16/1995	4770	3/24/2000	1430	10/31/2004	886
1/8/1991	1460	8/17/1995	741	3/25/2000	1160	11/1/2004	921
1/9/1991	1520	8/18/1995	535	3/26/2000	1230	11/2/2004	923
1/10/1991	2540	8/19/1995	527	3/27/2000	1020	11/3/2004	913
1/11/1991	3510	8/20/1995	524	3/28/2000	759	11/4/2004	914
1/12/1991	6660	8/21/1995	540	3/29/2000	722	11/5/2004	954
1/13/1991	8210	8/22/1995	551	3/30/2000	637	11/6/2004	1040
1/14/1991	8420	8/23/1995	561	3/31/2000	597	11/7/2004	1040
1/15/1991	4320	8/24/1995	571	4/1/2000	581	11/8/2004	953
1/16/1991	3330	8/25/1995	546	4/2/2000	573	11/9/2004	791
1/17/1991	3620	8/26/1995	545	4/3/2000	642	11/10/2004	787
1/18/1991	2470	8/27/1995	557	4/4/2000	907	11/11/2004	789
1/19/1991	1850	8/28/1995	462	4/5/2000	1270	11/12/2004	767
1/20/1991	1090	8/29/1995	502	4/6/2000	1140	11/13/2004	2010
1/21/1991	1420	8/30/1995	530	4/7/2000	1200	11/14/2004	2800
1/22/1991	1760	8/31/1995	539	4/8/2000	575	11/15/2004	2060
1/23/1991	1480	9/1/1995	524	4/9/2000	675	11/16/2004	1560
1/24/1991	1010	9/2/1995	150	4/10/2000	790	11/17/2004	1300
1/25/1991	995	9/3/1995	504	4/11/2000	558	11/18/2004	996
1/26/1991	1010	9/4/1995	520	4/12/2000	570	11/19/2004	790
1/27/1991	1010	9/5/1995	535	4/13/2000	579	11/20/2004	727
1/28/1991	1000	9/6/1995	541	4/14/2000	570	11/21/2004	739
1/29/1991	1020	9/7/1995	611	4/15/2000	569	11/22/2004	763
1/30/1991	1210	9/8/1995	556	4/16/2000	869	11/23/2004	1030
1/31/1991	1320	9/9/1995	584	4/17/2000	722	11/24/2004	3090
2/1/1991	1070	9/10/1995	577	4/18/2000	5510	11/25/2004	6910
2/2/1991	816	9/11/1995	1120	4/19/2000	9620	11/26/2004	7250
2/3/1991	807	9/12/1995	1610	4/20/2000	5330	11/27/2004	1920
2/4/1991	729	9/13/1995	277	4/21/2000	2520	11/28/2004	955
2/5/1991	735	9/14/1995	277	4/22/2000	1460	11/29/2004	1580
2/6/1991	944	9/15/1995	275	4/23/2000	1150	11/30/2004	1690
2/7/1991	1130	9/16/1995	298	4/24/2000	1460	12/1/2004	1590
2/8/1991	882	9/17/1995	241	4/25/2000	1340	12/2/2004	1660
2/9/1991	1240	9/18/1995	193	4/26/2000	2120	12/3/2004	1740
2/10/1991	1270	9/19/1995	22	4/27/2000	1890	12/4/2004	1770
2/11/1991	1170	9/20/1995	50	4/28/2000	1320	12/5/2004	1740
2/12/1991	735	9/21/1995	655	4/29/2000	1130	12/6/2004	1850
2/13/1991	697	9/22/1995	1710	4/30/2000	1200	12/7/2004	1820
2/14/1991	852	9/23/1995	553	5/1/2000	1330	12/8/2004	1830

Date	Flow (cfs)
2/15/1991	886
2/16/1991	918
2/17/1991	872
2/18/1991	827
2/19/1991	3670
2/20/1991	3460
2/21/1991	2140
2/22/1991	851
2/23/1991	1060
2/24/1991	1060
2/25/1991	1060
2/26/1991	1130
2/27/1991	1260
2/28/1991	1290
3/1/1991	1400
3/2/1991	1520
3/3/1991	3710
3/4/1991	5350
3/5/1991	8130
3/6/1991	8370
3/7/1991	5430
3/8/1991	1700
3/9/1991	1340
3/10/1991	1410
3/11/1991	1280
3/12/1991	961
3/13/1991	1350
3/14/1991	1540
3/15/1991	1730
3/16/1991	1920
3/17/1991	1990
3/18/1991	1870
3/19/1991	2020
3/20/1991	2130
3/21/1991	1710
3/22/1991	1630
3/23/1991	1820
3/24/1991	1780
3/25/1991	1990
3/26/1991	2060
3/27/1991	2250
3/28/1991	2890
3/29/1991	3820
3/30/1991	5600
3/31/1991	7940
4/1/1991	8100
4/2/1991	3390
4/3/1991	2030
4/4/1991	1560
4/5/1991	1390
4/6/1991	1420
4/7/1991	1460

Date	Flow (cfs)
9/24/1995	549
9/25/1995	530
9/26/1995	488
9/27/1995	469
9/28/1995	541
9/29/1995	526
9/30/1995	552
10/1/1995	523
10/2/1995	584
10/3/1995	536
10/4/1995	529
10/5/1995	0
10/6/1995	108
10/7/1995	469
10/8/1995	459
10/9/1995	497
10/10/1995	536
10/11/1995	535
10/12/1995	545
10/13/1995	994
10/14/1995	373
10/15/1995	161
10/16/1995	440
10/17/1995	516
10/18/1995	528
10/19/1995	535
10/20/1995	281
10/21/1995	327
10/22/1995	470
10/23/1995	494
10/24/1995	514
10/25/1995	520
10/26/1995	518
10/27/1995	524
10/28/1995	485
10/29/1995	498
10/30/1995	517
10/31/1995	537
11/1/1995	528
11/2/1995	518
11/3/1995	539
11/4/1995	560
11/5/1995	513
11/6/1995	553
11/7/1995	496
11/8/1995	342
11/9/1995	458
11/10/1995	489
11/11/1995	0
11/12/1995	0
11/13/1995	286
11/14/1995	455

Date	Flow (cfs)
5/2/2000	1290
5/3/2000	1190
5/4/2000	1160
5/5/2000	958
5/6/2000	961
5/7/2000	1070
5/8/2000	1440
5/9/2000	1400
5/10/2000	1150
5/11/2000	1080
5/12/2000	1100
5/13/2000	1120
5/14/2000	1270
5/15/2000	1530
5/16/2000	1360
5/17/2000	1090
5/18/2000	1040
5/19/2000	1060
5/20/2000	1080
5/21/2000	1270
5/22/2000	958
5/23/2000	1080
5/24/2000	872
5/25/2000	850
5/26/2000	837
5/27/2000	869
5/28/2000	887
5/29/2000	437
5/30/2000	601
5/31/2000	587
6/1/2000	588
6/2/2000	592
6/3/2000	599
6/4/2000	773
6/5/2000	583
6/6/2000	522
6/7/2000	550
6/8/2000	584
6/9/2000	603
6/10/2000	630
6/11/2000	633
6/12/2000	648
6/13/2000	651
6/14/2000	697
6/15/2000	671
6/16/2000	755
6/17/2000	680
6/18/2000	652
6/19/2000	779
6/20/2000	587
6/21/2000	625
6/22/2000	619

Date	Flow (cfs)
12/9/2004	1590
12/10/2004	1780
12/11/2004	2340
12/12/2004	2660
12/13/2004	2750
12/14/2004	2800
12/15/2004	2120
12/16/2004	1280
12/17/2004	1020
12/18/2004	941
12/19/2004	776
12/20/2004	808
12/21/2004	646
12/22/2004	676
12/23/2004	333
12/24/2004	1940
12/25/2004	2350
12/26/2004	2390
12/27/2004	1610
12/28/2004	1140
12/29/2004	1010
12/30/2004	994
12/31/2004	950
1/1/2005	918
1/2/2005	794
1/3/2005	800
1/4/2005	869
1/5/2005	860
1/6/2005	862
1/7/2005	867
1/8/2005	853
1/9/2005	858
1/10/2005	853
1/11/2005	869
1/12/2005	869
1/13/2005	845
1/14/2005	1750
1/15/2005	7600
1/16/2005	7770
1/17/2005	3410
1/18/2005	2610
1/19/2005	1480
1/20/2005	1400
1/21/2005	1360
1/22/2005	1400
1/23/2005	1430
1/24/2005	1180
1/25/2005	953
1/26/2005	901
1/27/2005	898
1/28/2005	912
1/29/2005	853

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
4/8/1991	1490	11/15/1995	417	6/23/2000	632	1/30/2005	781
4/9/1991	1620	11/16/1995	468	6/24/2000	717	1/31/2005	852
4/10/1991	2290	11/17/1995	501	6/25/2000	648	2/1/2005	1090
4/11/1991	2090	11/18/1995	528	6/26/2000	631	2/2/2005	1120
4/12/1991	1680	11/19/1995	524	6/27/2000	590	2/3/2005	1110
4/13/1991	1260	11/20/1995	517	6/28/2000	588	2/4/2005	1080
4/14/1991	1320	11/21/1995	536	6/29/2000	648	2/5/2005	1080
4/15/1991	1930	11/22/1995	507	6/30/2000	620	2/6/2005	1060
4/16/1991	2210	11/23/1995	512	7/1/2000	630	2/7/2005	1080
4/17/1991	2200	11/24/1995	517	7/2/2000	637	2/8/2005	1110
4/18/1991	1700	11/25/1995	490	7/3/2000	634	2/9/2005	1120
4/19/1991	1670	11/26/1995	544	7/4/2000	648	2/10/2005	1120
4/20/1991	1960	11/27/1995	571	7/5/2000	634	2/11/2005	1150
4/21/1991	1970	11/28/1995	536	7/6/2000	588	2/12/2005	1140
4/22/1991	1550	11/29/1995	182	7/7/2000	635	2/13/2005	1140
4/23/1991	1500	11/30/1995	427	7/8/2000	646	2/14/2005	1110
4/24/1991	1400	12/1/1995	490	7/9/2000	637	2/15/2005	1110
4/25/1991	1260	12/2/1995	494	7/10/2000	730	2/16/2005	1150
4/26/1991	1200	12/3/1995	519	7/11/2000	674	2/17/2005	1180
4/27/1991	1190	12/4/1995	489	7/12/2000	645	2/18/2005	1120
4/28/1991	1150	12/5/1995	504	7/13/2000	672	2/19/2005	1040
4/29/1991	1210	12/6/1995	519	7/14/2000	605	2/20/2005	1220
4/30/1991	1390	12/7/1995	483	7/15/2000	622	2/21/2005	1020
5/1/1991	1710	12/8/1995	508	7/16/2000	662	2/22/2005	1030
5/2/1991	1550	12/9/1995	436	7/17/2000	632	2/23/2005	1250
5/3/1991	1260	12/10/1995	505	7/18/2000	656	2/24/2005	1060
5/4/1991	1200	12/11/1995	514	7/19/2000	655	2/25/2005	1060
5/5/1991	1020	12/12/1995	358	7/20/2000	579	2/26/2005	1070
5/6/1991	880	12/13/1995	208	7/21/2000	713	2/27/2005	1050
5/7/1991	886	12/14/1995	354	7/22/2000	681	2/28/2005	1110
5/8/1991	1110	12/15/1995	853	7/23/2000	651	3/1/2005	1310
5/9/1991	1150	12/16/1995	845	7/24/2000	375	3/2/2005	1610
5/10/1991	1130	12/17/1995	744	7/25/2000	468	3/3/2005	1630
5/11/1991	921	12/18/1995	549	7/26/2000	667	3/4/2005	1590
5/12/1991	907	12/19/1995	373	7/27/2000	646	3/5/2005	1170
5/13/1991	973	12/20/1995	315	7/28/2000	611	3/6/2005	1110
5/14/1991	995	12/21/1995	540	7/29/2000	689	3/7/2005	1250
5/15/1991	1080	12/22/1995	898	7/30/2000	472	3/8/2005	1570
5/16/1991	1200	12/23/1995	770	7/31/2000	716	3/9/2005	2030
5/17/1991	993	12/24/1995	786	8/1/2000	698	3/10/2005	2220
5/18/1991	994	12/25/1995	709	8/2/2000	1660	3/11/2005	1810
5/19/1991	1180	12/26/1995	527	8/3/2000	2330	3/12/2005	1640
5/20/1991	2390	12/27/1995	392	8/4/2000	1120	3/13/2005	1410
5/21/1991	3800	12/28/1995	420	8/5/2000	647	3/14/2005	1330
5/22/1991	3120	12/29/1995	429	8/6/2000	666	3/15/2005	1200
5/23/1991	1710	12/30/1995	418	8/7/2000	666	3/16/2005	1200
5/24/1991	1170	12/31/1995	446	8/8/2000	675	3/17/2005	1270
5/25/1991	1040	1/1/1996	507	8/9/2000	666	3/18/2005	1840
5/26/1991	1000	1/2/1996	496	8/10/2000	652	3/19/2005	1760
5/27/1991	911	1/3/1996	468	8/11/2000	677	3/20/2005	1750
5/28/1991	597	1/4/1996	503	8/12/2000	724	3/21/2005	1790
5/29/1991	1710	1/5/1996	501	8/13/2000	680	3/22/2005	1570

Date	Flow (cfs)
5/30/1991	1010
5/31/1991	802
6/1/1991	698
6/2/1991	534
6/3/1991	645
6/4/1991	988
6/5/1991	929
6/6/1991	861
6/7/1991	696
6/8/1991	633
6/9/1991	634
6/10/1991	603
6/11/1991	571
6/12/1991	566
6/13/1991	572
6/14/1991	572
6/15/1991	488
6/16/1991	475
6/17/1991	455
6/18/1991	476
6/19/1991	1890
6/20/1991	1880
6/21/1991	909
6/22/1991	669
6/23/1991	724
6/24/1991	654
6/25/1991	554
6/26/1991	512
6/27/1991	516
6/28/1991	522
6/29/1991	539
6/30/1991	522
7/1/1991	519
7/2/1991	556
7/3/1991	631
7/4/1991	452
7/5/1991	1530
7/6/1991	1310
7/7/1991	1300
7/8/1991	1260
7/9/1991	979
7/10/1991	721
7/11/1991	583
7/12/1991	443
7/13/1991	507
7/14/1991	579
7/15/1991	603
7/16/1991	571
7/17/1991	577
7/18/1991	585
7/19/1991	591
7/20/1991	552

Date	Flow (cfs)
1/6/1996	504
1/7/1996	790
1/8/1996	1670
1/9/1996	796
1/10/1996	2930
1/11/1996	2940
1/12/1996	1260
1/13/1996	1130
1/14/1996	559
1/15/1996	518
1/16/1996	1160
1/17/1996	2010
1/18/1996	3190
1/19/1996	2490
1/20/1996	11500
1/21/1996	13400
1/22/1996	9100
1/23/1996	4300
1/24/1996	5140
1/25/1996	544
1/26/1996	4410
1/27/1996	4420
1/28/1996	6950
1/29/1996	2060
1/30/1996	2780
1/31/1996	2520
2/1/1996	2490
2/2/1996	2270
2/3/1996	2030
2/4/1996	1750
2/5/1996	1490
2/6/1996	1460
2/7/1996	1440
2/8/1996	1280
2/9/1996	5160
2/10/1996	7750
2/11/1996	3380
2/12/1996	2830
2/13/1996	2800
2/14/1996	1890
2/15/1996	1690
2/16/1996	1730
2/17/1996	1770
2/18/1996	1530
2/19/1996	786
2/20/1996	618
2/21/1996	1230
2/22/1996	1820
2/23/1996	1840
2/24/1996	1870
2/25/1996	1710
2/26/1996	960

Date	Flow (cfs)
8/14/2000	676
8/15/2000	677
8/16/2000	678
8/17/2000	680
8/18/2000	698
8/19/2000	691
8/20/2000	687
8/21/2000	680
8/22/2000	684
8/23/2000	709
8/24/2000	689
8/25/2000	700
8/26/2000	690
8/27/2000	677
8/28/2000	360
8/29/2000	558
8/30/2000	634
8/31/2000	649
9/1/2000	954
9/2/2000	560
9/3/2000	0
9/4/2000	1310
9/5/2000	246
9/6/2000	902
9/7/2000	760
9/8/2000	603
9/9/2000	615
9/10/2000	629
9/11/2000	655
9/12/2000	640
9/13/2000	649
9/14/2000	664
9/15/2000	674
9/16/2000	669
9/17/2000	694
9/18/2000	697
9/19/2000	208
9/20/2000	4120
9/21/2000	1690
9/22/2000	936
9/23/2000	760
9/24/2000	503
9/25/2000	478
9/26/2000	902
9/27/2000	1220
9/28/2000	1180
9/29/2000	857
9/30/2000	528
10/1/2000	515
10/2/2000	522
10/3/2000	540
10/4/2000	541

Date	Flow (cfs)
3/23/2005	1460
3/24/2005	1860
3/25/2005	2460
3/26/2005	2460
3/27/2005	2210
3/28/2005	2780
3/29/2005	7120
3/30/2005	7880
3/31/2005	7990
4/1/2005	7730
4/2/2005	4910
4/3/2005	2800
4/4/2005	1990
4/5/2005	1500
4/6/2005	1540
4/7/2005	1270
4/8/2005	1220
4/9/2005	1060
4/10/2005	996
4/11/2005	970
4/12/2005	847
4/13/2005	1010
4/14/2005	1400
4/15/2005	1290
4/16/2005	1230
4/17/2005	945
4/18/2005	804
4/19/2005	779
4/20/2005	672
4/21/2005	679
4/22/2005	776
4/23/2005	1100
4/24/2005	1500
4/25/2005	1430
4/26/2005	1330
4/27/2005	1050
4/28/2005	1010
4/29/2005	1040
4/30/2005	1301
5/1/2005	1597
5/2/2005	1855
5/3/2005	1386
5/4/2005	1327
5/5/2005	1324
5/6/2005	1326
5/7/2005	1327
5/8/2005	1575
5/9/2005	1832
5/10/2005	1574
5/11/2005	1382
5/12/2005	1388
5/13/2005	1381

Date	Flow (cfs)
7/21/1991	577
7/22/1991	583
7/23/1991	578
7/24/1991	587
7/25/1991	420
7/26/1991	627
7/27/1991	587
7/28/1991	1030
7/29/1991	1710
7/30/1991	2350
7/31/1991	1750
8/1/1991	695
8/2/1991	565
8/3/1991	585
8/4/1991	591
8/5/1991	589
8/6/1991	620
8/7/1991	656
8/8/1991	612
8/9/1991	569
8/10/1991	551
8/11/1991	567
8/12/1991	604
8/13/1991	611
8/14/1991	598
8/15/1991	572
8/16/1991	609
8/17/1991	607
8/18/1991	597
8/19/1991	600
8/20/1991	618
8/21/1991	584
8/22/1991	614
8/23/1991	622
8/24/1991	625
8/25/1991	629
8/26/1991	625
8/27/1991	620
8/28/1991	548
8/29/1991	560
8/30/1991	605
8/31/1991	621
9/1/1991	606
9/2/1991	584
9/3/1991	611
9/4/1991	615
9/5/1991	617
9/6/1991	601
9/7/1991	605
9/8/1991	614
9/9/1991	611
9/10/1991	637

Date	Flow (cfs)
2/27/1996	835
2/28/1996	841
2/29/1996	808
3/1/1996	969
3/2/1996	990
3/3/1996	999
3/4/1996	936
3/5/1996	886
3/6/1996	1340
3/7/1996	1730
3/8/1996	1100
3/9/1996	1010
3/10/1996	682
3/11/1996	455
3/12/1996	463
3/13/1996	478
3/14/1996	568
3/15/1996	673
3/16/1996	1700
3/17/1996	2190
3/18/1996	1800
3/19/1996	2920
3/20/1996	7210
3/21/1996	3060
3/22/1996	1110
3/23/1996	1270
3/24/1996	1540
3/25/1996	1430
3/26/1996	1250
3/27/1996	1580
3/28/1996	2330
3/29/1996	3660
3/30/1996	3270
3/31/1996	2370
4/1/1996	2240
4/2/1996	3950
4/3/1996	2520
4/4/1996	1100
4/5/1996	1180
4/6/1996	1200
4/7/1996	1200
4/8/1996	1210
4/9/1996	1220
4/10/1996	1260
4/11/1996	1250
4/12/1996	1170
4/13/1996	1010
4/14/1996	933
4/15/1996	862
4/16/1996	982
4/17/1996	1060
4/18/1996	983

Date	Flow (cfs)
10/5/2000	544
10/6/2000	547
10/7/2000	561
10/8/2000	560
10/9/2000	648
10/10/2000	559
10/11/2000	563
10/12/2000	562
10/13/2000	564
10/14/2000	564
10/15/2000	559
10/16/2000	561
10/17/2000	558
10/18/2000	561
10/19/2000	572
10/20/2000	563
10/21/2000	567
10/22/2000	562
10/23/2000	596
10/24/2000	567
10/25/2000	553
10/26/2000	548
10/27/2000	538
10/28/2000	557
10/29/2000	558
10/30/2000	562
10/31/2000	569
11/1/2000	562
11/2/2000	547
11/3/2000	536
11/4/2000	541
11/5/2000	545
11/6/2000	543
11/7/2000	548
11/8/2000	545
11/9/2000	537
11/10/2000	471
11/11/2000	485
11/12/2000	522
11/13/2000	545
11/14/2000	540
11/15/2000	535
11/16/2000	547
11/17/2000	556
11/18/2000	543
11/19/2000	551
11/20/2000	546
11/21/2000	550
11/22/2000	571
11/23/2000	549
11/24/2000	560
11/25/2000	540

Date	Flow (cfs)
5/14/2005	1372
5/15/2005	1636
5/16/2005	1868
5/17/2005	1458
5/18/2005	1386
5/19/2005	1361
5/20/2005	1211
5/21/2005	1107
5/22/2005	1229
5/23/2005	1308
5/24/2005	1308
5/25/2005	1319
5/26/2005	1277
5/27/2005	1038
5/28/2005	945
5/29/2005	937
5/30/2005	948
5/31/2005	670
6/1/2005	671
6/2/2005	668
6/3/2005	668
6/4/2005	671
6/5/2005	677
6/6/2005	671
6/7/2005	657
6/8/2005	674
6/9/2005	673
6/10/2005	925
6/11/2005	1133
6/12/2005	970
6/13/2005	893
6/14/2005	851
6/15/2005	722
6/16/2005	673
6/17/2005	670
6/18/2005	658
6/19/2005	650
6/20/2005	659
6/21/2005	653
6/22/2005	655
6/23/2005	655
6/24/2005	992
6/25/2005	745
6/26/2005	656
6/27/2005	678
6/28/2005	663
6/29/2005	669
6/30/2005	656
7/1/2005	654
7/2/2005	656
7/3/2005	650
7/4/2005	662

Date	Flow (cfs)
9/11/1991	892
9/12/1991	663
9/13/1991	633
9/14/1991	626
9/15/1991	625
9/16/1991	613
9/17/1991	642
9/18/1991	643
9/19/1991	628
9/20/1991	635
9/21/1991	657
9/22/1991	682
9/23/1991	639
9/24/1991	651
9/25/1991	621
9/26/1991	916
9/27/1991	586
9/28/1991	605
9/29/1991	600
9/30/1991	635
10/1/1991	570
10/2/1991	475
10/3/1991	477
10/4/1991	734
10/5/1991	1120
10/6/1991	480
10/7/1991	574
10/8/1991	620
10/9/1991	618
10/10/1991	608
10/11/1991	619
10/12/1991	642
10/13/1991	628
10/14/1991	610
10/15/1991	619
10/16/1991	603
10/17/1991	609
10/18/1991	624
10/19/1991	627
10/20/1991	627
10/21/1991	616
10/22/1991	607
10/23/1991	590
10/24/1991	593
10/25/1991	595
10/26/1991	604
10/27/1991	624
10/28/1991	612
10/29/1991	616
10/30/1991	574
10/31/1991	577
11/1/1991	612

Date	Flow (cfs)
4/19/1996	764
4/20/1996	582
4/21/1996	451
4/22/1996	596
4/23/1996	950
4/24/1996	882
4/25/1996	885
4/26/1996	877
4/27/1996	853
4/28/1996	886
4/29/1996	888
4/30/1996	981
5/1/1996	1410
5/2/1996	1980
5/3/1996	1250
5/4/1996	958
5/5/1996	895
5/6/1996	3980
5/7/1996	3490
5/8/1996	2200
5/9/1996	1530
5/10/1996	1160
5/11/1996	996
5/12/1996	1360
5/13/1996	1460
5/14/1996	1070
5/15/1996	947
5/16/1996	1930
5/17/1996	3690
5/18/1996	1680
5/19/1996	1510
5/20/1996	1120
5/21/1996	963
5/22/1996	895
5/23/1996	723
5/24/1996	696
5/25/1996	571
5/26/1996	690
5/27/1996	756
5/28/1996	2250
5/29/1996	1280
5/30/1996	918
5/31/1996	865
6/1/1996	756
6/2/1996	758
6/3/1996	780
6/4/1996	849
6/5/1996	765
6/6/1996	799
6/7/1996	682
6/8/1996	642
6/9/1996	2690

Date	Flow (cfs)
11/26/2000	450
11/27/2000	433
11/28/2000	503
11/29/2000	507
11/30/2000	517
12/1/2000	460
12/2/2000	425
12/3/2000	342
12/4/2000	304
12/5/2000	312
12/6/2000	311
12/7/2000	314
12/8/2000	311
12/9/2000	321
12/10/2000	316
12/11/2000	304
12/12/2000	313
12/13/2000	322
12/14/2000	314
12/15/2000	302
12/16/2000	295
12/17/2000	41
12/18/2000	119
12/19/2000	218
12/20/2000	270
12/21/2000	288
12/22/2000	321
12/23/2000	291
12/24/2000	291
12/25/2000	312
12/26/2000	300
12/27/2000	325
12/28/2000	328
12/29/2000	325
12/30/2000	346
12/31/2000	318
1/1/2001	338
1/2/2001	349
1/3/2001	352
1/4/2001	345
1/5/2001	344
1/6/2001	336
1/7/2001	323
1/8/2001	332
1/9/2001	346
1/10/2001	338
1/11/2001	333
1/12/2001	331
1/13/2001	419
1/14/2001	453
1/15/2001	553
1/16/2001	618

Date	Flow (cfs)
7/5/2005	666
7/6/2005	1334
7/7/2005	3642
7/8/2005	3169
7/9/2005	899
7/10/2005	884
7/11/2005	660
7/12/2005	664
7/13/2005	663
7/14/2005	659
7/15/2005	887
7/16/2005	905
7/17/2005	653
7/18/2005	400
7/19/2005	397
7/20/2005	400
7/21/2005	1425
7/22/2005	2497
7/23/2005	2883
7/24/2005	1104
7/25/2005	303
7/26/2005	321
7/27/2005	339
7/28/2005	308
7/29/2005	307
7/30/2005	1452
7/31/2005	1542
8/1/2005	845
8/2/2005	820
8/3/2005	824
8/4/2005	824
8/5/2005	822
8/6/2005	811
8/7/2005	804
8/8/2005	964
8/9/2005	1045
8/10/2005	1207
8/11/2005	1277
8/12/2005	829
8/13/2005	663
8/14/2005	660
8/15/2005	661
8/16/2005	659
8/17/2005	668
8/18/2005	660
8/19/2005	660
8/20/2005	658
8/21/2005	663
8/22/2005	661
8/23/2005	660
8/24/2005	660
8/25/2005	658

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
11/2/1991	652	6/10/1996	8810	1/17/2001	566	8/26/2005	807
11/3/1991	632	6/11/1996	12400	1/18/2001	577	8/27/2005	873
11/4/1991	599	6/12/1996	6100	1/19/2001	474	8/28/2005	1026
11/5/1991	635	6/13/1996	2460	1/20/2001	83	8/29/2005	1802
11/6/1991	607	6/14/1996	1800	1/21/2001	182	8/30/2005	1262
11/7/1991	607	6/15/1996	1470	1/22/2001	277	8/31/2005	660
11/8/1991	596	6/16/1996	1530	1/23/2001	316	9/1/2005	655
11/9/1991	606	6/17/1996	1010	1/24/2001	241	9/2/2005	656
11/10/1991	554	6/18/1996	660	1/25/2001	232	9/3/2005	658
11/11/1991	335	6/19/1996	463	1/26/2001	248	9/4/2005	654
11/12/1991	529	6/20/1996	1350	1/27/2001	262	9/5/2005	649
11/13/1991	584	6/21/1996	1400	1/28/2001	272	9/6/2005	656
11/14/1991	592	6/22/1996	1140	1/29/2001	261	9/7/2005	659
11/15/1991	609	6/23/1996	793	1/30/2001	262	9/8/2005	663
11/16/1991	602	6/24/1996	485	1/31/2001	240	9/9/2005	663
11/17/1991	588	6/25/1996	600	2/1/2001	257	9/10/2005	658
11/18/1991	622	6/26/1996	597	2/2/2001	269	9/11/2005	651
11/19/1991	619	6/27/1996	562	2/3/2001	284	9/12/2005	652
11/20/1991	606	6/28/1996	532	2/4/2001	282	9/13/2005	657
11/21/1991	620	6/29/1996	515	2/5/2001	285	9/14/2005	662
11/22/1991	505	6/30/1996	515	2/6/2001	305	9/15/2005	652
11/23/1991	469	7/1/1996	559	2/7/2001	295	9/16/2005	653
11/24/1991	593	7/2/1996	524	2/8/2001	293	9/17/2005	652
11/25/1991	638	7/3/1996	366	2/9/2001	295	9/18/2005	639
11/26/1991	618	7/4/1996	506	2/10/2001	298	9/19/2005	656
11/27/1991	580	7/5/1996	548	2/11/2001	300	9/20/2005	647
11/28/1991	568	7/6/1996	569	2/12/2001	299	9/21/2005	653
11/29/1991	574	7/7/1996	576	2/13/2001	301	9/22/2005	656
11/30/1991	597	7/8/1996	515	2/14/2001	294	9/23/2005	657
12/1/1991	554	7/9/1996	829	2/15/2001	290	9/24/2005	656
12/2/1991	429	7/10/1996	1300	2/16/2001	286	9/25/2005	660
12/3/1991	373	7/11/1996	1500	2/17/2001	174	9/26/2005	659
12/4/1991	83	7/12/1996	2270	2/18/2001	159	9/27/2005	662
12/5/1991	420	7/13/1996	561	2/19/2001	218	9/28/2005	664
12/6/1991	487	7/14/1996	593	2/20/2001	245	9/29/2005	668
12/7/1991	523	7/15/1996	278	2/21/2001	262	9/30/2005	665
12/8/1991	504	7/16/1996	452	2/22/2001	265	10/1/2005	657
12/9/1991	511	7/17/1996	601	2/23/2001	263	10/2/2005	656
12/10/1991	528	7/18/1996	511	2/24/2001	256	10/3/2005	662
12/11/1991	517	7/19/1996	552	2/25/2001	242	10/4/2005	662
12/12/1991	528	7/20/1996	578	2/26/2001	206	10/5/2005	672
12/13/1991	531	7/21/1996	562	2/27/2001	230	10/6/2005	651
12/14/1991	525	7/22/1996	559	2/28/2001	250	10/7/2005	652
12/15/1991	587	7/23/1996	569	3/1/2001	255	10/8/2005	4656
12/16/1991	516	7/24/1996	573	3/2/2001	259	10/9/2005	5032
12/17/1991	557	7/25/1996	570	3/3/2001	266	10/10/2005	801
12/18/1991	541	7/26/1996	449	3/4/2001	250	10/11/2005	990
12/19/1991	546	7/27/1996	502	3/5/2001	220	10/12/2005	1082
12/20/1991	541	7/28/1996	588	3/6/2001	241	10/13/2005	1042
12/21/1991	545	7/29/1996	562	3/7/2001	388	10/14/2005	892
12/22/1991	554	7/30/1996	458	3/8/2001	399	10/15/2005	889
12/23/1991	575	7/31/1996	538	3/9/2001	412	10/16/2005	707

Date	Flow (cfs)
12/24/1991	558
12/25/1991	549
12/26/1991	538
12/27/1991	556
12/28/1991	571
12/29/1991	396
12/30/1991	440
12/31/1991	452
1/1/1992	468
1/2/1992	483
1/3/1992	0
1/4/1992	881
1/5/1992	4550
1/6/1992	2410
1/7/1992	1370
1/8/1992	1280
1/9/1992	1150
1/10/1992	1080
1/11/1992	840
1/12/1992	851
1/13/1992	848
1/14/1992	666
1/15/1992	722
1/16/1992	685
1/17/1992	598
1/18/1992	548
1/19/1992	542
1/20/1992	497
1/21/1992	492
1/22/1992	500
1/23/1992	458
1/24/1992	400
1/25/1992	726
1/26/1992	769
1/27/1992	709
1/28/1992	545
1/29/1992	507
1/30/1992	493
1/31/1992	493
2/1/1992	501
2/2/1992	508
2/3/1992	506
2/4/1992	510
2/5/1992	515
2/6/1992	521
2/7/1992	515
2/8/1992	489
2/9/1992	510
2/10/1992	523
2/11/1992	506
2/12/1992	509
2/13/1992	549

Date	Flow (cfs)
8/1/1996	707
8/2/1996	589
8/3/1996	524
8/4/1996	398
8/5/1996	502
8/6/1996	656
8/7/1996	593
8/8/1996	501
8/9/1996	476
8/10/1996	461
8/11/1996	515
8/12/1996	3170
8/13/1996	6170
8/14/1996	7560
8/15/1996	3140
8/16/1996	1340
8/17/1996	813
8/18/1996	865
8/19/1996	714
8/20/1996	494
8/21/1996	460
8/22/1996	457
8/23/1996	487
8/24/1996	504
8/25/1996	425
8/26/1996	478
8/27/1996	512
8/28/1996	508
8/29/1996	629
8/30/1996	1070
8/31/1996	1050
9/1/1996	575
9/2/1996	552
9/3/1996	1360
9/4/1996	7960
9/5/1996	10300
9/6/1996	0
9/7/1996	9800
9/8/1996	13400
9/9/1996	11800
9/10/1996	10200
9/11/1996	4780
9/12/1996	1910
9/13/1996	1670
9/14/1996	3290
9/15/1996	1310
9/16/1996	1270
9/17/1996	1620
9/18/1996	1540
9/19/1996	1210
9/20/1996	992
9/21/1996	997

Date	Flow (cfs)
3/10/2001	414
3/11/2001	416
3/12/2001	410
3/13/2001	383
3/14/2001	374
3/15/2001	403
3/16/2001	650
3/17/2001	847
3/18/2001	871
3/19/2001	556
3/20/2001	280
3/21/2001	2380
3/22/2001	5390
3/23/2001	3230
3/24/2001	2490
3/25/2001	924
3/26/2001	566
3/27/2001	591
3/28/2001	582
3/29/2001	1050
3/30/2001	6060
3/31/2001	6840
4/1/2001	2040
4/2/2001	2700
4/3/2001	3750
4/4/2001	2380
4/5/2001	743
4/6/2001	570
4/7/2001	571
4/8/2001	551
4/9/2001	732
4/10/2001	884
4/11/2001	802
4/12/2001	980
4/13/2001	1170
4/14/2001	994
4/15/2001	657
4/16/2001	500
4/17/2001	514
4/18/2001	508
4/19/2001	518
4/20/2001	533
4/21/2001	534
4/22/2001	618
4/23/2001	828
4/24/2001	915
4/25/2001	954
4/26/2001	967
4/27/2001	997
4/28/2001	992
4/29/2001	1080
4/30/2001	1310

Date	Flow (cfs)
10/17/2005	678
10/18/2005	658
10/19/2005	666
10/20/2005	654
10/21/2005	654
10/22/2005	660
10/23/2005	659
10/24/2005	664
10/25/2005	677
10/26/2005	671
10/27/2005	1810
10/28/2005	2004
10/29/2005	745
10/30/2005	698
10/31/2005	669
11/1/2005	659
11/2/2005	667
11/3/2005	665
11/4/2005	664
11/5/2005	652
11/6/2005	637
11/7/2005	664
11/8/2005	686
11/9/2005	660
11/10/2005	663
11/11/2005	661
11/12/2005	658
11/13/2005	642
11/14/2005	661
11/15/2005	734
11/16/2005	680
11/17/2005	695
11/18/2005	693
11/19/2005	664
11/20/2005	650
11/21/2005	655
11/22/2005	668
11/23/2005	666
11/24/2005	663
11/25/2005	660
11/26/2005	665
11/27/2005	657
11/28/2005	650
11/29/2005	1449
11/30/2005	4211
12/1/2005	4285
12/2/2005	4340
12/3/2005	2428
12/4/2005	1161
12/5/2005	1388
12/6/2005	1637
12/7/2005	1672

Date	Flow (cfs)
2/14/1992	550
2/15/1992	523
2/16/1992	428
2/17/1992	494
2/18/1992	633
2/19/1992	897
2/20/1992	885
2/21/1992	781
2/22/1992	640
2/23/1992	643
2/24/1992	731
2/25/1992	1800
2/26/1992	5740
2/27/1992	8530
2/28/1992	3810
2/29/1992	1930
3/1/1992	1640
3/2/1992	861
3/3/1992	305
3/4/1992	847
3/5/1992	837
3/6/1992	831
3/7/1992	1520
3/8/1992	3870
3/9/1992	2300
3/10/1992	1860
3/11/1992	2880
3/12/1992	2700
3/13/1992	1510
3/14/1992	816
3/15/1992	849
3/16/1992	848
3/17/1992	867
3/18/1992	866
3/19/1992	861
3/20/1992	873
3/21/1992	888
3/22/1992	899
3/23/1992	879
3/24/1992	811
3/25/1992	636
3/26/1992	622
3/27/1992	1100
3/28/1992	1380
3/29/1992	1400
3/30/1992	1410
3/31/1992	1130
4/1/1992	777
4/2/1992	692
4/3/1992	686
4/4/1992	638
4/5/1992	608

Date	Flow (cfs)
9/22/1996	969
9/23/1996	960
9/24/1996	698
9/25/1996	572
9/26/1996	551
9/27/1996	476
9/28/1996	546
9/29/1996	1430
9/30/1996	1350
10/1/1996	1470
10/2/1996	1250
10/3/1996	1040
10/4/1996	682
10/5/1996	519
10/6/1996	435
10/7/1996	570
10/8/1996	2760
10/9/1996	2340
10/10/1996	828
10/11/1996	998
10/12/1996	773
10/13/1996	873
10/14/1996	793
10/15/1996	614
10/16/1996	662
10/17/1996	801
10/18/1996	926
10/19/1996	915
10/20/1996	895
10/21/1996	884
10/22/1996	838
10/23/1996	767
10/24/1996	555
10/25/1996	488
10/26/1996	494
10/27/1996	481
10/28/1996	501
10/29/1996	507
10/30/1996	505
10/31/1996	570
11/1/1996	567
11/2/1996	589
11/3/1996	543
11/4/1996	479
11/5/1996	444
11/6/1996	469
11/7/1996	448
11/8/1996	1970
11/9/1996	4610
11/10/1996	3310
11/11/1996	2150
11/12/1996	1060

Date	Flow (cfs)
5/1/2001	1190
5/2/2001	1000
5/3/2001	1010
5/4/2001	1050
5/5/2001	1050
5/6/2001	1320
5/7/2001	1830
5/8/2001	1790
5/9/2001	1650
5/10/2001	1050
5/11/2001	1040
5/12/2001	1090
5/13/2001	1140
5/14/2001	1180
5/15/2001	1210
5/16/2001	922
5/17/2001	670
5/18/2001	779
5/19/2001	849
5/20/2001	634
5/21/2001	893
5/22/2001	0
5/23/2001	4310
5/24/2001	1950
5/25/2001	1110
5/26/2001	1360
5/27/2001	2120
5/28/2001	1720
5/29/2001	1330
5/30/2001	1160
5/31/2001	1030
6/1/2001	998
6/2/2001	859
6/3/2001	991
6/4/2001	990
6/5/2001	805
6/6/2001	466
6/7/2001	562
6/8/2001	537
6/9/2001	577
6/10/2001	604
6/11/2001	618
6/12/2001	605
6/13/2001	613
6/14/2001	615
6/15/2001	623
6/16/2001	633
6/17/2001	641
6/18/2001	637
6/19/2001	649
6/20/2001	645
6/21/2001	653

Date	Flow (cfs)
12/8/2005	1247
12/9/2005	773
12/10/2005	778
12/11/2005	759
12/12/2005	1025
12/13/2005	1262
12/14/2005	1266
12/15/2005	1497
12/16/2005	2192
12/17/2005	2294
12/18/2005	1664
12/19/2005	1615
12/20/2005	1231
12/21/2005	1224
12/22/2005	1229
12/23/2005	871
12/24/2005	864
12/25/2005	888
12/26/2005	1050
12/27/2005	1347
12/28/2005	1442
12/29/2005	1459
12/30/2005	1436
12/31/2005	1437
1/1/2006	1430
1/2/2006	1426
1/3/2006	1436
1/4/2006	1448
1/5/2006	1377
1/6/2006	1070
1/7/2006	866
1/8/2006	841
1/9/2006	846
1/10/2006	884
1/11/2006	997
1/12/2006	1079
1/13/2006	1071
1/14/2006	3009
1/15/2006	4481
1/16/2006	3874
1/17/2006	4520
1/18/2006	3301
1/19/2006	2389
1/20/2006	1877
1/21/2006	1884
1/22/2006	1873
1/23/2006	1878
1/24/2006	1788
1/25/2006	1409
1/26/2006	1279
1/27/2006	1213
1/28/2006	1033

Date	Flow (cfs)
4/6/1992	647
4/7/1992	768
4/8/1992	748
4/9/1992	638
4/10/1992	644
4/11/1992	653
4/12/1992	654
4/13/1992	626
4/14/1992	564
4/15/1992	531
4/16/1992	522
4/17/1992	533
4/18/1992	464
4/19/1992	783
4/20/1992	1410
4/21/1992	2800
4/22/1992	9660
4/23/1992	13900
4/24/1992	13800
4/25/1992	9070
4/26/1992	8660
4/27/1992	6510
4/28/1992	1620
4/29/1992	2600
4/30/1992	1700
5/1/1992	1420
5/2/1992	1310
5/3/1992	1330
5/4/1992	1320
5/5/1992	1060
5/6/1992	570
5/7/1992	1280
5/8/1992	4280
5/9/1992	2840
5/10/1992	1420
5/11/1992	1930
5/12/1992	1400
5/13/1992	1070
5/14/1992	1010
5/15/1992	5100
5/16/1992	3920
5/17/1992	5760
5/18/1992	1530
5/19/1992	2590
5/20/1992	2360
5/21/1992	1900
5/22/1992	1510
5/23/1992	1280
5/24/1992	1300
5/25/1992	1300
5/26/1992	1220
5/27/1992	876

Date	Flow (cfs)
11/13/1996	817
11/14/1996	760
11/15/1996	715
11/16/1996	632
11/17/1996	552
11/18/1996	532
11/19/1996	691
11/20/1996	1100
11/21/1996	1020
11/22/1996	1130
11/23/1996	1700
11/24/1996	1660
11/25/1996	648
11/26/1996	550
11/27/1996	1610
11/28/1996	1250
11/29/1996	1530
11/30/1996	1530
12/1/1996	4420
12/2/1996	8900
12/3/1996	9660
12/4/1996	4660
12/5/1996	3030
12/6/1996	1300
12/7/1996	1640
12/8/1996	3630
12/9/1996	3040
12/10/1996	1810
12/11/1996	1420
12/12/1996	1370
12/13/1996	2570
12/14/1996	2790
12/15/1996	1660
12/16/1996	447
12/17/1996	1380
12/18/1996	1680
12/19/1996	1610
12/20/1996	1690
12/21/1996	1240
12/22/1996	1050
12/23/1996	1020
12/24/1996	999
12/25/1996	947
12/26/1996	1070
12/27/1996	1200
12/28/1996	1220
12/29/1996	1210
12/30/1996	1090
12/31/1996	982
1/1/1997	982
1/2/1997	1040
1/3/1997	1140

Date	Flow (cfs)
6/22/2001	619
6/23/2001	671
6/24/2001	546
6/25/2001	587
6/26/2001	616
6/27/2001	622
6/28/2001	594
6/29/2001	602
6/30/2001	648
7/1/2001	661
7/2/2001	634
7/3/2001	669
7/4/2001	673
7/5/2001	568
7/6/2001	607
7/7/2001	621
7/8/2001	628
7/9/2001	554
7/10/2001	671
7/11/2001	645
7/12/2001	633
7/13/2001	636
7/14/2001	648
7/15/2001	643
7/16/2001	648
7/17/2001	666
7/18/2001	662
7/19/2001	634
7/20/2001	648
7/21/2001	688
7/22/2001	683
7/23/2001	672
7/24/2001	648
7/25/2001	641
7/26/2001	630
7/27/2001	644
7/28/2001	678
7/29/2001	912
7/30/2001	533
7/31/2001	588
8/1/2001	591
8/2/2001	605
8/3/2001	612
8/4/2001	623
8/5/2001	642
8/6/2001	631
8/7/2001	642
8/8/2001	611
8/9/2001	610
8/10/2001	640
8/11/2001	653
8/12/2001	705

Date	Flow (cfs)
1/29/2006	1033
1/30/2006	1055
1/31/2006	1068
2/1/2006	1089
2/2/2006	886
2/3/2006	993
2/4/2006	1204
2/5/2006	1730
2/6/2006	1736
2/7/2006	1739
2/8/2006	1736
2/9/2006	1626
2/10/2006	1258
2/11/2006	1259
2/12/2006	1236
2/13/2006	1234
2/14/2006	1258
2/15/2006	1247
2/16/2006	1152
2/17/2006	1005
2/18/2006	1043
2/19/2006	1032
2/20/2006	1030
2/21/2006	1033
2/22/2006	1045
2/23/2006	1096
2/24/2006	1023
2/25/2006	174
2/26/2006	0
2/27/2006	0
2/28/2006	854
3/1/2006	898
3/2/2006	659
3/3/2006	664
3/4/2006	667
3/5/2006	657
3/6/2006	670
3/7/2006	673
3/8/2006	659
3/9/2006	662
3/10/2006	660
3/11/2006	649
3/12/2006	675
3/13/2006	668
3/14/2006	719
3/15/2006	664
3/16/2006	660
3/17/2006	663
3/18/2006	667
3/19/2006	677
3/20/2006	691
3/21/2006	717

Date	Flow (cfs)
5/28/1992	754
5/29/1992	1060
5/30/1992	1370
5/31/1992	1380
6/1/1992	1430
6/2/1992	1170
6/3/1992	1060
6/4/1992	3000
6/5/1992	6250
6/6/1992	8140
6/7/1992	8670
6/8/1992	6350
6/9/1992	7070
6/10/1992	2820
6/11/1992	2440
6/12/1992	1960
6/13/1992	1820
6/14/1992	1220
6/15/1992	1030
6/16/1992	1500
6/17/1992	1790
6/18/1992	1190
6/19/1992	1000
6/20/1992	967
6/21/1992	986
6/22/1992	1000
6/23/1992	945
6/24/1992	804
6/25/1992	707
6/26/1992	598
6/27/1992	676
6/28/1992	491
6/29/1992	675
6/30/1992	870
7/1/1992	809
7/2/1992	818
7/3/1992	859
7/4/1992	838
7/5/1992	878
7/6/1992	893
7/7/1992	922
7/8/1992	880
7/9/1992	694
7/10/1992	613
7/11/1992	573
7/12/1992	525
7/13/1992	554
7/14/1992	617
7/15/1992	617
7/16/1992	561
7/17/1992	552
7/18/1992	545

Date	Flow (cfs)
1/4/1997	1120
1/5/1997	1080
1/6/1997	1260
1/7/1997	1340
1/8/1997	2190
1/9/1997	1760
1/10/1997	1060
1/11/1997	874
1/12/1997	723
1/13/1997	552
1/14/1997	561
1/15/1997	545
1/16/1997	629
1/17/1997	1310
1/18/1997	1390
1/19/1997	1480
1/20/1997	1490
1/21/1997	1450
1/22/1997	1390
1/23/1997	1380
1/24/1997	1570
1/25/1997	2420
1/26/1997	2640
1/27/1997	1260
1/28/1997	2470
1/29/1997	3850
1/30/1997	3340
1/31/1997	1760
2/1/1997	1190
2/2/1997	1230
2/3/1997	1360
2/4/1997	1570
2/5/1997	1530
2/6/1997	1560
2/7/1997	1420
2/8/1997	1220
2/9/1997	1090
2/10/1997	1650
2/11/1997	2450
2/12/1997	1820
2/13/1997	2590
2/14/1997	2570
2/15/1997	2460
2/16/1997	3470
2/17/1997	3930
2/18/1997	2830
2/19/1997	1530
2/20/1997	1550
2/21/1997	2160
2/22/1997	3030
2/23/1997	2270
2/24/1997	1560

Date	Flow (cfs)
8/13/2001	661
8/14/2001	611
8/15/2001	637
8/16/2001	630
8/17/2001	649
8/18/2001	661
8/19/2001	652
8/20/2001	615
8/21/2001	648
8/22/2001	647
8/23/2001	660
8/24/2001	629
8/25/2001	574
8/26/2001	627
8/27/2001	651
8/28/2001	597
8/29/2001	616
8/30/2001	652
8/31/2001	656
9/1/2001	672
9/2/2001	656
9/3/2001	645
9/4/2001	557
9/5/2001	582
9/6/2001	575
9/7/2001	567
9/8/2001	611
9/9/2001	512
9/10/2001	511
9/11/2001	605
9/12/2001	525
9/13/2001	525
9/14/2001	559
9/15/2001	626
9/16/2001	566
9/17/2001	566
9/18/2001	561
9/19/2001	577
9/20/2001	564
9/21/2001	561
9/22/2001	623
9/23/2001	566
9/24/2001	554
9/25/2001	428
9/26/2001	503
9/27/2001	556
9/28/2001	618
9/29/2001	623
9/30/2001	594
10/1/2001	592
10/2/2001	603
10/3/2001	606

Date	Flow (cfs)
3/22/2006	642
3/23/2006	668
3/24/2006	690
3/25/2006	669
3/26/2006	668
3/27/2006	666
3/28/2006	664
3/29/2006	728
3/30/2006	694
3/31/2006	664
4/1/2006	679
4/2/2006	653
4/3/2006	662
4/4/2006	682
4/5/2006	659
4/6/2006	676
4/7/2006	673
4/8/2006	662
4/9/2006	656
4/10/2006	656
4/11/2006	655
4/12/2006	656
4/13/2006	662
4/14/2006	657
4/15/2006	670
4/16/2006	1463
4/17/2006	1882
4/18/2006	1416
4/19/2006	1271
4/20/2006	1155
4/21/2006	1158
4/22/2006	1226
4/23/2006	1331
4/24/2006	1405
4/25/2006	1121
4/26/2006	745
4/27/2006	678
4/28/2006	677
4/29/2006	712
4/30/2006	1010
5/1/2006	1675
5/2/2006	756
5/3/2006	663
5/4/2006	654
5/5/2006	653
5/6/2006	707
5/7/2006	1098
5/8/2006	1195
5/9/2006	846
5/10/2006	683
5/11/2006	679
5/12/2006	678

