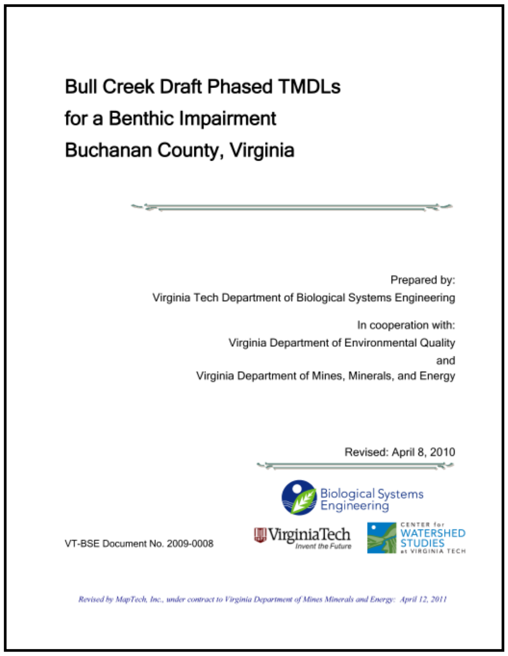
Draft Phase II Benthic TMDL Development for Bull Creek in Buchanan County, Virginia


Bull Creek Draft Phased TMDLs
for a Benthic Impairment
Buchanan County, Virginia

Prepared by:
Virginia Tech Department of Biological Systems Engineering

In cooperation with:
Virginia Department of Environmental Quality
and
Virginia Department of Mines, Minerals, and Energy

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VirginiaTech Invent the Future

Center for Watershed Studies at Virginia Tech

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Table of Contents

List of Tables

List of Figures

List of Acronyms

AML	Abandoned Mine Land
AVGWLF	ArcView Generalized Watershed Loading Functions
BMP	Best Management Practices
BSE	Biological Systems Engineering
COD	Chemical Oxygen Demand
DCR	Department of Conservation and Recreation
DEQ	Department of Environmental Quality
DGO	Division of Gas & Oil
DMLR	Division of Mined Land Reclamation
DMME	Department of Mine, Minerals, and Energy
DO	Dissolved Oxygen
E&S	Erosion and Sediment Control Program
GIS	Geographic Information Systems
GWLF	Generalized Watershed Loading Functions
HRU	Hydrologic Response Unit
HSPEXP	Expert System for Calibration of HSPF
HSPF	Hydrological Simulation Program - FORTRAN
LA	Load Allocation
MDL	Minimum Detection Limit
MFBI	Modified Family Biotic Index
MOS	Margin of Safety
MPID	Monitoring Point Identification Number
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
PEC	Probable Effect Concentrations
RBP	Rapid Bioassessment Protocol
RBP II	Rapid Bioassessment Protocol 2
RESAC	Regional Earth Science Application Center
SMC	Unsaturated Soil Moisture Capacity
TAC	Technical Advisory Committee
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VaSCI	Virginia Stream Condition Index
VBMP	Virginia Base Mapping Project

VDOT	Virginia Department of Transportation
VPDES	Virginia Pollutant Discharge Elimination System
VT	Virginia Tech
WLA	Waste Load Allocation

PREFACE

Virginia's Phased Resource Extraction TMDLs: Bull Creek

In order to meet the U.S. Environmental Protection Agency's (EPA) May 1, 2010 Consent Decree deadline, Virginia agencies worked diligently to complete a Total Maximum Daily Load (TMDL) study for Bull Creek. The following report represents the product of a Phased TMDL approach for the watershed spanning from 2007 to 2015.

During initial TMDL development, uncertainties and differences of interpretation regarding report narrative, report format, data, and predictive tools were identified. Assistance with the TMDL was solicited from the U.S. Office of Surface Mining, U.S. EPA, and private contractors. The Phase 1 TMDL was developed with the best available data and information to determine pollutant load reductions. The TMDL report was submitted to EPA as "Phased" TMDL in accordance with EPA guidance with the understanding that the Commonwealth of Virginia would utilize an adaptive management approach to completing the TMDLs. The Virginia Department of Environmental Quality (DEQ) and the Virginia Department of Mines, Minerals, and Energy (DMME) completed the Phase 1 TMDL in 2010. The report was approved by EPA in April 2011.

In the course of developing the Phase 1 TMDL, it was recommended that additional monitoring would help alleviate any uncertainties in pollutant sources. The issuance of the phased TMDL was intended to provide time to address uncertainties and to make any necessary revisions while interim water quality improvements were initiated. A monitoring plan and experimentation for model refinement was implemented by DEQ and DMME during the period of time beginning with the submittal to EPA of the DRAFT Phased TMDLs.

Although additional monitoring data, modeling refinements, allocations for pollutants, and long-term implementation actions were expected in the revised TMDL, on-going, long-term efforts to improve the watershed continued. In the interim, DMME's Division on Mine Land Reclamation (DMLR) utilized existing TMDL processes and software to maintain or decrease existing pollution waste loads from active mining for TSS and TDS. DMLR also restricted additional mining, through the use of offset requirements.

After the data needs were identified and monitoring completed, an addenda (Phase II TMDL) was developed for the Bull Creek watershed. The Phase II TMDL report was submitted to EPA and the public for comment. One of EPA's main concerns was that the Phase I and Phase II reports were hard to follow and requested a more comprehensive single report. DEQ and DMME have attempted to represent both the Phase I and Phase II information in this report which will supersede/replace all previous versions.

Please note that sections of the draft TMDL report, *Bull Creek Draft Phased TMDLs for a Benthic Impairment, Buchanan County, Virginia*, have been revised.

EXECUTIVE SUMMARY

Background

The purpose of this report is to describe the Total Maximum Daily Loads (TMDLs) developed to address the benthic impairments on Bull Creek. A part of the Big Sandy River basin, the Bull Creek watershed comprises state hydrologic unit Q08 (National Watershed Boundary Dataset BS14), and is located west of Harman Junction and US Highway 460 in Buchanan County, Virginia, Figure ES-1. The watershed is 3,128.5 ha (7,731 acres) in size. The main land use in Bull Creek is forest, 88% of the total watershed area. The remaining land uses include 6.5% in mining-related land uses, 4.5% in urban/residential, and 1% in agriculture. Bull Creek flows east and discharges into Levisa Fork, which flows northwesterly into Kentucky, where it enters the Big Sandy River. The Big Sandy River is a tributary of the Ohio River which flows into the Mississippi River and then to the Gulf of Mexico.

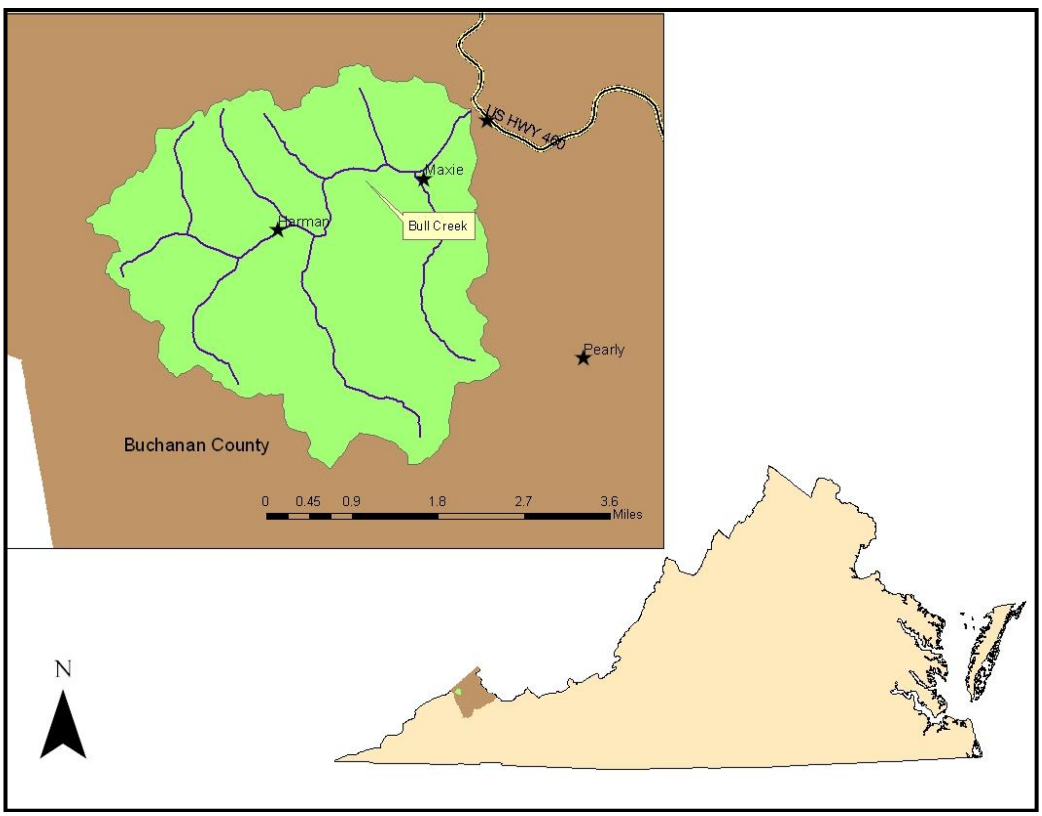

Figure ES- 1. Location of Bull Creek Watershed

Aquatic Life Use Impairment

Bull Creek and its tributaries – Left Fork Bull Creek (Convict Hollow), Belcher Branch, Deel Fork, and Cove Hollow − were originally listed as impaired on Virginia's 1998 Section 303(d) TMDL Priority List and Report due to water quality violations of the general aquatic life (benthic) standard. As a result, the U.S. Environmental Protection Agency (USEPA) added Bull Creek to the 1998 consent order requiring a TMDL by May 2010.

The Virginia Department of Environmental Quality (DEQ) has delineated the benthic impairment as 16.84 miles on Bull Creek and its tributaries (stream segment VAS-Q08R_BLC01A98). The impaired stream segment begins in the headwaters and extends to the confluence of Bull Creek with Levisa Fork.

Benthic Stressor Analysis

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on an assessment of the stream's biological community, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified, as is the case with physical and chemical parameter-based impairments. A stressor analysis was conducted to identify the sources of stress on the biological community in Bull Creek. The candidate stressors considered in this analysis were ammonia, hydrologic modifications, nutrients, organic matter, pH, sediment, total dissolved solids (TDS) and related parameters, temperature, and toxics. The information in this report was adapted from the Stressor Analysis Report for Bull Creek (Yagow et al., 2007).

Bull Creek (VAS-Q08R_BLC01A98) is severely to moderately impaired, with individual Virginia Stream Condition Index (VaSCI) scores varying between 26.1 and 43.2 (a score of 60 or above is considered non-impaired on a 0 to 100 scale). Biological and ambient monitoring within this watershed is sparse with limited biological monitoring conducted in 1996, 2001, and 2006. Ambient DEQ water quality data has been collected only since May 2005. The available Virginia Department of Mines, Minerals, and Energy's (DMME) Division of Mined Land Reclamation (DMLR) in-stream monitoring concentration data for TDS and related parameters are all frequently greater than the DEQ screening values used for selection of reference conditions. Although a mixture of possible stressors are present in the watershed, TDS and excess sediment were identified as the most probable stressors to the benthic community in Bull Creek and its tributaries. Bull Creek is impacted by abandoned mine land (AML), mining activities, logging, gas well activities, stream bank instability, and hydrologic modification in the watershed.

The case for sediment as a stressor is supported by the consistently low proportion of haptobenthos organisms (those requiring clean substrates) and the poor habitat metrics (the result of increased embeddedness) both due to excess sediment deposition in Bull Creek. Additionally, poor metrics scores were reported in earlier samples for bank stability and riparian vegetation. A few elevated total suspended solids (TSS) measurements were reported by DEQ during the 1998 assessment period. Since storm runoff is not typically monitored, a lack of elevated TSS concentrations does not provide evidence to rule out sediment as a stressor. Elevated TSS concentrations have been more widely and more frequently reported through DMLR's in-stream monitoring. Sediment is also supported by the high degree of embeddedness noted in the 1996 habitat assessment, and AML sites that exist in the area that have yet to be remined/reclaimed. The high levels of in-stream TDS and its correlates are also likely contributors to the stress evidenced by the benthic community.

Coal mining activities, including surface, auger, and deep mining, have been conducted in the Bull Creek watershed since the 1930's. Most of the mining was conducted prior to the current Surface Mining Control and Reclamation Regulations and resulted in over 1,000 acres of pre-law abandoned mined lands (AML) within the watershed. Five deep mines operated in the watershed prior to 1996. Although currently AML and barren areas (including active surface mining) are the major suspected sources of impairment in Bull Creek, prior to the first benthic sample taken in 1996, no surface mines were active in the watershed and so, surface mining activities could not have been the cause of the original impairment. One of the deep mines ceased operation in 1994, and another was downstream from the biological monitoring station, 6ABLC002.30. Additionally, during the 1998 assessment period, a coal processing plant operated adjacent to Bull Creek around stream mile 3.0, just above its confluence with Starr Branch (and upstream from biological monitoring station 6ABLC002.30, whose initial measurement resulted in the "impaired" listing). This plant loaded coal out of the watershed on a rail spur, which ran alongside Bull Creek from the plant to the mouth of the watershed. Stakeholders reported that Bull Creek often ran black from the processing plant discharges. The coal processing plant ceased operations in the late 1990s and the rail spur has since been removed.

Prior to 1996, approximately 10 gas wells were producing above station 6ABLC002.30 and one abandoned mine contributed discharge on Belchers Branch, which enters Bull Creek just downstream from 6ABLC002.30. From DMLR monitoring, repeated low pH values were reported for Jess Fork in the mid-1990s, together with high values of conductivity, TDS, and sulfates from Jess Fork, Deel Fork, Starr Branch, and Belcher Branch. Therefore, the initial cause of the impairment appears to have been a combination of low pH, high TDS and sediment, and to be attributable to the coal processing plant discharge, with additional impacts from AML runoff and deep mine discharges. Although the major suspected source of the 1996 impairment no longer exists and pH values all currently fall within an acceptable range, the TDS and sediment stressors continue to be elevated and are most likely the cause of the present day impairment. The location of the impaired segments of Bull Creek and its tributaries are shown in Figure ES-2.

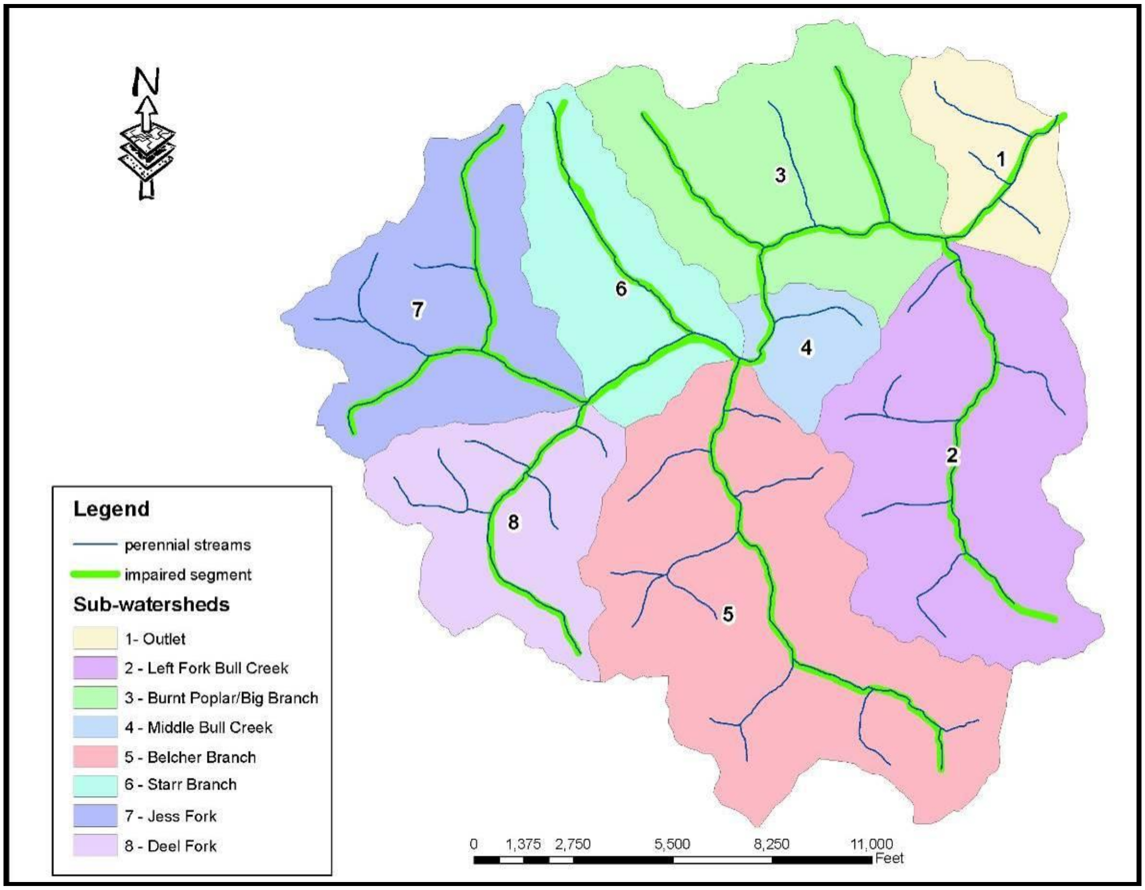

Figure ES- 2. Impaired Segments in Bull Creek

Bull Creek biological monitoring metrics have shown a slight improvement over time. At the same time, TDS concentrations have shown a slight decrease. This further supports the association between the biological metrics and TDS and/or its constituents. Although mining activities appear to be the source of the increased TDS concentrations, it is not possible at this time to discriminate between contributions from surface and deep mining sources. Sediment and TDS were selected as the most probable stressors based on the repeated poor scores for sediment metrics in the habitat assessment and elevated observed TSS and TDS concentrations.

Sediment TMDL Development

Sources of Sediment

Sediment is generated in the Bull Creek watershed through the processes of surface runoff, in-channel disturbances, and streambank and channel erosion. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses.

Modeling

The sediment TMDL was developed using a "reference watershed" approach to establish the allowable load in the impaired watershed, because Virginia has no numeric in-stream criteria for sediment. The reference watershed approach uses one watershed whose streams are supportive of their designated uses (the TMDL reference watershed) to establish the target TMDL load for the watershed whose streams are impaired (the TMDL watershed). Upper Dismal Creek, which is not impaired (biological reference station 6ADIS017.94), was selected as the TMDL reference watershed.

The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was selected for comparative modeling for the sediment TMDL study. All parameters were initially evaluated in a consistent manner between the reference and impaired watersheds, in order to ensure their comparability for the reference watershed approach. All GWLF parameter values were evaluated from a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures (Evans et al., 2001), procedures developed during the 2002 statewide NPS pollution assessment (Yagow et al., 2002), and best professional judgment. Parameters for active mining and AML land uses were evaluated from available literature sources.

Historically in Virginia, the GWLF model has been used in a variety of TMDLs to address sediment as a stressor in streams with benthic impairments. In these previous TMDLs, sediment has only been subject to accounting and reductions from non-permitted sources, and the successful restoration of the impaired stream was to be judged solely by the recovery of the benthic macro-invertebrate population and associated metrics, not by measured in-stream sediment. This is clearly not the case in Bull Creek, where permitted waste load allocations for sediment are closely monitored and tracked by DMLR, and will serve as the basis for determining existing waste load allocations for new mining permits. Although GWLF was originally developed for use in non-gaged watersheds and, therefore, did not require calibration, calibration was performed for flow and sediment in both Bull Creek and its reference watershed, in order to obtain a greater correlation with available observed data, and to achieve a greater degree of consistency with DMLR's tracking software for Waste Load Allocations.

Calibration endpoints were set as unit-area TSS measures developed using the observed data at available DMLR monitoring stations in both the reference and TMDL watershed. Unit-area measures allow for comparison between watersheds of different sizes. The GWLF model was calibrated for both hydrology and sediment, using sub-watersheds defined by the above-mentioned DMLR stations in Bull Creek and Upper Dismal Creek. The hydrology parameters adjusted during calibration included: monthly evapotranspiration (ET) coefficients, the seepage coefficient, and the curve number by landuse. The sediment parameters adjusted during calibration included: sediment pond efficiency, and the curve number by landuse. The calibrated reference and TMDL watershed models yielded simulated results, each within 4% of the calibration targets. These calibration adjustments were then applied to models of the full Bull Creek and Upper Dismal Creek watersheds and model simulations run for the 1995-2007 period.

Bull Creek was sub-divided into eighteen sub-watersheds for representation in the GWLF model, while Upper Dismal Creek was represented as a single watershed. TMDL modeling was then performed using weather input data sets for the 13-yr (1995-2007) period from stations representative of each watershed. The existing sediment loads (both point and nonpoint sources) were modeled and averaged over the 13-year period to account for both wet and dry periods in the hydrologic cycle, which were affected by seasonal variations in model inputs such as precipitation, temperature, evapotranspiration, and erosivity. The 13-yr average annual sediment loads (metric tons per year, t/yr) for both the Bull Creek and Upper Dismal Creek watersheds are listed in Table ES-1 by source category. Unit area sediment loads (metric tons per hectare, t/ha) are also shown for individual land use categories.

Table ES- 1. Existing Sediment Loads (t/yr) and Unit-Area Loads (t/ha) in Bull Creek and its Reference Watershed

Sediment Source	Bull Creek		Area-adjusted Upper Dismal Creek	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area				
Row Crop - High Till	123.09	51.70	0.00	0.00
Row Crop - Low Till	3.79	9.28	1.69	5.17
Pasture	365.12	14.19	239.28	4.87
Hay	0.34	0.51	0.00	0.00
Forest	393.21	0.15	369.77	0.13
Barren	2547.50	88.40	1516.38	60.85
Low Density Residential	66.60	1.27	52.40	0.98
Medium Density				
Residential	1.84	1.13	0.18	1.34
High Density Residential	16.26	1.52	13.14	1.35
AML	3137.78	14.77	2117.25	14.19
Mining Land Uses [1]				
Extractive	*	*	296.79	75.50
Reclaimed	*	*	20.14	7.42
Released	229.84	11.68	18.59	6.41
Impervious Area				
Low Density Residential	3.27	0.46	3.35	0.46
Medium Density				
Residential	0.92	1.13	0.07	1.14
High Density Residential	14.19	0.71	12.95	0.71
Direct Sources				
Channel Erosion	3.12		2.00	
Permitted Sources				
Mining Permits	8.93			
Gas Well Construction	3.32			
Watershed Totals	6919.13	3.83	4663.98	1.49

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

The Phase II Sediment TMDL

The phased sediment TMDL for Bull Creek was calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where $\sum WLA$ = sum of the wasteload (permitted) allocations;

$\sum LA$ = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

The TMDL is quantified in Table ES-2. The phased sediment TMDL for Bull Creek watershed in metric tons per year (t/yr) was calculated as the average annual sediment load from the area-adjusted Upper Dismal Creek watershed for existing conditions (Table ES-1). The WLA was calculated for individual permits based on their area in the Bull Creek watershed, simulated runoff from their respective land uses, and permitted maximum TSS concentrations, with allowances for future growth of the coal mining and gas and oil industries. The margin of safety (MOS) was explicitly specified as 10% of the TMDL, and the load allocation (LA) −the allowable sediment load from nonpoint sources− was calculated as the TMDL minus the MOS minus the WLA. The phase II sediment TMDL for Bull Creek is 4,660.44 t/yr.

Table ES- 2. Bull Creek Phase II Sediment TMDL (t/yr)

	WLA t/yr	LA t/yr	MOS t/yr	TMDL t/yr
Bull Creek	**58.89**	**4,135.15**	**466.40**	**4,660.44**
Gas Well Construction Permits	3.32			
Surface Coal Mining Transient Permits				
1101701	0.77			
1101736	1.95			
1101903	0.04			
1101979	1.03			
1200129	0.01			
1200281	0.10			
1200343	0.09			
1200589	0.07			
1201678	0.04			
1201922	0.19			
1201940	0.09			
1601788	4.54			
Future Growth	46.64			

Sediment TMDL Reductions and Allocations

For development of the allocation scenarios: pasture and hay were grouped into the “pasture/hay” category; and all residential sources were grouped together as “residential/urban”. The modeling target sediment load is the TMDL minus the MOS (4,660.44 – 466.40 = 4,194.04 t/yr), so that the overall reduction required for sediment is 32.6%, from 6,919.3 to 4,660.44 t/yr. Several TMDL allocation scenarios were developed based on reductions from different combinations of sediment sources under existing conditions (Table ES- 3). Scenario 1 was chosen to use for the final TMDL because it has similar reductions on different land uses throughout the watershed.

Table ES- 3. Phase II Sediment TMDL Load Allocation Scenarios for Bull Creek

Sediment Source	Existing Bull Creek Loads	Scenario 1 Reductions	Scenario 1 Allocated Loads	Scenario 2 Reductions	Scenario 2 Allocated Loads
	t/yr	%	t/yr	%	t/yr
Pervious Area					
Row Crop - High Till	123.09	42.60	70.66	0.00	123.09
Row Crop - Low Till	3.79	0.00	3.79	0.00	3.79
Pasture	365.12	42.60	209.58	0.00	365.12
Hay	0.34	0.00	0.34	0.00	0.34
Forest	393.21	0.00	393.21	0.00	393.21
Barren	2,547.50	42.60	1,462.27	48.70	1,306.87
Low Density Residential	66.60	42.60	38.23	0.00	66.60
Med. Density Residential	1.84	42.60	1.06	0.00	1.84
High Density Residential	16.26	42.60	9.33	0.00	16.26
AML	3,137.78	42.60	1,801.09	48.70	1,609.68
Mining Land Uses[1]					
Extractive	*	*	*	*	*
Reclaimed	*	*	*	*	*
Released	229.84	42.60	131.93	0.00	229.84
Impervious Area					
Low Density Residential	3.27	42.60	1.88	0.00	3.27
Med. Density Residential	0.92	42.60	0.53	0.00	0.92
High Density Residential	14.19	42.60	8.14	0.00	14.19
Direct Sources					
Channel Erosion	3.12	0.00	3.12	0.00	3.12
Permitted Sources					
Mining Permits	8.93	0.00	8.93	0.00	8.93
Gas Well Construction	3.32	0.00	3.32	0.00	3.32
Future Load			46.64		46.64
Margin of Safety			466.40		466.40
Watershed Totals	6,919.13	32.64	4,660.44	32.60	4,663.43

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

AML and barren areas were assessed as the primary sources of sediment in the Bull Creek Watershed. AML reclamation and improved erosion control management and minimization of disturbed area footprints are recommended as the primary targets of implementation efforts. Barren land uses result from construction of access roads and drilling sites for gas and oil wells, logging, and from residential activities.

Total Dissolved Solids (TDS) TMDL Development

Sources of TDS

TDS loads are generated in the Bull Creek watershed through surface runoff, interflow, groundwater, and direct discharge. The majority of TDS appears to be related to a mixture of current and historical mining activities, together with background groundwater loads. TDS are coming from both active and abandoned mining areas during surface runoff events, and in-between storms through loading from interflow, groundwater, and pre-law mine discharges. Residential TDS sources within the watershed include failing septic systems and straight pipes. Road salt application is another source of TDS within the watershed during the winter.

Modeling

Virginia has no numeric in-stream criteria for TDS. Lower Dismal Creek was selected as the reference watershed to set an in-stream concentration endpoint for the TDS TMDL. Lower Dismal Creek is in the same county (Buchanan) and physiographic sub-region (Central Appalachians, Cumberland Mountain) as Bull Creek, is currently non-impaired, and has available DEQ-monitored TDS concentration data. While the Lower Dismal Creek watershed is larger than the Upper Dismal Creek watershed which was used as the sediment TMDL reference, it has similar physical characteristics (landuse distribution, soils and slopes), has some mining activity, and has had several bioassessment samples taken which show healthy aquatic communities at stations 6ADIS003.52 and 6ADIS013.73. In addition, TDS data from station 6ADIS0001.24 in Lower Dismal Creek has been used previously to set the TDS TMDL endpoint for the

Knox Creek TMDL (MapTech, 2006). The TDS TMDL concentration endpoint for Bull Creek was set at 369 mg/L, the 90th percentile of 34 DEQ-monitored TDS samples taken at station 6ADIS001.24.

The model selected for development of the TDS TMDL was Hydrological Simulation Program–FORTRAN (HSPF), version 12 (Bicknell et al., 2001; Duda et al., 2001). Model development for Bull Creek was performed by assessing the sources of TDS in the watershed, evaluating the necessary parameters for modeling, calibrating to observed data, and running the model to simulate in-stream TDS concentrations and loads. Sources of TDS accounted for in the model include surface disturbances related to mining activities (extractive, AML, reclaimed, and released land uses), pre-law mine discharges, road salt runoff, and failing septic systems and straight pipes. TDS was simulated as a conservative pollutant with load contributed from the various sources through surface runoff, interflow, groundwater, and direct mine discharges. TDS parameter values in the model were initially estimated and then adjusted to match observed in-stream concentrations through calibration.

Because no continuous hydrology data is available on Bull Creek, a detailed hydrology calibration was performed for nearby Cranes Nest River based on flow data from the USGS monitoring station 03208950, and the calibration adjustments transferred to Bull Creek. Simulated mean daily flow was then visually compared to the available instantaneous DMLR-monitored flow data at multiple (7) points throughout the Bull Creek watershed and further adjusted. The calibrated simulated mean daily flow for one of these monitoring points near the outlet of Jess Fork is shown in Figure ES- 3.

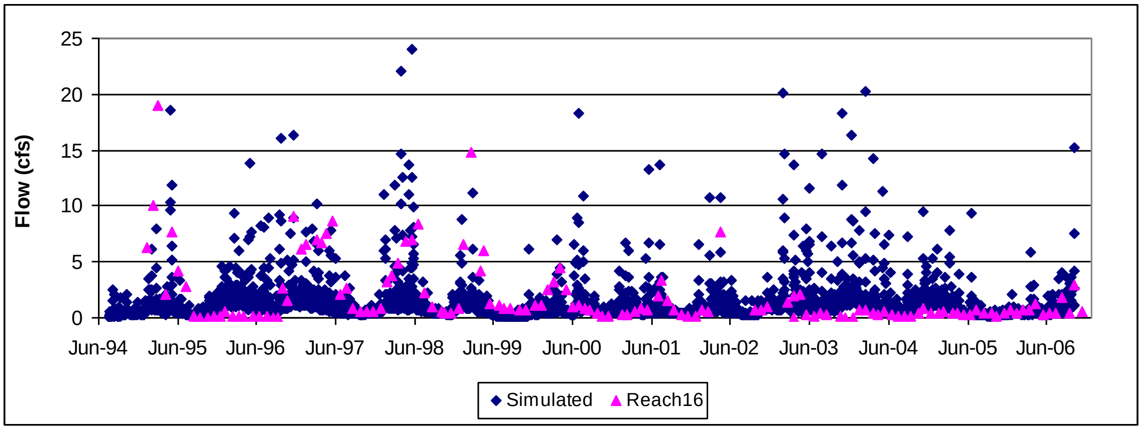

Figure ES- 3. Simulated flow and DMLR observed flow in Bull Creek sub-watershed 16 (Jess Fork) after calibration

Parameters for active mining and AML land uses were initially evaluated from available literature sources, but only limited information was available to differentiate between these sources. Because of the uncertainties in the exact distribution of these loads, a phased TMDL was determined to be appropriate for the TDS stressor in Bull Creek.

Although the distributions among the various pathways of surface transport, interflow, and groundwater contributions to stream loads and between permitted mining and AML sources are somewhat uncertain, the total TDS loads from the watershed appear reasonable in relation to observed in-stream concentrations, and loads from the other sources of TDS - residential, road salt, and pre-law mining - have been estimated with a degree of confidence. To calculate TDS loads generated for each mining permit, the model was first run with loads calculated from individual sub-watersheds with TDS sources from AML, road salt, pre-law mine discharges and residential septic sources turned off. Individual WLAs for each mining permit were based on the proportionate area of each permit within each of the 18 modeling sub-watersheds multiplied times the TDS load from permitted mining sources in each sub-watershed. The watershed load for each permit was then calculated by summing all sub-watershed loads from that permit.

During TDS calibration, parameters values for each sub-watershed were adjusted until simulated in-stream mean daily TDS concentrations and patterns agreed with available instantaneous DMLR TDS data collected in Bull Creek for the period January 2000 - December 2005. TDS calibration was performed at four of the DMLR flow monitoring points within the Bull Creek watershed, where TDS concentrations were also monitored. Inputs for TDS loads from road salt applications, failing septic systems, straight pipes and pre-law mine discharges were quantified, and were not adjusted during calibration. Calibration focused on parameters affecting the largest components of the TDS loads that were less certain: surface runoff, interflow, and groundwater. A multi-point calibration was performed by adjusting appropriate parameter values starting with upstream sub-watersheds and working progressively downstream. Calibrated TDS concentration comparisons are shown in Figure ES- 4 for Bull Creek near the watershed outlet.

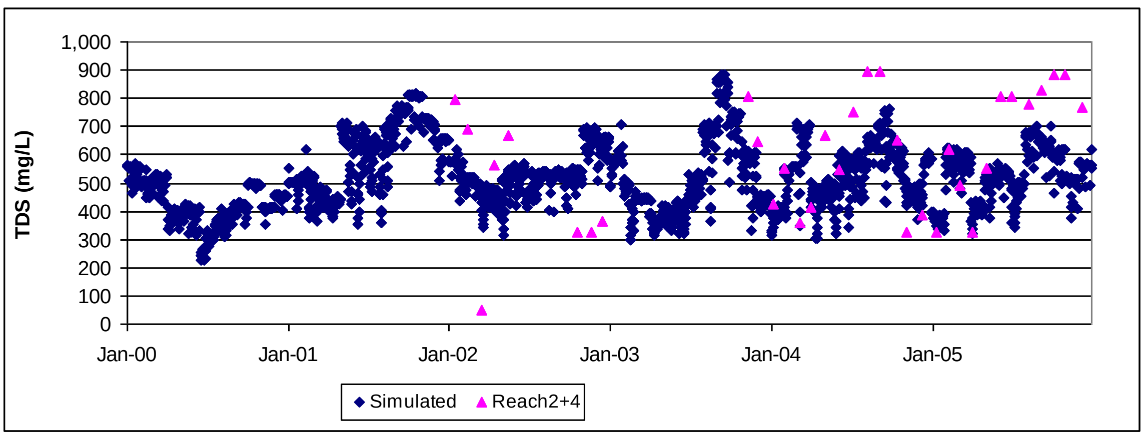

Figure ES- 4. Simulated TDS concentrations and DMLR observed TDS concentrations in Bull Creek sub-watersheds 2+4 (Bull Creek near outlet) after calibration.

A visual comparison of simulated and observed in-stream TDS concentrations and best professional judgment were used to assess when a reasonable model calibration had been achieved. Additionally, the range and average of TDS concentrations were considered during calibration. Taken together, the visual data comparison and the descriptive statistics were evidence of a reasonable calibration of this highly variable parameter.

Average annual TDS loads were simulated using the calibrated model for the existing conditions in the Bull Creek watershed, as reported in Table ES- 4. A 6-year period (January 2000 – December 2005) was used for the Bull Creek simulation.

Table ES- 4. Sources of Existing TDS Loads in Bull Creek

TDS Sources	Bull Creek Existing TDS Load (kg/yr)
AML (Groundwater, Interflow, and Runoff)	600,924
Non-AML groundwater (background)	2,931,440
Mining Interflow	20,435
Background Interflow	563,862
Abandoned Mine Discharge	4,218,873
Mining Runoff	24,467
Road Salt	18,565
Septic	28,063
Total	**8,406,629**

TDS Allocation Scenarios

The TDS concentration endpoint for Bull Creek was achieved by making incremental reductions from various anthropogenic sources of TDS and then simulating the corresponding TDS concentrations and loads. Residential sources of TDS were reduced first, followed by elimination of AML TDS sources. Scenarios 7 and 8 show reductions that are adequate for reaching the TMDL endpoint. The scenarios focus first on residential (straight pipe and failing septic systems), pre-law mine discharge, and AML sources. Scenarios 2 and 3 explore the impact of reductions to permitted surface mine discharges. The remaining scenarios examine reductions to "non-background groundwater." This latter source includes persistent loads to the stream that are not dependent on active rainfall events (*e.g.*, unaccounted-for drainage from abandoned underground mine workings, and slow drainage from fill areas). Scenario 8 is recommended as a starting point during implementation.

A summary of the reduction percentages, the resulting maximum daily average concentration, the corresponding annual TDS load, and the overall percent load reduction for a number of scenarios are shown in Table ES- 5.

Table ES- 5. Allocation Reduction Scenarios for Bull Creek

Scenario	Reductions by Source (%)							Max Ave Daily TDS (mg/L)	Number of Days > 369 mg/L	TDS Load (kg/yr)
	Mine Pond Discharge	AML	Pre-Law Mine Discharge	Road Salt	Residential (Direct)[1]	Non-Background Groundwater[2]	Background[3]			
0	0	0	0	0	0	0	0	842	2,114	8,408,547
1	0	100	100	0	100	0	0	499	93	3,559,583
2	20	100	100	0	100	0	0	499	93	3,550,600
3	80	100	100	0	100	0	0	499	93	3,523,654
4	20	100	100	0	100	29	0	400	22	2,964,178
5	20	100	100	0	100	36	0	375	8	2,817,572
6	20	100	100	0	100	37	0	370	2	2,788,251
7	20	100	100	0	100	39	0	365	0	2,758,930
8	0	100	100	0	100	39	0	365	0	2,767,913

[1]Includes straight pipes and failing septic systems.
[2]Includes persistent loads to the stream, such as, unaccounted-for drainage from abandoned underground mine workings, slow drainage from fill areas, and any load contributed through groundwater that results from human activity.
[3]Includes loads from undisturbed forest, and naturally occurring groundwater loads.

The Phase II TDS TMDL

The TDS TMDL was developed as the load corresponding to Scenario 9 in Table ES- 5. The TDS TMDL for Bull Creek was calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where $\sum WLA$ = sum of the waste load (permitted) allocations;

$\sum LA$ = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

The LA component load was calculated as the TDS load from road salts, from pre-law direct mine discharges, and from background sources in interflow. The MOS used in this TMDL was implicit, based on the use of the conservative 90th percentile of observed TDS concentrations in the reference watershed for setting the TMDL TDS concentration endpoint. In Lower Dismal Creek, the 90^{th} percentile values were actually 15.5% lower than the maximum observed values. The WLA was calculated as the TMDL minus the LA. The WLA includes the combined allocations for mining sources from a combination of surface runoff, interflow, and groundwater loads. Individual WLAs for each mining permit were based on the proportionate area of each permit within each of the 18 modeling sub-watersheds multiplied times the TDS load from permitted mining sources in each sub-watershed. The distribution of permit areas by sub-watershed is given in Appendix Table D.1. The TMDL and its component loads are shown in Table ES- 6 for Scenario 8.

Table ES- 6. Bull Creek Phase II TDS TMDL (kg/yr)

WLA			LA[1]	MOS	TMDL
44,902			2,723,011	Implicit	2,767,913
Mining Permit Numbers	NPDES MPIDs	Permit WLAs			
1101701	0003437, 0003438, 0003440, 0003441, 0003442	3,878			
1101736	0003572, 0003573, 0003574, 0003575, 0004887, 0005632	9,833			
1101903	0006747, 0006748, 0006749, 0006750, 0006751, 0006752	221			
1101979	0006435, 0006436, 0006437, 0006438, 0006439, 0006440, 0006441, 0006442, 0006443, 0006444, 0006445, 0006446, 0006447, 0006448, 0006449, 0006450, 0006451, 0006452	5,179			
1200129	none	69			
1200281	5683359	494			
1200343	5640069, 5653489	435			
1201678	5684527	213			
1201922	0003439, 0004312, 0006086, 0006087, 0006397	972			
1201940	0005964, 0005965	459			
1601788	0004449, 0004450, 0004451, 0004452, 0004453, 0004454, 0004455, 0004456, 0004457, 0004458, 0004459, 0004460	22,811			
1200589	none	338			

In this watershed, after source characterization and modeling were completed, AML areas, pre-law mine discharges, and active mining sources were assessed as the primary contributors of TDS. AML reclamation and improved

TDS source reduction and site management of active mining areas should be the primary targets of implementation efforts.

Reasonable Assurance of Implementation

TMDL Compliance Monitoring

DEQ will continue monitoring benthic macroinvertebrates at station 6ABLC002.30 in accordance with its biological monitoring program and TSS and TDS at station 6ABLC000.85 in accordance with its ambient monitoring program. DEQ will continue to use data from this monitoring station and related ambient monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

Additionally, DMME monitoring of the NPDES discharge points for the TMDL stressor pollutants – TSS and TDS – will continue to be in accordance with DMLR's monitoring guidance DMME, 2008.

Since TMDLs are expressed in terms of annual loads, discharge flow rates should be measured concurrently with water quality sampling, and recorded together with existing daily precipitation data monitored by DMLR-approved sources. When monitoring indicates that the TMDL TDS WLAs are being exceeded DMLR will implement the agency's Waste Load Reduction Actions.

Regulatory Framework

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of the first step for the benthic impairment on Bull Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, Virginia Department of Conservation and Recreation (DCR), DMME, and other cooperating agencies.

Implementation

Implementation of this TMDL will contribute to on-going water quality improvement efforts in the Bull Creek watershed. Improvements in the watershed are underway for the control of suspected sources of sediment. These include the on-going efforts to re-mine and reclaim all previously abandoned mine land.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. A Technical Advisory Committee (TAC) meeting was held on October 10, 2007 followed that evening with a public meeting. The benthic stressor analysis report for Bull Creek was circulated on February 7, 2008 to all members attending both the TAC and public meetings for comment. One comment was received in response, and responses to these comments have been included in the final TMDL report.

The draft sediment and TDS TMDLs report on Bull Creek for the benthic impairment were presented at a public meeting, held on March 20, 2008, at the Harman Memorial Baptist Church in Maxie, Virginia. This public meeting was attended by 12 stakeholders. The public comment period ended on April 20, 2008.

Due to revisions to the draft TMDLs, another public meeting was held on September 23, 2008 to present the revised draft sediment and TDS TMDLs. This meeting was also held at the Harman Memorial Baptist Church in Maxie, Virginia. This public meeting was attended by 8 stakeholders. The public comment period ended on October 22, 2008.

Uncertainties related to the modeling and source differentiation led to the development of phased TMDLs which were presented at a public meeting January 14, 2010 at Riverview Elementary and Middle School in Grundy, Virginia.

This meeting will be held in conjunction with a TMDL public meeting for a downstream impairment on Levisa Fork. The public meeting was attended by 34 stakeholders. The public comment period ended on February 15, 2010.

Amended pollutant loads and wasteload allocations for the Bull Creek and Tributaries TMDL were presented at a public meeting on March 8, 2011 at the Virginia Department of Mines, Minerals, and Energy Office in Big Stone Gap, Virginia. The public meeting was attended by 11 stakeholders. The public comment period was open from February 28, 2011 to March 30, 2011.

To complete the development of phased TMDLs additional monitoring was needed. The monitoring plan for the phased TMDLs was presented at a public meeting on July 26, 2011 at the Virginia Department of Environmental Quality's Southwest Regional office in Abingdon, Virginia. The public meeting was attended by 22 participants. The public comments period closed on August 26, 2011. A second public meeting on the TMDL revision process was held on April 25, 2013 at the Virginia Department of Environmental Quality's Southwest Regional Office in Abingdon, Virginia. The public meeting was attended by 10 participants. The public comment period closed on May 25, 2013. The final public meeting to present the Phase II TMDL revisions was held on October 24, 2013 at the Norton Community Center in Norton, Virginia. The public meeting was attended by 14 participants. The public comment period closed on November 25, 2013.

A public meeting to present the combined Phase I and Phase II TMDL report was held on August 11, 2015 at the Riverview Elementary/Middle School in Grundy, Virginia. The public meeting was attended by XX participants. The public comment period closed on September 11, 2015.

CHAPTER 1: INTRODUCTION

1.1. Background

1.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2. Impairment Listing

Bull Creek and its tributaries − Left Fork Bull Creek (Convict Hollow), Belcher Branch, Deel Fork, and Cove Hollow − were originally listed as impaired on Virginia's 1998 Section 303(d) Total Maximum Daily Load Priority List and Report due to water quality violations of the general aquatic life (benthic) standard. As a result, the USEPA added this stream to a 1998 consent order requiring a TMDL by May 2010.

The Virginia Department of Environmental Quality (DEQ) has delineated the benthic impairment as 16.84 miles on Bull Creek and its tributaries (stream segment VAS-Q08R_BLC01A98). The impaired stream segment begins in the headwaters and extends to the confluence of Bull Creek with Levisa Fork, a tributary of the Big Sandy River.

1.1.3. Watershed Location and Description

A part of the Big Sandy River basin, the Bull Creek watershed comprises state hydrologic unit Q08 (National Watershed Boundary Dataset BS14), and is located west of Harman Junction and U.S. 460 in Buchanan County, Virginia, as shown in Figure 1.1. The watershed is 3,128 ha (7,731 acres) in size. The main land use category in Bull Creek is forest, which comprises approximately 88% of the total watershed area. The remaining land uses include 6.5% in mining-related land uses, 4.5% in urban/residential, and 1% in agriculture. Bull Creek flows east and discharges into Levisa Fork, which flows northwesterly into Kentucky, where it enters the Big Sandy River. The Big Sandy River is a tributary of the Ohio River which flows into the Mississippi River and then to the Gulf of Mexico.

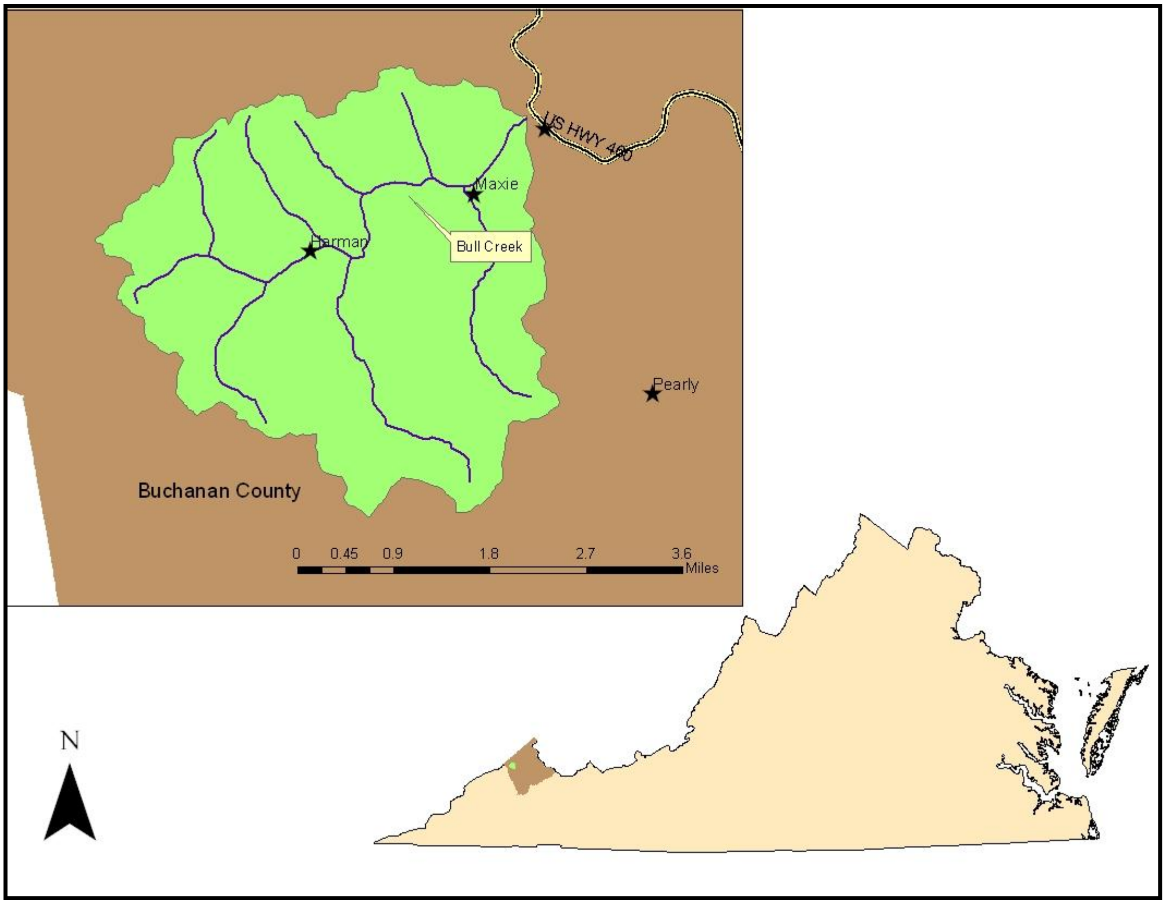

Figure 1.1. Location of Bull Creek Watershed

1.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to a violation of the benthic standard. A violation of this standard is assessed on the basis of measurements of the in-stream benthic macro-invertebrate community. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia’s waters.

1.2. Designated Uses and Applicable Water Quality Standards

1.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)." SWCB, 2002.

1.2.2. General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia is stated as follows:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2002.

The biological monitoring program in Virginia that is used to evaluate compliance with the above standard is run by the Virginia Department of Environmental Quality (DEQ). Evaluations of monitoring data from this program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment has a benthic impairment. Changes in water quality generally result in alterations to the quantity and diversity of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Qualitative and semi-quantitative biological monitoring has been conducted by DEQ since the early 1970's. The U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize standardized and repeatable assessment methodology. For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, benthic samples are typically collected and analyzed twice a year in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring "network" stations to "reference" sites. A reference site is one that has been determined to be representative of a natural, non-impaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different eco-regions. One additional product of the RBP II evaluation is a habitat assessment. This is a stand-alone assessment that describes bank condition and other stream and riparian corridor characteristics and serves as a measure of habitat suitability for the benthic community.

Beginning in 2006, DEQ switched their bioassessment procedures. While the RBP II protocols were still followed for individual metrics, a new index, the Virginia Stream Condition Index (VaSCI), was developed based on comparison of observed data to a set of reference conditions, rather than with data from a reference station. The new index was also calculated for all previous samples in order to better assess trends over time.

Determination of the degree of support for the aquatic life designated use is based on biological monitoring data and the best professional judgment of the regional biologist, relying primarily on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of "moderately impaired" or "severely impaired" is placed on the state's 303(d) list of impaired streams (DEQ, 2002).

CHAPTER 2: WATERSHED CHARACTERIZATION

2.1. Water Resources

The DEQ has delineated the benthic impairment on Bull Creek and tributaries (stream segment VAS-Q08R_BLC01A98) as a stream length of 16.84 miles. The impaired stream segment begins at the confluence of Bull Creek and Levisa Fork and extends to its headwaters. Named tributaries to Bull Creek within the impaired watershed include Left Fork Bull Creek (Convict Hollow), Belcher Branch, Deel Fork, and Cove Hollow. Bull Creek and Left Fork Bull Creek join together near Maxie. Belcher Branch and Starr Branch are tributaries to Bull Creek, entering Bull Creek about 2.73 and 3.01 miles upstream of the confluence of Bull Creek, respectively. Bull Creek begins at the confluence of Jess Fork and Deel Fork, which is approximately located at stream mile 3.97 along the main channel of Bull Creek. The relationship between the impaired segments and major sub-watersheds is shown in Figure 2.1.

2.2. Eco-region

The Bull Creek watershed is located entirely within the Cumberland Mountains sub-division of the Central Appalachians eco-region. The Central Appalachians is primarily a high, dissected, rugged plateau which is composed of sandstone, shale, conglomerate and coal. The land cover is mostly forested due to rugged terrain, cool climate and infertile soils which limit agriculture. Bituminous coal mines that may cause siltation and acidification of streams are common in this region (USEPA, 2002).

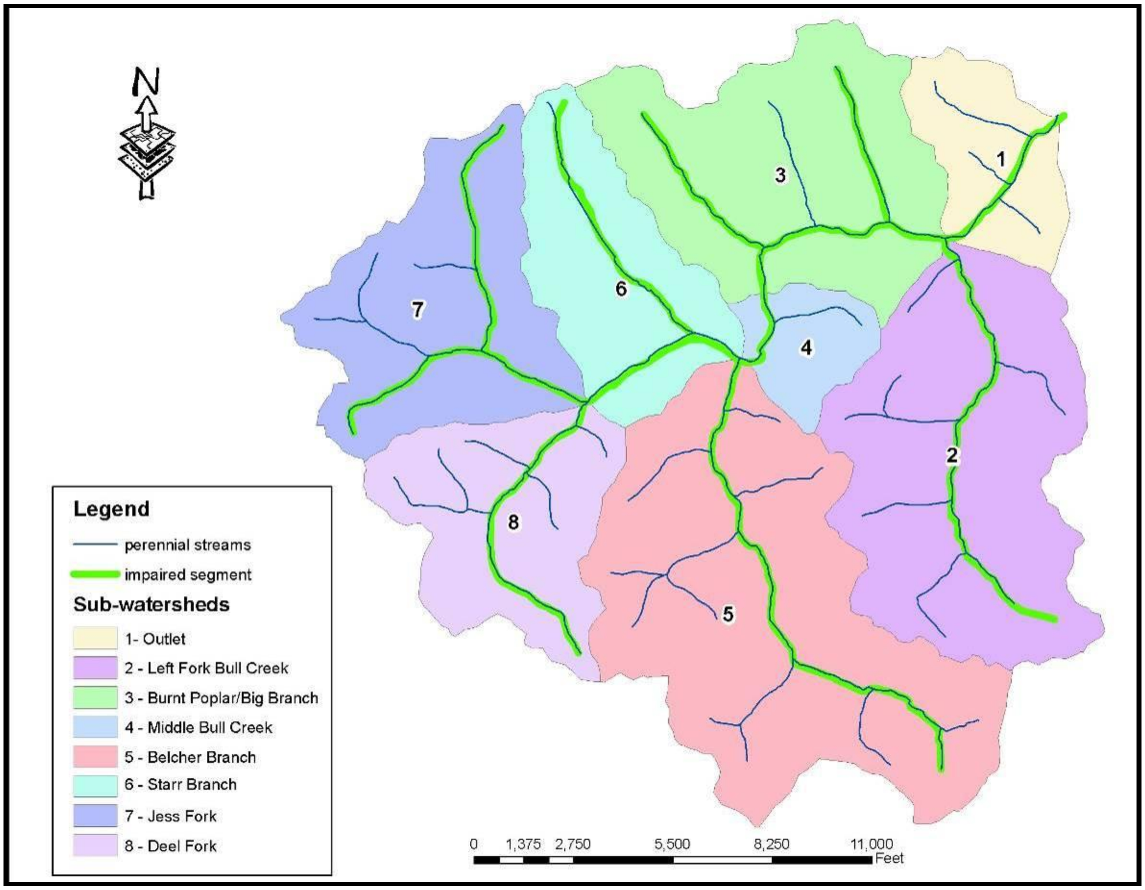

Figure 2.1. Impaired Segments in Bull Creek

2.3. Soils and Geology

The soils found in Bull Creek watershed are primarily in the Shelocta, Cloverlick and Matewan series. The Cloverlick-Shelocta complex is a well drained soil comprised of gravelly loam located on mountaintop ridges, spurs, and drainageways. Matewan soils are a flaggy fine sandy loam, shallow, well drained, and contain rock outcrops. These soil types are typically found on ridge tops and side slopes (USDA-NRCS, 2004).

2.4. Climate

Climate data for the Bull Creek watershed was based on meteorological observations from the Grundy National Climatic Data Center station (443640) located within Buchanan County, Virginia approximately 4 miles east of the watershed. Average annual precipitation at this station is 45.84 inches. Average annual daily temperature at the Grundy station is 55.3°F. The highest average daily temperature of 87.2°F occurs in July while the lowest average daily temperature of 23.2°F occurs in January, as obtained from the 1971-2000 climate norms (NCDC-NOAA, 2007).

2.5. Land Use

Land use for the Bull Creek watershed was derived from the Mid-Atlantic Regional Earth Science Application Center (RESAC, 2000), modified with abandoned mine land (AML) features digitized from USGS 7½-minute topographic maps, and merged with a digital map of current mining permit boundaries from the Virginia Department of Mines, Minerals, and Energy's (DMME) Division of Mined Land Reclamation (DMLR). The RESAC data is available from the Virginia Department of Conservation and Recreation (DCR) upon request and was derived from digital remote sensing and spatial information technologies. Some additional editing was done to reclassify portions of the "barren" and "extractive" classifications which were inconsistent with residential features observed in aerial imagery from the Virginia Base Mapping Program (VBMP, 2002). The 38 land uses in the RESAC data were then categorized into 8 categories. Abandoned mine land (AML) was digitized from USGS topographic maps and added to the RESAC data to identify these historic mining features. A distribution of RESAC and RESAC plus AML land use category areas are shown in Table 2.1. Mining permit areas were then added to this mix to show the broader categories of land uses shown in Figure 2.2. Based on these classifications, the main land use category in Bull Creek is forest (88%). Mining land uses (extractive plus AML) account for approximately 6.5%, while urban/residential land uses (all residential categories plus barren) and agriculture land uses (cropland plus pasture/hay) account for about 4.5% and 1%, respectively.

Table 2.1. Bull Creek RESAC Land Use Category Distribution plus AML

Land Use Category	RESAC		RESAC + AML	
	Area (ha)	% of Total	Area (ha)	% of Total
Low Density Residential	58.5	1.9%	58.5	1.9%
Medium Density Residential	2.7	0.1%	2.7	0.1%
High Density Residential	29.7	1.0%	29.7	1.0%
Extractive	12.5	0.4%	12.5	0.4%
AML	0.0	0.0%	197.1	6.3%
Barren	49.8	1.6%	49.8	1.6%
Pasture/Hay	24.8	0.8%	24.8	0.8%
Cropland	2.8	0.1%	2.8	0.1%
Forest	2,947.7	94.2%	2,750.7	87.9%
Total Area	**3,128.5**	**100.0%**	**3,128.5**	**100.0%**

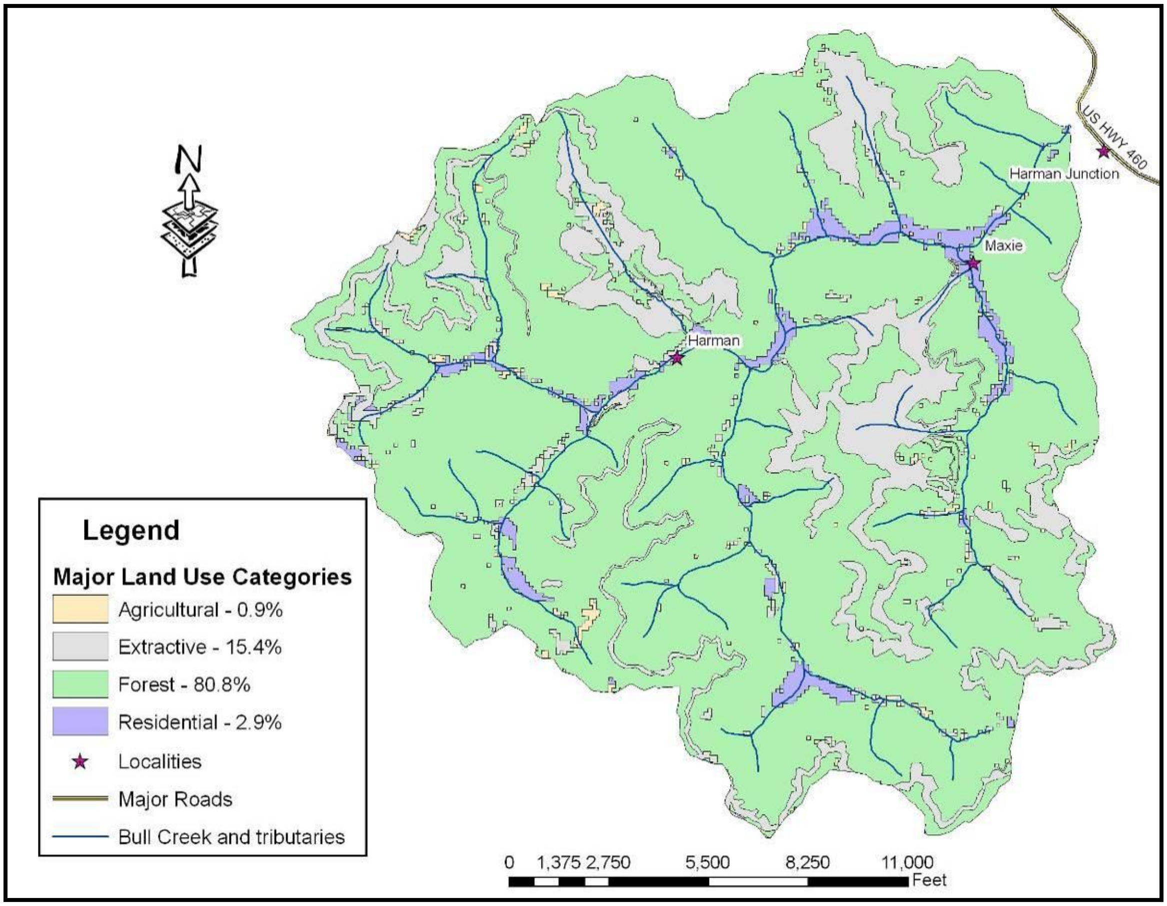

Figure 2.2. Land Use in Bull Creek Watershed

2.6. Future Land Use

Land use in Bull Creek for the foreseeable future was assumed to remain similar to existing conditions. Although mining continues within existing permitted areas, the amount of land disturbed at any one time remains approximately the same, since current guidance requires permit holders to minimize disturbed footprints and to reclaim disturbed areas as soon as possible. To account for some additional growth in the mining and gas & oil industries, their respective permitted WLAs for sediment were increased by 10%. The Coalfields Expressway – U.S. Route 121 – is a proposed four-lane highway stretching 51 miles from Pound in Wise County through Dickenson and Buchanan counties to the West Virginia line. An existing Virginia Department of Transportation plan (VDOT, 2006) showed the Coalfields Expressway to run through the center of the watershed (Figure 2.3). Information provided by one stakeholder after the first public meeting, however, placed the location on the eastern ridge of the watershed, so the exact footprint and impact on the watershed is unknown at this time. No other significant land use changes are anticipated.

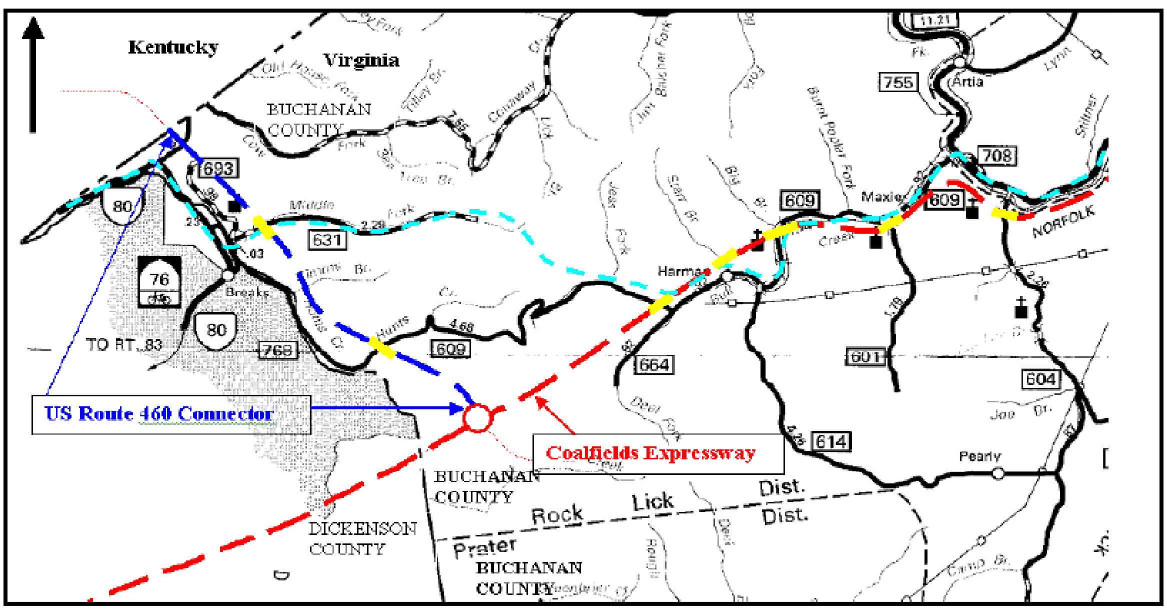

Figure 2.3. Potential Coalfields Expressway Route (VDOT, 2006)

2.7. Biological Monitoring Data

Biological monitoring consisted of sampling the benthic macro-invertebrate community along with corresponding habitat assessments. Three biological monitoring stations were located on Bull Creek. The main biological station – 6ABLC002.30 – was monitored four times; once each in 1996 and 2001, and twice in 2006. Two other biological stations – 6ABLC002.77 and 6ABLC003.63 – were each monitored once in 2001. The DEQ 2004 Fact Sheets for Category 5 Waters (DEQ, 2004) state that the 6ABLC002.30 biological station on Bull Creek is severely impaired. The initial listing of Bull Creek and its tributaries was on the 1998 303(d) list which was based on the May 1996 sample, the only sample included in the July 1992 through June 1997 assessment period. The cause of the benthic impairment in Bull Creek was listed as "Resource Extraction", with the fact sheet indicating other sources of impairment as urban impact. The locations of the DEQ biological and ambient monitoring stations in Bull Creek are shown in Figure 2.4, together with the major tributary sub-watersheds.

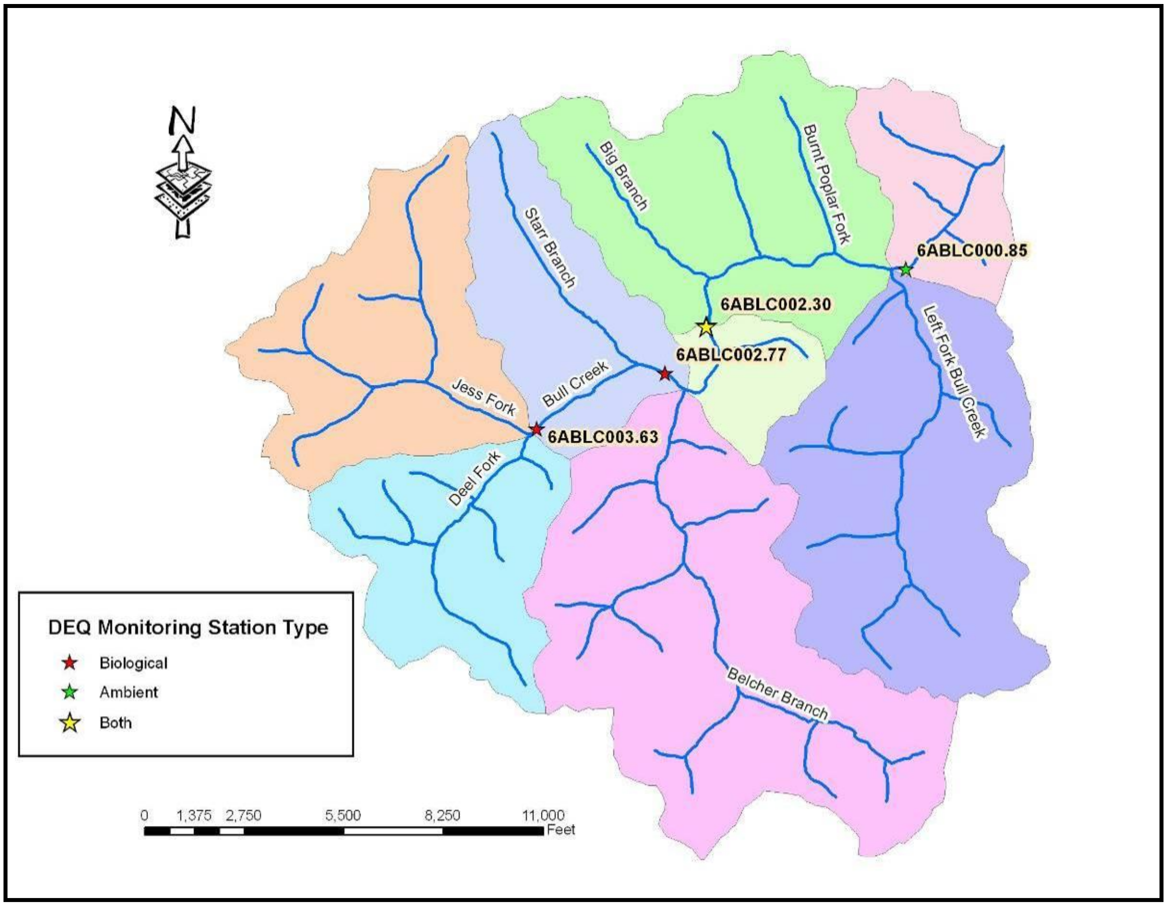

Figure 2.4. Locations of DEQ Monitoring Stations in Bull Creek Watershed

Biological samples were collected from a cross-section of the stream channel and from both pool and riffle environments. The organisms in each sample were separated out into identifiable family or species, and then a count was made of the number of organisms in each taxa. A full listing of the taxa inventory or distribution within each biological sample is given in Table 2.2.

Table 2.2. Bull Creek Benthic Species Distribution by Sample Date

Taxa	Tolerance Value	Functional Family Group	Habit	BLC002.30				BLC002.77	BLC003.63
				05/21/96	**09/13/01**	**05/15/06**	**11/27/06**	**09/13/01**	**09/13/01**
Glossosomatidae	0	Scraper	clinger				3		
Capniidae	1	Shredder							
Gomphidae	1	Predator	burrower						
Perlidae	1	Predator	clinger						
Athericidae	2	Predator	sprawler						
Isonychiidae	2	Filterer	swimmer						
Perlodidae	2	Predator	clinger						
Taeniopterygidae	2	Shredder	sprawler						
Philopotamidae	3	Collector	clinger						
Tipulidae	3	Shredder	burrower		2	3	4		6
Baetidae	4	Collector	swimmer		52	46	26	34	9
Elmidae	4	Scraper	clinger	2	4	1	6		1
Ephemerellidae	4	Collector	clinger						
Heptageniidae	4	Scraper	clinger						
Psephenidae	4	Scraper	clinger						
Corydalidae	5	Predator	clinger						
Hydrachnidae	5	Predator				1			
Hydrophilidae	5	Predator							
Ancylidae	6	Scraper	clinger						
Chironomidae (A)	6	Collector			20	67	16	46	46
Empididae	6	Predator	sprawler					3	
Hydropsychidae	6	Filterer	clinger	12	3	9	47	6	24
Simuliidae	6	Filterer	clinger		10	2		7	2
Asellidae	8	Collector	sprawler						1
Corbiculidae	8	Filterer	sprawler						
Corbiculidae	8	Filterer	sprawler						2
Lumbriculidae	8	Collector			1	4		1	2
Physidae	8	Scraper			2		1		
Tubificidae	10	Collector	burrower				2		
No. of Species				**2**	**8**	**8**	**8**	**6**	**9**
Total Abundance				**14**	**94**	**133**	**105**	**97**	**93**

Field Measurements	**Units**						
temperature	(°C)	18.2	16.9	13.7	11.4	17.4	19.3
dissolved oxygen	(mg/L)	8.93	9.7	9.5	11.6	9.4	8.66
conductivity	(µmhos/cm	850	1221	1011	875	1037	792
pH		7.92	8.23	8.6	8.6	8.18	7.83

[shaded] - Two dominant taxa per sample.

Habit Codes: bur = burrowers; cli = clingers; clm = climbers; ska = skaters; spr = sprawlers; swi = swimmers.

The Rapid Bioassessment Protocol II (RBP II) is the official protocol used to assess compliance with the general standard in Virginia (Barbour et al., 1999). The RBP II procedure evaluates the benthic macro-invertebrate community by comparing individual network biomonitoring stations with reference biomonitoring stations on reference streams. Reference biomonitoring stations have been identified by regional biologists that are both representative of regional physiographic and ecological conditions and have a healthy, non-impaired benthic community. Two different reference stations have been used for Bull Creek over time – Upper Dismal Creek (6ADIS017.94) and Fryingpan Creek (6AFRY002.25).

DEQ, with assistance from USEPA Region 3, has recently upgraded its biomonitoring and biological assessment methods to those currently recommended in the mid-Atlantic region. As part of this effort, a study was performed to assist the agency in moving from a paired-network/reference site approach to a regional reference condition approach, and has led to the development of the Virginia Stream Condition Index (VaSCI) for Virginia's non-coastal areas (Tetra Tech, 2002). This multi-metric index is based on 8 biomonitoring metrics, with a scoring range of 0-100, that include some different metrics than those used in the RBP II, but are based on the same taxa inventory. A maximum score of 100 represents the best benthic community sites. The current proposed threshold criteria would define "non-impaired" sites as those with a VaSCI of 60 or above, and "impaired" sites as those with a score below 60 (DEQ, 2006). The VaSCI scores for Bull Creek (Table 2.3) have all clearly fallen within the "impaired" category. Because of the inconsistent use of a single reference station and the incomplete calculation of metrics for one sample, the VaSCI ratings were considered more reliable than the RBP II ratings when attempting to look for relationships between these overall ratings, individual metrics, and potential pollutants in the stressor analysis. The ratings of all of the biological samples taken at all stations within the Bull Creek watershed are depicted graphically in Figure 2.5.

Table 2.3. Virginia Stream Condition Index (Scored against a fixed scale)

	BLC002.30				BLC002.77	BLC003.63	Overall
	05/21/96	09/13/01	05/15/06	11/27/06	09/13/01	09/13/01	Average
VaSCI Metric Values							
TotTaxa	2	8	8	8	6	9	
EPTTax	1	2	2	3	2	2	
%Ephem	0.0	55.3	34.6	24.8	35.1	9.7	
%PT - Hydropsychidae	0.0	0.0	0.0	2.9	0.0	0.0	
%Scrap	14.3	6.4	0.8	9.5	0.0	1.1	
%Chiro	0.0	21.3	50.4	15.2	47.4	49.5	
%2Dom	100.0	76.6	85.0	69.5	82.5	75.3	
MFBI	5.7	4.8	5.3	5.2	5.3	5.7	
VaSCI Metric Scores							
Richness Score	9.1	36.4	36.4	36.4	27.3	40.9	31.1
EPT Score	9.1	18.2	18.2	27.3	18.2	18.2	18.2
%Ephem Score	0.0	90.2	56.4	40.4	57.2	15.8	43.3
%PT-H Score	0.0	0.0	0.0	8.0	0.0	0.0	1.3
%Scraper Score	27.7	12.4	1.5	18.5	0.0	2.1	10.3
%Chironomidae Score	100.0	78.7	49.6	84.8	52.6	50.5	69.4
%2Dom Score	0.0	33.8	21.7	44.0	25.3	35.7	26.8
%MFBI Score	63.0	76.0	69.4	71.1	68.5	62.6	68.5
VaSCI Total Scores	**26.1**	**43.2**	**31.7**	**41.3**	**31.1**	**28.2**	**33.6**
VaSCI Rating	Severe Stress	Stressed	Severe Stress	Stressed	Severe Stress	Severe Stress	Severe Stress
Additional Biological Metrics							
Scraper/Filterer-Collector	0.17	0.07	0.01	0.11	0.00	0.01	
%Filterer-Collector	85.7%	91.5%	96.2%	86.7%	96.9%	92.5%	
%Haptobenthos	0.0%	0.0%	0.0%	0.0%	3.1%	3.2%	
%Shredder	0.0%	2.1%	2.3%	3.8%	0.0%	6.5%	

(pink) - Primary biological effects.

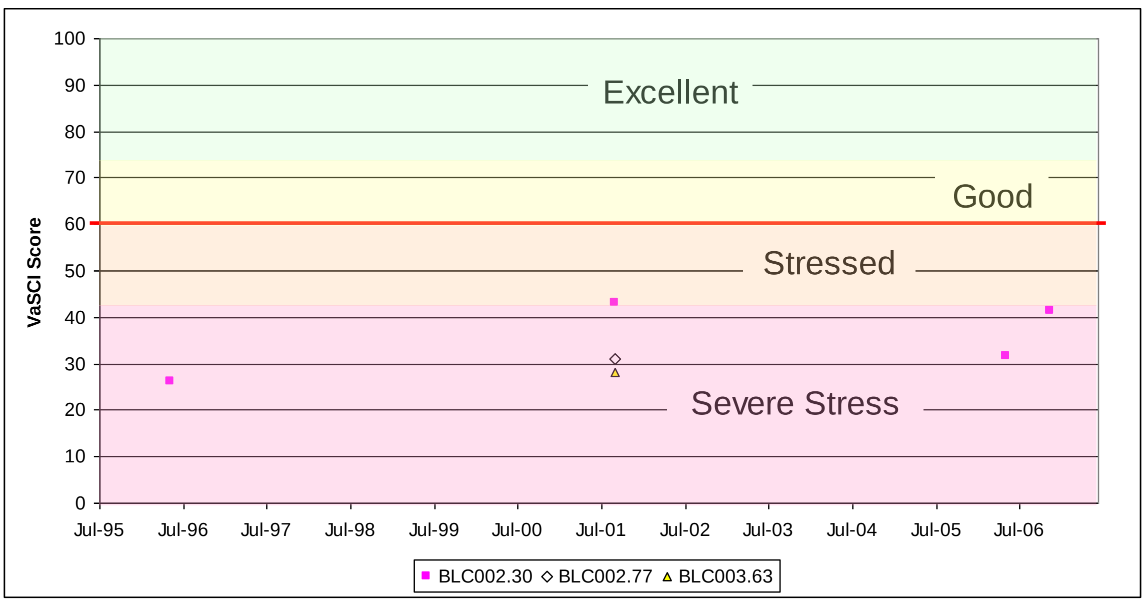

Figure 2.5. VaSCI Scores and Ratings for Bull Creek

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling event. Each of the 10 parameters listed in Table 2.4 was rated on a scale of 0-20, with a maximum score of 20 indicating the most desirable condition, and a score of 0 indicating the poorest habitat conditions. The best possible overall score for a single evaluation is 200. This table shows that bank stability, channel embeddedness, riparian vegetation and sediment deposition metrics have frequently received poor to marginal ratings.

Table 2.4. Habitat Evaluation Scores for Bull Creek

StationID	BLC002.30				BLC002.77	BLC003.63
Collection Date	05/21/96	09/13/01	05/15/06	11/27/06	09/13/01	09/13/01
Channel Alteration	18	15	17	18	14	18
Bank Stability	4	12	14	14	15	14
Bank Vegetation	18	13	11	13	11	12
Embeddedness	6	4	4	7	7	6
Channel Flow Status	17	15	18	19	15	14
Frequency of Riffles	17	18	18	18	18	18
Riparian Vegetation	9	12	10	13	6	6
Sediment Deposition	11	7	8	10	6	4
Substrate Availability	18	16	16	17	11	11
Velocity/Depth Regime	14	9	10	9	9	9
10-Metric Total	**132**	**121**	**126**	**138**	**112**	**112**

- Habitat metric score assessed as "marginal" or "poor".

RBP Habitat Evaluation Ratings
(Bank Stability, Bank Vegetation, Riparian Vegetation): Poor 0-4; Marginal 6-10; Sub-optimal 12-16; Optimal 18-20.
(All others): Poor 0-5; Marginal 6-10; Sub-optimal 11-15; Optimal 16-20.

2.8. Water Quality Data

2.8.1. DEQ Ambient Monitoring Data

DEQ monitored chemical and bacterial water quality in Bull Creek on a monthly basis from July 2005 through the present at station 6ABLC000.85, and from August 2006 through the present at the primary biological monitoring site, 6ABLC002.30. The monthly ambient water quality monitoring data are shown in Figures 2.6 – 2.23. Chemical parameters include various forms of nitrogen and phosphorus – ammonia-N, total kjeldahl nitrogen (TKN), nitrite plus nitrate-N, and total P; dissolved oxygen; various forms of solids – total dissolved solids, volatile solids, total suspended solids, and volatile suspended solids; alkalinity; turbidity; chlorides; and sulfates. Field physical parameters included temperature, pH, and conductivity. Where applicable, minimum and/or maximum water quality standards (WQS) are indicated on the plots, as are minimum detection limits (MDL) of various laboratory analysis techniques.

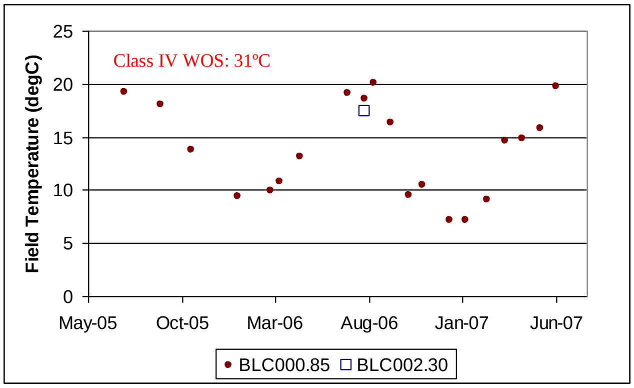

Figure 2.6. Field Temperature

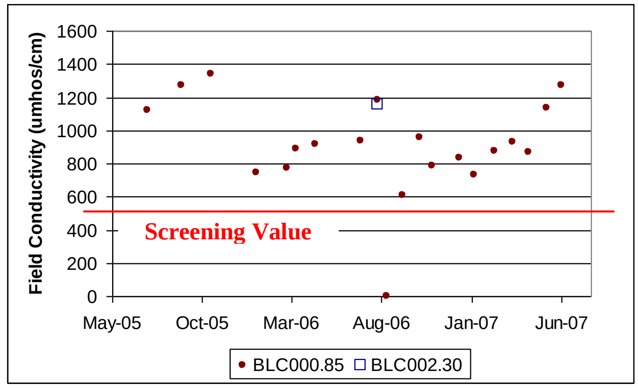

Figure 2.9. Field Conductivity

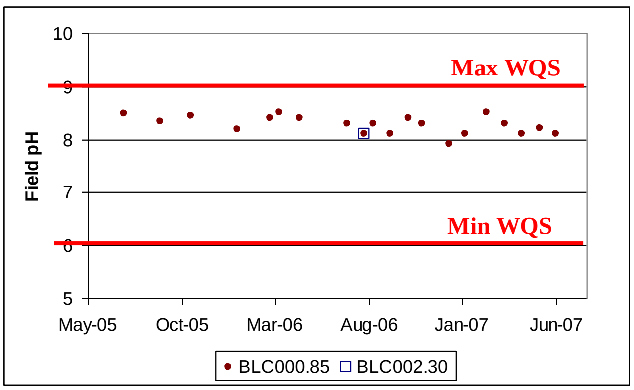

Figure 2.7. Field pH

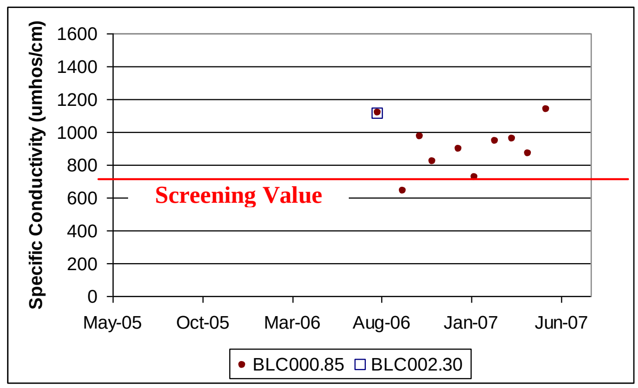

Figure 2.10. Lab Conductivity

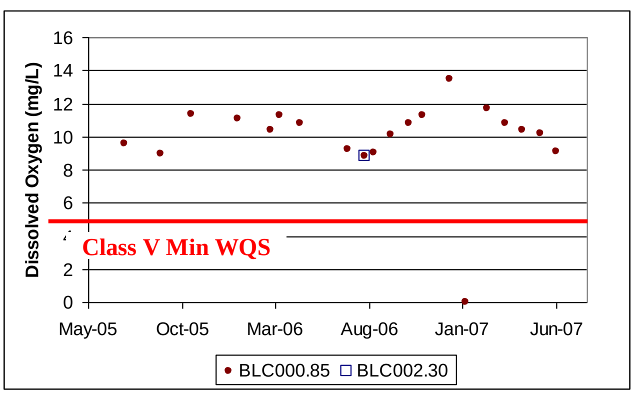

Figure 2.8. Field Dissolved Oxygen (DO)

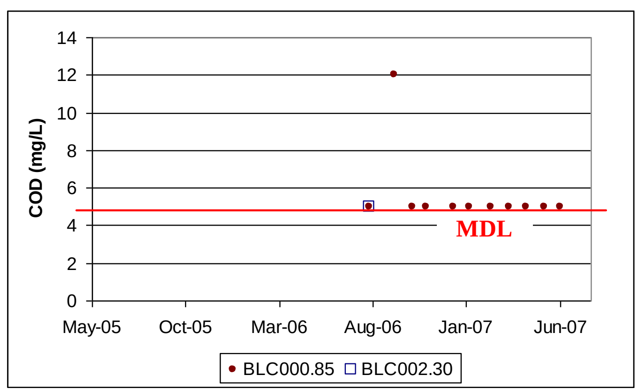

Figure 2.11. Lab Chemical Oxygen Demand (COD)

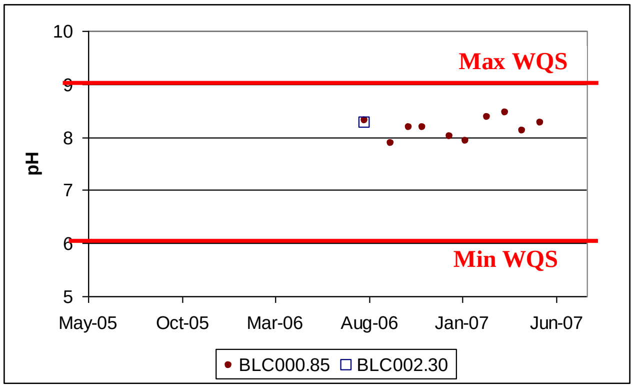

Figure 2.12. Lab pH

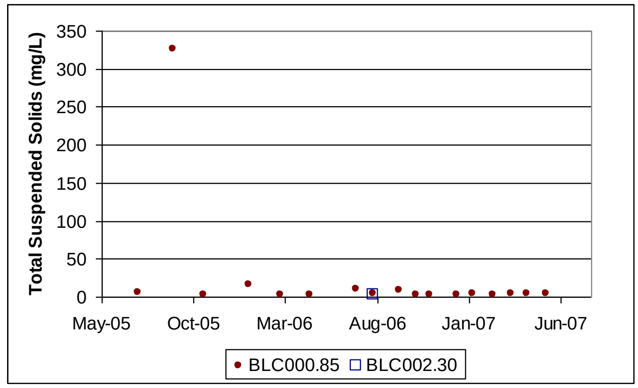

Figure 2.16. Total Suspended Solids (TSS)

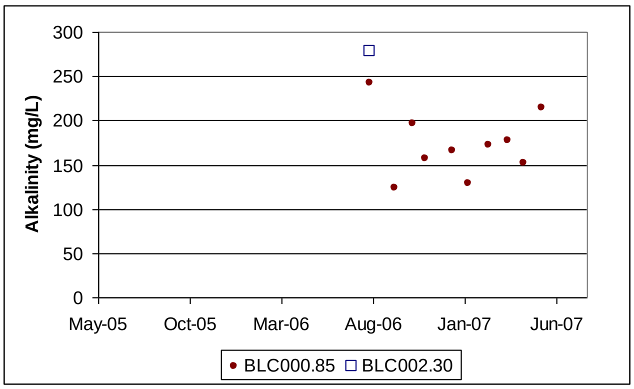

Figure 2.13. Alkalinity

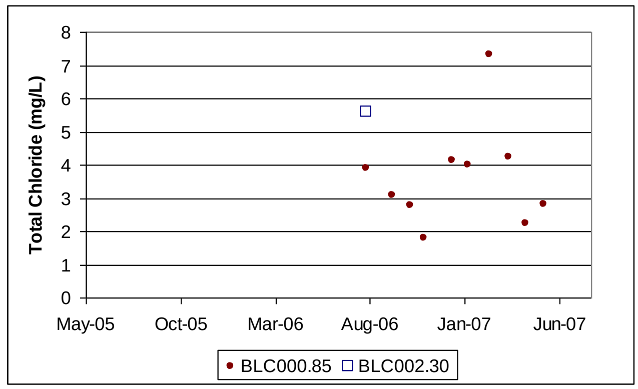

Figure 2.17. Total Chloride

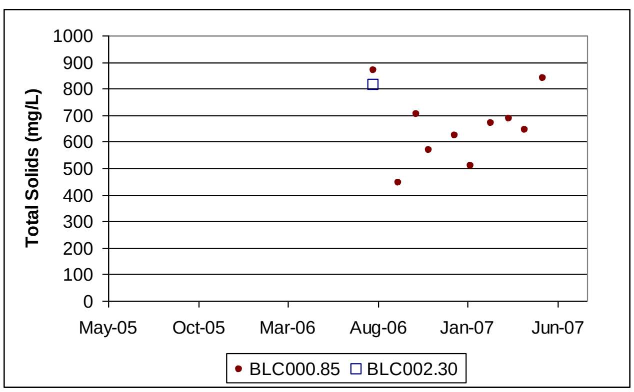

Figure 2.14. Total Solids

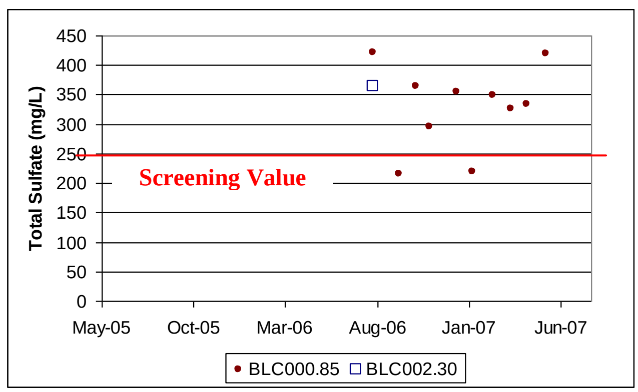

Figure 2.18. Total Sulfate

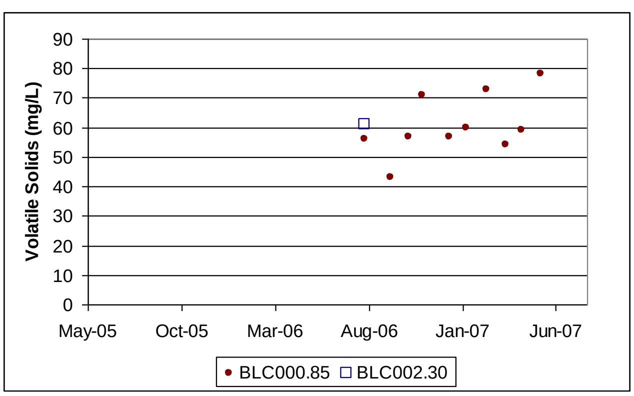

Figure 2.15. Volatile Solids

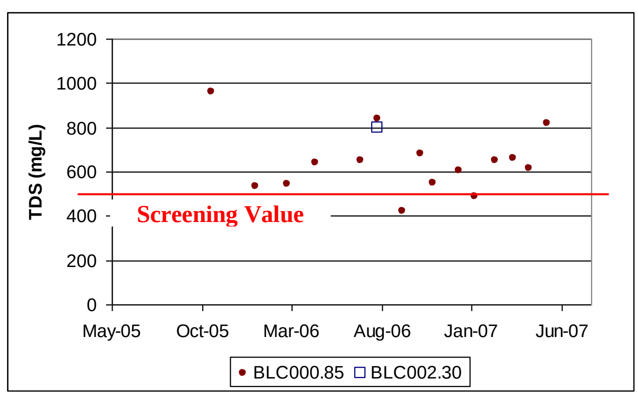

Figure 2.19. Total Dissolved Solids (TDS)

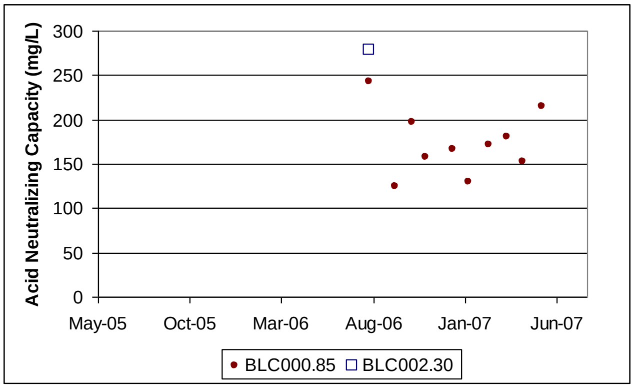

Figure 2.20. Acid Neutralizing Capacity

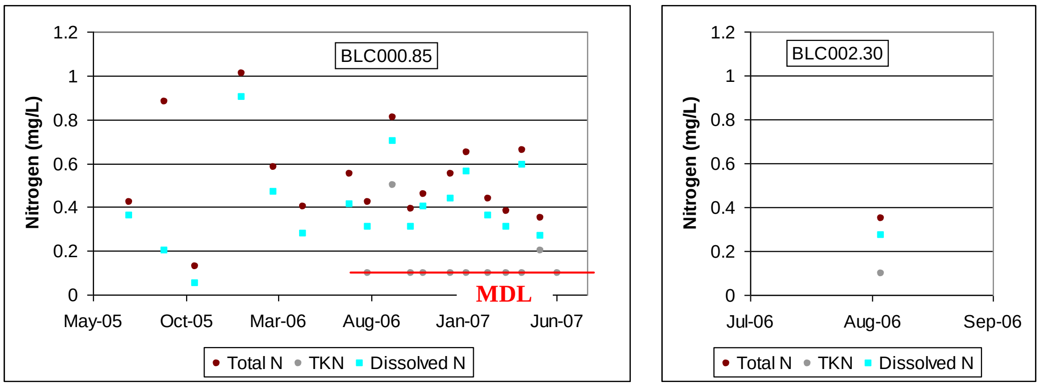

Figure 2.21. Total Nitrogen (TN)

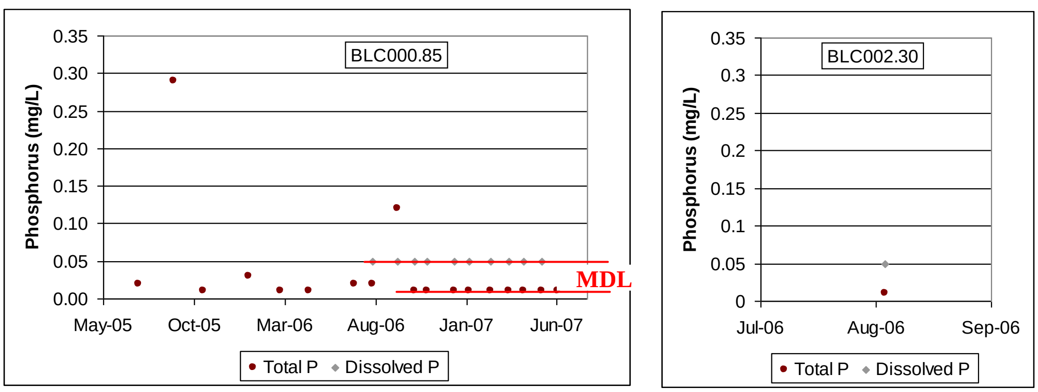

Figure 2.22. Total Phosphorus (TP)

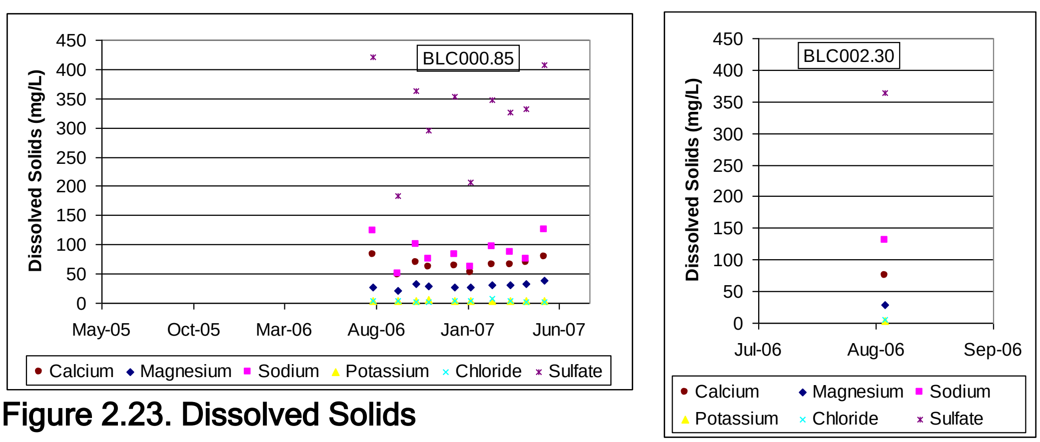

Figure 2.23. Dissolved Solids

2.8.2. DEQ Stream Metals Data

One set of stream sediment and water column samples have been collected and analyzed for a standard suite of metals and toxic substances in August 2006. None of the substances exceeded any known consensus-based probable effects concentrations (MacDonald et al., 2000) or freshwater aquatic life or human health criteria, and many of the substances were not detected above their minimum detection limits (MDL), as shown in Table 2.5.

Table 2.5. DEQ Metals Samples – 6ABLC002.30, August 15, 2006

Parameter Name	Parameter Code	Parameter Value	Minimum Detection Limit	Consensus-Based PECs	Freshwater Aquatic Life Criteria~		Human Health Criteria~	
					Chronic (ug/L)	Acute (ug/L)	PWS (ug/L)	Other (ug/L)
Channel Bottom Sediment Concentrations (mg/kg)								
ALUMINUM, SEDIMENT (MG/KG AS AL DRY WGT)	1108	6510						
ANTIMONY, SEDIMENT (MG/KG AS SB DRY WGT)	1098	5	5					
ARSENIC, SEDIMENT (MG/KG DRY WT)	1003	5.21	5	33				
BERYLIUM, SED (MG/KG AS BE DRY WT)	1013	5	5					
BERYLLIUM, DISSOLVED (UG/L AS BE)	1010	0.1	0.1					
CADMIUM, SEDIMENT (MG/KG DRY WT)	1028	1	1	4.98				
CHROMIUM, SEDIMENT (MG/KG DRY WT)	1029	8.73		111				
COPPER, SEDIMENT (MG/KG AS CU DRY WT)	1043	15.5		149				
IRON, SEDIMENT (MG/KG AS DRY WT)	1170	17300						
LEAD, SEDIMENT (MG/KG AS PB DRY WT)	1052	13.2		128				
MANGENESE, SEDIMENT (MG/KG AS DRY WT)	1053	628						
MERCURY, SEDIMENT (MG/KG AS HG DRY WT)	71921	0.1	0.1	1.06				
NICKEL, SEDIMENT (MG/KG DRY WT)	1068	32.1		48.6				
SELENIUM, SEDIMENT (MG/KG AS SE DRY WT)	1148	1	1					
SILVER, SEDIMENT (MG/KG AS AG DRY WT)	1078	1	1					
THALLIUM, SEDIMENT (MG/KG DRY WT)	34480	5	5					
ZINC, SEDIMENT (MG/KG AS ZN DRY WT)	1093	100		459				
Water Column Concentrations (µg/L)								
ALUMINUM, DISSOLVED (UG/L AS AL)	1106	7.9	1					
ANTIMONY, DISSOLVED (UG/L AS SB)	1095	0.5	0.5				14	4300
ARSENIC, DISSOLVED (UG/L AS AS)	1000	0.4	0.1		150	340	10	
BARIUM, DISSOLVED (UG/L AS BA)	1005	50.5	10				2000	
CADMIUM, DISSOLVED (UG/L AS CD)	1025	0.1	0.1		1.1	3.9	5	
CHROMIUM, DISSOLVED (UG/L AS CR)	1030	2	0.1		74	540	100	
COPPER, DISSOLVED (UG/L AS CU)	1040	1.3	0.1		9	13	1300	
IRON, DISSOLVED (UG/L AS FE)	1046	50	50				300	
LEAD, DISSOLVED (UG/L AS PB)	1049	0.1	0.1		14	120	15	
MANGANESE, DISSOLVED (UG/L AS MN)	1056	14.3	0.1				50	
NICKEL, DISSOLVED (UG/L AS NI)	1065	3.6	0.1		20	180	610	4600
SELENIUM, DISSOLVED (UG/L AS SE)	1145	0.9	0.5		5	20	170	11000
SILVER, DISSOLVED (UG/L AS AG)	1075	0.1	0.1			3.4		
THALLIUM, DISSOLVED (UG/L AS TL)	1057	0.1	0.1				1.7	6.3
ZINC, DISSOLVED (UG/L AS ZN)	1090	2.5	1		120	120	9100	69000

= Below MDL

2.8.3. DMME-DMLR Monitoring Data

The National Pollutant Discharge Elimination System (NPDES) is a federal program designed to eliminate stormwater pollutant discharges to receiving waters of the United States. The DMME-DMLR is responsible for monitoring NPDES discharges for mining permits in Virginia. DMLR NPDES monitoring sites (sediment ponds) and in-stream monitoring points located throughout Bull Creek are shown in Figure 2.24. The average parameter values from DMLR NPDES monitoring points with various sampling period durations and from varying time periods between January 1995 and June 2007 are shown in Table 2.6.

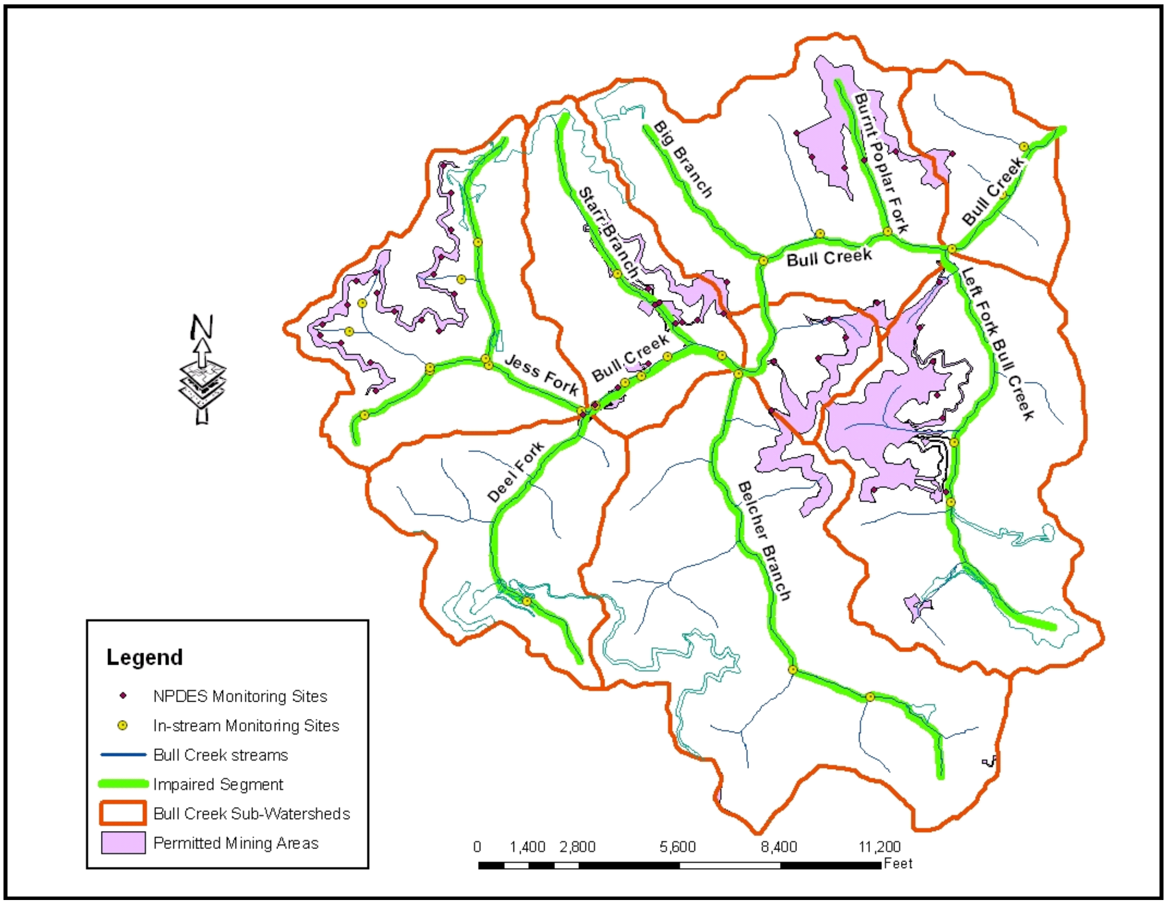

Figure 2.24. DMLR In-stream Monitoring Points in Bull Creek

Table 2.6. Bull Creek NPDES Monitoring Data

Average Concentrations over Period of Record

DMLR MPID	Flow (gpm)	pH	Iron	Manganese	TSS	Settleable Solids	First Sample Date	Last Sample Date	Permit Number	Sub-watershed
			(mg/L)							
0004450	19.55	7.50	0.18	0.31	5.3	0.40	Apr-02	Jun-07	1601788	Left Fork Bull Creek
5670071	17.36	7.26	0.29	0.18	5.7	0.20	Jan-95	Jun-05	1200343	Left Fork Bull Creek
5683337	2.15	7.67	0.18	0.10	8.0	0.10	Jan-95	Apr-03	1201703	Left Fork Bull Creek
5683339	3.38	7.76	0.20	0.10	22.5	0.10	Jan-95	May-02	1201703	Left Fork Bull Creek
5683359	0.32	7.40	0.70	0.20	16.5	0.40	Jan-95	Jun-07	1200281	Left Fork Bull Creek
5683490	1.87	7.12	0.18	0.09	6.1	0.25	Jan-95	Jun-05	1200343	Left Fork Bull Creek
5685197	43.02	7.40	0.33	0.19	7.3	0.10	Jan-95	Apr-03	1301704	Left Fork Bull Creek
0003572	28.81	7.74	0.35	0.12	182.4	0.10	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
5670249	11.71	7.53	0.30	0.23	179.3	0.10	Jan-95	Dec-02	1401509	Burnt Poplar/Big Branch
5684453	1.13	7.71	0.34	0.16	5.9	0.10	Jan-95	Aug-98	1201595	Burnt Poplar/Big Branch
5670187	1.28	7.65	1.20	0.10	19.0		Jan-95	Sep-95	1101205	Belcher Branch
5670371	6.91	7.94	0.35	0.17	5.5	0.10	Jan-95	Aug-98	1201363	Belcher Branch
5670372	2.74	7.51	0.35	0.18	6.5	0.10	Jan-95	Aug-98	1201363	Belcher Branch
5670373	216.75	7.53	0.31	0.18	3.4	0.10	Jan-95	Aug-98	1201363	Belcher Branch
5670374	0.93	7.39	0.21	0.11	5.8	0.10	Jan-95	Aug-98	1201363	Belcher Branch
5683782	10.21	7.13	0.29	0.09	12.1	0.10	Jan-95	Mar-96	1200589	Belcher Branch
5684995	12.71	7.62	0.48	0.88	16.0	0.10	Jan-95	Aug-98	1300469	Belcher Branch
0004312	28.02	7.94	0.45	0.16	18.0	0.20	Oct-02	Jun-07	1201922	Starr Branch
0006397	5.67	6.65	14.90	0.20	668.0	0.40	Mar-07	Jun-07	1201922	Starr Branch
5684994	35.25	7.32	0.25	0.79	7.8	0.10	Jan-95	Aug-98	1300469	Starr Branch
5684997	1.56	7.10	0.13	0.57	2.3		Jan-95	Aug-98	1300469	Starr Branch
5684998	17.03	7.99	0.11	0.10	6.1		Jan-95	Jun-96	1300469	Starr Branch
5685401	19.23	7.37	0.27	0.35	8.5		Jul-95	Sep-96	1300985	Starr Branch
5685402	9.13	7.94	0.30	0.13	3.6	0.10	Jan-95	Mar-99	1300985	Starr Branch
5685404	187.97	8.18	0.23	0.13	5.6		Jan-95	Mar-99	1300985	Starr Branch
5685405	0.20	7.73	0.13	0.10	8.0	0.10	Jan-95	Mar-99	1300985	Starr Branch
5685406	37.24	7.97	0.17	0.13	5.0	0.10	Jan-95	Mar-99	1300985	Starr Branch
5685408	1.55	7.73	0.11	0.12	3.0		Jan-95	Mar-99	1300985	Starr Branch
5670231	0.02	7.20	0.30	0.10	5.0		Jan-95	Aug-99	1201615	Jess Fork
5670232	2.97	7.77	1.00	0.18	21.9	0.12	Jan-95	Aug-99	1201615	Jess Fork
5670233	0.68	7.32	0.25	0.10	16.0	0.10	Jan-95	Aug-99	1201615	Jess Fork
5670234	0.03	7.00	0.10	0.10	35.0		Jan-95	Aug-99	1201615	Jess Fork
5670236	0.26	7.25	0.20	0.15	4.0		Jan-95	Aug-99	1201615	Jess Fork
5684527	4.22	7.66	0.36	0.15	16.6	0.11	Jan-95	Jun-07	1201678	Jess Fork

Average by Sub-watershed

Sub-watershed	Flow (gpm)	pH	Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	Settleable Solids (mg/L)
Outlet	--					
Left Fork Bull Creek	8.9	7.0	0.3	0.1	10.2	0.2
Burnt Poplar/Big Branch	16.2	7.6	0.3	0.2	145.4	0.1
Middle Bull Creek						
Belcher Branch	36.7	6.3	0.3	0.2	6.8	0.1
Starr Branch	29.5	6.4	0.3	0.2	11.4	0.1
Jess Fork	2.0	7.4	0.4	0.1	16.4	0.1
Deel Fork						

Thresholds used for evaluation: Iron (1.0 mg/L); Manganese (1.0 mg/L); TSS (100 mg/L).

The average parameter values from DMLR in-stream monitoring points from various sampling period durations and from varying time periods between January 1995 and June 2007 are shown in Table 2.7. The following relative values were used to indicate higher concentrations which are highlighted in the table: conductivity (> 500 µmhos/cm); TDS (> 500 mg/L); and sulfates (> 250 mg/L).