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
7/19/1992	560	2/25/1997	1730	10/4/2001	605	5/13/2006	652
7/20/1992	542	2/26/1997	1550	10/5/2001	641	5/14/2006	969
7/21/1992	546	2/27/1997	1300	10/6/2001	641	5/15/2006	1211
7/22/1992	543	2/28/1997	1290	10/7/2001	610	5/16/2006	1390
7/23/1992	210	3/1/1997	1740	10/8/2001	608	5/17/2006	1629
7/24/1992	82	3/2/1997	3010	10/9/2001	605	5/18/2006	1552
7/25/1992	0	3/3/1997	2260	10/10/2001	604	5/19/2006	1473
7/26/1992	820	3/4/1997	2530	10/11/2001	596	5/20/2006	1519
7/27/1992	1280	3/5/1997	3800	10/12/2001	633	5/21/2006	1570
7/28/1992	1670	3/6/1997	3760	10/13/2001	547	5/22/2006	1567
7/29/1992	1560	3/7/1997	3970	10/14/2001	476	5/23/2006	1053
7/30/1992	1070	3/8/1997	4060	10/15/2001	458	5/24/2006	616
7/31/1992	905	3/9/1997	4130	10/16/2001	416	5/25/2006	510
8/1/1992	549	3/10/1997	4180	10/17/2001	465	5/26/2006	375
8/2/1992	564	3/11/1997	2600	10/18/2001	484	5/27/2006	375
8/3/1992	572	3/12/1997	1830	10/19/2001	711	5/28/2006	612
8/4/1992	553	3/13/1997	1460	10/20/2001	497	5/29/2006	651
8/5/1992	580	3/14/1997	1270	10/21/2001	414	5/30/2006	660
8/6/1992	565	3/15/1997	1460	10/22/2001	413	5/31/2006	661
8/7/1992	532	3/16/1997	1650	10/23/2001	407	6/1/2006	632
8/8/1992	493	3/17/1997	1380	10/24/2001	412	6/2/2006	653
8/9/1992	493	3/18/1997	944	10/25/2001	413	6/3/2006	647
8/10/1992	505	3/19/1997	1810	10/26/2001	410	6/4/2006	649
8/11/1992	519	3/20/1997	3390	10/27/2001	413	6/5/2006	683
8/12/1992	546	3/21/1997	2050	10/28/2001	411	6/6/2006	678
8/13/1992	546	3/22/1997	1290	10/29/2001	406	6/7/2006	658
8/14/1992	361	3/23/1997	1540	10/30/2001	413	6/8/2006	656
8/15/1992	516	3/24/1997	1370	10/31/2001	382	6/9/2006	661
8/16/1992	548	3/25/1997	682	11/1/2001	384	6/10/2006	682
8/17/1992	551	3/26/1997	706	11/2/2001	382	6/11/2006	658
8/18/1992	560	3/27/1997	890	11/3/2001	382	6/12/2006	665
8/19/1992	492	3/28/1997	944	11/4/2001	380	6/13/2006	666
8/20/1992	489	3/29/1997	964	11/5/2001	366	6/14/2006	696
8/21/1992	515	3/30/1997	972	11/6/2001	378	6/15/2006	687
8/22/1992	523	3/31/1997	912	11/7/2001	375	6/16/2006	672
8/23/1992	526	4/1/1997	1030	11/8/2001	378	6/17/2006	657
8/24/1992	534	4/2/1997	1170	11/9/2001	373	6/18/2006	676
8/25/1992	540	4/3/1997	1180	11/10/2001	377	6/19/2006	650
8/26/1992	543	4/4/1997	1110	11/11/2001	373	6/20/2006	599
8/27/1992	663	4/5/1997	978	11/12/2001	371	6/21/2006	610
8/28/1992	2590	4/6/1997	959	11/13/2001	381	6/22/2006	621
8/29/1992	311	4/7/1997	922	11/14/2001	373	6/23/2006	817
8/30/1992	498	4/8/1997	975	11/15/2001	375	6/24/2006	646
8/31/1992	518	4/9/1997	909	11/16/2001	370	6/25/2006	616
9/1/1992	543	4/10/1997	543	11/17/2001	377	6/26/2006	923
9/2/1992	598	4/11/1997	480	11/18/2001	371	6/27/2006	10203
9/3/1992	622	4/12/1997	547	11/19/2001	366	6/28/2006	10856
9/4/1992	595	4/13/1997	1440	11/20/2001	363	6/29/2006	8392
9/5/1992	315	4/14/1997	1250	11/21/2001	371	6/30/2006	3722
9/6/1992	187	4/15/1997	953	11/22/2001	374	7/1/2006	1970
9/7/1992	186	4/16/1997	952	11/23/2001	370	7/2/2006	725
9/8/1992	549	4/17/1997	964	11/24/2001	366	7/3/2006	719

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
9/9/1992	516	4/18/1997	940	11/25/2001	348	7/4/2006	716
9/10/1992	541	4/19/1997	969	11/26/2001	342	7/5/2006	664
9/11/1992	517	4/20/1997	999	11/27/2001	343	7/6/2006	1043
9/12/1992	536	4/21/1997	1090	11/28/2001	352	7/7/2006	1584
9/13/1992	543	4/22/1997	1530	11/29/2001	364	7/8/2006	1593
9/14/1992	555	4/23/1997	2340	11/30/2001	366	7/9/2006	1100
9/15/1992	558	4/24/1997	1190	12/1/2001	359	7/10/2006	738
9/16/1992	568	4/25/1997	1120	12/2/2001	360	7/11/2006	656
9/17/1992	580	4/26/1997	998	12/3/2001	370	7/12/2006	638
9/18/1992	593	4/27/1997	976	12/4/2001	614	7/13/2006	661
9/19/1992	595	4/28/1997	876	12/5/2001	410	7/14/2006	687
9/20/1992	549	4/29/1997	1150	12/6/2001	350	7/15/2006	660
9/21/1992	544	4/30/1997	3500	12/7/2001	349	7/16/2006	655
9/22/1992	531	5/1/1997	3890	12/8/2001	349	7/17/2006	1324
9/23/1992	542	5/2/1997	2050	12/9/2001	340	7/18/2006	1781
9/24/1992	619	5/3/1997	1480	12/10/2001	342	7/19/2006	1712
9/25/1992	554	5/4/1997	1360	12/11/2001	31	7/20/2006	822
9/26/1992	483	5/5/1997	1070	12/12/2001	140	7/21/2006	709
9/27/1992	539	5/6/1997	1040	12/13/2001	267	7/22/2006	673
9/28/1992	475	5/7/1997	884	12/14/2001	300	7/23/2006	671
9/29/1992	453	5/8/1997	869	12/15/2001	315	7/24/2006	665
9/30/1992	553	5/9/1997	762	12/16/2001	320	7/25/2006	681
10/1/1992	557	5/10/1997	681	12/17/2001	312	7/26/2006	676
10/2/1992	565	5/11/1997	809	12/18/2001	294	7/27/2006	657
10/3/1992	588	5/12/1997	1070	12/19/2001	282	7/28/2006	667
10/4/1992	553	5/13/1997	892	12/20/2001	312	7/29/2006	658
10/5/1992	259	5/14/1997	676	12/21/2001	314	7/30/2006	2437
10/6/1992	446	5/15/1997	663	12/22/2001	318	7/31/2006	675
10/7/1992	518	5/16/1997	679	12/23/2001	324	8/1/2006	686
10/8/1992	533	5/17/1997	688	12/24/2001	307	8/2/2006	670
10/9/1992	448	5/18/1997	891	12/25/2001	294	8/3/2006	696
10/10/1992	335	5/19/1997	1250	12/26/2001	306	8/4/2006	678
10/11/1992	482	5/20/1997	974	12/27/2001	304	8/5/2006	676
10/12/1992	515	5/21/1997	706	12/28/2001	309	8/6/2006	658
10/13/1992	545	5/22/1997	728	12/29/2001	309	8/7/2006	648
10/14/1992	547	5/23/1997	727	12/30/2001	320	8/8/2006	655
10/15/1992	552	5/24/1997	747	12/31/2001	308	8/9/2006	657
10/16/1992	542	5/25/1997	938	1/1/2002	334	8/10/2006	747
10/17/1992	572	5/26/1997	1230	1/2/2002	340	8/11/2006	633
10/18/1992	583	5/27/1997	1170	1/3/2002	354	8/12/2006	621
10/19/1992	577	5/28/1997	759	1/4/2002	339	8/13/2006	641
10/20/1992	569	5/29/1997	774	1/5/2002	324	8/14/2006	667
10/21/1992	561	5/30/1997	778	1/6/2002	351	8/15/2006	657
10/22/1992	566	5/31/1997	785	1/7/2002	345	8/16/2006	657
10/23/1992	563	6/1/1997	896	1/8/2002	225	8/17/2006	661
10/24/1992	559	6/2/1997	1640	1/9/2002	233	8/18/2006	650
10/25/1992	555	6/3/1997	5750	1/10/2002	238	8/19/2006	663
10/26/1992	538	6/4/1997	4660	1/11/2002	261	8/20/2006	725
10/27/1992	551	6/5/1997	1810	1/12/2002	264	8/21/2006	652
10/28/1992	562	6/6/1997	1380	1/13/2002	248	8/22/2006	683
10/29/1992	563	6/7/1997	1160	1/14/2002	256	8/23/2006	673
10/30/1992	545	6/8/1997	778	1/15/2002	251	8/24/2006	652

Date	Flow (cfs)
10/31/1992	463
11/1/1992	435
11/2/1992	516
11/3/1992	272
11/4/1992	399
11/5/1992	186
11/6/1992	371
11/7/1992	462
11/8/1992	380
11/9/1992	461
11/10/1992	521
11/11/1992	516
11/12/1992	337
11/13/1992	0
11/14/1992	1960
11/15/1992	1290
11/16/1992	530
11/17/1992	541
11/18/1992	448
11/19/1992	430
11/20/1992	451
11/21/1992	439
11/22/1992	370
11/23/1992	1820
11/24/1992	2360
11/25/1992	1490
11/26/1992	3400
11/27/1992	2730
11/28/1992	1640
11/29/1992	683
11/30/1992	426
12/1/1992	665
12/2/1992	611
12/3/1992	589
12/4/1992	579
12/5/1992	568
12/6/1992	577
12/7/1992	522
12/8/1992	542
12/9/1992	607
12/10/1992	676
12/11/1992	1100
12/12/1992	1400
12/13/1992	1440
12/14/1992	1200
12/15/1992	849
12/16/1992	1120
12/17/1992	1930
12/18/1992	2520
12/19/1992	2050
12/20/1992	1600
12/21/1992	1350

Date	Flow (cfs)
6/9/1997	643
6/10/1997	647
6/11/1997	657
6/12/1997	665
6/13/1997	1010
6/14/1997	1340
6/15/1997	1310
6/16/1997	763
6/17/1997	607
6/18/1997	505
6/19/1997	532
6/20/1997	714
6/21/1997	746
6/22/1997	997
6/23/1997	682
6/24/1997	567
6/25/1997	615
6/26/1997	849
6/27/1997	1010
6/28/1997	1170
6/29/1997	1200
6/30/1997	886
7/1/1997	527
7/2/1997	654
7/3/1997	691
7/4/1997	568
7/5/1997	567
7/6/1997	566
7/7/1997	566
7/8/1997	575
7/9/1997	597
7/10/1997	555
7/11/1997	549
7/12/1997	584
7/13/1997	595
7/14/1997	591
7/15/1997	587
7/16/1997	639
7/17/1997	598
7/18/1997	548
7/19/1997	581
7/20/1997	560
7/21/1997	557
7/22/1997	529
7/23/1997	3520
7/24/1997	867
7/25/1997	573
7/26/1997	564
7/27/1997	570
7/28/1997	526
7/29/1997	571
7/30/1997	532

Date	Flow (cfs)
1/16/2002	265
1/17/2002	262
1/18/2002	257
1/19/2002	254
1/20/2002	211
1/21/2002	191
1/22/2002	173
1/23/2002	91
1/24/2002	0
1/25/2002	36
1/26/2002	79
1/27/2002	127
1/28/2002	169
1/29/2002	177
1/30/2002	186
1/31/2002	187
2/1/2002	189
2/2/2002	213
2/3/2002	222
2/4/2002	220
2/5/2002	222
2/6/2002	235
2/7/2002	169
2/8/2002	121
2/9/2002	131
2/10/2002	163
2/11/2002	170
2/12/2002	180
2/13/2002	187
2/14/2002	197
2/15/2002	206
2/16/2002	211
2/17/2002	213
2/18/2002	227
2/19/2002	228
2/20/2002	228
2/21/2002	227
2/22/2002	222
2/23/2002	230
2/24/2002	228
2/25/2002	234
2/26/2002	243
2/27/2002	242
2/28/2002	245
3/1/2002	252
3/2/2002	249
3/3/2002	21
3/4/2002	50
3/5/2002	228
3/6/2002	242
3/7/2002	181
3/8/2002	216

Date	Flow (cfs)
8/25/2006	679
8/26/2006	682
8/27/2006	656
8/28/2006	667
8/29/2006	665
8/30/2006	724
8/31/2006	663
9/1/2006	665
9/2/2006	660
9/3/2006	664
9/4/2006	664
9/5/2006	1440
9/6/2006	2302
9/7/2006	1474
9/8/2006	892
9/9/2006	794
9/10/2006	787
9/11/2006	710
9/12/2006	669
9/13/2006	905
9/14/2006	1258
9/15/2006	1916
9/16/2006	1910
9/17/2006	1801
9/18/2006	981
9/19/2006	658
9/20/2006	646
9/21/2006	651
9/22/2006	659
9/23/2006	667
9/24/2006	666
9/25/2006	661
9/26/2006	657
9/27/2006	657
9/28/2006	664
9/29/2006	665
9/30/2006	665
10/1/2006	665
10/2/2006	666
10/3/2006	668
10/4/2006	673
10/5/2006	661
10/6/2006	657
10/7/2006	1486
10/8/2006	1829
10/9/2006	1827
10/10/2006	1616
10/11/2006	791
10/12/2006	677
10/13/2006	677
10/14/2006	674
10/15/2006	669

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
12/22/1992	1100	7/31/1997	481	3/9/2002	225	10/16/2006	673
12/23/1992	811	8/1/1997	552	3/10/2002	216	10/17/2006	682
12/24/1992	912	8/2/1997	577	3/11/2002	230	10/18/2006	685
12/25/1992	801	8/3/1997	604	3/12/2002	231	10/19/2006	821
12/26/1992	569	8/4/1997	610	3/13/2002	202	10/20/2006	894
12/27/1992	507	8/5/1997	527	3/14/2002	159	10/21/2006	869
12/28/1992	825	8/6/1997	577	3/15/2002	179	10/22/2006	855
12/29/1992	938	8/7/1997	628	3/16/2002	195	10/23/2006	975
12/30/1992	1910	8/8/1997	627	3/17/2002	93	10/24/2006	1085
12/31/1992	1300	8/9/1997	612	3/18/2002	0	10/25/2006	1119
1/1/1993	1120	8/10/1997	582	3/19/2002	0	10/26/2006	1305
1/2/1993	972	8/11/1997	604	3/20/2002	0	10/27/2006	1564
1/3/1993	609	8/12/1997	621	3/21/2002	81	10/28/2006	2144
1/4/1993	499	8/13/1997	619	3/22/2002	145	10/29/2006	2495
1/5/1993	1440	8/14/1997	651	3/23/2002	179	10/30/2006	2502
1/6/1993	3840	8/15/1997	629	3/24/2002	159	10/31/2006	2507
1/7/1993	1980	8/16/1997	629	3/25/2002	153	11/1/2006	2508
1/8/1993	1540	8/17/1997	600	3/26/2002	170	11/2/2006	1309
1/9/1993	4170	8/18/1997	606	3/27/2002	121	11/3/2006	1063
1/10/1993	7320	8/19/1997	648	3/28/2002	146	11/4/2006	656
1/11/1993	2890	8/20/1997	516	3/29/2002	168	11/5/2006	672
1/12/1993	2770	8/21/1997	423	3/30/2002	164	11/6/2006	678
1/13/1993	2670	8/22/1997	589	3/31/2002	89	11/7/2006	672
1/14/1993	2240	8/23/1997	643	4/1/2002	45	11/8/2006	1239
1/15/1993	1630	8/24/1997	620	4/2/2002	112	11/9/2006	2262
1/16/1993	1300	8/25/1997	635	4/3/2002	132	11/10/2006	1974
1/17/1993	1320	8/26/1997	655	4/4/2002	157	11/11/2006	1785
1/18/1993	1200	8/27/1997	627	4/5/2002	161	11/12/2006	1313
1/19/1993	1020	8/28/1997	633	4/6/2002	168	11/13/2006	1288
1/20/1993	918	8/29/1997	630	4/7/2002	174	11/14/2006	1216
1/21/1993	1300	8/30/1997	649	4/8/2002	179	11/15/2006	1738
1/22/1993	1650	8/31/1997	659	4/9/2002	206	11/16/2006	6495
1/23/1993	1760	9/1/1997	692	4/10/2002	199	11/17/2006	12025
1/24/1993	1330	9/2/1997	632	4/11/2002	199	11/18/2006	6697
1/25/1993	1700	9/3/1997	655	4/12/2002	215	11/19/2006	2446
1/26/1993	2010	9/4/1997	657	4/13/2002	216	11/20/2006	1918
1/27/1993	1420	9/5/1997	655	4/14/2002	204	11/21/2006	1769
1/28/1993	1460	9/6/1997	631	4/15/2002	192	11/22/2006	1659
1/29/1993	1400	9/7/1997	666	4/16/2002	205	11/23/2006	4350
1/30/1993	1230	9/8/1997	655	4/17/2002	217	11/24/2006	3557
1/31/1993	1120	9/9/1997	687	4/18/2002	225	11/25/2006	1768
2/1/1993	768	9/10/1997	594	4/19/2002	657	11/26/2006	1694
2/2/1993	710	9/11/1997	70	4/20/2002	754	11/27/2006	1699
2/3/1993	575	9/12/1997	507	4/21/2002	780	11/28/2006	1671
2/4/1993	623	9/13/1997	519	4/22/2002	760	11/29/2006	1572
2/5/1993	753	9/14/1997	550	4/23/2002	832	11/30/2006	1421
2/6/1993	737	9/15/1997	536	4/24/2002	851	12/1/2006	1100
2/7/1993	745	9/16/1997	559	4/25/2002	847	12/2/2006	1085
2/8/1993	801	9/17/1997	555	4/26/2002	812	12/3/2006	940
2/9/1993	857	9/18/1997	529	4/27/2002	828	12/4/2006	873
2/10/1993	935	9/19/1997	526	4/28/2002	873	12/5/2006	890
2/11/1993	896	9/20/1997	550	4/29/2002	830	12/6/2006	726

Date	Flow (cfs)
2/12/1993	1430
2/13/1993	2170
2/14/1993	2080
2/15/1993	884
2/16/1993	866
2/17/1993	1560
2/18/1993	2310
2/19/1993	1380
2/20/1993	1200
2/21/1993	1700
2/22/1993	3380
2/23/1993	4130
2/24/1993	4220
2/25/1993	4230
2/26/1993	2020
2/27/1993	1500
2/28/1993	1300
3/1/1993	1150
3/2/1993	1810
3/3/1993	2450
3/4/1993	2560
3/5/1993	11100
3/6/1993	14900
3/7/1993	11600
3/8/1993	3930
3/9/1993	3970
3/10/1993	2880
3/11/1993	1980
3/12/1993	2260
3/13/1993	3250
3/14/1993	3620
3/15/1993	1010
3/16/1993	2540
3/17/1993	2260
3/18/1993	2870
3/19/1993	3990
3/20/1993	4530
3/21/1993	4350
3/22/1993	5300
3/23/1993	7120
3/24/1993	3810
3/25/1993	9370
3/26/1993	12000
3/27/1993	9040
3/28/1993	8720
3/29/1993	8960
3/30/1993	5920
3/31/1993	5080
4/1/1993	2910
4/2/1993	2140
4/3/1993	2120
4/4/1993	1840

Date	Flow (cfs)
9/21/1997	556
9/22/1997	544
9/23/1997	558
9/24/1997	542
9/25/1997	495
9/26/1997	515
9/27/1997	539
9/28/1997	503
9/29/1997	445
9/30/1997	506
10/1/1997	540
10/2/1997	547
10/3/1997	556
10/4/1997	553
10/5/1997	543
10/6/1997	543
10/7/1997	544
10/8/1997	562
10/9/1997	586
10/10/1997	564
10/11/1997	562
10/12/1997	558
10/13/1997	560
10/14/1997	568
10/15/1997	562
10/16/1997	553
10/17/1997	558
10/18/1997	544
10/19/1997	501
10/20/1997	485
10/21/1997	538
10/22/1997	535
10/23/1997	561
10/24/1997	538
10/25/1997	515
10/26/1997	535
10/27/1997	421
10/28/1997	547
10/29/1997	517
10/30/1997	522
10/31/1997	523
11/1/1997	394
11/2/1997	483
11/3/1997	419
11/4/1997	466
11/5/1997	531
11/6/1997	534
11/7/1997	545
11/8/1997	519
11/9/1997	542
11/10/1997	531
11/11/1997	554

Date	Flow (cfs)
4/30/2002	860
5/1/2002	836
5/2/2002	568
5/3/2002	321
5/4/2002	757
5/5/2002	987
5/6/2002	847
5/7/2002	799
5/8/2002	1040
5/9/2002	1170
5/10/2002	1130
5/11/2002	1270
5/12/2002	1350
5/13/2002	1360
5/14/2002	1210
5/15/2002	1120
5/16/2002	875
5/17/2002	897
5/18/2002	862
5/19/2002	773
5/20/2002	808
5/21/2002	800
5/22/2002	752
5/23/2002	614
5/24/2002	576
5/25/2002	574
5/26/2002	574
5/27/2002	571
5/28/2002	401
5/29/2002	506
5/30/2002	520
5/31/2002	593
6/1/2002	620
6/2/2002	771
6/3/2002	881
6/4/2002	816
6/5/2002	640
6/6/2002	652
6/7/2002	633
6/8/2002	628
6/9/2002	636
6/10/2002	645
6/11/2002	654
6/12/2002	667
6/13/2002	666
6/14/2002	668
6/15/2002	481
6/16/2002	357
6/17/2002	363
6/18/2002	361
6/19/2002	361
6/20/2002	357

Date	Flow (cfs)
12/7/2006	665
12/8/2006	668
12/9/2006	674
12/10/2006	667
12/11/2006	666
12/12/2006	668
12/13/2006	668
12/14/2006	659
12/15/2006	648
12/16/2006	669
12/17/2006	677
12/18/2006	682
12/19/2006	685
12/20/2006	841
12/21/2006	1334
12/22/2006	1849
12/23/2006	1840
12/24/2006	1467
12/25/2006	1346
12/26/2006	2350
12/27/2006	2548
12/28/2006	1830
12/29/2006	1505
12/30/2006	1499
12/31/2006	1275
1/1/2007	5040
1/2/2007	9081
1/3/2007	3861
1/4/2007	1902
1/5/2007	1949
1/6/2007	2371
1/7/2007	2152
1/8/2007	4122
1/9/2007	4646
1/10/2007	4647
1/11/2007	2758
1/12/2007	1918
1/13/2007	1582
1/14/2007	1443
1/15/2007	1404
1/16/2007	1265
1/17/2007	1093
1/18/2007	1039
1/19/2007	1042
1/20/2007	1037
1/21/2007	1034
1/22/2007	1158
1/23/2007	1173
1/24/2007	1190
1/25/2007	1184
1/26/2007	1186
1/27/2007	1175

Date	Flow (cfs)
4/5/1993	1960
4/6/1993	2500
4/7/1993	2700
4/8/1993	3920
4/9/1993	2680
4/10/1993	2210
4/11/1993	3470
4/12/1993	2420
4/13/1993	2460
4/14/1993	2180
4/15/1993	2240
4/16/1993	5060
4/17/1993	5050
4/18/1993	2360
4/19/1993	2260
4/20/1993	1810
4/21/1993	1800
4/22/1993	2010
4/23/1993	2250
4/24/1993	1820
4/25/1993	1490
4/26/1993	1660
4/27/1993	2140
4/28/1993	1820
4/29/1993	1600
4/30/1993	1410
5/1/1993	1280
5/2/1993	1270
5/3/1993	1320
5/4/1993	1230
5/5/1993	0
5/6/1993	4
5/7/1993	1910
5/8/1993	2090
5/9/1993	2680
5/10/1993	2560
5/11/1993	1710
5/12/1993	1610
5/13/1993	1430
5/14/1993	1670
5/15/1993	1700
5/16/1993	1800
5/17/1993	1130
5/18/1993	1150
5/19/1993	1160
5/20/1993	1340
5/21/1993	1400
5/22/1993	1480
5/23/1993	1380
5/24/1993	1300
5/25/1993	1000
5/26/1993	952

Date	Flow (cfs)
11/12/1997	552
11/13/1997	538
11/14/1997	467
11/15/1997	459
11/16/1997	477
11/17/1997	492
11/18/1997	538
11/19/1997	525
11/20/1997	541
11/21/1997	537
11/22/1997	490
11/23/1997	533
11/24/1997	512
11/25/1997	544
11/26/1997	548
11/27/1997	543
11/28/1997	546
11/29/1997	533
11/30/1997	547
12/1/1997	525
12/2/1997	518
12/3/1997	522
12/4/1997	513
12/5/1997	505
12/6/1997	511
12/7/1997	528
12/8/1997	520
12/9/1997	536
12/10/1997	527
12/11/1997	501
12/12/1997	520
12/13/1997	536
12/14/1997	521
12/15/1997	505
12/16/1997	531
12/17/1997	509
12/18/1997	526
12/19/1997	538
12/20/1997	550
12/21/1997	559
12/22/1997	519
12/23/1997	435
12/24/1997	465
12/25/1997	378
12/26/1997	386
12/27/1997	426
12/28/1997	348
12/29/1997	412
12/30/1997	417
12/31/1997	450
1/1/1998	493
1/2/1998	478

Date	Flow (cfs)
6/21/2002	470
6/22/2002	555
6/23/2002	370
6/24/2002	370
6/25/2002	369
6/26/2002	372
6/27/2002	375
6/28/2002	364
6/29/2002	438
6/30/2002	350
7/1/2002	381
7/2/2002	417
7/3/2002	426
7/4/2002	428
7/5/2002	491
7/6/2002	489
7/7/2002	433
7/8/2002	422
7/9/2002	449
7/10/2002	450
7/11/2002	425
7/12/2002	472
7/13/2002	448
7/14/2002	408
7/15/2002	391
7/16/2002	380
7/17/2002	400
7/18/2002	416
7/19/2002	490
7/20/2002	494
7/21/2002	425
7/22/2002	422
7/23/2002	427
7/24/2002	431
7/25/2002	308
7/26/2002	174
7/27/2002	388
7/28/2002	327
7/29/2002	394
7/30/2002	416
7/31/2002	421
8/1/2002	423
8/2/2002	517
8/3/2002	474
8/4/2002	439
8/5/2002	443
8/6/2002	433
8/7/2002	449
8/8/2002	459
8/9/2002	543
8/10/2002	491
8/11/2002	451

Date	Flow (cfs)
1/28/2007	1155
1/29/2007	1190
1/30/2007	1042
1/31/2007	894
2/1/2007	890
2/2/2007	1131
2/3/2007	650
2/4/2007	640
2/5/2007	662
2/6/2007	674
2/7/2007	674
2/8/2007	1051
2/9/2007	654
2/10/2007	646
2/11/2007	634
2/12/2007	633
2/13/2007	779
2/14/2007	4175
2/15/2007	4708
2/16/2007	2923
2/17/2007	2094
2/18/2007	1797
2/19/2007	1371
2/20/2007	1096
2/21/2007	1087
2/22/2007	1174
2/23/2007	1465
2/24/2007	1535
2/25/2007	1310
2/26/2007	1301
2/27/2007	1357
2/28/2007	1352
3/1/2007	1729
3/2/2007	4180
3/3/2007	4619
3/4/2007	3231
3/5/2007	1944
3/6/2007	1658
3/7/2007	1625
3/8/2007	1221
3/9/2007	1092
3/10/2007	1092
3/11/2007	1004
3/12/2007	905
3/13/2007	910
3/14/2007	914
3/15/2007	1313
3/16/2007	7012
3/17/2007	9413
3/18/2007	8428
3/19/2007	3677
3/20/2007	2246

Date	Flow (cfs)
5/27/1993	960
5/28/1993	1010
5/29/1993	952
5/30/1993	1190
5/31/1993	1480
6/1/1993	792
6/2/1993	643
6/3/1993	441
6/4/1993	514
6/5/1993	1470
6/6/1993	1740
6/7/1993	1700
6/8/1993	1530
6/9/1993	1250
6/10/1993	1480
6/11/1993	1730
6/12/1993	1200
6/13/1993	717
6/14/1993	469
6/15/1993	446
6/16/1993	457
6/17/1993	492
6/18/1993	483
6/19/1993	460
6/20/1993	494
6/21/1993	677
6/22/1993	910
6/23/1993	921
6/24/1993	840
6/25/1993	656
6/26/1993	588
6/27/1993	537
6/28/1993	533
6/29/1993	428
6/30/1993	434
7/1/1993	533
7/2/1993	2940
7/3/1993	3820
7/4/1993	1890
7/5/1993	941
7/6/1993	658
7/7/1993	489
7/8/1993	519
7/9/1993	568
7/10/1993	538
7/11/1993	536
7/12/1993	506
7/13/1993	520
7/14/1993	533
7/15/1993	560
7/16/1993	494
7/17/1993	522

Date	Flow (cfs)
1/3/1998	473
1/4/1998	466
1/5/1998	448
1/6/1998	473
1/7/1998	467
1/8/1998	0
1/9/1998	0
1/10/1998	234
1/11/1998	385
1/12/1998	955
1/13/1998	1460
1/14/1998	3050
1/15/1998	1810
1/16/1998	3720
1/17/1998	3960
1/18/1998	1470
1/19/1998	865
1/20/1998	1160
1/21/1998	1140
1/22/1998	3810
1/23/1998	1430
1/24/1998	2320
1/25/1998	1730
1/26/1998	1270
1/27/1998	1410
1/28/1998	0
1/29/1998	11600
1/30/1998	12300
1/31/1998	9600
2/1/1998	8220
2/2/1998	4490
2/3/1998	4090
2/4/1998	901
2/5/1998	7750
2/6/1998	10500
2/7/1998	9910
2/8/1998	8750
2/9/1998	8740
2/10/1998	4860
2/11/1998	1980
2/12/1998	2800
2/13/1998	2710
2/14/1998	2190
2/15/1998	1680
2/16/1998	1240
2/17/1998	3310
2/18/1998	8190
2/19/1998	10200
2/20/1998	8550
2/21/1998	4250
2/22/1998	3060
2/23/1998	5230

Date	Flow (cfs)
8/12/2002	447
8/13/2002	453
8/14/2002	451
8/15/2002	447
8/16/2002	546
8/17/2002	511
8/18/2002	429
8/19/2002	430
8/20/2002	430
8/21/2002	445
8/22/2002	445
8/23/2002	541
8/24/2002	494
8/25/2002	439
8/26/2002	433
8/27/2002	428
8/28/2002	430
8/29/2002	354
8/30/2002	446
8/31/2002	455
9/1/2002	348
9/2/2002	304
9/3/2002	343
9/4/2002	362
9/5/2002	365
9/6/2002	463
9/7/2002	425
9/8/2002	374
9/9/2002	371
9/10/2002	378
9/11/2002	380
9/12/2002	376
9/13/2002	377
9/14/2002	385
9/15/2002	378
9/16/2002	323
9/17/2002	284
9/18/2002	340
9/19/2002	359
9/20/2002	360
9/21/2002	362
9/22/2002	363
9/23/2002	352
9/24/2002	364
9/25/2002	363
9/26/2002	345
9/27/2002	199
9/28/2002	175
9/29/2002	222
9/30/2002	271
10/1/2002	305
10/2/2002	313

Date	Flow (cfs)
3/21/2007	1871
3/22/2007	1791
3/23/2007	1573
3/24/2007	1387
3/25/2007	1294
3/26/2007	1202
3/27/2007	1205
3/28/2007	1364
3/29/2007	2080
3/30/2007	2024
3/31/2007	1535
4/1/2007	1502
4/2/2007	1503
4/3/2007	1354
4/4/2007	1035
4/5/2007	896
4/6/2007	826
4/7/2007	829
4/8/2007	824
4/9/2007	851
4/10/2007	870
4/11/2007	977
4/12/2007	1872
4/13/2007	4126
4/14/2007	4229
4/15/2007	1962
4/16/2007	4379
4/17/2007	3986
4/18/2007	2591
4/19/2007	1953
4/20/2007	1471
4/21/2007	1161
4/22/2007	1189
4/23/2007	1169
4/24/2007	773
4/25/2007	1059
4/26/2007	1287
4/27/2007	1400
4/28/2007	1430
4/29/2007	1522
4/30/2007	1297
5/1/2007	894
5/2/2007	748
5/3/2007	913
5/4/2007	1393
5/5/2007	1429
5/6/2007	1529
5/7/2007	1617
5/8/2007	1211
5/9/2007	953
5/10/2007	955
5/11/2007	950

Date	Flow (cfs)
7/18/1993	522
7/19/1993	564
7/20/1993	381
7/21/1993	513
7/22/1993	532
7/23/1993	536
7/24/1993	526
7/25/1993	528
7/26/1993	487
7/27/1993	440
7/28/1993	502
7/29/1993	534
7/30/1993	533
7/31/1993	582
8/1/1993	582
8/2/1993	572
8/3/1993	569
8/4/1993	576
8/5/1993	561
8/6/1993	410
8/7/1993	448
8/8/1993	528
8/9/1993	510
8/10/1993	507
8/11/1993	517
8/12/1993	528
8/13/1993	529
8/14/1993	476
8/15/1993	508
8/16/1993	525
8/17/1993	549
8/18/1993	539
8/19/1993	589
8/20/1993	584
8/21/1993	539
8/22/1993	553
8/23/1993	541
8/24/1993	554
8/25/1993	561
8/26/1993	554
8/27/1993	536
8/28/1993	522
8/29/1993	578
8/30/1993	565
8/31/1993	573
9/1/1993	583
9/2/1993	563
9/3/1993	570
9/4/1993	629
9/5/1993	565
9/6/1993	585
9/7/1993	577

Date	Flow (cfs)
2/24/1998	6340
2/25/1998	2500
2/26/1998	1660
2/27/1998	1650
2/28/1998	1660
3/1/1998	1660
3/2/1998	1510
3/3/1998	1560
3/4/1998	1580
3/5/1998	1580
3/6/1998	1240
3/7/1998	944
3/8/1998	656
3/9/1998	809
3/10/1998	3600
3/11/1998	4120
3/12/1998	4300
3/13/1998	2720
3/14/1998	952
3/15/1998	923
3/16/1998	1080
3/17/1998	1340
3/18/1998	1620
3/19/1998	3160
3/20/1998	4980
3/21/1998	7340
3/22/1998	11200
3/23/1998	10300
3/24/1998	4360
3/25/1998	1830
3/26/1998	1850
3/27/1998	2050
3/28/1998	2050
3/29/1998	1480
3/30/1998	1290
3/31/1998	1310
4/1/1998	1320
4/2/1998	1500
4/3/1998	1250
4/4/1998	1850
4/5/1998	2880
4/6/1998	2240
4/7/1998	1430
4/8/1998	1090
4/9/1998	1030
4/10/1998	1410
4/11/1998	1690
4/12/1998	1460
4/13/1998	1290
4/14/1998	1240
4/15/1998	1150
4/16/1998	1120

Date	Flow (cfs)
10/3/2002	320
10/4/2002	318
10/5/2002	373
10/6/2002	377
10/7/2002	404
10/8/2002	376
10/9/2002	370
10/10/2002	372
10/11/2002	348
10/12/2002	217
10/13/2002	260
10/14/2002	295
10/15/2002	312
10/16/2002	250
10/17/2002	6
10/18/2002	190
10/19/2002	248
10/20/2002	274
10/21/2002	283
10/22/2002	277
10/23/2002	278
10/24/2002	287
10/25/2002	294
10/26/2002	290
10/27/2002	306
10/28/2002	293
10/29/2002	121
10/30/2002	0
10/31/2002	4
11/1/2002	155
11/2/2002	207
11/3/2002	230
11/4/2002	244
11/5/2002	240
11/6/2002	49
11/7/2002	122
11/8/2002	186
11/9/2002	217
11/10/2002	226
11/11/2002	0
11/12/2002	0
11/13/2002	0
11/14/2002	23
11/15/2002	143
11/16/2002	50
11/17/2002	0
11/18/2002	312
11/19/2002	427
11/20/2002	517
11/21/2002	931
11/22/2002	1230
11/23/2002	1110

Date	Flow (cfs)
5/12/2007	952
5/13/2007	1208
5/14/2007	1396
5/15/2007	867
5/16/2007	718
5/17/2007	713
5/18/2007	718
5/19/2007	718
5/20/2007	705
5/21/2007	718
5/22/2007	725
5/23/2007	723
5/24/2007	725
5/25/2007	720
5/26/2007	715
5/27/2007	708
5/28/2007	710
5/29/2007	673
5/30/2007	684
5/31/2007	680
6/1/2007	732
6/2/2007	958
6/3/2007	1483
6/4/2007	2275
6/5/2007	2143
6/6/2007	947
6/7/2007	753
6/8/2007	660
6/9/2007	665
6/10/2007	664
6/11/2007	662
6/12/2007	671
6/13/2007	670
6/14/2007	669
6/15/2007	667
6/16/2007	667
6/17/2007	666
6/18/2007	667
6/19/2007	668
6/20/2007	668
6/21/2007	670
6/22/2007	665
6/23/2007	676
6/24/2007	669
6/25/2007	665
6/26/2007	666
6/27/2007	675
6/28/2007	674
6/29/2007	678
6/30/2007	675
7/1/2007	676
7/2/2007	694

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
9/8/1993	525	4/17/1998	3530	11/24/2002	702	7/3/2007	680
9/9/1993	468	4/18/1998	7960	11/25/2002	594	7/4/2007	662
9/10/1993	534	4/19/1998	1660	11/26/2002	601	7/5/2007	659
9/11/1993	614	4/20/1998	7110	11/27/2002	613	7/6/2007	655
9/12/1993	602	4/21/1998	9420	11/28/2002	616	7/7/2007	666
9/13/1993	607	4/22/1998	3190	11/29/2002	620	7/8/2007	656
9/14/1993	611	4/23/1998	2230	11/30/2002	624	7/9/2007	665
9/15/1993	598	4/24/1998	1990	12/1/2002	631	7/10/2007	672
9/16/1993	565	4/25/1998	1750	12/2/2002	594	7/11/2007	672
9/17/1993	477	4/26/1998	1570	12/3/2002	480	7/12/2007	670
9/18/1993	408	4/27/1998	1080	12/4/2002	492	7/13/2007	661
9/19/1993	454	4/28/1998	1080	12/5/2002	442	7/14/2007	657
9/20/1993	614	4/29/1998	982	12/6/2002	404	7/15/2007	666
9/21/1993	578	4/30/1998	1310	12/7/2002	457	7/16/2007	668
9/22/1993	583	5/1/1998	1870	12/8/2002	428	7/17/2007	666
9/23/1993	602	5/2/1998	2640	12/9/2002	448	7/18/2007	672
9/24/1993	608	5/3/1998	4140	12/10/2002	457	7/19/2007	680
9/25/1993	607	5/4/1998	2610	12/11/2002	297	7/20/2007	670
9/26/1993	562	5/5/1998	2280	12/12/2002	428	7/21/2007	668
9/27/1993	558	5/6/1998	2310	12/13/2002	1200	7/22/2007	664
9/28/1993	556	5/7/1998	2230	12/14/2002	4160	7/23/2007	665
9/29/1993	605	5/8/1998	2300	12/15/2002	3920	7/24/2007	636
9/30/1993	615	5/9/1998	2220	12/16/2002	1490	7/25/2007	662
10/1/1993	612	5/10/1998	1900	12/17/2002	1250	7/26/2007	664
10/2/1993	608	5/11/1998	2010	12/18/2002	1080	7/27/2007	665
10/3/1993	630	5/12/1998	3410	12/19/2002	957	7/28/2007	665
10/4/1993	622	5/13/1998	2320	12/20/2002	884	7/29/2007	664
10/5/1993	620	5/14/1998	1870	12/21/2002	2120	7/30/2007	656
10/6/1993	618	5/15/1998	1670	12/22/2002	1530	7/31/2007	667
10/7/1993	617	5/16/1998	1390	12/23/2002	1030	8/1/2007	663
10/8/1993	611	5/17/1998	1340	12/24/2002	977	8/2/2007	662
10/9/1993	621	5/18/1998	1340	12/25/2002	4970	8/3/2007	666
10/10/1993	622	5/19/1998	1270	12/26/2002	4080	8/4/2007	670
10/11/1993	600	5/20/1998	1100	12/27/2002	1220	8/5/2007	668
10/12/1993	580	5/21/1998	1050	12/28/2002	1080	8/6/2007	668
10/13/1993	595	5/22/1998	984	12/29/2002	1040	8/7/2007	655
10/14/1993	602	5/23/1998	907	12/30/2002	1040	8/8/2007	655
10/15/1993	589	5/24/1998	1120	12/31/2002	1090	8/9/2007	653
10/16/1993	573	5/25/1998	1240	1/1/2003	1350	8/10/2007	655
10/17/1993	564	5/26/1998	1130	1/2/2003	2080	8/11/2007	653
10/18/1993	536	5/27/1998	1310	1/3/2003	1930	8/12/2007	650
10/19/1993	538	5/28/1998	2090	1/4/2003	3670	8/13/2007	656
10/20/1993	556	5/29/1998	1550	1/5/2003	1230	8/14/2007	659
10/21/1993	524	5/30/1998	1080	1/6/2003	853	8/15/2007	715
10/22/1993	495	5/31/1998	1140	1/7/2003	990	8/16/2007	574
10/23/1993	516	6/1/1998	1160	1/8/2003	882	8/17/2007	576
10/24/1993	500	6/2/1998	1070	1/9/2003	757	8/18/2007	657
10/25/1993	479	6/3/1998	927	1/10/2003	765	8/19/2007	516
10/26/1993	514	6/4/1998	906	1/11/2003	916	8/20/2007	505
10/27/1993	501	6/5/1998	906	1/12/2003	1330	8/21/2007	502
10/28/1993	512	6/6/1998	919	1/13/2003	1030	8/22/2007	501
10/29/1993	516	6/7/1998	921	1/14/2003	682	8/23/2007	503

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
10/30/1993	500	6/8/1998	827	1/15/2003	660	8/24/2007	581
10/31/1993	373	6/9/1998	637	1/16/2003	599	8/25/2007	660
11/1/1993	592	6/10/1998	566	1/17/2003	599	8/26/2007	515
11/2/1993	600	6/11/1998	509	1/18/2003	597	8/27/2007	508
11/3/1993	640	6/12/1998	1280	1/19/2003	601	8/28/2007	513
11/4/1993	616	6/13/1998	1360	1/20/2003	590	8/29/2007	509
11/5/1993	611	6/14/1998	975	1/21/2003	611	8/30/2007	501
11/6/1993	586	6/15/1998	743	1/22/2003	610	8/31/2007	592
11/7/1993	588	6/16/1998	644	1/23/2003	636	9/1/2007	652
11/8/1993	602	6/17/1998	481	1/24/2003	596	9/2/2007	632
11/9/1993	624	6/18/1998	756	1/25/2003	597	9/3/2007	494
11/10/1993	622	6/19/1998	693	1/26/2003	616	9/4/2007	506
11/11/1993	626	6/20/1998	605	1/27/2003	626	9/5/2007	561
11/12/1993	620	6/21/1998	623	1/28/2003	624	9/6/2007	540
11/13/1993	621	6/22/1998	629	1/29/2003	586	9/7/2007	590
11/14/1993	604	6/23/1998	495	1/30/2003	583	9/8/2007	640
11/15/1993	591	6/24/1998	411	1/31/2003	571	9/9/2007	501
11/16/1993	596	6/25/1998	450	2/1/2003	574	9/10/2007	502
11/17/1993	614	6/26/1998	445	2/2/2003	570	9/11/2007	500
11/18/1993	553	6/27/1998	462	2/3/2003	587	9/12/2007	565
11/19/1993	554	6/28/1998	883	2/4/2003	557	9/13/2007	500
11/20/1993	594	6/29/1998	597	2/5/2003	505	9/14/2007	588
11/21/1993	642	6/30/1998	608	2/6/2003	583	9/15/2007	640
11/22/1993	613	7/1/1998	552	2/7/2003	634	9/16/2007	505
11/23/1993	615	7/2/1998	460	2/8/2003	712	9/17/2007	512
11/24/1993	609	7/3/1998	430	2/9/2003	729	9/18/2007	507
11/25/1993	614	7/4/1998	431	2/10/2003	767	9/19/2007	503
11/26/1993	611	7/5/1998	390	2/11/2003	841	9/20/2007	504
11/27/1993	576	7/6/1998	418	2/12/2003	1040	9/21/2007	589
11/28/1993	34	7/7/1998	436	2/13/2003	1120	9/22/2007	666
11/29/1993	437	7/8/1998	403	2/14/2003	1080	9/23/2007	505
11/30/1993	514	7/9/1998	399	2/15/2003	916	9/24/2007	399
12/1/1993	557	7/10/1998	318	2/16/2003	4410	9/25/2007	401
12/2/1993	559	7/11/1998	391	2/17/2003	4630	9/26/2007	402
12/3/1993	553	7/12/1998	408	2/18/2003	2410	9/27/2007	403
12/4/1993	520	7/13/1998	432	2/19/2003	1720	9/28/2007	559
12/5/1993	0	7/14/1998	430	2/20/2003	2940	9/29/2007	591
12/6/1993	271	7/15/1998	420	2/21/2003	5200	9/30/2007	401
12/7/1993	402	7/16/1998	430	2/22/2003	777	10/1/2007	400
12/8/1993	469	7/17/1998	208	2/23/2003	9640	10/2/2007	403
12/9/1993	517	7/18/1998	366	2/24/2003	14600	10/3/2007	404
12/10/1993	794	7/19/1998	446	2/25/2003	13300	10/4/2007	400
12/11/1993	989	7/20/1998	427	2/26/2003	5110	10/5/2007	553
12/12/1993	1150	7/21/1998	453	2/27/2003	3120	10/6/2007	650
12/13/1993	701	7/22/1998	462	2/28/2003	2500	10/7/2007	405
12/14/1993	678	7/23/1998	405	3/1/2003	2230	10/8/2007	403
12/15/1993	815	7/24/1998	423	3/2/2003	2120	10/9/2007	402
12/16/1993	1010	7/25/1998	464	3/3/2003	2100	10/10/2007	405
12/17/1993	1460	7/26/1998	457	3/4/2003	2160	10/11/2007	399
12/18/1993	1630	7/27/1998	483	3/5/2003	2140	10/12/2007	533
12/19/1993	1340	7/28/1998	472	3/6/2003	1950	10/13/2007	403
12/20/1993	877	7/29/1998	460	3/7/2003	1720	10/14/2007	403

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
12/21/1993	612	7/30/1998	453	3/8/2003	1470	10/15/2007	402
12/22/1993	759	7/31/1998	482	3/9/2003	1430	10/16/2007	402
12/23/1993	774	8/1/1998	465	3/10/2003	1280	10/17/2007	405
12/24/1993	723	8/2/1998	479	3/11/2003	1280	10/18/2007	406
12/25/1993	714	8/3/1998	489	3/12/2003	1040	10/19/2007	532
12/26/1993	711	8/4/1998	492	3/13/2003	944	10/20/2007	405
12/27/1993	583	8/5/1998	503	3/14/2003	753	10/21/2007	401
12/28/1993	568	8/6/1998	505	3/15/2003	686	10/22/2007	401
12/29/1993	554	8/7/1998	512	3/16/2003	651	10/23/2007	404
12/30/1993	597	8/8/1998	571	3/17/2003	616	10/24/2007	408
12/31/1993	657	8/9/1998	107	3/18/2003	784	10/25/2007	400
1/1/1994	619	8/10/1998	356	3/19/2003	925	10/26/2007	401
1/2/1994	615	8/11/1998	396	3/20/2003	0	10/27/2007	402
1/3/1994	607	8/12/1998	451	3/21/2003	8120	10/28/2007	402
1/4/1994	1770	8/13/1998	470	3/22/2003	12000	10/29/2007	467
1/5/1994	3880	8/14/1998	473	3/23/2003	3500	10/30/2007	411
1/6/1994	1950	8/15/1998	483	3/24/2003	1870	10/31/2007	411
1/7/1994	1180	8/16/1998	1290	3/25/2003	1960	11/1/2007	404
1/8/1994	1660	8/17/1998	325	3/26/2003	1930	11/2/2007	402
1/9/1994	3150	8/18/1998	400	3/27/2003	1720	11/3/2007	401
1/10/1994	1140	8/19/1998	442	3/28/2003	1420	11/4/2007	402
1/11/1994	692	8/20/1998	454	3/29/2003	1250	11/5/2007	402
1/12/1994	4040	8/21/1998	463	3/30/2003	948	11/6/2007	402
1/13/1994	7620	8/22/1998	469	3/31/2003	1100	11/7/2007	403
1/14/1994	2550	8/23/1998	464	4/1/2003	1990	11/8/2007	403
1/15/1994	1570	8/24/1998	481	4/2/2003	2560	11/9/2007	401
1/16/1994	906	8/25/1998	1670	4/3/2003	3010	11/10/2007	398
1/17/1994	734	8/26/1998	1020	4/4/2003	2820	11/11/2007	401
1/18/1994	944	8/27/1998	473	4/5/2003	1970	11/12/2007	401
1/19/1994	3250	8/28/1998	477	4/6/2003	1970	11/13/2007	403
1/20/1994	5280	8/29/1998	2020	4/7/2003	1800	11/14/2007	404
1/21/1994	363	8/30/1998	554	4/8/2003	5350	11/15/2007	401
1/22/1994	307	8/31/1998	502	4/9/2003	7440	11/16/2007	402
1/23/1994	276	9/1/1998	508	4/10/2003	8390	11/17/2007	400
1/24/1994	286	9/2/1998	514	4/11/2003	8780	11/18/2007	398
1/25/1994	425	9/3/1998	541	4/12/2003	10900	11/19/2007	405
1/26/1994	417	9/4/1998	519	4/13/2003	4490	11/20/2007	404
1/27/1994	282	9/5/1998	517	4/14/2003	2240	11/21/2007	403
1/28/1994	788	9/6/1998	505	4/15/2003	2330	11/22/2007	402
1/29/1994	3410	9/7/1998	521	4/16/2003	2290	11/23/2007	400
1/30/1994	2040	9/8/1998	532	4/17/2003	2120	11/24/2007	401
1/31/1994	2040	9/9/1998	525	4/18/2003	1890	11/25/2007	401
2/1/1994	2580	9/10/1998	539	4/19/2003	1960	11/26/2007	399
2/2/1994	1880	9/11/1998	577	4/20/2003	2080	11/27/2007	405
2/3/1994	1150	9/12/1998	548	4/21/2003	2130	11/28/2007	406
2/4/1994	854	9/13/1998	555	4/22/2003	2180	11/29/2007	405
2/5/1994	887	9/14/1998	551	4/23/2003	1910	11/30/2007	401
2/6/1994	880	9/15/1998	552	4/24/2003	1570	12/1/2007	401
2/7/1994	900	9/16/1998	560	4/25/2003	1590	12/2/2007	401
2/8/1994	1130	9/17/1998	561	4/26/2003	1370	12/3/2007	400
2/9/1994	2250	9/18/1998	525	4/27/2003	1380	12/4/2007	402
2/10/1994	4070	9/19/1998	551	4/28/2003	1190	12/5/2007	400