Table 2.7. Bull Creek In-stream Monitoring Data

Average Concentrations over Period of Record

DMLR MPID	Flow (gpm)	pH	Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	Temperature (°C)	Acidity (mg/L)	Alkalinity (mg/L)	Conductivity (µmhos/cm)	TDS (mg/L)	Sulfate (mg/L)	Date of First Sample	Date of Last Sample	Permit Number	Sub-watershed
0003583	24.2	7.14	0.27	0.08	7.1	13.88	6.73	30.0	317.9	243.3	259.2	Mar-00	Jun-07	1101736	Outlet
0003584	8.5	7.46	0.24	0.14	45.1	14.68	2.16	53.4	210.5	159.4	99.9	Mar-00	Jun-07	1101736	Outlet
0004468	5,210.2	7.88	3.45	0.22	179.9	14.60	0.85	155.2	785.7	578.0	302.8	Jan-02	Jun-07	1601788	Outlet
5620068	35.8	7.48	0.33	0.15	16.0	14.04	0.43	78.8	548.4	400.6	196.9	May-95	Nov-05	1200343	Left Fork Bull Creek
5620116	49.8	7.15	0.24	0.12	12.3	14.67	0.32	64.2	507.7	422.0	184.7	Jan-95	Sep-05	1201909	Left Fork Bull Creek
5620117	62.8	7.54	0.31	0.14	14.8	14.78	0.19	85.9	636.1	498.0	272.1	Jan-95	Sep-05	1201909	Left Fork Bull Creek
5620130	282.4	7.57	0.58	0.18	20.1	14.26	0.46	96.8	710.0	525.4	283.1	May-95	Jun-07	1200281	Left Fork Bull Creek
5620131	267.5	7.64	0.57	0.16	26.5	14.30	0.31	94.1	723.4	568.1	305.4	May-95	Jun-07	1200281	Left Fork Bull Creek
5620343	71.5	7.51	0.27	0.17	9.7	14.75	0.17	68.8	808.2	628.4	386.4	Jan-95	Sep-05	1301908	Left Fork Bull Creek
0003447	2,228.6	7.98	0.35	0.11	16.2	14.61	0.82	176.8	852.0	606.6	278.5	Nov-99	Jun-07	1101701	Burnt Poplar/Big Branch
0003581	330.4	7.99	0.38	0.09	150.7	15.06	0.54	205.4	1,233.2	948.3	564.2	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
0003582	79.0	8.14	0.43	0.11	12.3	15.47	0.54	184.0	996.2	696.7	414.3	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
5620257	23.2	7.68	0.33	0.25	225.3	11.12	5.36	111.3	709.3	463.0	264.6	Jan-95	Dec-02	1401509	Burnt Poplar/Big Branch
5620362	227.3	7.81	0.24	0.13	9.0	14.27	--	175.3	974.0	669.9	294.1	Jan-95	Aug-98	1201595	Burnt Poplar/Big Branch
5620363	50.1	7.87	0.23	0.11	8.7	14.20	--	133.8	865.0	522.5	217.2	Jan-95	Aug-98	1201595	Burnt Poplar/Big Branch
5620364	190.7	7.83	0.26	0.11	7.8	14.00	--	149.6	1,142.8	742.5	315.9	Jan-95	Aug-98	1201595	Burnt Poplar/Big Branch
0004469	1,569.6	8.08	0.20	0.08	13.7	14.87	0.83	175.5	835.1	604.3	295.7	Jan-02	Jun-07	1601788	Belcher Branch
0005467	63.0	7.06	0.71	0.06	8.5	13.70	--	75.2	538.5	372.2	167.2	Mar-04	Jun-07	1101903	Belcher Branch
0005468	77.3	6.82	0.81	0.06	41.9	13.10	--	55.0	410.2	289.7	126.5	Mar-04	Jun-07	1101903	Belcher Branch
5620213	138.1	7.42	0.10	0.27	10.2	13.33	--	26.7	1,014.2	812.8	481.7	Jan-95	Dec-95	1200589	Belcher Branch
5620214	150.7	7.43	0.11	0.28	10.3	13.67	--	31.7	989.2	738.2	373.3	Jan-95	Dec-95	1200589	Belcher Branch
5620369	514.0	7.54	0.19	0.13	12.5	13.69	--	59.2	657.8	471.2	199.8	Jan-95	Aug-98	1201363	Belcher Branch
5620370	1,065.7	7.69	0.25	0.15	8.8	14.48	--	134.0	1,018.0	727.2	313.2	Jan-95	Aug-98	1201363	Belcher Branch
5620376	501.8	7.54	0.21	0.13	10.1	13.57	--	60.3	670.0	476.4	237.8	Jan-95	Mar-99	1201364	Belcher Branch
5620377	1,020.7	7.74	0.20	0.14	8.2	14.12	--	140.4	1,042.9	736.5	339.7	Jan-95	Mar-99	1201364	Belcher Branch
5620419	1,841.8	7.97	0.24	0.15	7.7	14.30	--	141.7	918.2	668.1	286.8	Jan-95	Mar-99	1300985	Belcher Branch
5620420	3,768.6	7.93	0.17	0.16	11.2	14.28	--	123.8	844.0	549.4	251.8	Jan-95	Mar-99	1300985	Belcher Branch
0001297	1,826.1	7.93	0.26	0.15	9.6	14.84	--	137.4	882.0	637.3	268.0	Jan-95	Aug-98	1201363	Starr Branch
0004315	1,837.4	7.65	0.25	0.11	6.3	16.15	0.71	184.7	651.3	491.1	212.3	Apr-02	Jun-07	1201922	Starr Branch
0004316	1,840.8	7.66	0.22	0.15	7.2	16.27	0.71	174.6	811.7	607.6	289.7	Apr-02	Jun-07	1201922	Starr Branch
0004317	109.6	7.46	0.16	1.20	7.9	17.33	1.27	100.1	1,625.5	1,486.3	868.9	Apr-02	Jun-07	1201922	Starr Branch
0005966	359.4	7.50	0.29	0.10	7.1	16.28	0.96	209.0	725.0	476.2	131.3	Jun-05	Jun-07	1201940	Starr Branch
0005967	418.0	7.59	0.25	0.10	7.4	15.68	0.96	146.5	693.3	474.9	180.0	Jun-05	Jun-07	1201940	Starr Branch
5620014	2,304.3	7.65	0.21	0.18	9.3	14.36	--	79.4	709.3	616.0	229.6	Jan-95	Aug-98	1300469	Starr Branch
5620015	1,498.0	7.76	0.43	0.17	18.2	14.58	1.01	172.5	750.4	521.9	212.8	Jan-95	Jun-07	1101701	Starr Branch
0006453	45.2	7.37	0.49	0.09	13.4	12.20	1.00	85.8	592.7	393.2	136.4	Sep-06	Jun-07	1101979	Jess Fork
0006454	36.2	7.53	0.39	0.12	7.2	12.70	1.00	92.2	728.9	509.0	206.2	Sep-06	Jun-07	1101979	Jess Fork
0006455	27.8	7.48	0.35	0.01	6.6	11.60	1.40	35.0	232.9	156.2	54.9	Sep-06	Jun-07	1101979	Jess Fork
0006456	32.4	7.49	0.19	0.01	5.2	11.60	1.00	81.0	466.7	282.2	51.3	Sep-06	Jun-07	1101979	Jess Fork
0006457	27.6	7.07	0.37	0.10	7.8	12.60	3.40	54.0	628.2	429.6	197.6	Sep-06	Jun-07	1101979	Jess Fork
5620228	225.4	6.50	0.29	0.54	10.2	13.61	25.95	25.4	779.1	647.1	357.9	Jan-95	Aug-99	1201615	Jess Fork
5620229	237.7	6.80	0.54	0.49	15.5	13.88	21.32	30.5	779.1	629.6	335.0	Jan-95	Aug-99	1201615	Jess Fork
5620365	860.1	7.66	0.50	0.20	15.3	14.19	0.31	72.8	617.7	523.4	262.3	Jan-95	Jun-07	1201678	Jess Fork
5620417	1,059.5	7.39	0.20	0.20	12.7	13.78	--	50.6	665.8	448.5	233.8	Jan-95	Mar-99	1300985	Jess Fork
0005968	161.3	7.43	0.34	0.21	8.0	14.67	8.05	77.6	591.6	403.5	161.8	Jun-05	Jun-07	1201940	Deel Fork
5620418	504.0	7.57	0.28	0.18	7.8	13.71	--	65.7	578.2	410.7	186.6	Jan-95	Mar-99	1300985	Deel Fork

Average by Sub-watershed

Sub-watershed	Flow (gpm)	pH	Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	Temperature (°C)	Acidity (mg/L)	Alkalinity (mg/L)	Conductivity (µmhos/cm)	TDS (mg/L)	Sulfate (mg/L)
Outlet	1,366.7	7.5	1.1	0.1	66.1	14.4	3.5	71.2	399.8	299.3	211.6
Left Fork Bull Creek	148.9	7.5	0.4	0.2	17.3	14.4	0.3	83.6	669.1	514.5	277.5
Burnt Poplar/Big Branch	716.0	7.9	0.3	0.1	68.9	14.1	1.3	165.5	945.7	659.6	340.8
Middle Bull Creek	--	--	--	--	--	--	--	--	--	--	--
Belcher Branch	1,163.8	7.6	0.3	0.1	13.0	14.0	0.1	105.5	794.0	564.3	260.5
Starr Branch	1,401.2	7.7	0.3	0.3	10.9	15.5	0.8	153.2	859.8	666.0	306.2
Jess Fork	572.7	7.3	0.4	0.3	13.1	13.7	7.8	55.0	663.1	525.3	266.1
Deel Fork	389.8	7.5	0.3	0.2	7.9	14.0	2.7	69.7	582.7	408.3	178.3

Thresholds used for evaluation: Iron (1.0 mg/L); Manganese (1.0 mg/L); TSS (100 mg/L); Conductivity (500 µmhos/cm); TDS (500 mg/L); Sulfate (250 mg/L).

Because TMDL development is concerned with individual monitored concentrations, as well as with overall average concentrations, the following time-series of DMLR in-stream monitoring of pH, TSS, iron, manganese, TDS and sulfate (Figures 2.25 to 2.30) are included to show typical ranges of values and variations over time. In order to show details of the typical range of values, extreme values were omitted from these graphs, but are discussed later. Although DMLR Mining Permit Effluent Limits only apply to NPDES outfalls, and not to in-stream monitoring, these limits were included for perspective in Figures 2.26 to 2.28.

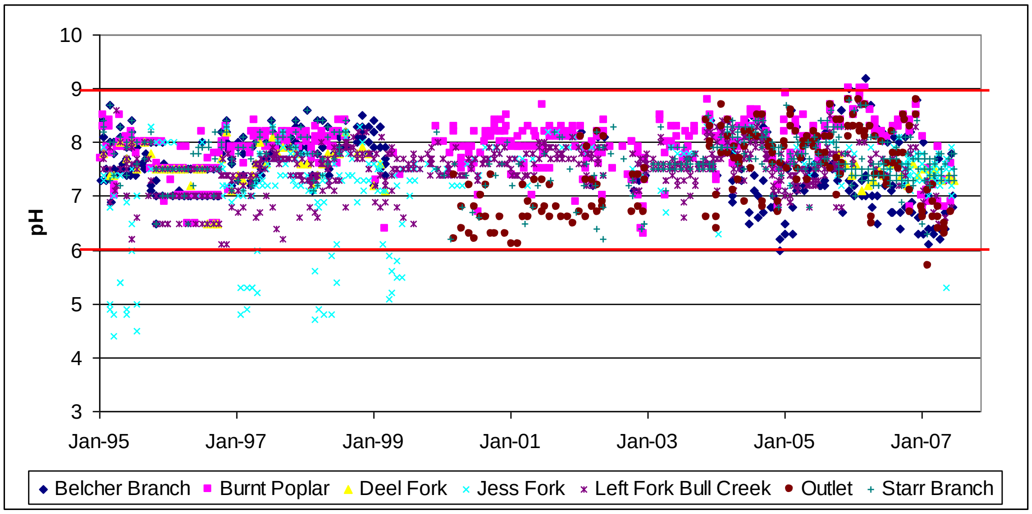

Figure 2.25. DMLR In-stream pH monitoring by sub-watershed

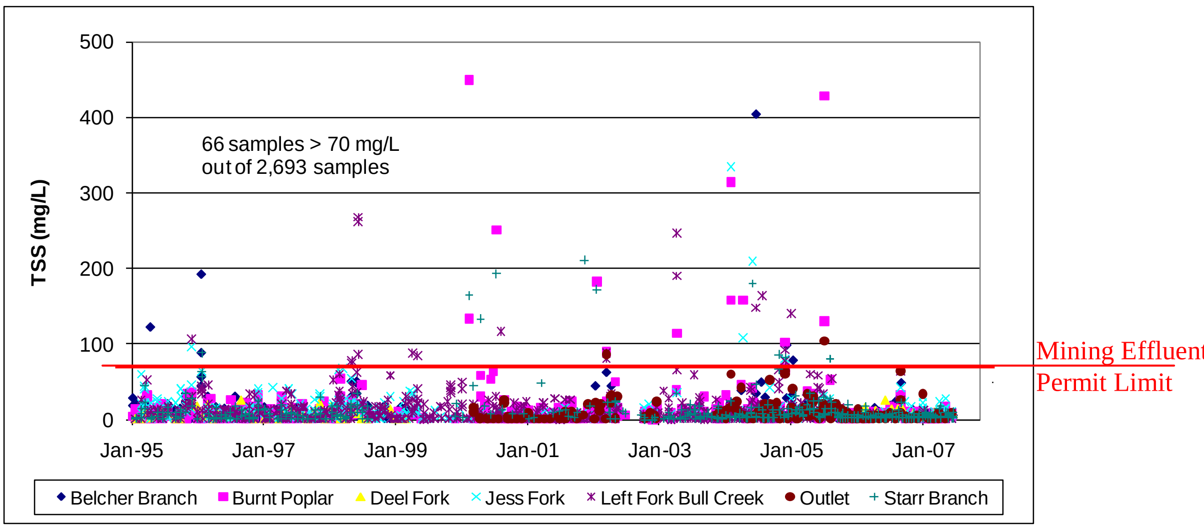

Figure 2.26. DMLR In-stream TSS monitoring by sub-watershed (excludes extreme events)

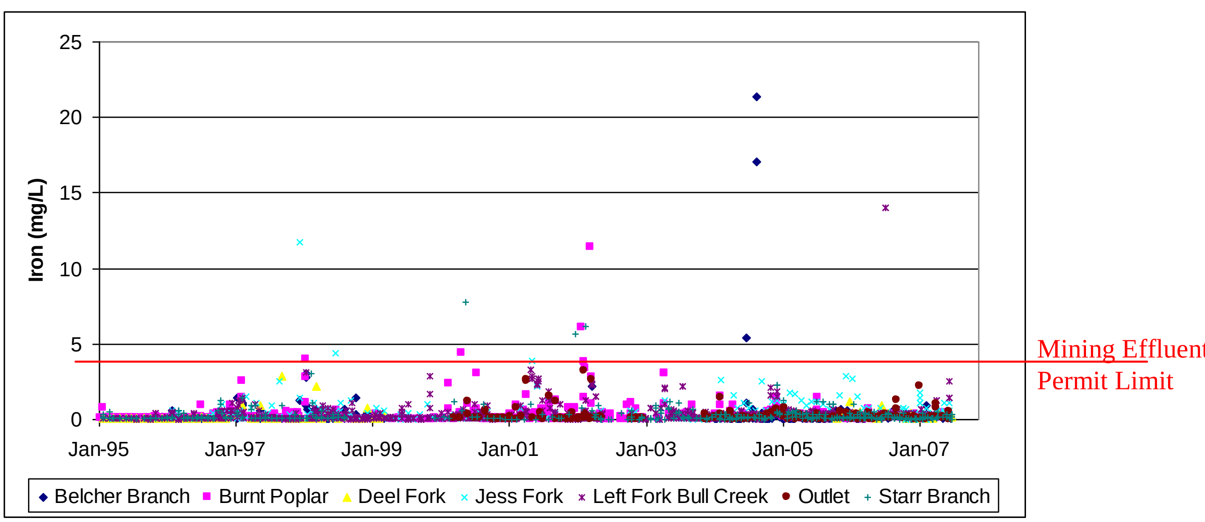

Figure 2.27. DMLR In-stream Iron monitoring by sub-watershed (excludes extreme events)

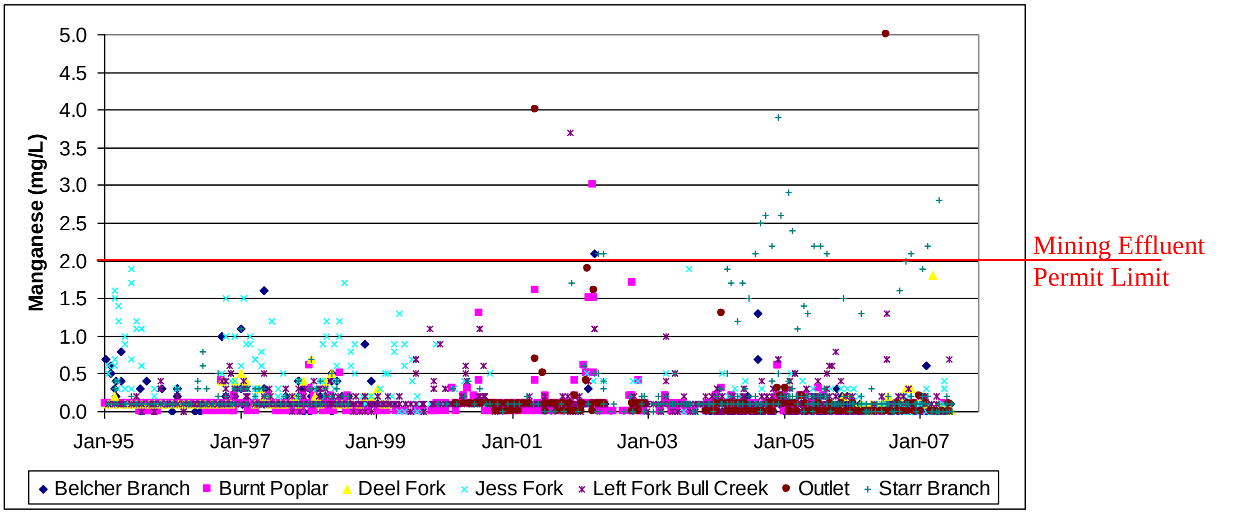

Figure 2.28. DMLR In-stream Manganese monitoring by sub-watershed

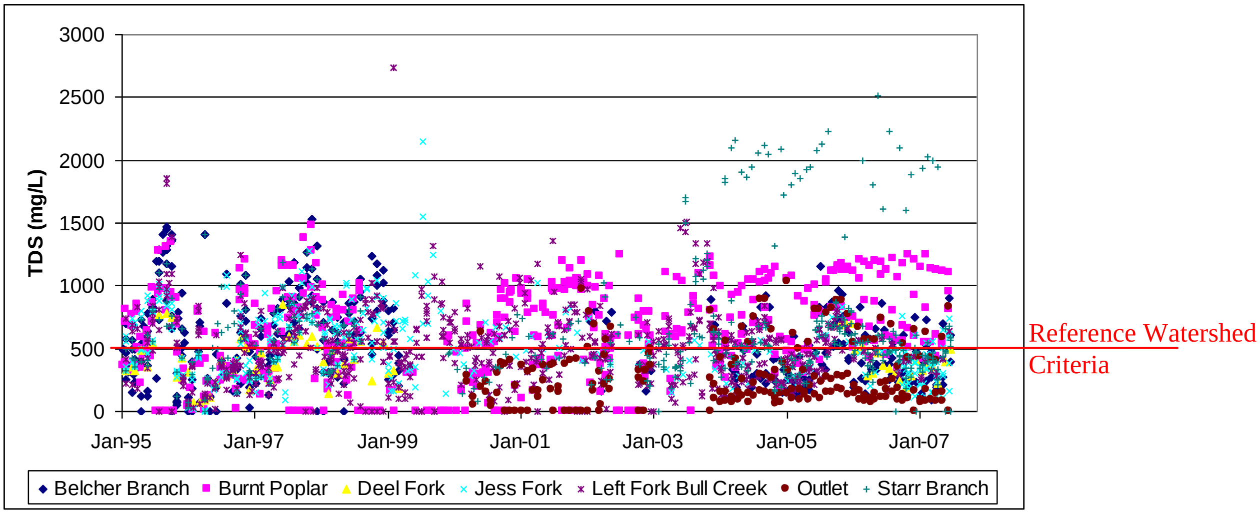

Figure 2.29. DMLR In-stream TDS monitoring by sub-watershed

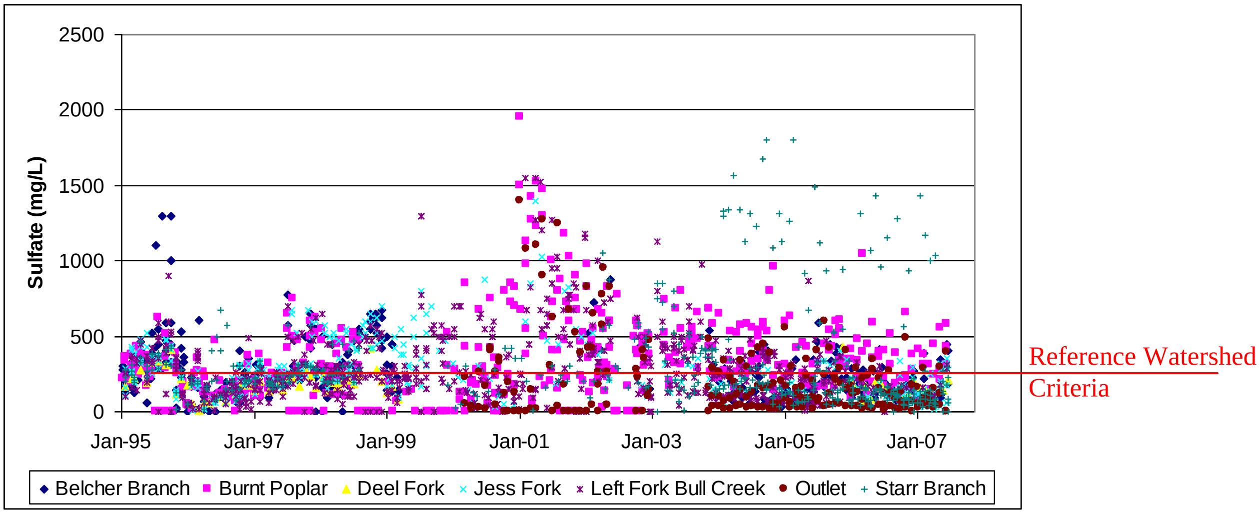

Figure 2.30. DMLR In-stream Sulfate Monitoring by Sub-watershed

Since many of the DMLR monitoring stations are below the biological monitoring point, average concentrations were calculated in Table 2.8 by year and sub-watershed, and summarized above and below the primary monitoring site – 6ABLC002.30 – to better evaluate potential TDS influences on the various biological samples.

Table 2.8. Average TDS Concentrations by Year, Above and Below 6ABLC002.30

	Above BLC002.30				Below BLC002.30				
	No. of Samples / year								
	Belcher Branch	Starr Branch	Deel Fork	Jess Fork	Left Fork Bull Creek	Burnt Poplar /Big Branch	Outlet	**Total above BLC002.30**	**Total below BLC002.30**
1995	94	36	12	48	55	44		**190**	**99**
1996	70	36	12	48	72	46		**166**	**118**
1997	71	36	12	48	70	40		**167**	**110**
1998	58	24	11	47	68	29		**140**	**97**
1999	12	2	3	31	59	6		**48**	**65**
2000		12		12	54	39	17	**24**	**110**
2001		12		11	56	43	17	**23**	**116**
2002	9	24		7	49	42	20	**40**	**111**
2003	2	44		9	64	29	5	**55**	**98**
2004	32	48		12	85	49	36	**92**	**170**
2005	36	62	3	12	74	48	36	**113**	**158**
2006	36	70	12	32	36	48	35	**150**	**119**
2007	18	34	6	36	18	24	16	**94**	**58**
1995-1999 Average	**61.0**	**26.8**	**10.0**	**44.4**	**64.8**	**33.0**	**--**	**165.8**	**106.0**
2000-2003 Average	**5.5**	**23.0**	**--**	**9.8**	**55.8**	**38.3**	**14.8**	**33.8**	**100.5**
2004-2007 Average	**30.5**	**53.5**	**7.0**	**23.0**	**53.3**	**42.3**	**30.8**	**100.8**	**120.6**
	Average TDS concentration (mg/L)								
	Belcher Branch	Starr Branch	Deel Fork	Jess Fork	Left Fork Bull Creek	Burnt Poplar /Big Branch	Outlet	**Average Above BLC002.30**	**Average Below BLC002.30**
1995	642.1	541.2	476.8	563.8	619.7	615.8		**592.8**	**618.0**
1996	433.9	506.1	271.7	339.9	371.5	409.5		**410.6**	**386.3**
1997	756.0	873.2	503.2	793.3	613.8	765.3		**773.8**	**668.9**
1998	659.1	577.0	427.5	640.0	542.7	611.3		**620.4**	**563.2**
1999	511.0	461.5	271.3	632.2	653.8	347.7		**572.2**	**625.5**
2000		342.6		523.5	512.1	689.1	246.4	**433.0**	**533.8**
2001		552.0		616.5	566.9	796.6	323.3	**582.9**	**616.3**
2002	539.2	457.9		488.7	439.9	640.1	375.1	**481.6**	**504.0**
2003	795.0	682.8		371.4	637.5	725.7	405.6	**635.9**	**651.8**
2004	404.0	852.9		350.8	413.9	665.9	287.4	**631.3**	**459.8**
2005	487.5	762.0	704.7	503.8	453.2	760.5	368.9	**645.6**	**527.4**
2006	406.9	631.0	350.5	358.4	440.3	762.2	276.5	**496.6**	**521.9**
2007	385.3	615.6	359.0	353.8	394.2	714.6	274.1	**454.9**	**493.7**
1995-1999 Average	**600.4**	**591.8**	**390.1**	**593.8**	**560.3**	**549.9**	**--**	**599.4**	**559.1**
2000-2003 Average	**667.1**	**508.8**	**--**	**500.1**	**539.1**	**712.9**	**337.6**	**517.4**	**569.9**
2004-2007 Average	**420.9**	**715.4**	**471.4**	**391.7**	**425.4**	**725.8**	**301.7**	**572.9**	**530.9**

Surface mining Start Date(s)	2001*, 2004	1999	none	none	2001*	2000, 2001*	2000
Remining* Start Date(s)	2001	none	none	none	2001	2001	none

It is difficult to determine exact periods of disturbance in each sub-watershed and to relate that with TDS concentrations and mining activity.

However, as in the combined time-series graph (Figure 2.29), TDS concentrations have varied within the same range fairly consistently over time, with the exception of the recent increases above the historic range exhibited in Starr Branch. Annual averages and multi-year averages in Table 2.8 show very slight trends that vary from slightly increasing to slightly decreasing from sub-watershed to sub-watershed. Overall, it appears that the TDS concentrations have remained fairly constant over time, with average concentrations during 2004-2007 increasing in Starr Branch and the Burnt Poplar/Big Branch. The 2004-2007 averages upstream and downstream of 6ABLC002.30 have decreased slightly from the 1995-1999 averages.

Extremely high concentrations of iron and TSS have been observed in both the NPDES and in-stream data sets and are reported in Table 2.9. Extreme values were defined as those values greater than approximately one order of magnitude above the mining permit effluent limits. Extreme concentration values were verified by evaluating relationships to recorded flow and rainfall on the day of, and on days preceding the date of, sampling, and by comparison with monitoring at nearby stations. DMLR provided the following explanations for these extreme values. On 04/10/03, the discharge resulted from 0.25 inches of rainfall with 2.28 inches of rainfall on previous days and a permit violation where a needed pond cleanout was not performed (noted in a DMLR inspection report). The elevated concentrations on 07/13/00 (rainfall = 0.04 inches), following 2.32 inches of rainfall on previous days, were monitored in the discharge of an upstream pond, whose discharge is contained by a newer downstream pond that was reported to be functioning properly by an inspector 2 weeks earlier. The event on 07/05/06 resulted from a daily rainfall of 0.11 inches, following 0.48 inches on previous days, in a portion of the watershed where active mining could not have caused the discharge. The concentration reported on 08/12/04 corresponded with a daily rainfall amount of 0.15 inches with 0.20 inches on preceding days, from a watershed with approved, but not constructed, NPDES outfalls, and no active mining. The concentration reported on 02/06/04 was due to a daily rainfall amounting to 0.69 inches with 0.26 inches on previous days and a permit violation that corresponded with a disturbance in the permit area prior to pond construction. On 03/16/07, where 0.46 inches of rainfall was received following 0.35 inches on previous days, the discharge was from a pond that had been noted by the inspector as nearing cleanout level. A follow-up report stated the pond had been cleaned out.

The extreme values from these 10 samples led to most of the elevated site-averages for metals and TSS in Tables 2.6 and 2.7. The three NPDES samples in this table were responsible for all of the flagged TSS site-averages, the largest iron site-average, and the one sub-watershed average TSS in Table 2.6. The extreme in-stream samples were responsible for all flagged site-averages and the one sub-watershed average of iron and TSS in Table 2.7.

Table 2.9. Summary of Extreme DMLR Iron, Manganese and TSS Concentrations

MPID	Monitoring Type	Date	Flow (gal/min)	Iron	Manganese	TSS	Sub-watershed
				(mg/L)			
0003572	NPDES	04/10/03	95	3.0	3.0	**22,860**	Burnt Poplar/Big Branch
0003581	Instream		185	3.0	0.2	**10,430**	Burnt Poplar/Big Branch
5670249	NPDES	07/13/00	460	2.9	1.2	**10,640**	Burnt Poplar/Big Branch
5620257	Instream		400	3.0	1.3	**8,780**	Burnt Poplar/Big Branch
0004468	Instream	07/05/06	16,655	**164.0**	5.0	**8,704**	Outlet
5620131	Instream		1,805	**31.5**	1.3	**1,760**	Left Fork Bull Creek
5620130	Instream		1,750	14.0	0.7	**776**	Left Fork Bull Creek
0003584	Instream	02/06/04	80	1.4	1.3	**1,908**	Outlet
0006397	NPDES	03/16/07	50	**26.3**	0.3	**1,160**	Starr Branch
0005468	Instream	08/12/04	60	17.1	0.7	**882**	Belcher Branch
	Extreme values are in **Bold** type.						

DMLR groundwater monitoring locations in Bull Creek are shown in Figure 2.31. Site-average concentrations of monitored parameters are shown by monitoring point identification number (MPID) in Table 2.10. The DMLR monitored data represents 42 groundwater monitoring sites around the Bull Creek watershed with monitoring periods ranging between January 1995 and June 2007.

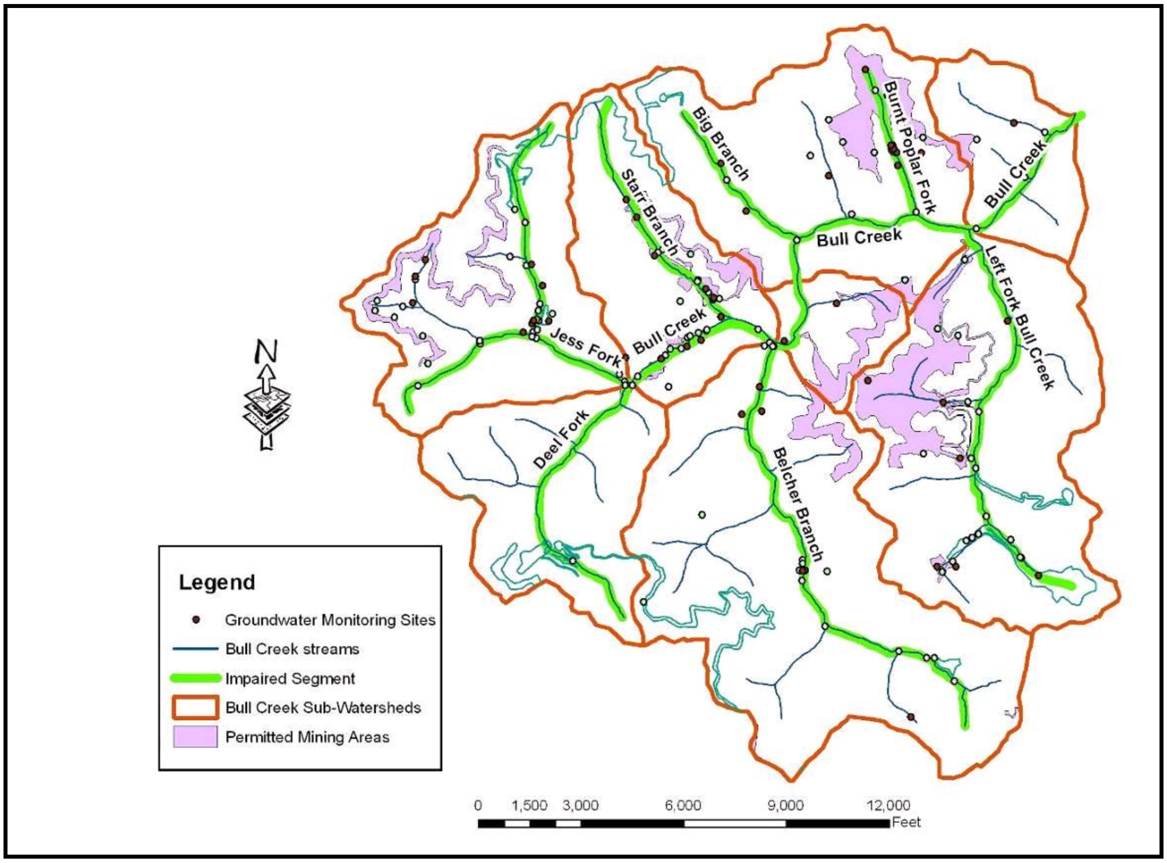

Figure 2.31. DMME-DMLR Groundwater Monitoring Sites, January 2005 – June 2007

Table 2.10. Bull Creek Groundwater Monitoring Data, Jan-95 through Jun-07

Average Concentrations over Period of Record

DMLR MPID	Flow (gpm)	pH	Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	Temperature (°C)	Acidity (mg/L)	Alkalinity (mg/L)	Conductivity (µmhos/cm)	TDS (mg/L)	Sulfate (mg/L)	Date of First Sample	Date of Last Sample	Permit Number	Sub-watershed
0001296	37.42	7.86	0.21	0.11	3.7	14.4	--	237.2	1,108.3	981.2	383.5	Jan-95	Aug-98	1201363	Belcher Branch
0004463	0.29	8.43	0.56	0.08	4.9	16.4	1.0	187.7	373.0	214.4	6.6	Jan-02	Jun-07	1601788	Belcher Branch
0005459	12.90	6.93	0.53	0.04	20.8	12.2	--	62.9	337.7	264.2	59.1	Apr-04	Jun-07	1101903	Belcher Branch
5600368	208.36	7.48	0.49	0.13	2.4	14.4	--	210.8	1,398.9	1,013.7	441.1	Jan-95	Aug-98	1201363	Belcher Branch
5645398	--	6.75	10.82	0.43	64.7	13.9	--	139.3	705.2	523.3	518.0	Jan-95	Mar-99	1300985	Belcher Branch
5650118	248.95	7.48	0.32	0.09	4.4	15.3	0.2	196.9	1,305.1	903.8	401.6	Jan-95	Sep-05	1201909	Belcher Branch
0001942	18.12	7.24	0.39	0.42	29.5	12.4	--	175.2	851.7	546.4	292.3	Dec-95	Dec-02	1401509	Burnt Poplar/Big Branch
0003444	18.70	7.63	0.69	0.81	13.2	13.8	0.5	178.7	1,552.7	939.5	643.9	Nov-99	Jun-07	1101701	Burnt Poplar/Big Branch
0003445	5.07	7.39	9.33	0.33	172.7	13.8	0.6	53.6	679.9	312.3	193.1	Nov-99	Jun-07	1101701	Burnt Poplar/Big Branch
0003576	29.02	7.69	0.16	0.03	6.7	15.2	0.4	223.9	1,449.4	814.4	432.5	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
0003578	0.28	7.43	1.72	0.09	15.6	15.7	0.4	117.9	865.7	574.6	323.9	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
0003579	185.12	7.41	0.13	0.03	5.3	15.2	0.4	179.8	1,260.4	727.8	363.0	Mar-00	Jun-07	1101736	Burnt Poplar/Big Branch
0003580	27.15	7.76	0.78	0.17	662.3	15.0	0.4	138.3	1,421.0	1,002.5	652.4	Jun-00	Jun-07	1101736	Burnt Poplar/Big Branch
5643333	--	7.13	0.63	0.60	36.3	14.0	--	231.0	654.0	497.3	176.7	Jan-95	Sep-95	1200272	Burnt Poplar/Big Branch
5644451	121.48	7.15	0.30	0.14	3.8	14.0	--	234.4	1,159.9	890.4	360.0	Jan-95	Aug-98	1201595	Burnt Poplar/Big Branch
5650252	3.32	7.55	1.76	0.15	64.1	14.0	--	93.3	581.3	373.8	242.4	Jan-95	Dec-02	1401509	Burnt Poplar/Big Branch
0000083	3.44	5.97	0.15	1.23	3.0	13.2	14.0	3.5	580.3	296.7	219.1	Jan-95	Jun-07	1401467	Jess Fork
0004539	--	7.35	0.01	--	0.1	20.8	--	7.6	514.5	48.4	35.1	Apr-03	Jul-04	1201574	Jess Fork
0004540	7.51	6.58	0.07	0.78	2.7	15.9	13.3	5.1	518.0	303.2	143.0	Apr-03	Jun-07	1201574	Jess Fork
0006430	1.00	7.18	2.00	0.18	5.0	13.3	1.0	120.5	278.9	163.0	5.3	Sep-06	Jun-07	1101979	Jess Fork
0006432	11.37	6.56	0.03	1.00	2.0	14.5	18.0	11.3	495.0	406.0	178.0	Sep-06	Jun-07	1101979	Jess Fork
5643399	1.26	6.73	0.80	1.00	100.0	15.3	--	355.0	521.4	226.0	120.0	Jan-95	Aug-99	1201615	Jess Fork
5643400	--	6.93	3.34	0.51	22.7	15.9	--	73.6	707.5	469.1	284.3	Jan-95	Aug-99	1201615	Jess Fork
5645399	0.16	6.71	9.24	0.28	76.1	13.8	--	101.6	660.3	571.3	309.1	Jan-95	Mar-99	1300985	Jess Fork
0004461		7.27	1.19	0.22	6.7	16.6	0.8	108.3	376.0	258.6	98.5	Jan-02	Jun-07	1601788	Left Fork Bull Creek
0004465	38.45	7.63	2.45	5.04	700.3	16.3	3.9	118.9	1,761.6	1,688.6	920.7	Dec-03	Jun-07	1601788	Left Fork Bull Creek
5640069	1.67	7.34	1.01	0.44	17.0	14.5	10.2	139.5	680.2	447.2	194.3	May-95	Nov-05	1200343	Left Fork Bull Creek
5650195	--	6.97	0.10	0.10	8.0	11.0	--	359.0	516.7	290.0	110.0	Jan-95	Sep-95	1201209	Left Fork Bull Creek
5653489	--	7.20	0.63	1.04	10.2	13.1	--	139.8	418.7	330.4	159.1	May-95	Nov-05	1200343	Left Fork Bull Creek
5655196	30.40	7.11	0.82	0.48	10.6	14.6	0.2	56.6	919.3	712.1	523.1	Jan-95	Aug-05	1301908	Left Fork Bull Creek
0003446	--	7.29	1.40	0.13	4.2	15.1	0.7	152.8	522.0	271.8	80.9	Nov-99	Jun-07	1101701	Middle Bull Creek
0004462	7.97	7.60	0.43	0.05	7.6	14.9	0.8	179.5	1,069.0	756.1	367.9	Jan-02	Jun-07	1601788	Middle Bull Creek
0003577	0.46	7.47	2.05	0.66	20.4	16.0	1.1	60.8	582.4	460.0	276.2	Mar-00	Jun-07	1101736	Outlet
0000942	29.67	7.16	0.10	0.10	48.0	18.9	--	124.0	753.8	1,441.0	717.5	Jan-95	May-97	1300985	Starr Branch
0000943	73.51	7.12	0.10	0.10	45.5	15.8	--	145.0	901.7	1,439.0	697.5	Jan-95	May-97	1300985	Starr Branch
0003443	2.05	7.18	23.34	0.71	808.5	17.1	17.9	37.9	689.5	428.8	193.0	Nov-99	Jun-07	1101701	Starr Branch
0004313	8.70	7.53	5.62	0.41	208.7	17.5	9.1	105.6	704.9	552.4	254.3	Apr-02	Jun-07	1201793	Starr Branch
5600375	241.35	7.89	1.20	0.20	9.9	13.7	--	257.6	801.0	676.9	275.3	Jan-95	Mar-99	1201364	Starr Branch
5640218	--	7.30	3.40	0.53	17.5	17.4	--	191.1	825.3	597.1	226.4	Jan-95	Aug-98	1300469	Starr Branch
5640219	22.34	7.46	0.91	1.26	25.3	16.0	--	81.1	2,115.4	1,837.4	562.9	Jan-95	Aug-98	1300469	Starr Branch
5650220	26.85	7.24	0.67	1.36	11.9	16.6	--	163.1	2,786.6	2,427.7	491.9	Jan-95	Aug-98	1300469	Starr Branch
5650221	--	5.28	5.57	3.77	66.7	18.0	20.3	20.9	2,425.9	2,592.7	804.2	Jan-95	Aug-98	1300469	Starr Branch

Average by Sub-watershed

Sub-watershed	Flow (gpm)	pH	Iron (mg/L)	Manganese (mg/L)	TSS (mg/L)	Temperature (°C)	Acidity (mg/L)	Alkalinity (mg/L)	Conductivity (µmhos/cm)	TDS (mg/L)	Sulfate (mg/L)
Outlet	0.5	7.5	2.0	0.7	20.4	16.0	1.1	60.8	582.4	460.0	276.2
Left Fork Bull Creek	12.1	7.3	1.0	1.0	72.0	14.5	3.1	116.0	736.5	574.5	326.6
Burnt Poplar/Big Branch	39.8	7.5	1.8	0.3	109.5	14.3	0.3	150.1	1,074.2	667.3	385.7
Middle Bull Creek	2.2	7.4	1.1	0.1	5.1	15.1	0.7	160.0	669.6	402.5	158.3
Belcher Branch	108.0	7.5	2.0	0.1	15.5	14.6	0.2	177.6	934.4	685.0	319.7
Starr Branch	41.6	7.2	6.6	1.0	208.4	16.7	6.9	116.8	1,294.8	1,211.3	415.5
Jess Fork	2.8	6.5	2.0	0.8	29.8	14.6	7.3	82.1	582.1	343.3	205.9
Deel Fork											

Thresholds used for evaluation: Iron (1.0 mg/L); Manganese (1.0 mg/L); TSS (100 mg/L); Conductivity (500 µmhos/cm); TDS (500 mg/L); Sulfate (250 mg/L).

2.8.4. DMME-DGO Permit Summary

Gas and oil permits are issued by the DMME Division of Gas and Oil (DGO) for construction of gas and oil well pumping facilities and are subject to stormwater erosion and sediment control (E&S) sediment permit limits. Contributions from gas and oil operations in the watershed are transient, and regulations require that any disturbed acreage during construction and drilling must be stabilized within 30 days. Sediment loads from both the pumping sites and the access roads are covered under the stormwater E&S permits, unless existing roads are used for access.

Currently there are 24 active gas wells in the watershed with an additional 5 wells permitted that have not yet been constructed. A summary of the current active well, plugged release, and pending well permits are shown in Table 2.11, with their locations shown in Figure 2.32.

Because of the recent flurry of activity surrounding the energy-producing industry, an increased number will likely be seen. Reclaimed areas not in other uses might be prime target areas for these applications.

Table 2.11. DMME Division of Gas and Oil (DGO) Well Permit Summary: June 2007

Permit No.	Operation ID	County	USGS Quad	Subwatershed	Operation Description	Permits Description
			Active Wells			
BU-0566	EH-110	BUCHANAN	HARMAN	Belcher Branch	Gas	Constructed/Never Drilled
BU-3081	825903 (HY-137	BUCHANAN	HARMAN	Starr Branch	Gas/Pipeline	Construction
BU-2478	CBM N-76	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-2669	CBM N78	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-2688	CBM M77	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-2709	CBM L77	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-3000	CBM K76	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-3009	CBM L76	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/
BU-2477	CBM N-75	BUCHANAN	HARMAN	Belcher Branch	Coalbed/Pipeline	Drilled/Waiting Completion/
BU-3049	CNR 823540 (H	BUCHANAN	HARMAN	Jess Fork	Gas/Pipeline	Drilled/Waiting Completion/
BU-2335	CBM M76	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Not Connected
BU-2345	CBM K-75	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Not Connected
BU-2479	CBM N-77	BUCHANAN	HARMAN	Left Fork Bull Creek	Coal Bed	Not Connected
BU-0098	9591	BUCHANAN	HARMAN	Jess Fork	Gas	Producing
BU-0116	9692	BUCHANAN	HARMAN	Deel Fork	Gas	Producing
BU-0117	9678	BUCHANAN	HARMAN	Middle Bull Creek	Gas	Producing
BU-0118	9681	BUCHANAN	HARMAN	Deel Fork	Gas	Producing
BU-0126	9701	BUCHANAN	HARMAN	Jess Fork	Gas	Producing
BU-0131	9765	BUCHANAN	HARMAN	Burnt Poplar/Big Branch	Gas	Producing
BU-0147	20340	BUCHANAN	HARMAN	Jess Fork	Gas	Producing
BU-0167	20546	BUCHANAN	HARMAN	Deel Fork	Gas	Producing
BU-0564	EH-112	BUCHANAN	HARMAN	Belcher Branch	Gas	Producing
BU-0572	EH-114	BUCHANAN	HARMAN	Starr Branch	Gas	Producing
BU-0754	21732	BUCHANAN	HARMAN	Starr Branch	Gas	Producing
			Plugged/Released Wells			
BU-0087	9582	BUCHANAN	HARMAN	Left Fork Bull Creek	Gas	Plugging/Plugged/Abandoned
BU-0135	9766	BUCHANAN	HARMAN	Burnt Poplar/Big Branch	Gas	Released
BU-0145	20342	BUCHANAN	HARMAN	Deel Fork	Gas	Released
BU-0606	EH-111	BUCHANAN	HARMAN	Deel Fork	Gas	Released
			Pending Permits			
8869	4/26/2006	BUCHANAN	HARMAN	Belcher Branch		Pending
8870	4/26/2006	BUCHANAN	HARMAN	Belcher Branch		Pending
8871	4/26/2006	BUCHANAN	HARMAN	Belcher Branch		Pending
8872	4/26/2006	BUCHANAN	HARMAN	Belcher Branch		Pending
8880	4/27/2006	BUCHANAN	HARMAN	Belcher Branch		Pending

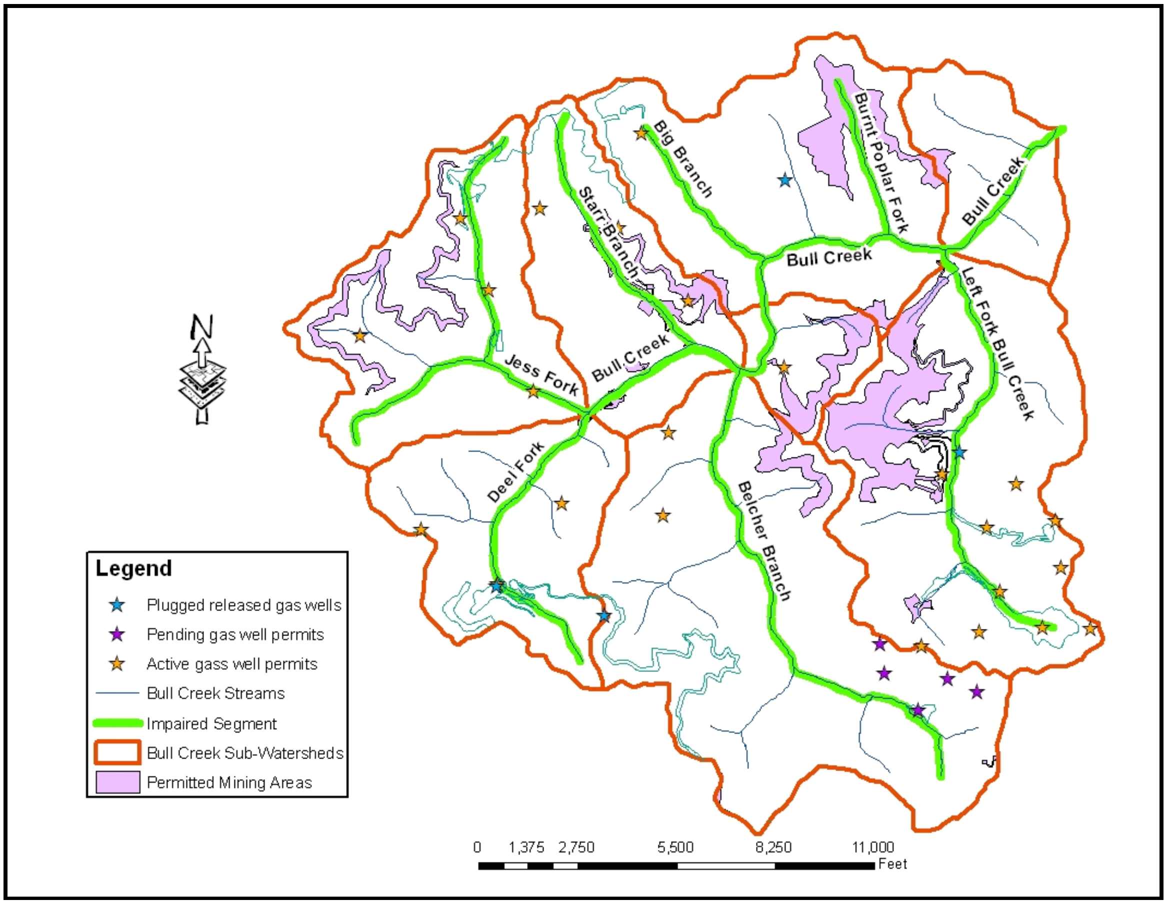

Figure 2.32. DMME DGO Gas Well Locations in Bull Creek

2.9. Point Source Permits

2.9.1. DEQ – VPDES Permits in Bull Creek

There are no Virginia Pollution Discharge Elimination System (VPDES) permits currently active in Bull Creek.

2.9.2. DMLR – NPDES Permit Summary

Within the Bull Creek watershed, the eleven mining permits, Table 2.12, are in various stages of activity, and are monitored at eighteen monitoring points. These permits require stormwater detention ponds to reduce the loading of sediment and other pollutants and downstream monitoring in order to check their compliance with permit requirements of a maximum daily effluent concentration of 70 mg/L for TSS. The locations, extent, and type of mining permits and DMLR in-stream monitoring points are shown in Figure 2.33 prior to 1997 (during the original listing of the impaired segments) and in Figure 2.34 at the present time.

Table 2.12. DMLR Mining Permit Summary: June 2007

Permit Number	Mining Operation Name	Outlet	Convict Hollow	Burnt Poplar / Big Branch	Middle Bull Creek	Starr Branch	Belcher Branch	Jess Fork	Deel Fork	PENO Total
		Area in hectares								
1101701	Starr Branch Strip			3.07	0.09	16.23				19.40
1101736	Burnt Poplar Surface Mine #1	3.51		45.67						49.18
1101903	Hawks Nest Surface Mine						1.10			1.10
1101979	Jess Fork Mine							25.90		25.90
1200129	Supreme Energy Corporation						0.34			0.34
1200281	Mine #1		2.47							2.47
1200343	K & H Coal Company		2.18							2.18
1201678	Apollo Mine #1					0.13		0.34	0.59	1.06
1201922	Mine #1					4.86				4.86
1201940	Clintwood Elkhorn H-1 Mine					2.22			0.08	2.29
1601788	Convict Hollow Remining Permit		72.04	3.53	23.80		14.72			114.09
Total by Sub-watershed		3.51	76.69	52.27	23.89	23.45	16.17	26.25	0.66	222.88

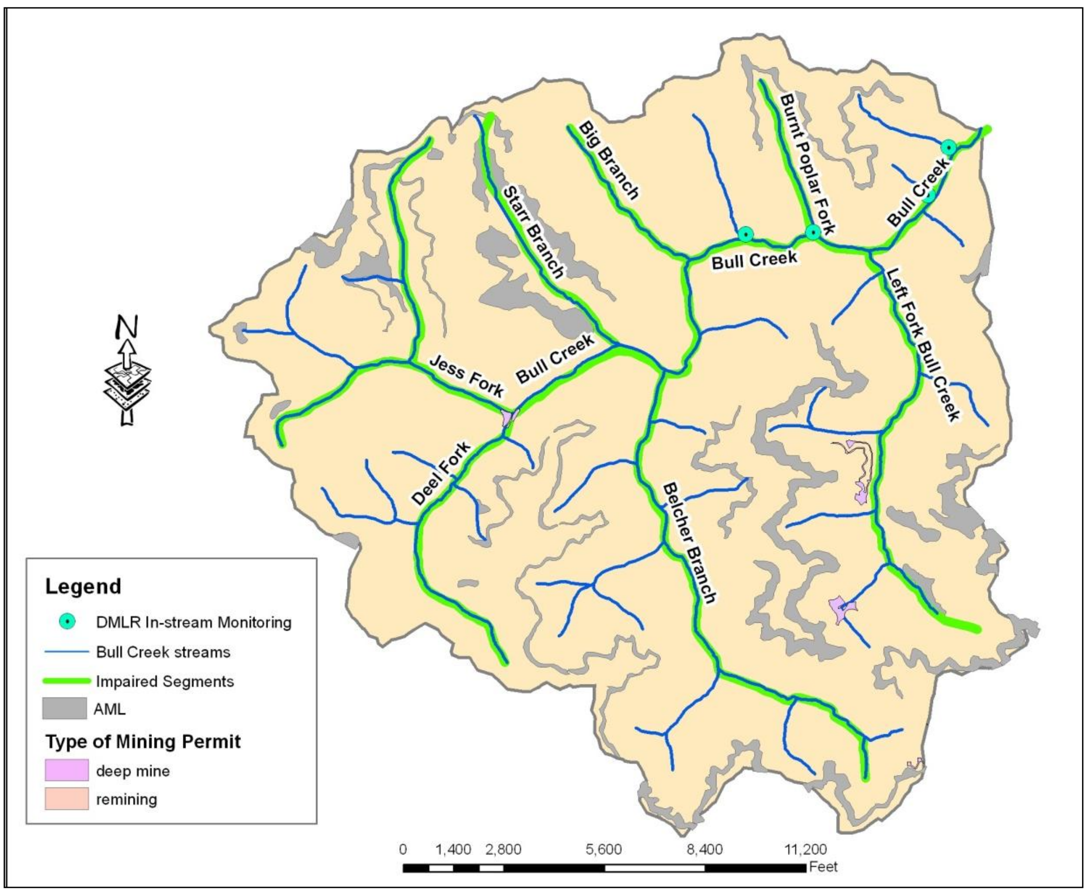

Figure 2.33. DMLR 1997 Permitted Mining Areas and In-stream Monitoring Points

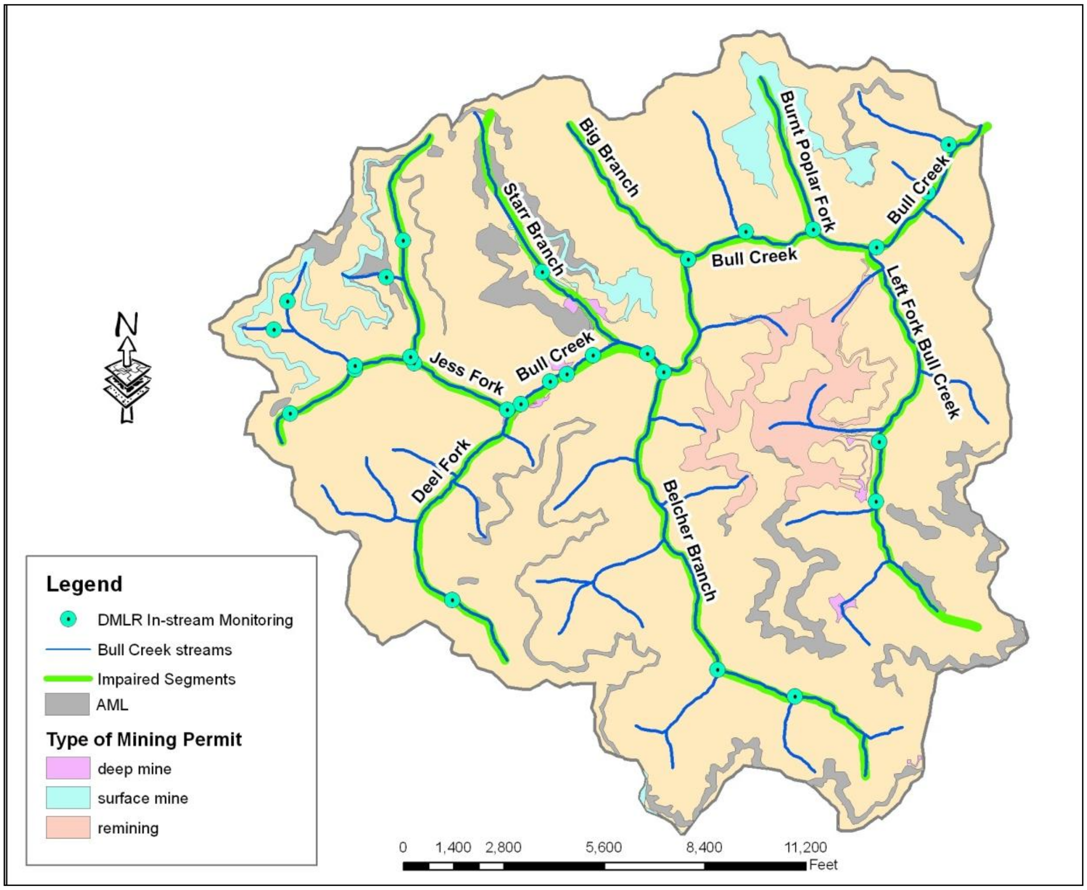

Figure 2.34. DMLR 2007 Permitted Mining Areas and In-stream Monitoring Points

2.9.3. DMME's Division of Gas & Oil (DGO) – Permit Summary

A summary of all DMME permits in the area encompassing the impaired segments and their related drainage are shown by major sub-watershed in Table 2.13. The sub-watershed location map was shown previously in Figure 1.1.