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
2/11/1994	5200	9/20/1998	593	4/29/2003	1320	12/6/2007	402
2/12/1994	9140	9/21/1998	549	4/30/2003	1090	12/7/2007	404
2/13/1994	4520	9/22/1998	518	5/1/2003	912	12/8/2007	405
2/14/1994	4100	9/23/1998	503	5/2/2003	1060	12/9/2007	404
2/15/1994	3330	9/24/1998	523	5/3/2003	1200	12/10/2007	405
2/16/1994	1750	9/25/1998	537	5/4/2003	1710	12/11/2007	403
2/17/1994	2280	9/26/1998	553	5/5/2003	3890	12/12/2007	404
2/18/1994	3140	9/27/1998	535	5/6/2003	3410	12/13/2007	405
2/19/1994	3190	9/28/1998	555	5/7/2003	2350	12/14/2007	402
2/20/1994	3210	9/29/1998	626	5/8/2003	1890	12/15/2007	418
2/21/1994	3220	9/30/1998	543	5/9/2003	1520	12/16/2007	416
2/22/1994	3230	10/1/1998	539	5/10/2003	1320	12/17/2007	402
2/23/1994	5600	10/2/1998	549	5/11/2003	1570	12/18/2007	401
2/24/1994	7920	10/3/1998	590	5/12/2003	1560	12/19/2007	404
2/25/1994	5940	10/4/1998	575	5/13/2003	1580	12/20/2007	375
2/26/1994	2400	10/5/1998	568	5/14/2003	1390	12/21/2007	353
2/27/1994	1800	10/6/1998	557	5/15/2003	1150	12/22/2007	352
2/28/1994	1550	10/7/1998	543	5/16/2003	1140	12/23/2007	355
3/1/1994	4040	10/8/1998	526	5/17/2003	1320	12/24/2007	353
3/2/1994	7000	10/9/1998	416	5/18/2003	2760	12/25/2007	355
3/3/1994	8030	10/10/1998	517	5/19/2003	8760	12/26/2007	352
3/4/1994	6000	10/11/1998	561	5/20/2003	8310	12/27/2007	352
3/5/1994	3720	10/12/1998	549	5/21/2003	5150	12/28/2007	351
3/6/1994	4210	10/13/1998	556	5/22/2003	4010	12/29/2007	352
3/7/1994	4340	10/14/1998	565	5/23/2003	3400	12/30/2007	353
3/8/1994	4360	10/15/1998	568	5/24/2003	2770	12/31/2007	355
3/9/1994	4370	10/16/1998	572	5/25/2003	1830	1/1/2008	356
3/10/1994	3630	10/17/1998	575	5/26/2003	2570	1/2/2008	353
3/11/1994	2780	10/18/1998	580	5/27/2003	3260	1/3/2008	354
3/12/1994	1680	10/19/1998	573	5/28/2003	3480	1/4/2008	352
3/13/1994	1230	10/20/1998	576	5/29/2003	3850	1/5/2008	351
3/14/1994	1640	10/21/1998	580	5/30/2003	3840	1/6/2008	351
3/15/1994	1750	10/22/1998	600	5/31/2003	3770	1/7/2008	352
3/16/1994	1780	10/23/1998	590	6/1/2003	3160	1/8/2008	353
3/17/1994	1460	10/24/1998	585	6/2/2003	2960	1/9/2008	351
3/18/1994	866	10/25/1998	589	6/3/2003	2170	1/10/2008	354
3/19/1994	805	10/26/1998	566	6/4/2003	1950	1/11/2008	356
3/20/1994	892	10/27/1998	572	6/5/2003	1780	1/12/2008	350
3/21/1994	1060	10/28/1998	569	6/6/2003	2300	1/13/2008	352
3/22/1994	1550	10/29/1998	580	6/7/2003	3170	1/14/2008	354
3/23/1994	1450	10/30/1998	566	6/8/2003	6490	1/15/2008	352
3/24/1994	1020	10/31/1998	589	6/9/2003	7210	1/16/2008	357
3/25/1994	762	11/1/1998	599	6/10/2003	4250	1/17/2008	353
3/26/1994	792	11/2/1998	553	6/11/2003	2290	1/18/2008	356
3/27/1994	3410	11/3/1998	564	6/12/2003	1950	1/19/2008	350
3/28/1994	6480	11/4/1998	540	6/13/2003	1950	1/20/2008	371
3/29/1994	9770	11/5/1998	542	6/14/2003	0	1/21/2008	356
3/30/1994	11000	11/6/1998	568	6/15/2003	7420	1/22/2008	355
3/31/1994	11200	11/7/1998	584	6/16/2003	6120	1/23/2008	355
4/1/1994	7480	11/8/1998	564	6/17/2003	7320	1/24/2008	355
4/2/1994	6450	11/9/1998	566	6/18/2003	7470	1/25/2008	358
4/3/1994	2880	11/10/1998	582	6/19/2003	7060	1/26/2008	353

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
4/4/1994	2190	11/11/1998	515	6/20/2003	7540	1/27/2008	354
4/5/1994	1820	11/12/1998	503	6/21/2003	4840	1/28/2008	355
4/6/1994	1820	11/13/1998	510	6/22/2003	3140	1/29/2008	353
4/7/1994	1840	11/14/1998	541	6/23/2003	2200	1/30/2008	352
4/8/1994	1560	11/15/1998	573	6/24/2003	1600	1/31/2008	354
4/9/1994	1310	11/16/1998	601	6/25/2003	1360	2/1/2008	354
4/10/1994	1290	11/17/1998	520	6/26/2003	1340	2/2/2008	356
4/11/1994	1920	11/18/1998	568	6/27/2003	889	2/3/2008	378
4/12/1994	2670	11/19/1998	547	6/28/2003	890	2/4/2008	363
4/13/1994	302	11/20/1998	544	6/29/2003	1340	2/5/2008	352
4/14/1994	309	11/21/1998	547	6/30/2003	1310	2/6/2008	355
4/15/1994	797	11/22/1998	557	7/1/2003	1980	2/7/2008	358
4/16/1994	959	11/23/1998	551	7/2/2003	4040	2/8/2008	356
4/17/1994	783	11/24/1998	543	7/3/2003	6140	2/9/2008	351
4/18/1994	798	11/25/1998	564	7/4/2003	6020	2/10/2008	419
4/19/1994	795	11/26/1998	542	7/5/2003	3220	2/11/2008	359
4/20/1994	985	11/27/1998	543	7/6/2003	2150	2/12/2008	359
4/21/1994	1180	11/28/1998	554	7/7/2003	2840	2/13/2008	350
4/22/1994	1200	11/29/1998	561	7/8/2003	3090	2/14/2008	407
4/23/1994	1460	11/30/1998	561	7/9/2003	2500	2/15/2008	356
4/24/1994	1010	12/1/1998	578	7/10/2003	2180	2/16/2008	366
4/25/1994	827	12/2/1998	586	7/11/2003	1850	2/17/2008	350
4/26/1994	804	12/3/1998	555	7/12/2003	1970	2/18/2008	349
4/27/1994	750	12/4/1998	524	7/13/2003	1830	2/19/2008	354
4/28/1994	663	12/5/1998	581	7/14/2003	2040	2/20/2008	352
4/29/1994	747	12/6/1998	575	7/15/2003	2210	2/21/2008	470
4/30/1994	2600	12/7/1998	560	7/16/2003	1590	2/22/2008	552
5/1/1994	2890	12/8/1998	555	7/17/2003	1360	2/23/2008	551
5/2/1994	1210	12/9/1998	447	7/18/2003	1260	2/24/2008	556
5/3/1994	960	12/10/1998	453	7/19/2003	1210	2/25/2008	551
5/4/1994	1300	12/11/1998	506	7/20/2003	1020	2/26/2008	555
5/5/1994	2320	12/12/1998	549	7/21/2003	784	2/27/2008	551
5/6/1994	1940	12/13/1998	296	7/22/2003	831	2/28/2008	551
5/7/1994	1540	12/14/1998	137	7/23/2003	1280	2/29/2008	551
5/8/1994	1260	12/15/1998	450	7/24/2003	1550	3/1/2008	551
5/9/1994	1200	12/16/1998	469	7/25/2003	1660	3/2/2008	554
5/10/1994	905	12/17/1998	465	7/26/2003	1230	3/3/2008	555
5/11/1994	625	12/18/1998	369	7/27/2003	1090	3/4/2008	553
5/12/1994	638	12/19/1998	382	7/28/2003	879	3/5/2008	555
5/13/1994	671	12/20/1998	386	7/29/2003	840	3/6/2008	560
5/14/1994	694	12/21/1998	377	7/30/2003	1090	3/7/2008	573
5/15/1994	853	12/22/1998	386	7/31/2003	1320	3/8/2008	788
5/16/1994	1100	12/23/1998	383	8/1/2003	1350	3/9/2008	1275
5/17/1994	1170	12/24/1998	327	8/2/2003	1420	3/10/2008	1337
5/18/1994	864	12/25/1998	164	8/3/2003	1840	3/11/2008	993
5/19/1994	519	12/26/1998	213	8/4/2003	3780	3/12/2008	965
5/20/1994	523	12/27/1998	234	8/5/2003	3160	3/13/2008	850
5/21/1994	530	12/28/1998	234	8/6/2003	1960	3/14/2008	771
5/22/1994	743	12/29/1998	244	8/7/2003	2390	3/15/2008	745
5/23/1994	1210	12/30/1998	255	8/8/2003	2800	3/16/2008	1944
5/24/1994	818	12/31/1998	272	8/9/2003	2560	3/17/2008	903
5/25/1994	693	1/1/1999	279	8/10/2003	6560	3/18/2008	675

Date	Flow (cfs)
5/26/1994	644
5/27/1994	557
5/28/1994	603
5/29/1994	830
5/30/1994	1240
5/31/1994	908
6/1/1994	657
6/2/1994	493
6/3/1994	497
6/4/1994	496
6/5/1994	495
6/6/1994	501
6/7/1994	410
6/8/1994	440
6/9/1994	427
6/10/1994	491
6/11/1994	423
6/12/1994	460
6/13/1994	452
6/14/1994	441
6/15/1994	469
6/16/1994	489
6/17/1994	577
6/18/1994	513
6/19/1994	525
6/20/1994	511
6/21/1994	533
6/22/1994	522
6/23/1994	551
6/24/1994	495
6/25/1994	551
6/26/1994	555
6/27/1994	466
6/28/1994	251
6/29/1994	438
6/30/1994	465
7/1/1994	433
7/2/1994	502
7/3/1994	532
7/4/1994	1610
7/5/1994	1680
7/6/1994	474
7/7/1994	501
7/8/1994	514
7/9/1994	519
7/10/1994	539
7/11/1994	536
7/12/1994	526
7/13/1994	528
7/14/1994	518
7/15/1994	524
7/16/1994	585

Date	Flow (cfs)
1/2/1999	273
1/3/1999	1
1/4/1999	0
1/5/1999	92
1/6/1999	153
1/7/1999	148
1/8/1999	222
1/9/1999	202
1/10/1999	79
1/11/1999	133
1/12/1999	194
1/13/1999	208
1/14/1999	186
1/15/1999	93
1/16/1999	61
1/17/1999	146
1/18/1999	27
1/19/1999	0
1/20/1999	80
1/21/1999	144
1/22/1999	177
1/23/1999	195
1/24/1999	0
1/25/1999	0
1/26/1999	28
1/27/1999	109
1/28/1999	149
1/29/1999	182
1/30/1999	208
1/31/1999	211
2/1/1999	215
2/2/1999	0
2/3/1999	0
2/4/1999	38
2/5/1999	113
2/6/1999	162
2/7/1999	183
2/8/1999	177
2/9/1999	207
2/10/1999	223
2/11/1999	226
2/12/1999	228
2/13/1999	213
2/14/1999	231
2/15/1999	268
2/16/1999	246
2/17/1999	247
2/18/1999	195
2/19/1999	4
2/20/1999	104
2/21/1999	158
2/22/1999	188

Date	Flow (cfs)
8/11/2003	8550
8/12/2003	6480
8/13/2003	1760
8/14/2003	1570
8/15/2003	1350
8/16/2003	605
8/17/2003	852
8/18/2003	1900
8/19/2003	2360
8/20/2003	2290
8/21/2003	1980
8/22/2003	1590
8/23/2003	1430
8/24/2003	1030
8/25/2003	1070
8/26/2003	899
8/27/2003	758
8/28/2003	693
8/29/2003	649
8/30/2003	724
8/31/2003	979
9/1/2003	1160
9/2/2003	1090
9/3/2003	1030
9/4/2003	968
9/5/2003	1020
9/6/2003	1380
9/7/2003	1400
9/8/2003	1130
9/9/2003	978
9/10/2003	725
9/11/2003	662
9/12/2003	668
9/13/2003	660
9/14/2003	606
9/15/2003	659
9/16/2003	878
9/17/2003	1380
9/18/2003	3050
9/19/2003	2920
9/20/2003	3490
9/21/2003	1560
9/22/2003	834
9/23/2003	0
9/24/2003	3410
9/25/2003	3730
9/26/2003	3830
9/27/2003	2370
9/28/2003	794
9/29/2003	898
9/30/2003	523
10/1/2003	560

Date	Flow (cfs)
3/19/2008	676
3/20/2008	666
3/21/2008	682
3/22/2008	679
3/23/2008	678
3/24/2008	669
3/25/2008	661
3/26/2008	655
3/27/2008	651
3/28/2008	645
3/29/2008	662
3/30/2008	654
3/31/2008	653
4/1/2008	653
4/2/2008	656
4/3/2008	654
4/4/2008	648
4/5/2008	650
4/6/2008	1136
4/7/2008	4311
4/8/2008	4399
4/9/2008	1859
4/10/2008	1299
4/11/2008	980
4/12/2008	911
4/13/2008	1515
4/14/2008	1917
4/15/2008	1005
4/16/2008	965
4/17/2008	672
4/18/2008	710
4/19/2008	721
4/20/2008	982
4/21/2008	1127
4/22/2008	1137
4/23/2008	1142
4/24/2008	1140
4/25/2008	1107
4/26/2008	1063
4/27/2008	1114
4/28/2008	3195
4/29/2008	4550
4/30/2008	4530
5/1/2008	2246
5/2/2008	1632
5/3/2008	1661
5/4/2008	1401
5/5/2008	1237
5/6/2008	834
5/7/2008	726
5/8/2008	731
5/9/2008	1512

Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)	Date	Flow (cfs)
7/17/1994	427	2/23/1999	231	10/2/2003	575	5/10/2008	2203
7/18/1994	0	2/24/1999	239	10/3/2003	581	5/11/2008	2434
7/19/1994	265	2/25/1999	244	10/4/2003	575	5/12/2008	2738
7/20/1994	632	2/26/1999	244	10/5/2003	569	5/13/2008	1810
7/21/1994	870	2/27/1999	257	10/6/2003	587	5/14/2008	1166
7/22/1994	952	2/28/1999	244	10/7/2003	603	5/15/2008	903
7/23/1994	1200	3/1/1999	286	10/8/2003	607	5/16/2008	831
7/24/1994	853	3/2/1999	477	10/9/2003	629	5/17/2008	830
7/25/1994	446	3/3/1999	464	10/10/2003	661	5/18/2008	1171
7/26/1994	621	3/4/1999	437	10/11/2003	668	5/19/2008	1190
7/27/1994	2180	3/5/1999	470	10/12/2003	789	5/20/2008	834
7/28/1994	4140	3/6/1999	509	10/13/2003	807	5/21/2008	667
7/29/1994	6060	3/7/1999	513	10/14/2003	823	5/22/2008	676
7/30/1994	2130	3/8/1999	500	10/15/2003	812	5/23/2008	714
7/31/1994	778	3/9/1999	460	10/16/2003	1080	5/24/2008	723
8/1/1994	384	3/10/1999	454	10/17/2003	991	5/25/2008	1224
8/2/1994	147	3/11/1999	462	10/18/2003	827	5/26/2008	1328
8/3/1994	1740	3/12/1999	476	10/19/2003	824	5/27/2008	996
8/4/1994	4200	3/13/1999	487	10/20/2003	660	5/28/2008	709
8/5/1994	1390	3/14/1999	485	10/21/2003	766	5/29/2008	679
8/6/1994	416	3/15/1999	1080	10/22/2003	820	5/30/2008	666
8/7/1994	431	3/16/1999	2440	10/23/2003	824	5/31/2008	674
8/8/1994	462	3/17/1999	2140	10/24/2003	833		
8/9/1994	475	3/18/1999	1410	10/25/2003	715		

Appendix E:
Roanoke River PCB TMDL Model Hydrologic Calibration and Validation Results

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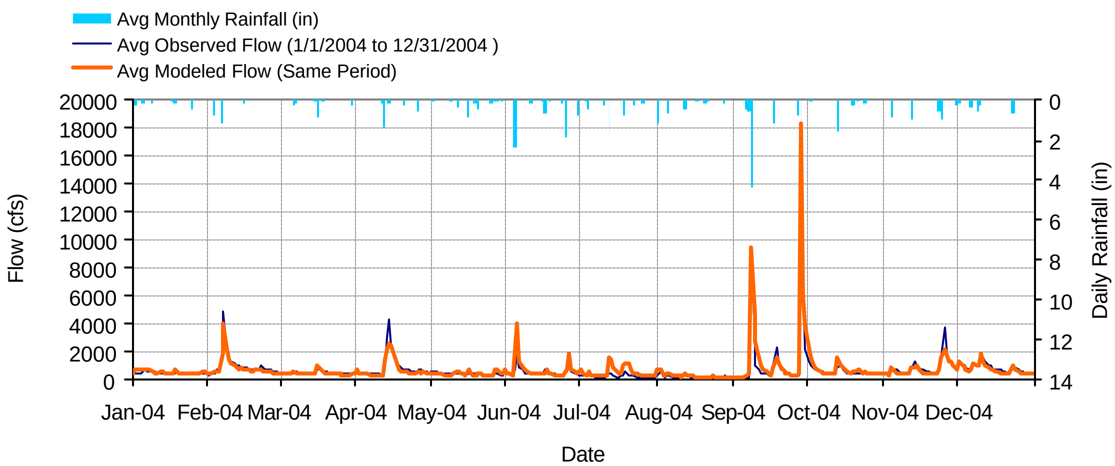


Figure E-1. Calibration mean daily flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

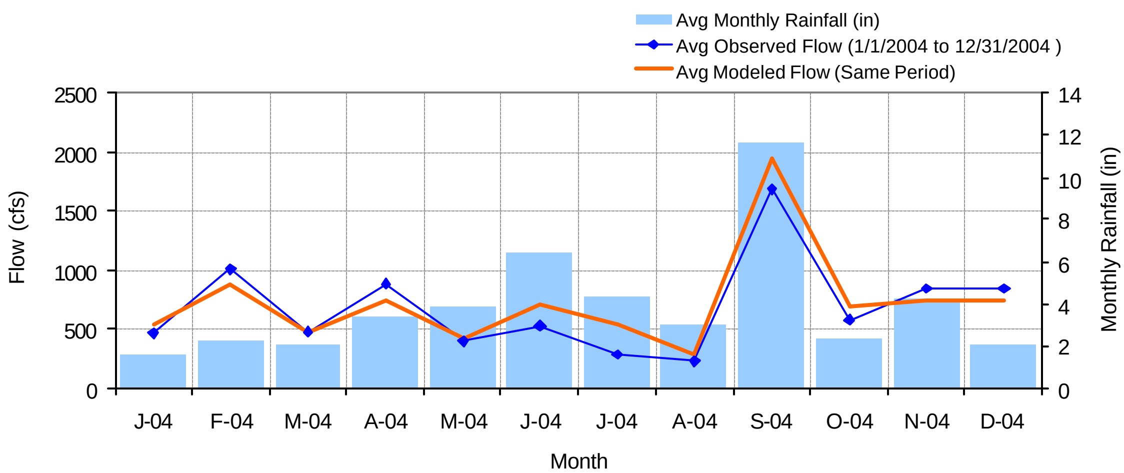


Figure E-2. Calibration mean monthly flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

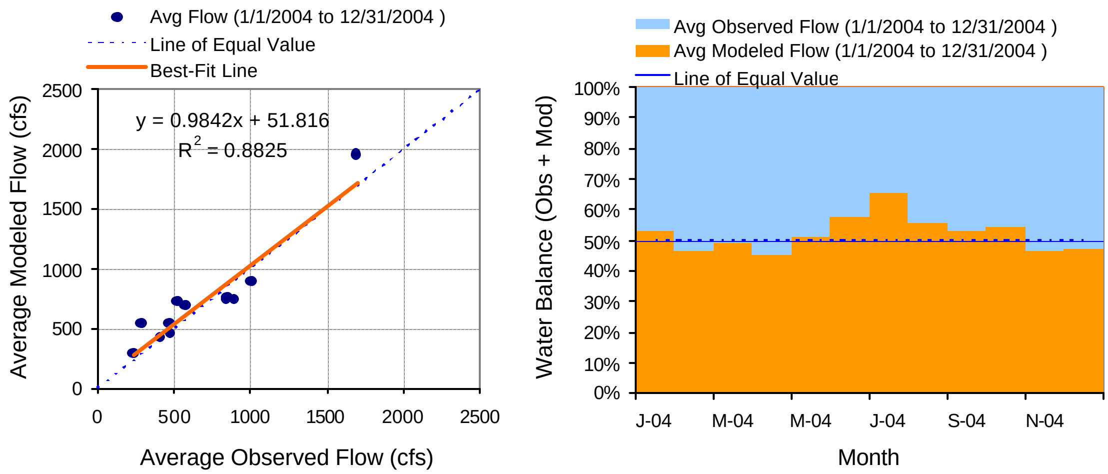


Figure E-3. Calibration monthly flow regression and temporal variation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

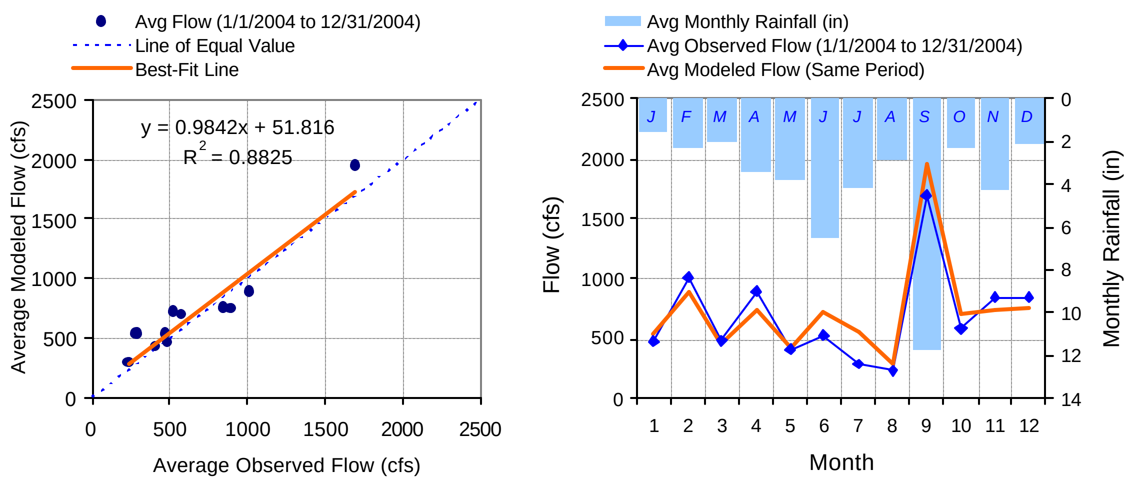


Figure E-4. Calibration seasonal regression and temporal aggregate: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

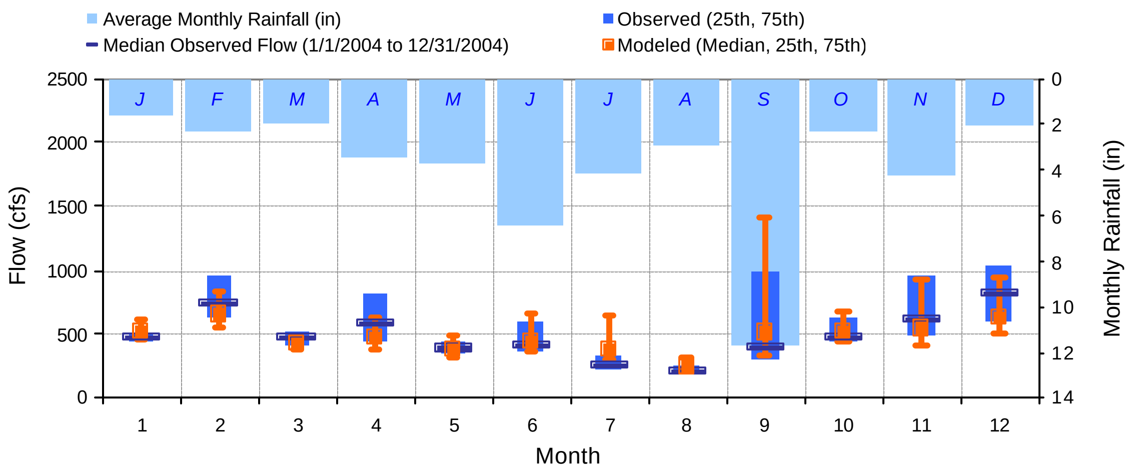


Figure E-5. Calibration seasonal medians and ranges: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-1. Calibration seasonal summary: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	475.61	480.00	438.50	511.00	540.57	522.03	460.34	610.33
Feb	1011.31	743.00	629.00	951.00	889.86	657.34	548.73	834.01
Mar	480.68	473.00	412.50	516.50	462.43	432.38	388.77	474.82
Apr	890.03	590.50	431.25	810.50	741.13	470.22	374.46	624.69
May	407.71	394.00	350.00	439.00	427.55	379.49	320.53	490.96
Jun	526.97	421.50	368.25	590.50	720.11	455.63	362.42	662.06
Jul	285.03	255.00	230.50	328.00	547.17	377.60	296.07	647.38
Aug	235.29	210.00	194.00	254.00	290.93	246.75	206.80	324.29
Sep	1693.17	396.00	302.50	993.00	1953.82	519.04	330.14	1415.32
Oct	579.97	478.00	436.00	621.00	693.34	529.02	440.99	682.23
Nov	845.80	612.50	494.75	948.00	746.19	551.11	412.13	918.73
Dec	846.52	818.00	597.50	1035.00	756.26	636.06	499.64	946.05

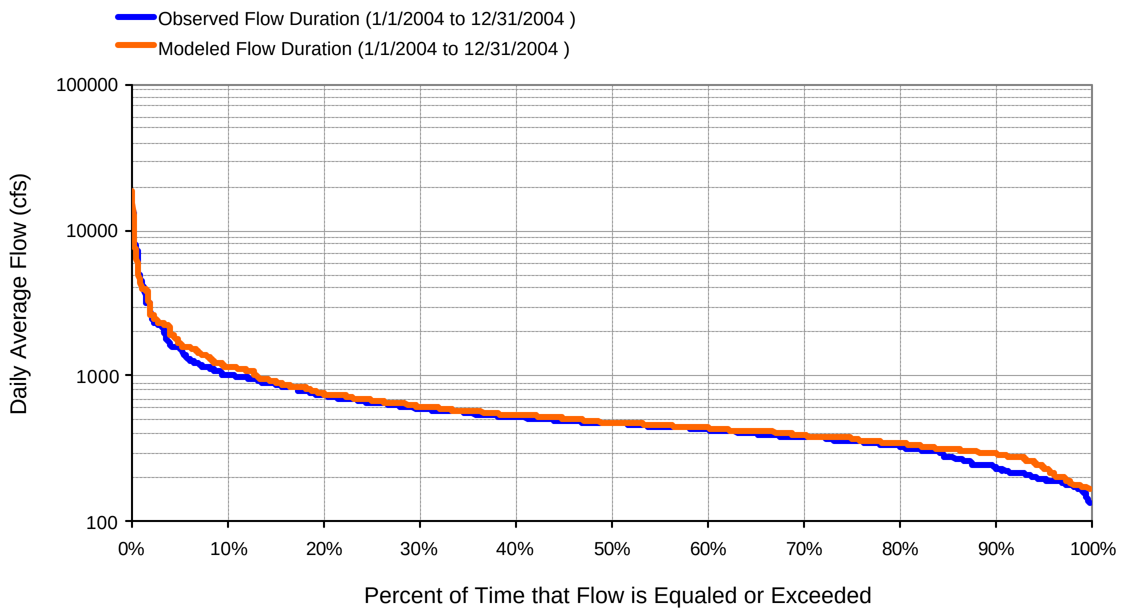


Figure E-6. Calibration flow exceedence: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

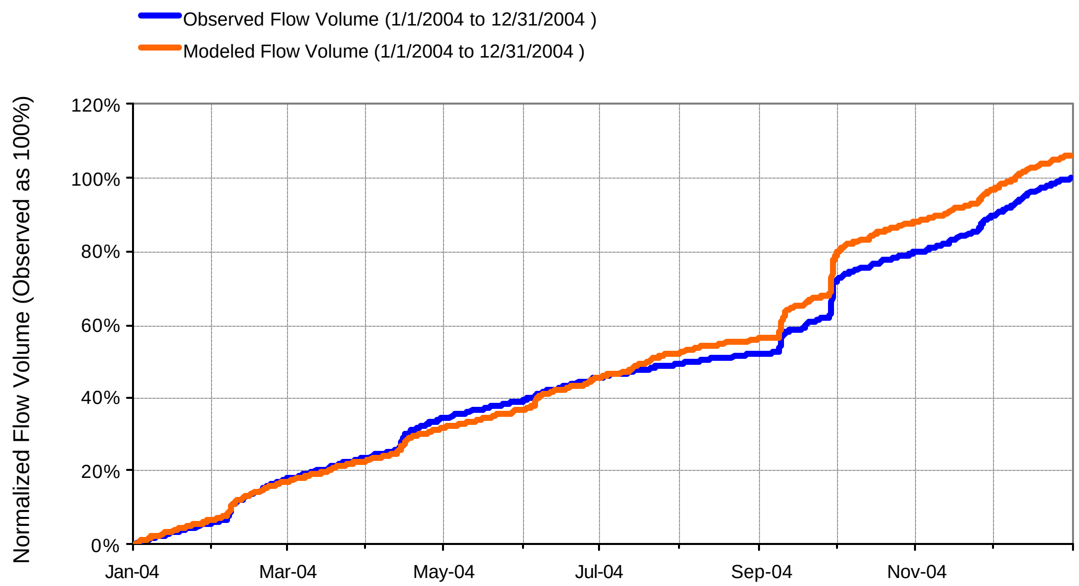


Figure E-7. Calibration flow accumulation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-2. Calibration summary statistics: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3011		USGS 02056000 ROANOKE RIVER AT NIAGARA, VA		
1-Year Analysis Period: 1/1/2004 - 12/31/2004 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 3010101 Latitude: 37.2551384 Longitude: -79.87142539 Drainage Area (sq-mi): 509		
Total Simulated In-stream Flow:	**19.39**	Total Observed In-stream Flow:		**18.28**
Total of simulated highest 10% flows:	**7.49**	Total of Observed highest 10% flows:		**6.98**
Total of Simulated lowest 50% flows:	**4.83**	Total of Observed Lowest 50% flows:		**4.55**
Simulated Summer Flow Volume (months 7-9):	**6.17**	Observed Summer Flow Volume (7-9):		**4.88**
Simulated Fall Flow Volume (months 10-12):	**4.91**	Observed Fall Flow Volume (10-12):		**5.07**
Simulated Winter Flow Volume (months 1-3):	**4.15**	Observed Winter Flow Volume (1-3):		**4.30**
Simulated Spring Flow Volume (months 4-6):	**4.16**	Observed Spring Flow Volume (4-6):		**4.02**
Total Simulated Storm Volume:	**8.51**	Total Observed Storm Volume:		**7.12**
Simulated Summer Storm Volume (7-9)	**4.17**	Observed Summer Storm Volume (7-9):		**3.32**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	6.09	10	-1.43	7.35
Error in 50% lowest flows:	6.26	10	-1.60	-3.91
Error in 10% highest flows:	7.40	15	2.26	1.75
Seasonal volume error - Summer:	26.40	30	13.27	-2.52
Seasonal volume error - Fall:	-3.26	30	4.49	12.42
Seasonal volume error - Winter:	-3.52	30	-18.21	13.31
Seasonal volume error - Spring:	3.52	30	1.90	6.11
Error in storm volumes:	19.46	20	1.13	12.07
Error in summer storm volumes:	25.70	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.917	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.620	as E or E' approaches 1.0	0.517	0.549

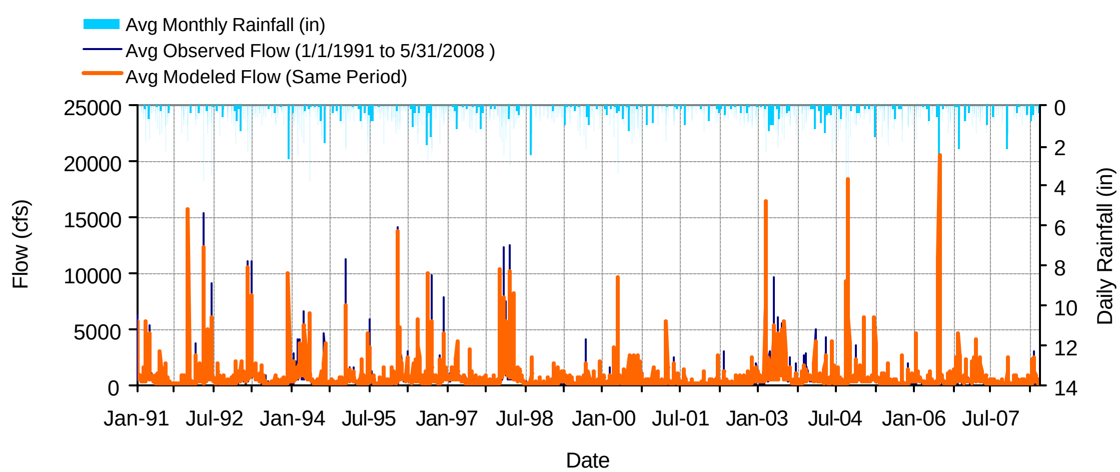


Figure E-8. Validation mean daily flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

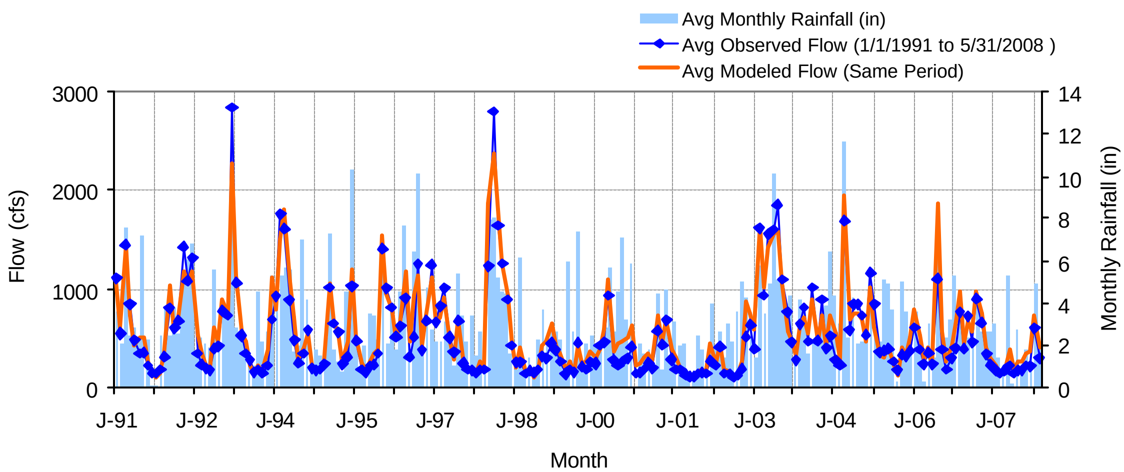


Figure E-9. Validation mean monthly flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

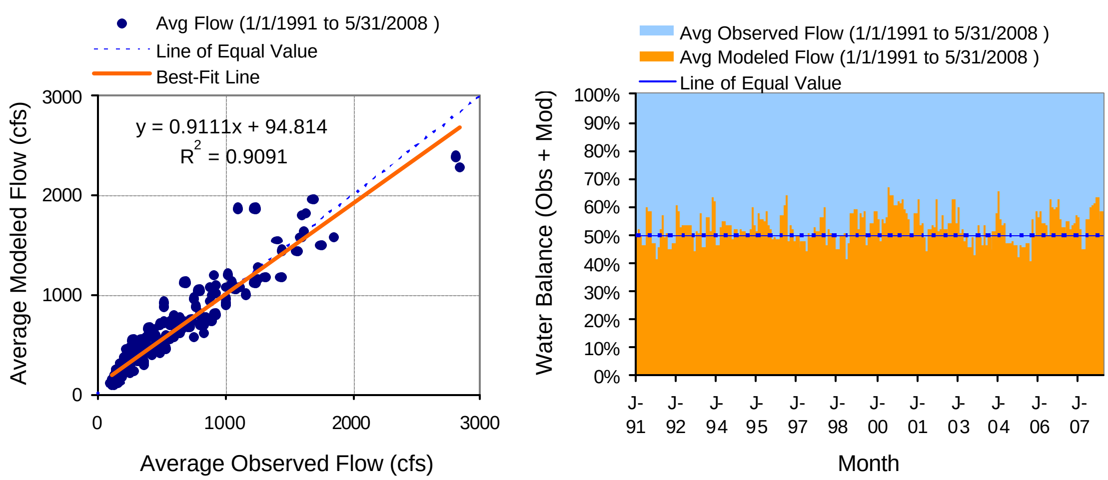


Figure E-10. Validation monthly flow regression and temporal variation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

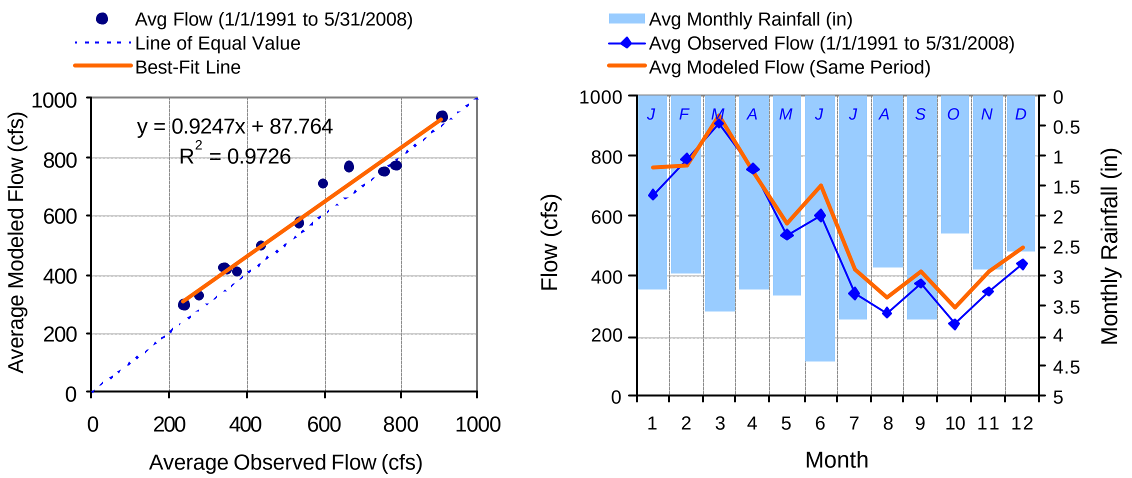


Figure E-11. Validation seasonal regression and temporal aggregate: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

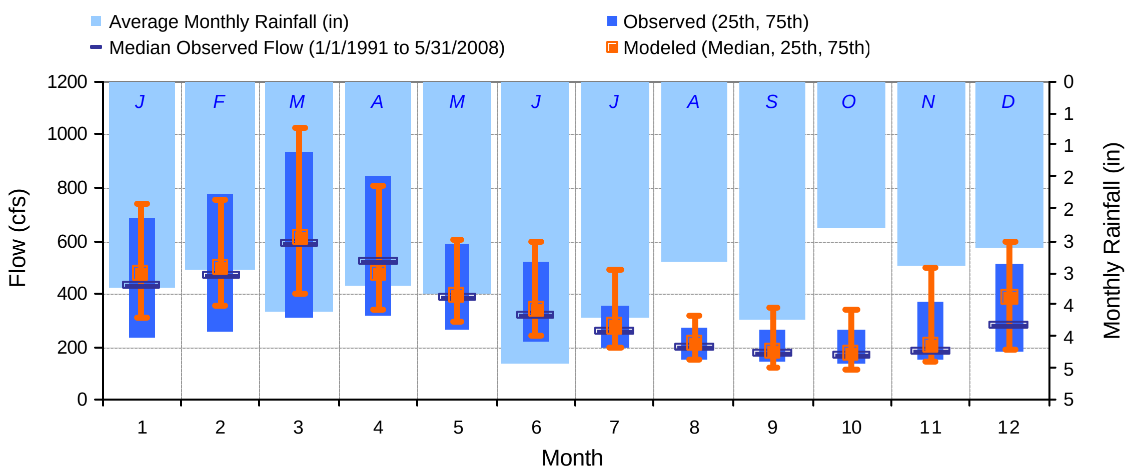


Figure E-12. Validation seasonal medians and ranges: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-3. Validation seasonal summary: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	668.21	434.00	237.25	683.75	763.41	473.11	312.12	736.08
Feb	789.55	471.00	256.00	778.00	768.08	498.60	358.37	755.82
Mar	906.11	590.00	305.50	931.50	935.42	609.58	398.10	1022.25
Apr	758.49	522.00	317.00	842.00	748.16	479.30	338.95	805.00
May	537.77	384.00	264.00	588.75	572.82	393.90	288.36	603.89
Jun	600.41	319.50	219.00	517.00	704.41	340.38	245.17	590.83
Jul	340.59	255.00	195.50	349.50	421.96	278.05	195.38	494.41
Aug	274.89	198.00	153.00	270.50	325.77	214.38	146.08	316.00
Sep	376.06	178.00	144.00	267.00	410.57	183.82	121.09	345.95
Oct	237.68	170.00	137.00	260.00	296.43	178.13	112.68	334.07
Nov	348.15	188.00	152.25	372.75	415.39	205.13	144.15	497.82
Dec	438.82	281.00	179.50	512.00	494.98	384.18	190.23	595.31

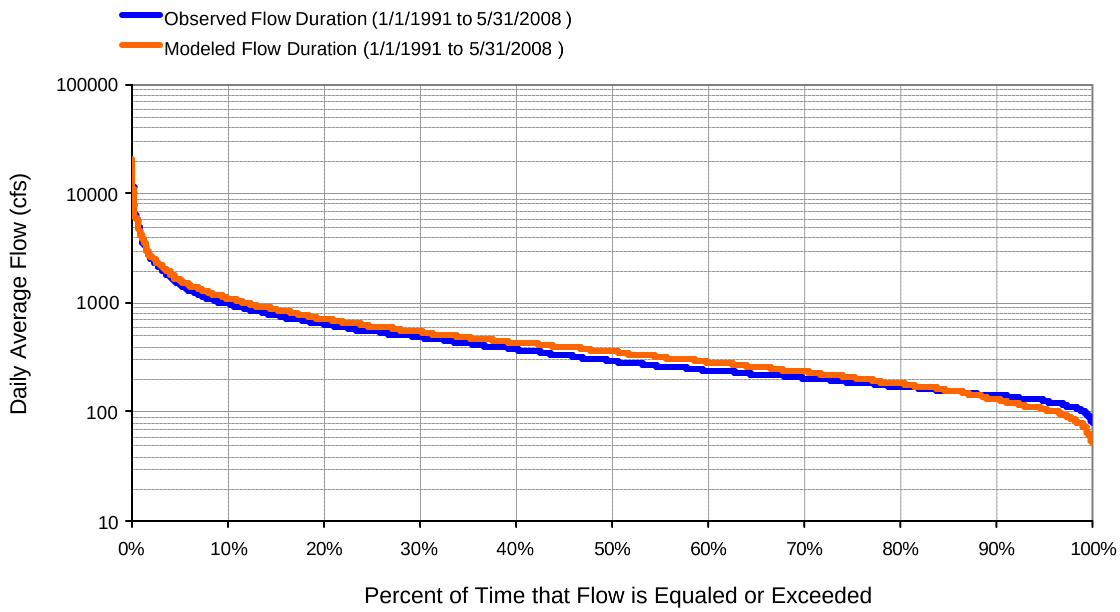


Figure E-13. Validation flow exceedence: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

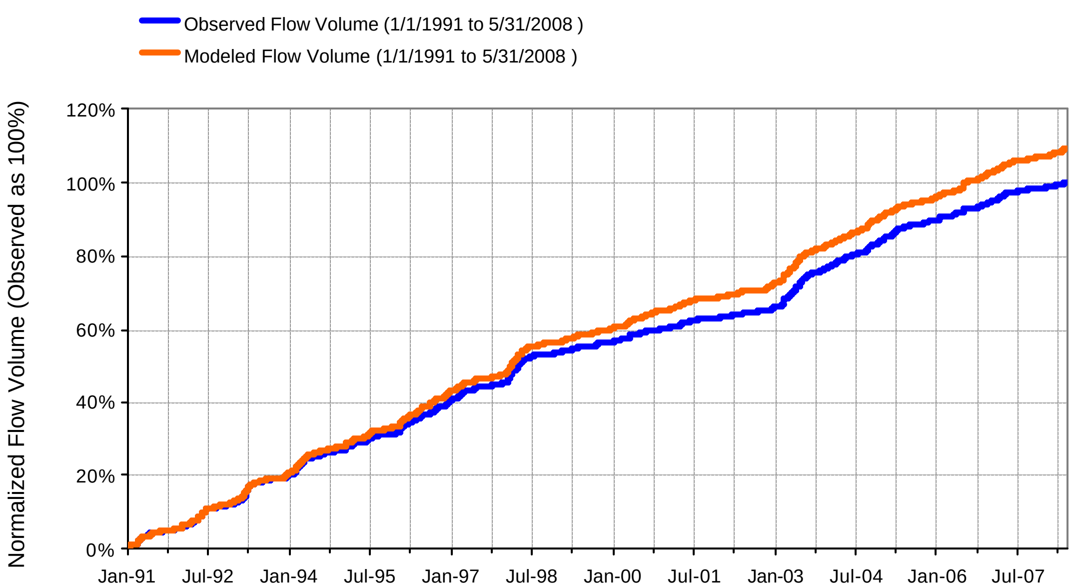


Figure E-14. Validation flow accumulation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-4. Validation summary statistics: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3011 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02056000 ROANOKE RIVER AT NIAGARA, VA Hydrologic Unit Code: 3010101 Latitude: 37.2551384 Longitude: -79.87142539 Drainage Area (sq-mi): 509		
Total Simulated In-stream Flow:	**15.33**	Total Observed In-stream Flow:		**14.04**
Total of simulated highest 10% flows:	**6.20**	Total of Observed highest 10% flows:		**5.92**
Total of Simulated lowest 50% flows:	**2.79**	Total of Observed Lowest 50% flows:		**2.54**
Simulated Summer Flow Volume (months 7-9):	**2.53**	Observed Summer Flow Volume (7-9):		**2.17**
Simulated Fall Flow Volume (months 10-12):	**2.64**	Observed Fall Flow Volume (10-12):		**2.24**
Simulated Winter Flow Volume (months 1-3):	**5.62**	Observed Winter Flow Volume (1-3):		**5.37**
Simulated Spring Flow Volume (months 4-6):	**4.54**	Observed Spring Flow Volume (4-6):		**4.26**
Total Simulated Storm Volume:	**6.12**	Total Observed Storm Volume:		**5.20**
Simulated Summer Storm Volume (7-9)	**1.07**	Observed Summer Storm Volume (7-9):		**0.79**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	9.19	10	-1.43	7.35
Error in 50% lowest flows:	9.78	10	-1.60	-3.91
Error in 10% highest flows:	4.76	15	2.26	1.75
Seasonal volume error - Summer:	16.91	30	13.27	-2.52
Seasonal volume error - Fall:	17.76	30	4.49	12.42
Seasonal volume error - Winter:	4.57	30	-18.21	13.31
Seasonal volume error - Spring:	6.60	30	1.90	6.11
Error in storm volumes:	17.66	20	1.13	12.07
Error in summer storm volumes:	35.02	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.799	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.607	as E or E' approaches 1.0	0.517	0.549

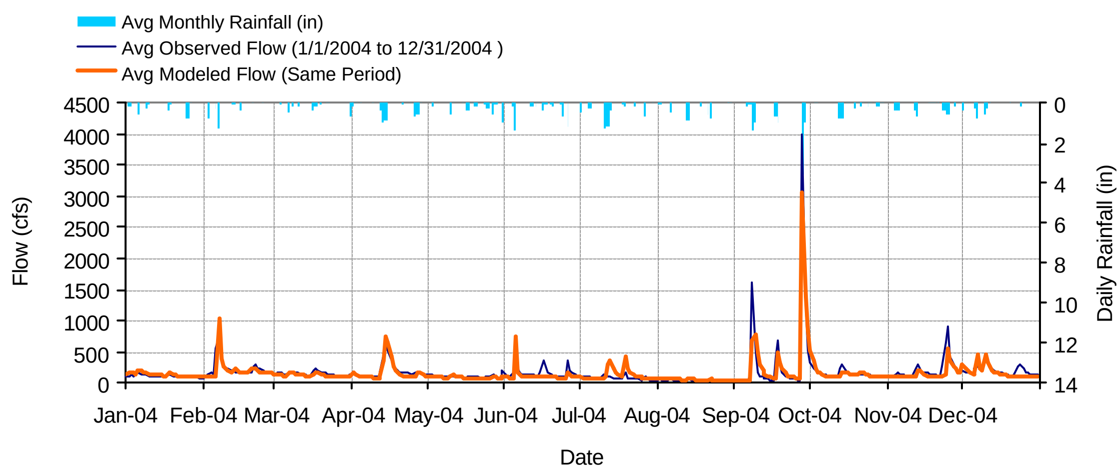


Figure E-15. Calibration mean daily flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

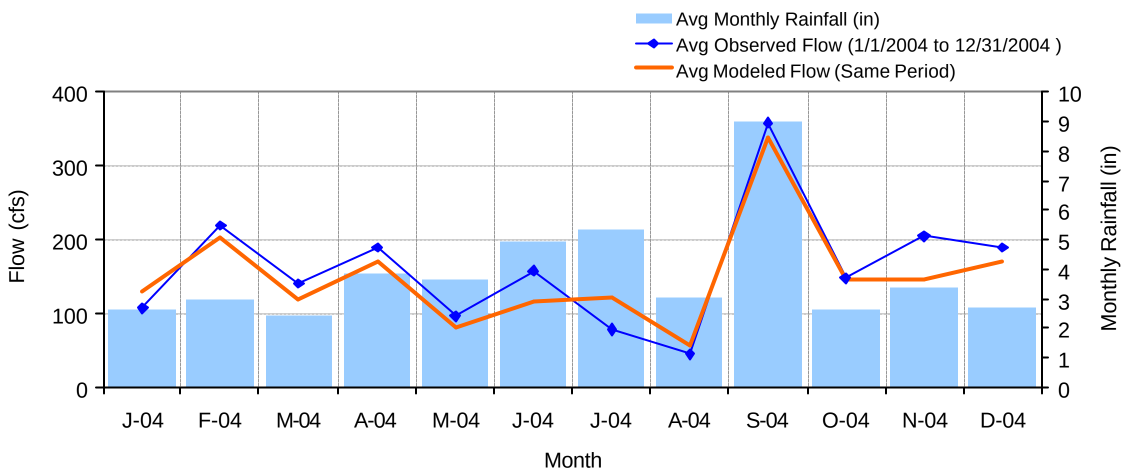


Figure E-16. Calibration mean monthly flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

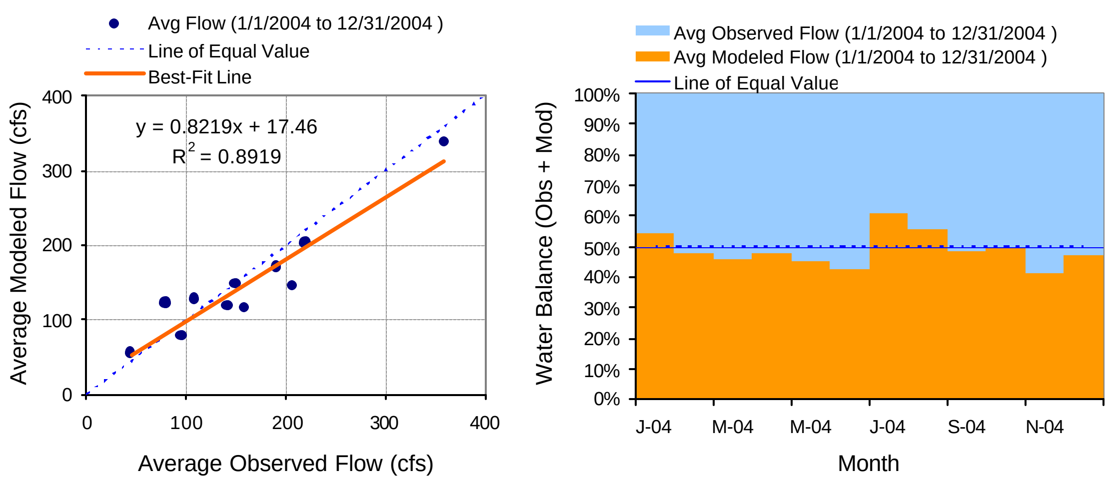


Figure E-17. Calibration monthly flow regression and temporal variation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

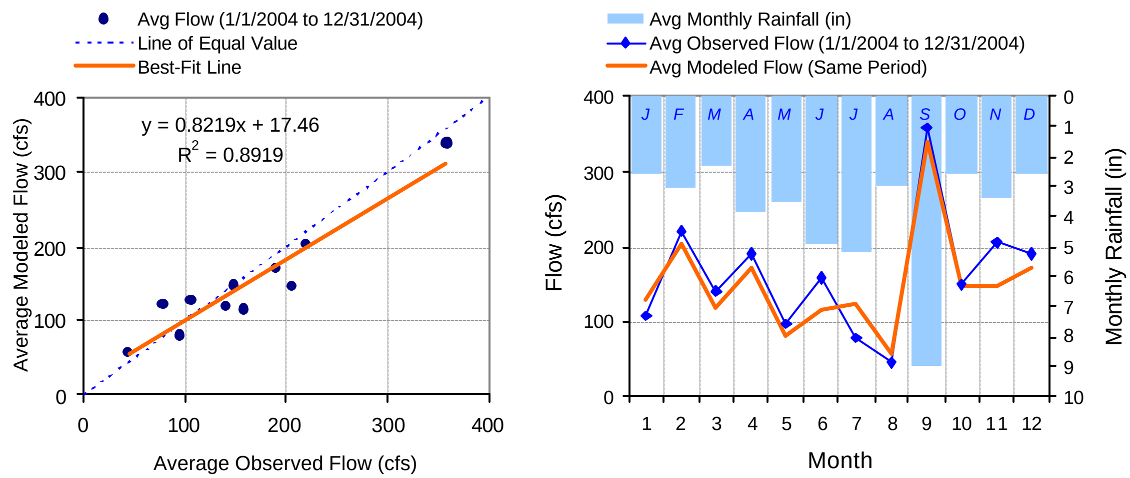


Figure E-18. Calibration seasonal regression and temporal aggregate: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

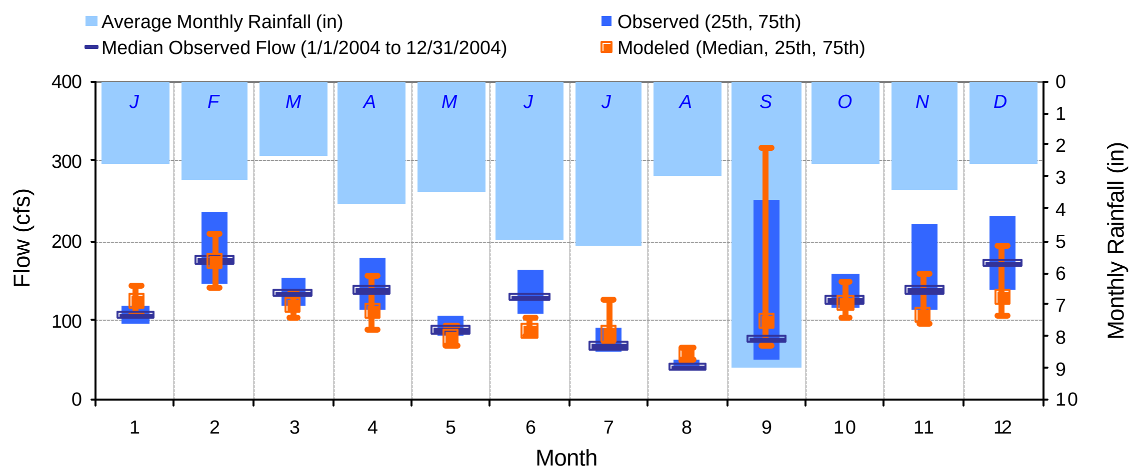


Figure E-19. Calibration seasonal medians and ranges: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-5. Calibration Seasonal summary: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	107.06	106.00	94.50	117.50	128.56	124.94	107.52	141.49
Feb	219.59	176.00	145.00	235.00	203.67	173.29	141.45	207.55
Mar	140.61	135.00	117.50	153.00	118.60	118.72	102.43	133.27
Apr	190.37	137.00	112.00	177.50	171.76	110.53	89.04	155.41
May	95.94	88.00	81.00	105.50	80.43	76.52	68.40	91.19
Jun	158.17	128.50	108.00	163.75	115.71	86.55	79.90	102.90
Jul	78.42	68.00	59.50	89.50	122.75	82.29	67.99	125.51
Aug	44.65	42.00	37.00	50.00	57.07	56.63	50.68	64.58
Sep	358.27	76.00	50.50	251.50	338.37	98.18	68.93	316.87
Oct	149.03	125.00	115.00	158.00	147.99	121.29	103.90	149.11
Nov	205.37	137.00	113.50	222.25	146.55	106.16	94.45	157.21
Dec	190.23	171.00	138.50	230.00	170.59	128.54	104.71	193.55

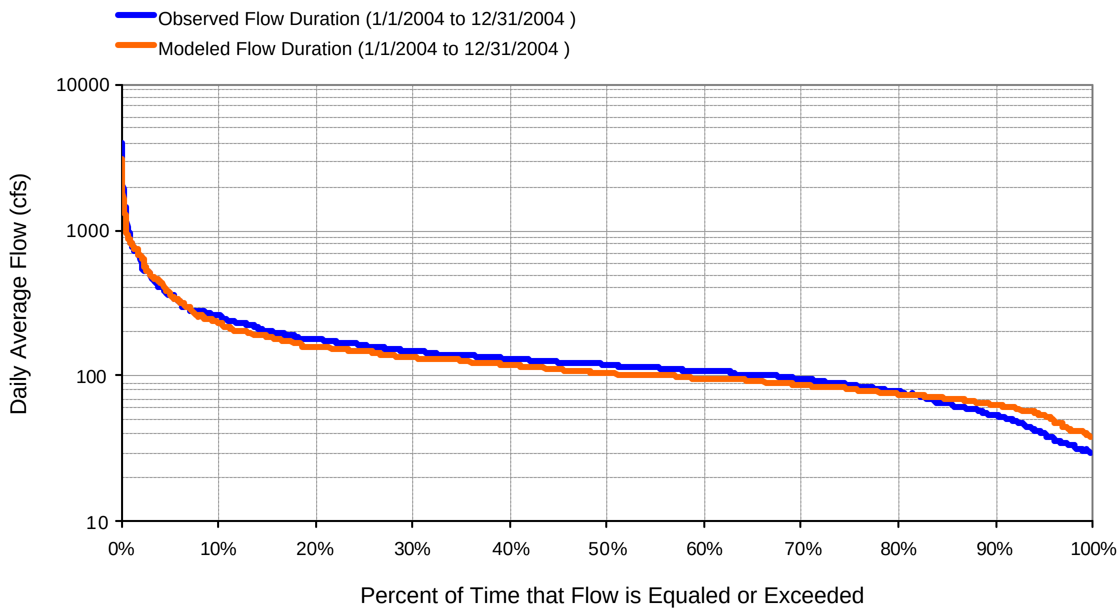


Figure E-20. Calibration flow exceedence: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

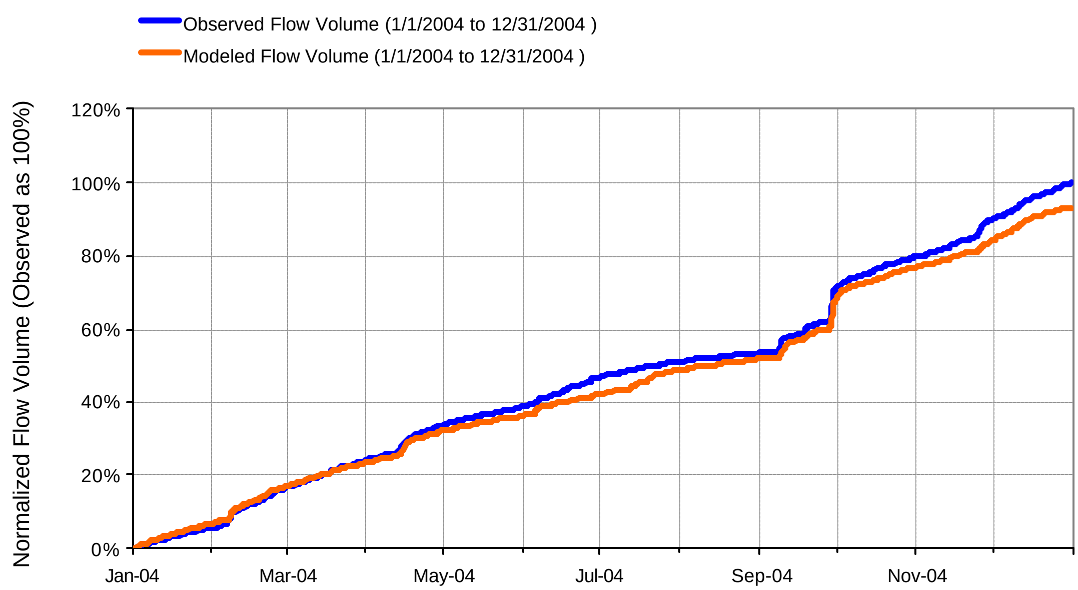


Figure E-21. Calibration flow accumulation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-6. Calibration summary statistics: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3029 1-Year Analysis Period: 1/1/2004 - 12/31/2004 Flow volumes are (inches/year) for upstream drainage area		USGS 02053800 S F ROANOKE RIVER NEAR SHAWSVILLE, VA Hydrologic Unit Code: 3010101 Latitude: 37.1401323 Longitude: -80.2664328 Drainage Area (sq-mi): 109		
Total Simulated In-stream Flow:	**18.62**	Total Observed In-stream Flow:		**19.99**
Total of simulated highest 10% flows:	**6.71**	Total of Observed highest 10% flows:		**7.14**
Total of Simulated lowest 50% flows:	**4.95**	Total of Observed Lowest 50% flows:		**5.11**
Simulated Summer Flow Volume (months 7-9):	**5.35**	Observed Summer Flow Volume (7-9):		**4.96**
Simulated Fall Flow Volume (months 10-12):	**4.86**	Observed Fall Flow Volume (10-12):		**5.68**
Simulated Winter Flow Volume (months 1-3):	**4.62**	Observed Winter Flow Volume (1-3):		**4.78**
Simulated Spring Flow Volume (months 4-6):	**3.79**	Observed Spring Flow Volume (4-6):		**4.57**
Total Simulated Storm Volume:	**5.92**	Total Observed Storm Volume:		**6.54**
Simulated Summer Storm Volume (7-9)	**2.86**	Observed Summer Storm Volume (7-9):		**3.13**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-6.87	10	-1.43	7.35
Error in 50% lowest flows:	-3.26	10	-1.60	-3.91
Error in 10% highest flows:	-5.98	15	2.26	1.75
Seasonal volume error - Summer:	7.98	30	13.27	-2.52
Seasonal volume error - Fall:	-14.42	30	4.49	12.42
Seasonal volume error - Winter:	-3.40	30	-18.21	13.31
Seasonal volume error - Spring:	-17.22	30	1.90	6.11
Error in storm volumes:	-9.55	20	1.13	12.07
Error in summer storm volumes:	-8.76	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.818	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.482	as E or E' approaches 1.0	0.517	0.549

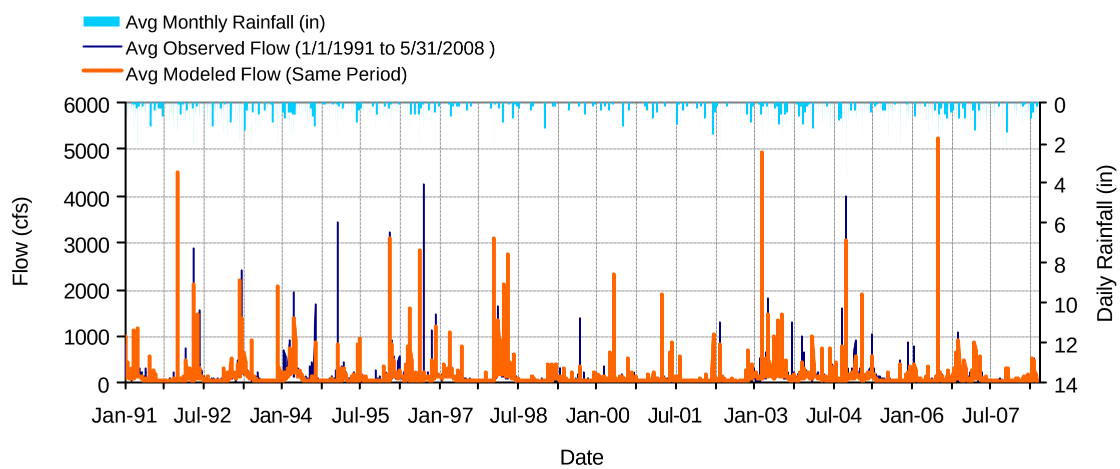


Figure E-22. Validation mean daily flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

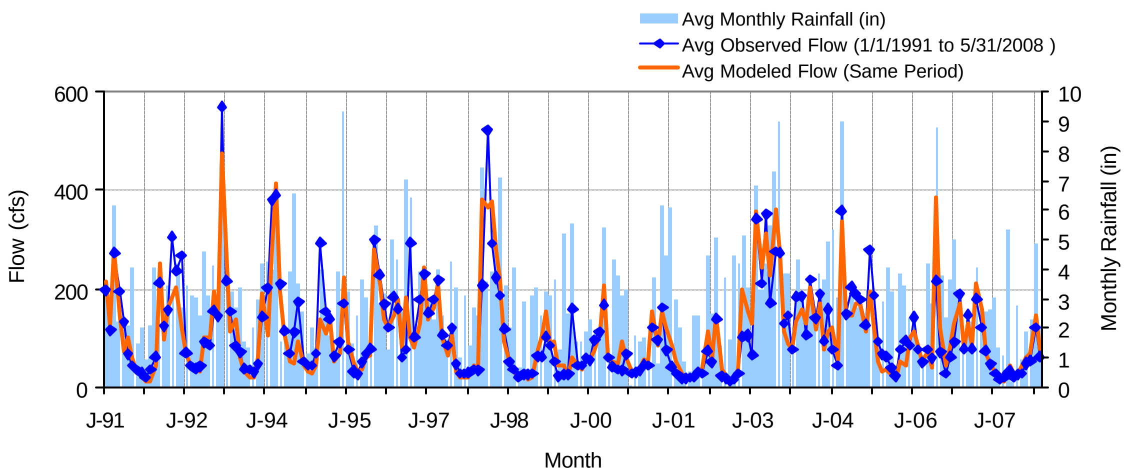


Figure E-23. Validation mean monthly flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

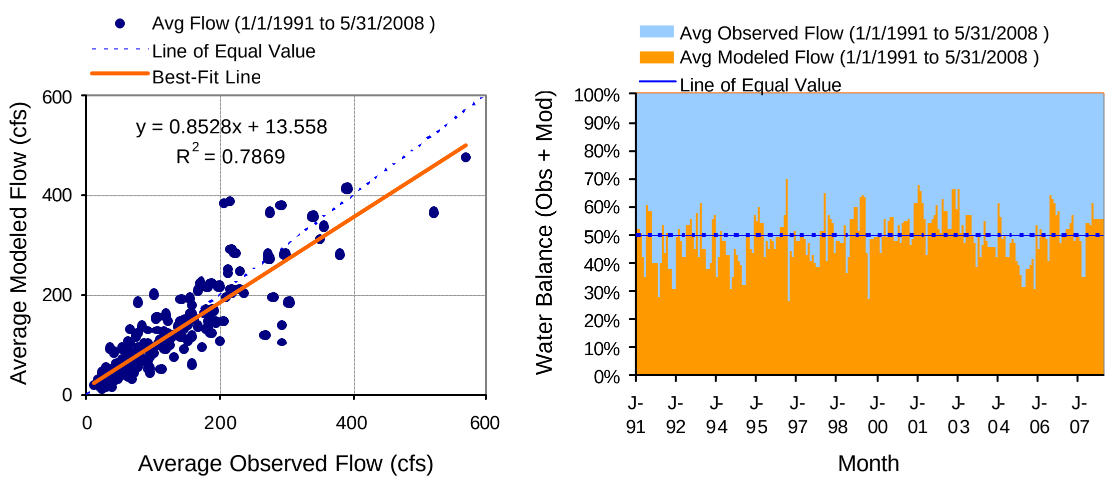


Figure E-24. Validation monthly flow regression and temporal variation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

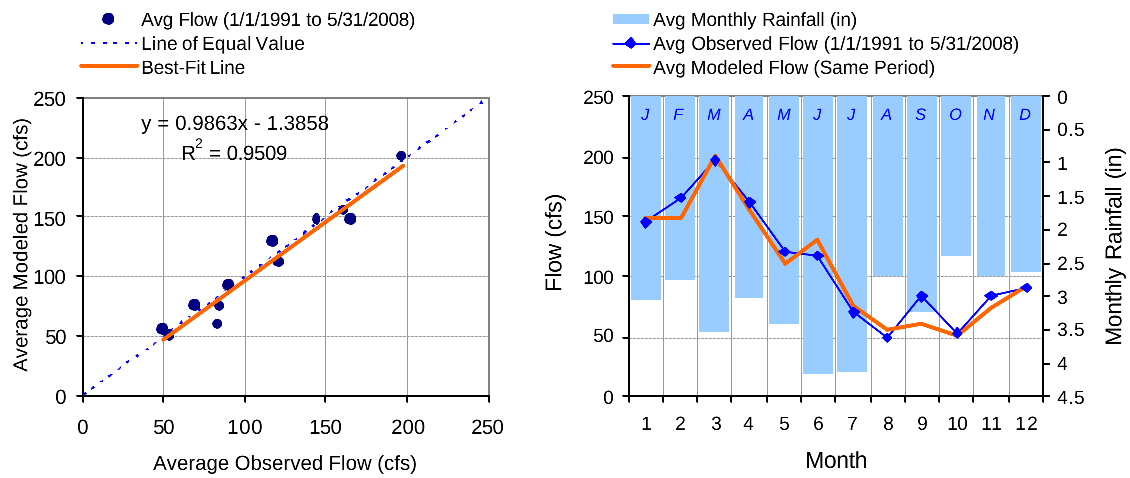


Figure E-25. Validation seasonal regression and temporal aggregate: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

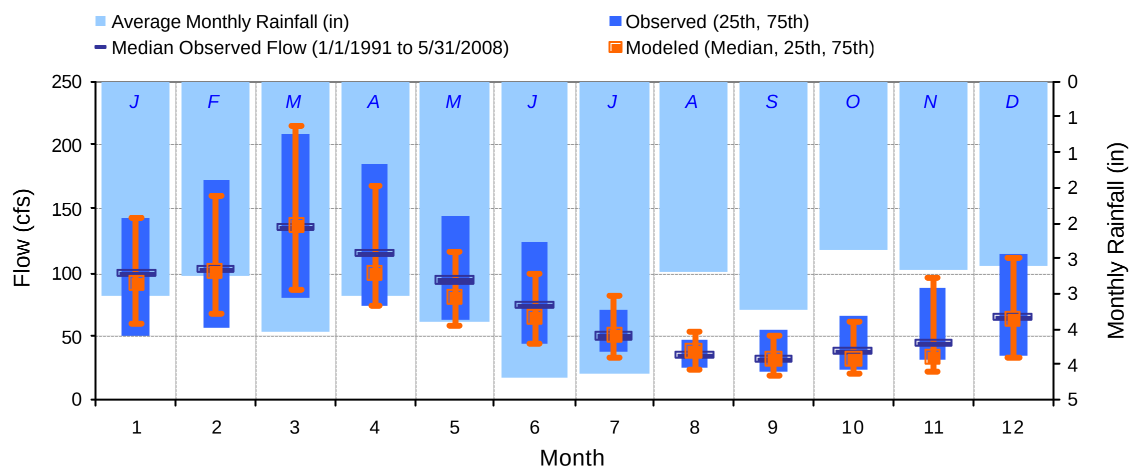


Figure E-26. Validation seasonal medians and ranges: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-7. Validation seasonal summary: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	144.09	99.50	51.00	143.00	147.50	91.87	59.06	141.98
Feb	165.35	102.00	56.00	172.00	148.07	101.11	67.39	158.94
Mar	196.89	135.00	79.00	208.50	200.81	136.61	86.70	214.30
Apr	160.95	115.00	74.00	185.50	155.04	99.20	74.31	167.86
May	120.38	94.00	63.00	144.00	111.22	79.76	58.59	116.62
Jun	116.99	74.00	45.00	124.00	129.88	64.72	43.59	99.73
Jul	69.52	50.00	38.00	71.00	75.21	50.60	32.83	81.72
Aug	49.25	35.00	26.00	48.00	55.26	38.44	23.37	53.31
Sep	82.94	32.00	23.00	54.75	59.26	31.68	19.17	49.86
Oct	53.37	38.00	24.00	66.00	50.50	31.79	20.17	60.77
Nov	84.09	45.00	31.00	88.00	74.01	33.64	21.66	94.77
Dec	89.89	64.00	35.00	115.50	92.03	62.90	32.88	111.57

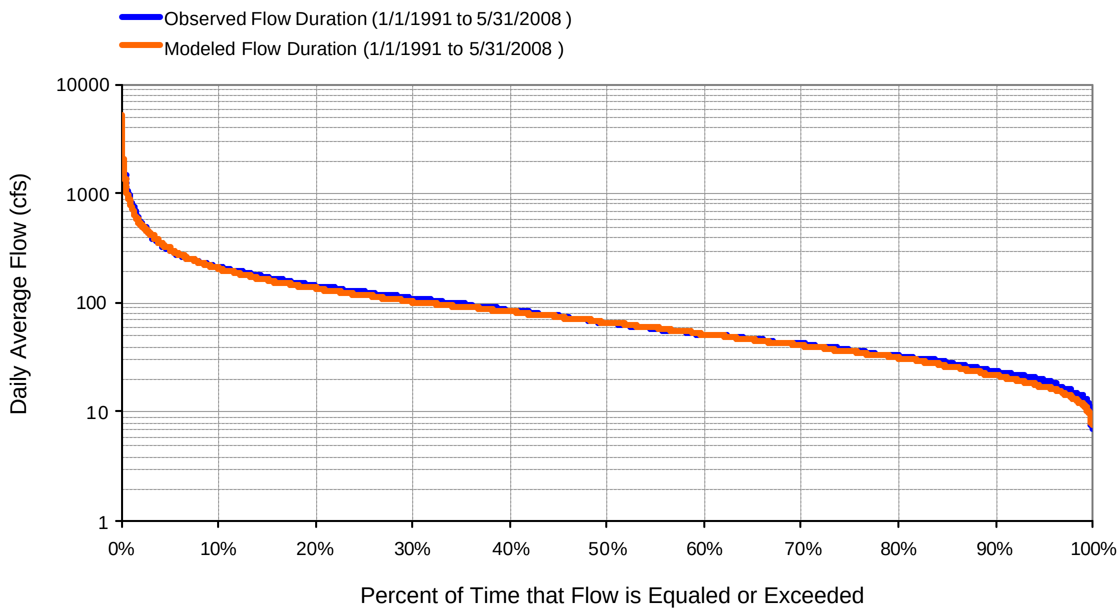


Figure E-27. Validation flow exceedence: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

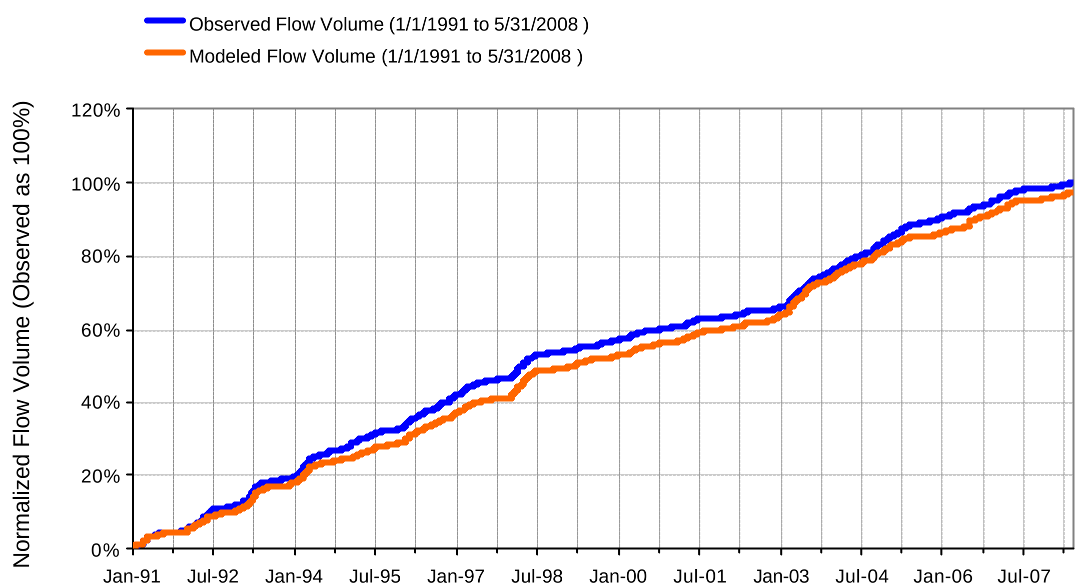


Figure E-28. Validation flow accumulation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-8. Validation summary statistics: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 3029 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02053800 S F ROANOKE RIVER NEAR SHAWSVILLE, VA Hydrologic Unit Code: 3010101 Latitude: 37.1401323 Longitude: -80.2664328 Drainage Area (sq-mi): 109	
Total Simulated In-stream Flow:	**13.59**	Total Observed In-stream Flow:	**13.94**
Total of simulated highest 10% flows:	**5.70**	Total of Observed highest 10% flows:	**5.72**
Total of Simulated lowest 50% flows:	**2.29**	Total of Observed Lowest 50% flows:	**2.35**
Simulated Summer Flow Volume (months 7-9):	**1.94**	Observed Summer Flow Volume (7-9):	**2.05**
Simulated Fall Flow Volume (months 10-12):	**2.21**	Observed Fall Flow Volume (10-12):	**2.32**
Simulated Winter Flow Volume (months 1-3):	**5.28**	Observed Winter Flow Volume (1-3):	**5.38**
Simulated Spring Flow Volume (months 4-6):	**4.15**	Observed Spring Flow Volume (4-6):	**4.19**
Total Simulated Storm Volume:	**4.21**	Total Observed Storm Volume:	**4.24**
Simulated Summer Storm Volume (7-9)	**0.56**	Observed Summer Storm Volume (7-9):	**0.73**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-2.51	10	-1.43	7.35
Error in 50% lowest flows:	-2.56	10	-1.60	-3.91
Error in 10% highest flows:	-0.31	15	2.26	1.75
Seasonal volume error - Summer:	-5.64	30	13.27	-2.52
Seasonal volume error - Fall:	-4.66	30	4.49	12.42
Seasonal volume error - Winter:	-1.72	30	-18.21	13.31
Seasonal volume error - Spring:	-0.81	30	1.90	6.11
Error in storm volumes:	-0.75	20	1.13	12.07
Error in summer storm volumes:	-22.59	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.430	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.504	as E or E' approaches 1.0	0.517	0.549

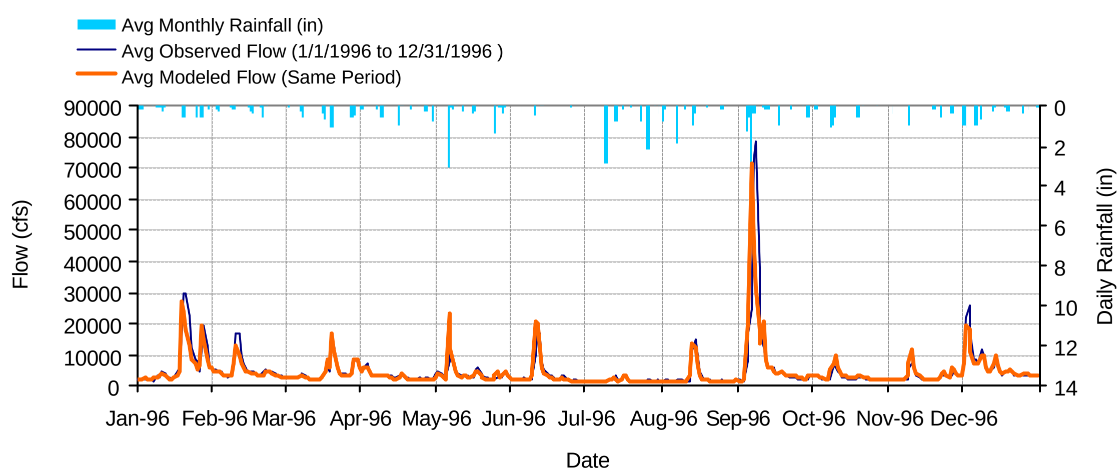


Figure E-29. Calibration mean daily flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

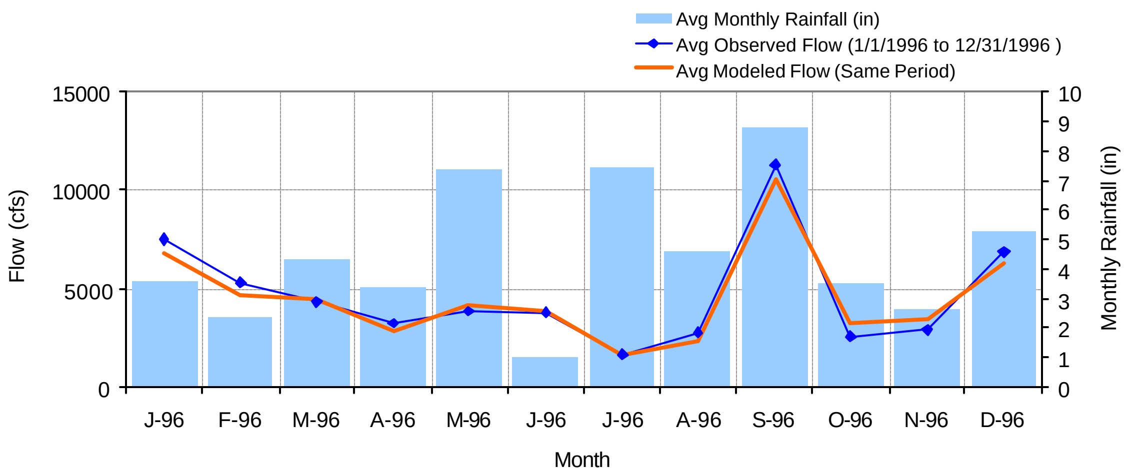


Figure E-30. Calibration mean monthly flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

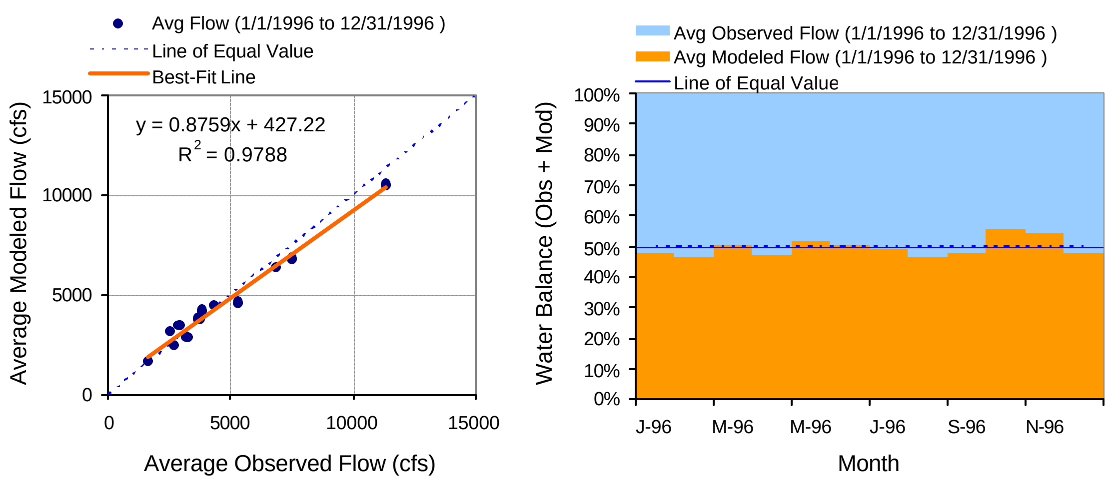
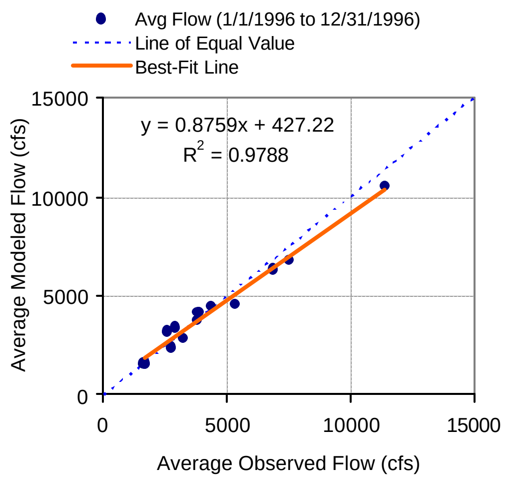


Figure E-31. Calibration monthly flow regression and temporal variation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA



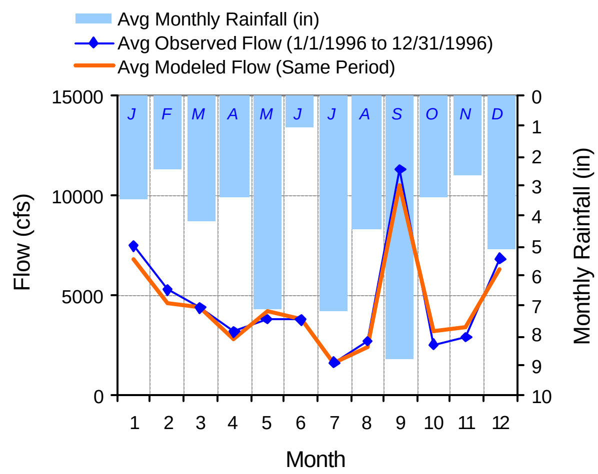


Figure E-32. Calibration seasonal regression and temporal aggregate: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

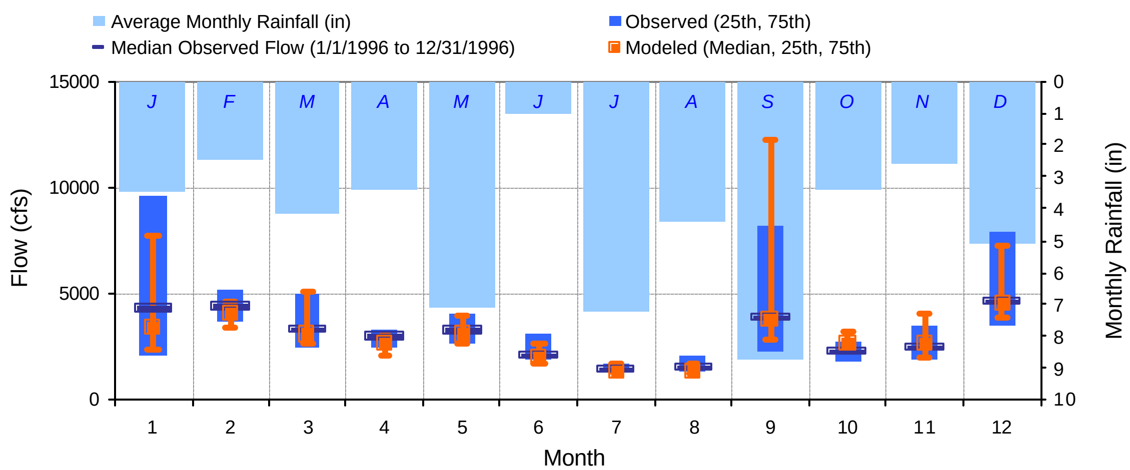


Figure E-33. Calibration seasonal medians and ranges: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-9. Calibration seasonal summary: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	7511.29	4320.00	2025.00	9615.00	6806.82	3413.78	2368.68	7737.07
Feb	5315.86	4380.00	3680.00	5200.00	4618.06	4051.07	3401.95	4667.08
Mar	4360.00	3340.00	2500.00	4970.00	4453.88	3076.50	2682.13	5099.02
Apr	3230.33	2995.00	2435.00	3340.00	2873.64	2639.30	2078.70	3030.93
May	3834.52	3240.00	2630.00	4080.00	4183.42	3093.38	2634.64	3961.04
Jun	3755.33	2125.00	1862.50	3137.50	3792.11	2023.44	1714.45	2669.31
Jul	1660.32	1430.00	1325.00	1715.00	1620.99	1376.04	1309.44	1682.03
Aug	2757.10	1540.00	1370.00	2100.00	2419.64	1368.39	1215.25	1651.71
Sep	11348.00	3900.00	2242.50	8172.50	10552.90	3812.64	2895.65	12216.21
Oct	2593.23	2290.00	1825.00	2730.00	3208.20	2647.75	2248.63	3205.89
Nov	2919.33	2440.00	1890.00	3482.50	3432.63	2669.26	2014.73	3991.53
Dec	6886.77	4590.00	3465.00	7865.00	6364.00	4539.81	3879.30	7271.16

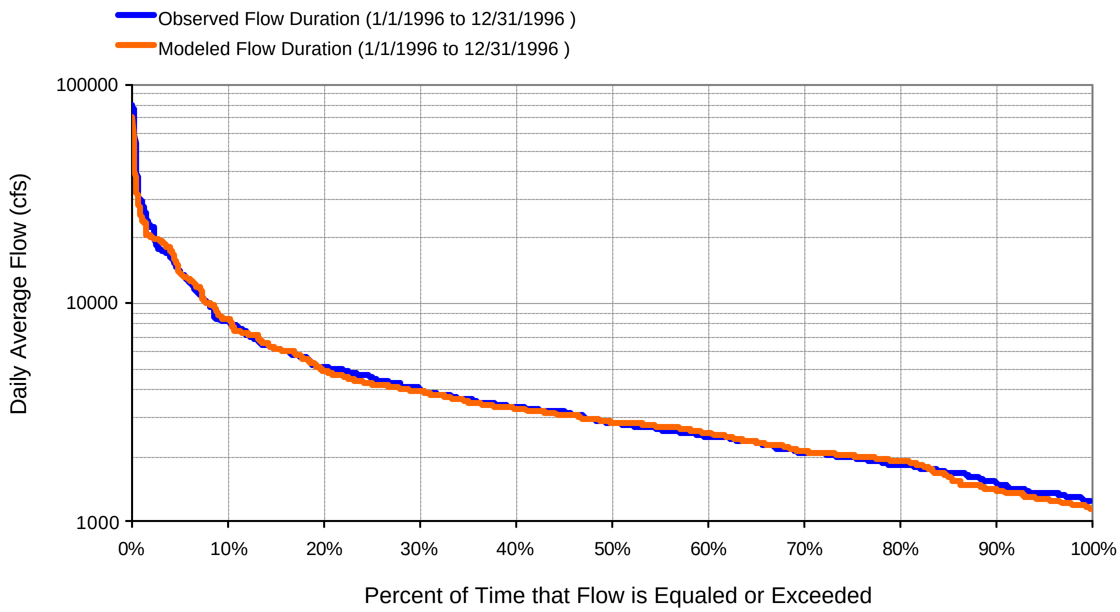


Figure E-34. Calibration flow exceedence: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

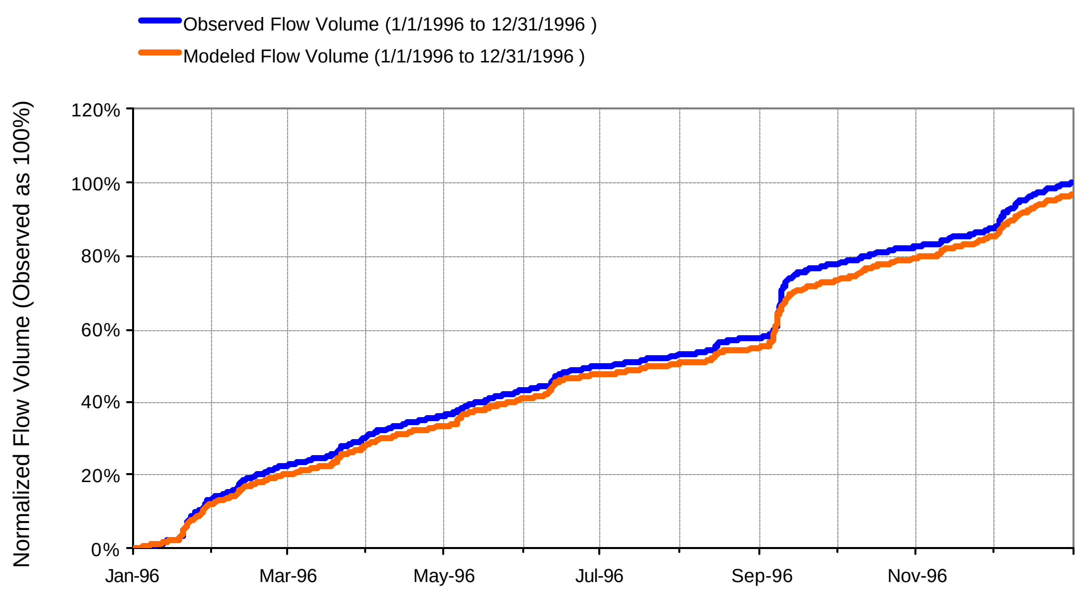


Figure E-35. Calibration flow accumulation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-10. Calibration summary statistics: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1018 1-Year Analysis Period: 1/1/1996 - 12/31/1996 Flow volumes are (inches/year) for upstream drainage area		USGS 02066000 ROANOKE (STAUNTON) RIVER AT RANDOLPH, VA Hydrologic Unit Code: 3010102 Latitude: 36.91514189 Longitude: -78.7408384 Drainage Area (sq-mi): 2966		
Total Simulated In-stream Flow:	**20.70**	Total Observed In-stream Flow:		**21.39**
Total of simulated highest 10% flows:	**8.31**	Total of Observed highest 10% flows:		**8.87**
Total of Simulated lowest 50% flows:	**4.60**	Total of Observed Lowest 50% flows:		**4.59**
Simulated Summer Flow Volume (months 7-9):	**5.53**	Observed Summer Flow Volume (7-9):		**5.97**
Simulated Fall Flow Volume (months 10-12):	**5.00**	Observed Fall Flow Volume (10-12):		**4.77**
Simulated Winter Flow Volume (months 1-3):	**6.04**	Observed Winter Flow Volume (1-3):		**6.53**
Simulated Spring Flow Volume (months 4-6):	**4.13**	Observed Spring Flow Volume (4-6):		**4.11**
Total Simulated Storm Volume:	**9.60**	Total Observed Storm Volume:		**10.46**
Simulated Summer Storm Volume (7-9)	**3.31**	Observed Summer Storm Volume (7-9):		**3.82**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-3.23	10	-1.43	7.35
Error in 50% lowest flows:	0.33	10	-1.60	-3.91
Error in 10% highest flows:	-6.25	15	2.26	1.75
Seasonal volume error - Summer:	-7.44	30	13.27	-2.52
Seasonal volume error - Fall:	4.79	30	4.49	12.42
Seasonal volume error - Winter:	-7.50	30	-18.21	13.31
Seasonal volume error - Spring:	0.37	30	1.90	6.11
Error in storm volumes:	-8.24	20	1.13	12.07
Error in summer storm volumes:	-13.32	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.601	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.615	as E or E' approaches 1.0	0.517	0.549

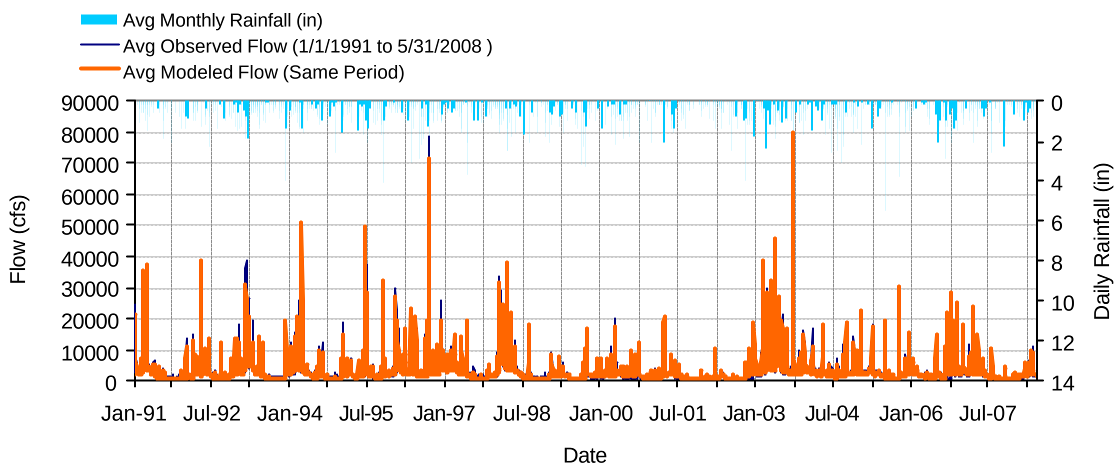


Figure E-36. Validation mean daily flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