Table 2.13. Summary of DMME Permits and Monitoring Sites in Bull Creek, Jan-05 through Jun-07

Type of DMME Permits/Monitoring	Outlet	Left Fork Bull Creek	Burnt Poplar/ Big	Middle Bull Creek	Belcher Branch	Starr Branch	Jess Fork	Deel Fork	Total
DGO Active Wells		9	1	1	3	3	4	3	**24**
DGO Pending Wells					5				**5**
DGO Plugged Release Wells		1	1					2	**4**
DMLR NPDES Discharging Outfalls		7	3		7	11	6		**34**
DMLR NPDES Non-Discharging Outfalls	1	4	5		1	7	7		**25**
DMLR Instream Monitoring Sites	3	3	4		3	6	10	1	**30**

2.10. Ancillary Data

2.10.1. 305(b) Monitored Exceedances

In the three biennial reports between 1998 and 2002 (DEQ, 1998, 2000, 2002), station 6ABLC002.30 was listed with a biological impairment. Ambient water quality data was only available for the 2002 305(b) report, and included no standards exceedences of temperature, pH, or DO, as shown in Table 2.14 below.

No ambient or biological data were available during the time periods assessed for the 2004 and 2006 reports. Monitored data in 2006 and 2007 will appear in the 2008 report.

Table 2.14. 305(b) Monitored Exceedences in Bull Creek

				CONVENTIONAL WATER COLUMN MONITORING DATA #Violations/# Samples/Status			OTHER WATER COLUMN DATA #Violations/# Samples/Status				SEDIMENT #Violations/Status		BENTHIC	
Year	WBID	Monitoring Station	Type	Temperature	Dissolved Oxygen	pH	Fecal Coliform	Total Phosphorus	Chlorophyll A	Organics	Metals	Organics	Bio Mon	Station Type
1998	**S-Q08R**	**6ABLC002.30**	B	/	0 /	0 /	/	/	/				**VI**	net
2000	**S-Q08R**	**6ABLC002.30**	B	/	0 /	0 /	/	/	/				**VI**	net
2002	**S-Q08R**	**6ABLC002.30**	B	0 / 1 W	0 / 1 W	0 / 1 W	/	/	/				**VI**	net
2004		**None Listed**												
2006		**None Listed**												
		Bold/Shaded = Impaired Waters												

2.10.2. DCR Watershed NPS Pollutant Load Ratings

DCR performs a biennial assessment of NPS pollutant loads for each of the state's 493 14-digit hydrologic units (DCR, 2004). Bull Creek and its tributary impaired segments are located within hydrologic unit Q08.

This NPS pollutant potential assessment in this hydrologic unit ranks forestry land uses as having a high potential, urban land uses as increasing from moderate to high potential, and agriculture with low potential for sediment loading, as shown in Table 2.15. In this classification, urban land uses include mining and barren. Riverine impairment potential was also rated as high in 2000, but since has been rated as low. Rating changes between 2000 and 2002 may be due to the changes in the rating categories and methodologies between those years.

Table 2.15. DCR Watershed NPS Pollutant Ratings – Q08

Watershed-ID	Year	AGR_N	AGR_P	AGR_S	URB_N	URB_P	URB_S	FOR_N	FOR_P	FOR_S	TOT_N	TOT_P	TOT_S	RIMP	EIMP	LIMP	SWP	IBI
Q08	2006	L	L	L	M	H	H	H	H	H	L	L	M	L	N	N	B	E
Q08	2004	L	L	L	M	M	M	H	M	H	L	L	L	L	N	L	E	C
Q08	2002	L	L	L	M	M	M	H	M	H	L	L	L	L	N	L	E	C
Q08	2000		L			L			L		L	--	--	H	N	--	--	--

Header Codes
AGR - agriculture
URB - urban
FOR - forestry
N - nitrogen
P - phosphorus
S - sediment
RIMP - Riverine Impairments
EIMP - Estuarine Impairments
LIMP - Lacustrine Impairments

Nutrient & Impairment Rank Codes
H - High
M - Medium
L - Low
N - Not Applicable

SWP - Source Water Protection Codes
A - Very High
B - High
C - Moderate
D - Low
E - None

IBI - miniMIBI Codes
A: 16-24/5
B: 16-24/1-3
C: 13-15
D: 1-12
E: Insufficient Data

CHAPTER 3: BENTHIC STRESSOR ANALYSIS

3.1. Introduction

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Bull Creek and its impaired tributaries. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from DEQ monitoring provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, Virginia Base Mapping Project (VBMP) aerial imagery, and visual assessment of conditions in and along the stream corridor provided additional information to investigate specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors considered in the following sections are ammonia, hydrologic modifications, nutrients, organic matter, pH, sediment, TDS/conductivity/sulfates, temperature, and toxics. The information in this section is adapted from the original Stressor Analysis Report for Bull Creek (Yagow et al., 2007).

The purpose of the stressor analysis is to look for a stressor that was present in the 1996 sample which caused Bull Creek's initial 1998 listing on the 303(d) impaired waters list and whose current response is consistent with current levels of the stressor. The stressor may be something that either directly affected the benthic community or indirectly affected its habitat. Virginia SCI ratings suggest that the benthic community has been severely to moderately stressed at different times during the period from 1996 to 2006. There was a slight improvement in the VaSCI biological assessment score from 1996 to 2001, and there is a slightly increasing trend of improvement from 1996 to 2006. There is no DEQ ambient monitoring data prior to 2005, so the only data that can be assessed for association with the 1996 biological sample are DMLR monitored data and land uses.

A list of candidate stressors was developed for Bull Creek and evaluated to determine the pollutant(s) responsible for the benthic impairment. A potential stressor checklist was used to evaluate known relationships or conditions that may show associations between potential stressors and changes in the benthic community. An outline of available evidence was then summarized as the basis for each potential stressor. Candidate stressors included ammonia, hydrologic modifications, metals, nutrients, organic matter, pH, sediment, the TDS/conductivity/sulfate suite of parameters, temperature, and toxics.

Depending on the weight of evidence available, each potential stressor was placed into one of the following three categories:

- Eliminated Stressors: Potential stressors with data indicating normal conditions, without violations of a governing standard, or without observable impacts usually associated with a specific stressor. These stressors were eliminated from the list of possible stressors.
- Possible Stressors: Stressors with data indicating possible links, but with inconclusive data, were considered to be possible stressors.
- Most Probable Stressor(s): Stressor(s) with the most consistent data linking it with the poorer benthic metrics, or the most plausible of the possible stressors were called the most probable stressor(s). This stressor(s) was then used for TMDL development.

3.2. Eliminated Stressors

<u>Ammonia</u>

High values of ammonia are toxic to many fish species and may impact the benthic community as well. All the values recorded at DEQ ambient monitoring stations were at or below the minimum detection limit (MDL) of 0.04 mg/L. No fish kills have been reported in this watershed and nothing in the ambient monitored data indicates ammonia as a stressor, therefore it was eliminated from further consideration as a stressor for Bull Creek.

<u>Nutrients</u>

Excessive nutrient inputs can lead to excessive algal growth, eutrophication, and low dissolved oxygen (DO) concentrations which may adversely affect the survival of benthic macroinvertebrates. In particular, DO levels may become low during overnight hours due to respiration. The majority of DEQ-monitored dissolved phosphorus concentrations have been at or below their minimum analytical detection limit at all stations and, therefore, the segment has never exceeded DEQ's "threatened waters" threshold for total phosphorus (TP). Total nitrogen (TN) concentrations are slightly elevated within the watershed but not at levels that would indicate problems since phosphorus concentrations are so low in the watershed. Sources of nitrogen include residential, atmospheric deposition, and mining activities (explosives and hydro-seeding fertilizers).

While the benthic community in Bull Creek has occasional high populations of Chironomidae or Hydropsychidae – organisms associated with excessive nutrients, it has also contained high numbers of low pollution tolerant organisms. Several low riparian vegetation habitat metric scores have been recorded, which could promote increased nutrient transport through surface runoff. There also appear to be some seasonal differences in VaSCI, but these do not appear to be related to nutrients, and since there is almost no phosphorus in the system, excessive production due to nutrients is limited. Therefore, nutrients have been eliminated as a possible stressor.

Organic Matter

Excessive organic matter can lead to low in-stream dissolved oxygen concentrations which may adversely affect the survival and growth of benthic macroinvertebrates. Potential sources of organic matter in Bull Creek include household wastewater discharges, malfunctioning septic systems, and runoff from impervious areas. Organic enrichment is also supported by the types of abundant benthic organisms found in many of the samples – Hydropsychidae and Simuliidae – typical of organic-enriched sites, and the low ratios of scrapers to filterer-collectors, indicative of abundant suspended organic matter, which is used as a food source for the filterer-collectors. The abundance of these organisms, however, could also be attributed to high TDS levels. Although modified family biotic index (MFBI) metric scores are elevated, excessive enrichment is not evident. Ambient dissolved oxygen concentrations are all within standards, and another measure of organic enrichment – chemical oxygen demand (COD) – was at minimal levels. Therefore, organic matter has been eliminated as a possible stressor.

pH

Benthic macroinvertebrates require a specific pH range of 6.0 to 9.0 to thirve. Changes in pH may adversely affect the survival of benthic macroinvertebrates. Treated wastewater, mining discharge and urban runoff can potentially alter in-stream levels of pH. No exceedances of the minimum or maximum pH standard were reported at either of the DEQ stations on the impaired segment. Exceedances were observed in the DMLR data upstream in Jess Fork specifically during the time of the 1998 assessment. Therefore, pH may have been a contributing source of stress but recent improvements in pH levels have not resulted in improved benthic metrics, so pH was eliminated from further consideration as a stressor.

Temperature

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Bull Creek is classified as a Class IV mountain stream with a maximum temperature standard of 31°C. No exceedances of the temperature standard were recorded either by DMLR, or by DEQ ambient monitoring, or by monitoring during collection of the biological samples. Low riparian vegetation habitat metric scores were observed during several biological samplings, but did not correspond with elevated temperature levels. Therefore, no evidence supported temperature as a stressor, and it was eliminated.

3.3. Possible Stressors

<u>Hydrologic Modifications</u>

Hydrologic modifications can cause shifts in the supply of water, sediment, food supply, habitat, and pollutants from one part of the watershed to another, thereby causing changes in the types of biological communities that can be supported by the changed environment. Much of the headwaters of the Bull Creek and other tributaries in the watershed have been intensively mined. Residences throughout the watershed [particularly noted in Left Fork of Bull Creek (Convict Hollow) sub-watershed and in the Burnt Poplar sub-watershed around the town of Maxie] are crowded into the riparian corridor along the impaired segment with many of the stream channel walls armored with concrete and stone. Although these modifications are considered as “pollution” and not “pollutants” covered by the TMDL legislation, hydrologic modifications are considered a possible stressor as they are likely to increase channel erosion and sediment loads downstream.

<u>Metals</u>

Increased metals concentrations lead to low diversity and low total abundance of benthic organisms, with specific reduced abundance of metal-sensitive mayflies and increased abundance of metal-tolerant chironomids (Clements, 1994). Some monitoring site average concentrations of iron and manganese are above average daily permitted values (3.5 mg/L iron, 2,0 mg/L manganese; eCFR, 2007), but the majority of DMLR samples reported average iron and manganese concentrations within the average daily permitted levels. Total organism abundance was low with low diversity in the one sample that led to the initial 1996 listing, but it could possibly have been due to discharges from a historical coal processing plant that is no longer in operation, as the low diversity in the 1996 sample has not been seen in more recent samples. Therefore, while it is doubtful that they are the dominant stressor, elevated levels of iron and manganese are found throughout the watershed (Table 2.6, Table 2.7, and Table 2.10) and are considered possible stressors.

Toxics

Toxic substances by definition are not well tolerated by living organisms. The presence of toxics as a stressor in a watershed may be supported by very low numbers of any type of organisms, low organism diversity, exceedances of freshwater aquatic life criteria or consensus-based probable effect concentrations (PEC) for metals or inorganic compounds, by low percentages of the shredder population, reports of fish kills, or by the presence of available sources. Coal mining has occurred, or is occurring, in all parts of the Bull Creek watershed which led to the unusual listing not only of Bull Creek, but also to all of its tributary first-order stream segments as well. Prior to 1995, a coal processing plant sat on Bull Creek just above its confluence with Starr Branch. Local residents reported that weekly, and some times more frequently, discharges from the plant consisted of “black” coal water whose constituents were unknown. However, since the plant is no longer in operation and the biological impairment still exists, the plant is unlikely to be contributing to the current source of the impairment. Failing septic systems, straight pipes, and grey-water discharges still present in the watershed could also be possible sources of toxic substances to Bull Creek. Because of the possibility of contributions from these various sources, toxics are considered to be a possible stressor.

3.4. Most Probable Stressor

The two most probable stressors to the benthic community are considered to be sediment and TDS based on the following summary of available evidence.

Sediment

Excessive sedimentation can impair benthic communities through loss of habitat. Excess sediment can fill the pores in gravel and cobble substrate, eliminating macroinvertebrate habitat. Potential sources of sediment include residential runoff, forestry, mining operations, construction sites, and in-stream disturbances. Permitted point sources of sediment discharge, other than permitted mining discharges, are not present in this watershed and agricultural sources are sparse. Sediment problems appear to be primarily related to disturbed areas in the watershed that are subject to soil detachment and to runoff from impervious areas. The steep terrain of this watershed is also a contributing factor to sediment loads from disturbed areas. Disturbed or barren areas, often located close to streams, include recently cleared forested areas, new construction, surface mining operations, and poorly vegetated riparian areas along streams. Sediment is supported as a stressor for this impairment through the consistently low proportion of haptobenthos organisms, which require clean substrates for habitat, and through poor habitat metrics related to sediment including embeddedness and sediment deposition. Additionally, lower metric scores were reported in earlier samples for bank stability and riparian vegetation. DEQ ambient TSS concentrations are low, with one elevated concentration likely associated with a runoff event. Elevated TSS concentrations have been more widely and more frequently reported through DMLR's in-stream monitoring by the mining industry. Sediment is considered a most probable stressor in Bull Creek because of the poor habitat metrics related to sediment, the periodically-elevated TSS concentrations (Figure 2.26), and the availability of areas with poor vegetative cover or otherwise subject to erosion during runoff.

TDS

Total dissolved solids (TDS) are the inorganic salts, organic matter and other dissolved materials in water. Since sulfates are one of the constituent components of the TDS measurement, and conductivity measurements are a correlate of TDS, TDS will be used as the stressor that is evidenced by this suite of parameters. Elevated levels of TDS cause osmotic stress and alter the osmoregulatory functions of organisms (McCulloch et al., 1993). The average TDS and conductivity measurements reported in DMLR in-stream and groundwater monitoring data for Bull Creek watershed were greater than the screening values of 500 mg/L and 500 µmhos/cm, respectively. Sulfate values were greater than the screening value of 250 mg/L for Bull Creek for in-stream monitoring. The high levels of TDS and its related parameters are likely contributors to the stress evidenced by the benthic community.

Bull Creek (VAS-Q08R_BLC01A98) is severely to moderately impaired for its aquatic life use, with individual VaSCI scores varying between 26.1 and 43.2. A score of 60 or above represents a non-impaired condition (scale: 0 – 100). DEQ biological and ambient monitoring within this watershed is sparse with limited biological monitoring conducted in 1996, 2001, and 2006. Ambient water quality data has only been collected since May 2005. The longer term record of available DMLR in-stream monitoring data for TDS, conductivity, and sulfate concentrations are all frequently greater than the DEQ screening values used for selection of reference conditions. This watershed is impacted by mining activities.

Coal mining activities, including surface, auger, and deep mining, have been conducted in the Bull Creek watershed since the 1930's. Most of the mining was conducted prior to the current Surface Mining Control and Reclamation Regulations and resulted in over 1,000 acres of pre-law abandoned mined lands (AML) within the watershed. Five deep mines operated in the watershed prior to 1996. Although AML and surface mining activities are currently the major suspected sources of impairment in Bull Creek, immediately prior to the first benthic sample taken in 1996, no surface mines were active in the watershed, so that recent surface mining activities could not have been the cause of the original impairment. One of the deep mines ceased operation in 1994, and another was downstream from the biological monitoring station, 6ABLC002.30. Additionally, during the 1998 assessment period, a coal processing plant operated adjacent to Bull Creek, just above its confluence with Starr Branch, which may have contributed to the initial impairment. The coal processing plant ceased operations in the late 1990s and the rail spur has since been removed.

Prior to 1996, approximately 10 gas wells were producing above station 6ABLC002.30 and one abandoned mine contributed discharge on Belchers Branch. From DMLR monitoring, repeated low pH values were reported for Jess Fork in the mid-1990s, together with high values of conductivity, TDS, and sulfates from Jess Fork, Deel Fork, Starr Branch, and Belcher Branch. Therefore, the initial cause of the impairment appears to have been a combination of low pH, high TDS and sediment, associated primarily with the coal processing plant discharge, with additional impacts from AML runoff and deep mine discharges. Although the major suspected source of the 1996 impairment no longer exists and pH values all currently fall within an acceptable range, the TDS and sediment stressors continue to remain elevated and are most likely the cause of the present day impairment.

Biological monitoring metrics have shown a slight improvement over time. At the same time, TDS concentrations have shown a slight decrease. This further supports the association between the biological metrics and TDS and/or its constituents, even if it is not possible to discriminate between surface and deep mining sources causing the impairment. Sediment and TDS were selected as the most probable stressors based on the repeated poor scores for sediment metrics in the habitat assessment and elevated observed TSS and TDS concentrations.

CHAPTER 4: THE REFERENCE WATERSHED MODELING APPROACH

4.1. Introduction

Virginia has no numeric in-stream criteria for either sediment or TDS – the most probable stressors identified in this study. As a result, a "reference watershed" approach was used to set allowable loads for these constituents in the impaired watershed.

The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. This reference watershed may be, but does not have to be, the watershed corresponding to the reference monitoring site used for determining comparative biological metric scores. The reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization and pollutant simulation within the TMDL watershed, definition of the TMDL endpoint, and development of alternative TMDL reduction (allocation) scenarios. TMDL endpoints may be developed using either modeled loads or a statistical measure of monitored pollutant concentrations from the reference watershed. Where a simulated load is used as the TMDL endpoint, pollutant loads are also simulated from the reference watershed.

4.2. Selection of a Reference Watershed

4.2.1. Comparison of Potential Watersheds

Five watersheds were considered as references for Bull Creek – Upper Dismal Creek, Fryingpan Creek, Baileys Trace, Martin Creek, and Burns Creek. Upper Dismal Creek and Fryingpan Creek have been used as biological monitoring reference sites for Bull Creek. Baileys Trace, Martin Creek, and Burns Creek have been used as biological references for other southwest Virginia mined watersheds. Minimal differences exist among the eco-region classifications for all of the potential reference watersheds. Table 4.1 compares the various characteristics of the candidate reference watersheds to the characteristics of the impaired watershed. Representative characteristics that were compared include land use distribution, relative percentage of present and historic extractive land uses, average soil erodibility, average percent slope, average elevation, number of non-sewered homes, population density, and VaSCI scores. The Universal Soil Loss Equation (USLE) K-factor was used as an index of the erosivity of soils in the watersheds, and was calculated as a weighted average of all soil K-factors in each watershed.

Table 4.1. Reference Watershed Comparisons for Bull Creek

Station ID	Stream Name	Area (ha)	Landuse Distribution Urban (%)	Forest (%)	Agr (%)	Extr (%)	Historic AML area (%)	DMLR Permit Area (%)	Watershed Average STATSGO K-factor	Slope (%)	Elevation (meters)	Latest SCI Score	Date	SubEco Region
				Impaired Watershed										
6ABLC002.30	Bull Creek	3,129	3%	81%	1%	15%	8.0%	7.4%	0.202	48.4	525.0	41.30	Nov-06	69d
			Potential TMDL Reference Watersheds											
6BBAI000.26	Baileys Trace	1,085	3%	81%	3%	13%	8.1%	17.0%	0.207	44.7	688.2	53.40	Sep-99	69d
6ADIS017.94	Upper Dismal Creek	7,228	3%	94%	2%	1%	5.1%	1.6%	0.206	41.1	748.4	68.62	Nov-97	69d
6ADIS003.52	Lower Dismal Creek	22,069	0%	97%	1%	2%	0.0%	1.8%	0.240	24.1	675.4	66.30	Nov-06	69d
6AFRY002.25	Fryingpan Creek	6,611	3%	94%	1%	2%	4.6%	2.1%	0.199	43.2	602.5	51.16	Jun-96	69d
6BMTN003.56	Martin Creek	4,731	2%	52%	46%	1%	0.0%	0.0%	0.288	22.2	492.6	61.58	Jun-98	67f
6BBUC000.24	Burns Creek	737	1%	84%	1%	15%	0.0%	0.0%	0.201	24.9	879.8	70.11	May-06	69d

EcoRegion 67 Central Appalachian Ridges and Valleys
69 Central Appalachians
SubEcoRegion 67f Southern Limestone/Dolomite Valleys and Low Rolling Hills
69d Cumberland Mountains

- Impaired watershed (green)
- Closest matches (orange)
- Selected Reference Watershed (blue)

Footnote: AML = Abandoned Mine Land; DMLR = Division of Mined Land Reclamation; K-factor = Universal Soil Loss Equation index of soil erodibility; VaSCI = Virginia Stream Condition Index

4.2.2. The Selected Reference Watershed

The watershed characteristics in Table 4.1 were evaluated and considered during this comparison between Bull Creek and potential reference watersheds. During the analysis, Martin Creek was eliminated as it had a very large agricultural component, no historic AML, and was in a slightly different eco-region than the other watersheds. Burns Creek was considerably smaller in size, had no land currently permitted for mining, and a much lower average slope. Although Baileys Trace had a similar landuse distribution and percentage of historic AML area to Bull Creek, its disadvantages were its smaller size, larger percentage permitted area and a less than desirable VaSCI score.

Upper Dismal Creek and Fryingpan Creek watersheds are similar in size and somewhat larger than Bull Creek, but both had comparable landuse distributions and historic AML percentages. Upper Dismal Creek was selected over Fryingpan Creek as the reference watershed for Bull Creek based on its most recent VaSCI scores. These VaSCI scores were calculated as part of this study and were not used in the original assessment, as the VaSCI has only recently been developed. Since the VaSCI uses a fixed set of scales to score individual metrics, rather than relative measures from biological reference watersheds, VaSCI index scores are more directly comparable between watersheds than they were with the previous RBP II scoring and rating system. Using the VaSCI ratings, not only did Upper Dismal Creek score higher than Fryingpan Creek, but its score was indicative of a healthy biological community (was rated as “non-impaired” by the VaSCI), whereas Fryingpan Creek was rated as “impaired”, and therefore not appropriate for use as a reference watershed .

4.3. TMDL Modeling Endpoints

4.3.1. Sediment

Both the TMDL and reference watersheds were modeled to develop the sediment TMDL for Bull Creek. The size of the selected reference watershed, Upper Dismal Creek, was adjusted to match the area of the Bull Creek watershed. Land use distributions and other watershed characteristics were preserved throughout the adjustment. The sediment load TMDL target endpoint (t/yr) was established as the sediment load from the area-adjusted reference watershed, Upper Dismal Creek.

4.3.2. TDS

Concentration was determined to be the more meaningful endpoint in determining the TDS TMDL. Although there were no ambient DEQ monitoring stations in the Upper Dismal Creek watershed with which to assess an appropriate TDS endpoint, DEQ did have a downstream monitoring site with TDS data available at station 6ADIS001.24, referred to as Lower Dismal Creek. While the Lower Dismal Creek watershed is larger than the Upper Dismal Creek watershed, it has similar physical characteristics (landuse distribution, soils and slopes), has some mining activity, and has had several bioassessment samples taken which show a healthy aquatic community at stations 6ADIS003.52 and 6ADIS013.73. In addition, TDS data from station 6ADIS0001.24 in Lower Dismal Creek has been used previously to set the TDS TMDL endpoint for the Knox Creek TMDL (MapTech, 2006). The TDS TMDL concentration endpoint for Bull Creek was set at 369 mg/L, the 90th percentile of 34 DEQ-monitored TDS samples taken at station 6ADIS001.24 (369 mg/L).

Reductions in sediment to the TMDL target load and reductions in TDS loads to the TMDL target concentration are expected to allow benthic conditions to return to a non-impaired state.

CHAPTER 5: MODELING PROCESS FOR DEVELOPMENT OF THE SEDIMENT TMDL

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the waterbody of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In the development of the sediment TMDL for the Bull Creek watershed, the relationship between sediment sources and sediment loading to the stream was defined through computer modeling. In this chapter, the modeling process, input data requirements, and model calibration procedures for the sediment TMDL are discussed.

Due to the phased nature of this TMDL, sections 5.1-5.9 cover model developments for the Phase I TMDL, whereas section 5.10 discusses new point source TSS monitoring data and model adjustments for the Phase II TMDL. Sections 5.1-5.9 come directly from the Phase I document and should be read considering the Phase I historical context.

5.1. Model Selection

The reference watershed approach was used in this study to develop a sediment TMDL to partially address the benthic impairment in the Bull Creek watershed. The model selected for development of the sediment TMDL was the Generalized Watershed Loading Functions (GWLF) model, originally developed by Haith et al. (1992), with modifications by Evans et al. (2001), Yagow et al. (2002), and Yagow and Hession (2007).

The loading functions upon which the GWLF model is based are compromises between the empiricism of export coefficients and the complexity of process-based simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater. The hydrology in the model is simulated with a daily water balance procedure that considers different types of storages within the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986).

GWLF uses three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains input data primarily related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Penn State Visual Basic™ version of GWLF with modifications for use with ArcView was the starting point for additional modifications (Evans et al., 2001). The following modifications related to sediment were made to the Penn State version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Urban sediment buildup was added as a variable input.
- Urban sediment washoff from impervious areas was added to total sediment load.
- Formulas for calculating monthly sediment yield by land use were corrected.
- Mean channel depth was added as a variable to the streambank erosion calculation.

The current Virginia Tech (VT) modified version of GWLF (Yagow and Hession, 2007) was used in this study. The VT version includes a correction to the flow accumulation calculation in the channel erosion routine that was implemented in December 2005 (DEQ, 2005). This version also includes modifications from Schneiderman et al. (2002) to remove the limitation that prevented carry-over of excess detached sediment from one simulated year (that runs from April through March of the following year) to the next, and to add in missing bounds for the calculation of erosivity using Richardson equations which were intended to have minimum and maximum bounds on daily calculations. These minimum and maximum bounds were not included in GWLF 2.0, and have been added to keep calculations within physically expected bounds.

Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (DEQ, 2005).

5.2. GWLF Model Development

As described in the previous chapter, Upper Dismal Creek in Buchanan County was selected as the reference watershed. Using a reference watershed with a history of coal mining and benthic impairment ensures that the sediment TMDL developed for Bull Creek is achievable. The average annual sediment load from the area-adjusted Upper Dismal Creek was used to define the sediment TMDL for the Bull Creek watershed. Model development for Bull Creek and its reference watershed were performed by assessing the sources of sediment in the watershed, applying procedures to represent some of the sources supplemental to the model, evaluating the necessary parameters for modeling loads, calibrating to observed flow and sediment data, and finally applying the model and procedures for calculating loads.

Eighteen sub-watersheds were delineated within the Bull Creek watershed in order to represent the spatial distribution of land uses and pollutant sources in the watershed for modeling purposes, as shown in Figure 5.1.

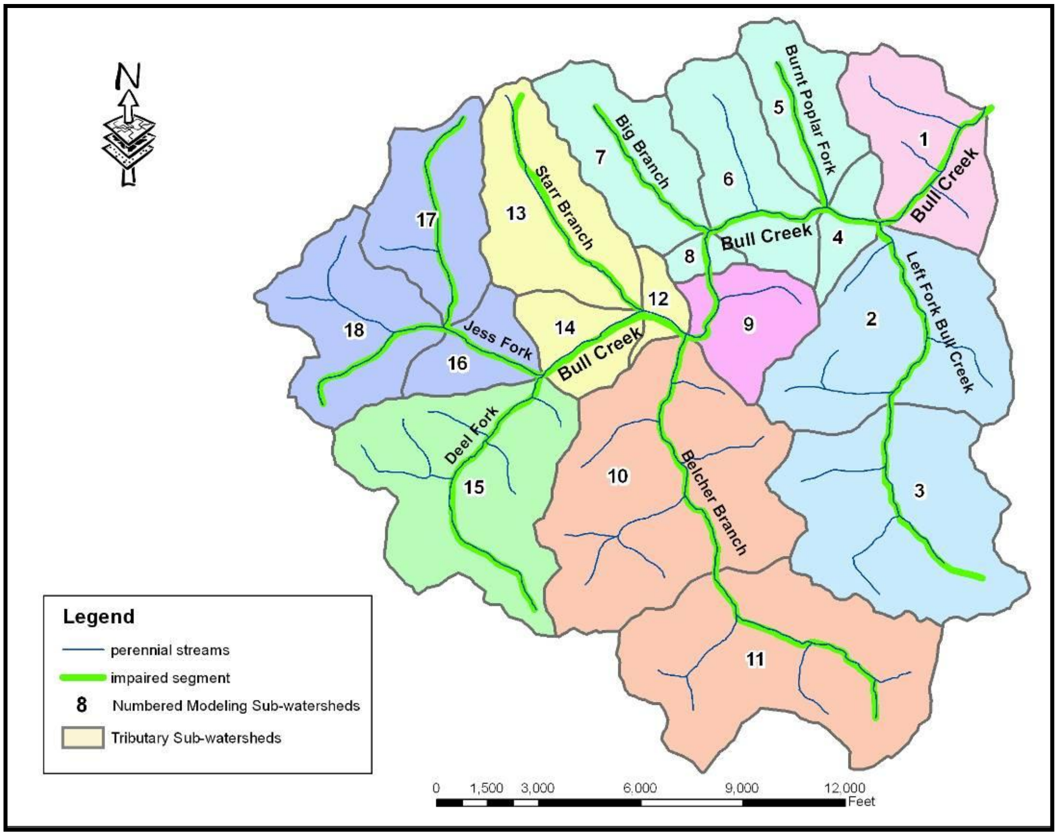

Figure 5.1. GWLF Modeling Sub-watersheds in Bull Creek

Sediment is generated in the Bull Creek watershed through the processes of surface runoff, in-channel disturbances, and streambank and channel erosion, as well as from background geologic forces. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses.

During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Sediment generated from impervious areas can be reduced through the use of management practices that reduce the surface load subject to washoff.

Vegetative cover and stream buffers in the riparian zone are essential to maintaining stable stream banks. The topography of Bull Creek is such that roads, railroads, residences, and businesses are all located in the riparian zones of the narrow valleys throughout this watershed, leaving minimal buffers, if any, and spotty vegetative cover. Additionally, impervious areas, especially in the riparian zone, increase the percentage of rainfall that runs off the land surface leading to larger volumes of runoff with higher peak flows and greater channel erosion potential. The majority of the Bull Creek impaired stream segments have their streambanks armored, which could also contribute to increased velocities and channel erosion below those sections.

Permitted stormwater dischargers in Bull Creek include both short-term and long-term activities. Short-term activities include VPDES construction permits regulated through Virginia's Erosion and Sediment Control Program, and permits for construction of gas and oil wells and facilities under the administration of DMME-DGO. Currently, there are no VPDES permitted facilities within the Bull Creek watershed. Long-term permitted activities contributing sediment include industrial stormwater dischargers and runoff from areas permitted for mining. All permitted stormwater dischargers have requirements for installation of best management practices (BMPs) to minimize the impact of their activities on water quality. Permitted mining activities are required to have sediment detention pond BMPs installed to detain stormwater runoff from all disturbed areas.

5.3. Input Data Requirements

5.3.1. Climate Data

The climate in Bull Creek watershed was characterized by meteorological observations from the National Weather Service Cooperative Station 443640 at Grundy, Virginia, while Upper Dismal Creek was modeled using data from station 447174 in nearby Richlands, Virginia in Tazewell County. The Grundy station is located in Buchanan County approximately 4 miles east of the Bull Creek DEQ monitoring station 6ABLC002.30. The period of record used for modeling was a thirteen-year period from January 1995 through December 2007, with the preceding 9 months of data used to initialize storage parameters. The beginning of this period was chosen to correspond with the beginning of DMLR monitoring data being stored in an electronic format. The locations of Bull Creek and the Grundy station are shown in Figure 5.2.

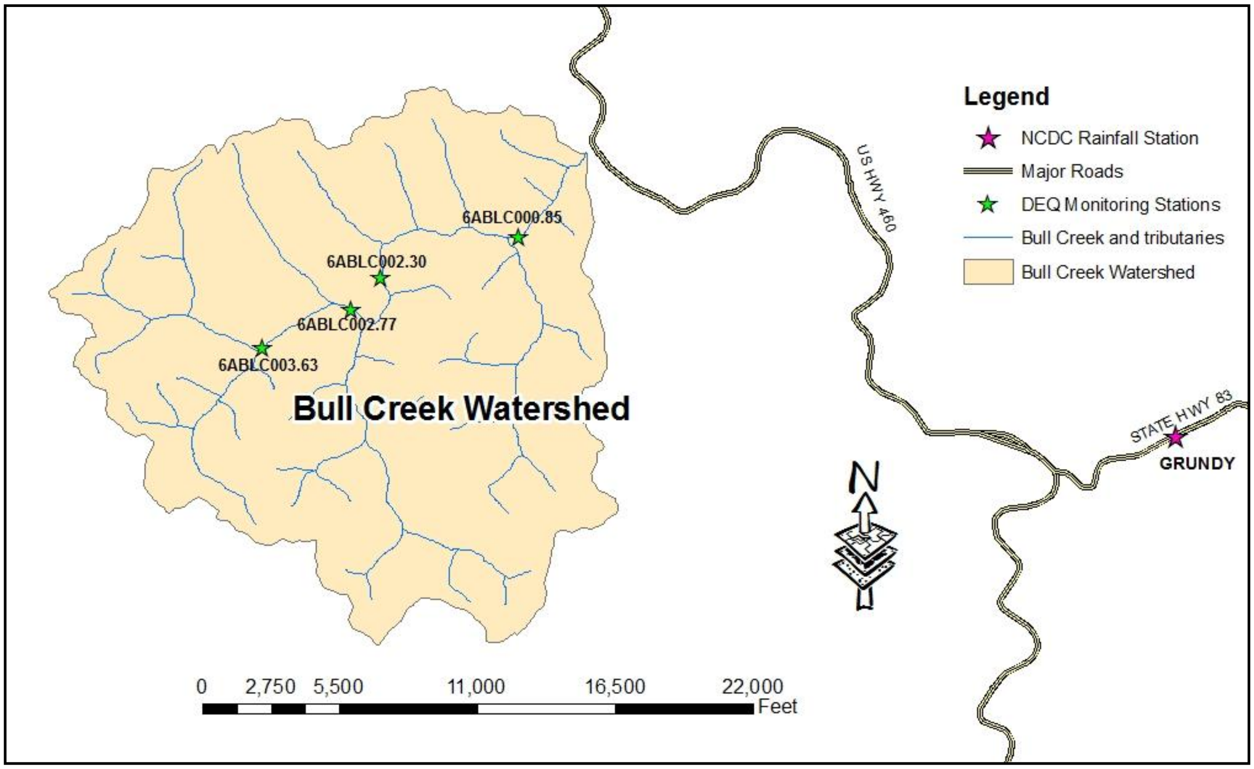

Figure 5.2. Location of Bull Creek and the Grundy Weather Station

5.3.2. Land Use

Land use for the Bull Creek watershed was derived from the Mid-Atlantic RESAC land use-land cover digital data, as discussed in Section 2.5. The RESAC categories were consolidated into a smaller number of categories based on the similarities in associated sediment sources, Table 5.1. The pasture/hay category was subdivided into "Pasture" and "Hay" categories based on percentages assessed during the 2002 Statewide NPS Pollution Assessment study (Yagow et al., 2002). Some additional editing was done to reclassify portions of the "barren" and "extractive" classifications which were inconsistent with residential features observed in VBMP aerial imagery. Barren land uses result from construction of access roads and drilling sites for gas and oil wells, logging, and from residential activities; whereas extractive land uses refer to actively disturbed surface mining areas. The 38 land uses in the RESAC data were re-categorized and three mined land use categories added for spatial analysis: AML, AML within a permit (to be reclaimed), and other permit areas (new mining). Permitted mining areas were further divided into 4 land use categories: “disturbed”, “reclaimed”, “released”, and “to be disturbed”.

Table 5.1. Consolidation of RESAC Land Use Categories for Bull Creek

TMDL Land Use Categories	Pervious/Impervious (percentage)	RESAC or Mined Land Use Categories
Cropland	Pervious (100%)	Cropland (26)
Pasture	Pervious (100%)	Pasture/hay (25), Natural grass (30)
Hay	Pervious (100%)	
Forest	Pervious (100%)	Open water (1), Urban deciduous (10), Urban evergreen (11), Urban mixed (12), Deciduous forest (20), Evergreen forest (21), Mixed forest (22), Deciduous woody wetland (35), Evergreen woody wetland (36), Emergent herbaceous (37), Mixed wetlands (38), also includes fractional portions of mining permits listed as “to be disturbed”
Extractive	Pervious (100%)	Extractive (17), includes fractional portions of existing mining permits listed as “disturbed”
Barren	Pervious (100%)	Barren (18)
Abandoned mine land (AML)	Pervious (100%)	Digitized from USGS 7½-min topographic maps, excluding existing permit areas
Reclaimed	Pervious (100%)	Fractional portions of existing mining permits listed as “reclaimed”
Released	Pervious (100%)	Fractional portions of existing mining permits listed as “released” from bond
Low Density Residential (LDR)	Pervious (88%) Impervious (12%)	Low intensity developed (3)
Medium Density Residential (MDR)	Pervious (70%) Impervious (30%)	Medium intensity developed (4)
High Density Residential	Pervious (35%) Impervious (65%)	High intensity developed (5)

The pervious and impervious portions of the residential categories were modeled separately and cropland was broken down into hi-till and lo-till fractions based on county statistics from the statewide modeling (Yagow et al., 2002). Based on this categorization, the main land uses in Bull Creek are forest, mining, residential, and agricultural, comprising approximately 86%, 8%, 5%, and 1%, respectively, of the total watershed area. This re-distribution of mining permitted areas resulted in a shift of forested area into the mining and barren categories of

1.5% and 0.5%, respectively. The existing land use distribution within the Bull Creek watershed is not expected to change significantly in the near future. Consolidation of the land use data resulted in the 15 land use categories and distributions within Bull Creek and its reference watershed (Upper Dismal Creek), shown in Table 5.2. The areas shown for the area-adjusted Upper Dismal Creek were used for simulation purposes.

Table 5.2. Land Use Distribution in Bull Creek and its Reference Watershed

Modeled Land Use Categories	Bull Creek (ha)	Area-Adjusted Upper Dismal Creek (ha)	Upper Dismal Creek (ha)
Cropland	2.8	0.3	0.8
Pasture	25.7	49.2	113.6
Hay	0.7	0.0	0.0
Forest	2,686.9	2,806.5	6,484.0
Barren	62.8	24.9	57.6
Mining*			
Extractive	15.0	3.9	9.1
Reclaimed	9.7	2.7	6.3
Released	19.7	2.9	6.7
AML	212.4	149.2	344.6
LDR - pervious	52.4	53.6	123.7
MDR - pervious	1.9	0.1	0.3
HDR - pervious	10.7	9.8	22.5
LDR - impervious	7.2	7.3	16.9
MDR - impervious	0.8	0.1	0.1
HDR - impervious	19.9	18.1	41.8
Total Area	**3,128.5**	**3,128.5**	**7,228.1**
% Forest	85.9%	89.7%	89.7%
% Agriculture	0.9%	1.6%	1.6%
% Urban/residential	3.0%	2.8%	2.8%
% Mining	8.2%	5.1%	5.1%
% Barren	2.0%	0.8%	0.8%

* The portion of permitted mining areas "To Be Disturbed" are included in the Forest category.

Each land use within a sub-watershed formed a hydrologic response unit (HRU). Model parameters were then calculated for each HRU using GIS analysis to reflect the variability in topographic and soil characteristics across the watershed. A description of model parameters follows in section 5.4.

5.4. GWLF Parameter Evaluation

All parameters were initially evaluated in a consistent manner between the reference and impaired watersheds, in order to ensure their comparability for the reference watershed approach. All GWLF parameter values were evaluated from a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures (Evans et al., 2001), procedures developed during the 2002 statewide NPS pollution assessment (Yagow et al., 2002), and best professional judgment. Initial parameter values for active mining and AML land uses were evaluated from available literature sources, as shown in Table 5.3.

Table 5.3. Initially Assigned Curve Numbers and C-Factors Prior to Calibration

Mining Land Use	Curve Number (CN)[1]	C-factor (vegetative cover)	C-factor Definition and Source
Extractive	88	0.664	MPWS[2]: 60% bare soil (0.45); 30% active mining (1.00); 10% regrading (0.94); Barfield et al., p.339
AML	88	0.288	MPWS[2]: 30% residue cover, poor soil, 50% weed cover; Barfield et al., p.391
Reclaimed	81.5	0.071	Pasture: no appreciable canopy, 60% cover (40% grass-60% weed); Wischmeier and Smith, p.32
Released	72.6	0.028	Pasture: no appreciable canopy, 80% cover (half grass-half weed); Wischmeier and Smith, p.32

[1] CN source: Technical Release 55 (TR-55), USDA-SCS, 1986; reclaimed and released values are weighted averages by hydrologic soil type.
[2] MPWS - mechanically prepared woodland sites.

Soil erodibility (K-factors) and %slope for barren, extractive, and AML were evaluated using GIS. K-factors for reclaimed and released land uses were calculated as 1.2 and 1.1 times the extractive land use values, respectively, to simulate the higher bulk density, lower porosity, and lower hydraulic conductivity in post-mined soils (Galbraith, 2004; Ritter and Gardner, 1991), which are expected to decrease over time in the released areas. Percent slope for reclaimed and released land uses were calculated as 0.9 times the extractive land use values. Select initial parameter values were then calibrated as discussed in section 5.8.

Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file. Descriptions of each of the hydrologic and sediment parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses.

5.4.1. Hydrology Parameters

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC, cm): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. This parameter was evaluated using the following relationship from Lee et al. (2000): RecCoeff = 0.045+1.13/(0.306+Area in square kilometers)
- Seepage coefficient (day^{-1}): The seepage coefficient represents the amount of flow lost as seepage to deep storage and initially set to zero.

The following parameters were initialized by running the model for a 9-month period prior to the period used for load calculation:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceding the first day in the weather file

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model.
- ET_CV: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.
- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance.

5.4.2. Sediment Parameters

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997); and then adjusted after consultation with local NRCS personnel.
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans et al., 2003)

- % Developed land: percentage of the watershed with urban-related land uses – defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Curve Number: area-weighted average value for the watershed.
- K Factor: area-weighted USLE soil erodibility factor for the watershed.
- Slope: mean percent slope for the watershed.
- Stream length: calculated as the total stream length of natural perennial stream channels, in meters. Excludes any non-erosive hardened and piped sections of the stream.
- Mean channel depth (m): calculated from relationships developed either by the Chesapeake Bay Program or by USDA-NRCS by physiographic region, of the general form – $y = a * A^b$, where y = mean channel depth in ft, and A = drainage area in square miles (USDA-NRCS, 2005).

5.5. Supplemental Post-Model Processing

After modeling was performed on individual and cumulative sub-watersheds, model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of BMPs already implemented within the Bull Creek watershed.

The extent and effect of existing agricultural BMPs was based on the DCR State Cost-Share Database. The DCR database tracks the implementation of BMPs within each state 1995 Hydrologic Unit Program (HUP) watershed. These data are then used by USEPA's Chesapeake Bay Program to calculate sediment reduction and pass-through fractions of the sediment load from each land use in each HUP for use with the Chesapeake Bay model and with the Virginia 2002 Statewide NPS Pollution Assessment (Yagow et al., 2002). Since Bull Creek lies within the Q08 watershed, the modeled land use categories used for this TMDL study were assigned sediment pass-through fractions for related land use categories from the Q08 watershed. In addition to the agricultural BMPs, mining sediment detention ponds were simulated as reducing existing extractive and reclaimed loads by 85% from all sub-watersheds containing sediment ponds. The chosen efficiency was based on an approximate average of literature values on sediment pond efficiency estimates, which vary widely based on pond design, rainfall intensities, and sediment particle sizes, including values of 60% for urban wet ponds (Simpson and Weammert, 2009), 91.8-96.7% for simulated detention of 17 ponds (USEPA, 1979), and 81-98% for small reservoirs (Dendy, 1974). Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs.

5.6. Representation of Sediment Sources

5.6.1. Surface Runoff

Pervious unit-area sediment loads (kg/ha) were modeled with the GWLF model using sediment detachment based on a modified USLE erosion algorithm, and a sediment delivery ratio to calculate loads at the watershed outlet, and were reported on a monthly basis by land use. Impervious area sediment loads were modeled in the GWLF model using an exponential buildup-washoff algorithm.

5.6.2. Channel and Streambank Erosion

Streambank erosion was modeled within the GWLF model using a modification of the routine included in the AVGWLF version of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of percentage developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, average slope, streamflow volume, mean channel depth, and total stream length in the watershed. Livestock population, which figures into animal density, was estimated based on the available pasture, hay and reclaimed areas in each sub-watershed times a stocking density of 0.378 animal units per acre (AU/acre).

5.6.3. Stormwater Sources

Construction Permits: No construction or industrial stormwater runoff discharges are currently permitted in Bull Creek.

Gas & Oil Permits: Contributions from gas and oil operations in the watershed are transient, and stormwater E&S regulations require that any disturbed acreage during construction and drilling must be stabilized within 30 days. Currently there are 11 producing wells, 13 wells that are in some stage of construction or drilling, 4 older wells that have been plugged and released, and 5 wells that are pending, as listed in Table 5.4. The DMME-DGO estimates footprints of the pumping sites to average 50'-100' by 100'-200', or an average of approximately 0.26 acres each. Access road lengths vary widely but average around 0.5 miles in length and 20 feet wide for another 1.21 acres each. Sediment loads from both the pumping sites and the access roads are covered under the stormwater E&S permits, unless existing roads are used for access. For purposes of allowing for future growth in this industry, two additional wells were estimated as being built each year, each at the average disturbed acreage (7 ac.) from the existing wells in the Bull Creek, multiplied by the average monthly runoff from the "barren" land use category (19.11/12 = 1.59 cm), times the maximum permitted daily sediment concentration of 60 mg/L.

Table 5.4. Gas and Oil Permits in Bull Creek

Permit No.	Operation ID	Company Name	Sub-watershed	Operation Description	Permit Status	Construction Area (ac)
			Active Wells			
BU-0566	EH-110	Appalachian Energy	Belcher Branch	Gas	Constructed/Never Drilled	
BU-3081	825903 (HY-137) W/PL	Chesapeake Appalachia, LLC	Starr Branch	Gas/Pipeline	Construction	24
BU-2478	CBM N-76	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	4
BU-2669	CBM N78	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	7
BU-2688	CBM M77	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	4
BU-2709	CBM L77	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	4
BU-3000	CBM K76	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	4
BU-3009	CBM L76	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Drilled/Waiting Completion/	8
BU-2477	CBM N-75	CNX Gas Company LLC	Belcher Branch	Coalbed/Pipeline	Drilled/Waiting Completion/	5
BU-3049	CNR 823540 (HY-19) W/PL	Chesapeake Appalachia, LLC	Jess Fork	Gas/Pipeline	Drilled/Waiting Completion/	16
BU-2335	CBM M76	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Not Connected	3
BU-2345	CBM K-75	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Not Connected	2
BU-2479	CBM N-77	CNX Gas Company LLC	Left Fork Bull Creek	Coal Bed	Not Connected	3
BU-0098	9591	Chesapeake Appalachia, LLC	Jess Fork	Gas	Producing	
BU-0116	9692	Chesapeake Appalachia, LLC	Deel Fork	Gas	Producing	
BU-0117	9678	Chesapeake Appalachia, LLC	Middle Bull Creek	Gas	Producing	
BU-0118	9681	Chesapeake Appalachia, LLC	Deel Fork	Gas	Producing	
BU-0126	9701	Chesapeake Appalachia, LLC	Jess Fork	Gas	Producing	
BU-0131	9765	Chesapeake Appalachia, LLC	Burnt Poplar/Big Branch	Gas	Producing	
BU-0147	20340	Chesapeake Appalachia, LLC	Jess Fork	Gas	Producing	
BU-0167	20546	Chesapeake Appalachia, LLC	Deel Fork	Gas	Producing	
BU-0564	EH-112	Appalachian Energy	Belcher Branch	Gas	Producing	
BU-0572	EH-114	Appalachian Energy	Starr Branch	Gas	Producing	
BU-0754	21732	Chesapeake Appalachia, LLC	Starr Branch	Gas	Producing	
			Plugged/Released Wells			
BU-0087	9582	United Fuel (Columbia)	Left Fork Bull Creek	Gas	Plugging/Plugged/Abandoned	
BU-0135	9766	Columbia Natural Resources LLC	Burnt Poplar/Big Branch	Gas	Released	
BU-0145	20342	Columbia Natural Resources LLC	Deel Fork	Gas	Released	
BU-0606	EH-111	Virginia Gas Company	Deel Fork	Gas	Released	
			Pending Permits			
8869		CNX Gas Company LLC	Belcher Branch		Pending	
8870		CNX Gas Company LLC	Belcher Branch		Pending	
8871		CNX Gas Company LLC	Belcher Branch		Pending	
8872		CNX Gas Company LLC	Belcher Branch		Pending	
8880		CNX Gas Company LLC	Belcher Branch		Pending	

Coal Mining: Stormwater from an individual coal mining permit may be controlled by one or more NPDES-permitted sediment detention ponds, and individual sediment ponds may control runoff from parts of areas under more than a single mining permit. During the 1995-2007 period, monitored flow and pollutants were recorded from 34 permitted sediment ponds in Bull Creek that control runoff from parts of eleven different mining permits, while 25 permitted outfalls recorded no discharge. Individual sediment detention ponds are designed to capture 0.125 ac-ft of runoff per acre of disturbed land (barren and extractive land uses) for each storm event, and assuming that the entire permitted acreage is disturbed. In the modeling, existing loads from these areas were represented by combinations of loads from a number of land use categories explained previously, and the sediment ponds were simulated with an 85% sediment reduction.

5.6.4. Point Source

There are no DEQ permitted point source dischargers in the Bull Creek watershed.

5.7. Accounting for Critical Conditions and Seasonal Variations

5.7.1. Selection of Representative Modeling Period

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed, with the beginning of the simulation period chosen to correspond with the beginning of electronic record-keeping by DMLR (January 1995). A long period of weather inputs was selected to represent long-term variability in the watershed. The model was run using a weather time series from April 1994 through December 2007, with the first 9 months used as an initialization period for internal storages within the model. The remaining 13-year period was used to calculate average annual sediment loads in both the Bull Creek and Upper Dismal Creek watersheds.

5.7.2. Critical Conditions

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

5.7.3. Seasonal Variability

The GWLF model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model also allows for monthly-variable parameter inputs for evapo-transpiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

5.8. Model Calibration

Model calibration is the process of adjusting model parameter values so that simulated loads from a watershed match loads calculated from corresponding monitored ("observed") flow and concentrations at a given point in a stream. Although GWLF was originally developed for use in non-gaged watersheds and, therefore, does not require calibration, hydrologic calibration has been recommended where observed flow data is available (Dai et al., 2000). Historically in Virginia, the GWLF model has been used to develop TMDLs to address sediment as a stressor in streams with benthic impairments. In these previous TMDLs, sediment has only been subject to accounting and reductions from non-permitted sources, and the successful restoration of the impaired stream was to be judged solely by the recovery of the benthic macro-invertebrate population and associated metrics, not by measured in-stream sediment. This is clearly not the case in Bull Creek, where permitted waste load allocations for sediment are closely monitored and tracked, and will serve as the basis for determining existing waste load allocations for new mining permits. Therefore, calibration was performed for flow and sediment in both Bull Creek and its reference watershed, in order to obtain a greater correlation with available observed data, and to achieve a greater degree of consistency with DMLR's tracking software for Waste Load Allocations.

Within Bull Creek watershed, the closest in-stream monitoring point – MPID #4468 – is a monthly DMLR station located just below the confluence of Left Fork Bull Creek (Convict Hollow) and Bull Creek, 0.89 miles upstream from the outlet and representing 94.6% of the Bull Creek watershed area. Monitoring at this station began in January 2002 and continues through the present. However, the DMLR flow data during the 2003-2005 period looked inconsistent with other monitored flow at that station and was considered inappropriate for use in calibration. Because of this limitation, therefore, Apr-05 through Mar-07 was used as the period for calibrating DMLR monitored data with GWLF simulated

TSS loads. Data from one large monitored event (Jul-06) that did not correspond with a significant monitored rainfall event was not used for calibration. Within Upper Dismal Creek, the closest in-stream monitoring point – MPID #4569 – is a monthly DMLR station located just below the confluence of Laurel Fork and Dismal Creek, 3.8 miles upstream from the outlet and representing 13.9% of the Upper Dismal Creek watershed area. The same Apr-05 through Mar-07 period was used for calibration of flow and sediment at this station.

The GWLF model was calibrated for both hydrology and sediment, using sub-watersheds above each of the selected calibration DMLR stations in Bull Creek and Upper Dismal Creek. The hydrology parameters adjusted during calibration included: monthly evapotranspiration (ET) coefficients, the seepage coefficient, and the curve number by landuse. The sediment parameters adjusted during calibration included: sediment pond efficiency, and the curve number by landuse. The adjustments made to the calibration parameters are given in Table 5.5.

Table 5.5. Calibrated parameters and value adjustments, Apr-05 through Mar-07

Calibration Adjustments	Bull Creek at MPID 4468	Upper Dismal Creek at MPID 4569
ET Dormant period MF*	1.05	1.05
ET Growing period MF*	0.756	0.97
Seepage coefficient	0.020	0.074
Curve number MF*	0.890	0.765
Sediment pond efficiency	0.85	0.85

* MF = multiplication factor.

Calibration endpoints were set as unit-area TSS measures developed using the observed data at available DMLR monitoring stations in both the reference and TMDL watershed. Unit-area measures allow for comparison between watersheds of different sizes. The average unit-area flow and unit-area TSS loads from the observed data used as calibration targets and the results of simulated output from the calibrated model in each calibration sub-watershed are shown in Table 5.6.

Table 5.6. Calibration targets and results for calibration sub-watersheds, Apr-05 to Mar-07 (excluding Jul-06)

Unit-area Measures	Bull Creek at DMLR MPID 4468		Upper Dismal Creek at DMLR MPID 4569	
	Calibration Target	Result	Calibration Target	Result
Flow (cfs/sq.mi.)	1.027	1.026	0.787	0.787
TSS Load (kg/ha-yr)	59.68	59.83	18.52	19.18

The simulated unit-area output for both flow and sediment (TSS) from both the calibrated reference and TMDL watershed models were each within 4% of their respective calibration targets. The calibration adjustments (shown in Table 5.6) were then applied to models of the full Bull Creek and Upper Dismal Creek watersheds and model simulations run for the 1995-2007 period. A comparison of simulated flow and loads for the full watersheds for both the calibration and simulation periods, shown in Table 5.7, further support the reasonableness of these calibrations.

Table 5.7. Calibrated simulation results for Bull Creek and the area-adjusted Upper Dismal Creek for both the calibration and TMDL simulation periods

	Bull Creek calibrated		Upper Dismal Creek calibrated	
Parameter	Apr-05 to Mar-07	1995 - 2007	Apr-05 to Mar-07	1995 - 2007
Unit-area Flow (cfs/sq.mi.)	1.02	1.38	0.60	0.72
Unit-area TSS Load (kg/ha-yr)	6.65	158.2	1.83	77.0
Average [TSS] (mg/L)	40.6	245.7	36.4	290.4
Median [TSS] (mg/L)	4.1	9.2	0.3	0.3
Flow-weighted [TSS] (mg/L)	22.6	387.4	10.6	380.4

For each watershed, the unit-area flows are similar, with small increases, between the calibration period (Apr-05 to Mar-07) and the full simulation period (1995-2007). The unit-area TSS loads for the full watersheds (Table 5.8) are smaller than those from the smaller calibration sub-watersheds (Table 5.7), as they should be, since sediment delivery tends to decrease the larger the watershed. The unit-area flows and loads increase during the longer 13-yr simulation period, because the calibration period was limited to a set of drier years, while the longer simulation period included a broader range of rainfall conditions, including some wetter years. The *median* TSS concentrations reflect the typically low levels observed during baseflow conditions. The model simulated larger *average* TSS concentrations during the longer period with greater rainfall, as would be expected. The higher *average* TSS concentrations reflect larger loads associated with stormwater runoff, which was fairly minimal during the drier calibration period. Overall, the calibrated Bull Creek and Upper Dismal Creek models simulated flow and TSS loads that match the observed data and performed as expected under wetter conditions of the full simulation period.

5.9. GWLF Model Parameters

The GWLF parameter values used for the Bull Creek and Upper Dismal Creek watershed simulations are shown in Table 5.9 through Table 5.10.Table 5.9 lists the various watershed-wide parameters and their values, Table 5.10 displays the monthly variable evapo-transpiration cover coefficients, and Table 5.11 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP product - used for erosion modeling. Calibrated parameters and their calibrated values are indicated in each of the tables.

Table 5.8. GWLF Watershed Parameters for Bull Creek

GWLF Watershed Parameters	units	TMDL: Bull Creek	Reference: Area-adjusted Dismal Creek
recession coefficient	(day^{-1})	0.0808	0.0808
seepage coefficient*	(day^{-1})	0.0200	0.0740
sediment delivery ratio		0.1591	0.1591
unsaturated water capacity	(cm)	11.87	12.00
erosivity coefficient (Nov - Apr)		0.126	0.143
erosivity coefficient (growing season)		0.244	0.241
% developed land	(%)	3.0	2.8
no. of livestock	(AU)	10	19
area-weighted runoff curve number		67.43	70.07
area-weighted soil erodibility		0.200	0.208
area-weighted slope	(%)	47.90	41.63
aFactor		0.0000842	0.0000821
total stream length	(m)	48,139.2	43,250.1
Mean Channel Depth	(m)	0.625	0.625
* Calibrated value			

Table 5.9. GWLF Monthly Evapotranspiration Cover Coefficients

Watershed	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Bull Creek	0.740	0.735	0.734	**0.734**	0.734	0.739	0.774	0.809	0.824	**0.834**	0.784	0.750
Area-adjusted Dismal Creek	0.949	0.954	0.955	**0.955**	0.955	0.950	0.911	0.873	0.856	**0.845**	0.900	0.938

* July values represent the maximum composite ET coefficients during the growing season, calibrated.
** Jan values represent the minimum composite ET coefficients during the dormant season, calibrated.

Table 5.10. GWLF Land Use Parameters – Existing Conditions

Landuse	Bull Creek		Area-adjusted Dismal Creek	
	KLSCP	CN*	KLSCP	CN*
HIGH_TILL	0.9110	69.7	1.2852	61.8
LOW_TILL	0.3848	69.0	0.5429	61.2
pasture2	0.1364	64.6	0.1145	57.8
hay	0.0633	64.3	0.0532	57.3
forest	0.0283	57.5	0.0292	52.4
barren	1.3747	78.2	1.3830	68.3
extractive	2.7805	78.3	4.5791	67.3
AML	1.2728	78.3	1.6715	67.3
reclaimed	0.3257	72.5	0.5100	63.9
released	0.1170	64.6	0.2194	57.8
pur_LDR	0.0169	64.6	0.0186	57.8
pur_MDR	0.0107	64.6	0.0174	57.8
pur_HDR	0.0176	64.6	0.0183	57.8
imp_LDR	0.0000	80.1	0.0000	69.6
imp_MDR	0.0000	87.2	0.0000	75.0
imp_HDR	0.0000	87.2	0.0000	75.0

* Calibrated value
pur = pervious urban areas
imp = impervious urban areas
LDR = low density residential
MDR = medium density residential
HDR = high density residential

5.10. Phase II Monitoring and Model Adjustments

All of the preceding information on TSS model development comes from the Phase I model development. After the approval of the Phase I TMDL, a TSS monitoring study was conducted to refine the model for the Phase II TMDL.

5.10.1. TSS Monitoring

During the development of the Phase I TMDL, questions regarding uncertainties in the TSS loads in the model arose. As a result a study aimed at better quantifying sediment contributions to the watershed from active mining operations during larger storm events was conducted. Specifically, the study aimed to answer the following questions:

1.) What is the best approach for representing existing contributions from permitted mining discharges?

2.) What is the best approach for representing allocated loads (i.e., waste load allocations – WLAs) from permitted mining discharges?

The full report on the sediment monitoring effort and analyses is included in Appendix E (Representation of TSS Loads in Coalfield TMDLs). The results indicated that existing TSS loading from actively mined areas may have been moderately underestimated in the Phase I TMDL, however the modeling of the TMDL was validated.

The recommended approach for estimating both existing and allocated loads from permitted surface mine discharges is to use the maximum permitted concentration (70 mg/L) applied to the runoff volume from active mine (disturbed) areas.

5.10.2. Phase II TSS Model Adjustments

Based on assessment of the existing model, available data, and an effort to maintain consistency across TMDL projects, some changes were made to the existing Bull Creek GWLF model. The land use distribution developed for the Phase I model was used for the Phase II GWLF. The model parameter changes are outlined in **Table 5.11** and **Table 5.12**, which replace *Tables 5.9 and 5.11* from the Phase I model development outlined above.

Table 5.11 GWLF watershed parameters in the impaired (Bull Creek) and reference (Upper Dismal Creek) watersheds.

GWLF Watershed Parameter[1]	Units	Bull Creek	Upper Dismal Creek
Recession Coefficient*	Day^{-1}	0.0808	0.0808
Seepage Coefficient*	Day^{-1}	0.020	0.074
Sediment Delivery Ratio	---	0.1591	0.1591
Unsaturated Water Capacity	(cm)	10.14	10.05
Erosivity Coefficient (May-Oct)*	---	0.28	0.28
Erosivity Coefficient (Sep-Apr)*	---	0.1	0.1
Evapotranspiration Cover Coefficient*	---	0.734 - 0.834	0.845 - 0.955
% Developed Land*	(%)	2.97	2.84
Livestock Density*	(AU/ac)	0.001290	0.002408
Area-weighted Soil Erodibility (K)	---	0.200	0.208
Area-weighted Runoff Curve Number (CN)	---	67.43	70.07
Total Stream Length[2]	(m)	15,913	15,913
Mean Channel Depth[2]	(m)	0.313	0.313

[1] Parameters identified with an asterisk (*), were maintained at the value set in the Phase I model.
[2] Parameter values are equal in the two watersheds due to scaling of reference watershed.

Table 5.12 GWLF curve numbers and KLSCP values for existing conditions in Bull Creek and Upper Dismal Creek watersheds.

Sediment Source	Bull Creek		Upper Dismal Creek	
	CN	KLSCP	CN	KLSCP
Pervious Area:				
Row Crop - High Till	81.40	1.1604	81.50	0.6538
Row Crop - Low Till	78.76	0.2275	78.90	0.1282
Pasture	75.99	0.3865	75.85	0.1361
Hay	67.08	0.0206	66.91	0.0073
Forest	65.28	0.0063	65.10	0.0055
Barren	86.77	1.8066	86.56	1.2562
Low Density Residential	69.28	0.0443	69.20	0.0342
Medium Density Residential	68.85	0.0351	68.11	0.0518
High Density Residential	69.15	0.0530	68.80	0.0487
AML	79.27	0.3554	78.97	0.3492
Mining Land Uses:				
Extractive/Active Mining	86.80	2.6164	86.25	1.5626
Reclaimed	74.00	0.3794	72.62	0.2266
Released	65.80	0.4906	63.87	0.2930
Impervious Area:				
Low Density Residential	98.00	0.0000	98.00	0.0000
Medium Density Residential	98.00	0.0000	98.00	0.0000
High Density Residential	98.00	0.0000	98.00	0.0000

The sediment loads were modeled for existing conditions in Bull Creek and reference watershed Upper Dismal Creek (area-adjusted to match conditions in the Bull Creek watershed). Construction stormwater permitted loads were included in the Phase II model and were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 60 mg/L. The modeled runoff for the construction stormwater discharge was estimated based on the annual runoff from barren areas. As discussed in Section 5.10.1 of this report, the existing TSS concentration from active mining and reclaimed areas within mining permits was assumed to be the permitted concentration of 70 mg/L. The remainder of the area in the mining permit areas consists of released lands and areas that have yet to be disturbed.

Sediment loads from these areas are included with their respective land uses, while the disturbed areas are allocated as mining permit loads.

The hydrologic model was calibrated again for the development of the Phase II TMDLs. The sediment loading model was not calibrated as the change in allocated load modeling removed the need to calibrate sediment pond efficiencies.

CHAPTER 6: MODELING PROCESS FOR TDS TMDL DEVELOPMENT

In the development of the total dissolved solids (TDS) TMDL for the Bull Creek watershed, the relationship between pollutant sources and in-stream water quality was defined through computer modeling. In this chapter, the modeling process, input data requirements, and model calibration procedures for TDS are discussed. Due to the phased nature of this TMDL, sections 6.1-6.8 cover model developments for the Phase I TMDL, whereas section 6.9 discusses new TDS monitoring data and model adjustments for the Phase II TMDL. Sections 6.1-6.8 come directly from the Phase I document and should be read considering the Phase I historical context.

6.1. Model Selection

The model selected for development of the TDS TMDL was Hydrological Simulation Program – FORTRAN (HSPF), version 12 (Bicknell et al., 2001; Duda et al., 2001).

The TMDL development process requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. HSPF was used to model TDS transport and fate throughout the Bull Creek watershed. The ArcGIS™ 9.1 Geographic Information System (GIS) software was used to display and analyze landscape information for the development of inputs to HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality processes. HSPF estimates runoff from both pervious and impervious parts of the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget, on pervious areas (e.g., agricultural land). Runoff from impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow and routing through the stream network is performed using the sub-module HYDR within the module RCHRES. Transport of TDS on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. TDS was simulated in-stream as a conservative pollutant with load contributed from the various sources through surface runoff, interflow, groundwater, and direct discharge to the stream.

6.2. HSPF Model Development

As described previously, Lower Dismal Creek in Buchanan County was selected as the reference watershed for Bull Creek and the 90th percentile of DEQ-monitored surface water TDS samples was used to set the TMDL modeling concentration endpoint of 369 mg/L. In the absence of TDS water quality criteria, an assumption was made that the 90th percentile TDS concentration from a reference watershed with a healthy benthic community and a history of coal mining, will set an achievable, effective TDS endpoint for Bull Creek. Model development for Bull Creek was performed by assessing the sources of TDS in the watershed, evaluating the necessary parameters for modeling, calibrating the model to observed data, and applying the model to simulate TDS loads.

Eighteen sub-watersheds were delineated within the Bull Creek watershed to represent the spatial distribution of land uses and pollutant sources (see Figure 5.1).

The majority of TDS loads are associated with current and historical mining activities within the watershed. TDS are generated from active and abandoned mining areas within the watershed, both surface and underground, and are delivered to the stream through surface runoff, interflow, groundwater, and direct mine discharges. Residential sources of TDS within the watershed include failing septic systems and straight pipes. Road salt applications are another source of TDS within the watershed that will be accounted for in the modeling process. In addition, TDS is also present from natural geologic sources in both the impaired and reference watersheds.

While all groundwater contains some background TDS, elevated levels are usually indicative of human activities. Background levels of TDS in groundwater for the Appalachian Plateau region of Virginia average 230 mg/L (USGS, 1997). Mining-related current and historical groundwater monitoring show elevated levels of TDS in groundwater near mining activities. Groundwater TDS concentrations may also be greater in shallower groundwater, which eventually returns to streams as interflow. Areas with valley fill may provide larger TDS loads from interflow because the flow of water percolating below the upper surface of the valley fill may cause an increase in the volume of interflow, and as a result, an increase in exposure time and soluble ion surface area interaction with the water. Although under natural conditions, interflow may contribute a substantial fraction of 'total groundwater' flow, in fractured valley fills, interflow may be considerably greater than 'natural condition' volumes, and contribute even more to the TDS load on a percentage basis.

Sources of TDS that contribute during surface runoff events include disturbed land, abandoned mine land, active surface mining areas, and road salt. Contributions of TDS to surface waters between storms may arise from interflow, groundwater, direct mine discharges, failing septic systems, and straight pipes.

There are no VPDES permitted facilities within the Bull Creek Watershed. Eleven NPDES permits issued by DMME are currently active in Bull Creek for mining activities. There are 8 pre-law mine discharges in the watershed. Limits for TDS are not part of current mining permits.

6.3. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of any given watershed. The different types and sources of input data used to develop the TDS TMDL for the Bull Creek watershed are discussed below.

6.3.1. Climatological Data

Daily precipitation data for Bull Creek were obtained from the National Climatic Data Center weather station at Grundy (443640) in Buchanan County, located 4 miles (6.4 km) east of the Bull Creek DEQ monitoring station 6ABLC002.30 (Figure 5.2). Missing precipitation data was patched with data from Breaks Interstate Park and John Flannagan Lake located in Dickenson County. Because HSPF requires some climatic parameters that are not available at Grundy, data from Richlands, Lonesome Pine Airport, Bristol Tri City Airport, Abingdon, and Lynchburg Airport were also used to complete the meteorological data set required for running HSPF. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are presented in Appendix B.

6.3.2. Land Use

Land use categories were defined in a similar manner as for the GWLF modeling described in Section 5.3.2, with the exception that an impervious roads layer was added for simulation of road salt application.

6.4. HSPF Parameter Evaluation

The hydrology parameters required by HSPF were defined for each land use category. Required hydrology parameters are listed in the HSPF Version 12 User's Manual (Bicknell et al., 2001). Spatial analysis was performed using the ArcGIS™ geographical information system (GIS) to evaluate many of the HSPF input parameter values. Sub-watersheds were first delineated using GIS routines. Areas of individual land use categories were calculated using GIS within each sub-watershed and used to define the various PERLND (pervious land segments) and IMPLND (impervious land segments) model components. The spatially-defined sub-watershed/land use category areas were then used to evaluate other corresponding topographic and soils characteristics required by the model. Simplified representative stream reaches were then manually defined within each sub-watershed, and hydraulic stage-discharge relationships defined.

Since no daily flow gauging stations were available in the Bull Creek watershed, hydrologic calibration was performed on a surrogate watershed and the values of the selected calibrated parameters were applied to the Bull Creek model. The Cranes Nest River in Wise and Dickenson Counties was selected as the surrogate watershed, as it was one of the closest gauged stations and had previously been used as a surrogate for the Lick Creek TMDL modeling. Initial estimates for required hydrology parameters, outside of those evaluated from available digital spatial data, were evaluated for the surrogate watershed based on guidance in BASINS Technical Note 6 (USEPA, 2000a). Sub-watersheds were also created in Cranes Nest River at major confluences in order to represent the hydrology in the watershed. The stream reach in each sub-watershed requires a function table (FTABLE) to describe the relationship between water depth, surface area, volume, and discharge (Bicknell et al., 2001). The procedures described in Staley et al. (2006) were used to develop FTABLEs using NRCS bankfull equations and digital elevation models and to characterize the reaches in the Cranes Nest River watershed, while FTABLEs for Bull Creek were generated from digital data and NRCS regional curves (http://wmc.ar.nrcs.usda.gov/technical/HHSWR/Geomorphic/index.html). The calibrated hydrologic model was fine-tuned by comparing with periodic measurements of flow available at various DMLR in-stream monitoring stations.

6.5. Representation of TDS Sources

The HSPF model was then configured for representation of TDS as a conservative generalized water quality constituent. Required water quality parameters are given in the HSPF User's Manual (Bicknell et al., 2001). TDS was simulated as contributing to stream loads from surface runoff, direct discharges to the stream, and through interflow and groundwater. TDS parameter values for the model were initially estimated, and calibration was then performed using periodic DMLR in-stream observed concentrations at several points throughout the watershed.

6.5.1. Surface Runoff

Since TDS is associated with mining activities, TDS was simulated using buildup/washoff functions from extractive, abandoned mine land (AML), and reclaimed land uses. Since monitored surface runoff data were not available, initial loading rates were estimated and then adjusted during the water quality calibration.

An impervious land use was created for paved roads. Application of TDS from road salts was modeled as atmospheric deposition subject to surface runoff. Road salt was simulated as being applied on days with recorded snow events greater than 0.50 inches. Runoff TDS loads were calculated as a daily time series and summarized as annual loads by sub-watershed. The length of named paved roads in each sub-watershed was calculated using TIGER™ data and an assumed impervious width of 20 feet (2.424 ac/linear-mile). The Wise County office of the Virginia Department of Transportation (VDOT) estimated that 350 pounds of road salt was applied per linear mile of paved road on days with recorded snow events. A monthly time series of TDS loads was generated within the watershed from the Grundy NCDC daily surface data (Station 443640) for days with snow greater than 0.50 inches and then disaggregated to hourly loads. Hourly TDS loads were then calculated from this time-series as 350 lb/mi divided by 2.424 ac/linear-mile and 24 hrs/day (6.0156 lbs/ac-hr) and multiplied by the area of paved roads in each sub-watershed.

6.5.2. Interflow and Groundwater

The spatial variability of interflow TDS concentrations were simulated by land use and were determined through calibration.

Groundwater TDS concentrations were represented by time-series of DMLR groundwater monitoring data in each sub-watershed. The time-series were created from the existing network of DMLR sampling sites and adjusted with calibration multiplication factors. In Bull Creek, groundwater TDS concentrations were initially estimated as monthly average concentrations within each sub-watershed for the period of January 1995 through April 2007. Where possible, interpolation was performed to estimate TDS concentrations in months with missing data. Sub-watersheds without monitored data, or with missing monthly data at the beginning or ending of the period were assigned concentrations, either from a neighboring watershed, or as an average from several neighboring watersheds for that month. The monthly time-series for each sub-watershed was then minimally adjusted during calibration. The time-series multiplication factors ranged from 1.0 to 1.1, and the adjusted monthly concentrations ranged from 24 to 2,990 mg/L, with an overall average groundwater TDS concentration of 712 mg/L.

6.5.3. Direct Discharge Sources

There were eight pre-law direct mine discharges from underground mines located within the Bull Creek watershed. The eight discharges (MPID nos. 00011296, 0003444, 0003576, 0003577, 0003579, 5600368, 5600375 and 5650118) occurred in 6 of the 18 sub-watersheds. Flow and concentration data for these discharges were accounted for in HSPF as time-series input from MUTSIN files.

Septic system effluent TDS loads were simulated from areas in Bull Creek without sewer access. Sewer lines follow the main stem of Bull Creek from U.S. Route 460 to Cove Hollow and part way down Convict Hollow. Therefore, no septic systems were included in the model for the corresponding sub-watersheds (1, 2, 4, 5, and 6; Figure 5.1). The number of houses per sub-watershed was estimated from USGS 7.5-min topographic maps, with older homes defined as those structures that did not show up as photo-revised additions (approximately after 1967). Each household was classified into three age categories (pre-1969, 1970-1989, and post-1990) based on population categories available in the 2000 census data. The population of the Bull Creek watershed is approximately 1,210, with 445 of those currently served by the sewer system operated by Buchanan County Public Service Authority. The TDS concentration in residential straight pipe discharges was simulated as 500 mg/L (EPA, 2007). The TDS concentration from failing septic systems was simulated as 425 mg/L, estimated as half the difference between straight pipes and effluent concentrations from normally functioning septic systems (350 mg/L; EPA, 2007). The numbers of houses with straight pipes were estimated from census data. The numbers of failing septic systems were based on estimates of failure rates in the three age categories as 20, 5, and 1%, respectively (based on personal communication with R.B. Reneau, 3 December 1999, Blacksburg, Virginia). The model, therefore, represents TDS in the effluent from older systems with potential maintenance problems (31), and from systems estimated to be discharging directly to streams via a straight pipe (205). TDS loads in effluent from normally functioning septic systems were assumed to be negligible.

6.6. Accounting for Critical Conditions and Seasonal Variations

6.6.1. Selection of Representative Modeling Period

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed. All available DMLR monitoring data was used for the hydrology calibration which ran from January 1995 through October 2006. However, a shorter time period, January 2000 through December 2005, was selected for the TDS calibration and TMDL modeling. The shorter period was selected because it represented the most recent period of mining activity with little change in land use. Therefore, during this period, monitoring results will most closely relate to the current mining activities and other land uses in the Bull Creek watershed.

6.6.2. Critical Conditions

The HSPF model is a continuous simulation model that uses hourly inputs of rainfall and climate to simulate runoff and pollutant loading, also on an hourly basis. The period of rainfall selected for modeling (January 2000 through December 2005) was chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

6.6.3. Seasonal Variability

The HSPF model used to develop this TMDL considers seasonal variation through a number of mechanisms. Some parameters varied monthly and additional parameters were entered as estimated or monitored time-series. TDS inputs in surface runoff were a direct response of seasonal weather variations.

Groundwater concentrations were simulated as monthly averages by sub-watershed from DMLR-monitored data. Direct mine discharges were simulated as a time-series of approximately monthly DMLR flow and discharge measurements. Road salt applications were simulated as a time-series related to days with snow events. All of the model inputs that are simulated as direct measurement time-series capture as much seasonal variability as possible and minimize the uncertainty inherent in estimation by annual or overall averages.

6.7. Model Calibration and Validation

Model calibration is the process of evaluating model parameter values so that the model is an accurate representation of the watershed. In this section, the procedures followed for calibrating the hydrologic and water quality components of the HSPF model are discussed.

6.7.1. Hydrology

Because no continuous daily monitoring data were available for Bull Creek, detailed hydrology calibration and validation were performed for nearby Cranes Nest River, and calibrated parameter values transferred to the Bull Creek model. Observed daily flow data for Cranes Nest River were available from the USGS monitoring station 03208950 on Cranes Nest River near Clintwood, VA. The HSPEXP decision support system developed by USGS (Lumb et al., 1994) was used to calibrate the hydrologic portion of HSPF for Cranes Nest River. The default HSPEXP criteria for evaluating the accuracy of the flow simulation were used in the calibration for Cranes Nest River. These criteria are listed in Table 6..

Table 6.1. Default hydrology calibration criteria for HSPEXP.

Variable	Percent Error Criteria
Total Volume	10%
50% Lowest Flows	10%
10% Highest Flows	15%
Storm Peaks	15%
Seasonal Volume Error	10%
Summer Storm Volume Error	15%

The hydrologic calibration period was August 1, 1989 to July 31, 1997. The hydrologic validation period was from May 1, 2001 to July 31, 2005. The output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range (USEPA, 2000a).

The simulated flow for both the calibration and validation matched the observed flow well, as shown in Figure 6.1 and Figure 6.2. The agreement with observed flows is further illustrated in Figure 6.3 and Figure 6.4 for a representative year and Figure 6.5 and Figure 6.6 for a representative storm. The agreement between the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figure 6.7 and Figure 6.8).

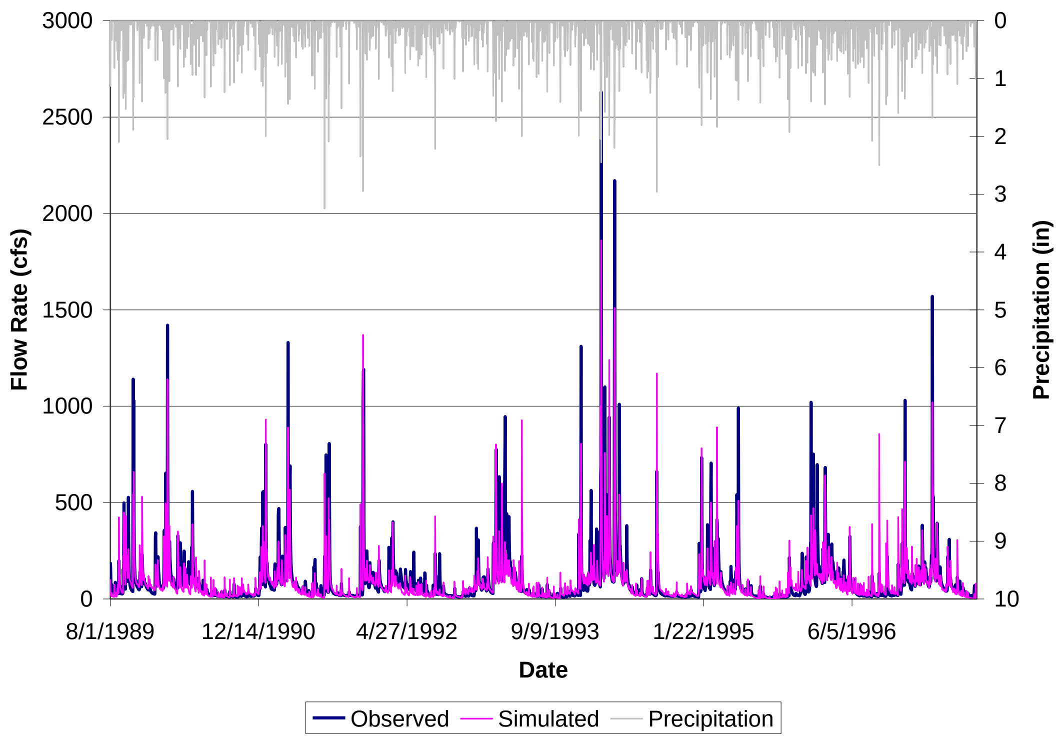

Figure 6.1. Observed and simulated flows and precipitation for Cranes Nest River for the calibration period.

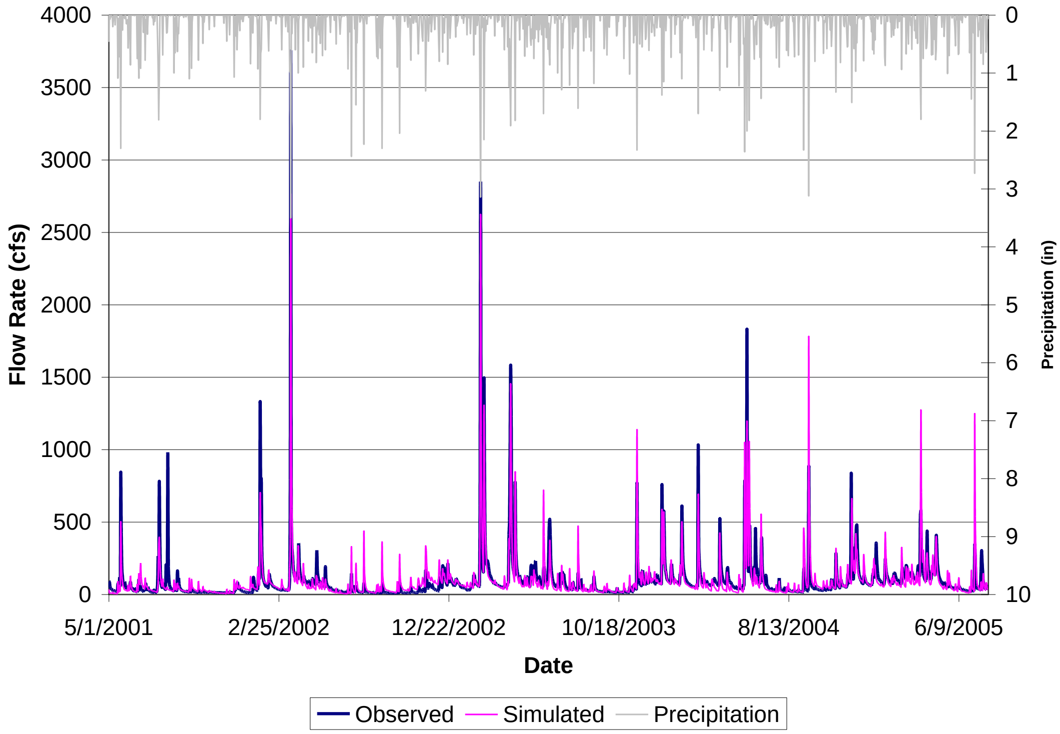

Figure 6.2. Observed and simulated flows and precipitation for Cranes Nest River during the validation period.

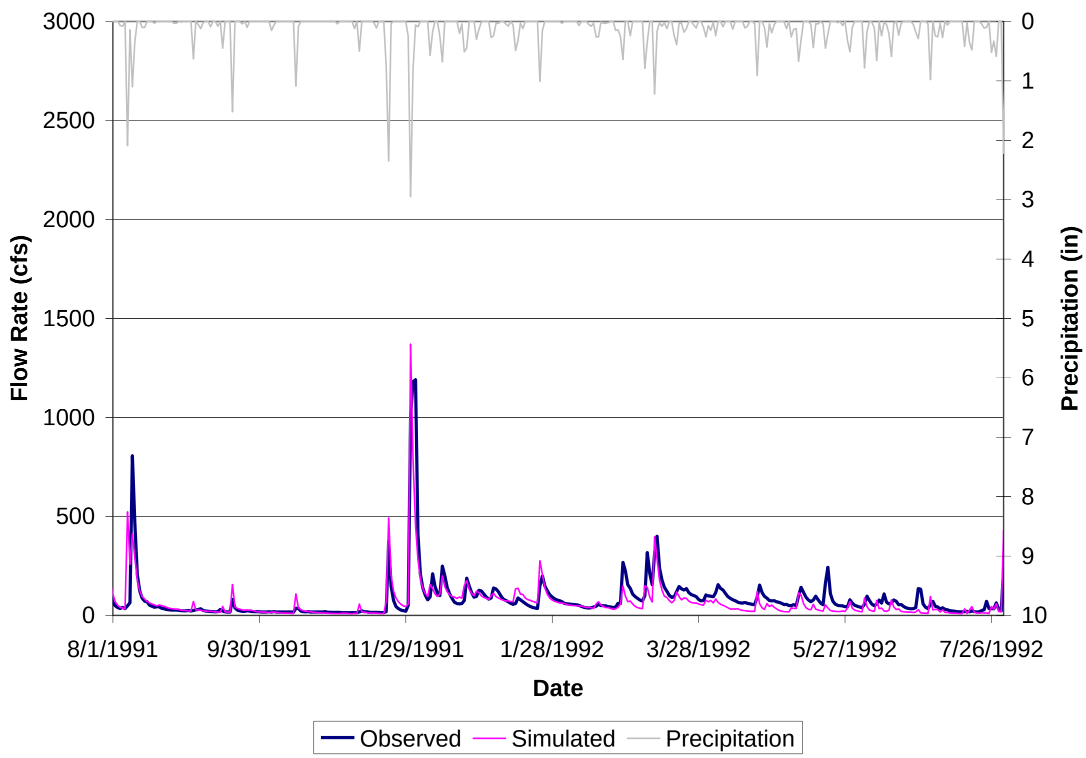

Figure 6.3. Observed and simulated flows and precipitation for a representative year in the calibration period for Cranes Nest River.

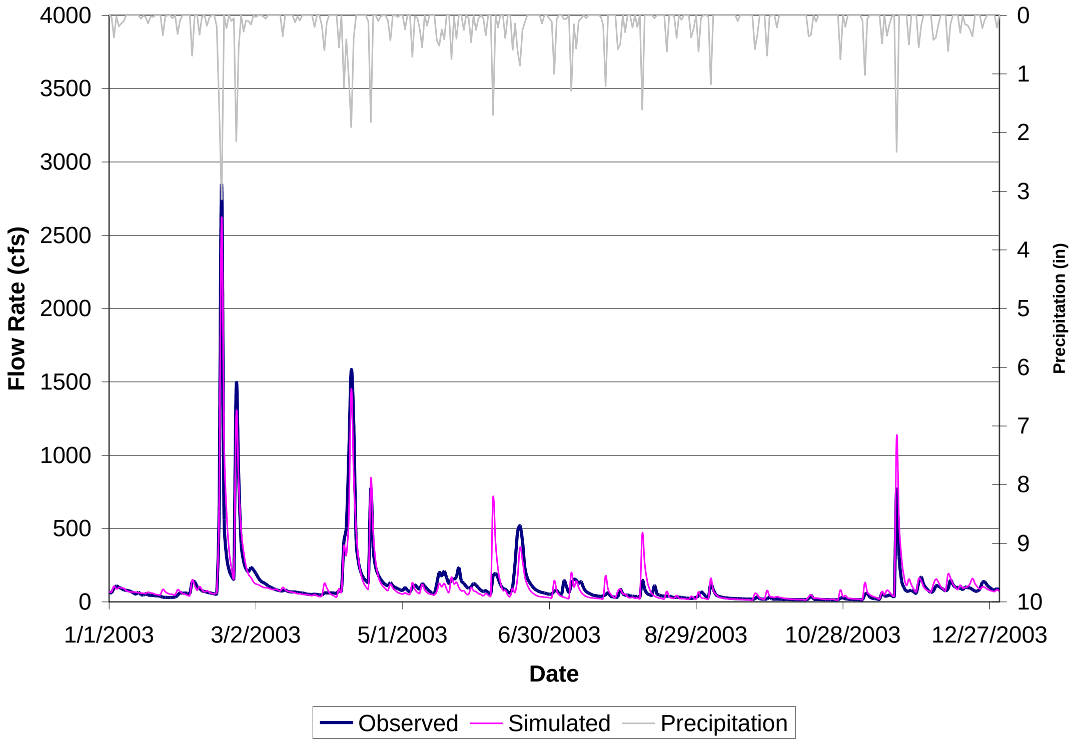

Figure 6.4. Observed and simulated flows and precipitation for Cranes Nest River during a representative year in the validation period.

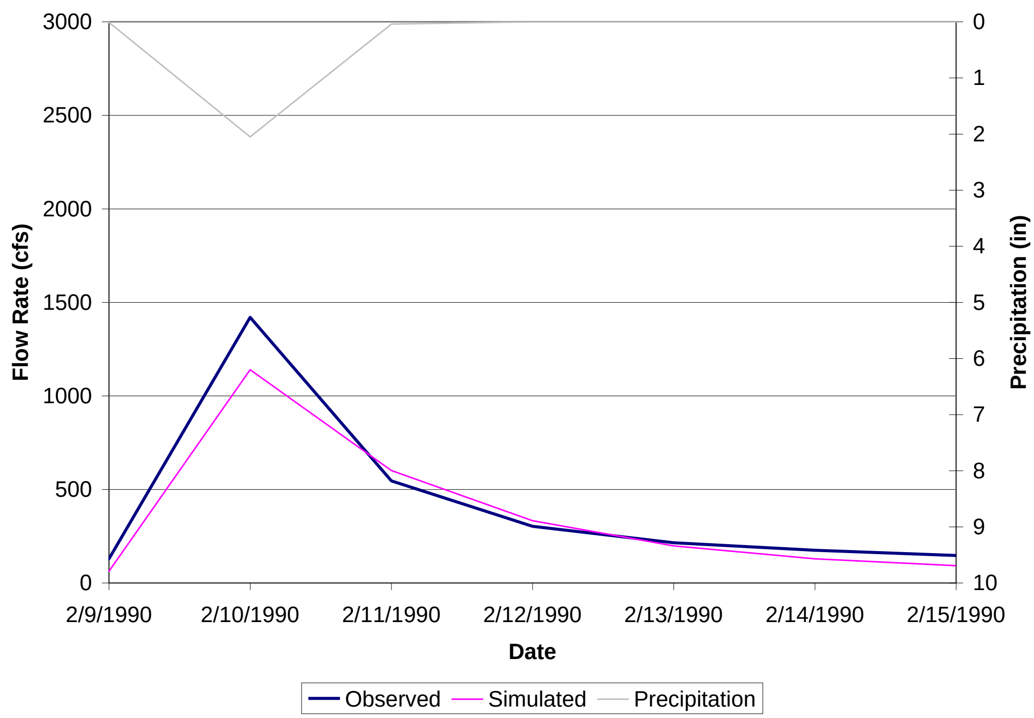

Figure 6.5. Observed and simulated flows and precipitation for Cranes Nest River for a representative storm in the calibration period.

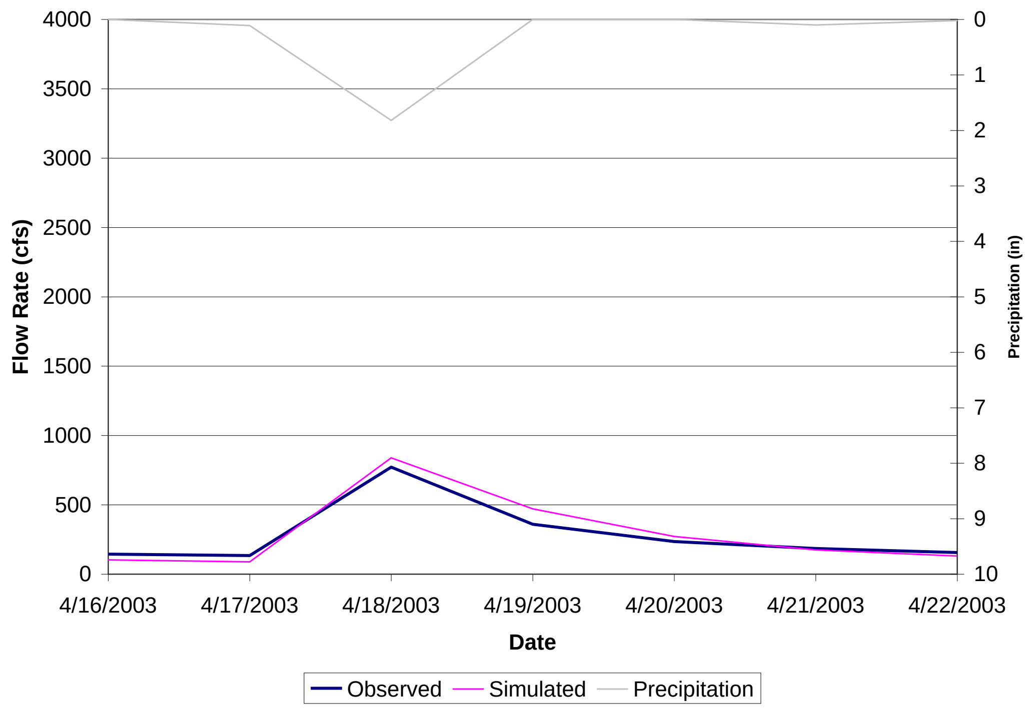

Figure 6.6. Observed and simulated flows, and precipitation for Cranes Nest River for a representative storm in the validation period.

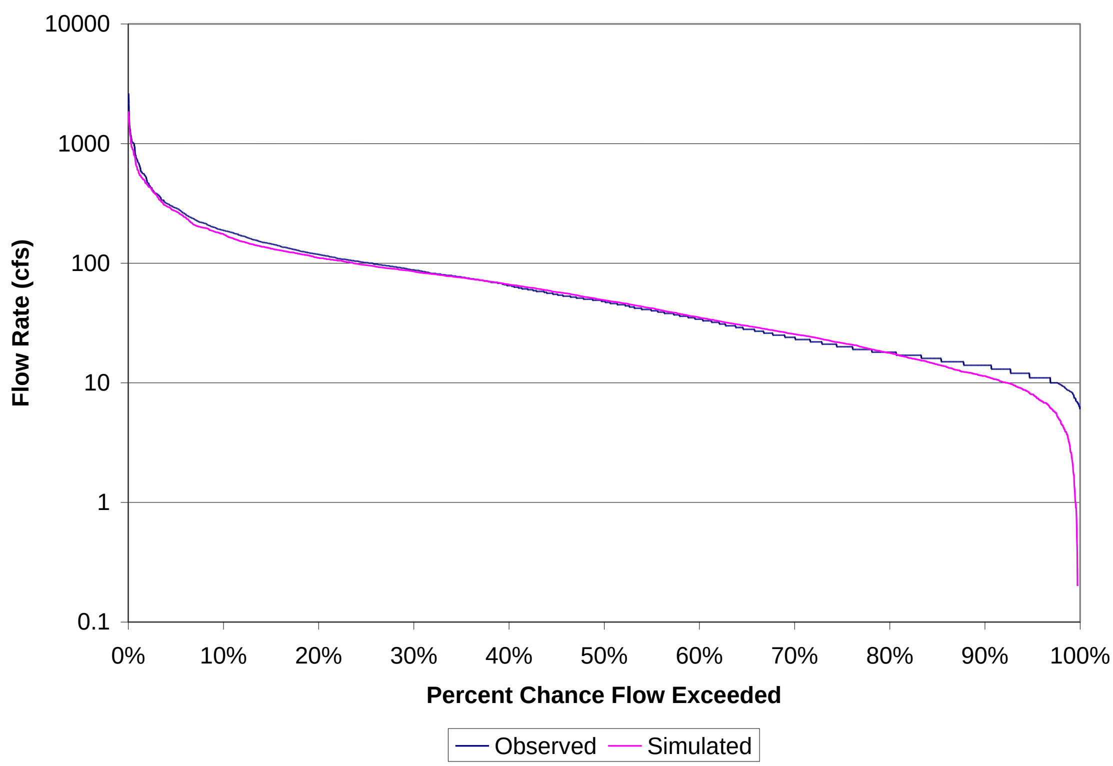

Figure 6.7. Cumulative frequency curves for the calibration period for Cranes Nest River.

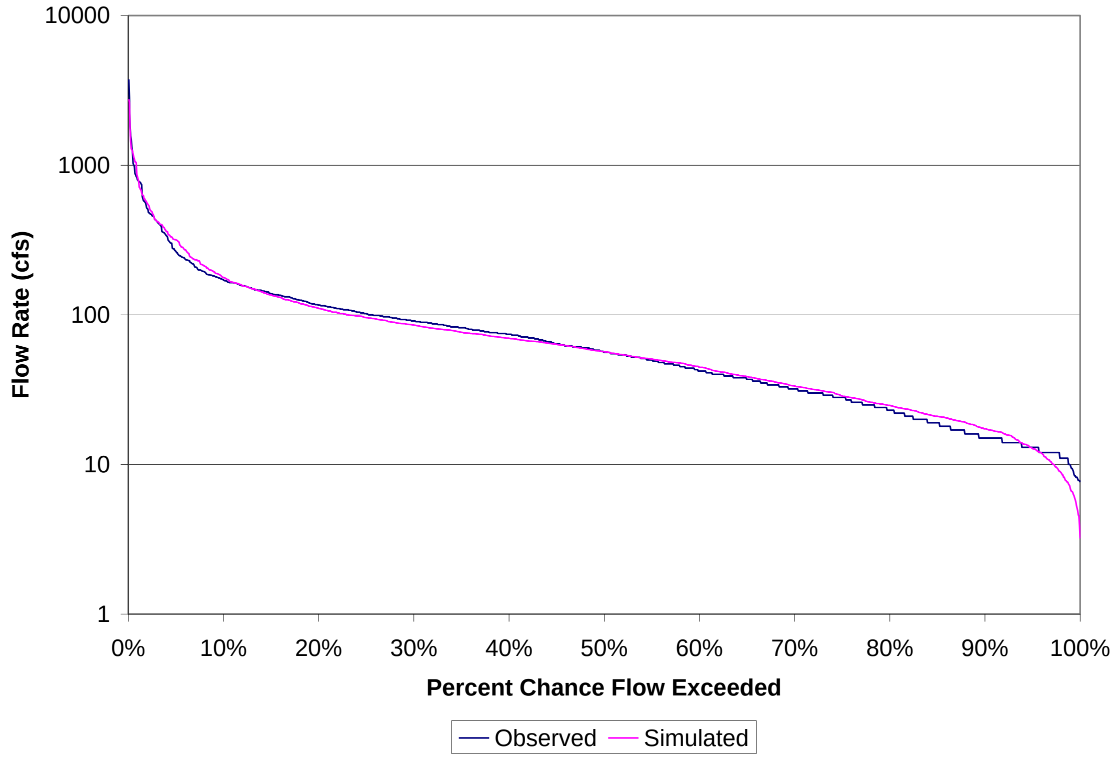

Figure 6.8. Cumulative frequency curves for the validation period for Cranes Nest River.

Selected diagnostic output from the HSPEXP program is listed in Table 6.2 and Table 6.3. All of the criteria were met for both the calibration and validation periods. The total winter runoff and total summer runoff errors are considered in the HSPEXP term 'seasonal volume error' (see Table 6.). The errors for seasonal volume error were 1.9% for the calibration period and 3.0% for the validation period; both are within the required range of ±10%.

Table 6.2. Summary statistics for the calibration period for Cranes Nest River.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)†	136.3	144.6	-5.8	10%
Average Annual Total Runoff (in)	17.04	18.08	-5.8	10%
Total of Highest 10% of flows (in)†	57.3	63.4	-9.6	15%
Total of Lowest 50% of flows (in)†	18.9	19.0	-0.3	10%
Total Winter Runoff (in)†	51.6	54.3	-5.0	na
Total Summer Runoff (in)†	15.5	16.0	-3.1	na
Coefficient of Determination, r^2	0.73			

†total for the 8-year calibration period
na = not applicable; these are not criteria directly considered by HSPEXP

Table 6.3. Summary statistics for the validation period for Cranes Nest River.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)†	83.7	83.0	+0.8	10%
Average Annual Total Runoff (in)	19.69	19.53	+0.8	10%
Total of Highest 10% of flows (in) †	37.8	36.5	+3.6	15%
Total of Lowest 50% of flows (in) †	13.2	12.6	+4.7	10%
Total Winter Runoff (in) †	25.9	26.0	-0.3	na
Total Summer Runoff (in) †	16.6	16.2	+2.7	na
Coefficient of Determination, r^2	0.76			

†total for the 4.25-year validation period
na = not applicable; these were not criteria directly considered by HSPEXP

Flow partitioning for the Cranes Nest River hydrologic model calibration and validation is shown in Table 6.4. When the observed flow data were evaluated using HYSEP (Sloto and Crouse, 1996), the average baseflow indices for the calibration and validation periods were 0.55 and 0.53, respectively. The annual baseflow indices ranged from 0.42 to 0.62 for the calibration period and from 0.42 to 0.60 for the validation period. The baseflow indices for the simulated data are also presented in Table 6.4. The simulated baseflow index is close to the observed index for both periods, and both simulated baseflow indices fall within the observed range of baseflow indices.

Table 6.4. Flow partitioning for the calibration and validation periods for Cranes Nest River.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	17.04	19.69
Surface Runoff (in)	3.17 (19%)	4.17 (21%)
Interflow (in)	4.92 (29%)	6.45 (33%)
Baseflow (in)	8.95 (53%)	9.07 (46%)
Baseflow Index	0.53	0.46

All of the criteria were met for both the calibration and the validation periods. This indicates that the developed hydrologic model provides an acceptable prediction of Cranes Nest River flows. The final list of calibrated hydrologic parameters and their calibrated values for Cranes Nest River are listed in Table 6.5.

Table 6.5. Final calibrated hydrology parameters for Cranes Nest River.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix C Table (if applicable)
PERLND					
LZSN	Lower zone nominal soil moisture storage	inches	4.0	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.186-0.286[a]	Soil and cover conditions	1
AGWRC	Base groundwater recession	none	0.965	Calibrate	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.40	Geology	
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	0.8	Soil properties	
INTFW	Interflow/surface runoff partition parameter	none	1.5	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.5	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	3
RCHRES					
KS	Weighting factor for hydraulic routing		0.5		

[a]Varies with land use
[b]Varies by month and with land use

These parameters were then transferred to the Bull Creek watershed model. Since DMLR requires periodic in-stream flow and TDS monitoring above and below various permitted mining sites around the Bull Creek watershed, these data were available for fine-tuning the hydrologic calibration. The DMLR data were available at multiple points throughout the watershed which made it possible to account for differences in headwater and main channel contributions to flow during the fine-tuning.

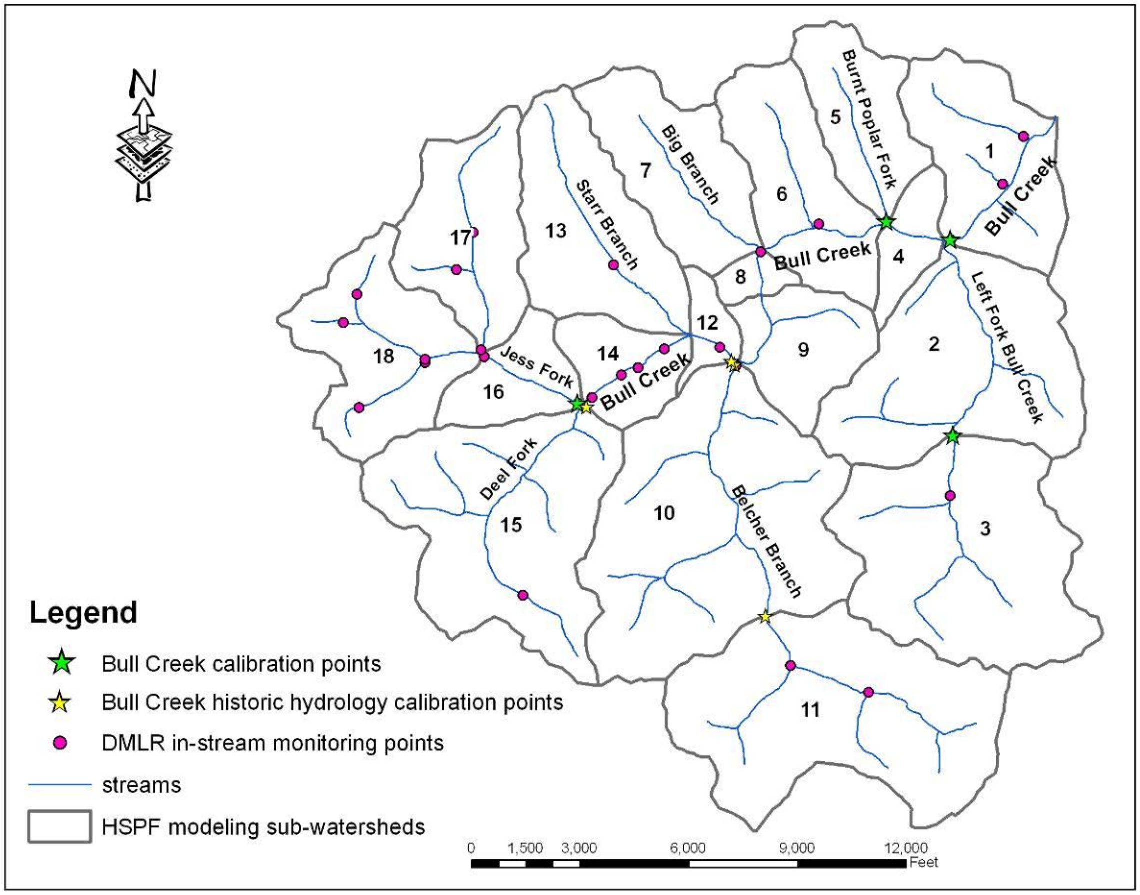

Figure 6.9. DMLR In-stream Monitoring Points in Bull Creek and Selected Calibration Points

Flows were then simulated with the Bull Creek model that incorporated the calibrated Cranes Nest River hydrologic parameter values. These simulated flows were then compared with DMLR observed flow data at the select monitoring points around the Bull Creek watershed. The locations of these DMLR in-stream monitoring points are shown in Figure 6.9. Although all of the hydrology calibration points were used for hydrology comparisons, the historic hydrology calibration points were not used for the TDS calibration.

Two minor changes were made during the hydrologic fine-tuning. One of these changes was made to eliminate the occurrence of non-typical no-flow days, by changing the value of the AGWRC parameter for forest land uses from 0.965 to 0.990, in conformance with guidance in BASINS Technical Note 6 (USEPA, 2000a). The second change made to Bull Creek was to adjust the DEEPFR parameter from a constant of 0.40 to a value varying from 0.20 to 0.50 by sub-watershed to better match the observed DMLR-monitored flows. The results are shown in Figure 6.10 through Figure 6.16. As can be seen from the figures, the simulated flows reasonably match the patterns and ranges of the observed data. Thus, the calibrated parameters were deemed acceptable for use in the Bull Creek watershed. The hydrology fine-tuning resulted in a flow distribution with 12% arising from surface runoff, 29% from interflow, and 59% from groundwater during the simulated period.

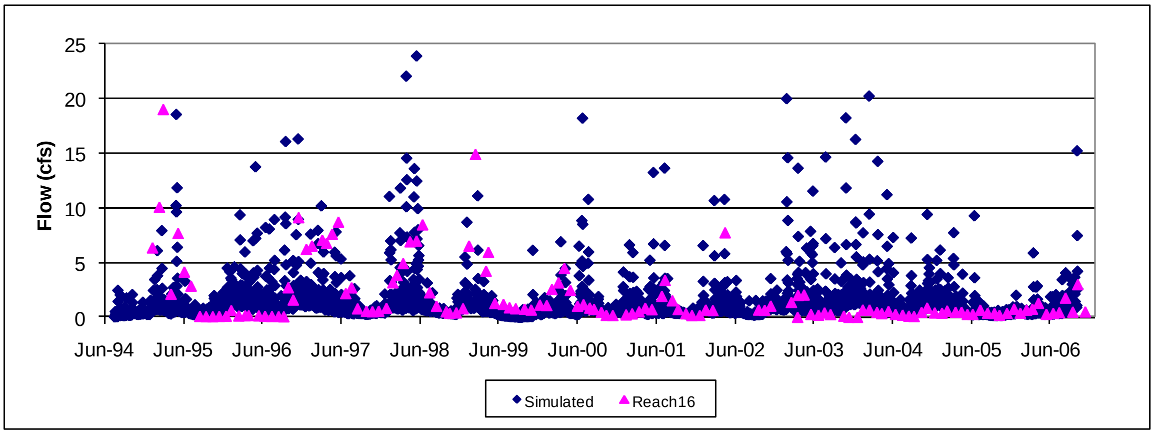

Figure 6.10. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 16 (Jess Fork).

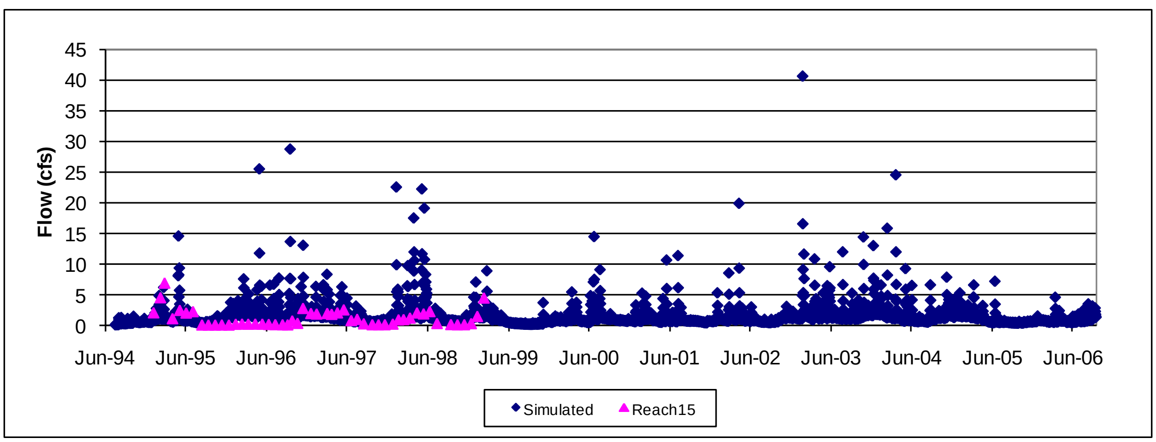

Figure 6.11. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 15 (Deel Fork).

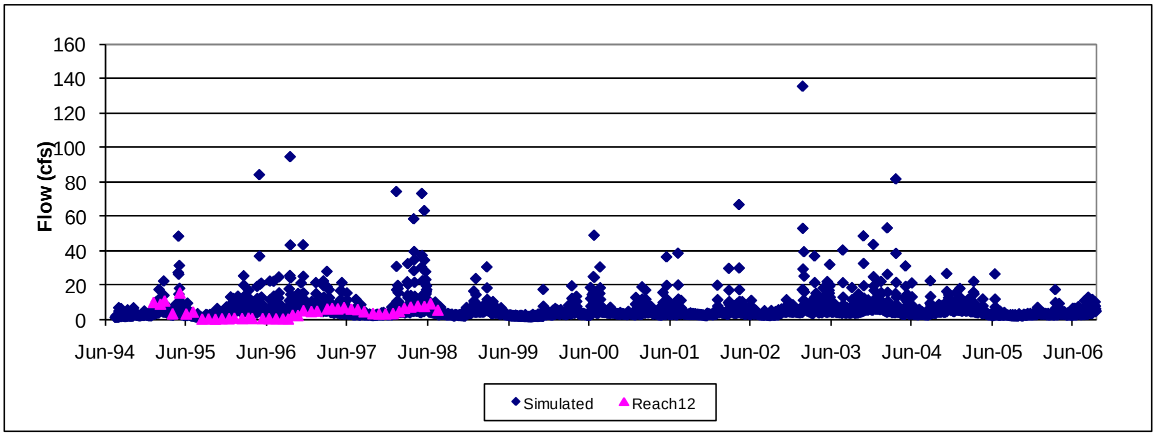

Figure 6.12. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 12 (Bull Creek below Starr Branch).