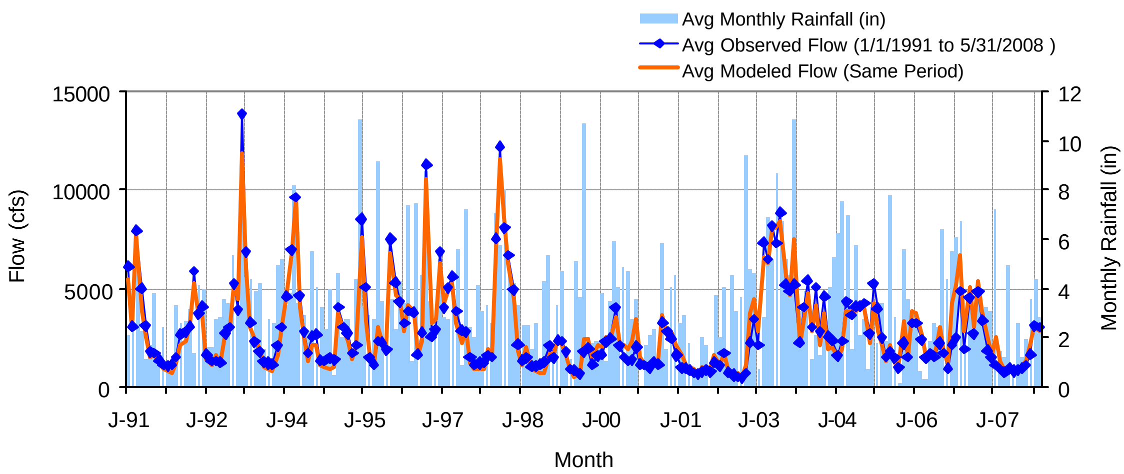
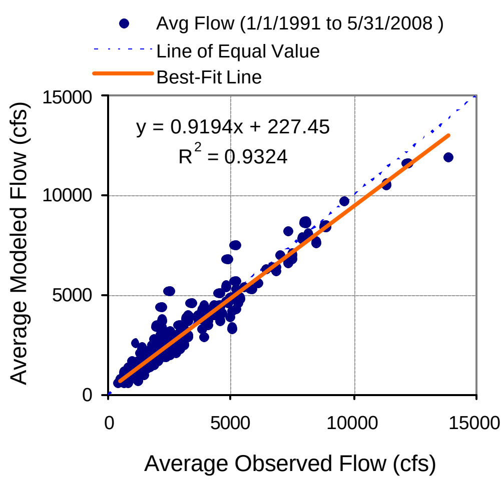


Figure E-37. Validation mean monthly flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA



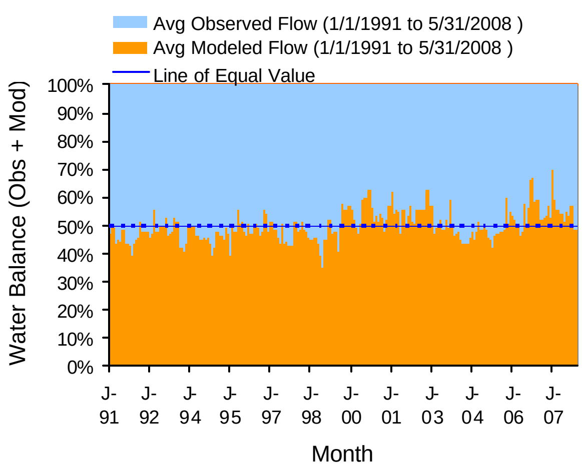


Figure E-38. Validation monthly flow regression and temporal variation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

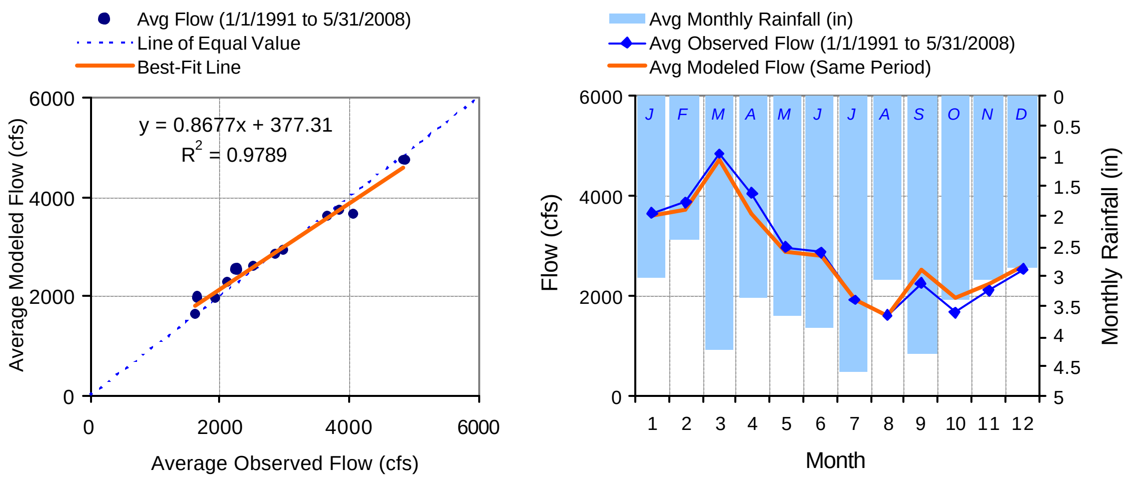


Figure E-39. Validation seasonal regression and temporal aggregate: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

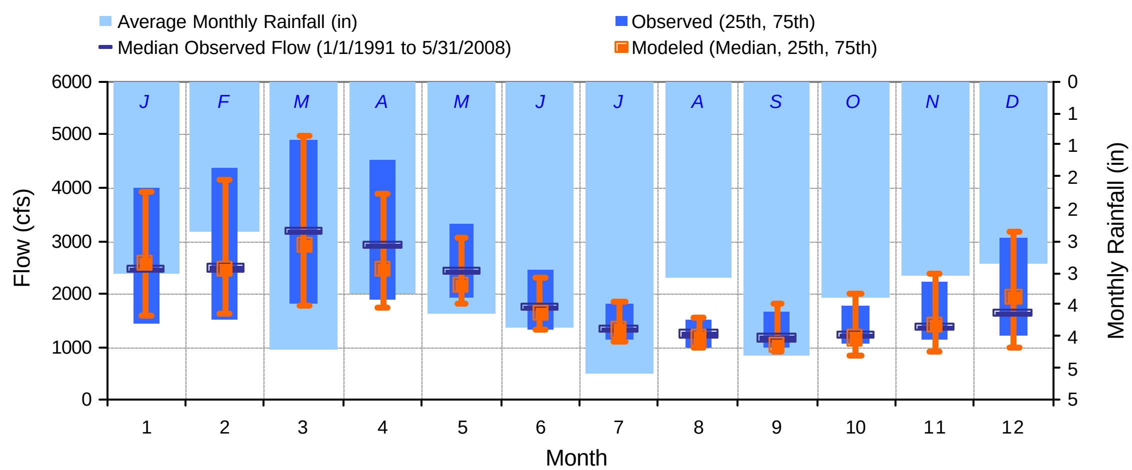


Figure E-40. Validation seasonal medians and ranges: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-11. Validation seasonal summary: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	3663.28	2460.00	1422.50	3997.50	3609.07	2577.71	1575.72	3930.53
Feb	3866.63	2490.00	1500.00	4360.00	3726.05	2460.69	1634.47	4139.55
Mar	4850.44	3175.00	1812.50	4897.50	4742.02	2923.08	1759.46	4956.19
Apr	4065.82	2925.00	1870.00	4517.50	3648.59	2437.07	1732.52	3885.68
May	2986.95	2420.00	1940.00	3295.00	2911.51	2175.13	1805.68	3080.05
Jun	2866.51	1735.00	1320.00	2435.00	2834.51	1622.53	1297.41	2288.17
Jul	1926.30	1340.00	1140.00	1810.00	1943.53	1309.90	1088.42	1847.53
Aug	1627.64	1220.00	998.50	1510.00	1630.14	1154.08	977.55	1539.24
Sep	2269.43	1170.00	982.50	1655.00	2536.19	1034.03	897.11	1801.26
Oct	1669.62	1210.00	1060.00	1745.00	1968.24	1152.95	847.47	2009.16
Nov	2126.20	1365.00	1140.00	2227.50	2266.36	1418.57	901.19	2368.25
Dec	2533.98	1630.00	1190.00	3060.00	2607.77	1953.03	993.08	3169.05

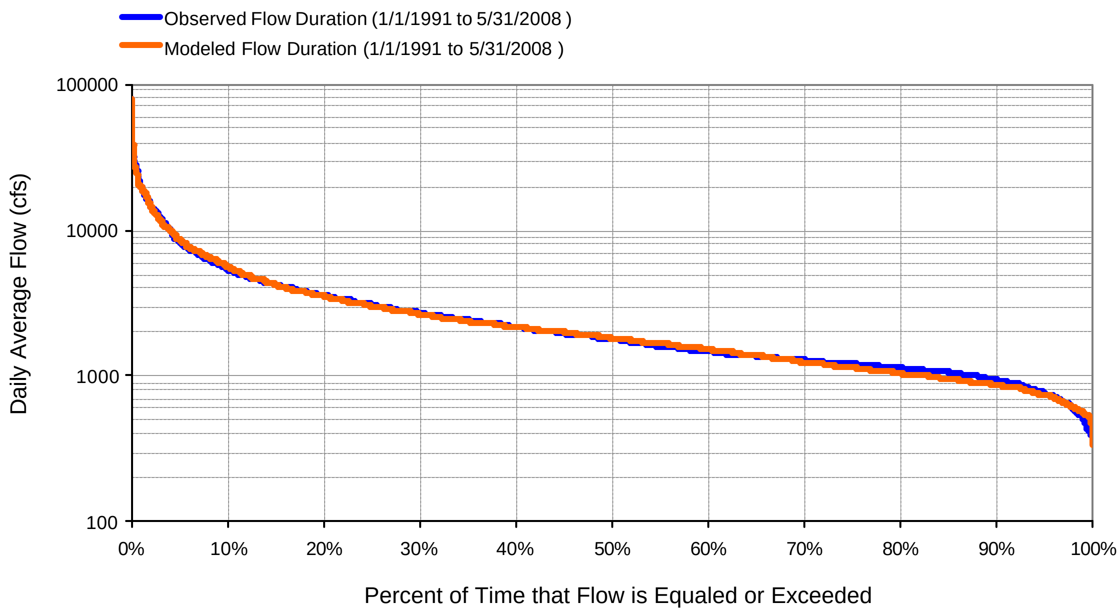


Figure E-41. Validation flow exceedence: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

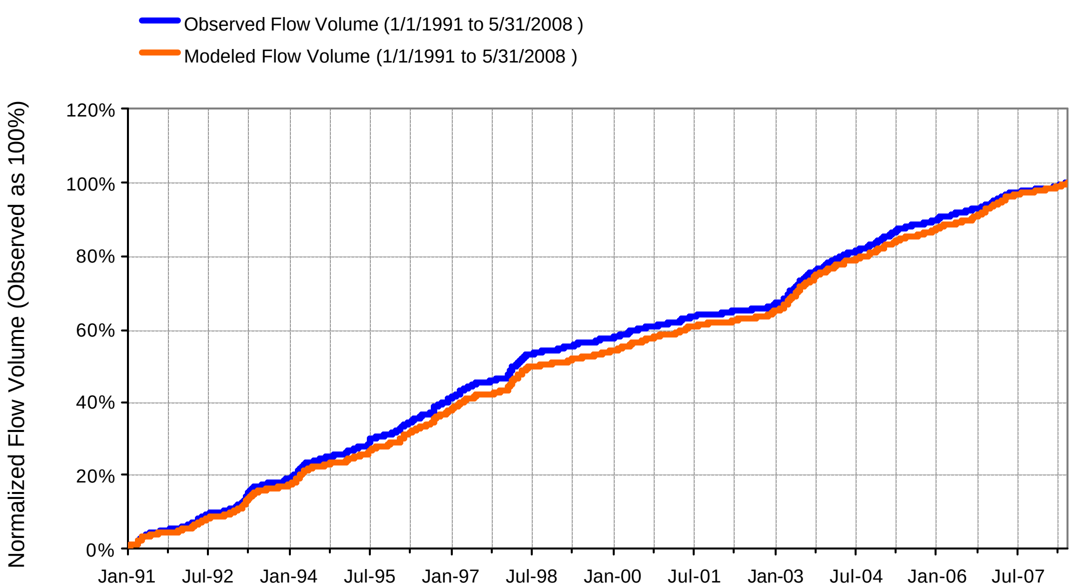


Figure E-42. Validation flow accumulation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-12. Validation summary statistics: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1018		USGS 02066000 ROANOKE (STAUNTON) RIVER AT RANDOLPH, VA		
17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 3010102 Latitude: 36.91514189 Longitude: -78.7408384 Drainage Area (sq-mi): 2966		
Total Simulated In-stream Flow:	**13.21**	Total Observed In-stream Flow:		**13.23**
Total of simulated highest 10% flows:	**5.18**	Total of Observed highest 10% flows:		**5.13**
Total of Simulated lowest 50% flows:	**2.67**	Total of Observed Lowest 50% flows:		**2.72**
Simulated Summer Flow Volume (months 7-9):	**2.29**	Observed Summer Flow Volume (7-9):		**2.18**
Simulated Fall Flow Volume (months 10-12):	**2.57**	Observed Fall Flow Volume (10-12):		**2.38**
Simulated Winter Flow Volume (months 1-3):	**4.72**	Observed Winter Flow Volume (1-3):		**4.84**
Simulated Spring Flow Volume (months 4-6):	**3.63**	Observed Spring Flow Volume (4-6):		**3.83**
Total Simulated Storm Volume:	**5.09**	Total Observed Storm Volume:		**4.97**
Simulated Summer Storm Volume (7-9)	**0.91**	Observed Summer Storm Volume (7-9):		**0.80**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-0.17	10	-1.43	7.35
Error in 50% lowest flows:	-1.77	10	-1.60	-3.91
Error in 10% highest flows:	0.93	15	2.26	1.75
Seasonal volume error - Summer:	4.83	30	13.27	-2.52
Seasonal volume error - Fall:	8.11	30	4.49	12.42
Seasonal volume error - Winter:	-2.42	30	-18.21	13.31
Seasonal volume error - Spring:	-5.33	30	1.90	6.11
Error in storm volumes:	2.59	20	1.13	12.07
Error in summer storm volumes:	13.24	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.640	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.635	as E or E' approaches 1.0	0.517	0.549

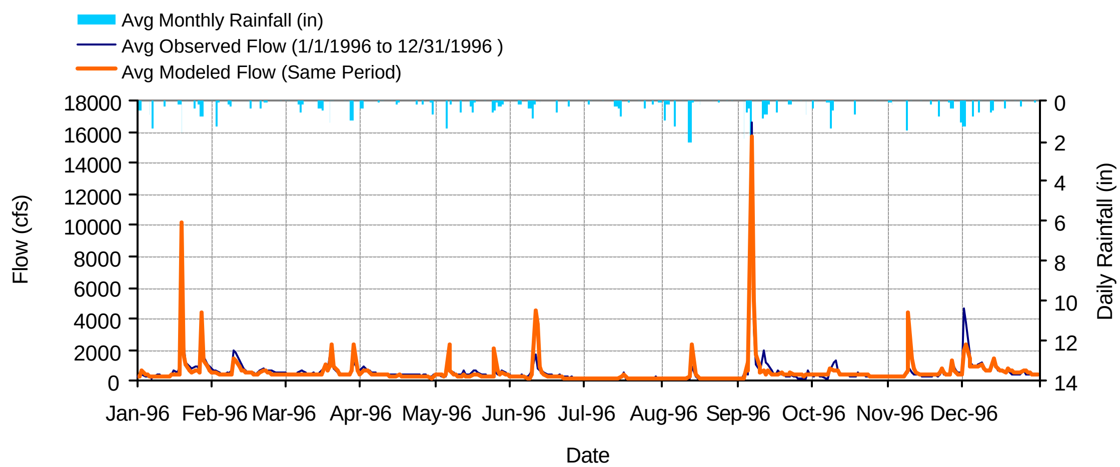


Figure E-43. Calibration mean daily flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

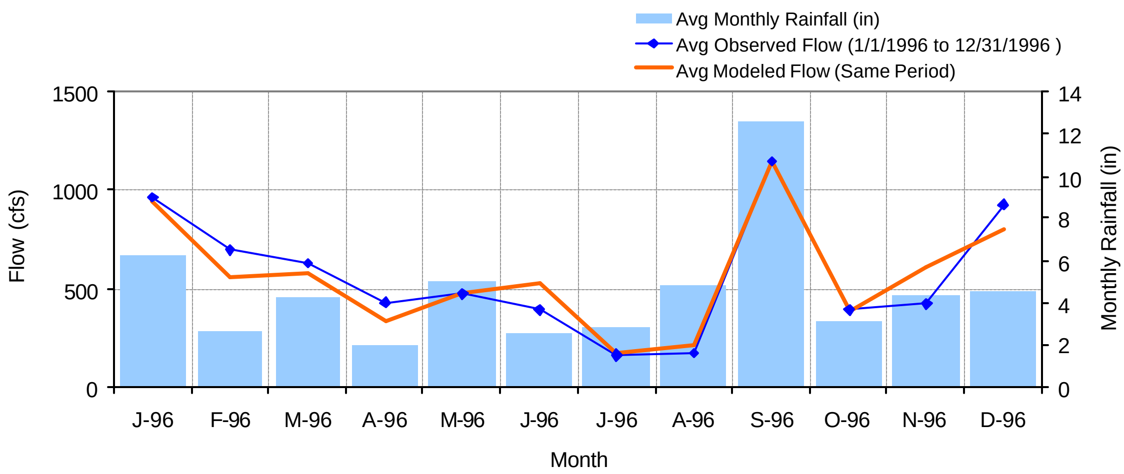
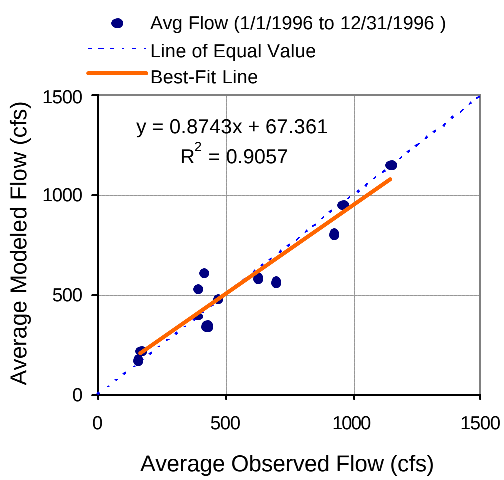


Figure E-44. Calibration mean monthly flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA



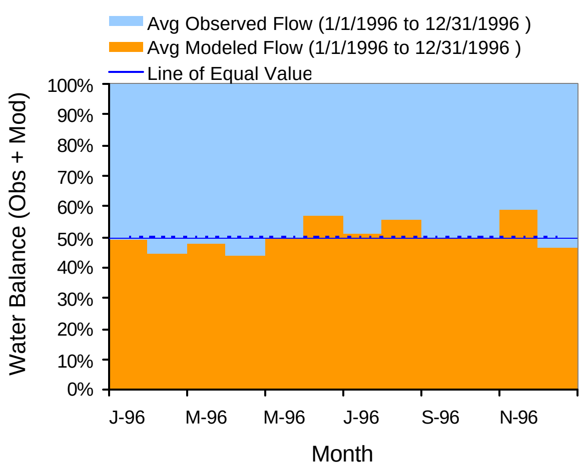


Figure E-45. Calibration mean monthly flow regression and temporal variation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

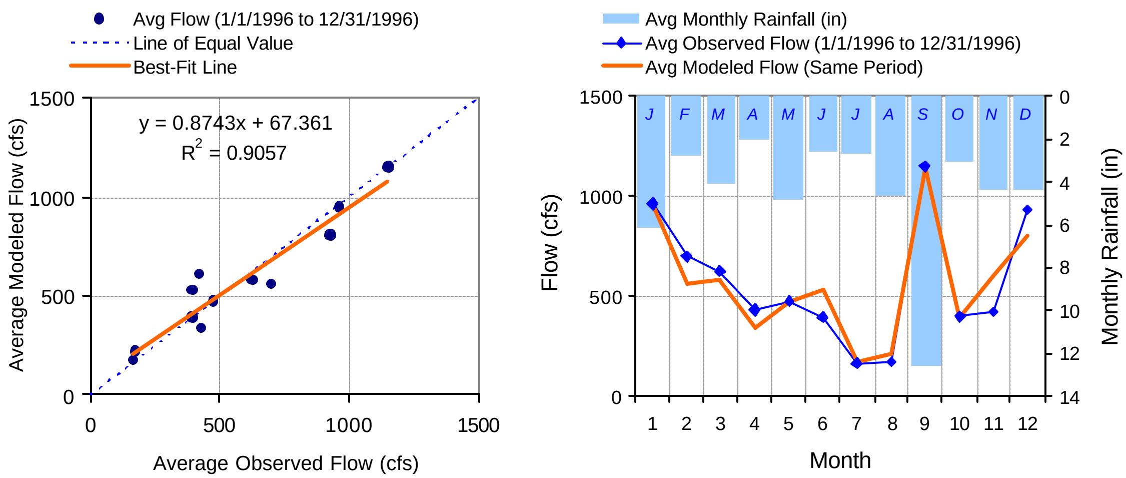


Figure E-46. Calibration seasonal regression and temporal aggregate: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

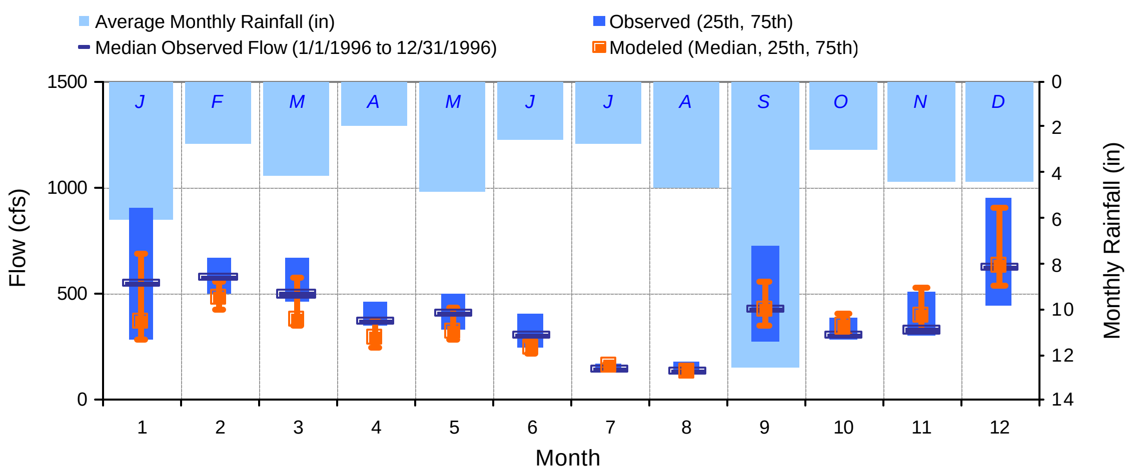


Figure E-47. Calibration seasonal medians and ranges: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-13. Calibration seasonal summary: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	962.13	549.00	278.00	909.00	945.33	367.36	279.14	685.69
Feb	700.17	575.00	500.00	675.00	561.75	478.34	428.70	549.15
Mar	628.61	495.00	455.00	668.00	583.18	380.54	348.25	571.28
Apr	431.07	371.00	341.75	457.75	337.48	296.76	251.68	369.97
May	474.10	405.00	331.50	503.50	474.75	321.55	281.19	430.24
Jun	392.83	301.50	247.00	404.00	529.67	246.09	220.62	276.87
Jul	164.55	143.00	127.50	164.50	173.58	161.80	147.73	174.25
Aug	174.48	131.00	122.00	181.50	220.16	129.54	121.52	153.62
Sep	1149.87	422.00	275.75	722.25	1146.05	425.38	349.82	553.89
Oct	394.48	302.00	284.00	379.00	388.92	347.66	314.22	405.42
Nov	420.97	325.50	304.75	505.75	609.37	396.29	319.14	528.49
Dec	928.16	625.00	441.50	950.50	802.33	637.51	538.09	905.10

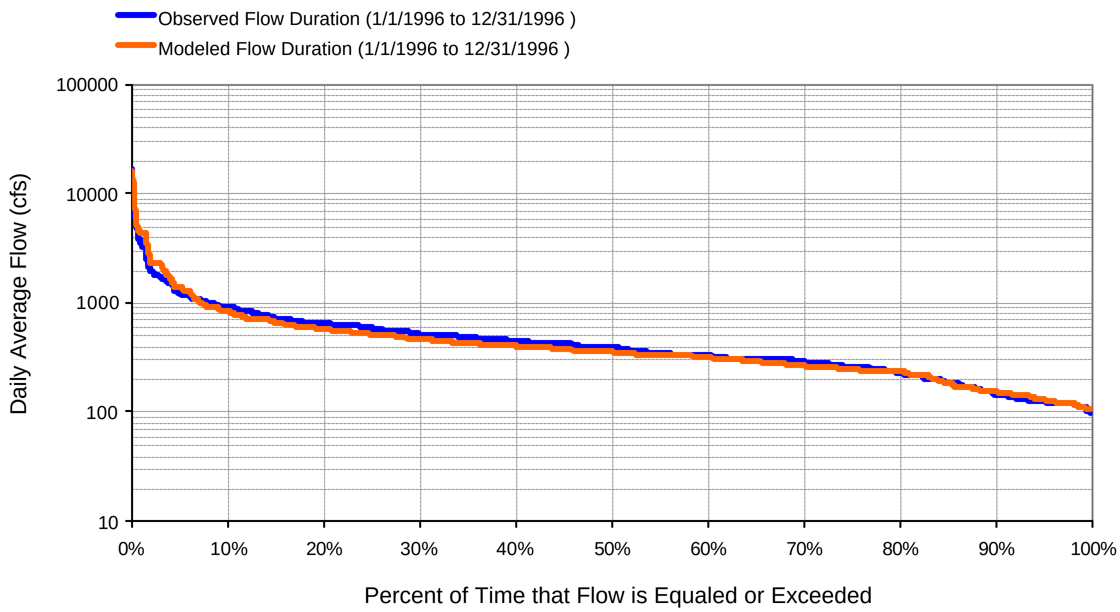


Figure E-48. Calibration flow exceedence: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

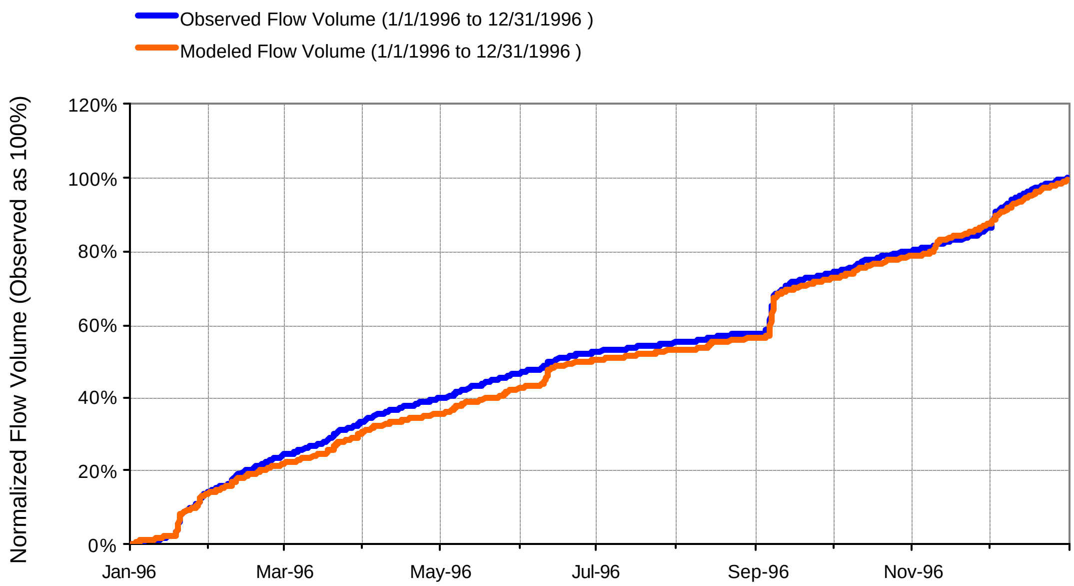


Figure E-49. Calibration flow accumulation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-14. Calibration summary statistics: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1070 1-Year Analysis Period: 1/1/1996 - 12/31/1996 Flow volumes are (inches/year) for upstream drainage area		USGS 02061500 BIG OTTER RIVER NEAR EVINGTON, VA Hydrologic Unit Code: 3010101 Latitude: 37.20847738 Longitude: -79.3036357 Drainage Area (sq-mi): 315		
Total Simulated In-stream Flow:	**24.30**	Total Observed In-stream Flow:		**24.47**
Total of simulated highest 10% flows:	**10.65**	Total of Observed highest 10% flows:		**9.60**
Total of Simulated lowest 50% flows:	**5.18**	Total of Observed Lowest 50% flows:		**5.37**
Simulated Summer Flow Volume (months 7-9):	**5.49**	Observed Summer Flow Volume (7-9):		**5.30**
Simulated Fall Flow Volume (months 10-12):	**6.50**	Observed Fall Flow Volume (10-12):		**6.32**
Simulated Winter Flow Volume (months 1-3):	**7.50**	Observed Winter Flow Volume (1-3):		**8.20**
Simulated Spring Flow Volume (months 4-6):	**4.80**	Observed Spring Flow Volume (4-6):		**4.64**
Total Simulated Storm Volume:	**10.95**	Total Observed Storm Volume:		**10.22**
Simulated Summer Storm Volume (7-9)	**3.32**	Observed Summer Storm Volume (7-9):		**3.35**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-0.71	10	-1.43	7.35
Error in 50% lowest flows:	-3.43	10	-1.60	-3.91
Error in 10% highest flows:	10.92	15	2.26	1.75
Seasonal volume error - Summer:	3.51	30	13.27	-2.52
Seasonal volume error - Fall:	2.94	30	4.49	12.42
Seasonal volume error - Winter:	-8.54	30	-18.21	13.31
Seasonal volume error - Spring:	3.34	30	1.90	6.11
Error in storm volumes:	7.07	20	1.13	12.07
Error in summer storm volumes:	-0.91	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.848	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.553	as E or E' approaches 1.0	0.517	0.549

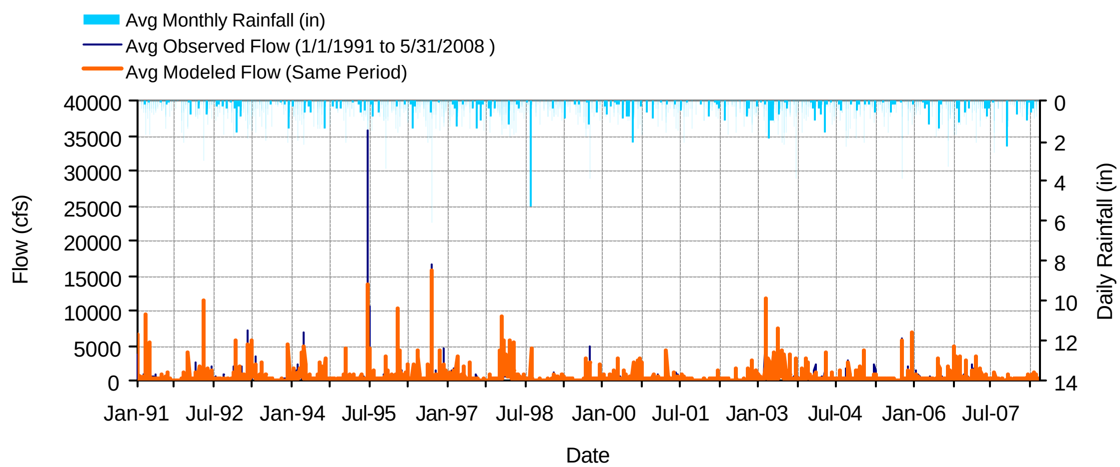


Figure E-50. Validation mean daily flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

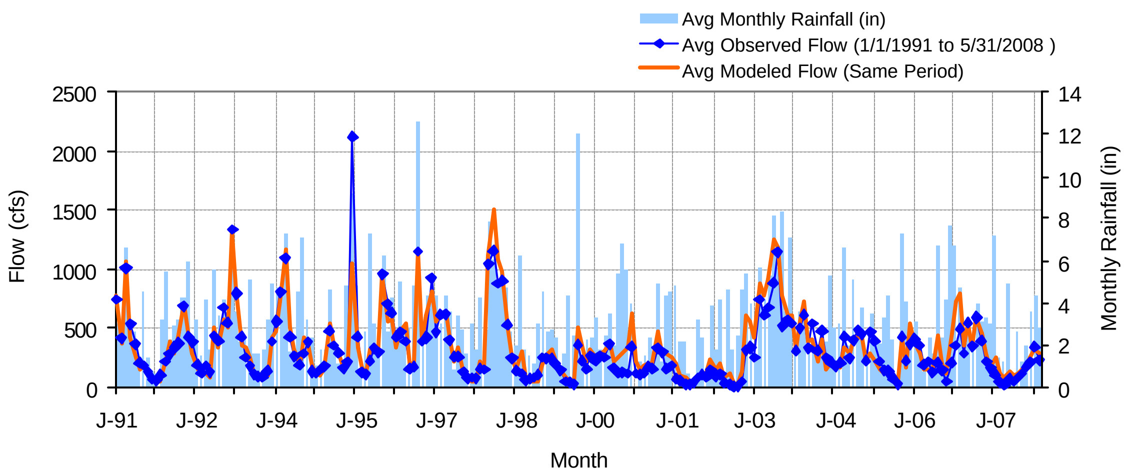


Figure E-51. Validation mean monthly flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

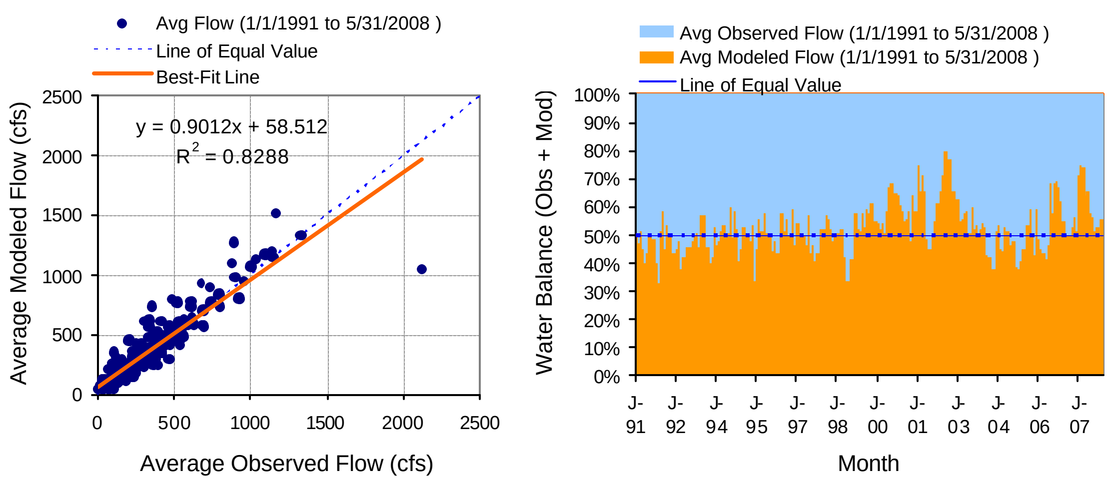


Figure E-52. Validation monthly flow regression and temporal variation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

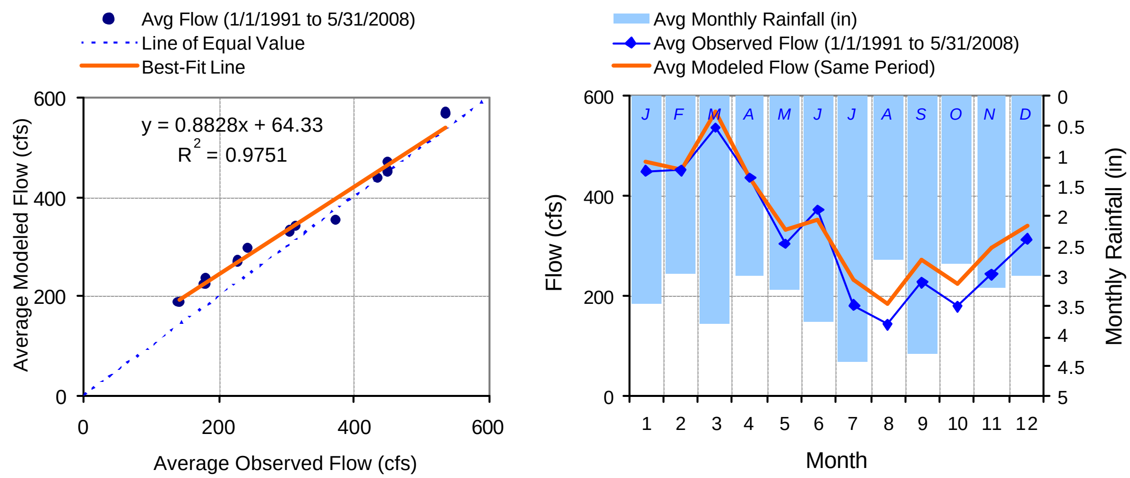


Figure E-52. Validation seasonal regression and temporal aggregate: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

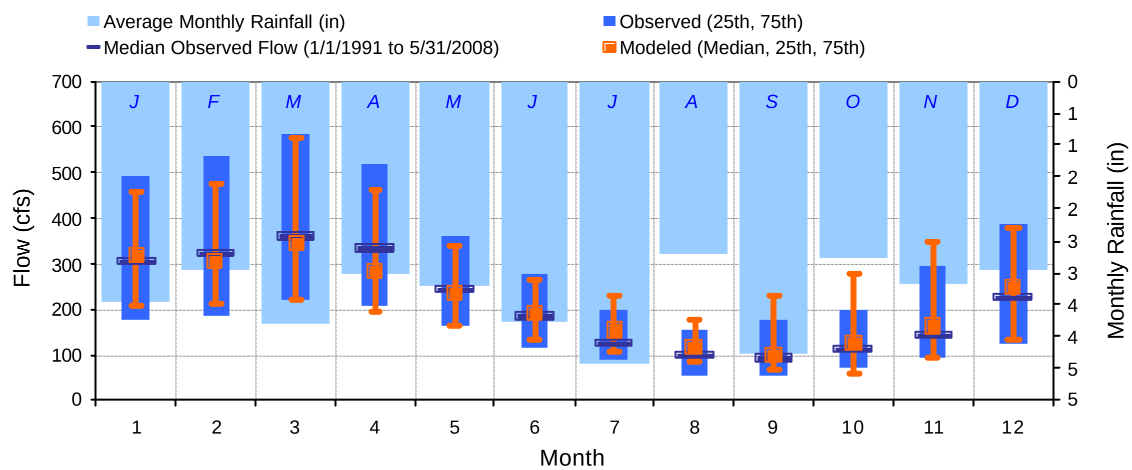


Figure E-53. Validation seasonal medians and ranges: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-15. Validation seasonal summary: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	450.18	305.00	176.50	494.00	470.28	318.13	208.76	455.08
Feb	451.06	320.00	183.00	535.00	451.33	303.11	211.18	476.75
Mar	535.23	358.00	220.00	581.00	568.33	344.30	218.99	576.50
Apr	436.67	334.00	203.75	520.25	438.04	282.91	193.13	461.59
May	306.10	243.00	159.25	359.75	331.14	236.24	162.84	336.34
Jun	373.74	184.00	117.25	278.75	352.02	190.15	134.83	264.19
Jul	181.32	127.00	85.50	199.50	235.12	151.80	107.78	227.17
Aug	142.40	97.00	53.00	152.00	186.59	114.66	84.31	174.72
Sep	228.67	92.50	51.00	174.00	271.43	97.94	66.10	227.45
Oct	179.49	112.00	70.00	200.00	223.51	125.75	55.92	278.37
Nov	244.29	140.50	94.00	294.50	298.16	161.81	91.90	350.09
Dec	315.04	225.00	124.00	388.50	339.79	248.53	132.19	377.19

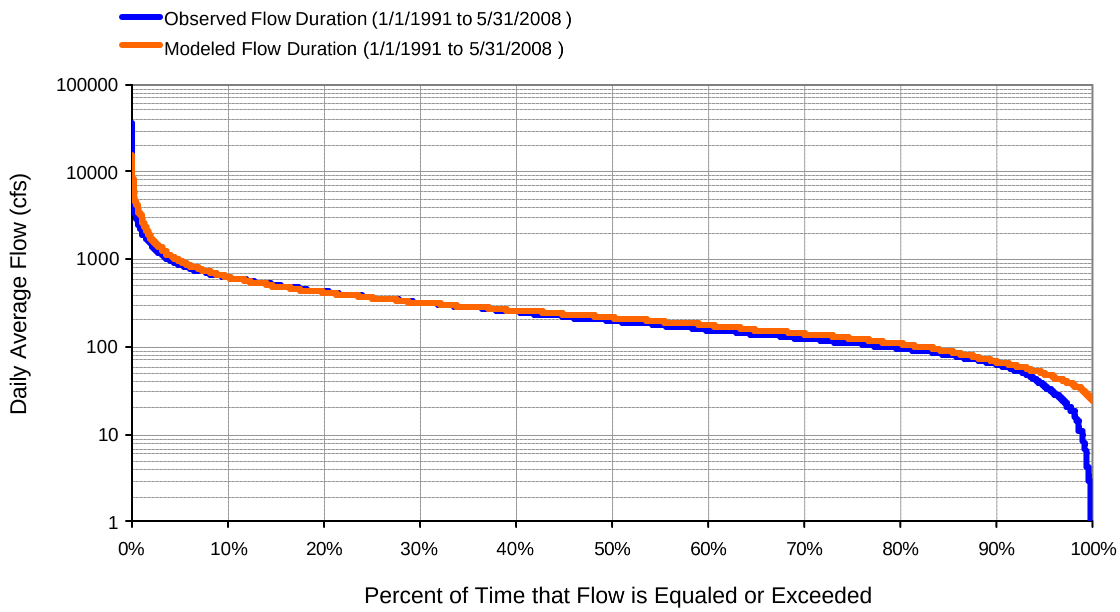


Figure E-54. Validation flow exceedence: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

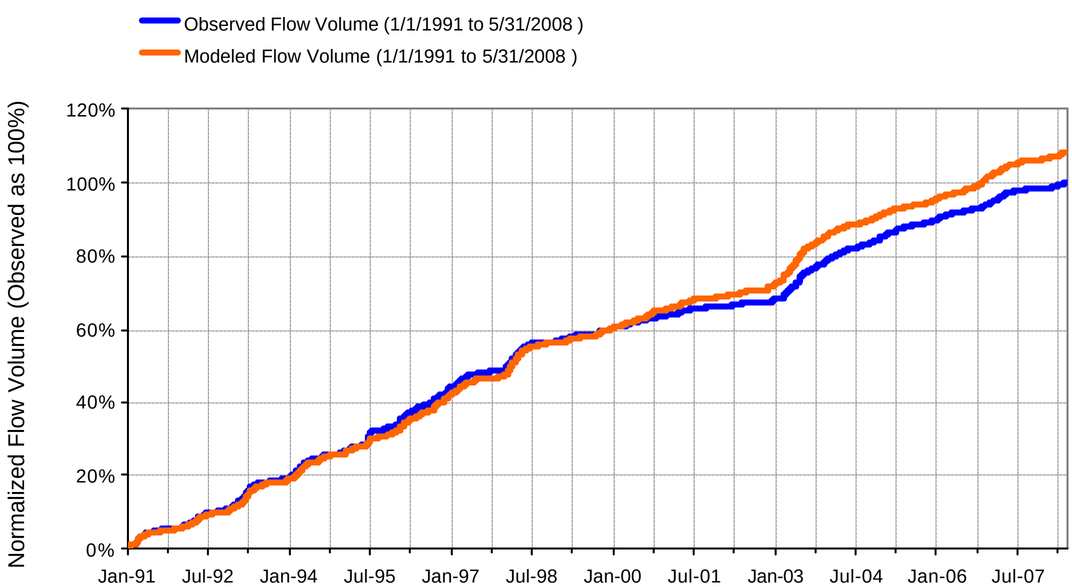


Figure E-55. Validation flow accumulation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-16. Validation summary statistics: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1070 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02061500 BIG OTTER RIVER NEAR EVINGTON, VA Hydrologic Unit Code: 3010101 Latitude: 37.20847738 Longitude: -79.3036357 Drainage Area (sq-mi): 315		
Total Simulated In-stream Flow:	**15.05**	Total Observed In-stream Flow:		**13.89**
Total of simulated highest 10% flows:	**6.44**	Total of Observed highest 10% flows:		**5.63**
Total of Simulated lowest 50% flows:	**2.63**	Total of Observed Lowest 50% flows:		**2.32**
Simulated Summer Flow Volume (months 7-9):	**2.45**	Observed Summer Flow Volume (7-9):		**1.95**
Simulated Fall Flow Volume (months 10-12):	**3.04**	Observed Fall Flow Volume (10-12):		**2.61**
Simulated Winter Flow Volume (months 1-3):	**5.49**	Observed Winter Flow Volume (1-3):		**5.28**
Simulated Spring Flow Volume (months 4-6):	**4.07**	Observed Spring Flow Volume (4-6):		**4.05**
Total Simulated Storm Volume:	**5.80**	Total Observed Storm Volume:		**5.05**
Simulated Summer Storm Volume (7-9)	**1.02**	Observed Summer Storm Volume (7-9):		**0.81**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	8.33	10	-1.43	7.35
Error in 50% lowest flows:	13.47	10	-1.60	-3.91
Error in 10% highest flows:	14.47	15	2.26	1.75
Seasonal volume error - Summer:	25.57	30	13.27	-2.52
Seasonal volume error - Fall:	16.54	30	4.49	12.42
Seasonal volume error - Winter:	3.83	30	-18.21	13.31
Seasonal volume error - Spring:	0.61	30	1.90	6.11
Error in storm volumes:	14.91	20	1.13	12.07
Error in summer storm volumes:	25.99	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.591	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.529	as E or E' approaches 1.0	0.517	0.549

Appendix F: Roanoke River PCB TMDL Model Water Quality Calibration Results

LIST OF FIGURES

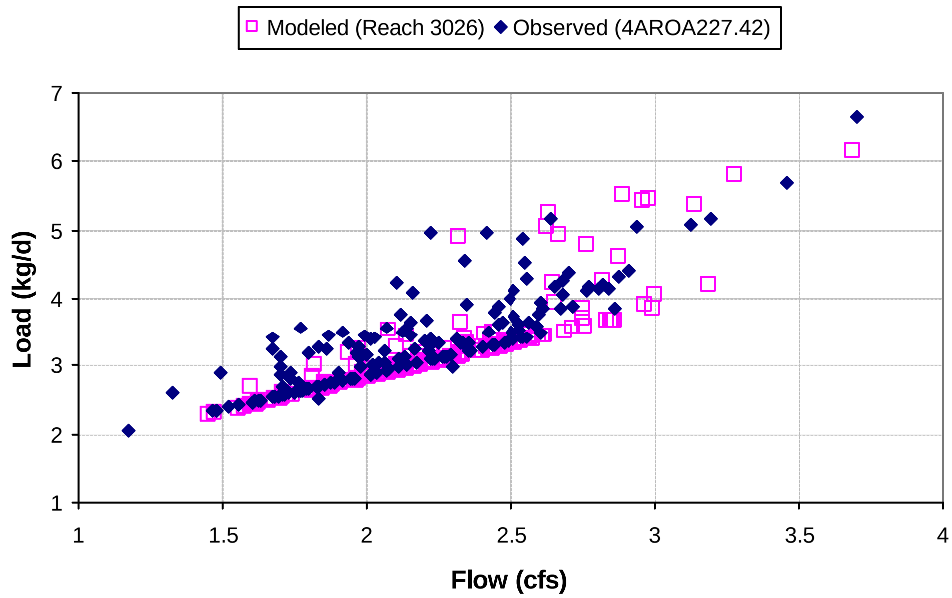


Figure F-1. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA227.42

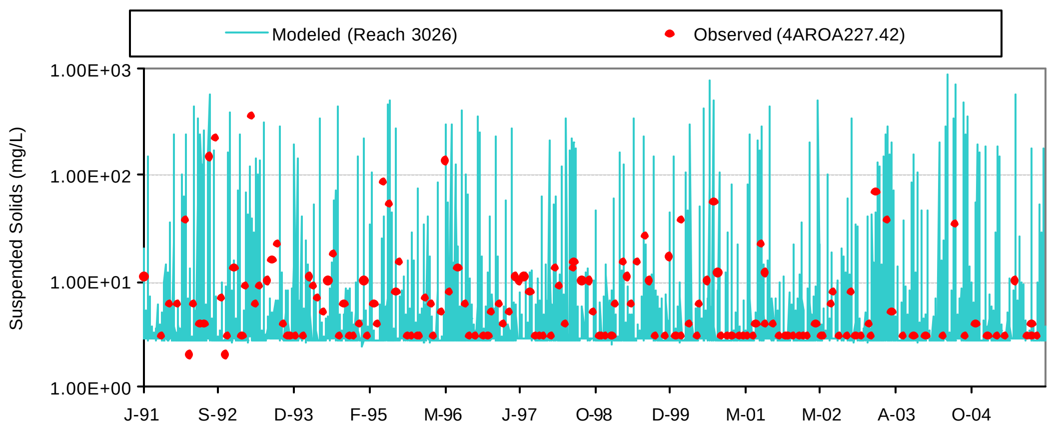


Figure F-2. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA227.42

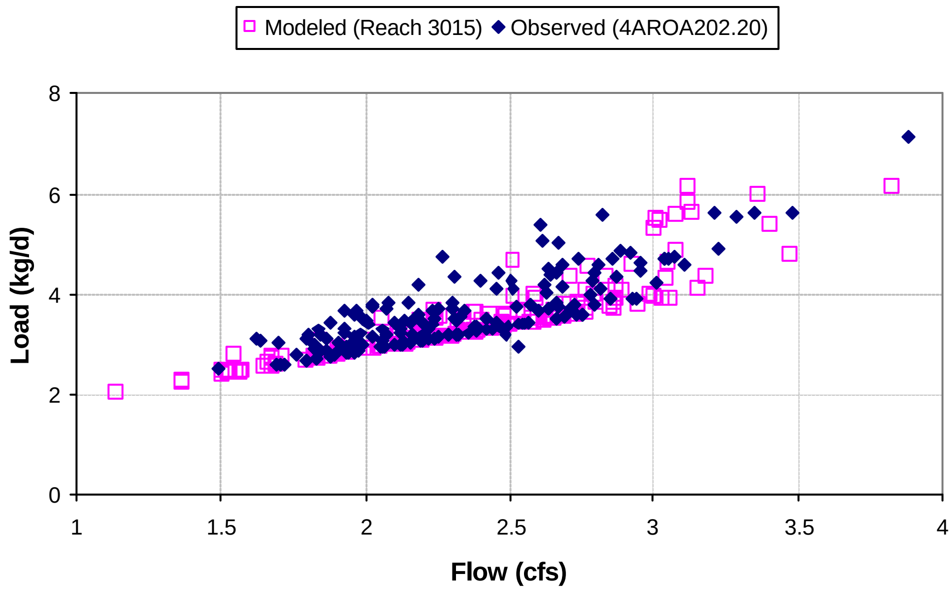


Figure F-3. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA202.20

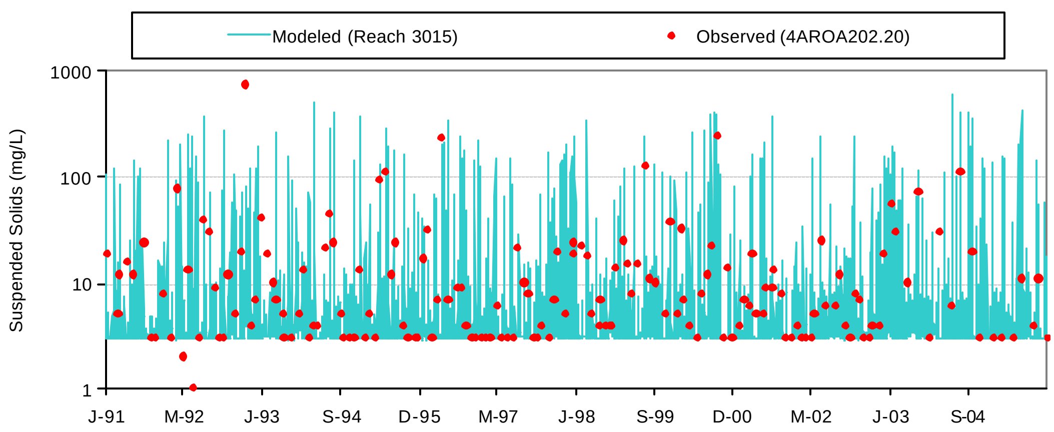


Figure F-4. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA202.20

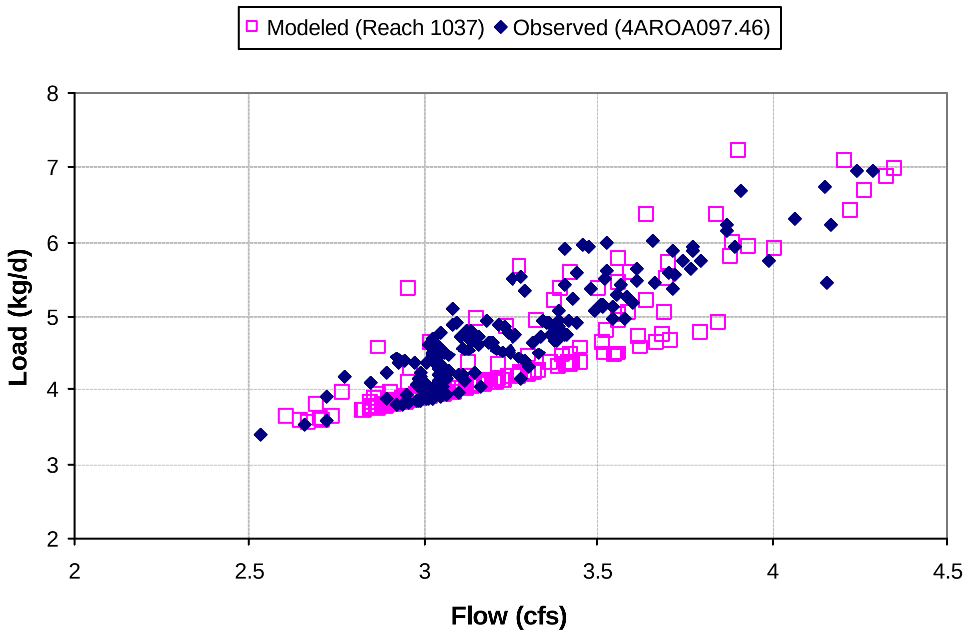


Figure F-5. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA097.46

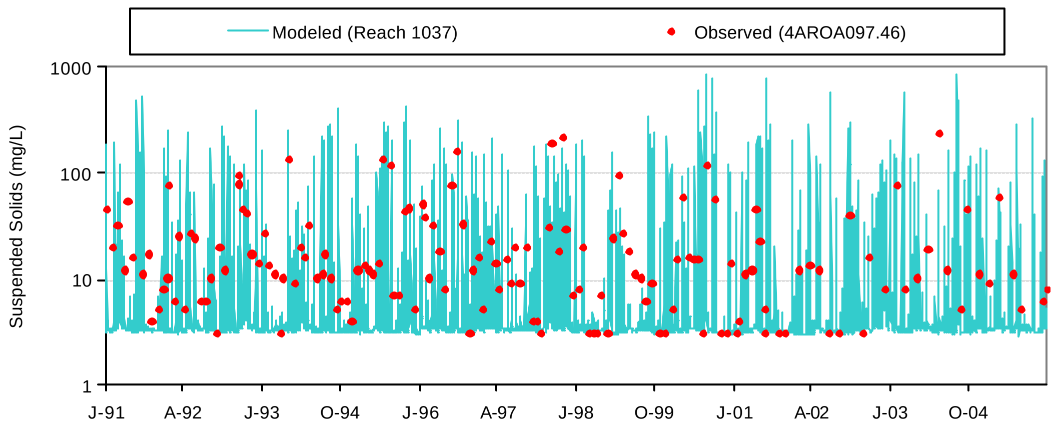


Figure F-6. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA097.46

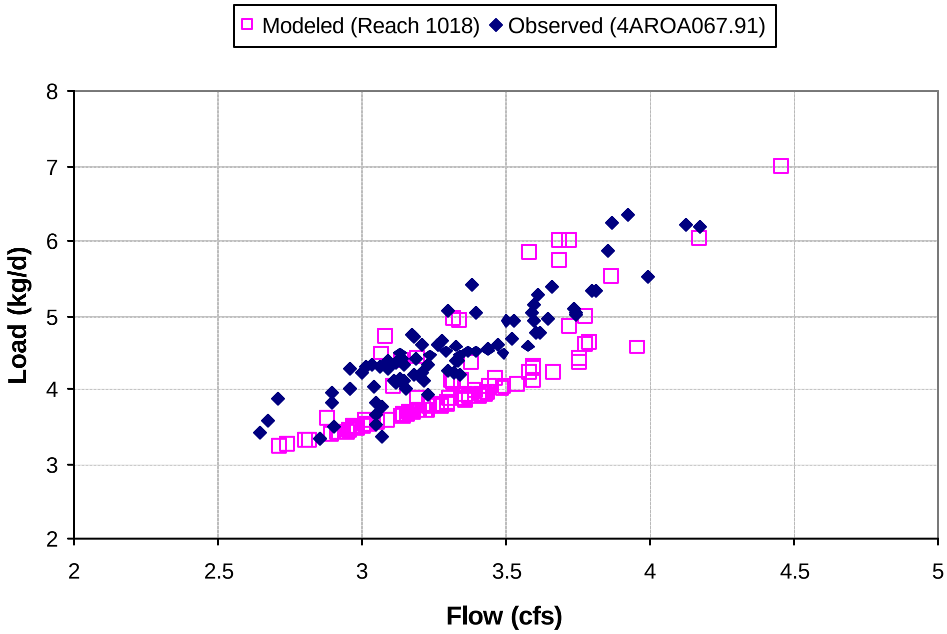
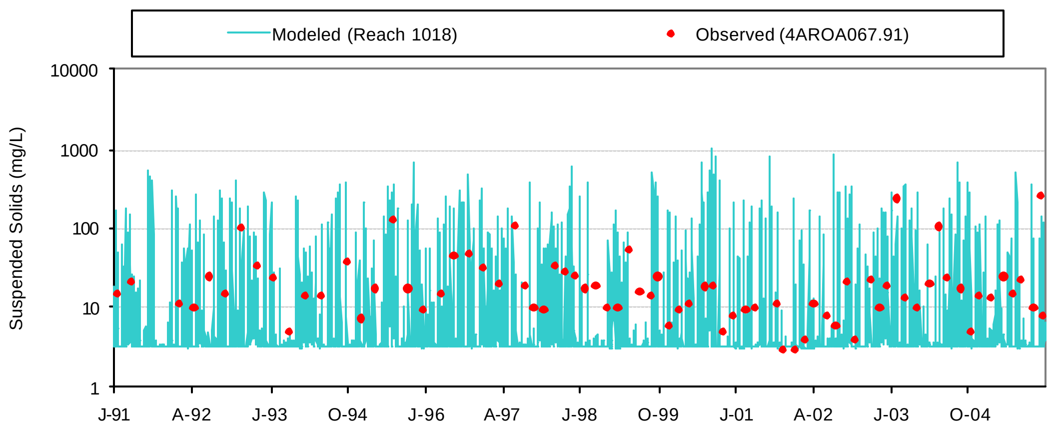


Figure F-7. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA067.91



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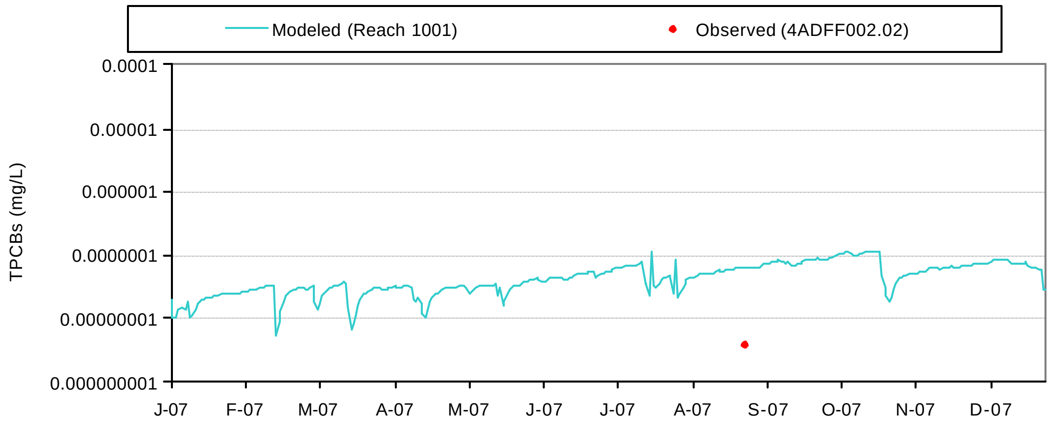

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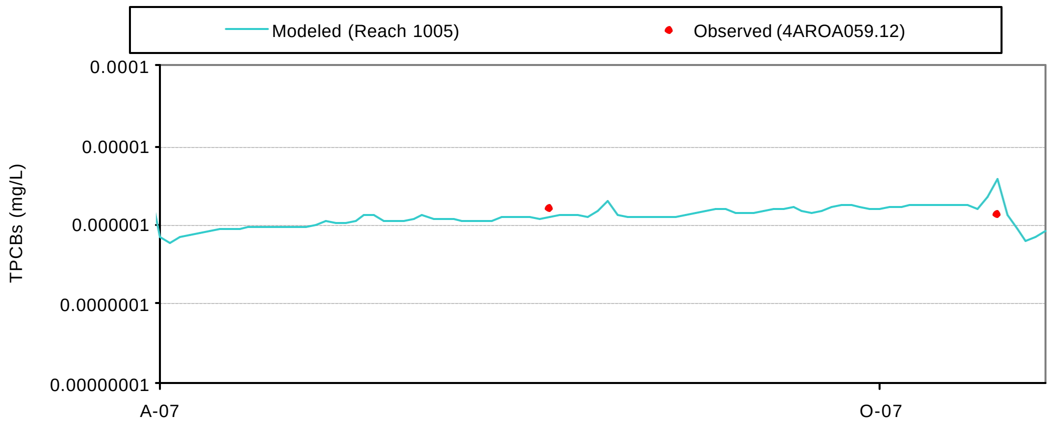

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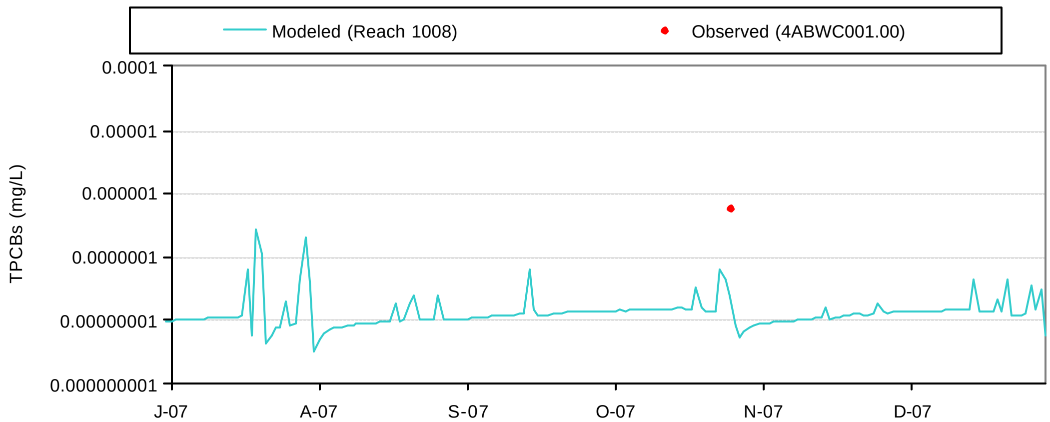

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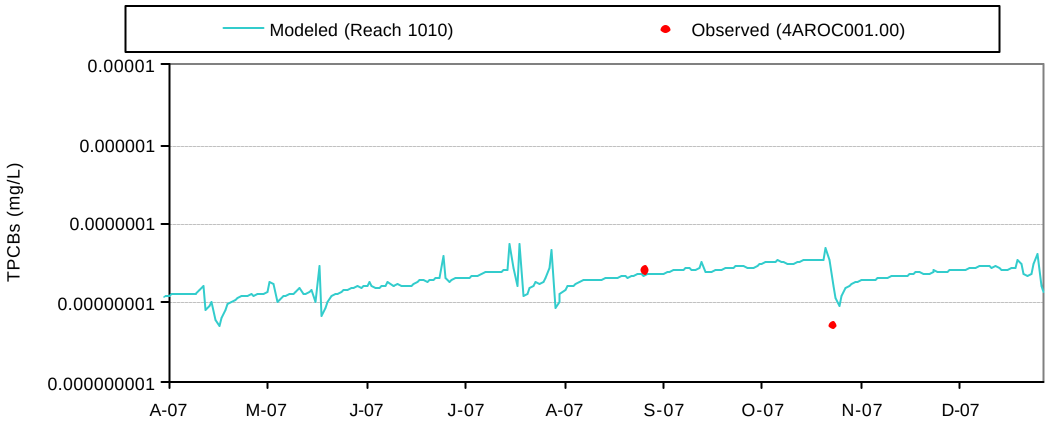

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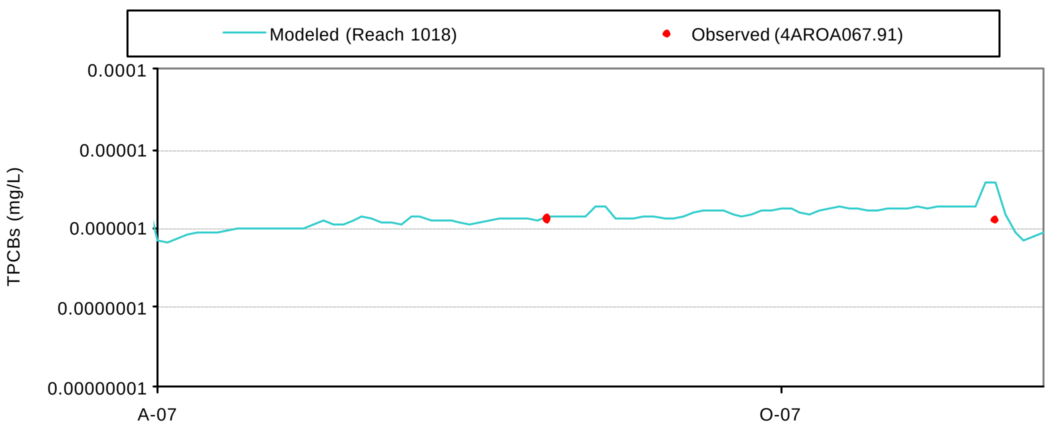

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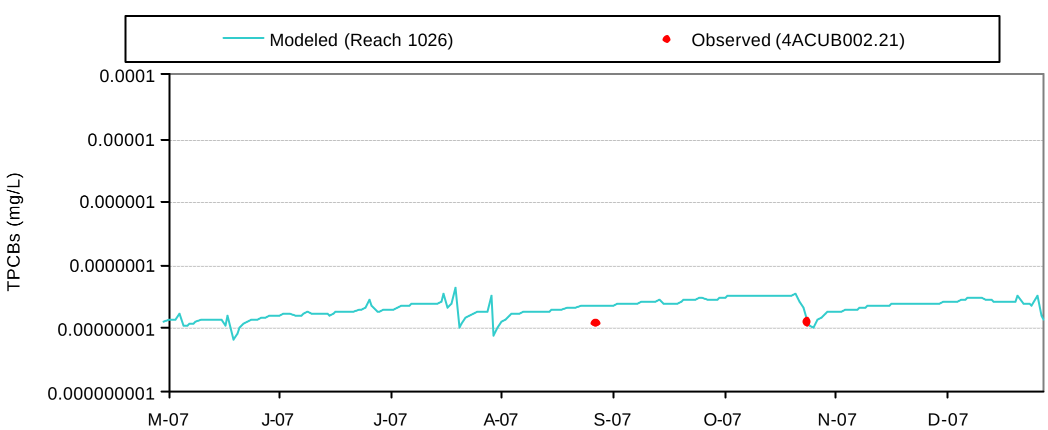

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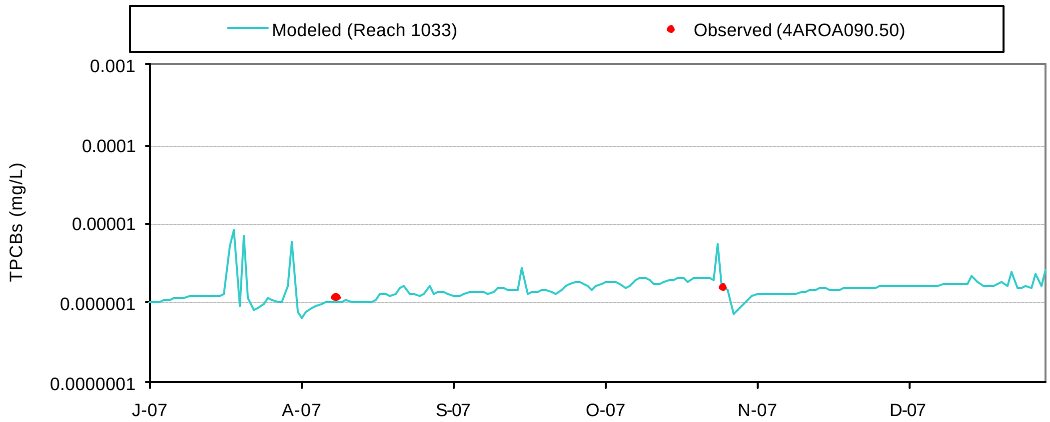

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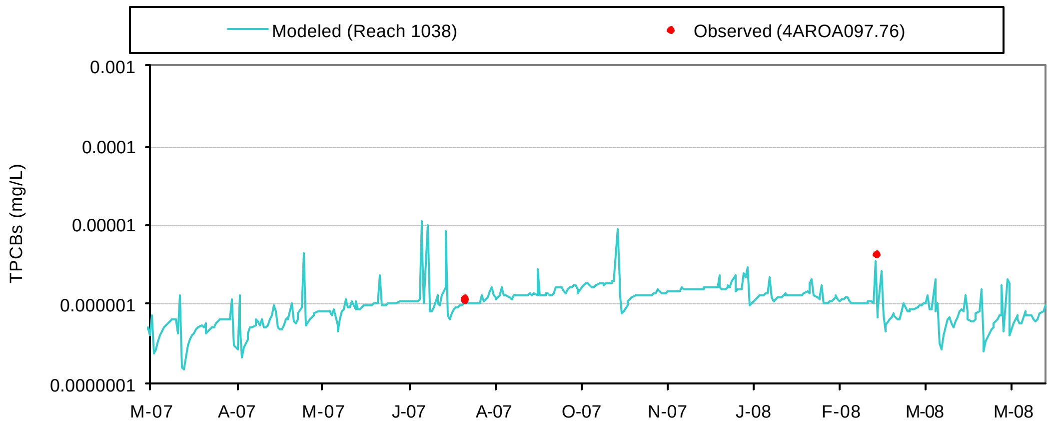

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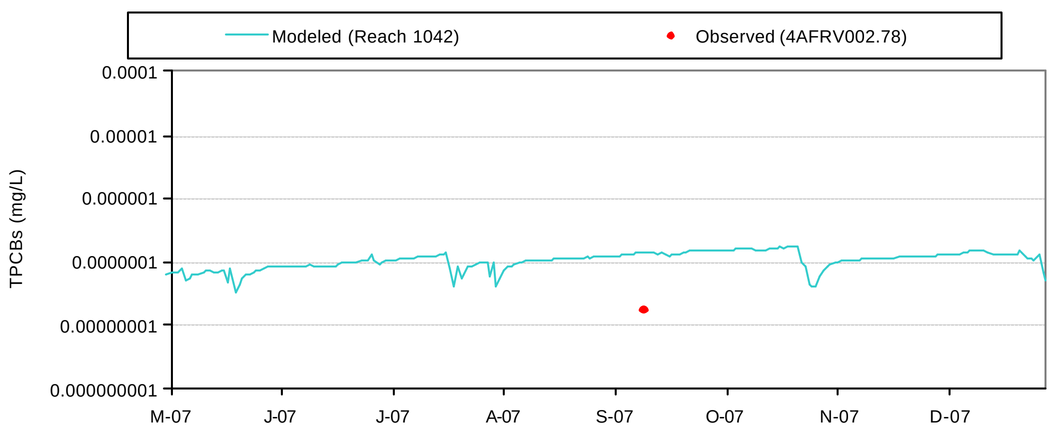

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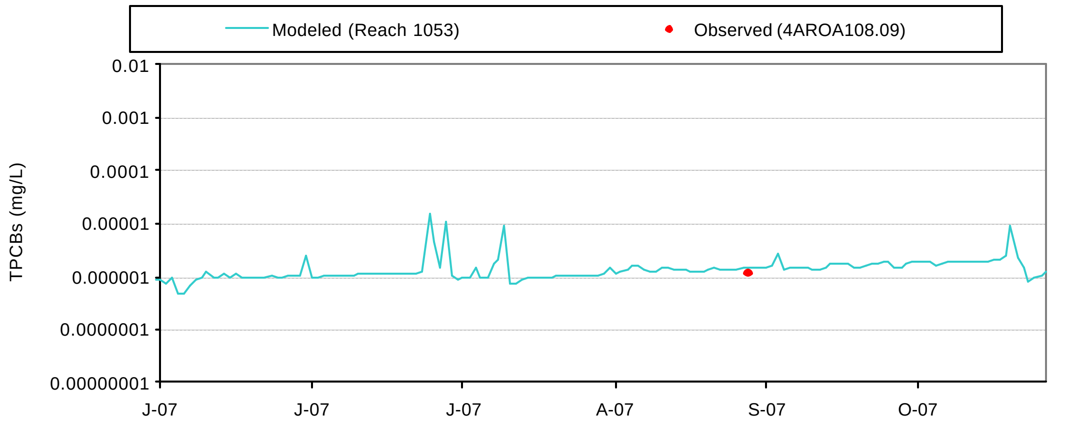

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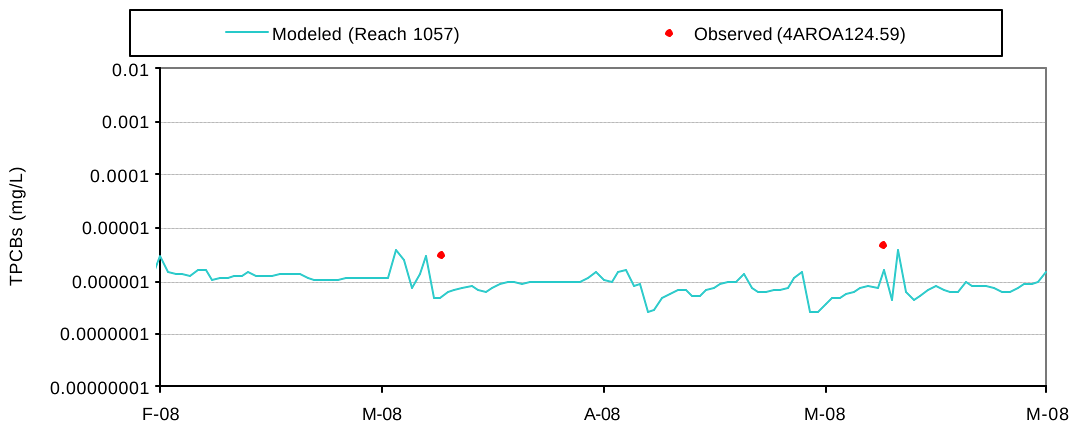

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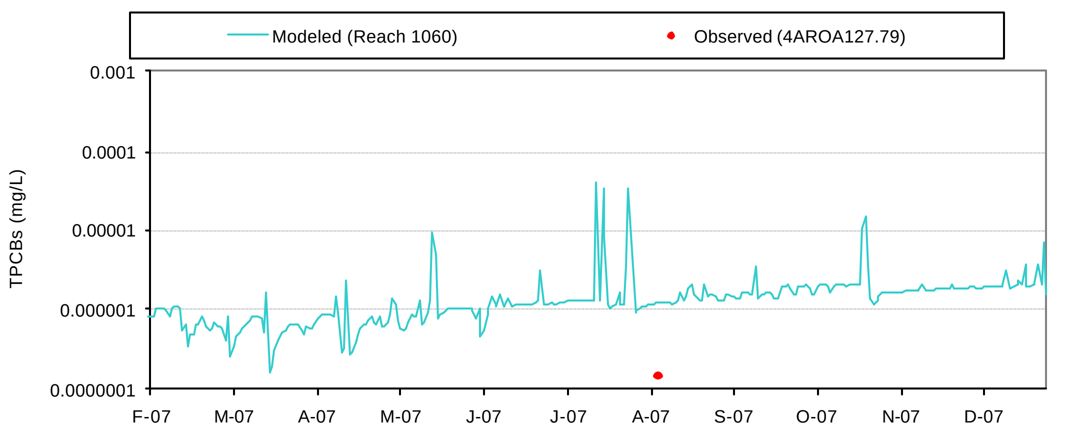

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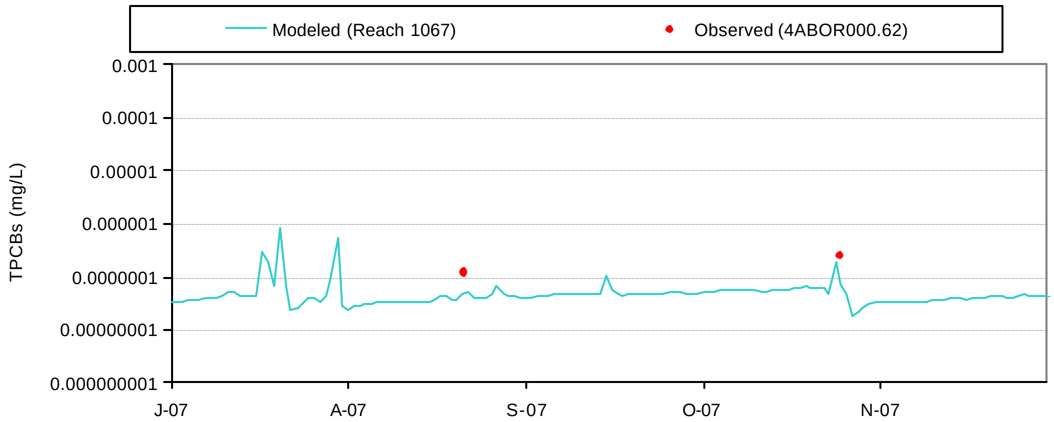

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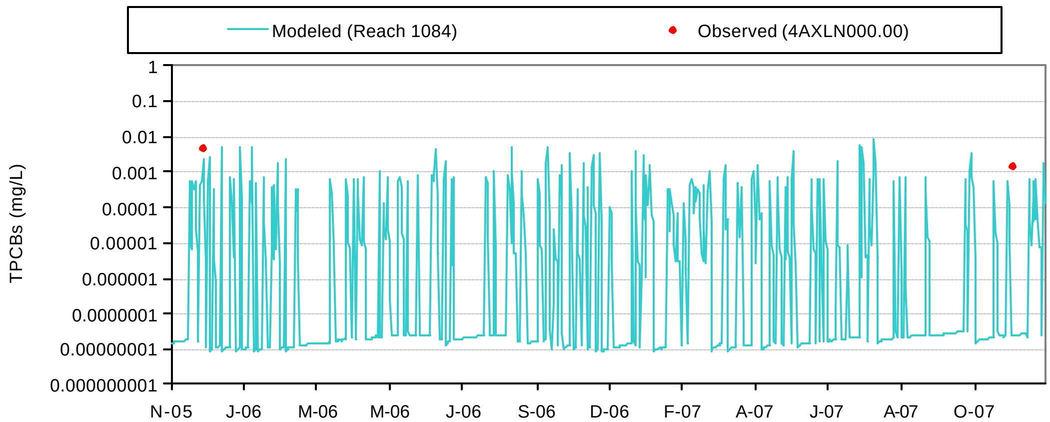

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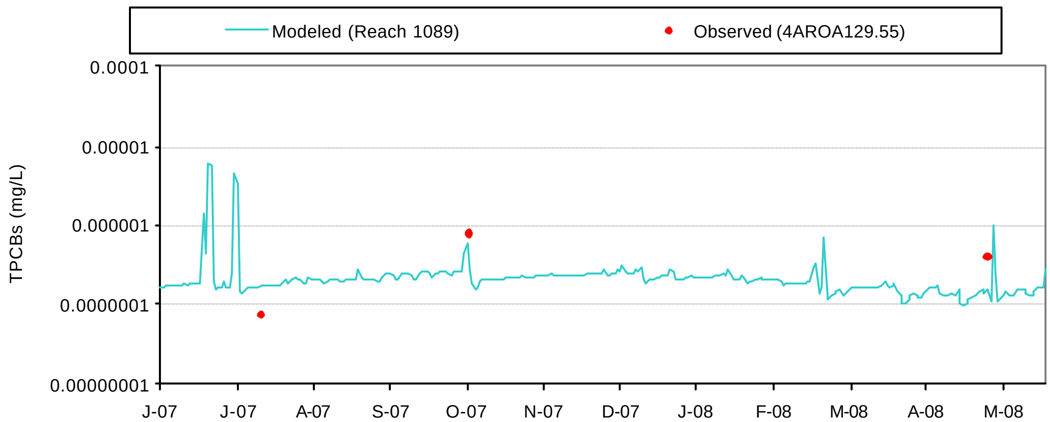

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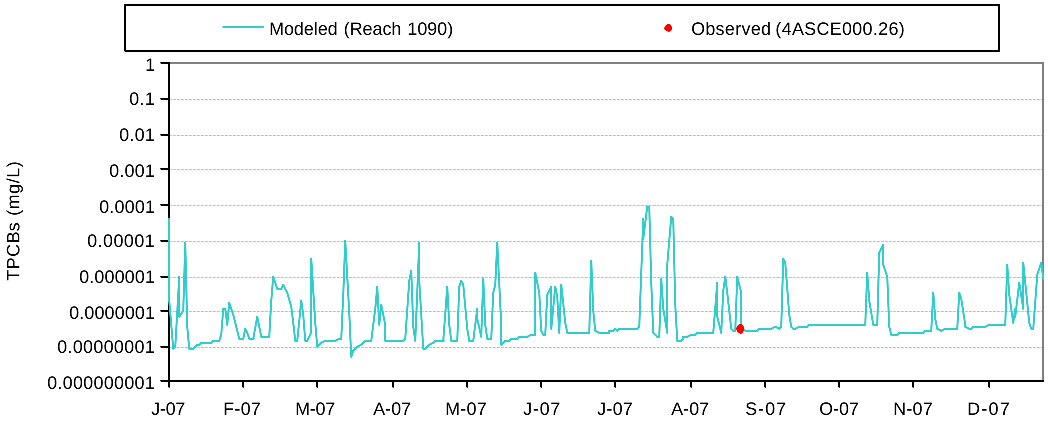

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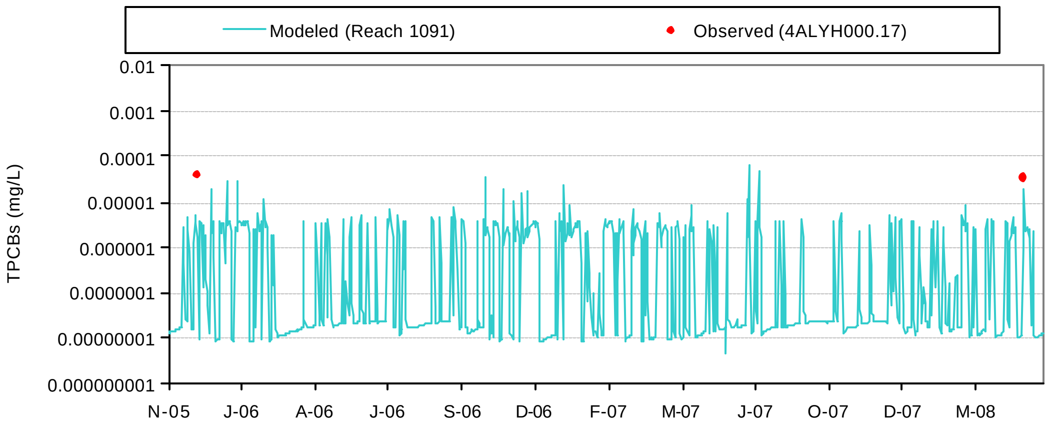

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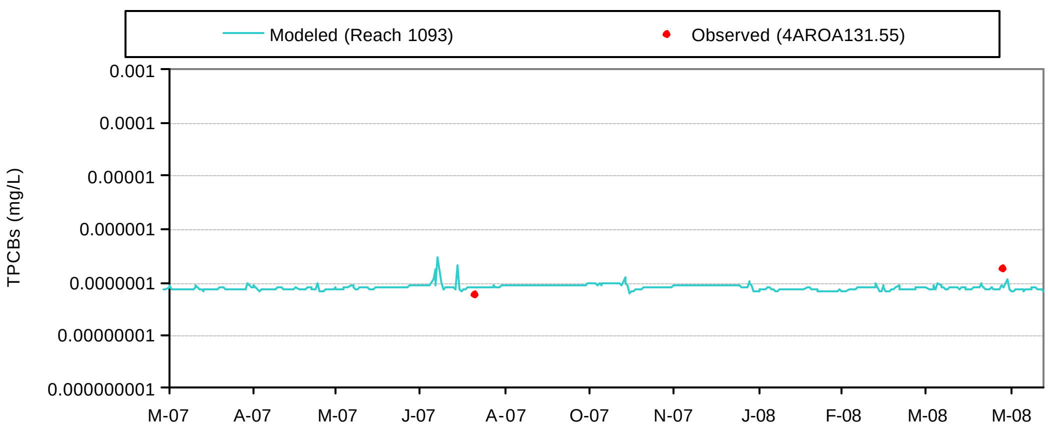

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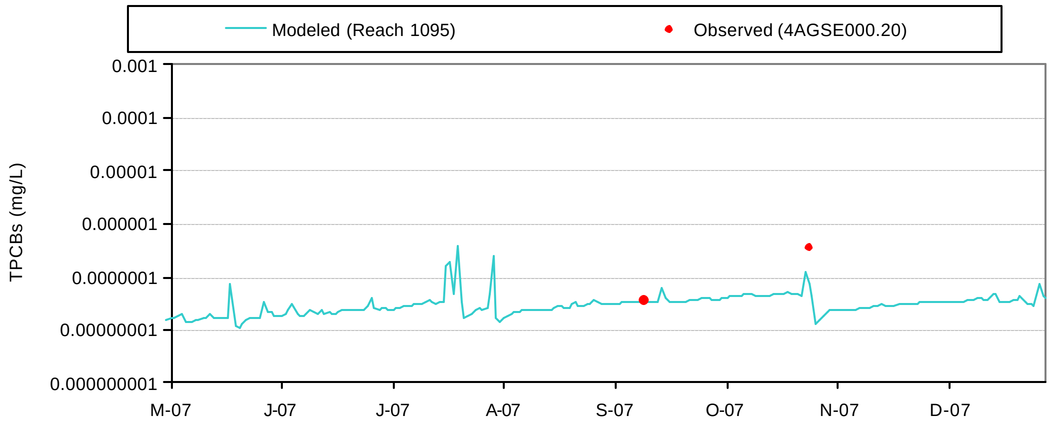

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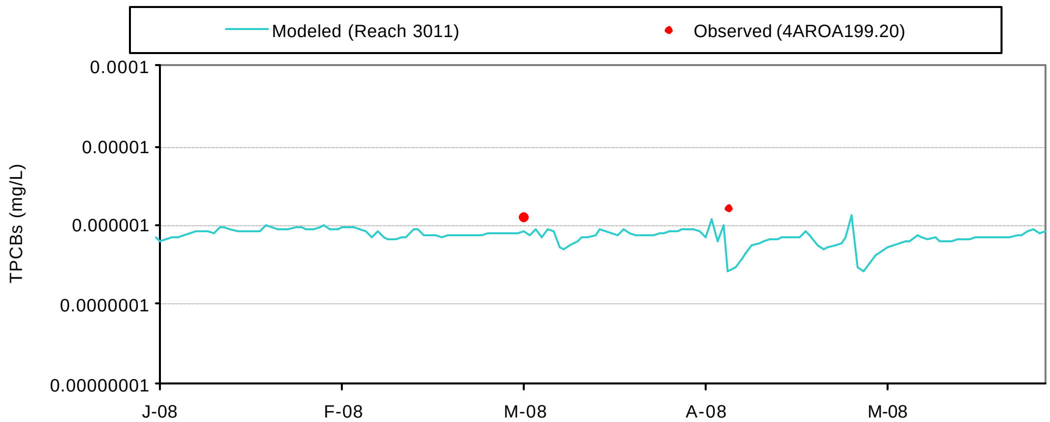

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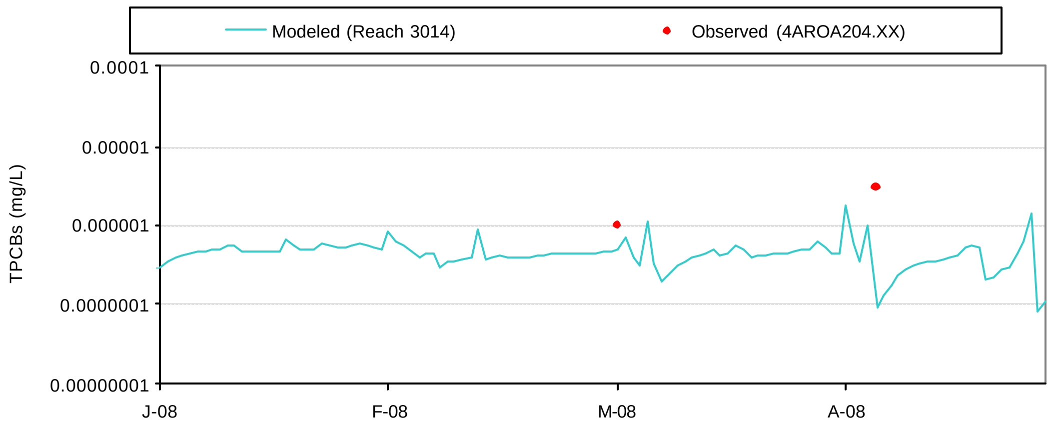

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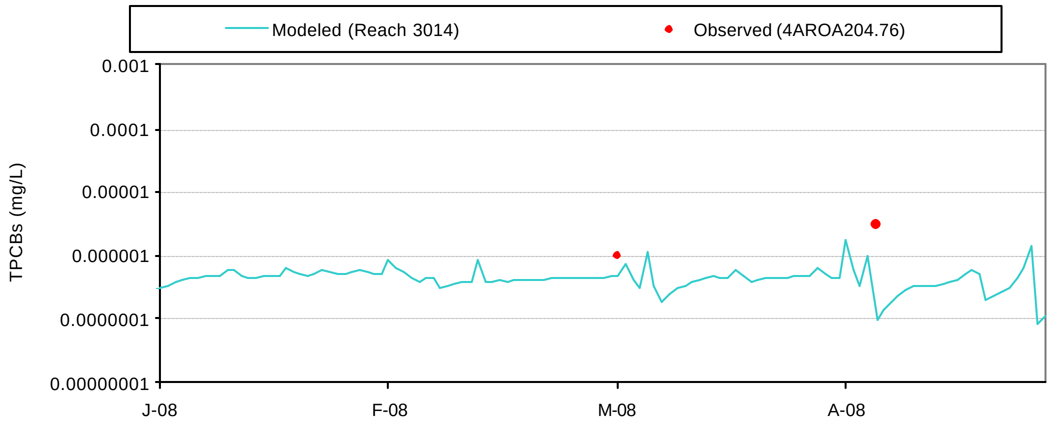

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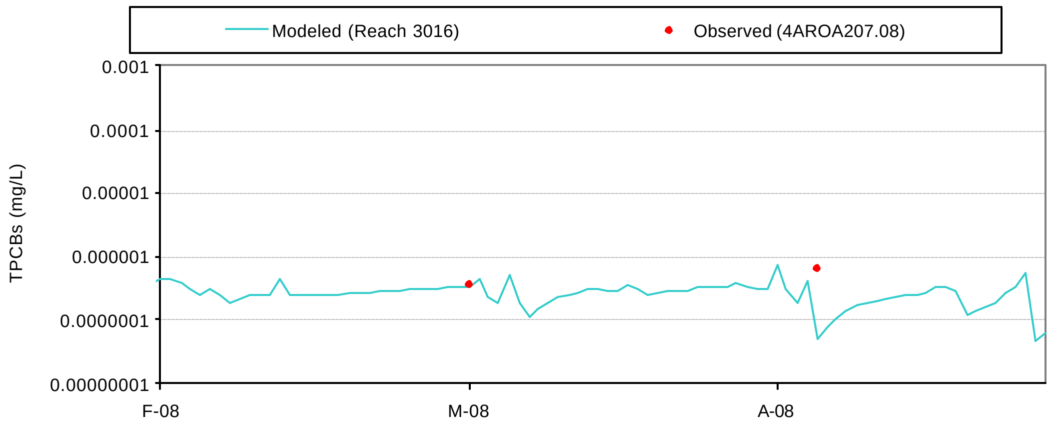

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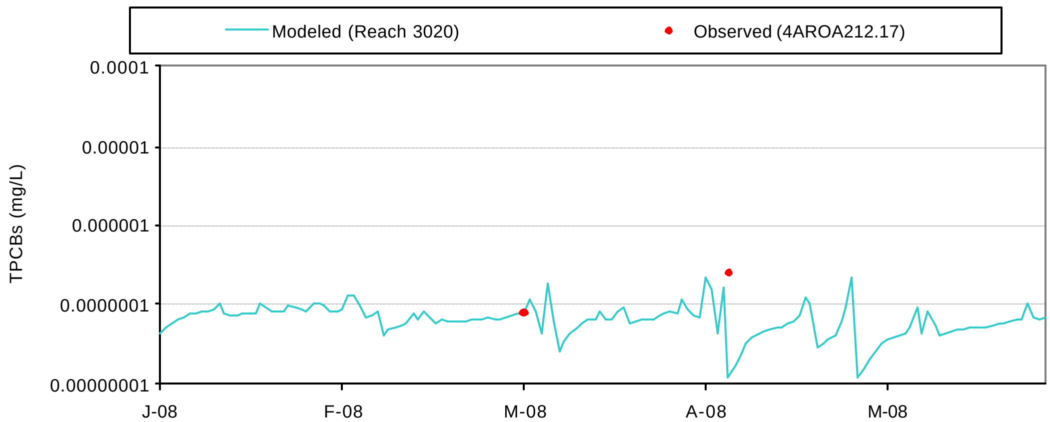

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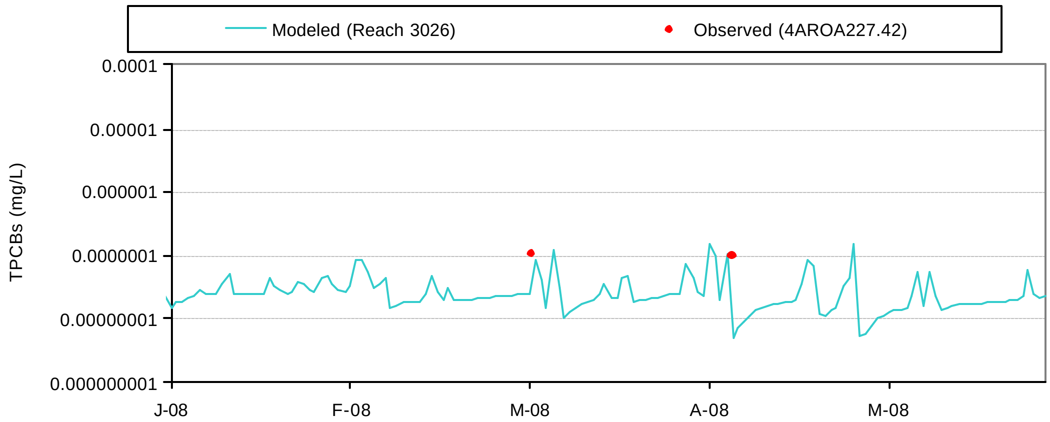

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Appendix G:
TMDL Technical Approach and Model Setup

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FIGURES

G1. TMDL TECHNICAL APPROACH

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of Total Maximum Daily Load (TMDL) development. It allows for evaluating management options that will achieve the desired source load reductions necessary to meet water quality standards. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions.

This section presents the modeling approach for developing polychlorinated biphenyl (PCB) TMDLs for the Roanoke River basin. The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination and to determine the reductions required to achieve water quality criteria for PCB impaired segments.

G1.1. Critical Considerations

The pollutant of concern for the current modeling application is total PCBs (tPCBs). PCBs are a hydrophobic, nonpolar, organic chemical species that tend to associate with fine sediments. PCBs associate with sediments by the process of adsorption. Adsorption describes the tendency of PCBs to accumulate on the surface of sediments in an aqueous environment as a function of energetic favorability, where the strength of the PCB-sediment association is proportional to the availability of adsorption surfaces [total suspended sediments (TSS) concentration], sediment organic content, and the PCB species degree of chlorination.

Land use in the Roanoke River basin includes extensive areas of largely undeveloped forest and pastoral lands and relatively small areas of concentrated development. Each land use affects the hydrology and sediment loads of the basin in a different way. Available monitoring data, as described in Section 2.2 of *Roanoke River PCB TMDL Development*, suggests that potential sources of PCBs are often associated with developed land uses.

Technical, regulatory, and stakeholder considerations informed the selection criteria for a watershed model to simulate PCB loading in the Roanoke River basin. On the basis of the considerations, the following factors were critical to selecting an appropriate watershed model. The model should do the following:

- Be able to represent the physical properties and loading and transport processes specific to the pollutant of concern (tPCBs)
- Be able to represent associated watershed processes critical to quantification of the pollutant of concern (TSS loading)
- Be able to address a watershed that has a combination of rural and urban land uses
- Be appropriate for simulating a large number of subwatersheds
- Provide adequate time-step estimation of flow and not oversimplify storm events to provide accurate representation of rainfall events/snowmelt and resulting peak runoff
- Be flexible enough to accommodate issues such as topography and meteorological variability over a large land area
- Be able to be calibrated and validated with the existing monitoring data
- Be able to be linked to an appropriate receiving water/lake model
- Be a sound platform for evaluating both existing baseline and hypothetical management decisions

- Be based on best available data and science
- Be nonproprietary, tested, and approved by the U.S. Environmental Protection Agency (EPA)
- Be adaptable and available for future applications

G1.2. Modeling Framework

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements, was used to develop PCB TMDLs for the Roanoke River basin. A watershed model is a series of algorithms that integrate meteorological forcing data and watershed characteristics to simulate upland and tributary routing processes, including hydrology and pollutant transport. Once a model has been adequately set up and calibrated and the dominant unit processes are deemed representative on the basis of comparison with available monitored conditions, it becomes a useful tool to quantify existing flows and loads from tributaries without gages and from diffuse, overland flow sources.

G1.2.1. Loading Simulation Program C++ (LSPC)

On the basis of the considerations described above and previous modeling experience, EPA-approved LSPC (http://www.epa.gov/athens/wwqtsc/html/lspc.html) was selected for Roanoke River watershed modeling. LSPC is a watershed modeling system that includes Hydrologic Simulation Program–FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. During the past several years it has been used to develop hundreds of EPA-approved TMDLs, and it is generally considered the most advanced hydrologic and watershed loading model available.

LSPC integrates a geographic information systems (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient, PC-based Windows environment. The algorithms of LSPC are identical to a subset of those in the HSPF model. EPA's Office of Research and Development in Athens, Georgia, maintains LSPC, and it is a component of EPA's National TMDL Toolbox (http://www.epa.gov/athens/wwqtsc/index.html). A brief overview of the HSPF model is provided below, and a detailed discussion of HSPF-simulated processes and model parameters is in the HSPF user's manual (Bicknell et al. 1997).

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970s. The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley 1966), which was one of the pioneering watershed models. The HSPF framework is composed of modules with components that can be assembled in different ways, depending on the objectives of the project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes

All three modules include many submodules that calculate the various hydrologic, sediment, and water quality processes in the watershed. Table G1-1 lists the modules from HSPF that are used in LSPC.

Table G1-1. HSPF modules included in LSPC

Receiving water modules (RCHRES)	HYDR	Simulates in-stream hydraulic behavior
	ADCALC	Simulates in-stream advection of dissolved or entrained constituents
	CONS	Simulates in-stream conservative constituents
	HTRCH	Simulates in-stream heat exchange
	SEDTRN	Simulates in-stream behavior of inorganic sediment
	GQUAL	Simulates in-stream behavior of a generalized quality constituent

Watershed modules PERLND/IMPLND	SNOW	Simulates snow fall, accumulation, and melting
	PWATER/IWATER	Simulates water budget for a pervious/impervious land segment
	SEDMNT/SOLIDS	Simulates production and removal of sediment for a pervious/impervious land segment
	PSTEMP	Simulates soil layer temperatures
	PWTGAS/IWTGAS	Estimates water temperature and dissolved gas concentrations in the outflows from pervious/impervious land segments
	PQUAL/IQUAL	Simulates water quality in the outflows from pervious/impervious land segments

Source: (Bicknell et al. 1997)

Spatially, the watershed is divided into a series of subbasins or subwatersheds representing the drainage areas that contribute to each of the stream reaches. These subwatersheds are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and subsurface flow contributions from each of the land segments and subwatersheds and routes them through the waterbodies using storage-routing techniques.

The stream-routing component considers direct precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals and diversions can also be accommodated. The stream network is constructed to represent all the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Important routines for water quality simulation include the QUAL and SED modules, both of which have PERLND/IMPLND and RCHRES components that define the upland and in-stream characteristics of each. Together, these routines provide the basic framework for simulating pollutant loading and transport in a watershed.