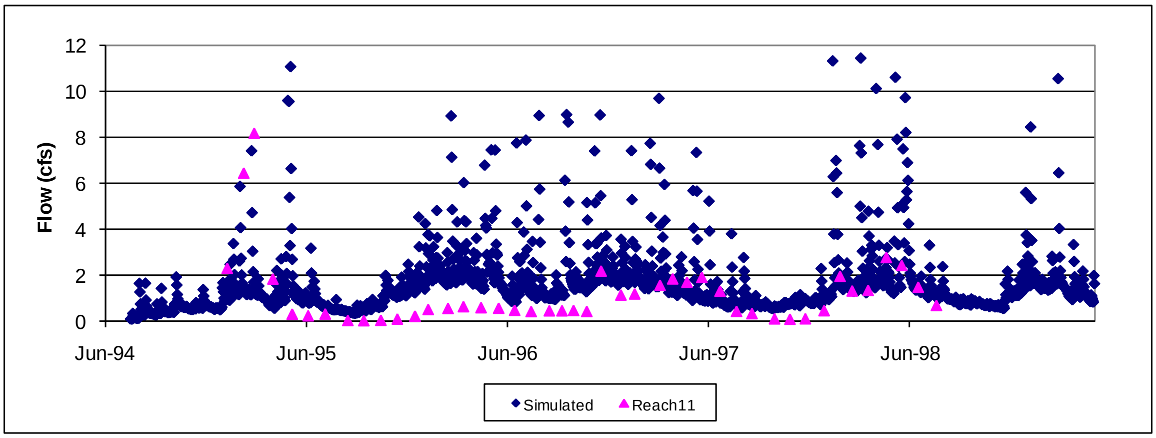

Figure 6.13. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 11 (Upper Belcher Branch).

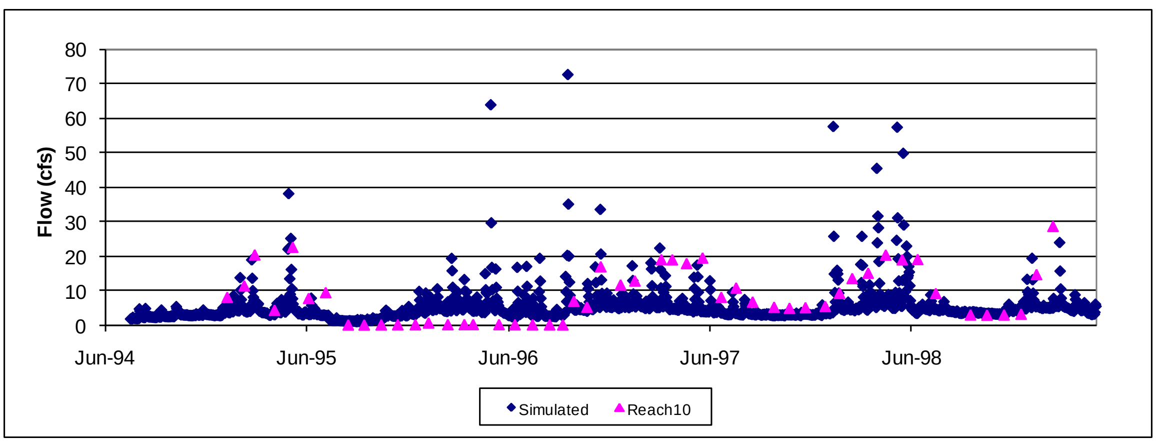

Figure 6.14. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 10 (Lower Belcher Branch).

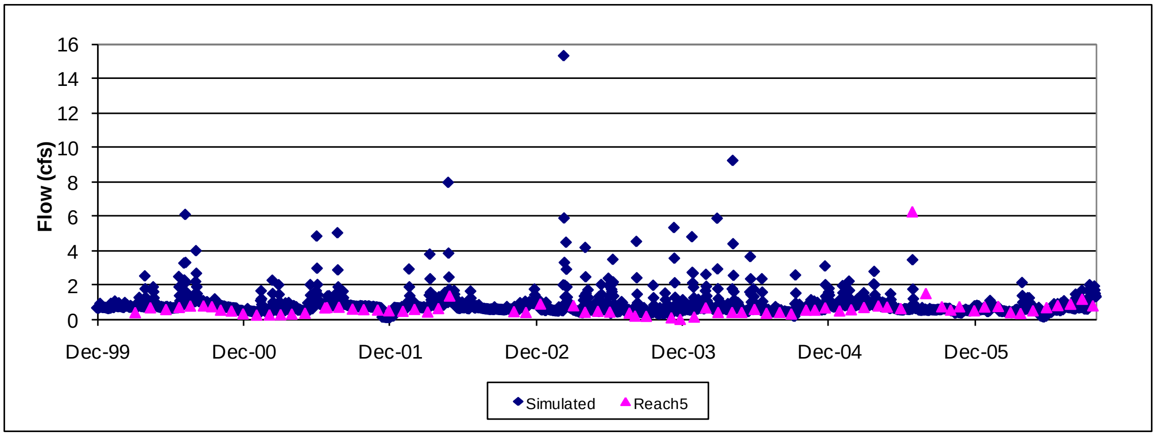

Figure 6.15. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watershed 5 (Burnt Poplar Fork).

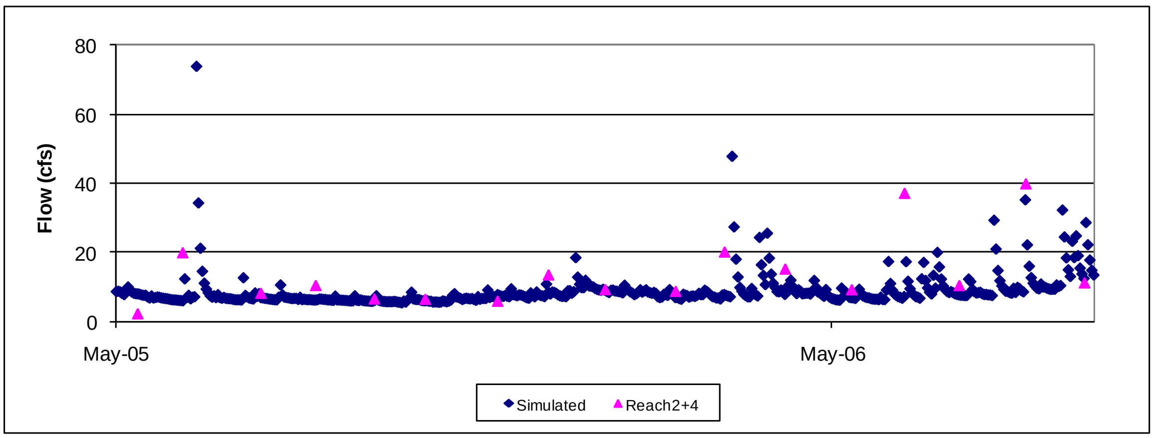

Figure 6.16. Calibrated simulated flow and DMLR observed flow in Bull Creek sub-watersheds 2+4 (Bull Creek near the outlet).

6.7.2. Water Quality (TDS)

Observed in-stream TDS concentrations from DMLR monitoring were also available at various points within the Bull Creek watershed. Four calibration points were selected in Bull Creek corresponding with the subset of points used for the hydrologic calibration assessment that also monitored for TDS.

During TDS calibration, parameter values were adjusted to match the available DMLR TDS data collected in Bull Creek for the period January 2000 - December 2005. Inputs for TDS loads from road salt applications, failing septic systems, straight pipes and pre-law mine discharges were quantified as described in Section 6.5 and were not subjected to calibration. TDS load calibration focused on parameters affecting the remaining TDS load components – surface runoff, interflow, and groundwater. Three parameters control surface runoff loads – ACQOP, SQOLIM, and WSQOP. ACQOP is the rate of daily TDS buildup or availability on the land surface; SQOLIM is the maximum level of TDS load on the land surface at any given time; and WSQOP is the rate of surface runoff that will remove 90% of the surface buildup in any given time step. Surface runoff loads were only simulated for the extractive and reclaimed land uses. Impervious area buildup and washoff of TDS was only simulated for the road surfaces. Additional calibration parameters included interflow TDS concentrations (IOQC) and groundwater concentrations (AOQC). The calibrated values and/or ranges for these parameters in the Bull Creek watershed are given in Table 6.6.

Table 6.6. TDS calibration parameters and values for Bull Creek

Parameter	Value/Range	Units	Spatially Variable	Temporally Variable
Pervious Land Segments				
ACQOP	200	lb/ac-day	constant	constant
SQOLIM	400	lb/ac-day	constant	constant
WSQOP	2.00	in/hr	constant	constant
AOQC	24 - 2,990	mg/L	by sub-watershed	monthly
IOQC	0.01436 - 0.04683	lb/ft3	by land use and sub-watershed	constant
	(230 - 750)	(mg/L)		
Impervious Land Segments				
CONS	144.4	lb/ac-day	roads	constant
SQOLIM	350	lb/ac-day	constant	constant
WSQOP	2.30	in/hr	constant	constant

The graphs comparing mean daily simulated and instantaneous observed TDS concentrations at the four calibration points along Bull Creek are shown in Figure 6.17 to Figure 6.20.

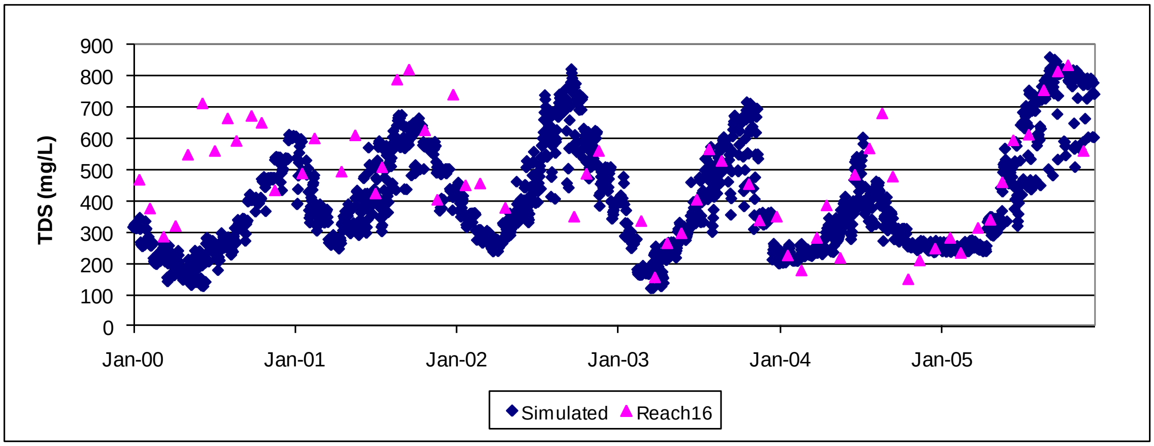

Figure 6.17. Simulated TDS concentrations and DMLR observed TDS concentrations in Bull Creek sub-watershed 16 (Jess Fork) after calibration.

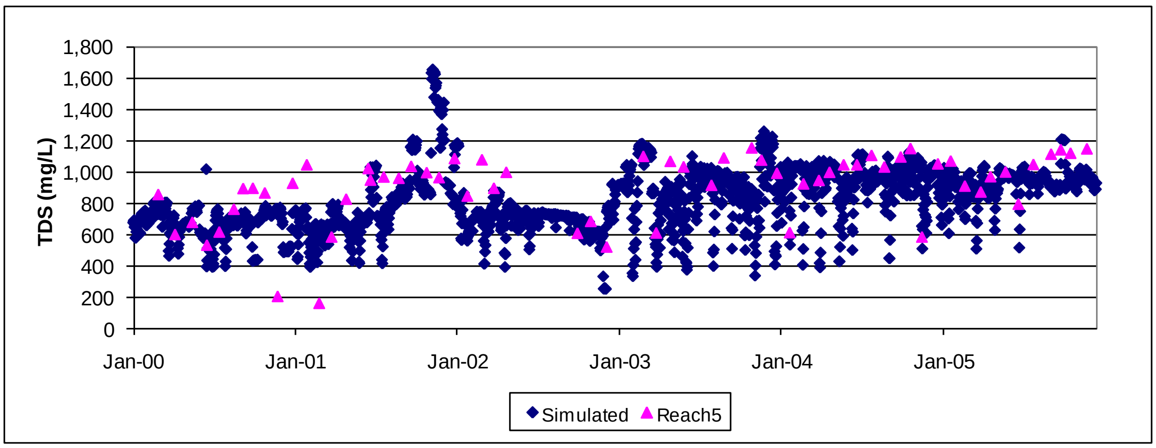

Figure 6.18. Simulated TDS concentrations and DMLR observed TDS concentrations in Bull Creek sub-watershed 5 (Burnt Poplar Fork) after calibration.

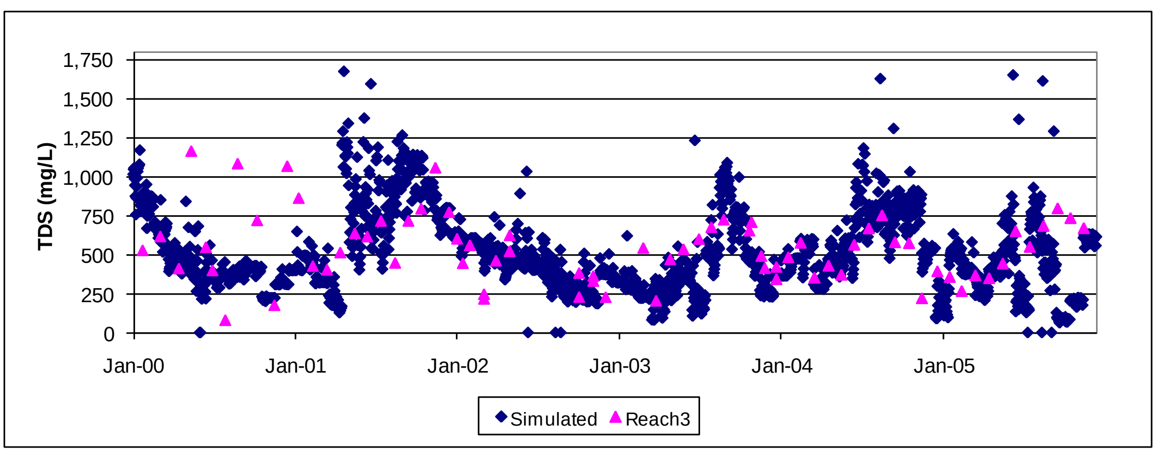

Figure 6.19. Simulated TDS concentrations and DMLR observed TDS concentrations in Bull Creek sub-watershed 3 (Upper Left Fork Bull Creek [Convict Hollow]).

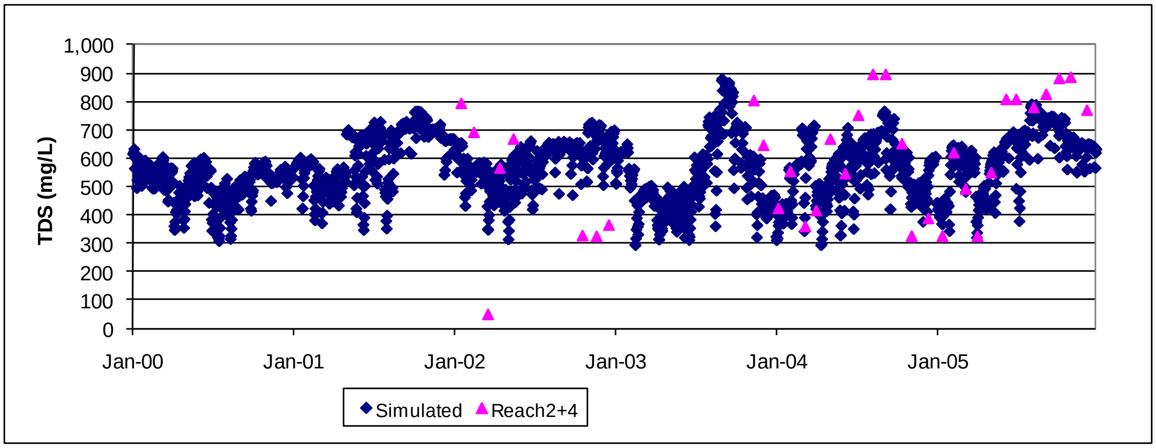

Figure 6.20. Simulated TDS concentrations and DMLR observed TDS concentrations in Bull Creek sub-watersheds 2+4 (Bull Creek near outlet) after calibration.

A visual comparison of simulated and observed in-stream TDS concentrations and best professional judgment were used to assess when a reasonable model calibration had been achieved. Additionally, the range and average of TDS concentrations were considered during calibration. Table 6.7 shows the comparison of these statistics and the percentage match between simulated and observed average TDS concentrations at each calibration point. Taken together, the visual data comparison and the descriptive statistics indicate a reasonable calibration of this highly variable parameter.

Table 6.7. TDS calibration statistics in 4 sub-watersheds of Bull Creek, January 2000 – December 2005

Sub-watershed Reach	Simulated		Observed		Sim Ave / Obs Ave
	Range (mg/L)	Average (mg/L)	Range (mg/L)	Average (mg/L)	(%)
Reach 16	120 - 859	399	150 - 1020	452	88.4%
Reach 5	250 - 1648	817	160 - 1248	960	85.1%
Reach 3	62 - 3235	508	78 - 1158	499	101.7%
Reach 2+4	290 - 882	568	50 - 896	578	98.2%

Although the total TDS loads from the watershed appear reasonable in relation to observed in-stream concentrations, the distributions among the various pathways of surface transport, interflow, and groundwater contributions to stream loads and between permitted mining and AML sources are somewhat uncertain. Loads from the other sources of TDS - residential, road salt, and pre-law mining – have been estimated with a degree of confidence. The parameters from the remaining sources of TDS in the watershed – active mining and AML land uses – were initially evaluated from available literature sources; however, only limited information was available to differentiate between these sources. Because of the uncertainties in the exact distribution of these loads, a phased TMDL was determined to be appropriate for the TDS stressor in Bull Creek. To calculate TDS loads generated for each mining permit, the model was first run with loads calculated from individual sub-watersheds with TDS sources from AML, road salt, pre-law mine discharges, residential septic source, and background interflow contributions turned off. The resulting sub-watershed TDS loads attributable to permitted mining sources were then apportioned to permits within each sub-watershed on an area-basis. The load for each permit was then summed from its area-weighted portions in each sub-watershed.

6.8. HSPF Model Parameters

A summary of the hydrologic parameter values used for Bull Creek are listed in Table 6.8. Complete listings of HSPF parameters that vary by month or by land use are included in Appendix C.

Table 6.8. Summary of HSPF hydrologic parameters and values for Bull Creek

Parameter	Definition	Units	Values	FUNCTION OF…	Appendix C Table (if applicable)
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	4.0	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.186-0.286[a]	Soil and cover conditions	1
LSUR	Length of overland flow	feet	30-200[a]	Topography	1
SLSUR	Slope of overland flowplane	none	0.16-0.54[a]	Topography	1
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.99 forest, 0.965 other	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is	deg. F	40	Climate,	

	reduced			vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.20 – 0.50	Sub-watershed	
BASETP	Fraction of remaining ET from baseflow	none	0.12	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0.10	Marsh/wetlands ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	monthly[b]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	0.8	Soil properties	
NSUR	Mannings' n (roughness)	none	0.011-0.6[a]	Land use, surface condition	4
INTFW	Interflow/surface runoff partition parameter	none	1.5	Soils, topography, land use	
IRC	Interflow recession parameter	none	0.5	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	monthly[b]	Vegetation	5
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	116	Topography	
SLSUR	Slope of overland flowplane	none	0.28	Topography	
NSUR	Mannings' n (roughness)	none	0.08	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.100	Land use, surface condition	

[a]Varies with land use
[b]Varies by month and with land use

6.9. Phase II Monitoring and Model Adjustments

All of the preceding information on TDS model development comes from the Phase I model development. After the approval of the Phase I TMDL, a TDS study was conducted to refine the model for the Phase II TMDL.

6.9.1. TDS Monitoring

A study was conducted by MapTech, Inc. of Blacksburg, VA to uncover any relationships between mining activities and in-stream TDS concentrations for use in other watersheds (*Phased TMDL: Bull Creek Watershed Total Dissolved Solids Evaluation, September 17, 2013* - Included in Appendix F). Monitoring data was collected by REI Consultants, Inc. on a semi-monthly basis over a six-month period from September 2012 to February 2013. Parameters measured were TDS, temperature, pH, dissolved oxygen, conductivity and flow. Nine springs in total were sampled in the Bull Creek watershed. In the Bull Creek mine springs the TDS concentrations varied from 300 to 1,400 mg/L. The lower concentrations were found in springs in the headwaters of Bull Creek. **Figure 6.21** shows the sampling locations in the Bull Creek watershed. **Table 6.9** shows the results of the flow-TDS monitoring at the nine sites in the Bull Creek watershed.

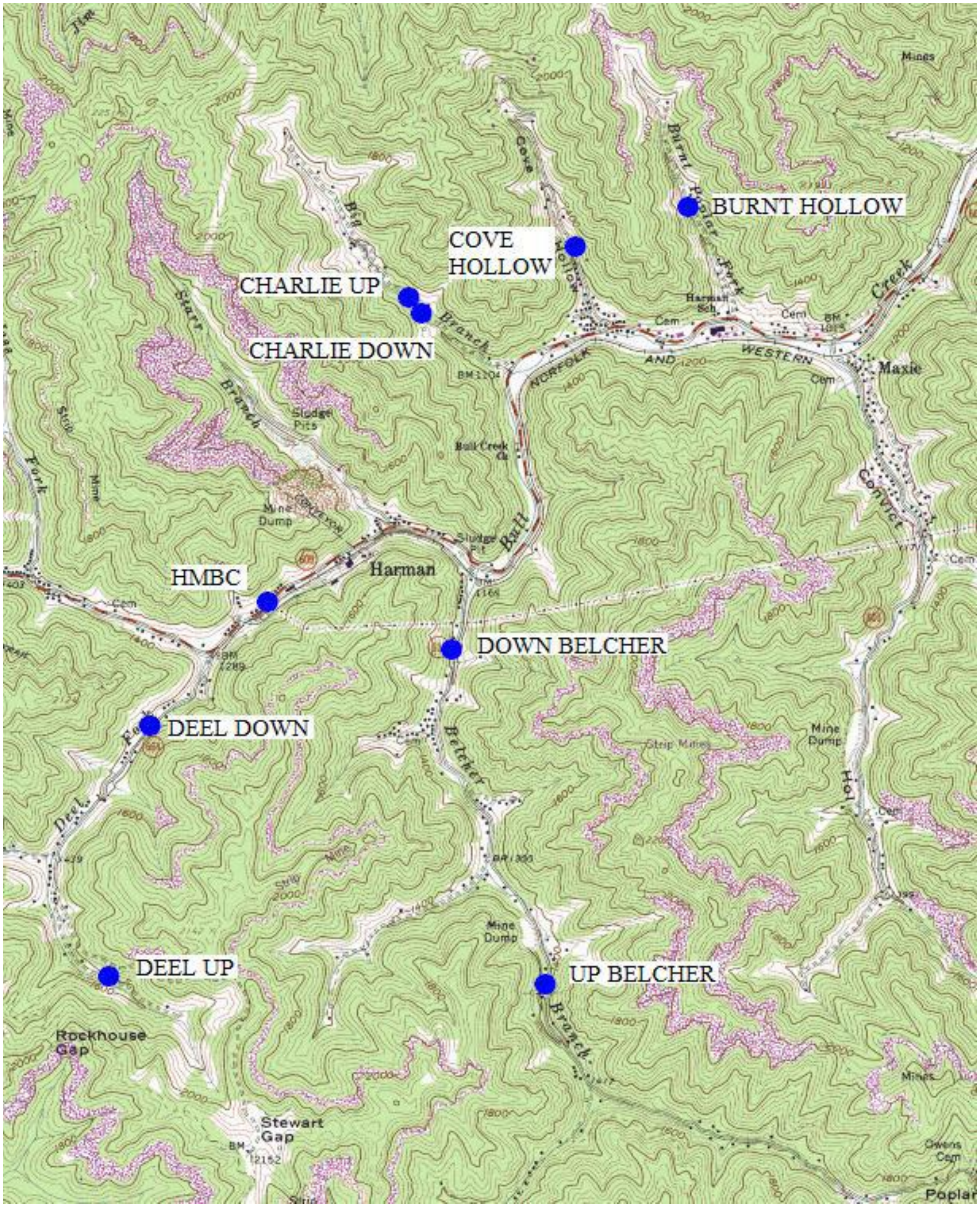

Figure 6.21 Sample locations for TDS in the Bull Creek watershed.

Table 6.9 Mine spring flow, and spring-TDS over the study period in the Bull Cr. watershed.

Site	Ave. Flow (cfs)	Median Flow (cfs)	Mean TDS mg/L	Median TDS mg/L	Mean TDS Mg/yr	Median TDS Load Mg/yr	Load Ratio[a]	Elevation (feet)
Down Belcher	1.49	0.85	999	1,035	1,239	790	118	1,232
Up Belcher	1.21	0.83	997	1,010	1,039	741	111	1,377
Burnt Hollow	0.74	0.61	1,050	1,065	684	569	85	1,305
HMBC	1.18	1.04	627	625	636	607	91	1,261
Cove Hollow	0.12	0.10	1,054	1,065	112	101	15	1,260
Charlie Up	0.20	0.10	990	1,004	165	93	14	1,309
Charlie Down	0.12	0.08	1,217	1,210	129	87	13	1,293
Deel Down	0.05	0.02	447	475	17	8	1	1,383
Deel Up	0.02	0.02	559	581	11	7	1	1,567
maximum:	1.49	1.04	1,217	1,210	1,239	790	118	1,567
minimum:	0.02	0.02	447	475	11	7	1	1,232
median:		0.10		1,010		101		1,332

[a] Median TDS Load divided by 7, the minimum Median TDS Load measured.

The results of the TDS monitoring study are summarized as follows:

- There is a seasonal trend in mine spring flow: low in autumn, moderate in early winter, and highest in late winter.
- The TDS concentration in mine springs decreases with flow increase.
- The volume of a spring primarily controls its TDS load.
- Large-volume springs provide the majority of the TDS load.
- The dominant TDS load springs in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.
- Spring elevation has a minor impact on flow volume and TDS load.
- Recent precipitation tends to increase TDS load at low flows. At high spring flows the relationship disappears.
- The volume of a spring tends to be larger from functional hydrologic islands with large footprints and volumes.
- Prominent abandoned mine scars above a mine spring dilute the TDS in springs but add substantially to the volume of the spring. Thus AML features lead to high TDS load.

- In the Bull Creek watershed, there is not a clear relationship between the mine parameters assessed and TDS load and flow volume as there is for hydrologic island footprint.

6.9.2. Phase II TDS Model Adjustments

TDS modeling was adjusted based on the monitoring results and review of the model. The Phase I TMDL model included loads from abandoned underground mine workings, based on the data recorded by DMME. Concentrations of TDS that were used to calculate these loads compare favorably with those collected in the TDS study found in Appendix F. However, the flow volumes measured for Phase II adjustments (Appendix F) were approximately 2.3 times greater than those used in calculating loads in the original model. To adjust for this difference, flows and loads used in the original model to simulate these outfalls were multiplied by a factor of 2.3. Because this increased flow in the system, the hydrologic and water quality calibrations were re-examined, however, the changes did not appear to warrant re-calibration. Base flow values increased, however this was consistent with the values monitored for the Phase II model adjustments (Appendix F). Additional TDS load was accompanied by additional flow, so concentrations were not altered significantly. The TDS loads were allocated under these revised conditions.

The original allocation for permitted discharges over-estimated the load through inclusion of groundwater contributions. The allocations were adjusted to represent only TDS loads that enter the stream through a permitted pond.

CHAPTER 7: PHASE II TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that appropriate actions can be taken to achieve water quality standards (USEPA, 1991). The stressor analysis indicated that sediment and TDS were the "most probable stressors" in the watershed (Yagow et al., 2007), and therefore, a TMDL was developed for each constituent.

7.1. Bull Creek Phase II Sediment TMDL

7.1.1. TMDLs and Existing Conditions

Table 7.1 shows annual sediment loads (t/yr) and unit area sediment loads (t/ha/yr) averaged over the 13-yr simulation period by source category for both the impaired watershed (Bull Creek) and the reference watershed (Upper Dismal Creek).

Table 7.1. Existing sediment loads (t/yr) and unit-area sediment loads (t/ha/yr) in Bull Creek and Upper Dismal Creek

Sediment Source	Bull Creek		Area-adjusted Upper Dismal Creek	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area				
Row Crop - High Till	123.09	51.70	0.00	0.00
Row Crop - Low Till	3.79	9.28	1.69	5.17
Pasture	365.12	14.19	239.28	4.87
Hay	0.34	0.51	0.00	0.00
Forest	393.21	0.15	369.77	0.13
Barren	2547.50	88.40	1516.38	60.85
Low Density Residential	66.60	1.27	52.40	0.98
Medium Density				
Residential	1.84	1.13	0.18	1.34
High Density Residential	16.26	1.52	13.14	1.35
AML	3137.78	14.77	2117.25	14.19
Mining Land Uses [1]				
Extractive	*	*	296.79	75.50
Reclaimed	*	*	20.14	7.42
Released	229.84	11.68	18.59	6.41
Impervious Area				
Low Density Residential	3.27	0.46	3.35	0.46
Medium Density				
Residential	0.92	1.13	0.07	1.14
High Density Residential	14.19	0.71	12.95	0.71
Direct Sources				
Channel Erosion	3.12		2.00	
Permitted Sources				
Mining Permits	8.93			
Gas Well Construction	3.32			
Watershed Totals	6919.13	3.83	4663.98	1.49

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

The phase II sediment TMDL for Bull Creek was calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where $\sum WLA$ = sum of the wasteload (permitted) allocations;

$\sum LA$ = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

The phase II sediment TMDL for Bull Creek watershed was calculated as the average annual sediment load from the area-adjusted Upper Dismal Creek watershed for existing conditions (4,663.98 t/yr, Table 7.2).

Annual waste load allocations were calculated for individual stormwater permits in the Bull Creek watershed based on their area in the watershed, the permitted maximum daily concentration of TSS, and the average annual simulated runoff from the corresponding land use, as detailed in section 5.10.2. A future growth allowance is also included for all permitted sources as 1% of the TMDL.

An explicit MOS of 10% was used in the sediment TMDL to reflect the uncertainty involved in developing a TMDL. The LA was calculated as the TMDL minus the MOS minus the WLA. The TMDL load and its components are shown in Table 7.2.

Table 7.2. Bull Creek Phase II Sediment TMDL (t/yr)

	WLA t/yr	LA t/yr	MOS t/yr	TMDL t/yr
Bull Creek	**58.89**	**4,135.15**	**466.40**	**4,660.44**
Gas Well Construction Permits	3.32			
Surface Coal Mining Transient Permits				
1101701	0.77			
1101736	1.95			
1101903	0.04			
1101979	1.03			
1200129	0.01			
1200281	0.10			
1200343	0.09			
1200589	0.07			
1201678	0.04			
1201922	0.19			
1201940	0.09			
1601788	4.54			
Future Growth	46.64			

Starting in 2007, the USEPA has mandated that TMDL studies include a maximum daily load (MDL) as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach found in the 2007 document titled Options for Expressing Daily Loads in TMDLs (USEPA, 2007). The procedure involved calculating the MDL from the long-term average annual TMDL load in addition to a coefficient of variation (CV) estimated from the annual load for ten years. The annual sediment load had a CV of 0.407. A multiplier was used to estimate the MDL from the long-term average based on the USEPA guidance and this CV. The multiplier estimated for Bull Creek was 2.755. In this case, the long-term average was the annual TMDL divided by 365 days (12.77 t/day), which when multiplied by the 2.755 results in an MDL of 35.15 t/day. The daily WLA was calculated as the annual WLA divided by 365. The daily MOS was calculated as 10% of the MDL. Finally, the daily LA was calculated as the MDL minus the daily MOS and the daily WLA. These results are shown in Table 7.3.

Table 7.3 Maximum daily sediment TMDL for Bull Creek.

	WLA t/day	LA t/day	MOS t/day	TMDL t/day
Bull Creek	**0.16**	**31.48**	**3.52**	**35.15**
Gas Well Construction Permits	0.00909			
Surface Coal Mining Transient Permits				
1101701	0.00211			
1101736	0.00535			
1101903	0.00012			
1101979	0.00282			
1200129	0.00004			
1200281	0.00027			
1200343	0.00024			
1200589	0.00018			
1201678	0.00012			
1201922	0.00053			
1201940	0.00025			
1601788	0.01242			
Future Growth	0.12769			

7.1.2. Allocation Scenarios

To reach the TMDL target goal (4,663.98 t/yr), two different scenarios were run with GWLF (Table 7.4). Scenario 1 shows 42.6% reductions to residential, pasture, high-till cropland, barren areas, and abandoned and released mine land. Scenario 2 shows reductions limited to the two land uses contributing the greatest sediment loads, abandoned mine land and barren or transitional areas (48.7%). Scenario 1 was chosen to use for the final TMDL because it has similar reductions on different land uses throughout the watershed. The final overall sediment load reduction required for Bull Creek is 32.6%.

Table 7.4. Final TMDL allocation scenarios for the Bull Creek watershed.

Sediment Source	Existing Bull Creek Loads	Scenario 1 Reductions	Scenario 1 Allocated Loads	Scenario 2 Reductions	Scenario 2 Allocated Loads
	t/yr	%	t/yr	%	t/yr
Pervious Area					
Row Crop - High Till	123.09	42.60	70.66	0.00	123.09
Row Crop - Low Till	3.79	0.00	3.79	0.00	3.79
Pasture	365.12	42.60	209.58	0.00	365.12
Hay	0.34	0.00	0.34	0.00	0.34
Forest	393.21	0.00	393.21	0.00	393.21
Barren	2,547.50	42.60	1,462.27	48.70	1,306.87
Low Density Residential	66.60	42.60	38.23	0.00	66.60
Med. Density Residential	1.84	42.60	1.06	0.00	1.84
High Density Residential	16.26	42.60	9.33	0.00	16.26
AML	3,137.78	42.60	1,801.09	48.70	1,609.68
Mining Land Uses[1]					
Extractive	*	*	*	*	*
Reclaimed	*	*	*	*	*
Released	229.84	42.60	131.93	0.00	229.84
Impervious Area					
Low Density Residential	3.27	42.60	1.88	0.00	3.27
Med. Density Residential	0.92	42.60	0.53	0.00	0.92
High Density Residential	14.19	42.60	8.14	0.00	14.19
Direct Sources					
Channel Erosion	3.12	0.00	3.12	0.00	3.12
Permitted Sources					
Mining Permits	8.93	0.00	8.93	0.00	8.93
Gas Well Construction	3.32	0.00	3.32	0.00	3.32
Future Load			46.64		46.64
Margin of Safety			466.40		466.40
Watershed Totals	6,919.13	32.64	4,660.44	32.60	4,663.43

[1] An asterisk (*) denotes extractive and reclaimed land uses covered by DMME permits in the impaired watershed.

AML and barren areas were assessed as the primary sources of sediment in the Bull Creek watershed. AML reclamation and improved erosion control management and minimization of disturbed area footprints are recommended as the primary targets of implementation efforts. Barren land uses result from construction of access roads and drilling sites for gas and oil wells, logging, and from residential activities.

7.2. Bull Creek Phased TDS TMDL

7.2.1. Existing Conditions

Table 7.5 shows the annual TDS loads (kg/yr) averaged over the 6-yr simulation period by source category for existing conditions in Bull Creek.

Table 7.5. Sources of Existing TDS Loads in Bull Creek

TDS Sources	Bull Creek Existing TDS Load (kg/yr)
AML (Groundwater, Interflow, and Runoff)	600,924
Non-AML groundwater (background)	2,931,440
Mining Interflow	20,435
Background Interflow	563,862
Abandoned Mine Discharge	4,218,873
Mining Runoff	24,467
Road Salt	18,565
Septic	28,063
Total	**8,406,629**

7.2.2. TMDL Endpoint

The TMDL endpoint for Bull Creek is 369 mg/L, the 90^{th} percentile of DEQ-monitored TDS concentrations from Lower Dismal Creek at DEQ monitoring station 6ADIS001.24.

7.2.3. Allocation Scenarios

The in-stream water quality endpoint, as established in the Phase I TMDL for Bull Creek, is the 90th percentile of DEQ-monitored TDS concentrations from Lower Dismal Creek at DEQ monitoring station 6ADIS001.24 (369 mg/L). To reach the TMDL target goal, multiple scenarios were run with HSPF. Eight of the scenarios are shown in

Table 7.6. The scenarios explored paralleled those in the original TMDL. Scenarios 7 and 8 show reductions that are adequate for reaching the TMDL endpoint. The scenarios focus first on residential (straight pipe and failing septic systems), pre-law mine discharge, and AML sources. Scenarios 2 and 3 explore the impact of reductions to permitted surface mine discharges. The remaining scenarios examine reductions to “non-background groundwater.” This latter source includes persistent loads to the stream that are not dependent on active rainfall events (*e.g.*, unaccounted-for drainage from abandoned underground mine workings, and slow drainage from fill areas). Scenario 8 is recommended as a starting point during implementation.

Table 7.6. Bull Creek TDS TMDL Re-Allocation.

Scenario	Reductions by Source (%)							Max Ave Daily TDS (mg/L)	Number of Days > 369 mg/L	TDS Load (kg/yr)
	Mine Pond Discharge	AML	Pre-Law Mine Discharge	Road Salt	Residential (Direct)[1]	Non-Background Groundwater[2]	Background[3]			
0	0	0	0	0	0	0	0	842	2,114	8,408,547
1	0	100	100	0	100	0	0	499	93	3,559,583
2	20	100	100	0	100	0	0	499	93	3,550,600
3	80	100	100	0	100	0	0	499	93	3,523,654
4	20	100	100	0	100	29	0	400	22	2,964,178
5	20	100	100	0	100	36	0	375	8	2,817,572
6	20	100	100	0	100	37	0	370	2	2,788,251
7	20	100	100	0	100	39	0	365	0	2,758,930
8	0	100	100	0	100	39	0	365	0	2,767,913

[1]Includes straight pipes and failing septic systems.
[2]Includes persistent loads to the stream, such as, unaccounted-for drainage from abandoned underground mine workings, slow drainage from fill areas, and any load contributed through groundwater that results from human activity.
[3]Includes loads from undisturbed forest, and naturally occurring groundwater loads.

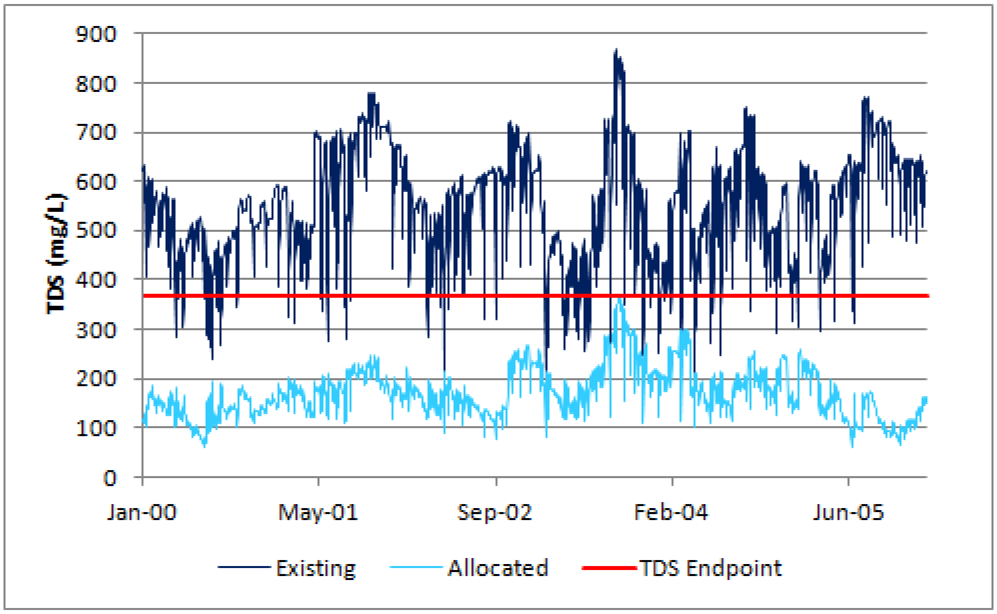

Figure 7.1. Existing and Allocated TDS time-series concentrations in Bull Creek

7.2.4. Bull Creek Phase II TDS TMDL

The phase II TDS TMDL is the load corresponding to Scenario 9 (Table 7.6). The TDS TMDL for Bull Creek was calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where ∑WLA = sum of the waste load (permitted) allocations;

∑LA = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

The LA component load was calculated as the TDS load from road salts, from pre-law direct mine discharges, and from background sources in interflow. The MOS used in this TMDL was implicit, based on the use of the conservative 90th percentile of observed TDS concentrations in the reference watershed for setting the TMDL TDS concentration endpoint. In Lower Dismal Creek, the 90th percentile values were actually 15.5% lower than the maximum observed values. The WLA was calculated as the combined allocations for all permitted surface mine dischargers. The allocations were adjusted to represent only TDS loads that enter the stream through permitted ponds. Individual WLAs for each mining permit were based on the sum of mining runoff and mining interflow transported through the permitted ponds. The TMDL and its component loads are shown in Table 7.7, based on Allocation Scenario 9.

Table 7.7. Bull Creek Phase II TDS TMDL (kg/yr)

WLA			LA[1]	MOS	TMDL
44,902			2,723,011	Implicit	2,767,913
Mining Permit Numbers	**NPDES MPIDs**	**Permit WLAs**			
1101701	0003437, 0003438, 0003440, 0003441, 0003442	3,878			
1101736	0003572, 0003573, 0003574, 0003575, 0004887, 0005632	9,833			
1101903	0006747, 0006748, 0006749, 0006750, 0006751, 0006752	221			
1101979	0006435, 0006436, 0006437, 0006438, 0006439, 0006440, 0006441, 0006442, 0006443, 0006444, 0006445, 0006446, 0006447, 0006448, 0006449, 0006450, 0006451, 0006452	5,179			
1200129	none	69			
1200281	5683359	494			
1200343	5640069, 5653489	435			
1201678	5684527	213			
1201922	0003439, 0004312, 0006086, 0006087, 0006397	972			
1201940	0005964, 0005965	459			
1601788	0004449, 0004450, 0004451, 0004452, 0004453, 0004454, 0004455, 0004456, 0004457, 0004458, 0004459, 0004460	22,811			
1200589	none	338			

[1] LA includes loads from road salt, Pre-law direct mine dischargers, and background interflow contributions.

As noted earlier in this document, the USEPA has mandated that TMDL studies include a daily maximum load in addition to the average annual load. The approach to developing a daily maximum load for TDS is similar to the approach used for sediment. The coefficient of variation was estimated (*i.e.*, the CV was set to 0.6) due to a lack of data. This resulted in a multiplier of 4.0. The results are shown in **Table 7.8**.

Table 7.8 Maximum daily TDS TMDL for Bull Creek.

WLA			LA[1]	MOS	TMDL
123			30,210	Implicit	30,333
Mining Permit Numbers	**NPDES MPIDs**	**Permit WLAs**			
1101701	0003437, 0003438, 0003440, 0003441, 0003442	10.6			
1101736	0003572, 0003573, 0003574, 0003575, 0004887, 0005632	26.9			
1101903	0006747, 0006748, 0006749, 0006750, 0006751, 0006752	0.6			
1101979	0006435, 0006436, 0006437, 0006438, 0006439, 0006440, 0006441, 0006442, 0006443, 0006444, 0006445, 0006446, 0006447, 0006448, 0006449, 0006450, 0006451, 0006452	14.2			
1200129	none	0.2			
1200281	5683359	1.4			
1200343	5640069, 5653489	1.2			
1201678	5684527	0.6			
1201922	0003439, 0004312, 0006086, 0006087, 0006397	2.7			
1201940	0005964, 0005965	1.3			
1601788	0004449, 0004450, 0004451, 0004452, 0004453, 0004454, 0004455, 0004456, 0004457, 0004458, 0004459, 0004460	62.4			
1200589	none	0.9			

[1] LA includes loads from Road Salt and Background Interflow contributions.

In this watershed, after source characterization and modeling were completed, AML areas, pre-law mine discharges, and active mining sources were assessed as the primary contributors of TDS. AML reclamation and improved source reduction and site management of active mining areas are recommended as the primary targets of implementation efforts.

CHAPTER 8: PHASED TMDLS

8.1. Guidance on Phased TMDLs

Current EPA guidance recommends that the phased TMDL approach be used in situations "where limited existing data are used to develop a TMDL and the State believes that the use of additional data or data based on better analytical techniques would likely increase the accuracy of the TMDL load calculation and merit development of a second phase TMDL" (USEPA, 2006c). All phased TMDLs must include all elements of a regular TMDL, including load allocations, wasteload allocations and a margin of safety. Each phase must be established to attain and maintain the applicable water quality standard. In addition, EPA recommends that a phased TMDL document include a monitoring plan and a scheduled timeframe for revision of the TMDL in a second phase (EPA, 2006). Because of the uncertainties in representing mining sources in preliminary modeling and the subsequent load allocations, phased TMDLs are being developed for both sediment and TDS in Bull Creek.

8.2. State TMDL Regulatory Agencies

The Virginia Department of Mines, Minerals and Energy (DMME) is the delegated agency to administer the VPDES permit program for regulating stormwater runoff from mining sites.

The Virginia Department of Conservation and Recreation (DCR) is the delegated agency to administer the VPDES permit program for regulating stormwater runoff from urban areas.

The Virginia Department of Environmental Quality (DEQ) is authorized by the Code of Virginia to develop TMDLs and plans to implement TMDLs in accordance with the provisions of the Clean Water Act and EPA's enabling regulation 40 CFR § 130.7.

Also, EPA's 40 CFR § 122.44 (d)(1)(vii)(B) states that VPDES permits must be consistent with new or revised TMDL WLAs.

8.3. Rationale for the Use of a Phased Sediment TMDL for Bull Creek

Modeling of the Bull Creek watershed produced monthly flow volumes and total suspended sediment (TSS) loads, with major contributions from abandoned mine land (AML) and barren land uses. This modeling relied on land use-based parameters that governed surface runoff and erodibility, with limited data available in the literature to evaluate and differentiate between AML and extractive (active mining) areas, two of the major sediment sources. Furthermore, the trapping efficiencies of sediment ponds are highly variable, and sufficient data were not available in Bull Creek to evaluate site specific values, leading to the use of debatable values obtained through calibration. In addition, the limited TSS data available at the calibration station in Bull Creek, with a limited range of rainfall-runoff response, made it difficult to judge the reasonableness of modeled load estimates and of relative loads from various mining sources.

EPA's 40 CFR § 434 contains TSS criteria for storms with provisions for alternate measurements during certain conditions. In a DMLR 1994 Memorandum to Operators, the "settleable solids" parameter was allowed as an alternative to TSS on days with a rainfall total of greater that 0.2 inches/day.

Between the 0.2 in/day storm and the 10-yr 24-hr design storm, settleable solids may be analyzed instead of TSS for mining permit compliance purposes. Since sediment is more likely to be contributed from nonpoint sources during larger rainfall events, this has resulted in fewer TSS measurements from permitted sources against which to evaluate the reasonableness of modeled TSS loads due to surface runoff.

Large TSS loads from AML areas were modeled in the TMDL and represent the largest single source of TSS in the Bull Creek watershed. There is a general consensus by the state agencies that an effective way to reduce the majority of excessive TSS loads is through incentives for re-mining and reclaiming these AML areas. As the first phase of the Bull Creek TMDL is proposed to last two years, this phased TMDL provides a 2-year window to encourage mine operators to re-mine or reclaim AML and to demonstrate the potential of re-mining, by itself, to make the sediment reductions called for in this TMDL and to restore the aquatic health of Bull Creek.

Bull Creek is also under the Consent Decree schedule for the Commonwealth of Virginia and its TMDLs must be completed by May 2010.

8.4. Rationale for the Use of a Phased TDS TMDL for Bull Creek

Although calibration to in-stream observed TDS concentrations instills confidence in the overall TDS loading in the watershed, the load distribution between permitted mining sources and AML, and between surface, interflow, and groundwater flow paths from each of these sources is highly uncertain. Additional monitoring is needed to determine the most equitable distribution of the required TDS load reductions between pre-existing and currently permitted mining sources.

8.5. Components of the Bull Creek Phased Sediment TMDL

The Bull Creek Phased TMDL for sediment will be developed in accordance with EPA's 2006 Guidance on Phased TMDL and will include the following components:

1. The TSS load from permitted mining areas will be calculated from the maximum daily TSS permit criterion of 70 mg/L and the simulated average annual surface runoff volume from extractive land uses for all storms, and will comprise the permitted mining component of the WLA.
2. Consistent with current permit conditions, no additional reductions will be required from permitted mining sites below a maximum daily TSS concentration of 70 mg/L, pending further data collection and analysis during the next phase.
3. To address the TSS data deficiency for storm events, monitoring during the 2-yr phased TMDL period will include the full range of storm events occurring below the 10-yr, 24-hr design storm. This will improve the assessment of sediment loads from active mining areas.

DMME's March 30, 2009 Memorandum will assist the phased TMDL monitoring effort, by requiring additional TSS sampling for all National Pollutant Discharge Elimination System (NPDES) discharges in TMDL watersheds where TSS is a stressor and in impaired watersheds where resource extraction is listed as causing the impairment. It is important that TSS monitoring be performed during all storm events, because TSS loads are currently not tracked when alternate effluent limits are utilized. The use of the alternate "settleable solids" compliance criterion will be allowed during the 2-year phased period, even though monitoring will also be required to characterize flow and TSS concentrations occurring during these events.

8.6. Components of the Bull Creek Phased TDS TMDL

The Bull Creek Phased TMDL for TDS will be developed in accordance with EPA's 2006 Guidance on Phased TMDL and will include the following components:

1. For the phased TDS TMDL, TDS loads will be calculated for each mining permit based on simulated loads with all TDS sources turned off except those related to permitted mining. The TDS loads from each sub-watershed will then be apportioned on an area-basis to all permits within each sub-watershed. TDS loads attributed to each permit will be summed from all sub-watersheds that included part of each permit's area.
2. Expanded DMLR requirements, as noted in a March 30, 2009 Memorandum to coal mining permittees, will include TDS monitoring at all outfalls in watersheds where an Aquatic Life Use impairment has been identified, in addition to those where TDS has already been identified as a stressor.
3. Although difficult to quantify, additional monitoring is needed to more accurately distinguish between levels of TDS attributable to permitted mining and AML from surface runoff, interflow and groundwater, as well as relative contributions between surface and deep mining.

4. DMLR's joint SMCRA/NPDES permits are made consistent with approved coalfield TMDLs. Since 2005, DMLR has utilized electronic permitting processes and specially designed TMDL software to insure consistency. During the two year phased TMDL revision period, DMLR will implement the same process that the agency has used in other TMDL watersheds – except that, because the phased process will examine wasteload allocations (WLA) in the TMDLs, the WLA values included in the "phased" documents will not be used. Instead, the allocations used by DMLR will be generated from existing monitoring data for regulatory purposes and be directly generated by the software.
5. DEQ will not adopt a phased TMDL WLA into the WQMP regulation. This will occur in 2 years after the phased TMDLs are converted to conventional TMDLs.

CHAPTER 9: TMDL IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairment on Bull Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by USEPA and then the State Water Control Board (SWCB), measures must be taken to reduce pollutant levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

DCR and DEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable implementation plan that will result in meeting the water quality target. Stream delisting of Bull Creek will be based on biological health and not on numerical pollution loads. Since this TMDL consists of NPS load allocations originating from abandoned mine lands and wasteloads originating from permitted active mines, DMME will share responsibilities with DCR during implementation.

9.1. Staged Implementation

Implementation of BMPs in these watersheds will occur in stages. The benefit of staged implementation is that it provides a mechanism for developing public support and for evaluating the efficacy of the TMDL in achieving the water quality standard.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Among the sediment and TDS sources identified in the Bull Creek watershed, the following BMPs should be useful in effecting the necessary reductions. AML areas could be addressed through remining, offsets, and through stabilization of critical areas; barren areas through establishment of vegetative cover; residential/urban areas and channel erosion through a combination of streambank stabilization measures and establishment of riparian buffers.

The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. Specific goals for BMP implementation will be established as part of the implementation plan development.

It is recommended that reclamation of AML be one of the initial targets for both sediment and TDS reductions during implementation. Additionally, it is recommended that straight pipes and failing septic systems also be addressed during the initial stages of implementation. It is anticipated that waste load allocations and pollutant load reductions of sediment and TDS to address benthic impairments will be achieved in watersheds with active mining through properly installed and maintained sediment control measures and BMPs (the BMP Approach) instead of altered effluent limitations.

9.2. Link to ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts in Bull Creek.

One such effort in the Bull Creek watershed is a project under the Southern River Wastewater Enhancement Program (SRWEP), funded through a state Water Quality Improvement Grant. Under the SRWEP program, Buchanan County will receive $550,000 for a sewer line extension in the Convict Hollow sub-watershed in Bull Creek. The county will provide public wastewater service to 25 households that are currently using individual septic systems, many of which are failing to meet local permit requirements. Recent testing indicates that 57% of the local water supplies in the area are contaminated with coliform and are also positive for fecal coliform. As a result of this project, 6,500 linear feet of eight-inch sewer line, 1,250 linear feet of 4-inch sewer line, and 2,500 linear feet of 4-inch sewer line will be installed. The grant award was announced by Governor Kaine in May 2008.

9.3. Reasonable Assurance for Implementation

9.3.1. TMDL Compliance Monitoring

DEQ will continue monitoring benthic macroinvertebrates and habitat at station 6ABLC002.30 in accordance with its biological monitoring program and TDS and TSS at station 6ABLC000.85 in accordance with its ambient monitoring program. DEQ will continue to use data from these monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

DMLR requires all NPDES discharge permittees to monitor total dissolved solids (TDS) in TMDL watersheds where aquatic life use impairments have been identified. Additionally, in a March 30, 2009 Memorandum to all coal mining permittees, DMLR is now requiring permittees to analyze for TSS during qualifying precipitation events, where previously only an alternative parameter – settleable solids – was required. Therefore, TSS data will be available for the full range of precipitation events up through the 10-yr, 24-hr design storm. BMPs specified in NPDES permits are currently required to control runoff from a 10-yr, 24-hr precipitation event (Title 40 §434, Electronic Code of Federal Regulations). The enhanced TMDL stressor monitoring will be in accordance with DMLR's monitoring guidance DMME, 2008.

Since TMDLs are expressed in terms of annual loads, discharge flow rates should be measured concurrently with water quality sampling, and recorded together with daily precipitation data monitored by DMLR-approved sources. When monitoring indicates that the TMDL TDS WLAs are being exceeded DMLR will implement the agency's Waste Load Reduction Actions.

9.3.2. Regulatory Framework

Federal Regulations

While section 303(d) of the Clean Water Act and current USEPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Federal regulations also require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to USEPA for review.

State Regulations

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section

62.1-44.19.7). WQMIRA 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. USEPA 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.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process and implementation plan development, especially those implemented through water quality based effluent limitations. However, those requirements that are considered best management practices (BMPs) may be enhanced by inclusion in the TMDL IP, and their connection to the targeted impairment. New permitted point source discharges will be allowed under the waste load allocation provided they implement applicable VPDES and Virginia's Coal Surface Mining Reclamation Regulations (CSMRR) requirements (including any BMP, offset, trading or payment-in-lieu conditions established to meet any future reduction requirements).

Stormwater Permits

The impaired portions of Bull Creek watershed being addressed in this TMDL primarily contain land uses of active mining, abandoned mine lands, forest, and reclaimed lands. USEPA delegated the authority for stormwater management of historic and active mining lands to DEQ through Virginia's NPDES permit program. This program is currently administered through DMME (§45.1-254 of the Code of Virginia). DMME monitoring data and modeling have shown the major sediment loading source in this watershed to be stormwater runoff from AML and barren land uses.

Existing Active Mine Drainage Controls

In November 2005, DMME's Division of Mined Land Reclamation (DMLR) issued Guidance Memorandum No. 14-05 to address the implementation of coal mining-related TMDL wasteload allocations. The memorandum can be accessed at http://www.dmme.virginia.gov/DMLR/docs/operatormemos.shtml. As of December 1, 2005 the Division of Mined Land Reclamation (Division) has been implementing the steps outlined in the memorandum regarding permit applications in watersheds with adopted benthic Total Maximum Daily Loads (TMDLs), as described below.

Active mining operations are required to use sediment control measures and BMPs to prevent additional contributions of solids to streams and to minimize erosion to the extent possible by Virginia's Coal Surface Mining Reclamation Regulations (CSMRR; 4 VAC 25-130). The measures include practices carried out within and adjacent to the disturbed mining area and consist of the utilization of proper mining and reclamation methods and control practices, singly or in combination. These methods and practices include, but are not limited to:

1. Disturbing the smallest area at any one time during the mining operation through progressive backfilling, grading, and prompt revegetation;
2. Stabilizing the backfill material to promote a reduction in the rate and volume of runoff;
3. Diverting runoff away from disturbed areas;
4. Directing water and runoff with protected channels;
5. Using straw, mulches, vegetative filters, and other measures to reduce overland flow;
6. Reclaiming all lands disturbed by mining as contemporaneously as practicable.

Additional Active Mine Drainage TMDL Controls

In addition to the use of sediment control measures and BMPs within the disturbed area, CSMRR require coal mining haulroads to be designed and constructed to ensure environmental protection appropriate for their intended use. In a watershed where pollution load reductions for solids are necessary for active mining operations to meet an approved TMDL, haulroad design, construction, and maintenance shall be performed in consideration of the TMDL. This may include, but not be limited to:

1. Using non-toxic-forming substances in road surfacing;
2. Paving haulroads;
3. Increasing the detention capacity of haulroad sumps;
4. Increasing the frequency of inspection and maintenance of haulroad sumps.

Reduction in the sedimentation and mineralization of runoff attendant to mined land erosion and strata exposure may also be achieved with sediment control measures and BMPs. Operation and reclamation plans mandated by CSMRR can be designed and developed to incorporate a BMP approach for meeting waste load allocations and pollutant load reductions included in a TMDL for stream segments and watersheds where sediment and TDS have been identified as the benthic stressors, as outlined by the November 23, 2005 DMME guidance (DMME, 2005).

Significant sediment and TDS loads in the Bull Creek watershed arise from AML, and one of the most important existing incentives for addressing this source is the alternative effluent limitations regulations [Section 301(p) in the 1987 Clean Water Act Amendments], also known as the Rahall Amendment. These regulations provide an incentive to mine operators to gradually improve the water quality from these problem areas until reclamation is completed, at which time water quality standards should be met.

Generally, a BMP approach will be used in Virginia to meet WLAs in lieu of alternate effluent limitations for permitted coal mine point source discharges. DMME will track assigned and available WLAs. Prior to approval of new NPDES points within a TMDL watershed, the DMME Division of Water Quality staff will conduct a waste load evaluation to determine whether a WLA is available.

1. Redundant, additional, and/or over-engineered BMPs or practices within permitted mining acreages to better control stormwater transport of pollutants should be implemented.
    a. Enhancement or increasing stream bank buffers in permit acreage or along haul roads should be included;
    b. Streambank stabilization, where possible, in permit acreage or downstream affected areas.
2. Effective windrows (such as those required by Division of Gas and Oil, Department of Mines Minerals and Energy) should be installed below drainage paths of existing haul roads.
3. Prompt reclamation or restoration of disturbed lands should be implemented to reduce the generation and transport of sediment and TDS from the disturbed areas.

9.3.3. Implementation Funding Sources

Implementation funding sources will be determined during the implementation planning process by the local watershed stakeholder planning group with assistance from DEQ, DCR, and DMME. Potential sources of funding include Section 319 funding for Virginia's Nonpoint Source Management Program, the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, the Virginia Water Quality Improvement Fund, and the Abandoned Mine Lands program, although other sources are also available for specific projects and regions of the state. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

9.3.4. Reasonable Assurance Summary

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and DEQ, DEQ also submitted a draft Continuous Planning Process to USEPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Taken together, the follow-up monitoring, WQMIRA, the DMME guidance, the Rahall Amendment, public participation, the Continuing Planning Process, a focus on the legacy of impacts associated with historical coal mining in the Bull Creek Watershed through the state's AML Program, and the promotion of remining comprise a reasonable assurance that the Bull Creek TMDLs will be implemented and water quality will be restored.

CHAPTER 10: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made.

The first Technical Advisory Committee meeting was held on October 4, 2007 at the Harman Memorial Baptist Church on Route 609 in Maxie, Virginia, to gather information on and to verify existing data for the Bull Creek watershed. The meeting was preceded by a tour of the watershed led by Heather McDonald-Taylor, an area inspector with the DMME-DMLR. Copies of the presentation materials were available for public distribution at the meeting and on a web site The TAC meeting was attended by 8 people.

The first public meeting was held later that same day at the Harman Memorial Baptist Church to gather further information about the Bull Creek watershed. Copies of the presentation materials were available for public distribution at the meeting and on a web site forum, The public meeting was attended by 10 people.

The benthic stressor analysis report for Bull Creek was circulated to all members attending both the TAC and public meetings on February 7, 2008. One comment was received in response, and responses to these comments have been included in the final TMDL report.

A public meeting which presented the draft sediment and TDS TMDLs report on Bull Creek for the benthic impairment was held on March 20, 2008, also at the Harman Memorial Baptist Church in Maxie, Virginia. This public meeting was attended by 12 stakeholders. The public comment period ended on April 20, 2008.

Due to revisions to the draft TMDLs, another public meeting was held on September 23, 2008 to present the revised draft sediment and TDS TMDLs. This meeting was also held at the Harman Memorial Baptist Church in Maxie, Virginia.

This public meeting was attended by 8 stakeholders. The public comment period ended on October 22, 2008.

Uncertainties related to the modeling and source differentiation led to the development of phased TMDLs which were presented at a public meeting January 14, 2010 at Riverview Elementary and Middle School in Grundy, Virginia. This meeting will be held in conjunction with a TMDL public meeting for a downstream impairment on Levisa Fork. The public meeting was attended by 34 stakeholders. The public comment period ended on February 15, 2010.

Amended pollutant loads and wasteload allocations for the Bull Creek and Tributaries TMDL were presented at a public meeting on March 8, 2011 at the Virginia Department of Mines, Minerals, and Energy Office in Big Stone Gap, Virginia. The public meeting was attended by 11 stakeholders. The public comment period was open from February 28, 2011 to March 30, 2011.

To complete the development of phased TMDLs additional monitoring was needed. The monitoring plan for the phased TMDLs was presented at a public meeting on July 26, 2011 at the Virginia Department of Environmental Quality's Southwest Regional office in Abingdon, Virginia. The public meeting was attended by 22 participants. The public comments period closed on August 26, 2011. A second public meeting on the TMDL revision process was held on April 25, 2013 at the Virginia Department of Environmental Quality's Southwest Regional Office in Abingdon, Virginia. The public meeting was attended by 10 participants. The public comment period closed on May 25, 2013. The final public meeting to present the Phase II TMDL revisions was held on October 24, 2013 at the Norton Community Center in Norton, Virginia. The public meeting was attended by 14 participants. The public comment period closed on November 25, 2013.

A public meeting to present the combined Phase I and Phase II TMDL report was held on August 11, 2015 at the Riverview Elementary/Middle School in Grundy, Virginia. The public meeting was attended by XX participants. The public comment period closed on September 11, 2015.

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Appendix A: Glossary of Terms

Provided by Virginia Tech Department of Biological Systems Engineering

Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost- effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Calibration
The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Direct nonpoint sources
Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

E-911 digital data
Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

Hydrology
The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Load allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model

Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Simulation

The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Total Maximum Daily Load (TMDL)

The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff

Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Wasteload allocation (WLA)
The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard
Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed
A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

Appendix B: Weather Data Preparation

Weather Data Preparation

Introduction

A weather data file for providing the weather data inputs into the HSPF Model was created for the period July 1989 through October 2006 using the Watershed Data Management Utility (WDMUtil). Raw data required for creating the weather data file included daily precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi/hr), total daily solar radiation (Langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station 443640 in Grundy, Virginia, which was located 4 miles (6.4 km) east of the watershed. Data from other NCDC stations were also including Richlands for average daily temperature. The raw data required varying amounts of preprocessing within WDMUtil to obtain the following hourly values: precipitation (PREC) (in), air temperature (ATEM) (°F), dew point temperature (DEWP) (°F), solar radiation (SOLR) (Langleys), wind speed (WIND) (mi/hr), potential evapotranspiration (PEVT) (in), potential evaporation (EVAP) (in), and cloud cover (CLOU) (tenths, range 0-10). The final WDM file contains these hourly datasets.

Raw data collection and processing

Weather data were obtained from the NCDC's weather stations in Grundy, Virginia (443640, Lat.Long. 37°17'N / 82°05'W, elev 1170 ft); Breaks Interstate Park (440982, 37°17'N / 82°18'W, elev 1893 feet) ;John Flannagan Lake (444410 lat.long 37°14'N / 82°21'W elev 1460 ft);Richlands, VA (447174, Lat./Long. 37°06'N / 81°48'W, elevation 1910 ft); Lebanon, VA (444777 Lat./Long. 36°54'N / 82°02'W, elevation 1912 ft); Bristol Tri City Airport, TN (401094 Lat./Long. 36°28'N / 82°24'W, elevation 1500 ft); and Lynchburg Airport, VA (445120, Lat./Long. 37°20'N/79°12'W, elevation 286.5 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. Data collection for many of the parameters did not being until 1989, which set the starting point of the period of record. Percent sun (PSUN) data were available from Lynchburg Airport and then only through July 1996. The majority of the water quality data were collected from 2001 through 2003. In order to make the best use of the available water quality data, the period of record was chosen to be July 1989-October 2006. There are 6,332 days within this period. Substitutions for missing data are described below. The procedures used to process the raw data to obtain finished data required for input to HSPF are also described in the following sections.

1. <u>Hourly Precipitation</u>
   Daily precipitation (PRCP) data were downloaded from NCDC's web site for Grundy, VA for the July 1989-October 2006 period. Of the 6,332 possible daily values in this period, 49 values were missing. The closest station that records daily precipitation data overlapping the July 1999-October 2006 period was Breaks Interstate Park. Missing values from Grundy data were filled in with the daily precipitation (PRCP) from Breaks Interstate Park and or John Flannagan Lake prior to 1999. The resulting

file was imported into WDMUtil, disaggregated to hourly precipitation using WDMUtil's disaggregation routine and given the constituent label "PREC."

2. Temperature
Separate daily maximum temperature (TMAX) and daily minimum temperature (TMIN) files were downloaded from the NCDC website for Richlands. The TMAX dataset was missing 107 days of data; the TMIN dataset was missing 155 days of data. Data from the Lebanon station were used to fill in the missing days. Daily dew point temperature (DPTP) was taken as the daily minimum temperature. These data had units of tenths of degrees Fahrenheit. The *disaggregate temperature* function in WDMUtil was used to create an hourly average temperature file (ATEM). The *disaggregate dewpoint temperature* function in WDMUtil was used to create an hourly dewpoint temperature file (DEWP).

3. Average Daily Wind Speed
Average daily wind speed (AWND) was not recorded at the Richlands station; therefore, average daily wind speed was obtained from the Bristol Tri City Airport. The units of the data were tenths of miles per hour; therefore, the timseries was divided by a factor of 10 prior to use in the WDM file. The *compute wind travel* function in WDMUtil was used to calculate the total wind travel in miles/day. Then the *disaggregate wind travel* function in WDMUtil was used to calculate the hourly wind speed throughout the day (WIND) using the distribution coefficients shown in Table 1.

Table B.10.1. Hourly Distribution Coefficients for Wind Speed.

Hour	12	1	2	3	4	5	6	7	8	9	10	11
AM	0.035	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.035	0.037	0.041	0.046
PM	0.05	0.053	0.054	0.058	0.057	0.056	0.05	0.043	0.04	0.038	0.036	0.036

4. Cloud cover and solar radiation
In the absence of daily cloud cover, percent sun (PSUN) can be used to estimate DCLO. DCLO is used by WDMUtil to estimate hourly cloud cover in tenths (CLOU) as well as solar radiation (SOLR) in Langleys. The closest weather station that recorded PSUN was Lynchburg Airport, and these data was used to develop the weather file. As previously mentioned, PSUN was only available at this station for the period January 1984-July 1996. It is the experience of the authors that the model is rather insensitive to the parameters derived from PSUN; therefore, to bridge the gap of missing data, values from August 1996-December 2006 were filled in by copying the values from August 1986-December 1996.

   The *compute percent cloud cover* function in WDMUtil was used to calculate the daily percent cloud cover in tenths (DCLO) from PSUN. Because there is not a *disaggregate percent cloud cover* function available, the *disaggregate wind travel* function was used with hourly distribution coefficients all set to 1 to calculate the hourly percent cloud cover in tenths (CLOU).

The *compute solar radiation* function in WDMUtil was used to calculate the daily solar radiation in Langleys (DSOL) from DCLO and the Richlands station latitude (37°06'N). The *disaggregate solar radiation* function was then used to calculate the hourly solar radiation (SOLR).

5. Evaporation/Evapotranspiration
   Two types of evaporation/evapotranspiration are required for input to HSPF: potential evaporation from a reach or reservoir surface (EVAP), represented as Penman pan evaporation; and potential evapotranspiration (PEVT), represented as Hamon potential evapotranspiration.

   The *compute Penman pan evaporation* function in WDMUtil was used to calculate daily Penman pan evaporation (DEVP) from TMIN, TMAX, DPTP, TWND, and DSOL. Then the *disaggregate evapotranspiration* function was used to calculate EVAP from DEVP.

   The *compute Hamon PET* function in WDMUtil was used to calculate daily potential evapotranspiration (DEVT) from TMIN, TMAX, the Richlands station latitude (37°06'N), and monthly coefficients all equal to 0.005. Then the *disaggregate evapotranspiration* function was used to calculate PEVT from DEVT.

Summary of weather data preparation
The weather data were prepared for input to HSPF as described in the previous section. A summary of the NCDC input parameters, WDMUtil functions used, and final HSPF parameters is presented in Table B.10.2.

Table B.10.2. Weather parameters and processing in WDMUtil required for HSPF modeling.

NCDC Input Parameters	Intermediate Input	WDMUtil Functions	Intermediate Output	Final HSPF Parameter
PRCP	--	Disaggregate precipitation	--	PREC
TMAX, TMIN	--	Disaggregate temperature	--	ATEM
DPTP	--	Disaggregate dewpoint temperature	--	DEWP
PSUN	--	Compute percent cloud cover	DCLO	--
	DCLO	Disaggregate wind travel[1]	--	CLOU
	DCLO	Compute solar radiation	DSOL	--
	DSOL	Disaggregate solar radiation	--	SOLR
AWND	--	Compute wind travel	TWND	--
	TWND	Disaggregate wind travel	--	WIND
TMAX, TMIN, DPTP	TWND, DSOL	Compute Penman pan evaporation	DEVP	--
	DEVP	Disaggregate evapotranspiration	--	EVAP
TMAX, TMIN	--	Compute Hamon PET	DEVT	--
	DEVT	Disaggregate evapotranspiration	--	PEVT

[1]all hourly coefficients set to 1

Appendix C: HSPF Parameters that Vary by Month or Land Use

Table C.1. PWAT-PARM2 parameters varying by land use for Bull Creek.

	LZSN (in)	INFILT (in/hr)	LSUR (ft)	SLSUR (ft/ft)	KVARY (1/in)	AGWRC (1/day)
Low Intensity Res.	4	0.186	100	0.376	0	0.965
Med. Intensity Res.	4	0.186	200	0.163	0	0.965
High Intensity Res.	4	0.186	100	0.328	0	0.965
Extractive	4	0.186	50	0.408	0	0.965
Barren	4	0.186	100	0.445	0	0.965
Pasture/Hay	4	0.252	150	0.415	0	0.965
Croplands	4	0.286	200	0.206	0	0.965
Forest	4	0.284	30	0.496	0	0.99
AML	4	0.186	30	0.487	0	0.965
Reclaimed	4	0.186	30	0.540	0	0.965
Released	4	0.186	30	0.476	0	0.965

Table C.2. PWAT-PARM4 parameters varying by land use for Bull Creek.

	CEPSC (in)	UZSN (in)	NSUR	INTFW	IRC (1/day)	LZETP
Low Intensity Res.	0.13	0.8	0.1	1.5	0.5	0.7
Med Intensity Res.	0.25	0.8	0.07	1.5	0.5	0.6
High Intensity Res.	0.05	0.8	0.05	1.5	0.5	0.5
Extractive	0.05	0.8	0.011	1.5	0.5	0.4
Barren	0.05	0.8	0.05	1.5	0.5	0.4
Pasture/Hay	0.13	0.8	0.37	1.5	0.5	0.7
Croplands	0.25	0.8	0.27	1.5	0.5	0.6
Forest	0.05	0.8	0.6	1.5	0.5	0.5
AML	0.05	0.8	0.011	1.5	0.5	0.4
Reclaimed	0.05	0.8	0.011	1.5	0.5	0.4
Released	0.05	0.8	0.011	1.5	0.5	0.4

Table C.3. PWAT-STATE1 parameters varying by land use for Bull Creek.

	UZS	IFWS	LZS	AGWS
Low Intensity Res.	0.499	0	5.714	0.358
Med Intensity Res.	0.505	0	5.245	0.406
High Intensity Res.	0.472	0	5.488	0.411
Extractive	0.674	0.001	5.917	0.362
Barren	0.683	0.003	6.786	0.444
Pasture/Hay	0.499	0	5.714	0.358
Croplands	0.505	0	5.245	0.406
Forest	0.472	0	5.488	0.411
AML	0.656	0.001	6.159	0.388
Reclaimed	0.674	0.001	5.917	0.362
Released	0.683	0.003	6.786	0.444

Table C.4. MON-INTERCEP (monthly CEPSC) - Monthly Interception Storage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
L/M/H Residential	0.09	0.09	0.09	0.09	0.09	0.11	0.11	0.11	0.09	0.09	0.09	0.09
Extractive	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Barren	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Pasture	0.08	0.09	0.13	0.16	0.18	0.2	0.2	0.2	0.19	0.14	0.1	0.08
Crop	0.06	0.07	0.1	0.18	0.21	0.26	0.26	0.23	0.2	0.18	0.08	0.06
Forest	0.1	0.1	0.13	0.16	0.2	0.32	0.32	0.32	0.2	0.14	0.12	0.1
AML	0.09	0.09	0.09	0.09	0.09	0.11	0.11	0.11	0.09	0.09	0.09	0.09

Table C.5. MON-LZETP - Monthly Lower Zone Evapotranspiration Parameter.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
LDR	0.25	0.25	0.3	0.3	0.35	0.35	0.35	0.3	0.3	0.3	0.25	0.25
MDR	0.25	0.25	0.28	0.28	0.33	0.33	0.33	0.3	0.28	0.28	0.25	0.25
HDR	0.25	0.25	0.27	0.27	0.3	0.3	0.3	0.3	0.27	0.27	0.25	0.25
Extractive	0.1	0.1	0.1	0.1	0.15	0.15	0.2	0.2	0.2	0.15	0.1	0.1
Barren	0.1	0.1	0.1	0.1	0.15	0.15	0.2	0.2	0.2	0.15	0.1	0.1
Pasture	0.25	0.35	0.45	0.5	0.55	0.75	0.75	0.65	0.6	0.5	0.4	0.25
Croplands	0.25	0.35	0.45	0.5	0.55	0.75	0.75	0.65	0.6	0.5	0.4	0.25
Forest	0.35	0.35	0.45	0.5	0.55	0.75	0.75	0.65	0.6	0.5	0.45	0.35
AML	0.25	0.25	0.27	0.27	0.3	0.3	0.3	0.3	0.27	0.27	0.25	0.25

Table C.6. QUAL-INPUT -TDS input parameters for Bull Creek.

	ACQOP lb/ac.day	SQOLIM lb/ac	WSQOP in/hr	AOQC lb/ft3
Low Intensity Res.				0.01436
Med Intensity Res.				0.01436
High Intensity Res.				0.01436
Extractive	200	400	2.00	0.04683
Barren				0.01436
Pasture/Hay				0.01436
Croplands				0.01436
Forest				0.01436
AML	200	400	2.30	0.04683
Reclaimed	200	400	2.30	0.02342
Released				0.01436

Appendix D: Existing Mining Permits Distributed by Sub-watershed

Table D.1. DMLR Current Joint Mining and Discharge Permits in the Bull Creek Watershed.

	Permit Number	Previous Permit Number(s)
The Black Diamond Company	1101701	None
Hokie Mining Company	1201678	1201090, 1200859, 1200170, 357202X
The Black Diamond Company	1601788	None
Clintwood Elkhorn Mining Company	1201940	None
Clintwood Elkhorn Mining Company	1201922	1201793
Norton Coal Company, LLC	1102030	None

Appendix E: Representation of TSS Loads in Coalfield TMDLs

Phased TMDL Project
Representation of TSS Loads in Coalfield TMDLs

1. BACKGROUND

During development of aquatic life (benthic) TMDLs for Bull Creek, Levisa Fork, Pound River, and Powell River, questions arose regarding the representation of Total Suspended Solids (TSS) loads from permitted mining areas. Due to these questions, as well as other uncertainties and differences of interpretation regarding report narrative, report format, data, and predictive tools, the reports were presented as "phased" TMDLs in accordance with EPA guidance. The TMDL was developed with best available data and information to determine pollution load reductions. Additional monitoring was conducted to aid in resolving the uncertainties in pollutant sources. This report describes the effort to better characterize the TSS (sediment) loads in the models.

The goal of the TSS monitoring project, was to better quantify sediment contributions to the watershed from active mining operations during larger storm events. More specifically, the questions that need to be answered are:

- What is the best approach for representing existing contributions from permitted mining discharges?
- What is the best approach for representing allocated loads (*i.e.*, waste load allocations – WLAs) from permitted mining discharges?

Two approaches have been used for modeling these discharges. The "*Traditional*" approach assumes that the permitted discharges are in compliance with their permits, and that the semi-monthly sampling, required by Virginia's Department of Mines, Minerals, and Energy (DMME) is adequate to describe long-term loading conditions for the discharges in question. The "*Proposed*" approach, assumes that the TSS load from large storm events is not being fully characterized by semi-monthly sampling, with the result that TSS loads from permitted discharges are being under-represented in the TSS TMDL. The TMDLs for the Powell River and Levisa Fork were developed using the *Traditional* approach, while the TSS TMDLs for the Pound River and Bull Creek were developed using the *Proposed* approach.

The difference between these approaches is primarily related to the impact of large storms on sediment delivery from permitted discharges. In order to assess this impact, three sites were identified where auto-samplers, programmed to collect multiple samples during storm events, could be installed. Samples were collected and analyzed for TSS. Stream stage monitors were also installed at these sites, with the intent of estimating flow volumes during storm events. The results were used to assess the overall impact of storm events on TSS loads.

2. SITE SELECTION

Three sites were identified in the Powell River watershed where auto-samplers could be installed on surface mine discharges. The location of these sites is displayed in **Figure 2.1**. The site locations and general conditions of the contributing drainage areas are described in **Table 2.1**. These sites were selected primarily based on being granted permission to access the sites for the purposes of installing and servicing monitoring equipment. As such, there was a reasonable question as to whether they were representative of mine operations in the area. This was evaluated through assessment of land cover conditions in the drainages, as well as analysis of historical water quality data.

Table 2.1 provides a verbal interpretation of land cover, and **Figure 2.2** shows the spatial distribution of the land cover. As it happens, the sites appear to provide reasonable examples of a “worst case” scenario (Outfall A, with significant land disturbance), a “best case” scenario (Outfall B, with large proportion of the drainage reclaimed or undisturbed), and an “average” scenario (Outfall 004, with a significant amount of recently mined, but reclaimed area).

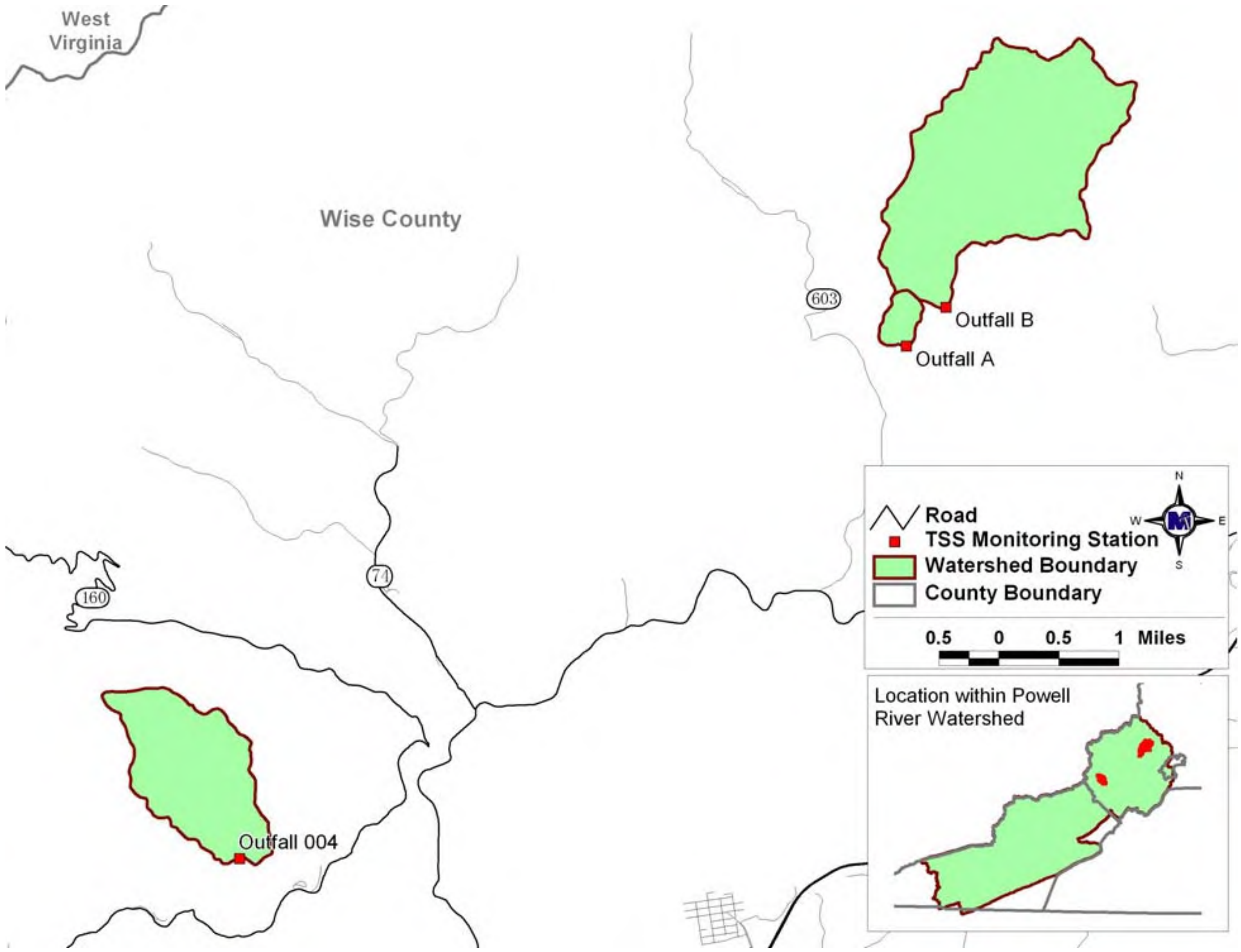

Figure 2.1 Location of Total Suspended Solids (TSS) monitoring sites.

Table 2.1 Description of monitoring sites in the Powell River watershed, where auto-samplers were installed for assessing TSS delivery during storm events.

MPID	Outfall	LAT	LON	Description of Drainage.[1]
0003400	004	36.8878	-82.8179	Approximately 760 acres, on Bearpen Branch, with approximately 30% undisturbed, 65% recently reclaimed, and 5% active mining.
0005433	A	36.9526	-82.7168	Approximately 85 acres, on a tributary to Canepatch Creek, with approximately 5% undisturbed and 95% active mining.
0005578	B	36.9575	-82.7108	Approximately 1,780 acres, on Canepatch Creek (headwaters), with approximately 50% undisturbed, 30% reclaimed, and 20% active mining.

[1] Land cover distribution estimates are based on visual assessment of 2011 aerial photos. "Undisturbed" areas may be reclaimed, but appear to have mature forest cover.

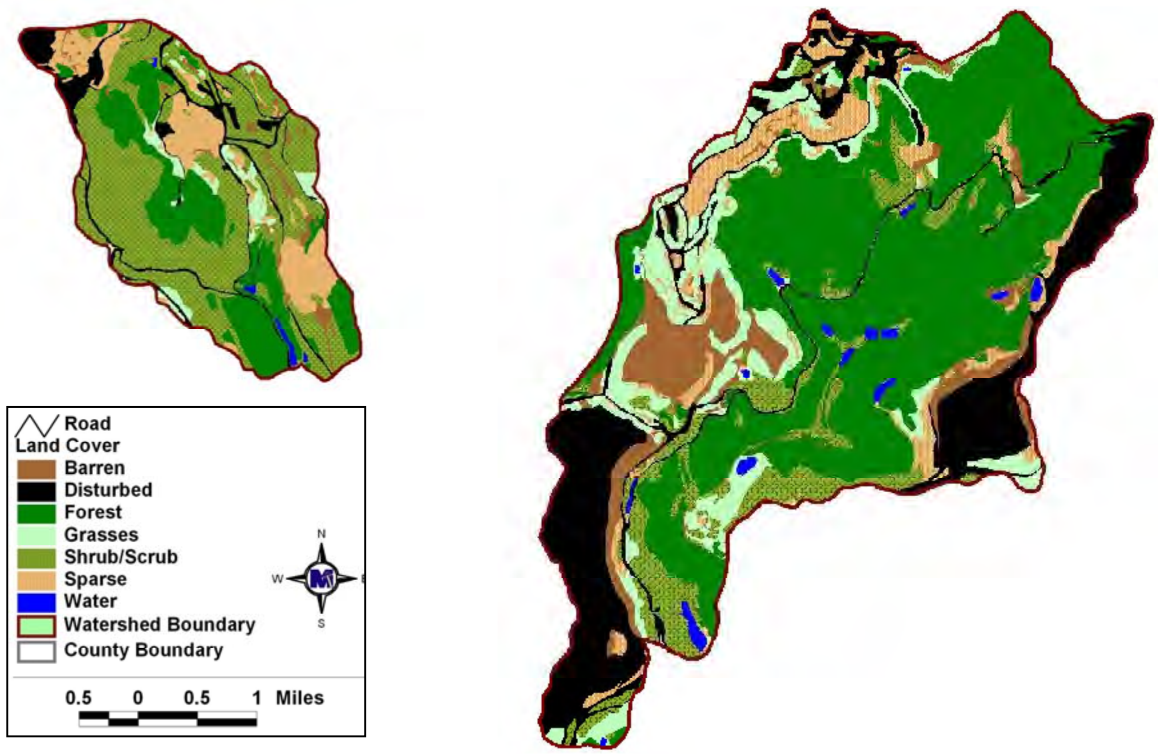

Figure 2.2 Land cover in Total Suspended Solids (TSS) monitoring site drasinages.

Historical monitored data were analyzed to further assess the representativeness of these sites. Samples collected by the permitted mining operators at the three sites were compared with data collected at 424 other permitted sediment control sites in the Powell River watershed. **Figure 2.3** shows a comparison of conditions at permitted surface mine discharges throughout the Powell River watershed. This plot uses all available data from 1987 through 2013. Percentile ranks of the TSS data from the three selected monitoring sites compared favorably with percentile ranks from the remaining permitted sites, especially the 10^{th}, 25^{th}, 50^{th} and 75^{th} percentiles, however, all of the sites in question had lower 90^{th} percentile concentrations. Since the sites in question have only been monitored in more recent years (2005 – 2013), and since sediment delivery can fluctuate widely, dependent on rainfall conditions, it was considered a more evenhanded comparison to only include data collected on the same dates in the comparison. The results of this analysis is presented in **Figure 2.4**. Overall, the sites seem reasonably representative of conditions in the area.

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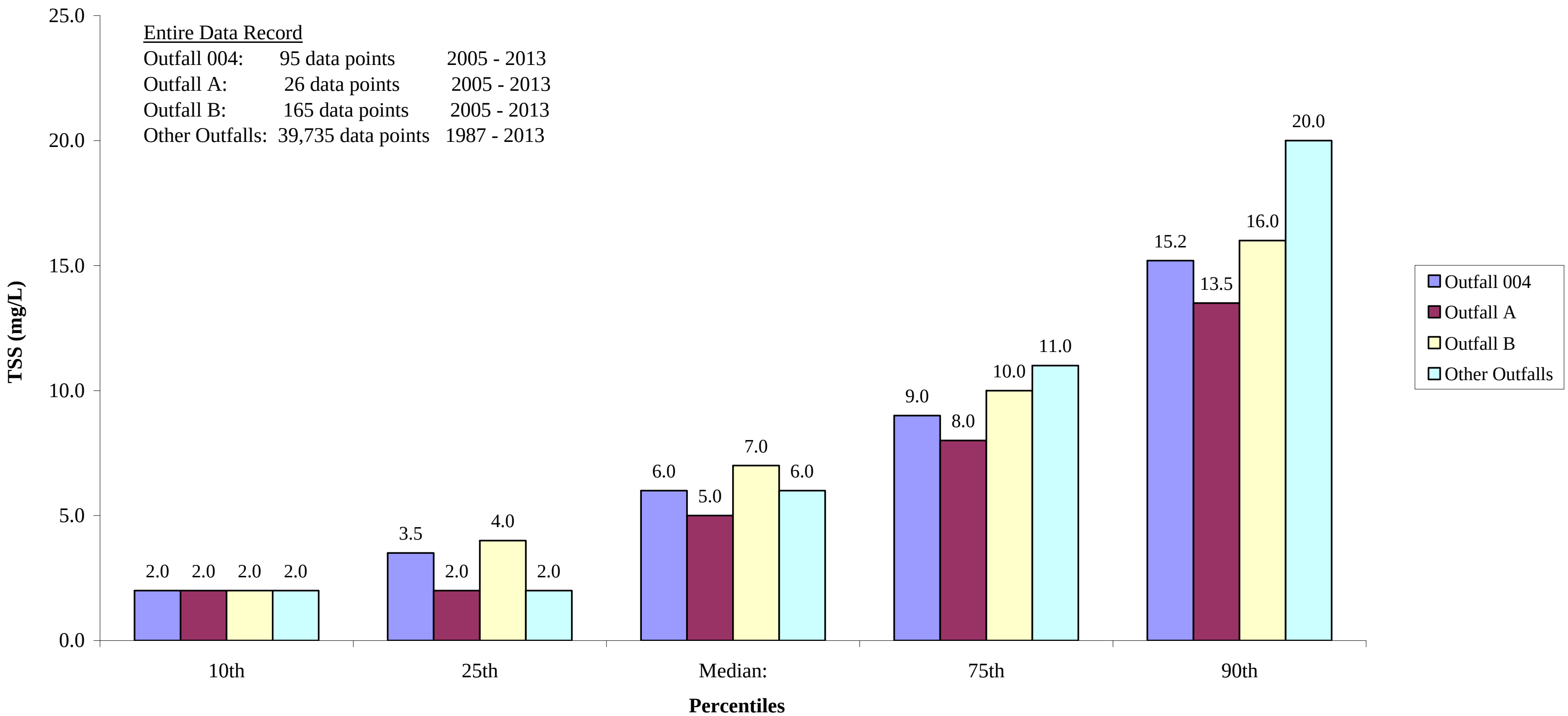

Figure 2.3 TSS data from selected DMME permitted sites in the Powell River Basin compared to data from all of the remaining permitted sites in the Powell River basin, using all available data from 1987 to the 2013.

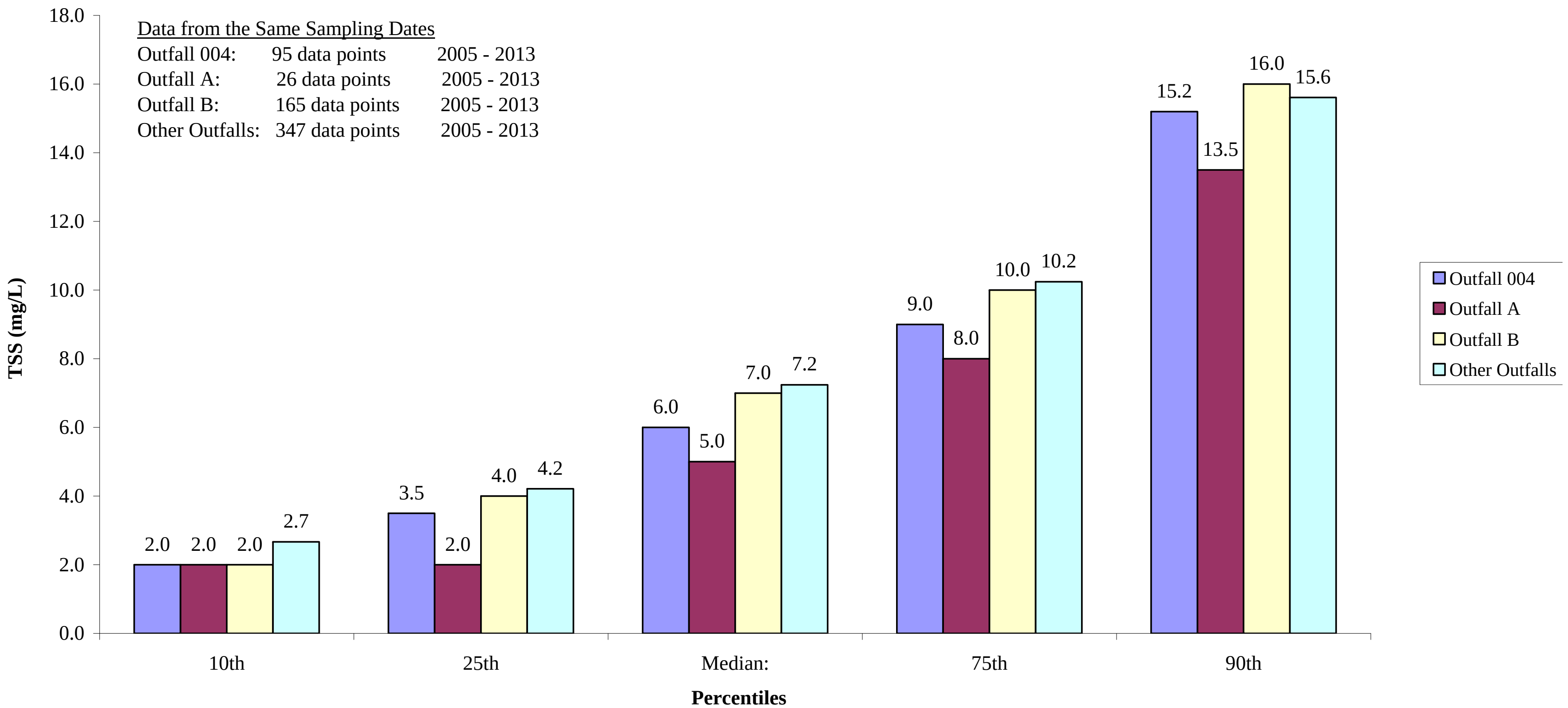

Figure 2.4 **TSS data from selected DMME permitted sites in the Powell River basin compared to data from all of the remaining permitted sites in the Powell River basin, on the same monitoring dates.**

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3. MONITORING DESCRIPTION

The goal of the monitoring effort was to assess the existing monitoring approach, and the model estimates, using a more comprehensive dataset. The focus was on the storm discharge from sediment ponds of active mines. This was accomplished through the use of automated samplers, rain gages, and stream gages. Each sediment sampling station consisted of a data collection platform (DCP) with pressure transducer to record stream levels, an auto-sampler, and a rain gauge (**Figure 3.1**). The automated samplers were configured to collect 24 individual samples during storm events. The samplers used were equipped with a liquid level sensor, which was designed to initiate the sampling routine when the stream level increased by a prescribed amount, as determined through trial and error on site. Upon initiation of a sampling event, sampling occurred at 30-minute intervals for the first 3.5 hours of the event, then continued at 3-hour intervals until all 24 sample bottles were utilized. One sampler was deployed at each of the three sites discussed earlier in this report.

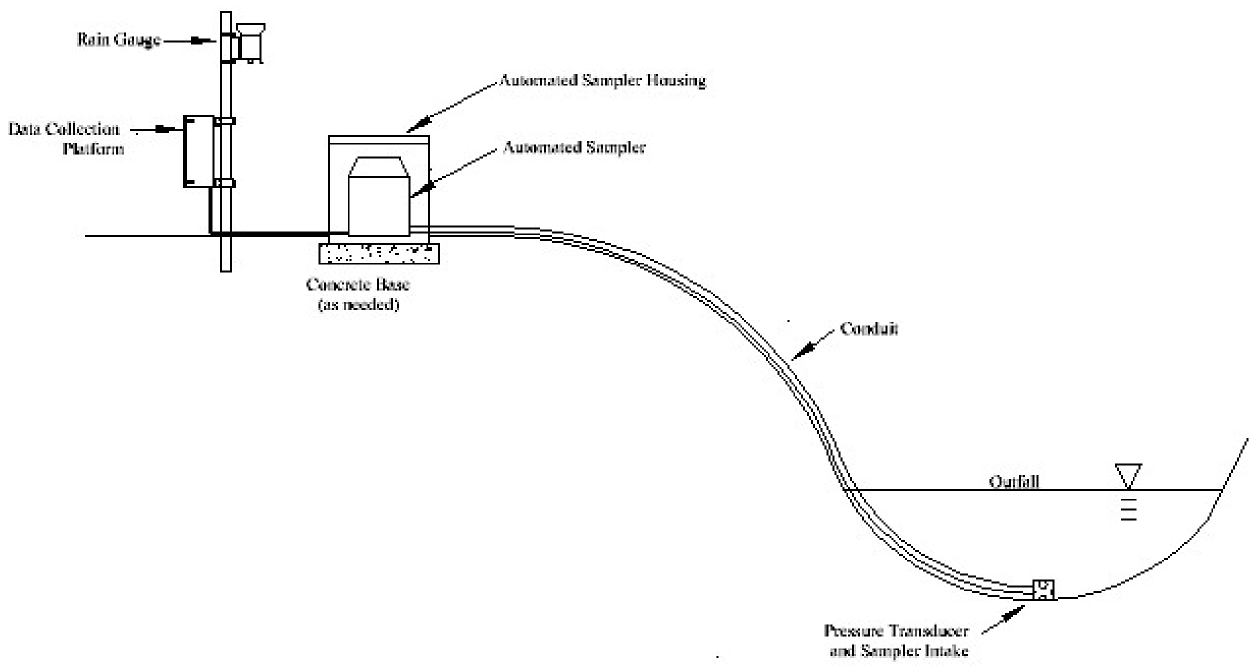

Figure 3.1 Sediment sampling station schematic, showing data collection platform connected to auto sampler, pressure transducer, and rain gauge.

Due to scheduling delays and equipment problems, the stream level measuring equipment (DCP and pressure transducer) were not installed until after the first seven of fourteen sampling events had occurred. One site (Outfall A) was equipped with a compound weir (**Figure 3.2**), to concentrate flow and provide an engineered structure for flow monitoring. Additional equipment malfunctions resulted in data being successfully collected during only four events.

Figure 3.2 Outfall A after weir installation. Data collection platform visible on left. Plastic sheeting is peeled back to expose structure for the photograph.

After each storm event, samples were collected from the auto-samplers and the auto-samplers were reset with new bottles. The collected samples were delivered to the laboratory for processing. The samplers were removed during the month of April while the flow monitoring equipment was being installed. During each site visit, a grab sample was collected and a flow measurement was taken.

4. RESULTS

As discussed earlier in this report, the drainages contributing to these sample sites varied in size and land cover. The effects of these differences can be seen in the flow response. **Table 4.1** shows the results of instantaneous sampling conducted during site visits. These measurements represent base flow conditions at each site. As might be expected, flow volume increases with drainage basin size, but the baseflow TSS concentrations are similar.

Table 4.1 Instantaneous flow measurements and TSS from grab samples.

Date	Outfall 004		Outfall A		Outfall B	
	Flow (CFS)	TSS (mg/L)	Flow (CFS)	TSS (mg/L)	Flow (CFS)	TSS (mg/L)
3/4/2013	2.401	------	0.004	------	5.415	------
3/8/2013	------	<5.0	0.13	2.0	7.272	17.0
3/14/2013	2.638	2.0	0.064	2.0	5.288	3.0
3/21/2013	1.292	5.0	0.067	5.0	7.708	7.0
3/28/2013	1.078	<2.0	0.107	<2.0	------	6.0
5/2/2013	1.71	8.0	------	------	5.236	2.5
5/9/2013	1.43	2.0	0.055	6.0	5.973	2.0
5/16/2013	0.869	2.0	0.036	3.0	4.492	6.0
5/23/2013	1.323	6.0	0.017	4.0	4.673	5.0
6/5/2013	0.92	5.0	0.005	<2.0	2.213	2.0
6/11/2013	1.365	8.0	0.095	7.0	8.29	10.0
6/17/2013	0.893	12.0	0.022	7.0	3.352	3.0
6/24/2013	0.919	17.0	0.024	6.0	4.393	11.0
7/1/2013	1.806	7.0	0.108	6.0	9.008	8.0
Average[1]	*1.4*	*6.0*	*0.06*	*4.2*	*5.6*	*6.3*

[1] For the purpose of calculating averages, non-detects were estimated at half of the detection limit.

Preliminary assessment of the TSS data collected from the auto-samplers showed that very few events had TSS values exceeding the 70 mg/L standard (**Table 4.2**). Flow-weighted concentration was only calculated for a limited number of events due to data limitations. Further, flow-weighted concentration calculations were only performed on events associated with outfall A, where the engineered structure (weir) was installed, as the rating curves developed for outfalls B and 004 were not considered accurate enough for use without further data collected for validation. Determining a relationship between rainfall and flow in order to make approximate flow-weighted calculations was unsuccessful. Correlations between TSS and rainfall were also unclear, though various methods were explored.

Six of the seven storm events that resulted in maximum TSS values above the 70 mg/L standard were associated with outfall A. The area that drains to outfall A contains a much higher percentage of recently disturbed land than either of the other two outfalls, so it is not surprising that it should have higher TSS concentrations as well. However, a weir was installed at this site on May 2, 2013, and the response in TSS concentrations to similarly sized storms appeared to have changed after the installation of the weir. This discrepancy led to further analysis.

Table 4.2 Total suspended solids (TSS) and rainfall data from sampling events. Flow-weighted concentration is provided where calculations were possible.

Event Date	Max TSS (mg/L)	Average TSS (mg/L)	Peak 5-min Rainfall (in)	Total Rainfall (in)	Flow-Weighted Concentration (mg/L)
Outfall A (weir site)					
3/5/2013	**150**	41.9	0.04	1.05	
3/11/2013	13	6.0	0.02	0.44	
3/18/2013	**83**	21.7	0.05	0.96	
3/24/2013	55	10.3	0.07	1.06	
5/18/2013*	**75**	22.8	0.20	1.15	31
5/24/2013*	38	9.3	0.04	0.23	13
6/5/2013*	**890**	138.2	0.36	1.11	
6/17/2013*	**317**	49.7	0.09	1.75	
6/27/2013*	**1,250**	243.0	0.16	1.39	685
Outfall B					
3/5/2013	56	23.5	0.04	1.23	
3/11/2013	9	6.8	0.02	0.46	
3/19/2013	19	9.2	0.06	0.94	
3/24/2013	12	6.5	0.07	1.11	
5/5/2013	11	5.3	0.02	1.20	
5/20/2013	18	7.8	0.23	0.66	
6/5/2013	22	15.5	0.29	1.20	
6/17/2013	85	46.6	0.12	1.80	
6/27/2013	**161**	75.6	0.16	1.36	
Outfall 004					
3/5/2013	33	8.3	0.04	1.10	
3/11/2013	8	3.7	0.02	0.54	
3/18/2013	12	7.4	0.06	0.96	
3/24/2013	7	3.4	0.06	1.07	
5/7/2013	7	3.8	0.04	0.27	
5/10/2013	49	6.2	0.01	0.18	
6/10/2013	26	12.5	0.01	0.05	
6/17/2013	47	12.6	0.15	1.46	
6/27/2013	63	21.0	0.10	0.48	

* Indicates measurements taken after installation of the weir.

As can be seen in **Figure 4.1**, before the installation of the weir there was consistently seen a ‘build-up’ of sediment concentration in the flow before reaching a peak concentration and then falling back off. This is the expected response for a system where sediment builds up in a retention or detention basin during rainfall events, with the concentration in the outfall water increasing and then falling back off. What is seen after the weir installation is an immediate peak of TSS concentration in conjunction with rainfall events (**Figure 4.2**), which is indicative of localized soil disturbance.

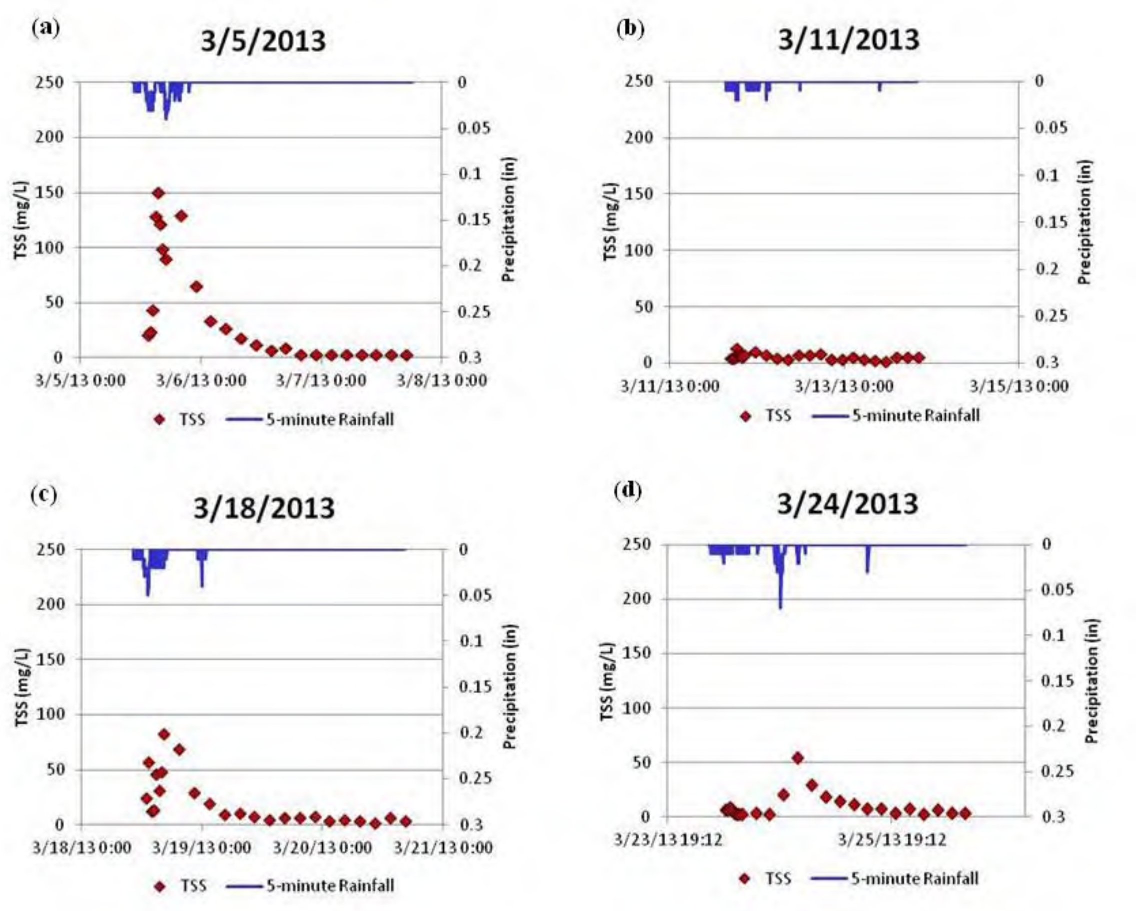

Figure 4.1. Total suspended solids (TSS) and 5-minute rainfall for the four monitored storm events prior to the installation of the weir.

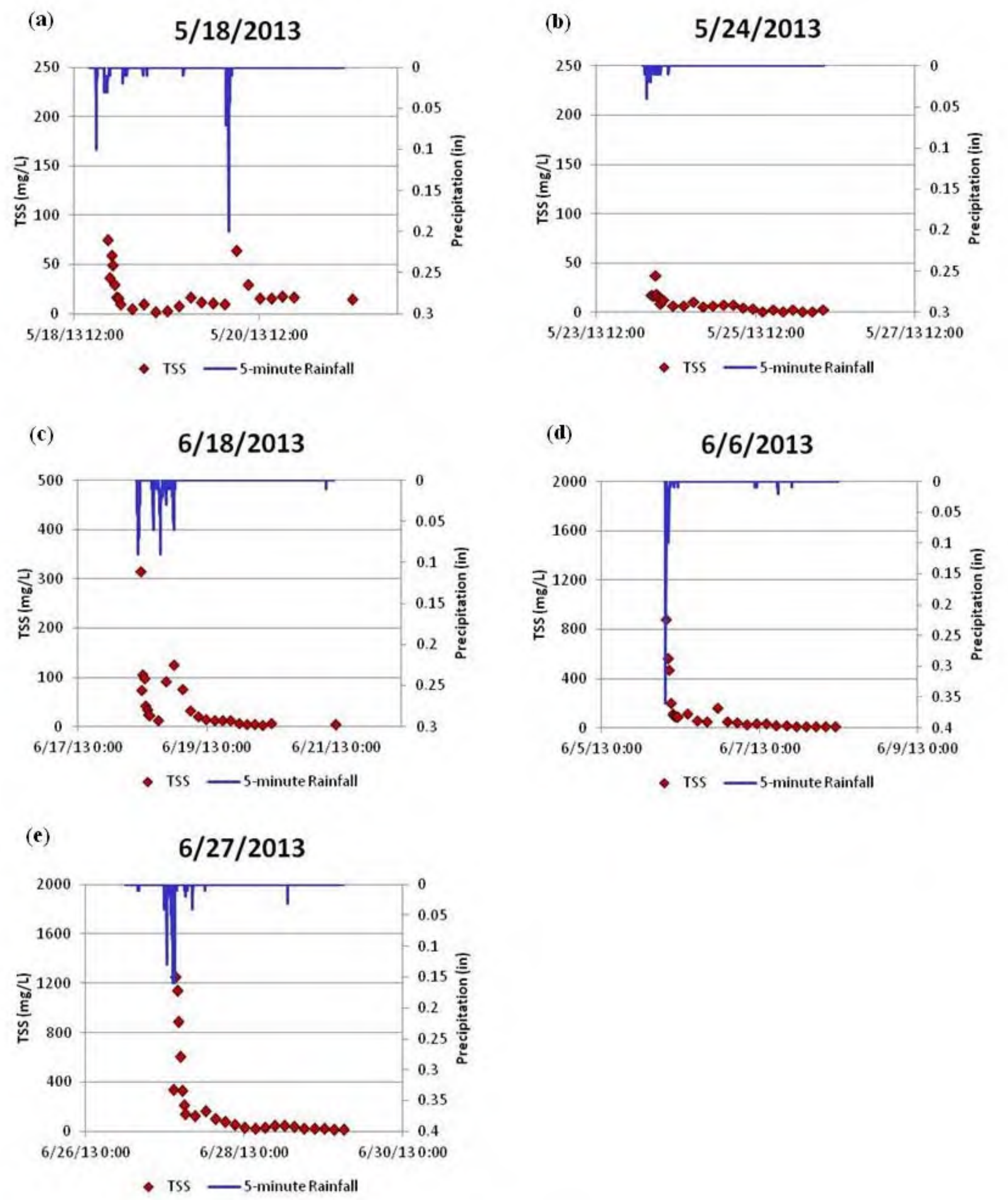

Figure 4.2. Total suspended solids (TSS) and 5-minute rainfall for the five monitored storm events after installation of the weir.