The QUAL module simulates the behavior of a generalized water quality constituent by linking land use surface runoff, associated pollutant loadings, and in-stream conditions. It allows for a constituent to be present in a dissolved or sediment-associated state, and in its simplest configuration, represents all transformations and removal processes using simple, first-order decay approaches. The framework is flexible and allows for different combinations of constituents to be modeled depending on data availability and the objectives of the study. When considering both the dissolved- and sediment-associated states, QUAL simulates the following processes:

- Advection
- Decay processes
- Deposition and scour of adsorbed material with sediment
- Adsorption/desorption between dissolved- and sediment-associated phases

The SED module simulates the production and transport of sediments. The parameterization of its upland component (SEDMNT) is closely related to the factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), while its in-stream component (SEDTRN) is highly dependant on the hydraulic characteristics of the model stream reaches.

The advantages of choosing LSPC as the watershed model for the Roanoke basin include the following:

- It simulates all the necessary constituents and applies to rural and urban watersheds.
- It allows for customization of algorithms and subroutines to accommodate the needs of the Roanoke River basin study, including the following:
    - Adsorptive/desorptive properties of PCBs
    - Deposition/resuspension of sediments

- The time-variable nature of the modeling enables a straightforward evaluation of the cause-effect relationship between source contributions and waterbody response, as well as direct comparison to relevant water quality criteria.
- It allows for the incorporation of Virginia Department of Environmental Quality (VADEQ) monitoring data.
- It has a comprehensive modeling framework that uses the proposed LSPC approach, thereby facilitating development of TMDLs not only for this project, but also for potential future projects to address other impairments throughout the Roanoke River basin.
- The proposed modeling tools are in the public domain and approved by EPA for use in TMDLs.
- The model includes both surface runoff and base flow (groundwater) conditions.
- It provides storage of all physiographic, point source/withdrawal data and process-based modeling parameters in a Microsoft Access database and text file formats to provide for efficient manipulation of data.
- It presents no inherent limitations with respect to the size and number of watersheds and streams that can be modeled.
- It provides flexible model output options for efficient post-processing and analysis designed specifically to support TMDL development and reporting requirements.
- It can be linked to a receiving water model.

G2. MODEL SETUP

An LSPC model was configured for the areas contributing to TMDL impaired streams (see Section 1.2 of *Roanoke River PCB TMDL Development*) in the Roanoke River basin as a series of hydrologically connected subwatersheds. Configuring the model involved subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for the units using meteorological, land use, soils, stream, and water quality data. Developing and applying the watershed model to address the project objectives involved the following major steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Representation of Watershed Sources
4. Model Calibration and Validation

G2.1. Watershed Segmentation

Watershed segmentation refers to the subdivision of the entire watershed into small, discrete subwatersheds for modeling and analysis. Subwatersheds represent hydrologically connected modeling units and capture the drainage areas of their associated stream segments. The delineated subbasins represent the scale at which model simulations take place.

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from its headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam downstream to its confluence with the Dan River. These large segments were further subdivided into subbasins primarily using the watershed stream network, locations of tPCB sources, and topographic variability, and secondarily using the locations of available water quality, fish tissue, and sediment tPCB monitoring stations; the locations of U.S. Geological Survey (USGS) continuous stream flow gages; and existing watershed boundaries [Virginia subwatersheds (VAWATBOD) developed by VADEQ]. Delineation of the Roanoke River watershed resulted in 45 and 107 model subwatersheds for the upper and lower Roanoke (Staunton) segments, respectively (Figures G2-1 and G2-2).

The middle Roanoke, which includes the drainage area of the Roanoke River mainstem beginning just downstream of Niagra dam and extending downstream to Leesville Lake, is *not* considered in these TMDLs because its waters are outside the scope of the tPCB-impairment listings that are under investigation. Smith Mountain Lake and Leesville Lake are concurrent reservoirs with outflows managed for generating electricity, including pump-back operations. The middle segment includes two major tributaries to the reservoirs, the Blackwater and Pigg rivers. The model subbasin delineation includes those areas; therefore, the middle section can be included in future modeling updates for the Roanoke River watershed if needed for TMDL development or other purposes.

The two modeled segments include the waters designated as impaired for tPCBs on Virginia's 1998 303(d) list. Because there is no dynamic link between the two, to accurately represent the lower Roanoke (Staunton), discharge data from the Leesville Dam, which represents all upstream flows and pollutant load contributions to that point on the River, were incorporated as a model boundary condition. Hourly discharge data for the Leesville Dam were obtained from its operator, American Electric Power (AEP), and summarized as daily average values for model input. The average daily discharge time series used as the model boundary condition is in Appendix D.

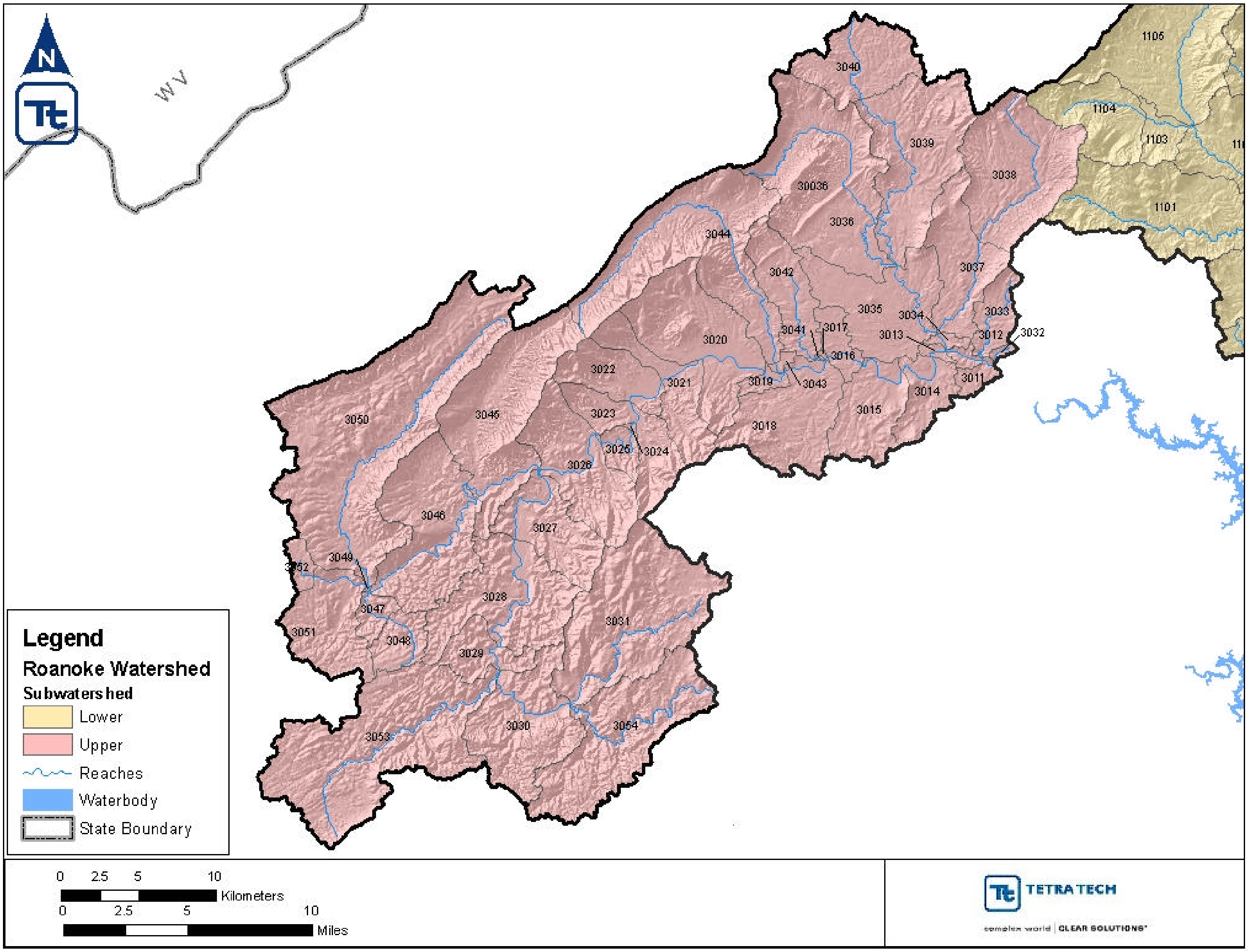

Figure G2-1. Subwatershed divisions of the upper Roanoke.

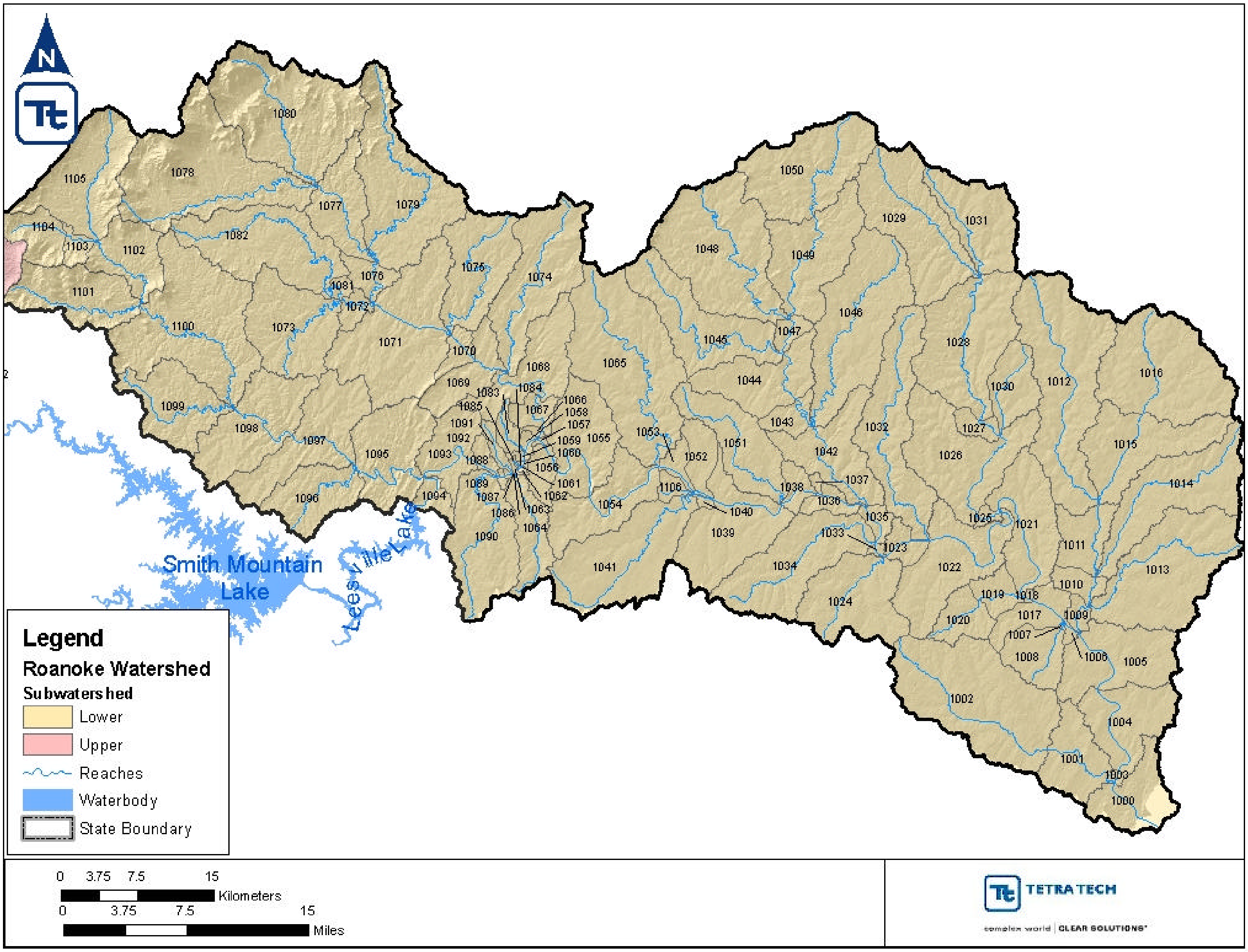

Figure G2-2. Subwatershed divisions of the lower Roanoke (Staunton).

G2.2. Configuration of Key Model Components

Configuring the model involved considering three major components, all of which provide the basis for the model's ability to estimate stream flow:

- Meteorological data, which drives the watershed model
- Land use representation, which provides the basis for distributing soils and pollutant loading characteristics throughout the basin
- Watershed physical attributes, which provide the basis for estimating stream channel geometry

G2.2.1. Meteorology

Hydrologic processes depend on changes in environmental conditions, particularly weather. As a result, meteorological data are a critical component of the watershed model. Such data are the driver of LSPC algorithms simulating watershed hydrology and water quality; thus, accurately representing climactic conditions is required to develop a valid modeling system.

The climate data requirements of the model vary depending on whether processes related to snowfall are represented. If snowfall is omitted from the simulation, precipitation (rainfall) and evapotranspiration are the only data needed. When snow is included, dry bulb air temperature, wind speed and direction, solar radiation, and dew point temperature are also required. Snowfall was included in the TMDL model setup because it is a significant component of the precipitation totals in the Roanoke River basin. Seasonal snowfall, accumulation, and melt affect the timing and magnitude of watershed stream flows.

Key meteorological data were accessed from the National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC) to develop a representative data set for the study area covering the modeling period. NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States. COOP stations record hourly or daily rainfall data, while airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover.

Rainfall and other meteorological data are taken directly from NCDC station records. Required climactic data not included in the NCDC records—evapotranspiration and solar radiation—were calculated from the available data using literature methodologies (Hamon 1961). All meteorological data were subsequently formatted for use as hourly time-series. An hourly time step is required to properly reflect diurnal temperature changes and provide adequate resolution for rainfall/runoff intensity to drive water quality processes during storms or snowmelt events.

Identifying the most representative weather data for the model was done using several factors, including geographic coverage, data record, and data completeness. Tables G2-1 and G2-2 list the selected daily COOP and WBAN stations and the completeness of the record expressed as the percentage of the data set not missing as reported by NCDC. Figure G2-3 presents the weather station locations.

Table G2-1. WBAN climate stations

WBAN ID	Elevation (ft)	Parameter	Period of record	% Complete
13733	940	Precipitation (in)	01/01/1979–5/31/2008	97%
		Dewpoint Temp (°F)	01/01/1979–5/31/2008	97%
		Dry-Bulb Temp (°F)	01/01/1979–5/31/2008	100%
		Wind Speed (mph)	01/01/1979–5/31/2008	99%
13741	1,149	Precipitation (in)	01/01/1979–5/31/2008	100%
		Dew point Temp (°F)	01/01/1979–5/31/2008	100%
		Dry-Bulb Temp (°F)	01/01/1979–5/31/2008	100%
		Wind Speed (mph)	01/01/1979–5/31/2008	100%

Table G2-2. COOP precipitation stations

ID	Station name	Elevation (ft)	Period of record	% Complete
440766	Blacksburg NWSO	2,100	11/01/1952–12/31/2005	96%
441121	Buchanan	880	01/01/1930–12/31/2005	94%
441692	Christianburg	2,100	08/01/1995–12/31/2005	95%
444148	Huddleston 4 SW	1,045	09/02/1950–12/31/2005	98%
444568	Keysville 2 S	530	09/01/1979–12/31/2005	86%
444676	Lafayette 1 NE	1,320	06/01/1951–12/31/2005	98%
445120	Lynchburg WSO Airport	940	01/01/1930–12/31/2005	92%
447285	Roanoke WSO Airport	1,149	08/01/1948–12/31/2005	98%

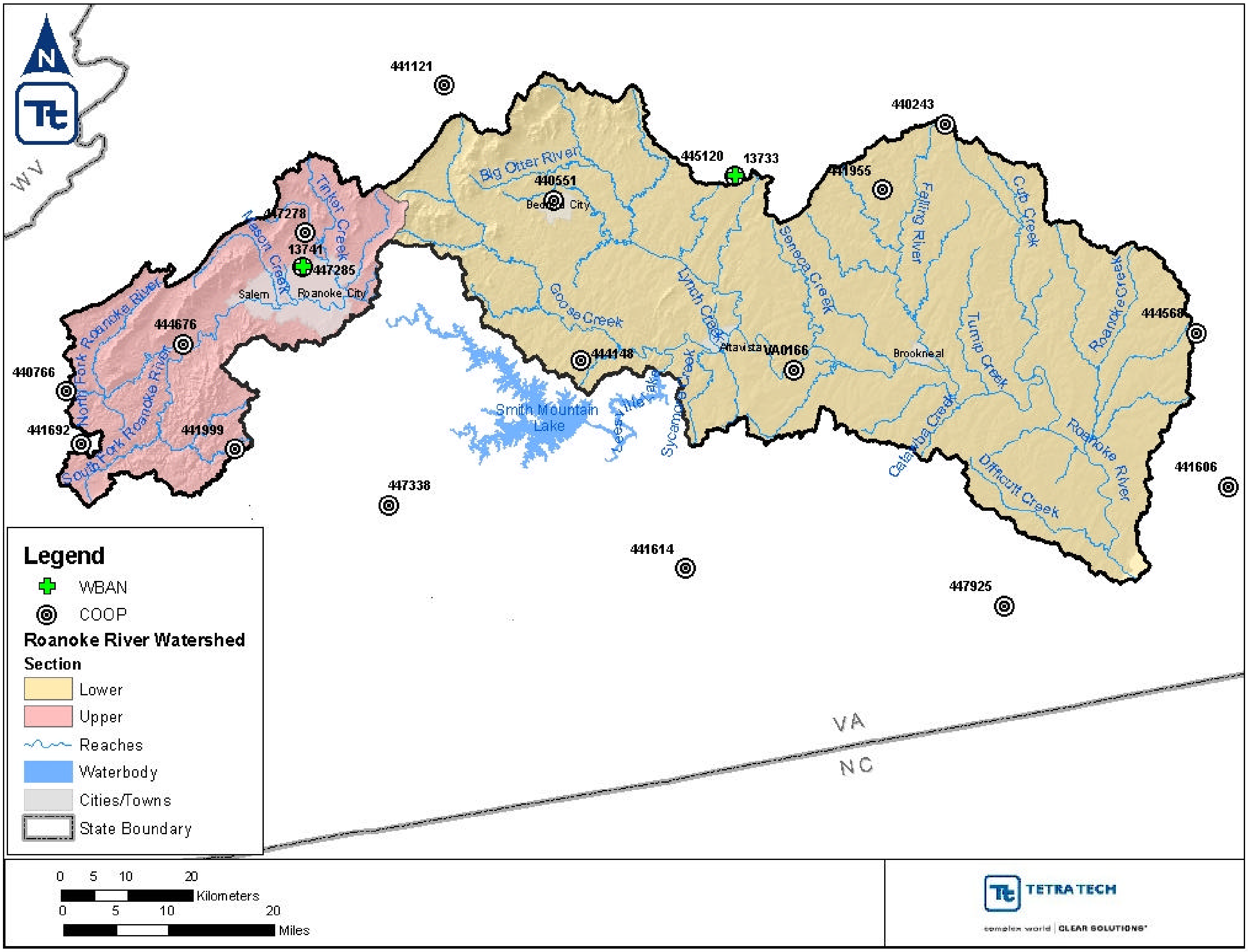

Figure G2-3. Weather stations near the Roanoke River watershed.

The data obtained were subjected to a quality assurance/quality control regime that identified gaps in data that could misrepresent observed conditions. An effort was made to select weather stations with a high level of completeness. However, data time series contain various intervals of accumulated, missing, or deleted data. In such cases, rainfall patching was performed to ensure proper representation. Patching involves using the *normal-ratio method*, which estimates a missing rainfall record with a weighted average from surrounding stations with similar rainfall patterns. Accumulated, missing, and deleted data records are repaired using hourly rainfall patterns at nearby stations with unimpaired data. Figure G2-4 presents an example of a patched precipitation time series with missing and accumulated data. Note that where no hourly data are available to disaggregate the accumulated data (February 13, 1994) a normal distribution is assumed.

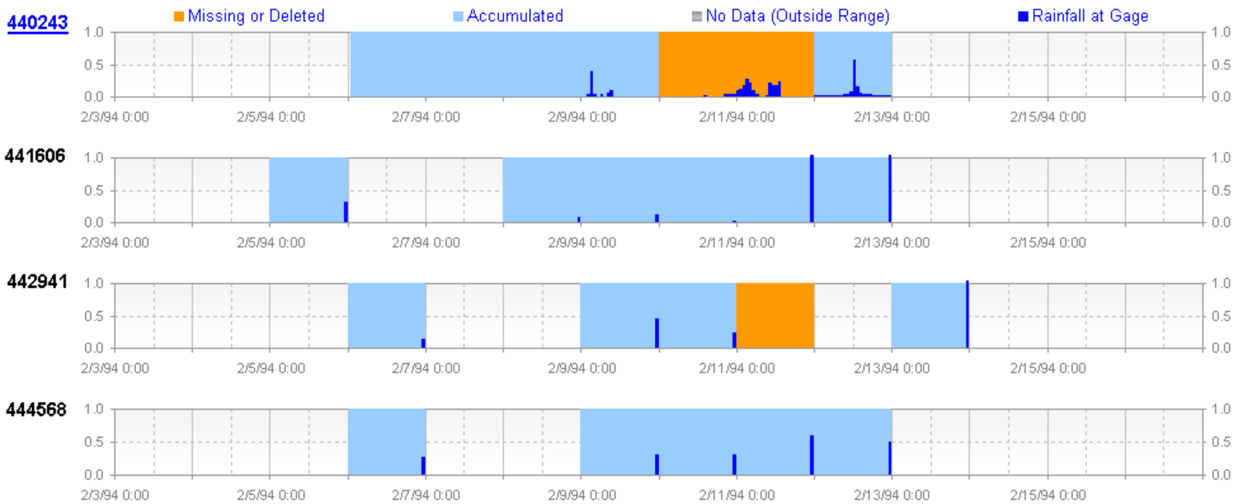

Figure G2-4. Example of a patched time series.

G2.2.2. Land Use and Soils Data

LSPC requires a basis for distributing hydrologic parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by land use and soils GIS data coverages for the watershed.

General land use/land cover data sets for the Roanoke River watershed were extracted from the National Land Cover Dataset (NLCD) database (MRLC 2001) (See Section 2.1.1 of *Roanoke River PCB TMDL Development*). NLCD data were derived from satellite imagery taken circa 2001 and provide detailed categorization of urban and natural areas. The detailed NLCD land cover descriptions were generalized for the model setup. Table G2-3 presents the original and grouped land uses used to characterize the watershed.

LSPC requires that land use categories be divided into separate pervious and impervious land units. This division was made for the appropriate land uses (urban) to represent impervious and pervious areas separately. The division was based on the impervious percentages description provided in the NLCD metadata.

Table G2-3. Model setup land use categories

Land use description	Group description	% Pervious	% Impervious
Open Water	Water/Wetland	100.0%	0.0%
Woody Wetlands		100.0%	0.0%
Herbaceous Wetlands		100.0%	0.0%
Pasture/Hay	Pasture	100.0%	0.0%
Grassland		100.0%	0.0%
Row Crops	Cropland	100.0%	0.0%
Deciduous Forest	Forest	100.0%	0.0%
Evergreen Forest		100.0%	0.0%
Mixed Forest		100.0%	0.0%
Shrub/Scrub		100.0%	0.0%
Barren Land	Other	100.0%	0.0%

Land use description	Group description	% Pervious	% Impervious
Developed, Open Space		100.0%	0.0%
Developed, Low Intensity	Developed	65.5%	34.5%
Developed, Medium Intensity		35.5%	64.5%
Developed, High Intensity		10.0%	90.0%

The Natural Resources Conservation Service (NRCS) has defined four hydrologic soil groups (Table G2-4 below) that classify soils according to their infiltration and runoff characteristics during periods of prolonged wetting (See Section 2.1.2 of *Roanoke River PCB TMDL Development*). Typically, clay soils (Group D) that are poorly drained have the lowest infiltration rates, while sandy soils (Group A) that are well drained have the highest infiltration rates. Data for the watershed were obtained from the State Soil Geographic Database (STATSGO) (USDA 1993) and were summarized by hydrologic soil groups.

Table G2-4. NRCS hydrologic soil groups

Hydrologic soils group	Description
A	Soils with high infiltration rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Source: (USDA 1993)

The hydrologic soil groups were overlain with model grouped land uses to create a composite data layer that describes both land cover and soil group distribution in the watershed (Figure G2-5). The result is a composite layer that specifies the land use and soil group of an area at the resolution provided in the NLCD data layer (30 meters). The composite layer was used as the model land use allowing for the accurate representation of hydrologic variability at the subbasin level by taking into account both land surface and subsurface characteristics.

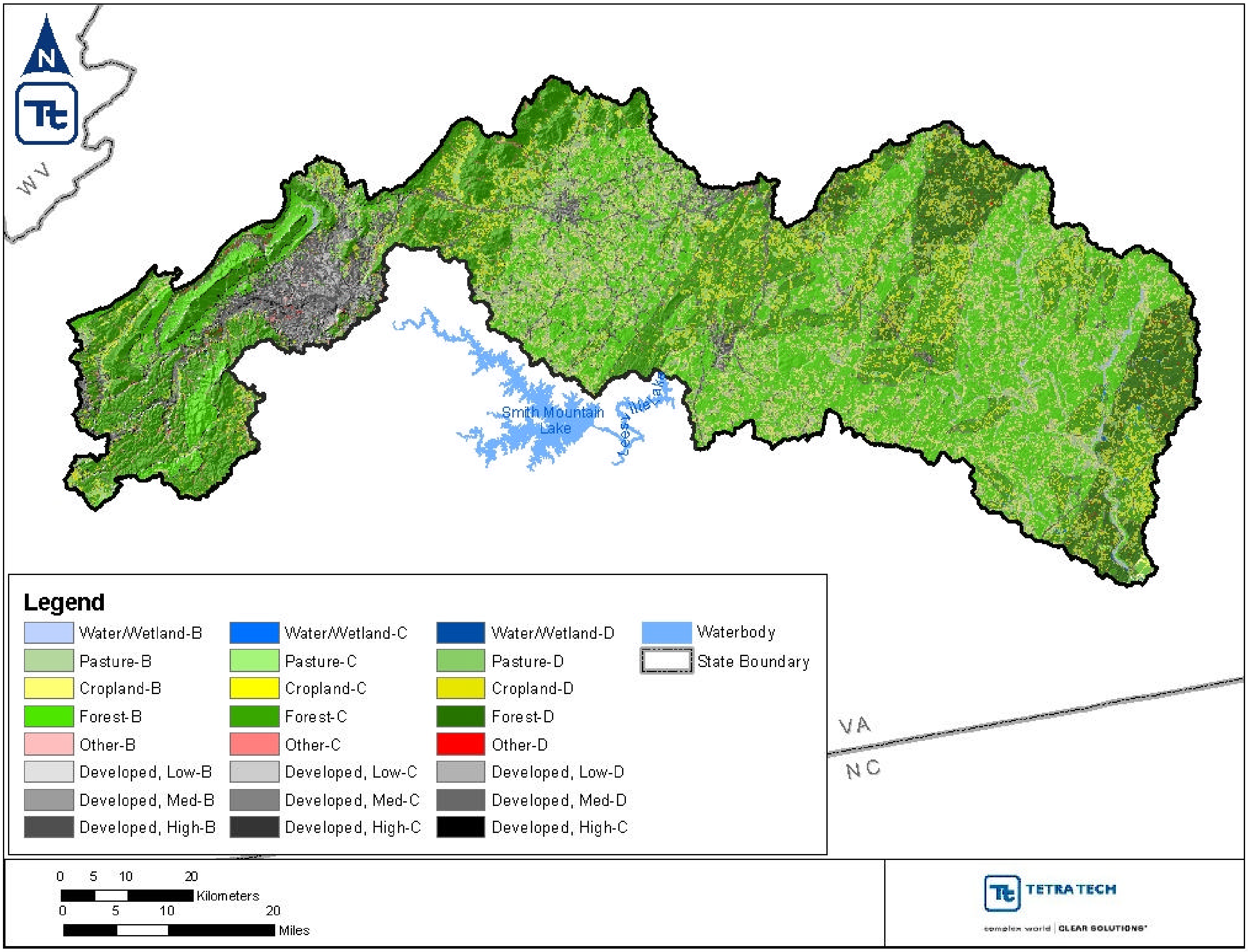

Figure G2-5. Composite model land use.

G2.2.3. Elevation Data/Stream Characteristics

LSPC requires a representative stream reach for each subwatershed to route flow throughout the subwatershed network. The stream network connects all the subwatersheds represented in the watershed model. Stream channels are assumed to be completely mixed, one-dimensional segments with a trapezoidal cross section. Stream channel bank-full widths and depth were estimated as a function of cumulative drainage area using the Rosgen stream cross-section coefficients for eastern North American streams (Rosgen 1994). LSPC automatically develops rating curves, referred to as function tables (FTABLES) in the model, for streams in the network using the defined channel cross sections. The FTABLE of a model stream reach defines its representative depth-outflow-volume-surface area relationship.

Watershed elevation data derived from the National Elevation Dataset (NED) (see Section 2.1.3 of *Roanoke River PCB TMDL Development*) was used to estimate stream channel slope (USGS 2009). In-stream flow calculations are made using the HYDR (hydraulic behavior simulation) module in LSPC, which is identical to the HYDR module in HSPF (Bicknell et al. 1997).

LSPC requires that each subwatershed representative stream reach be assigned to a stream class. A stream class defines the model parameters related to the simulation of in-stream pollutant transport and fate processes. A single stream class can be used to define these parameters for all representative stream reaches, or multiple stream classes can be defined in the model allowing parameter variability between stream reaches. For the Roanoke River LSPC model, an individual stream class was defined for each representative stream reach. This approach allowed a unique set of parameters to be assigned to each of the 152 reaches, 107 in the lower and 45 in the upper, corresponding to each model subwatershed.

G2.3. Source Representation

The Roanoke River PCB TMDL model considers TSS and PCB sources. Sources of TSS include nonpoint sources associated with the erosion and upland soils washoff and point source discharges from facilities. TSS sources are in the model setup because the representation of TSS point sources is required to accurately represent watershed hydrology, and nonpoint sediment loadings are the vehicle for sediment-associated tPCB loadings.

PCB sources are defined as either current or legacy as described in Section 3.0 of *Roanoke River PCB TMDL Development*. Both current and legacy sources are considered by the LSPC model representation of the Roanoke River basin. Current sources are point source dischargers, contaminated sites, urban background including unknown contaminated sites, and areas covered by general stormwater permits and municipal separate storm sewer systems (MS4s). All legacy sources are nonpoint and are composed of in-stream contaminated sediments and atmospheric deposition to surface waters. Available data were plotted in GIS and, as appropriate, assigned to the defined model subbasins, segments, and land uses.

Developing PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and ongoing source investigation whereby sources of tPCB contamination are continuously being reviewed and updated on the basis of the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time these TMDLs were developed, rather than a complete and final characterization.

G2.3.1. TSS Sources

VADEQ provided an inventory of discharge monitoring reports (DMRs) for facilities permitted for point source discharges of TSS in the Roanoke River watershed. There are 52 facilities representing 55 outfalls in the Roanoke River watershed that are permitted for discharging TSS loads. Effluent from such facilities is represented at the rate and concentrations presented in the DMRs, where available, or at design flow and concentration limits where records were unavailable. Tables G2-5 and G2-6 present the National Pollutant Discharge Elimination System (NPDES) IDs, names, receiving water, design flow, and average concentration limit for facilities in the upper and lower model segments, respectively.

Table G2-5. Model TSS point sources—Upper Roanoke model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
WVWA Falling Creek Water Treatment Plant	VA0001465	001	0	Falling Creek	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	001	0	Carvins Creek, unnamed tributary 1	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	002	0	Carvin Creek unnamed tributary 2	30
WVWA Carvins Cove Water Filtration Plant	VA0001473	003	0	Carvin Creek	30

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
				unnamed tributary 2	
Steel Dynamics	VA0001589	005	0.039	Peters Creek	No limit
Norfolk Southern Railway Co - Shaffers Crossing	VA0001597	002	0	Lick Run unnamed tributary	30
Shawsville Town - Sewage Treatment Plant	VA0024031	001	0.2	South Fork Roanoke River	30
WVWA Roanoke Regional Water Pollution Control Plant	VA0025020	001	55	Roanoke River	2.5
Blacksburg Country Club Sewage Treatment Plant	VA0027481	001	0.035	North Fork Roanoke River	30
Montgomery County PSA - Elliston-Lafayette Waste Water Treatment Plant	VA0062219	001	0.25	South Fork Roanoke River	30
Oak Ridge MHP Sewage Treatment Plant	VA0072389	001	0.015	Falling Creek unnamed tributary	30
Roanoke Moose Lodge	VA0077895	001	0.0047	Mason Creek	30
WVWA Crystal Springs Water Filtration Plant	VA0091065	001	0.092	Roanoke River	30

Table G2-6. Model TSS point sources—Lower Roanoke (Staunton) model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Motiva Enterprises LLC - Montvale	VA0001490	001	0.065	South Fork Goose Creek	No limit
Bedford City - Water Treatment Plant	VA0001503	001	0.038	Little Otter River unnamed tributary	30
Dan River, Inc – Brookneal	VA0001538	001	1.326	Roanoke (Staunton) River	No limit
ITG Burlington Industries, LLC, Hurt Plant	VA0001678	001	3.275	Roanoke (Staunton) River	No limit
Appomattox Trickling Filter Plant	VA0020249	001	0.17	Caldwells Creek	30
Altavista - Wastewater Treatment Plant	VA0020451	001	3.6	Roanoke (Staunton) River	30
Bedford County Schools - Liberty High School	VA0020796	001	0.024	Little Otter River unnamed tributary	30
Bedford County Schools - Body Camp Elem. School	VA0020818	001	0.005	Wells Creek unnamed tributary	30
Bedford Co - New London Academy	VA0020826	001	0.006	Buffalo Creek unnamed tributary	30
Bedford Co - Otter River Elem. School	VA0020851	001	0.005	Big Otter River unnamed tributary	30
Bedford County Schools - Thaxton Elem. School	VA0020869	001	0.004	Wolf Creek unnamed tributary	30
Brookneal - Staunton River Lagoon	VA0022241	001	0.078	Roanoke (Staunton) River	45
Brookneal - Falling River Lagoon	VA0022250	001	0.082	Falling River	30
Bedford City - Sewage Treatment Plant	VA0022390	001	2	Little Otter River	30
Halifax County Schools Clays Mill Elem. School	VA0022748	001	0.0072	Mill Branch unnamed tributary	30
DOC Rustburg Correctional Unit 9	VA0023396	001	0.028	Button Creek unnamed tributary	30
Moneta Adult Detention Facility	VA0023515	001	0.021	Mattox Creek unnamed tributary	30
Campbell Co Util and Serv Auth - Rustburg	VA0023965	001	0.2	Molley Creek	30
Keysville Waste Water Treatment Plant	VA0024058	001	0.5	Ash Camp Creek	30
Charlotte County Schools Bacon District Elem. School	VA0029319	001	0.006	Little Horsepen Creek unnamed tributary	30
Charlotte County Schools Phenix Elem. School	VA0029335	001	0.006	Terrys Creek unnamed tributary	30
Briarwood Village Mobile Home Park Sewage Treatment Plant	VA0031194	001	0.024	Smith Branch unnamed tributary	30

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
BP Products North America Incorporated	VA0054577	001	0	South Fork Goose Creek	No limit
BP Products North America Incorporated	VA0054577	003	0	South Fork Goose Creek unnamed tributary	No limit
Magellan Terminals Holdings LP - Montvale Terminal	VA0055328	001	0.008	South Fork Goose Creek unnamed tributary	No limit
Camp Virginia Jaycees Sewage Treatment Plant	VA0060909	001	0.015	Day Creek unnamed tributary	30
Charlotte County Schools Jeffress Elem. School	VA0063118	001	0.004	Sandy Creek unnamed tributary	30
Southern Mobile Home Park	VA0063568	001	0.0096	Piney Creek unnamed tributary	30
Bedford County Schools - Staunton River High School	VA0063738	001	0.026	Shoulder Run unnamed tributary	30
Thousand Trails Lynchburg Preserve	VA0068543	001	0.0396	Mollys Creek	30
Clover Waste Water Treatment Plant	VA0073733	001	0.035	Clover Creek	30
Woodhaven Nursing Home - Montvale	VA0074870	001	0.005	South Fork Goose Creek unnamed tributary	30
Campbell Co Utility and Service Authority - Otter River Water Filtration Plant	VA0078646	001	0.0428	Big Otter River	30
Alum Springs Shopping Center	VA0078999	001	0.04	Buffalo Creek	30
Old Dominion Clover Power Station	VA0083097	001	1.735	Roanoke (Staunton) River	30
Old Dominion Pittsylvania Power Station	VA0083399	001	0.192	Roanoke (Staunton) River	30
Old Dominion Altavista Power Station	VA0083402	001	0.117	Roanoke (Staunton) River	30
Brookneal Town Water Treatment Plant	VA0084034	001	0.0006	Phelps Creek	30
Drakes Branch Waste Water Treatment Plant	VA0084433	001	0.08	Twitty's Creek	30
Montvale Wastewater Treatment Plant	VA0087238	001	0.05	South Fork Goose Creek	30
Dillons Trailer Park - Sewage Treatment Plant	VA0087840	001	0.018	Poorhouse Creek	55
Cedar Rock Waste Water Treatment Plant	VA0091553	001	0.015	Elk Creek unnamed tributary	30
Moneta Regional Waste Water Treatment Plant	VA0091669	001	0.5	Hunting Creek	30

G2.3.2. PCB Sources

Current Sources

The 12 point sources and 21 nonpoint sources described in Section 3.0 of *Roanoke River PCB TMDL Development* are represented as current PCB sources in the model. In addition to the known current sources, urban land areas throughout the model watershed have been assigned a level of contamination to account for unknown contaminated sites. Such areas are referred to as *urban background/unidentified* sources for the purposes of this TMDL.

Nonpoint Sources

The LSPC model was set up to represent nonpoint source loading of PCBs as a sediment-associated process. The sediment loads are simulated as a function of precipitation events and model parameters describing the erosive properties of model land uses. These loadings are the vehicle by which tPCBs are transported to waterbodies. For the representation of known contaminated sites, a PCB-contaminated land use was created. Using estimates of site footprints and locations, PCB land use areas were assigned to model subbasins. To maintain the sediment loading calibration presented in Section G2.7.3, a PCB land use category was created for each general land use with identical model sediment and hydrologic parameters (PCB-pasture, PCB-forest, PCB-urban, and others). The areas of PCB land uses are shown in Figures G3-2 through G3-4 of *Roanoke River PCB TMDL Development*.

Sites known to have PCB-contaminated soils were delineated into parcels as depicted in available aerial photography and USGS topoquads to estimate the contamination footprint. General model land use areas within the footprint were converted to corresponding PCB land uses and assigned a soils total PCBs (tPCBs) concentration, or *potency factor*, on the basis of available monitoring data. The soils monitoring data from the literature sources listed in Section 3.1 of *Roanoke River PCB TMDL Development* were used to estimate potency factors for known contaminated sites. A potency factor calculated from available sediment monitoring was also assigned to the remaining land areas in the watershed to capture loadings from unidentified contaminated sites. The following discussion does not apply to such areas.

The available soils monitoring data was aggregated and analyzed to establish trends that could be used to generalize model representation of PCB soils concentrations for nonpoint source land areas. The data suggest that two tiers of PCB land uses, moderately and highly contaminated areas, would be sufficient to capture the variability in soils contamination.

The LSPC model is set up to represent two separate land use parameter groups for the upper and lower Roanoke (Staunton) watershed sections. Though the land uses for the two sections are the same, they can be assigned independent parameter values. As a result, land uses for the upper and lower sections are, for modeling purposes, separate, giving unique moderately and highly PCB-contaminated areas for each. Therefore, the separation of the upper and lower Roanoke (Staunton) allows for four individual PCB land use potency factors [individual highly and moderately contaminated areas in the upper and lower Roanoke (Staunton)].

Two sites, BGF Industries and a hotspot within the contaminated site Virginia Scrap Iron Co., had median tPCBs soils concentrations of approximately 88 and 102 parts per million (ppm), respectively. The median concentration observed at those sites was at least two orders of magnitude greater than median concentrations measured at all other sites. BGF Industries is in the lower Roanoke (Staunton), while Virginia Scrap Iron Co. is in the upper. Thus, the median concentrations for each were used as the potency factors for highly contaminated areas in the respective sections. These are the only areas represented as highly contaminated in the model. Note that BGF Industries is permitted for stormwater discharges. The soils potency factor developed for the site was used characterize associated stormwater loads (see *Point Sources* in Section G2.3.2).

The tPCBs soils concentrations observed at the remaining contaminated sites were used to characterize moderate contamination. To derive potency factors for moderately contaminated areas, such sites were grouped according to the section of Roanoke in which they are located, and the associated potency factor was calculated as the mean soils concentration—1.8 and 2.4 ppm for upper and lower Roanoke (Staunton) sites, respectively. Table G2-7 lists the model-represented known contaminated sites and associated land area.

Table G2-7. Model PCB-contaminated sites[a]

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
Upper Roanoke River					
Dixie Caverns Landfill	VAD980552095[c]	Roanoke	Roanoke River	38.7	Moderate
Roanoke River Floodway Bench Cuts		Roanoke	Roanoke River	47.4	Moderate
Norfolk Southern 12		Roanoke City	Roanoke River	64.3	Moderate
Evans Paint	VASFN0305570[c]	Roanoke City	Roanoke River	1.7	Moderate
Virginia Scrap Iron Co.	VRP00408[d]	Roanoke City	Roanoke River	7	Moderate
				0.17	High
Norfolk Southern 1		Roanoke City	Roanoke River	2.5	Moderate

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
Tinker-American Electric Power (AEP) property		Roanoke City	Roanoke River	23	Moderate
Riverdale Development (formerly American Viscose Co.)	VRP00394[d]	Roanoke City	Roanoke River	81.1	Moderate
Appalachian Power Co. (APCO) Yard		Roanoke City	Roanoke River	0.8	Moderate
Jacob Webb		Roanoke City	Roanoke River	5.5	Moderate
Lower Roanoke (Staunton) River					
Burlington Industries-Altavista[b]	VA0001678	Pittsylvania	Sycamore Creek	116.3	Moderate
English Construction		Pittsylvania	Roanoke (Staunton) River	12	Moderate
West town dump-Altavista		Campbell	Lynch Creek	28	Moderate
Oil distributors-Altavista		Campbell	Lynch Creek	5.7	Moderate
Lane Furniture Co.		Campbell	Roanoke (Staunton) River	49.6	Moderate
BGF Industries[b]		Campbell	Roanoke (Staunton) River unnamed tributary	20.6	High
East town Dump-Altavista		Campbell	Roanoke (Staunton) River	14.5	Moderate
Altavista STP	VA0020451	Campbell	Roanoke (Staunton) River	25.6	Moderate
A. O. Smith		Campbell	Roanoke (Staunton) River unnamed tributary	7.7	Moderate
Schrader Bridgeport[b]		Campbell	Roanoke (Staunton) River unnamed tributary	16	Moderate
Dan River, Inc.	VA0001538	Campbell	Roanoke (Staunton) River	37.7	Moderate

a. The site acreage and contamination levels are those used in the model. It should be noted that these data are based on best available information during the PCB Source investigation. Both acreage and contamination levels are estimated with emphasis on the boldfaced sites.
b. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (see *Point Sources* in Section G2.3.2)
c. EPA Superfund ID#
d. Virginia Voluntary Remediation Program (VRP) site#

Unidentified contaminated sites are represented in the model by a tPCBs potency factor assigned to urban land uses in the watershed. The available PCB sediment monitoring data record was used as a surrogate to estimate the PCB concentration of TSS loads from the areas. The sediment monitoring record was aggregated by watershed section, and the median concentration was assigned to generally represent the PCB concentration of upland soils. The potency factor calculated for the upper and lower sections, 6.8 and 4.9 parts per billion (ppb), are well below the currently applicable Toxic Substances Control Act PCB cleanup levels for high-occupancy areas (1 ppm) (USEPA 2005).

Point Sources

PCB point sources for the TMDLs include traditional facility effluent, MS4s, and sites permitted for stormwater discharges. VADEQ provided an inventory of the three types of point sources to be included in the Roanoke River watershed model. The methods used to represent PCB loads from those sources are discussed below.

Facilities found to be discharging PCB-contaminated effluent as part of the 2005–2008 Special Study monitoring are represented as PCB point sources in the model. Baseline tPCB loadings were derived using a mean effluent flow rate generated using Discharge Monitoring Reports (DMRs) and tPCB concentrations set at the mean concentration calculated from the Special Study data set. Several additional facilities that were not part of the Special Study were included as PCB point sources at the request of

VADEQ. For the TMDL condition, the facility design flow was used along with the water quality target calculated for the watershed section in which the facility is located—390 picograms per liter (pg/L) for the upper and 140 pg/L for the lower—to represent facility tPCB loads. Facilities represented as PCB point sources and associated information including NPDES ID, mean monthly flow, and model represented effluent PCB concentration are presented in Table G2-8.

Table G2-8. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Mean monthly flow (mgd)	Mean PCB conc. (pg/L)
Upper Roanoke River					
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.02	390
Montgomery County PSA - Shawsville Sewage Treatment Plant	Sewerage systems	VA0024031	001	0.06	390
Montgomery County PSA - Elliston Lafayette Waste Water Treatment Plant	Sewerage systems	VA0062219	001	0.07	390
Steel Dynamics	Steel works	VA0001589	005	0.06	1,090
Norfolk Southern Railway Co - Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.009	390
WVWA Roanoke Regional Water Pollution Control Plant	Sewerage systems	VA0025020	001	37.35	340
Lower Roanoke (Staunton) River					
ITG Burlington Industries, LLC - Hurt Plant	Fabrics finishing	VA0001678	001	2.13	19,150
Old Dominion Pittsylvania Power Station	Electric Services	VA0083399	001	0.11	140
Altavista Town - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	1.54	10,000
Old Dominion Altavista Power Station	Electric Services	VA0083402	001	0.117	140
Dan River, Inc. - Brookneal	Fabrics finishing	VA0001538	001	0.68	500
Brookneal Town - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.04	140
Old Dominion Clover Power Station	Electric Services	VA0083097	001	0.75	190

VADEQ provided an inventory of MS4s and sites and facilities issued general permits for stormwater discharges in the Roanoke River basin. Such facilities are not subject to numerical criteria, but have responsibilities related to minimizing stormwater runoff and pollutant loads, and may be subject to monitoring requirements. Such areas are not represented explicitly in the model but are assigned PCB wasteload allocations in the TMDL. PCB loads for the areas are estimated as an area-weighted fraction of nonpoint source, land-use contributions with the PCB concentration represented by the appropriate potency factor.

Modeled land uses were overlain with GIS coverages of MS4s and sites covered by general stormwater permits to characterize the land use distributions of those areas. PCB loads for the permitted areas were calculated as the load generated by their respective land areas. Table G2-9 lists MS4s in the Roanoke River basin. Appendix C provides a list of sites and facilities covered by general stormwater permits. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit.

Table G2-9. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613

Town of Christiansburg	VAR040025	1,193

Legacy Sources

Legacy sources represented in the model are PCB contributions from contaminated streambed sediments and background atmospheric deposition of PCBs to surface waters. Those sources exist at an interface with the affected waterbody and can be characterized as nonpoint sources.

Contaminated Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical or current loadings or both. The PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers. The processes of adsorption/desorption and diffusion are discussed in Section G2.7.4, and a discussion of the in-stream processes of streambed sediment resuspension and deposition is presented in Section G2.7.3.

The mass of PCBs in streambed sediments available for loading at the beginning of the simulation period is set as an initial condition in the LSPC model setup. It is defined by a sediment tPCBs concentration and streambed depth, density, and porosity assigned to each model-represented stream class. The Roanoke River basin model includes an individual stream class for each model subbasin-representative stream reach, as discussed in Section G2.2.3. Stream classes define critical in-stream parameters including initial sediment pollutant concentration, streambed depth, density, and porosity. Assigning individual stream classes to each subwatershed stream reach allows model parameters to be specific to each reach.

The streambed sediment PCB concentrations for each model stream class were initially estimated as the mean concentration from the data record for monitoring stations within its associated subwatershed. In some cases, the data were adjusted slightly during the water quality calibration (see Section G2.7.4). Streambed depths were estimated as a function of the average modeled shear stress in each subwatershed stream reach. Higher shear stresses are a function of increasing channel slope and decreasing cross-sectional area. Stream reaches with higher shear stress values were assigned shallower streambed depths. The initial sediment PCB concentrations and streambed depths assigned to each reach class and associated subwatershed stream reach are presented in Appendix D.

Background Atmospheric Deposition

The net exchange of gas-phase molecules between the atmosphere and a waterbody (dry atmospheric deposition) is a function of the relative concentrations of the chemical in each. There are no available data to characterize the atmospheric and water column concentrations of gaseous PCBs in the Roanoke River watershed. The Chesapeake Bay Program Atmospheric Deposition Study (Chesapeake Bay Program 1999) has estimated net dry atmospheric tPCBs deposition rates for urban and regional (nonurban) areas in the Chesapeake Bay watershed as 16.3 and 1.6 $\mu g/m^2/yr$, respectively (ICPRB 2007). The regional atmospheric deposition rate was applied to the entire Roanoke River watershed as an estimate of local conditions. If local data become available, they will be incorporated into future TMDL studies.

G2.4. Model Boundary Condition

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from the River headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam to its confluence with the Dan River. Because there is no dynamic link between the two, to accurately represent the lower watershed, discharge data for the Leesville Dam, which represents all upstream flows to that point on the river, were incorporated as a model boundary condition.

To account for the PCB loadings from sources in the upper and middle Roanoke, a boundary condition PCB water concentration was assigned to the model-represented Leesville Dam discharge. The boundary water column concentration was estimated from available fish tissue data collected at monitoring station ROA140.66—which is the only monitoring station in Leesville Reservoir—using calculated bioaccumulation factors (BAFs) for resident fish species. A BAF-converted fish tissue PCB concentration is an estimate of the ambient water quality that captures all upstream source contributions and associated watershed and in-stream processes.

Four fish tissue records were converted into equivalent water column concentrations, giving a concentration range of 40.0–120.0 pg/L and a median concentration of 79.0 pg/L. The median value was assigned as the model boundary condition. That value is significantly lower than the applicable state human health water quality criterion for PCBs (1,700 pg/L) and is indicative of Leesville Reservoir's status as unimpaired for PCBs. Discussion of the methodology for developing and applicability of BAFs is presented in Appendix A.

G2.5. Model Assumptions

The major underlying assumptions associated with the Roanoke River model development are as follows:

- Bioaccumulation interactions between organisms are assumed to be negligible.
- The impact of sediment transport and siltation on channel geometry is not significant.
- No significant vertical stratification is assumed in the stream reaches.
- Each LSPC reach is assumed to be completely mixed for water quality parameters.
- The Chesapeake Bay Program regional net atmospheric deposition rate provides a reasonable estimate of volatilization and atmospheric deposition in the watershed.
- The decay rate of PCBs is assumed to be negligible.

G2.6. Model Limitations

The major limitations associated with the Roanoke River model are as follows:

- LSPC is a spatially lumped model and does not represent the spatial orientation of individual land uses within a subwatershed.
- Land uses and stream channel cross sections are fixed and constant throughout the modeling period.
- Stratification effects cannot be simulated because of representation as a completely mixed system. Lateral spatial gradients within the main channel or within tributaries cannot be represented.
- The model simulates the behavior of tPCBs representing overall behavior and trends. Variability in behavior that is seen at the congener/homolog level is generalized for a homolog grouping that is representative of the system.
- No explicit representation of organic carbon exists in the model. Organic carbon content of sediments is incorporated in the calculation of PCB partition coefficients
- The completely mixed system results in a single PCB dissolved phase; thus, model representation of streambed sediment and water interactions consist of only water column interactions (no pore water).

G2.7. Existing Conditions/Model Calibration and Validation

The model was developed in a step-wise manner, beginning with basic watershed processes and building on them to ultimately represent tPCB loading and transport. The foundation of the model is simulated hydrology. On the basis of the calibrated hydrology, sediment loading and transport were simulated and calibrated. Watershed hydrology and sediment simulations provide the framework for PCB loadings and transport modeling. The sections that follow discuss the development of each aspect of the watershed model.

G2.7.1. Selecting a Representative Modeling Period

Selecting a representative modeling period was done using the availability of stream flow and water, fish tissue, and sediment monitoring data collected in the Roanoke River watershed that cover varying wet and dry periods. VADEQ has collected water, fish tissue, and sediment monitoring data for the Roanoke River since 1973, but the period of 1990–2008 was selected for modeling purposes. That period includes monitoring results in step with modern analytical methods and includes varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area.

G2.7.2. Hydrology

Hydrology and water quality calibration are performed in sequence, because water quality modeling is dependent on an accurate hydrology simulation. The driver of model hydrology is climatological data, described in Section G2.2.1. Such data are used as input to simulate the watershed water balance within the LSPC model framework that describes the watershed subbasin network, topology, land use, soils, and reach characteristics.

Hydrology Representation

The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, were used to represent hydrology for all pervious and impervious land units (Bicknell et al. 1997). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC was required. Such parameters are associated with infiltration, groundwater flow, and overland flow.

Water Withdrawals

The Western Virginia Water Authority (WVWA) Roanoke Regional Water Pollution Control Plant (RRWPCP) (NPDES ID VA0025020), also known as the WVWA Water Pollution Control Plant, the Roanoke City Regional Water Pollution Control Plant, and the Roanoke City Wastewater Treatment Plant (WWTP), represents a large, continuous discharge to the mainstem of the Roanoke River in the upper model segment. The facility processes wastewater collected by the municipal sewer system serving the cities of Roanoke, Salem, the Town of Vinton, and parts of Botetourt and Roanoke Counties. Data obtained from VADEQ's Water Supply Planning Program (WSP) indicates that seven surface water withdrawals in the upper segment provide water for municipal use in the sewer service area. Those withdrawals are represented in the model according to time series obtained from WSP to account for the discharge coming from the WVWA facility, balancing the water budget for the area. Major surface water withdrawals in the lower Roanoke (Staunton) segment are also represented in the model. Surface water withdrawals represented in the upper and lower model segments are presented in Table G2-10.

Table G2-10. Model surface water withdrawals

Owner	System	Source	Average withdrawal (cfs)	Model segment
Altavista, town of	Altavista	Mcminnis Spring	0.48	Lower
Altavista, town of	Altavista	Reed Creek	0.32	Lower
Altavista, town of	Altavista	Reynolds Spring	0.40	Lower
Altavista, town of	Altavista	Roanoke River	1.86	Lower
Bedford, city of	Bedford, City	Big Otter River	0.05	Lower
Bedford, city of	Bedford, City	Stoney Creek Reservoir	1.77	Lower
Brookneal, town of	Brookneal	Phelps Creek Reservoir	0.22	Lower
Campbell County USA	Central System Service Area	Big Otter River	2.24	Lower
Dan River, Inc	Brookneal Plant	Falling River	1.43	Lower
Furniture Brands International	Altavista Plant	Roanoke River	2.36	Lower
ITG/Burlington Industries Inc	Hurt Plant	Roanoke River	0.41	Lower
ITG/Burlington Industries Inc	Hurt Plant	Sycamore Creek	4.43	Lower
Salem, city of	Salem WTP	Roanoke River	5.43	Upper
Salem, city of	Salem WTP	Roanoke River-Salem old WTP 1	4.81	Upper
Western VA Water Authority	Roanoke, City	Beaver Creek Res - Falling Creek	0.93	Upper
Western VA Water Authority	Roanoke, City	Crystal Spring	5.06	Upper
Western VA Water Authority	Roanoke, City	Carvins Cove Reservoir	20.48	Upper
Western VA Water Authority	Spring Hollow Reservoir	from Roanoke River	14.23	Upper

Surface water withdrawals, on average, account for 64 percent of the volume being discharged from the RRWPCP (Figure G2-6). Though the RRWPCP is a dedicated sewer system, after discussion with VADEQ and reviewing available discharge records, it was concluded that a significant volume of rainwater runoff makes its way into the system through inflow and infiltration. For purposes of model representation, it was assumed that the difference in withdrawal and RRWPCP discharge volumes are due to the inflow and infiltration of stormwater into the sewer system. To represent this process, the volume difference between withdrawals and RRWPCP discharge was represented as a withdrawal evenly distributed to all model subwatersheds draining the cities of Salem and Roanoke.

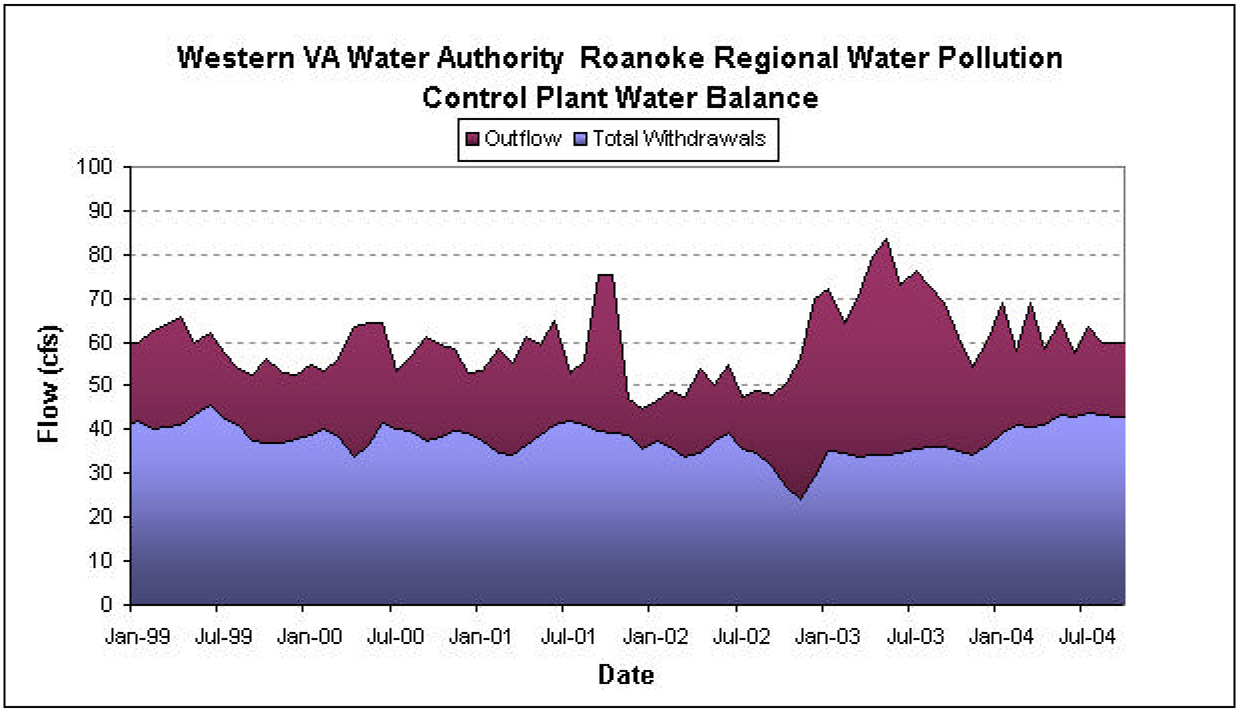

Figure G2-6. WVWA Roanoke Regional Water Pollution Control Plant water balance.

Hydrology Calibration/Validation

Land use-specific hydrology parameters are used to calibrate modeled hydrology. Calibration involves a comparison of the modeled and observed flow rates at locations in the watershed where observed data are available. Appendix D presents LSPC Hydrology parameters and the range of values used for the Roanoke River watershed model.

STATSGO served as a starting point for designating infiltration and groundwater flow parameters. Starting values were refined through the hydrologic calibration process. As discussed in Section G2.2.2, a custom land use data layer was developed that accounts for the variability of hydrologic characteristics throughout the watershed. To account for topography variability in the upper and lower Roanoke (Staunton), two groups of land use parameters were configured in the model. This allows for the designation of separate hydrology parameter values for the upper and lower segments. Assigning appropriate parameter values was dependent on the composite hydrologic soil group/land cover distribution of each subwatershed.

Average daily flow discharge data were available for eight and seven USGS gages in the upper and lower Roanoke (Staunton) River, respectively (Figure G2-7). The upper Roanoke watershed model was calibrated using daily stream flow data from USGS gages 02056000 and 02053800, while the lower Roanoke (Staunton) was calibrated using gages 02066000 and 02061500. USGS gages 02056000 and 02066000 were selected as calibration points because they represent the farthest downstream locations in the upper and lower sections and capture the distribution of land uses and soil groups in each. An accurate model calibration at those points would capture the overall water budget for the upper and lower Roanoke (Staunton) and reflect the cumulative range of flows for their entire stream networks.

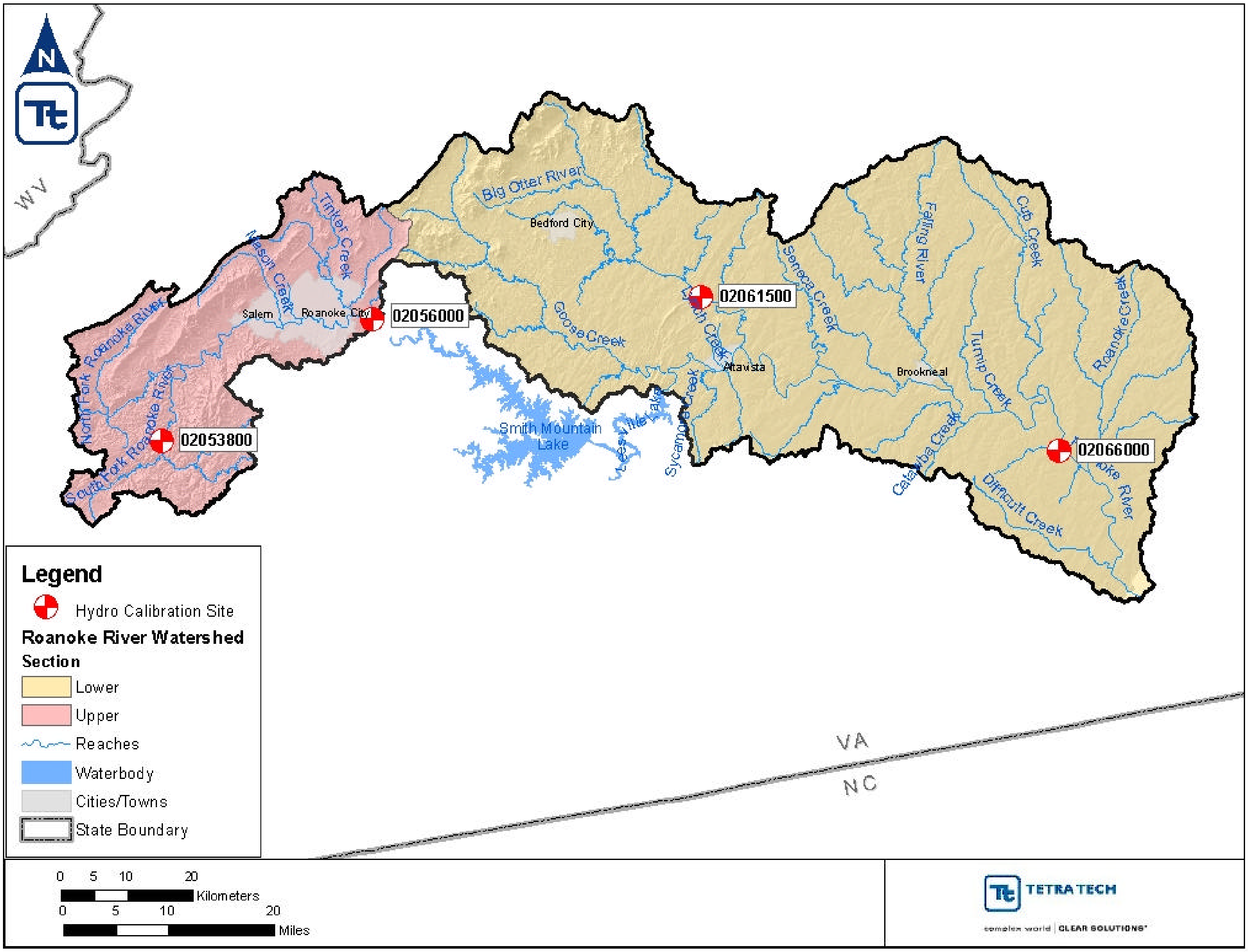

Figure G2-7. Locations of hydrology calibration USGS gages.

USGS gages 02053800 and 02061500 are on tributaries to the upper and lower Roanoke (Staunton)—South Fork Roanoke River and Big Otter River, respectively—and were used as calibration points to verify the applicability of the calibration to smaller areas within watersheds. Agreement between simulated and observed flows at both mainstem and tributary points would suggest an accurate hydrologic system representation of the upper and lower Roanoke (Staunton) watersheds. The USGS gages used for calibration are listed in Table G2-11.

Table G2-11. USGS continuous daily discharge gages used for hydrology calibration

Site ID	Station name	Drainage area (square miles)	Period of record
Upper Roanoke River			
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1990–5/31/2008
02056000	Roanoke River at Niagra, VA	509	1/1/1990–5/31/2008
Lower Roanoke (Staunton) River			

Site ID	Station name	Drainage area (square miles)	Period of record
02061500	Big Otter River near Evington, VA	315	1/1/1990–5/31/2008
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1990–5/31/2008

Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period
2. Representation of low-flow, average-flow, and high-flow water years
3. Consistency of selected period with key model inputs (i.e., land use coverage)
4. Quality of initial modeled versus observed data correlation

After a review of the data for these four selection criteria, the years 2004 and 1996 were chosen as calibration periods for the upper and lower Roanoke (Staunton), respectively. The NLCD land use coverage used in the model was developed in 2001; therefore, the selected calibration periods are consistent with that key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a period of 18.5 years (January 1, 1991, through May 31, 2008) for both the upper and lower watersheds.

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved adjusting infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results are presented in Appendix E. It is important to note that although the included log plots allow for comparative visualization of flows that span several orders of magnitude, that type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows.

Overall, the calibrated model predicted the watershed water budget well. All model validations showed the modeled water budget to be within 9 percent of observed conditions. Predicted seasonal volumes were also within recommended ranges at every location. Predicted storm volumes and storm peaks also closely matched observed data. Because the runoff and resulting stream flow are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorological and gage stations.

G2.7.3. Sediment

In-stream sediment concentrations are modeled as a function of discrete processes including erosion of soil particles from land areas, transport of eroded sediments to streams, and in-stream transport, scour, and deposition of sediments. Sediment loadings are dependent on hydrologic conditions, particularly the amount and timing of surface runoff, while in-stream processes are dependent on the unique hydraulics of each reach.

Sediment Representation

Land Loads

Sediment erosion from pervious land areas is represented as the net mass of soil particles detached from the land surface by rainfall and transported by overland flow. Sediment loadings to streams are estimated by land use category and are represented as the sum of three particle size fractions (sand, silt, and clay). Model parameters are closely related to the factors of the USLE (Wischmeier and Smith 1978). On impervious surfaces, sediment loadings are determined by an estimated rate of soil particle accumulation.

In addition to sediment loadings simulated as the result of soil detachment, LSPC allows for the specification of fixed event mean concentrations.

Point Sources

In the Roanoke River watershed, 52 facilities representing 55 outfalls are permitted for discharging TSS loads. TSS discharges from point sources are assumed to be composed entirely of silt. For a discussion of the model representation of such sources, see Section G2.3.1.

In-stream Processes

The in-stream processes of deposition, scour, and transport determine how sediment loadings are translated to water column sediment concentrations (TSS). In-stream sediment dynamics are dependent on the hydraulic characteristics of a stream reach, which are represented by an FTABLE that defines the relationships among stage (depth), storage (volume), surface area, and discharge. Model FTABLEs are automatically generated by LSPC as a function of stream channel cross sections. As discussed in Section G2.2.3, model stream channel cross sections were estimated as function of drainage area. To date, no field measurements of channel cross sections have been made for streams in the Roanoke River basin with which to verify estimates.

Streambed deposition, scour, and sediment transport for silt and clay are determined by adjustable critical shear stress values. Two shear stress parameters, one for scour and one for deposition, establish a range above and below which scour and deposition occur, respectively. If the shear stress resulting from stream velocity is within the established range, sediment transport occurs (Figure G2-8). In-stream deposition, scour, and transport of sand are determined by the average stream flow velocity. For a given velocity, sand transport capacity is established, and scour and deposition occur when in-stream concentrations are below and above capacity, respectively. Note that although scour and resuspension alter the depth of the streambed throughout the simulation period, the initial channel cross section is assumed to be fixed.

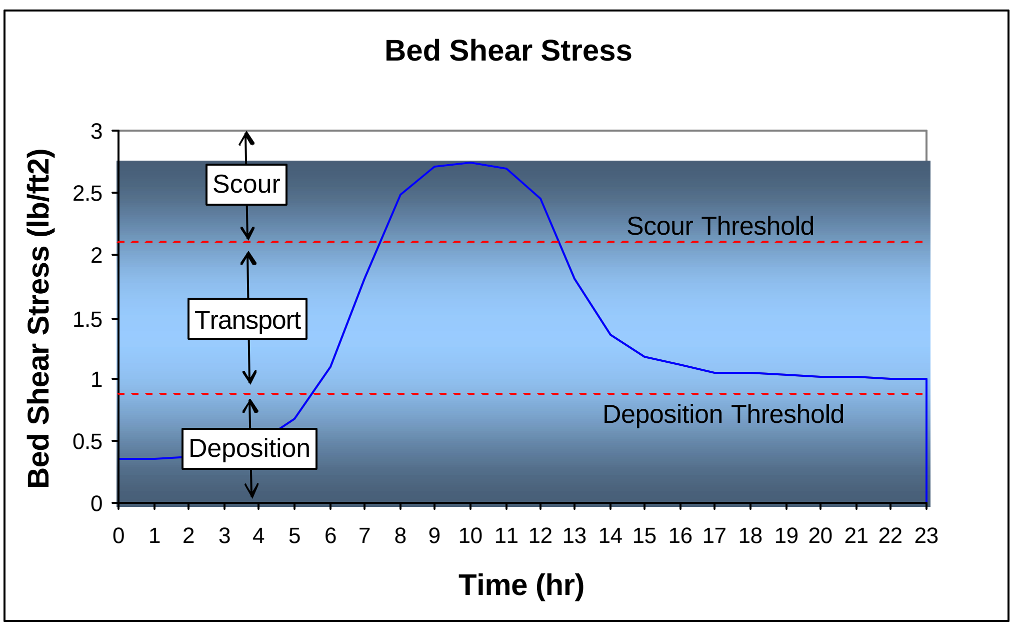

Figure G2-8. Model representation of in-stream cohesive particle dynamics.

Because no stream reach cross-section data were available at the time of TMDL development, the model generated FTABLEs were assumed to reasonably represent field conditions. To maintain a hydrologic regime where high- and low-flow events are associated with streambed scour and deposition, respectively, individual stream classes were assigned to each subwatershed stream reach as discussed in Section G2.2.3. Stream classes define critical in-stream parameters including the critical stress thresholds that determine the occurrence of streambed scour and deposition.

Sediment Calibration

Land use and stream class specific sediment parameters are used to calibrate modeled sediment loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed sediment loads and TSS concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC sediment parameters and the range of values used for the Roanoke River watershed model.

Sediment land use parameters are closely related to the factors of the USLE (Wischmeier and Smith 1978), which served as a starting point for designating related soil detachment and washoff parameters. Appropriate values were assigned to the composite land use on the basis of the land cover description and hydrologic soil group. Starting values were refined through the sediment calibration process. Event mean concentrations were also defined to represent background concentrations not captured by the discrete erosive processes simulated by the model, particularly for low-flow conditions. All sediments and soils represented in the model are assigned particle class fractions (e.g. % sand, silt, clay). Analysis of the distribution of STATSGO soil groups in the watershed was used to estimate the particle class fractions of eroded upland soils.

In-stream sediment parameters are based primarily on the physical properties of the particle class fractions including particle diameter, fall velocity, and density. Such properties were estimated from the range of literature values presented in *EPA BASINS Technical Note 8, Sediment Parameter and Calibration Guidance for HSPF* (USEPA 2006). Streambed volume and porosity are parameters describing physical properties that represent the streambed as a whole. Streambed volume was estimated as described in Section G2.3.2, and streambed porosity was estimated on the basis of the literature source mentioned above. VADEQ monitoring data was used to estimate the particle class composition of the streambed for each model stream class.

As described above, a unique stream class was assigned to each subwatershed stream reach, which allowed individual in-stream parameters to be designated for each, including critical stress thresholds and streambed characteristics. This allowed for the representation of a consistent hydrologic regime where high- and low-flow events are associated with streambed scour and deposition, respectively. Shear stress thresholds for scour were designated for each subwatershed as the modeled 70th percentile shear stress value. Because of the free-flowing nature of the modeled segments, shear stress values for deposition were set to values simulated in subwatersheds where deposition is likely to occur, including near impoundments. Such a simplification of field conditions was necessary in lieu of available monitoring data verifying stream channel cross-section geometry. If the data become available, they can be incorporated in future TMDL studies.

Observed TSS data are available for 21 and 43 monitoring stations in the upper and lower Roanoke (Staunton), respectively. On the basis of the number of data records and co-location with USGS continuous flow gages, the Roanoke River watershed model was calibrated for sediment using TSS monitoring stations ROA227.42, ROA204.76, ROA97.46, and ROA67.91 (Figure G2-9). Stations at river mile 227.42 and 204.76 are in the upper Roanoke model segment, while stations at river mile 97.46 and 67.91 are in the lower Roanoke (Staunton) model segment. General descriptions of those monitoring locations are presented in Table G2-12.

Table G2-12. TSS monitoring station used for TSS calibration

Station ID	Station description	Period of record	Associated flow gage
Upper Roanoke River			
4AROA227.42	Rt. 773 at gaging station in Lafayette, VA	1/10/1990–5/9/2007	USGS 02054500
4AROA204.76	Roanoke River at Roanoke City, VA	10/13/2005–11/22/2005	USGS 02055000
Lower Roanoke (Staunton) River			
4AROA097.46	Roanoke River at Brookneal gage, Rt. 50	1/24/1990–5/1/2007	USGS 02062500
4AROA067.91	Rt.746 bridge (Watkina Bridge) near Randolph, VA	2/1/1990–9/10/2007	USGS 02066000

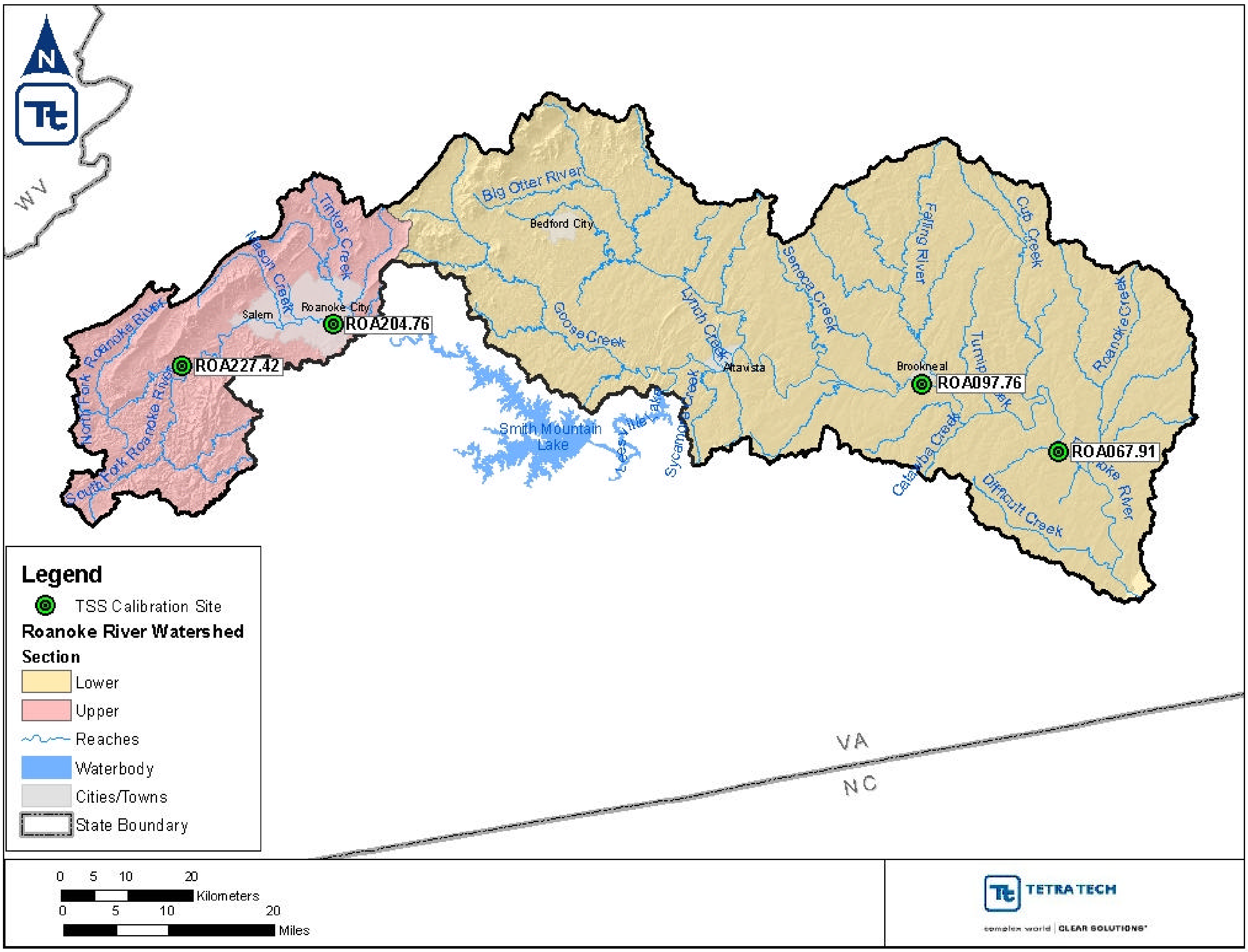

Figure G2-9. Locations of TSS monitoring calibration stations.

Sediment simulations were run for the model time series as described in Section G2.7.1. Antilog plots of flow versus sediment loads for observed and modeled data are presented in Appendix F for the selected calibration locations. In general, the magnitude of sediment loadings for observed and modeled data increase at a similar rate and are within the same range for the gradient of flow conditions. Observed loadings are, generally, more variable in relation to flow conditions than in modeled scenarios. Log plots comparing model output to observed TSS concentrations at the selected locations are also presented in Appendix F. Note that observed concentrations reported as detection limits have been assigned a concentration of 3 mg/L.

G2.7.4. PCBs

LSPC was configured to simulate tPCBs in both the dissolved- and sediment-associated states to characterize water quality conditions in the Roanoke River watershed. The simulation of loadings and in-stream behavior of tPCBs as a sediment-associated pollutant is dependent on the hydrologic and TSS calibrations that serve as its foundations.

The model was set up to represent a unique stream class for each subwatershed stream reach as discussed in Section G2.2.3. Each model stream class defines critical in-stream parameters, including the conditions related to the mass balance of PCBs for the sediment-water system in each stream reach. PCBs are partitioned into dissolved and particulate fractions in both the water (PCB with suspended sediment interaction) and sediment layers (PCB with bed sediment interaction). LSPC simulates deposition (settling) and scour (resuspension) of PCBs with sediment, in addition to sorption/desorption and in-stream losses.

PCB Representation

The LSPC model was configured to simulate PCBs in both the dissolved- and sediment-associated states. PCBs typically adsorb to sediment particles, which are transported into streams and rivers through erosion. Simulation of a pollutant as sediment-associated, therefore, requires that land loadings be tied to eroded soils. Once in-stream, the pollutant is partitioned into dissolved- and sediment-associated states. While sediment-associated, in-stream transport, accumulation, and attenuation of PCBs are subject to the processes of in-stream transport, deposition, and resuspension that characterize the movement of sediments. Dissolved PCB concentrations are defined by a partition coefficient that specifies the equilibrium concentration of PCBs in the water and on sediments. In LSPC, movement of PCBs between the dissolved- and sediment-associated states occurs solely as adsorption and desorption, which approaches equilibrium as defined by the partition coefficient and adsorption/desorption rate.

Partitioning Coefficient

A sediment partition coefficient (K_d) describes the tendency of a pollutant to exist in the dissolved state in an aqueous environment. The greater the K_d value, the less tendency the pollutant has to be dissolved. K_d is estimated for PCBs as a function of the PCB octanol-water partition coefficient (K_{ow}) and the organic carbon content of the sediments (f_{oc}) (Karickhoff et al. 1979). K_{ow} varies for different PCB homologs and increases with increased chlorination. The sediment partition coefficient is calculated as follows:

$$K_d = 1 \times 10^{-6} \times f_{oc} \times K_{ow}$$

where

K_d = the distribution coefficient between dissolved- and sediment-associated state (L/mg)
f_{oc} = weight fraction of the total carbon in the solid matter (gC/g)
K_{ow} = octanol-water partition coefficient (ug/$L_{octanol}$/ug/L_{water})

Simulation of Adsorption/Desorption

LSPC uses the equation developed by Onishi and Wise (1979) that describes the transfer of a chemical between the dissolved and adsorbed (sediment-associated) state on sediment type J. LSPC represents three particle classes (sand, silt, and clay) for suspended and streambed sediments giving six J sediment types.

$$\frac{d(RESDJ \times SQALJ)}{dt} = RESDJ \times KJT \times (K_d \times DQAL - SQALJ)$$

where

RSEDJ = total quantity of sediment type J in the stream (mg)
SQALJ = concentration of pollutant on sediment type J (mg/mg)
DQAL = concentration of dissolved pollutant (mg/L)
KJT = temperature corrected transfer rate between dissolved state and sediment type J

Thus, adsorption of a pollutant by sediment or desorption from sediment is assumed to occur toward an equilibrium condition with transfer rate KJT if the particulate pollutant concentration differs from its equilibrium value (Bicknell et al. 1997). The conservation of mass is in the stream is, therefore, described as follows:

$$\sum_{j=1}^{6}(RSEDJ \times SQALJ) + (VOL \times DQAL) = TOT$$

where

VOL = volume of water in the stream
TOT = total quantity of pollutant in the stream

Total PCBs

The model was set up to represent PCBs in the watershed as tPCBs, or the sum of all possible 209 congeners. This simplification required that congener-specific PCB properties (K_d and KJT) be generalized for model representation. K_d and KJT are defined in the model for both suspended and bed sediments. Available congener data was analyzed to determine dominant homolog groups, which were used to define the K_d and KJT parameters as described in the PCBs Calibration section.

PCB Calibration

Land use and stream class specific PCB parameters are used to calibrate modeled PCB loading and in-stream processes, respectively. Calibration involves a comparison of the modeled and observed PCB concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC PCB parameters and the range of values used for the Roanoke River watershed model.

Land use parameters define the PCB potency factors of the individual model land uses. Developing and applying land use potency factors is described in Section G2.3.2.

Monitoring data collected by VADEQ were used to define the model's design and representation of critical parameters required for simulating PCBs in each stream class. Such parameters include the following:

- Particle class fractions of upland soils and streambed sediments
- The initial tPCBs concentration of particle class fractions
- Partition coefficients as a function of the fraction of the organic carbon content in stream sediments and homolog composition of PCB contamination
- Adsorption/desorption rates as a function of the homolog composition of PCB contaminated suspended sediments

Particle Class Fractions

Particle class fractions of upland soils and streambed sediments were estimated as described in Section G2.7.3.

Initial Total PCBs Concentration in Particle Class Fractions

The initial tPCBs concentrations of upland soils were estimated as described in Section G2.3.2. This concentration was assumed to be evenly distributed throughout the three particle class fractions. PCBs' affinity for non-polar media is activated when in a polar (aqueous) environment. The organic carbon content of different particle classes in upland soils, therefore, has little or no effect on its distribution between them.

VADEQ monitoring data were used to estimate the particle class composition of the streambed in each model stream class as described in Section G2.7.3. On the basis of that estimated composition, the percent cohesive mass (e.g. silt + clay) was defined and used to assign a normalized tPCBs concentration to the cohesive fraction of streambed sediments using available whole sediment sample monitoring data. PCB sediment monitoring data was assigned to each stream class as described in Section G2.3.2. The sand fraction of streambed sediments was assumed to have a negligible PCB concentration. The sorption of PCBs to sediment in an aqueous environment is a function of organic carbon content. The organic carbon content of sand is assumed to be zero for the purposes of this TMDL study (Hamrick 2007). In addition, the difference in the organic carbon content of silt and clay is assumed to be negligible. PCBs, therefore, are not represented as having a greater affinity for either (see the discussion of developing partition coefficients).

Partition Coefficients

VADEQ sediment and water column PCB monitoring data included measures of total organic carbon (TOC) concentrations and tPCBs homolog composition. The data were used to develop partition coefficients for suspended and streambed sediment associated tPCBs. Note that the available TOC monitoring data are for whole samples and do not specify the organic content of individual particle classes. As a result, it was assumed that the organic content of sediments was evenly distributed throughout the cohesive fraction.

Individual partition coefficients were developed for bed sediment associated PCBs in each stream class, while watershed section specific (upper and lower) partition coefficients were developed for suspended sediment-associated PCBs. A distinction in the scale at which partition coefficients were developed was made because while streambed sediments tend to be relatively stationary, suspended sediments move rapidly through a stream system. Thus, variability in PCB homolog partitioning behavior is generalized at the subwatershed and watershed section scale for PCBs associated with streambed and suspended sediments, respectively.

Streambed sediment PCB homolog and organic carbon data were grouped by stream class to calculate partition coefficients for each. Partition coefficients were calculated as a function of the representative homolog and the average percent TOC, where a representative homolog is defined as the percent composition weighted average homolog. A representative homolog represents a hypothetical tPCBs homolog and is used to define the tPCBs K_{ow}. Stream classes for which there were no available TOC or homolog data were assigned median data set values. Suspended sediment-associated PCB partition coefficients were calculated similarly to those in streambed sediments, except water column homolog and organic carbon data were grouped by watershed section, and median values were used.

Adsorption/Desorption Rates

A range of adsorption/desorption rates for PCB homologs is presented in a study of PCB desorption in Hudson River sediments (Schneider 2005). Those rates were used to designate the adsorption/desorption rate for tPCBs on suspended sediments in the Roanoke River model. The median representative homologs from water column PCB monitoring data for the upper and lower Roanoke (Staunton) sections were used to define the representative rate for each. The adsorption/desorption rate for PCBs in streambed sediments was calibrated on the basis of observed low-flow water column PCB concentrations.

Observed water column PCB data are available for 29 monitoring stations throughout the Roanoke River watershed. The stations were sampled as part of the 2005–2008 PCB monitoring special study conducted by VADEQ (see Section 2.3 of *Roanoke River PCB TMDL Development*). On the basis of the confidence in the analytical results of the sampling data, the Roanoke River watershed model was calibrated at the 24 PCB monitoring stations shown in Figures G2-10 and G2-11. General descriptions of the monitoring locations are presented in Table G2-13.

Table G2-13. PCB monitoring stations used for PCB calibration

Monitoring station	Station description	Sample dates
Upper Roanoke River		
4AROA227.42	Rt. 773 at gaging station in Lafayette	3/3/08, 4/7/08
4AROA212.17	419 Bridge near Lewis Gale	3/3/08, 4/7/08
4AROA207.08	Roanoke River at Memorial Bridge	3/3/08, 4/7/08
4AROA204.76	Roanoke River at Walnut Ave. in Roanoke City	3/3/08, 4/7/08
4AROA199.20	Roanoke River just upstream Niagara Dam	3/3/08, 4/7/08
Lower Roanoke (Staunton) River		
4AGSE000.20	Goose Creek	9/10/07, 10/26/07
4AROA131.55	Rt. 29 Bridge bypass, Altavista	8/8/07, 5/9/08
4ALYH000.17	Lynch Creek at Riverside Park	5/9/2008
4ASCE000.26	Sycamore Creek near Pocket Road	8/27/2007
4AROA129.55	Roanoke River near business Rt. 29 bridge at USGS gage	8/8/07, 10/26/07, 5/9/08
4AXLN000.00	Unnamed trib on BGF property	12/1/2007
4ABOR000.62	Big Otter River at Rt. 712	8/21/07, 10/26/07
4AROA127.79	Roanoke River downstream of Altavista STP	8/9/2007
4AROA124.59	Roanoke River downstream Altavista	3/10/08, 5/9/08
4AROA108.09	Roanoke River near Long Island	9/10/2007
4AFRV002.78	Falling River downstream of lagoon outfall	9/10/2007
4AROA097.76	Roanoke River upstream of Brookneal	8/8/07, 3/6/08
4AROA090.50	Roanoke River at Rt. 620 South of Brookneal	8/8/07, 10/26/07
4ACUB002.21	Cub Creek at Rt. 649 (Coles Ferry Road)	8/28/07, 10/26/07
4AROA067.91	Roanoke River near Rt. 746	9/10/07, 10/26/07
4AROC001.00	Roanoke Creek near Saxe	8/28/07, 10/26/07
4ABWC001.00	Black Walnut Creek	10/26/2007
4AROA059.12	Roanoke River near Rt. 360 - Clover	9/10/07, 10/26/07
4ADFF002.02	Difficult Creek at Rt. 716	8/28/2007

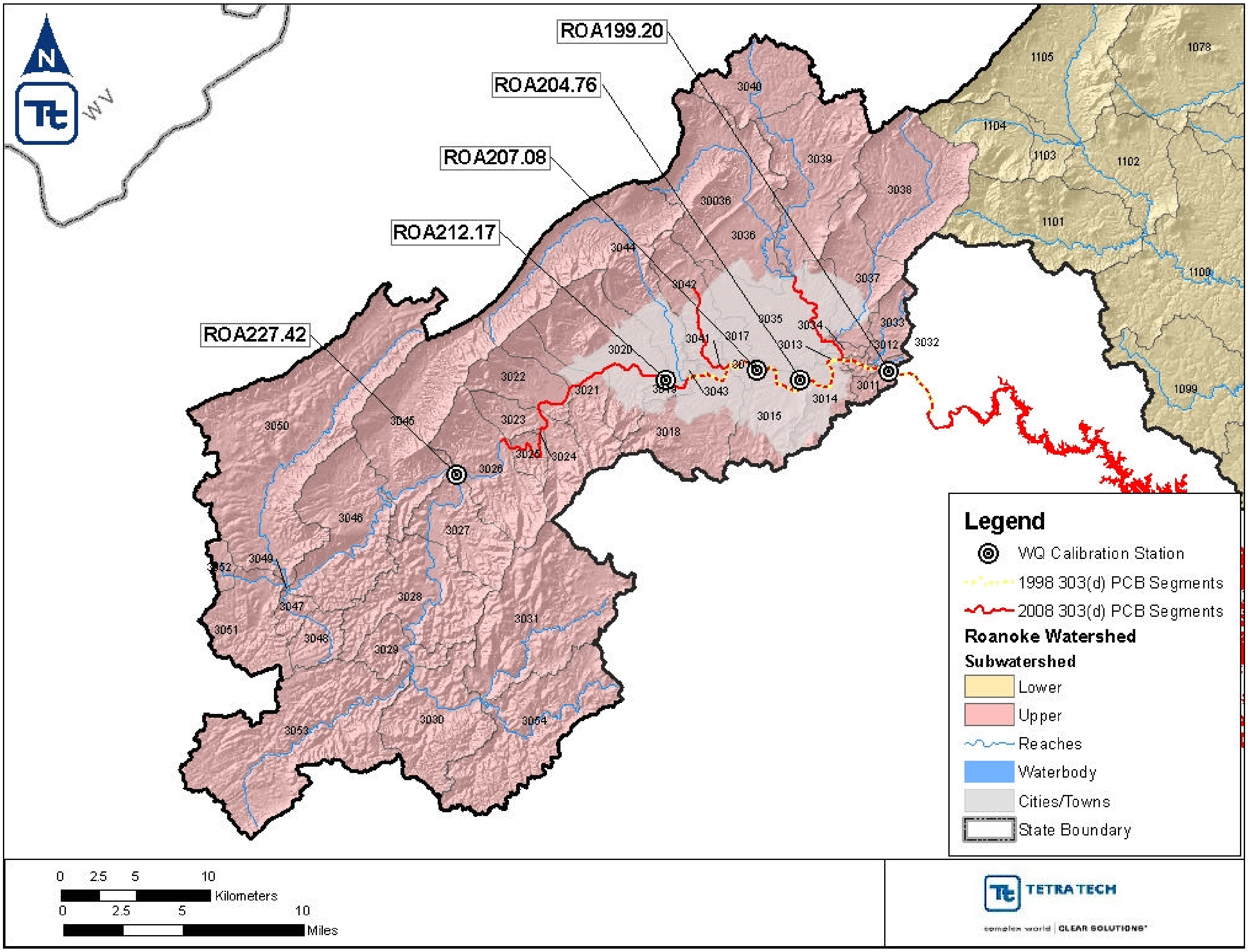

Figure G2-10. Locations of upper Roanoke PCB monitoring calibration stations.

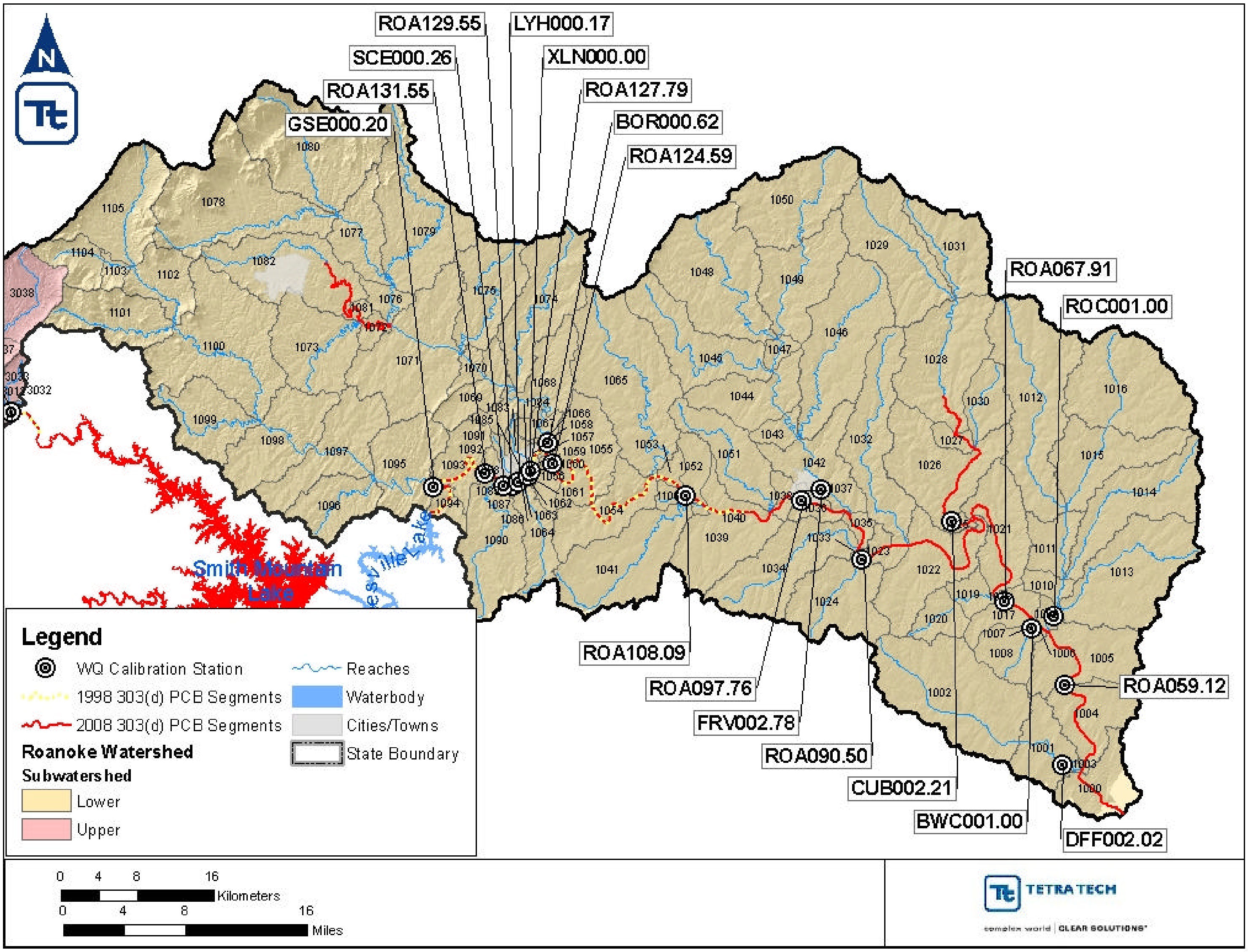

Figure G2-11. Locations of lower Roanoke (Staunton) PCB monitoring calibration stations.

PCB simulations were run for the model time series as described in Section G2.7.1. Log plots for observed and modeled tPCBs are presented at the selected calibration locations in Appendix F. In general, the model captures the trends and magnitude of contamination observed in the monitoring data.

At locations with significant upstream contaminated sources and high in-stream shear stresses, storm events cause in-stream concentration spikes as contaminated soils are transported to streams and contaminated streambed sediments are resuspended, releasing associated PCBs. In areas where there are few or no contaminated sites or streambed sediments, storm events cause in-stream tPCBs concentrations to decrease as clean inflows dilute the PCB concentrations directly fluxing from streambed sediments and atmospheric deposition. Finally, in areas where there are highly contaminated streambed sediments and relatively low in-stream shear stresses, the direct flux of PCBs from streambed sediments dominate water column concentrations, whereby storm events cause in-stream tPCBs concentrations to decrease even though there could be significant areas of upstream contaminated soil.

In addition, the magnitude of modeled low-flow and high-flow tPCBs concentrations are generally within the same magnitude as the observed data. This suggests that upland soils contamination areas and PCB concentrations, initial streambed sediment PCB concentrations, and water column-streambed sediment dynamics are being represented appropriately.

G3. REFERENCES

Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., A.S. Donigian, Jr., and R.C. Johanson. 1997. Hydrological Simulation Program—FORTRAN, User's manual for version 11. EPA/600/R-97/080. U.S. Environmental Protection Agency, Athens, GA.

CBP (Chesapeake Bay Program). 1999. *Chesapeake Bay Basin Toxics Loading and Release Inventory.* EPA 903-R99-006. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD.

Crawford, N.H., and R.K. Linsley. 1966. *Digital Simulation in Hydrology: Stanford Watershed Model IV*. Technical Report 39. Stanford University, Department of Civil Engineering, Palo Alto, CA.

Hamon, R.W. 1961. Estimating Potential Evapotranspiration, In *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulic Division*, 87(HY3):107–120.

Hamrick, J. 2007, December 17. Re: Pollutant affinity for and partition coefficients for different sediment classes. E-mail to Nikolai Gurdian (nikolai.gurdian@tetratech.com).

ICPRB (Interstate Commission on the Potomac River). 2007. *Total Maximum Daily Loads of Polychlorinated Biphenyls (PCBs) for Tidal Portions of the Potomac and Anacostia Rivers in the District of Columbia, Maryland, and Virginia (Draft)*. Prepared for District of Columbia Department of the Environment, Maryland Department of the Environment, and Virginia Department of Environmental Quality, by the Interstate Commission on the Potomac River, Rockville , MD.

Karickhoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of Hydrophobic Pollutants on Natural Sediments. *Water Resources* 13: 241–248.

MRLC (Multi-Resolution Land Characteristics Consortium). 2001. *National Land Cover Dataset*. Multi-Resolution Land Characteristics Consortium, Washington, DC. <http://www.mrlc.gov/nlcd_multizone_map.php>. Accessed March 1, 2006.

Onishi, Y., and S.E. Wise. 1979. *Mathematical Model, SERATRA, for Sediment-Contaminant Transport in Rivers and its Application to Pesticide Transport in Four Mile and Wolf Creeks in Iowa*. Battelle, Pacific Northwest Laboratories, Richland, WA.

Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

Schneider, R. 2005. PCB Desorption from Resuspended Hudson River Sediment. Unpublished Ph.D. thesis, University of Maryland, College Park.

USDA (U.S. Department of Agriculture). 1993. *Soil Survey Manual.* U.S. Department of Agriculture Handbook 18. U.S. Department of Agriculture, Soil Conservation Service. Soil Survey Division Staff, Natural Resources Conservation Service, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 2005. *Polychlorinated Biphenyl (PCB) Site Revitalization Guidance Under the Toxic Substances Control Act (TSCA).* U.S. Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances, Washington, DC.

———. 2006. *Basins Technical Note 8 Sediment Parameter and Calibration Guidance for HSPF*. EPA-67-C-0-037. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USGS (U.S. Geological Survey). 2009. *National Elevation Dataset*. Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD. <http://ned.usgs.gov/>. Accessed March 3, 2006.

Wischmeier, W.H., and D.D. Smith. 1978. *Predicting rainfall erosion losses – a guide to conservation planning*. The USDA Agricultural Handbook No. 537. U.S. Department of Agriculture, Washington, DC.