During the weir installation, an earthen berm was created to hold back the water flowing from the outlet. This obstruction was removed after installation of the weir was completed, however, the monitoring site at which all of the sediment samples were taken was located between the berm location and the weir. Changes in the response in TSS to rainfall events in the watershed indicate that the land disturbance associated with the construction and removal of the temporary berm have impacted the TSS measurements being taken at outfall A. As the TSS concentrations measured after the installation of the weir include sediment from local disturbance as well as sediment being carried out of the storm pond, it is recommended that the data from these sampling events be viewed as questionable.

One goal of this effort was to assess the usefulness of historical DMME monitoring of permitted discharges in representing existing TSS conditions. **Table 4.3** shows a comparison of DMME data to data collected during this study. As would be expected, the DMME averages are higher than the baseflow grab samples collected during this study, but lower than the average maximum TSS values collected during storm events. For Outfalls 004 and B, the DMME data is close to the average storm TSS recorded. However, for Outfall A, the DMME value is considerably less than the average storm TSS. In order to account for possible effects from the weir installation, the pre-weir data was assessed separately. The average storm TSS for Outfall A using these data is more comparable to the DMME data, however, the values at the other two outfalls (not impacted by the weir installation) also drop significantly, indicating that the storms monitored after the weir installation had a greater impact on TSS delivery.

Table 4.3 Comparison of DMME long-term monitoring to storm-event monitoring.

Data Source	Outfall 004 TSS (mg/L)	Outfall A TSS (mg/L)	Outfall B TSS (mg/L)
DMME Monitoring [1]	8.4	8.5	19.8
Baseflow Average [2]	6.0	4.2	6.3
Average Storm Max [3]	28	319	44
Average Storm [4]	9	60	22
Average Storm Max: Pre-Weir [5]	*15*	*75*	*24*
Average Storm: Pre-Weir	*6*	*20*	*12*

[1] "DMME Monitoring" data are flow-weighted averages based on all available permit compliance monitoring data.
[2] "Baseflow Average" represents the average of the TSS values recorded for during baseflow conditions.
[3] "Average Storm Max" represents the average of the maximum TSS values recorded for each storm.
[4] "Average Storm" represents the average of all TSS values recorded for during storms.
[5] "Pre-Weir" indicates that only data collected prior to the weir installation were used.

5. RECOMMENDATIONS

The data available from this monitoring effort is limited, however, it does provide insight toward answering the two questions stated earlier in this report.

- What is the best approach for representing existing contributions from permitted mining discharges?
- What is the best approach for representing allocated loads from permitted mining discharges?

As stated earlier, two approaches have been used for modeling these discharges (*Traditional* and *Proposed*). These recommendations will examine each, in light of the additional data that the monitoring proveds.

5.1 Existing Permit Loads

Both the *Traditional* and *Proposed* approaches calculate a load that is intended to represent long-term, average conditions across the broad spectrum of climate and land use circumstances that are encountered among permitted dischargers. The *Traditional* approach accomplished this by using long-term monitoring data to calculate flow-weighted average TSS concentrations, and apply them to flow volumes modeled from active mine areas. These long-term average concentrations are, typically, less than the permitted 70 mg/L. **Table 4.3** showed how this approach compared to the storm event data that was monitored during this effort. Keeping in mind that the goal is to provide a long-term average representation of varied conditions, this approach may be reasonable, but, arguably may be biased a bit low, particularly as compared to the "worst-case" scenario of Outfall A.

The *Proposed* approach calculated a load based on modeling conditions in the permitted areas (extractive, reclaimed, and released). This approach yields an annual sediment load from each land use, an annual runoff volume from each land use, and annual groundwater volume that is delivered to the stream. Using these values from the Bull Creek TMDL, a long-term average TSS concentration was calculated at greater than 2,000 mg/L. While it is conceivable that a peak TSS concentration could reach this level, based on the monitoring effort conducted for this study, it is, arguably, too large a concentration to represent long-term, average conditions.

The *Traditional* approach appears to be potentially biased low, while the *Proposed* approach appears to be biased high. A reasonable compromise, based on this monitored data, would be to model the existing load from permitted mine sources at the permitted level of 70 mg/L. This value is higher than the average storm event concentrations calculated for each site (**Table 4.3**), and is arguably a conservative estimate for the long-term average condition. This concentration should be applied to the average annual flow volume from disturbed areas to estimate the existing TSS load.

5.2 Allocated Permit Loads

Both the *Traditional* and *Proposed* approaches use the permitted TSS concentration (70 mg/L) to calculate the allocated permit loads. The *Traditional* approach applies this concentration to the average annual flow volume from disturbed areas to estimate the allocated TSS load. The *Proposed* approach applies this concentration to the average annual flow volume from all permitted areas. While the *Proposed* approach represents the "worst-case" scenario in terms of water quality, where all permitted mine areas within a watershed are disturbed at the same time, it does not represent a "typical" scenario. In fact, this condition has not been seen during any known TMDL development. Since surface mine operators are only permitted for discharge from storm ponds, as compared to all runoff from permitted areas whether actively being mined or not, and since mine operators only install ponds in conjunction with mine operations, TSS loads associated with runoff from non-disturbed lands should remain in the load allocation (LA), rather than the waste load allocation (WLA). While this may be somewhat limiting to the mine operators, it is protective of water quality.

5.3 Conclusions

In the current state of knowledge, regarding TSS delivery from surface mine operations, the following recommendation is offered.

- Both existing and permitted conditions should be modeled at the permitted level of 70 mg/L. This concentration should be applied to the average annual flow volume from disturbed areas to estimate TSS loads.

Appendix F: Bull Creek Watershed Total Dissolved Solids Evaluation, September 17, 2013

Phased TMDLs: Total Dissolved Solids Evaluation for Bull Creek and South Fork Pound Watersheds

Submitted to

Virginia Department of Mines, Minerals and Energy
Division of Mined Land Reclamation
Post Office Drawer 900
Big Stone Gap, VA 24219

September 17, 2013

Error! Bookmark not defined.

Prepared by:

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Table of Contents

Figures

Tables

Appendix Tables

PHASED TMDLS:

Total Dissolved Solids Evaluation for

Bull Creek and South Fork Pound Watersheds

1. Summary

MapTech, Inc. was contracted to furnish the necessary labor and resources to accomplish Task 8: Utilizing existing data and the additional data collected during the "phased" monitoring, provide the necessary evaluation, modeling, and technical services to complete revisions to each of the four "phased" TMDLs. Data collected as well as existing data were to be analyzed to determine the necessary course of action for the TMDL. MapTech will recommend a course of action based on an assessment of all available data.

The work documented here evaluates pre-existing Total Dissolved Solids (TDS) data, and data collected in 2012-2013 from mine springs in the Bull Creek watershed. The objective was to uncover any relationships between mining activities and in-stream TDS concentrations for use in other watersheds.

- There is a seasonal trend in spring flow is: low in autumn, moderate in early winter, and highest in late winter.
- The TDS concentration in mine springs decreases with flow increase.
- The volume of a spring primarily controls its TDS load.
- Large-volume springs provide the majority of the TDS load.
- The dominant TDS load springs in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.
- Spring elevation has a minor impact on flow volume and TDS load.
- Recent precipitation tends to increase TDS load at low flows. At high spring flows the relationship disappears.
- The volume of a spring tends to be larger from functional hydrologic islands with large footprints and volumes.
- Prominent abandoned mine scars above a mine spring dilute the TDS in springs but add substantially to the volume of the spring. Thus AML features lead to high TDS load.
- In the Bull Creek watershed, there is not a clear relationship between mine parameters and TDS load and flow volume as there is for hydrologic island footprint.

•

2. Background

2.1 Groundwater Flow

Topography, geologic structure, and stratigraphy control groundwater flow patterns. The discussion of the interrelationships is based on various sources in Callaghan et. al. (2000) and USEPA (1980).

Groundwater flow is divided into shallow, intermediate, and deep systems. The shallow flow system transports groundwater only short distances and rapidly responds to precipitation and other environmental changes. The lower, intermediate flow systems travel up to thousands of feet with response times of months to years. The deep flow systems transport groundwater up to tens of miles with response measured in decades to centuries (Freeze & Cherry 1979; Kleinmann, 2000).

Shallow groundwater flow systems typically exist near the land surface and in the vicinity of surface-drainage features. The depth of shallow groundwater circulation below the land surface is typically ten to sixty feet. The travel time is, in general, a few weeks to a few years after entry. The groundwater drainage divides of shallow flow systems usually coincide with surface water divides, and can be approximated from topographic maps. Variations in flow quantity and quality are more dependent on daily and seasonal climatological fluctuations. Meanwhile, intermediate and deep flow systems deviate progressively from shallow systems in every respect with the degree of difference depending upon depth.

In the Bull Creek watershed, shallow flow system can be thought of, in general, as occurring within isolated hydrologic islands within the steep-sided hills. The uppermost component of this flow system consists of infiltrated rainwater flowing through unconsolidated regolith covering the hill surfaces and slopes. It can be perched above low-permeability strata. The lower surface flow component found within the hill core is fed by the upper component through faults and porous strata. Recharge of hydrologic islands is completely from within the hydrologic island. Depending on the presence of low-permeability strata, discharge may be from springs in valley walls above local streams, or to local streams directly.

The intermediate flow system flows beneath two or more hydrologic islands and discharges in valleys above it. It is recharged by the shallow flow systems through faults and by its recharge area at the drainage basin divide.

The deep flow system lies below the hydrologic islands and the intermediate flow system. Recharge is from major drainage basin divides and leakage from many of the shallower systems.

2.2 Total dissolved solids (TDS)

Total dissolved solids (TDS) refer to the total dissolved solids content of a water sample. It is distinct from suspended solids consisting of silt and other fine ore material, which remains in suspension for a prolonged period and is retained upon passing through a fine filter. Electrical conductivity (EC) is a numerical expression of the ability of aqueous solution to carry an electric current. High level of mineralization is a typical characteristic of many coal mining discharges. In most cases, a direct relationship between conductivity and TDS can be established. This makes determination of TDS easier as conductivity can be measured readily in the field. The following relationship exists for Australian surface waters.

$$\text{TDS (mg/L)} = 0.62\ \text{EC}\ (\mu\text{S/cm})$$

The electrical conductivity for mine water can be substantially high due to the presence of dissolved salts. Where tap water has a conductivity of 60–100 (μS/cm) and river water ranges from 200–800 (μS/cm), mine water typically ranges from 1,000–10,000 (μS/cm). This translates into TDS ranges of 37-62 mg/L (tap water), 124-496 mg/L (river water), and 620-6,200 mg/L (mine water). Thus, the transition from fresh water to mine water is here chosen to be **620 mg/L**, the lower end of the mine water range. In a general sense fresh water tends to have TDS less than 1,500 mg/L[1].

2.3 TDS Sources

TDS originates from the dissolution of chemicals in the regolith which the groundwater contacts. Shallow groundwater flow is through the zone of highly weathered regolith. Weathering has removed most soluble minerals so this groundwater tends to be low in mineral matter and, thereby low in TDS (< 20 mg/L; Perry, 2000).

Shallow groundwater flow in the hill core may contain significant TDS if it circulates through un-weathered calcareous strata. If confined above a low-permeability layer, hill-core groundwater mounds and flows laterally, albeit slowly, to mix with flow from the weathered regolith groundwater into the adjacent valley. Intermediate groundwater flow also tends to become mineralized and behave similarly although it is found at greater depth.

1 Ela, Wendell P., *Introduction to Environmental Engineering and Science,* Prentice Hall, 3rd ed. 2007.

The deep groundwater flow system contains highly mineralized water naturally at depths of less than 500 feet. The uppermost zone is characterized by calcium bicarbonate water which chemically grades to NaCl-rich brine in the deepest level.

For pre-mined groundwater, there is a direct relationship between the amount of calcareous material in the overburden and the alkalinity, conductivity and pH (Callaghan et. al., 2000). On the other hand, mine drainage water quality is largely determined by sulfides and carbonates even though they usually constitute only a few percent of the rock mass (Perry, 2000). Mine drainage water quality is often moderated by mixing with shallow groundwater. The degree of mixing is important because groundwater from the weathered zone has low TDS and little alkalinity while groundwater from deeper strata and mines has much higher alkalinity and TDS.

2.4 Precipitation

In the study area, the infiltration rate is high enough to consistently flush groundwater through the shallow rock strata from recharge to discharge points. In general, 32% of the average precipitation infiltrates the groundwater system. Twenty percent is lost through evaporation and transpiration. About 26% runs off to surface waterways (Callaghan et. al., 2000). The vast majority of groundwater circulates in the fractured near-surface bedrock, along stress-relief fracture networks, open joints, and within the weathered regolith zone.

2.5 Mine Outflow

The study area is in the eastern edge of the southwest Virginia coal fields. Because of the high topographic relief, undisturbed groundwater systems are of small areal extent. Topographic highs are recharge areas. Water infiltrates the regolith and moves laterally and downward through bedrock fractures. With depth and decreasing permeability, most water moves laterally along the flat-lying bedding planes or through coal seams until it encounters fractures or more permeable rock to move downward. The pathways are stair-steps through the depths. But, topographic differences entrain groundwater causing it to conform to the topography, rising under and within hills and dropping below valley bottoms.

Mines located above stream levels serve as free drains and highly permeable aquifers. They often produce large man-made springs at mine openings (Callaghan et. al., 2000)

In the coal fields of southwest Virginia, coal seams have higher transmissivity than other rock types. Most rock layers are permeable to a depth of about 100 feet. Below 200 ft, on the other hand, only coal seams have measurable permeability. Therefore, at depth, most lateral groundwater flow is through coal seams (Kleinmann, 2000).

Potential mine water sources include precipitation/infiltration through the overburden into the mine, and groundwater infiltration of the mine. In mined areas rainwater infiltrates the land surface and may mix with resident groundwater. Interconnected underground workings act as man-made aquifers with high conductivities. In the flat-lying sedimentary rocks of the eastern bituminous coal measures which includes the study area, underground mining is routinely accompanied by overburden movement, fracturing, and separation along bedding planes. This increased permeability leads to more rapid groundwater flow.

In mined lands, water quality (including TDS) is directly related to the flow path, the dissolution of minerals encountered by the groundwater, and the contact time of the water in the rock. High TDS indicates the presence of calcareous strata, probably near the sampling point, within the groundwater flow path for that water.

In underground mines, recharge results in partial to complete flooding after closure. Recharge rates are controlled primarily by overburden thickness. Rates vary from 0.8 gpm/acre for shallow (< 250 ft) cover, to 0.05 gpm/acre or less under thick cover (Perry, 2000).

2.6 Mine Water

The flows that were monitored in the Bull Creek watershed are referred to as "mine springs". Some emerge from culverts that are connected directly to mines. Others are seeps issuing from hillsides that are also expected to derive their water from mines.

In areas that have experienced underground mining the source for mine water is essentially from seepage of the excavated area of the mine. During mining water is collected in underground sumps with a nominal retention time. The quantity of the mine water greatly depends on the level of the groundwater table and the ground conditions. The quality of the mine water varies widely from mine to mine depending upon the local conditions. The main pollutants of mine water are dissolved minerals (TDS) from the aquiferous rock strata. A typical range for the mine water total dissolved solids is 500 - 2000 mg/L. These dissolved minerals give high hardness to the water. The major pollutants associated with coal mining are suspended solids, dissolved salts (especially chlorides), acidity and iron compounds. These are also the main concern in springs that issue from abandoned mines (Kleinmann 2000).

Mining practices may generally be divided into surface and underground mining. The latter, used in the study area, takes on a variety of different forms (**Figure 2.1**).

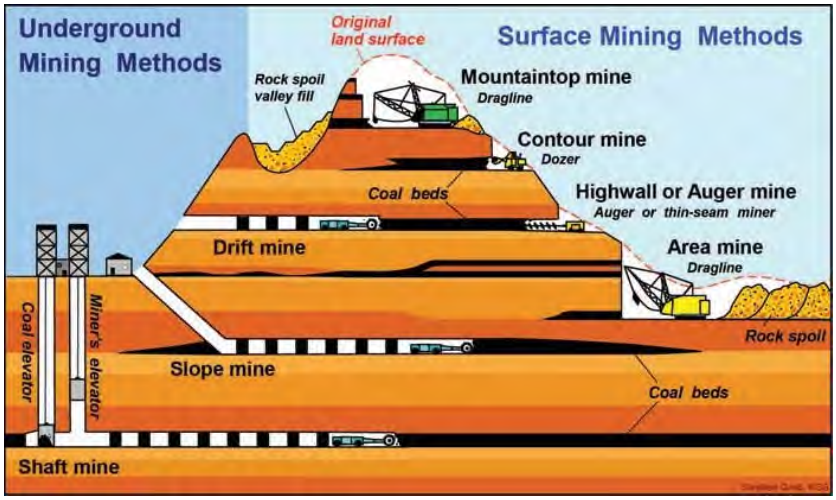

Figure 2.1 Surface versus underground mining (U. of KY 2013).

3. Bull Creek Watershed and Monitoring

The study area is the Bull Creek watershed for which a TMDL has been partially completed. The watershed is within the southeastern edge of the Appalachian Coal Basin. The topography is characterized by many steep-sided hills carved by steep-gradient dendritic streams (**Figure 3.1**).

Coinciding with the watershed's name, the main stream in the area is Bull Creek. It appears to be formed by the union of Jess Fork and Deel Fork. Mine spring HMBC was monitored on Bull Creek and two were monitored on Deel Fork: Deel Up and Deel Down. Two were also monitored on the Bull Cr. tributary Belcher Branch: Up Belcher and Down Belcher. Additional springs were monitored on other tributaries to Bull Creek: Charlie Up and Charlie Down on Big Branch, Cove Hollow on Cove Hollow stream, and Burnt Hollow on Burnt Popular Fork. Nine springs in all were monitored on the steep valley walls near streams in the Bull Creek watershed.

TDS, temperature, pH, dissolved oxygen, conductivity and flow were monitored at the springs. Sampling occurred bi-monthly over the six month period from September 2012 to February 2013. Spring flow varied from 0.0 to 6.8 cfs (cubic feet per second) and averaged 0.6 cfs. Most of these springs tend to have a slightly basic pH ranging from 6.5 to 8.4. Charlie Up and Up Belcher fluctuated from slightly acidic to slightly basic, while Burnt Hollow was consistently slightly acidic, 6.5 – 7.0, suggesting a moderate difference in bedrock chemistries.

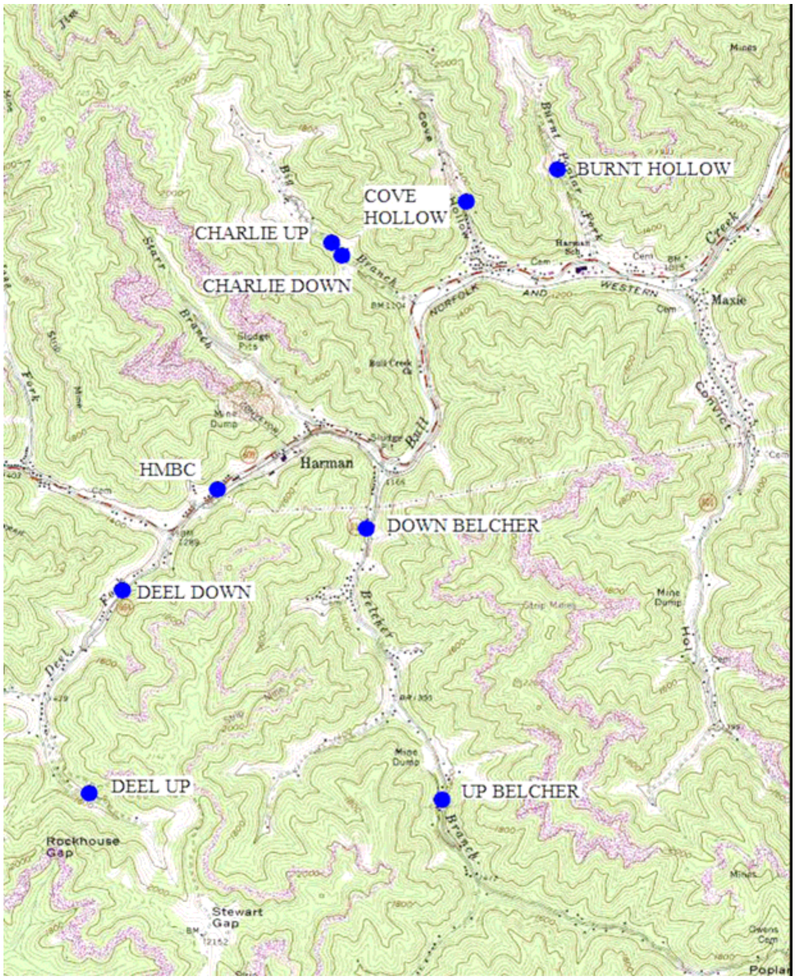

Figure 3.1 Sample locations in the Bull Cr. watershed (REI Consultants 2013).

3.1 Monitored TDS

TDS due to surface sources or transported by streams in the Bull Creek watershed is not considered in this section. TDS samples were collected from mine springs precluding input from overland TDS.

3.2 Seasonal trend

The concentration of TDS (mg/L) trended downward over the six-month sampling period. This period covered the typical low flow of autumn and early winter months, that is followed by increased flow accompanying increased rainfall and thawing in February. But, as to be discussed later, this period's precipitation was abnormal. Nevertheless, flow increased and TDS trended downward. The flow and TDS concentration for the HMBC spring is shown in **Figure 3.2.** For the HMBC spring the TDS concentration dropped 28% while the flow increased 270%.

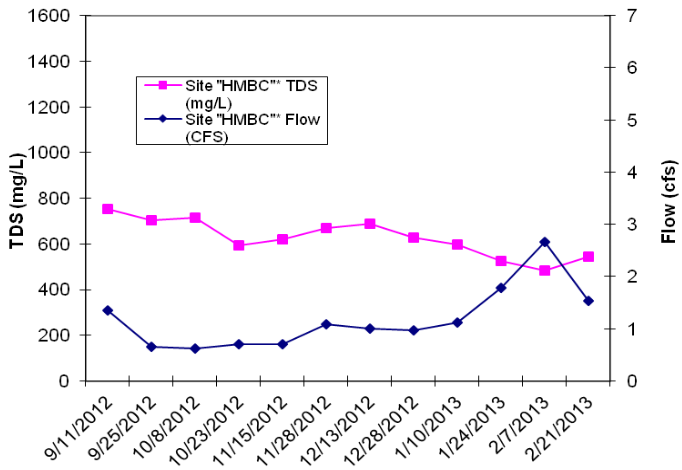

Figure 3.2 Recent TDS and flow trends at the HMBC spring.[2]

The TDS concentration trend for all stations is provided in **Figure 3.3**. With the exception of Deel Up (dark blue line), all springs show a decline in TDS concentration over the sample period. At the same time, the volume of the springs increased (**Figure 3.4**). Deel Up has very low flow and TDS. Consequently, its deviation from the general pattern is of negligible importance.

2 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[HMBC]".

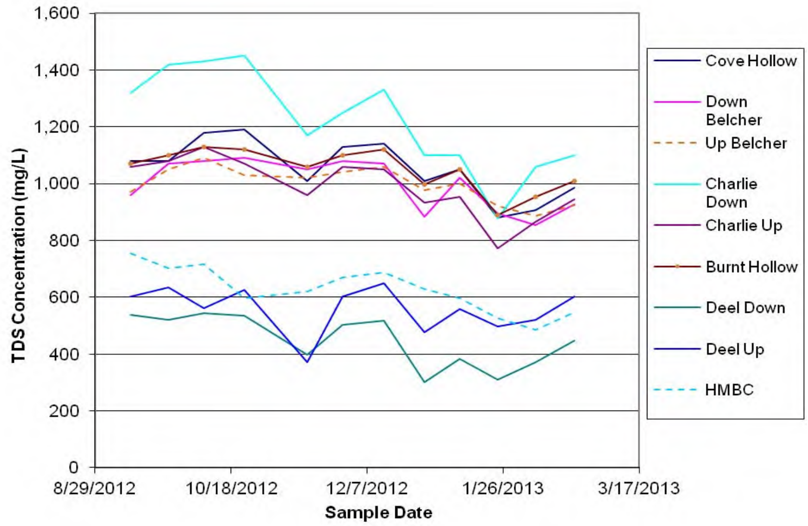

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Figure 3.3 TDS concentration in mine springs over the sample period in the Bull Cr. watershed. [3]

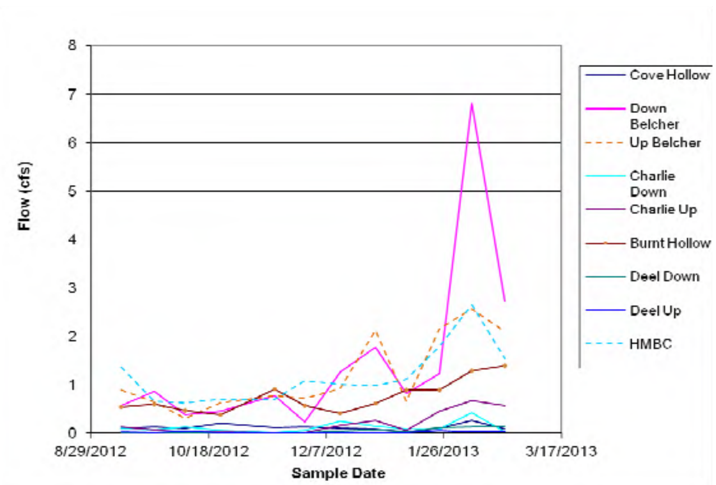


Figure 3.4 Mine spring volume over the sample period in the Bull Cr. watershed. [4]

3.3 Mining

Coal has been extensively removed from strata in the watershed by means of underground mining. Two mines, Splashdam Mine and Norton Mine, are responsible for most of the excavation shown in **Figure 3.5**. Four other minor mines contribute to the total mine footprint. The Bull Creek TMDL watershed

3 Data in Table A. 1 and Table A. 2figure from "E:\Projects\Proj_DMME_Phased-TMDLs\TDS Evaluation\[TDS v Flow with Totals and Averages_MJS_6.xlsx]Combined".

4 Data in Table A. 1 and figure from "E:\Projects\Proj_DMME_Phased-TMDLs\TDS Evaluation\[TDS v Flow with Totals and Averages_MJS_6.xlsx]Combined".

perimeter is marked by a dark red line in the figure. Mine units that are part of Splashdam Mine are shown in gray and Norton Mine units are outlined in black. The un-mined area of the watershed indicated in green generally occurs along streams and represents about 15% of the watershed. The Splashdam and Norton Mines both extend well beyond the Bull Creek watershed boundary although the Splashdam mine is much larger.

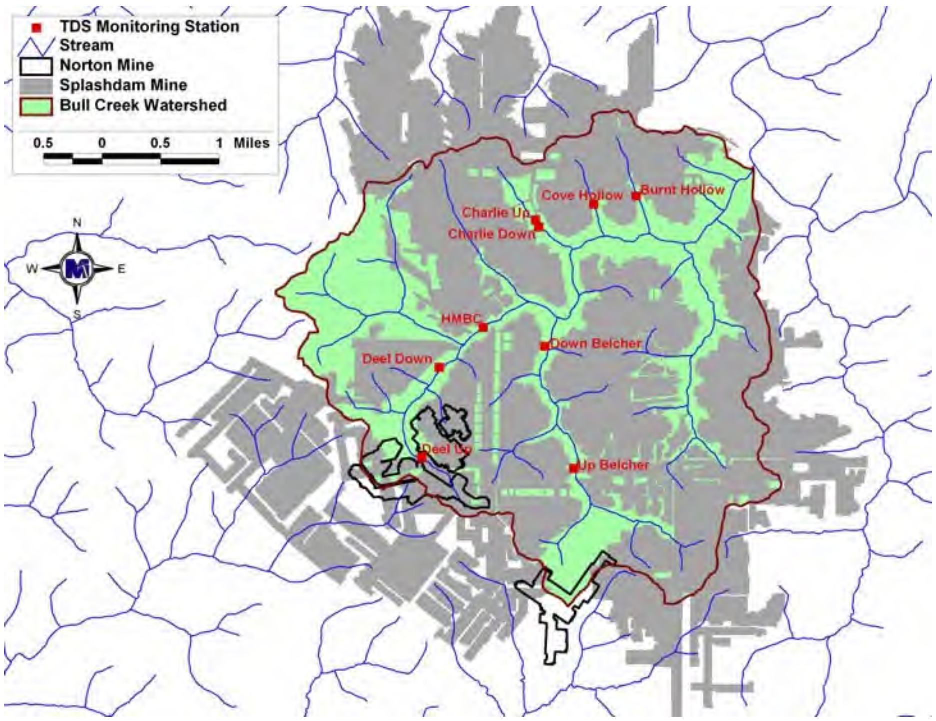


Figure 3.5 Location of monitored springs relative to underground mined footprint in the Bull Cr. watershed.

Underground mining has occurred at multiple depths in the watershed. As is indicated by dark shading in **Figure 3.6**, multiple levels generally occur within the ridges, and along the TMDL watershed boundary where the elevation is highest. In this mined area, the sedimentary rock layers and coal seams are expected to exhibit the typical flat-lying aspect of strata in the bituminous coal fields of the Appalachian Coal Basin.

Elevations for most of the mine footprint are uncertain. On the eastern edge of the watershed the depths are believed to span about 868 feet of elevation. The three units of the Norton Mine on the southwestern boundary of the watershed have mine floor elevations of approximately 1,600 feet while the land surface ranges from 1,700 to 2,100 feet. So these mines are about 300 feet deep and are at, or just above, the Deel Up spring elevation.

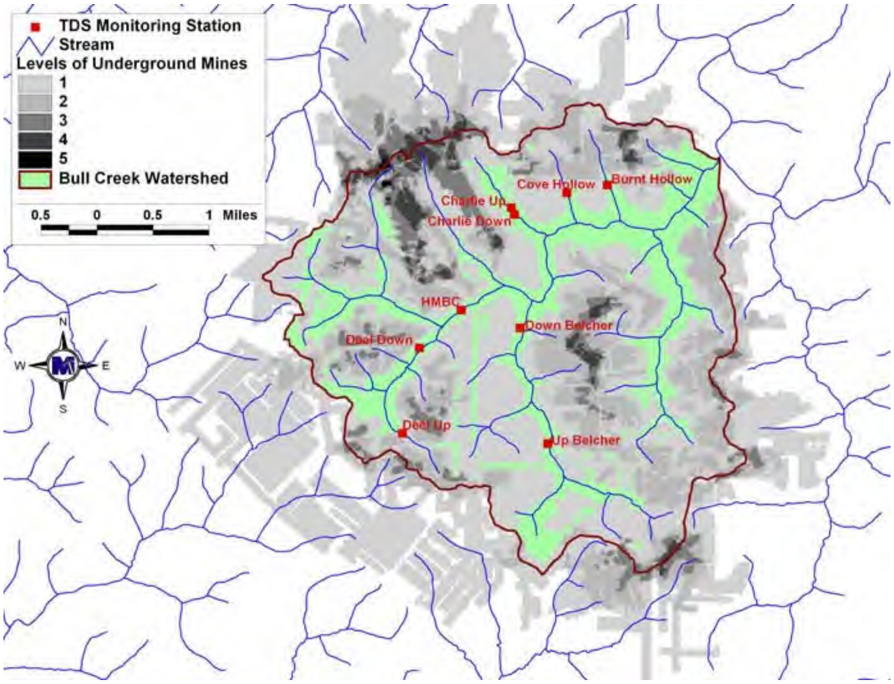


Figure 3.6 Underground mine layers in the Bull Cr. watershed.

Although the sampling focus was on underground mines, a large area in the southeastern part of the watershed was omitted from sampling (see area "E" of **Figure 3.20** on page **28**). This area equals about 30% of the TMDL watershed. It is bounded by Belcher Branch on the west and Bull Creek on the north. It is not unusual to omit portions of a project area from sampling because it is difficult to census the entire population of springs.

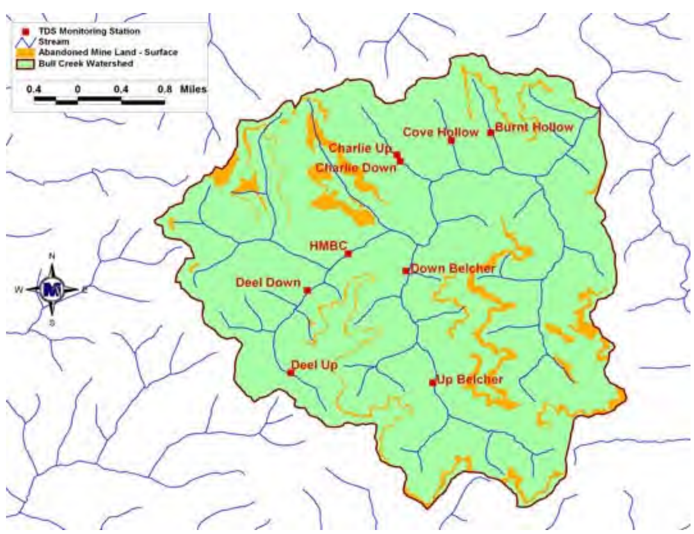


Figure 3.7 Abandoned surface mines in the Bull Cr. watershed.

While surface mining was not the focus of this study, it has been commonly employed in the watershed (**Figure 3.7**). Abandoned surface mine tracts present a ready path for precipitation to enter the ground through material-rich materials that provide TDS. Notably, there is a large, abandoned surface mine above the HMBC spring. This appears to provide increased infiltration and, consequently, lower than expected TDS groundwater to the spring (see later discussion).

3.4 TDS Concentration and Spring Flow

For the Bull Creek watershed, the relationship between flow volume and TDS concentration in the mine springs is graphed in **Figure 3.8**. Note the flow axis has a log scale. Freshwater streams typically range from 124 to 500 mg/L and mine water typically ranges from 620 to 6,200 mg/L. Here we use 620 mg/L as the mine water threshold.

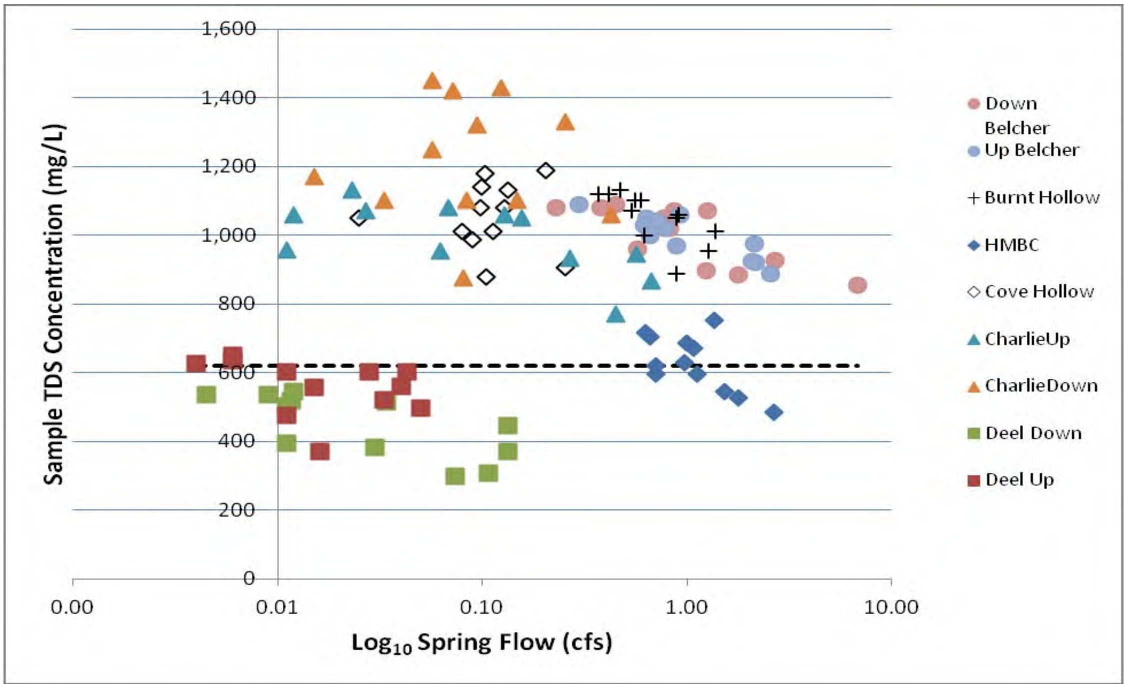


Figure 3.8 Relationship of TDS concentration to flow in mine springs of the Bull Cr. watershed. The dashed line at TDS 620 mg/L is the transition to mine water.[5]

In the Bull Creek mine springs the TDS concentration varies from 300 to 1,400 mg/L. That is, the lower concentrations are more akin to freshwater than to mine discharge. Most low TDS concentrations were found in the Deel Up and Deel Down springs even though these springs originate from mines. The low concentrations are believed due to Deel Up's location near the edge of the watershed, and that both springs are topographically the highest springs. Their low flow suggests there is very little hydrologic

5 Data source: TDS v Flow with Totals and Averages_MJS_6.xlsx.

head behind them. Spring HMBC has TDS concentrations in the middle range 500 to 800 mg/L straddling the transition from freshwater to mine water. The remaining springs have TDS concentrations consistently above 800 mg/L and so are certainly of mine origin.

Of the seven high-TDS springs, three have a high TDS concentration but low flow: Charlie Up, Charlie Down, and Cove Hollow. The remaining three springs have high TDS and high flow: Up Belcher, Down Belcher, and Burnt Hollow. But, the four springs with the highest flow are the dominant springs in the watershed from a TDS load perspective; HMBC, Up Belcher, Down Belcher, and Burnt Hollow (**Table 3.1**).

Bedrock minerals in mines dissolve when in contact with water. If the water in a mine deepens, less of the water is in contact with rock so there is less dissolution for the volume of water. If spring flow volume reflects mine groundwater volume, there should be a negative relationship between the volume of a spring and its TDS concentration. On the other hand, the volume in a spring may increase due to infiltration of low-TDS rain water that dilutes the mine water. Whatever the reason, the TDS concentration and flow patterns for individual springs graphed in **Figure 3.8** suggest there is a negative logarithmic relationship.

Table 3.1 Mine spring flow, and spring-TDS over the study period in the Bull Cr. watershed.[6]

Site	Ave. Flow (cfs)	Median Flow (cfs)	Mean TDS mg/L	Median TDS mg/L	Mean TDS Mg/yr	Median TDS Load Mg/yr	Load Ratio[a]	Elevation (feet)
Down Belcher	1.49	0.85	999	1,035	1,239	790	118	1,232
Up Belcher	1.21	0.83	997	1,010	1,039	741	111	1,377
Burnt Hollow	0.74	0.61	1,050	1,065	684	569	85	1,305
HMBC	1.18	1.04	627	625	636	607	91	1,261
Cove Hollow	0.12	0.10	1,054	1,065	112	101	15	1,260
Charlie Up	0.20	0.10	990	1,004	165	93	14	1,309
Charlie Down	0.12	0.08	1,217	1,210	129	87	13	1,293
Deel Down	0.05	0.02	447	475	17	8	1	1,383
Deel Up	0.02	0.02	559	581	11	7	1	1,567
maximum:	1.49	1.04	1,217	1,210	1,239	790	118	1,567
minimum:	0.02	0.02	447	475	11	7	1	1,232
median:		0.10		1,010		101		1,332

a ..= Median TDS Load divided by 7, the minimum Median TDS Load.

3.5 TDS Load

TDS load is the mass of dissolved solids produced over a period of time. Here the TDS load from a mine spring is calculated by multiplying the TDS concentration (mg/L) by the flow (cfs).

6 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Averages], and TDS v Flow with Totals and Averages_MJS_6.xlsx[Precip].

Mg/yr = mg/L * cfs * 0.89359105

The product is multiplied by 0.89359105 to convert the units to Mega grams per year (Mg/yr). The origin of the conversion factor is as follows.

$$0.89359105 = (ft^3 / sec) * (1L / 0.0353147\ ft^3) * (1\ kg/10^6\ mg) * (1\ Mg/10^3\ kg) * (3.15569*10^7\ sec/yr)$$

In **Figure 3.9**, where TDS load is graphed against spring flow, both graph axes are linear. Considering the data for all springs except HMBC, there is a significant, positive response of TDS-load to flow; the correlation coefficient R^2 is highly significant (0.99). There is a similar, significant relationship for the HMBC spring by itself but with a slower rate of increase. The consistent, positive relationship for TDS load and flow evident in this graph is the reverse of the relationship for TDS concentration and flow. That is, TDS load increases with flow volume. Among dominant springs Up Belcher, Down Belcher and Burnt Hollow, for a unit increase in flow, there is the same rate of increase in TDS load. However, dominant spring HMBC exhibits only half the increase (R^2 = 0.90). This situation for HMBC is opposite its quick decrease in TDS concentration with flow (see **Figure 3.8**).

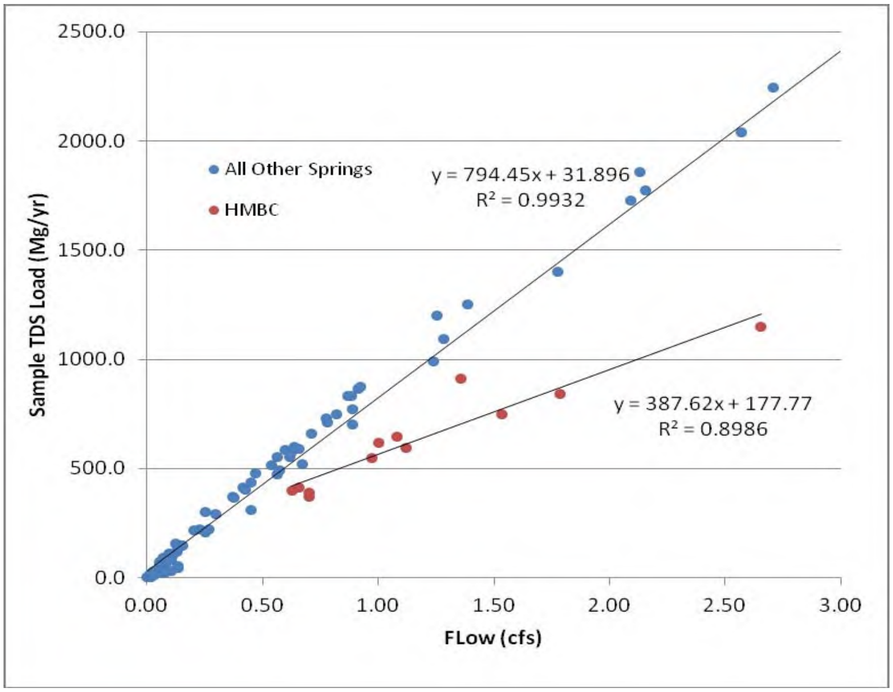


Figure 3.9 TDS load and flow for HMBC compared to all other mine springs (one extreme data point omitted = Down Belcher). [7]

7 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined]".

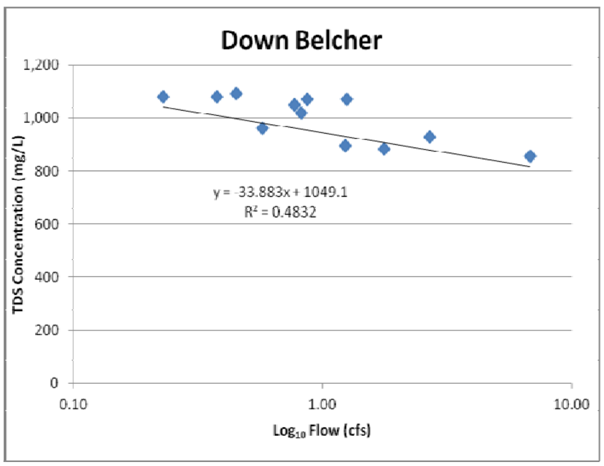
The uncertainty in the regression coefficients based on Monte Carlo permutation resampling is expressed by the approximate 95% confidence intervals (C.I.) in the following table. Because the regression slope intervals do not overlap, they are significantly different at the P(< 0.05) level.

Table 3.2 Uncertainty of coefficients for the regression of TDS load on spring flow.

Data	Resamples	Mean Intercept, a	Approximate 95% C.I. for a	Mean Regression	Approximate 95% C.I. for b
HMBC	1,000	155.0	+/- 132.0	413.5	+/- 130.8
Non-HMBC	300	26.3	+/- 19.8	808.6	+/- 45.7

Source: Bull Cr Regression MonteCarlo v05.xls.

The increase in TDS load with flow appears counterintuitive because, as demonstrated earlier, TDS concentration decreases with flow. The contradiction is resolved by the relatively minor fluctuation in TDS concentration compared to the major change in flow. That is, the volume of a spring controls its TDS load. The data for Down Belcher is used to demonstrate this point (**Figure 3.10**).



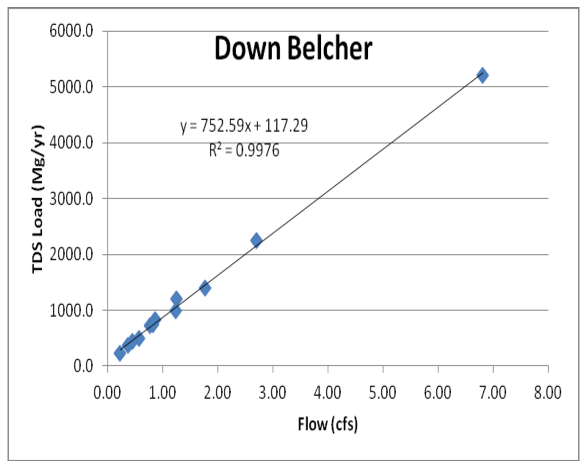


Figure 3.10 Change in TDS concentration and load with flow. [8]

TDS load is a product of TDS concentration and flow. Over the study period at Down Belcher, concentration decreased from about 1,040 to 820 mg/L; a decline of about 22%. Meanwhile, flow volume increased from about 0.25 to 6.9 cfs; an increase of 2,700%. Thus, while TDS concentration and flow volume are determinants of TDS load, by far the controlling variable is flow volume. TDS concentration can almost be considered constant. This provides a basis for projecting TDS loads in other mined watersheds with similar TDS concentration and flow volume ranges such as the South Fork Pound

8 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

River watershed. The same relationship is observed whether comparing the median TDS load for the springs in a hydrologic island or for a sample date (**Figure 3.11**).

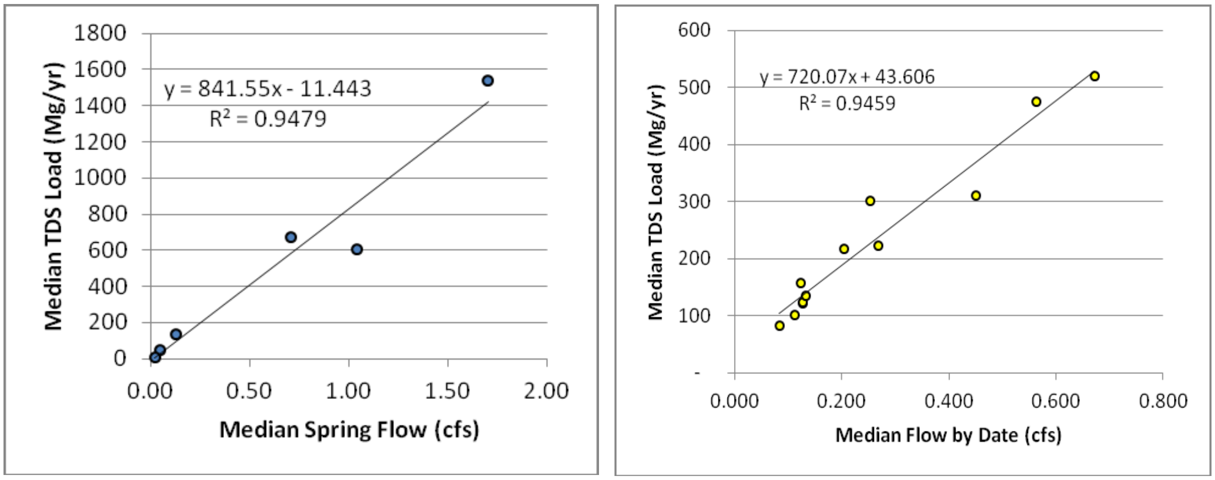


Figure 3.11 TDS load versus spring flow volume for 6 hydrologic islands (left) [9] and 12 sample dates (right) [10].

Among the four major springs, HMBC has an unusually slow rate of change in TDS load with flow (**Figure 3.9**). For the same increase in flow, HMBC shows a smaller increase in TDS load than the other dominant springs. But, the TDS concentration is also lower at HMBC. Coincidentally, the median HMBC flow is the highest monitored and less variable. Thus the source of groundwater for HMBC is less mineralized but larger in volume. This appears related to a large abandoned mine on the surface of the HMBC hill system (**Figure 3.7**). This surface mine scar is the largest of those on hydrologic islands with monitored springs in the watershed. Also, it covers a significant part of the surface of the hill system from which HMBC emerges. The hill system of HMBC is also extensively mined underground suggesting the groundwater should have a high TDS concentration. But if the groundwater is recharged in part through the surface mine with low-TDS rainwater (< 20 mg/L) that quickly moves through the hill caverns, the result would be the observed, moderate TDS concentration at HMBC. The AML (abandoned mine land) scar is very porous and should capture a larger fraction of rainfall. Therefore, it is proposed that the surface AML provides a large catchment for low-TDS rain which is rapidly conducted through mines in the HMBC hydrologic island to the spring. This would explain the unique relationship of TDS concentration and load to flow in the HMBC spring.

Belcher Branch is fed by Up and Down Belcher springs. Convict Hollow Creek flows parallel to Belcher Branch and is in the next stream valley to the east **(**see **Figure 3.1**). The hill systems bordering both sides

9 Source: Hydrologic Island Vars v02.xlsx.
10 Source: TDS_Monitoring_Analysis_v02_MJS.xls.

of Convict Hollow Creek have large AML areas. No spring monitoring was conducted along Convict Hollow Creek. However, based on the TDS and AML relationship for HMBC spring, it is proposed that if there are mine springs in the Convict Hollow Creek valley, they should be of high volume and low TDS concentration. The Up Belcher and Down Belcher springs emerge from hydrologic islands #1 and #2, respectively, in the southwestern part of the watershed. These islands are adjacent and mined mostly at one level and continuously from #1 to #2. Thus they are thought to be the same hill system. Their springs produce the largest TDS load in the watershed. The Belcher springs are also downhill from a large expanse of the Norton Mine.

3.5.1 Seasonal Patterns

Flow and TDS were measured in the mine springs from September 2012 through February 2013. Springs with high flow and moderate to high TDS concentration dominate TDS production in the Bull Creek watershed. Key contributors include Up Belcher, Down Belcher and Burnt Hollow due to combined high flow and high TDS concentration. Although the TDS concentration in HMBC is less than in these three springs, its higher flow volume makes it a large source as well. The TDS load dominance of these four sources is especially apparent in the later part of the sampling period when flow is elevated (**Figure 3.12**). Over the September to February sample period, the TDS load from the mine springs was low in autumn, moderate in early winter, and highest in late winter.

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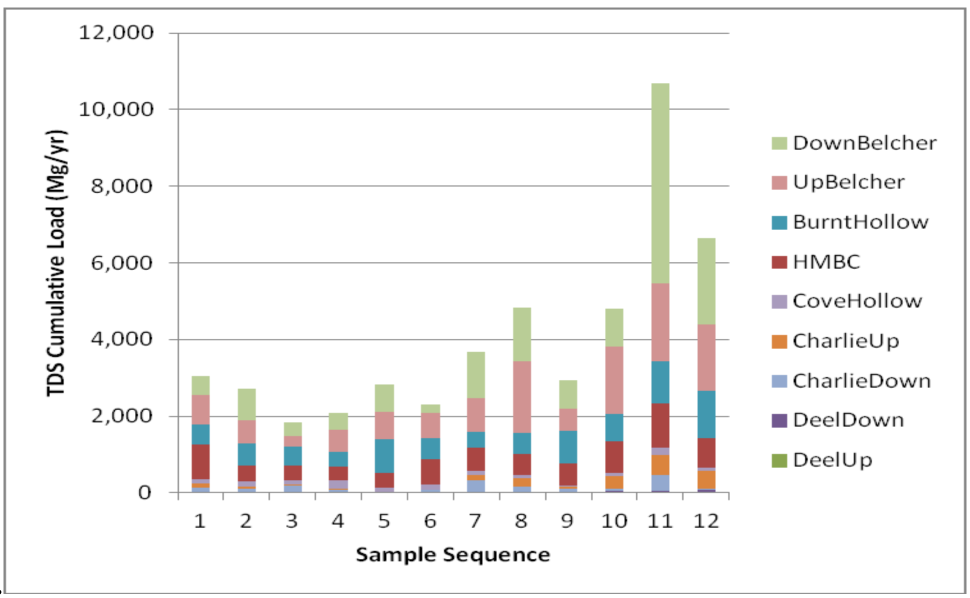

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Figure 3.12 TDS Load from mine springs over a six-month sample period from September 2012 through February 2013. [11]

3.5.2 Elevation

Elevation was expected to be inversely related to the flow of a spring because the hydrologic head typically increases with decreasing elevation. For example, Deel Up and Deel Down have the highest topographic position of the eight springs and lowest flow volumes. But when all springs are considered, there is only a minor indication of a relationship between the elevation at which a spring occurs and its median flow over the sample period (R^2 = 0.18, **Figure 3.13**). The four largest volume springs in the figures are the dominants Down Belcher, Up Belcher, Burnt Hollow and HMBC.

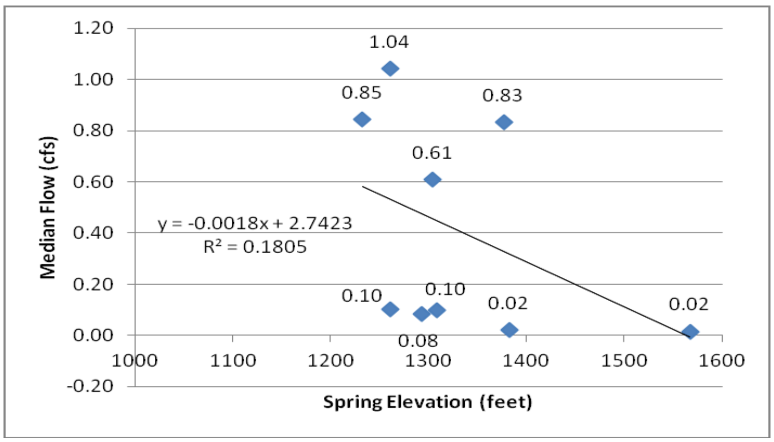
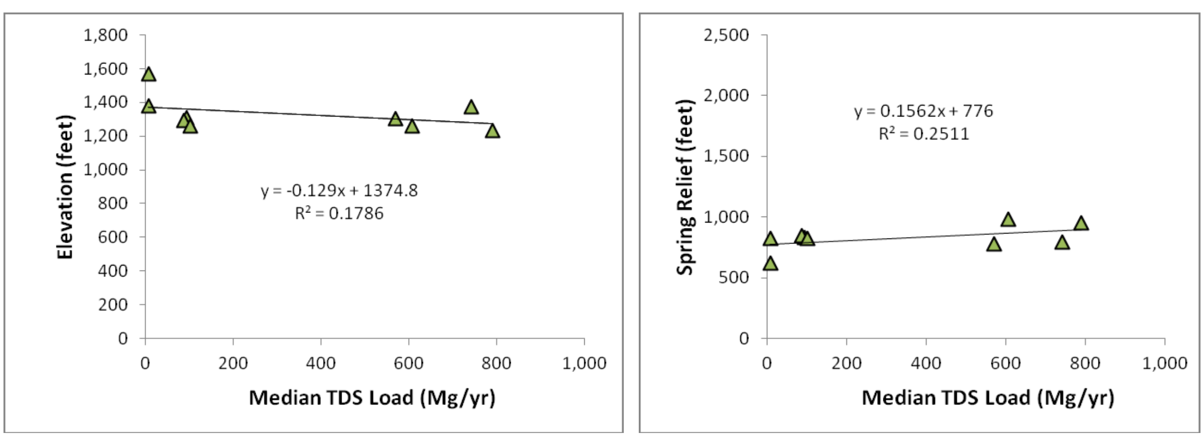


Figure 3.13 Median flow and elevation of mine springs. [12]

Likewise, springs at lower elevations might be expected to have a larger proportion of deep, mineralized water. There is a suggestion that spring elevation and the relief above the spring may play a role (**Figure 3.14**).



11 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].
12 From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

Figure 3.14 TDS Load with spring elevation (left) and relief (right) above spring. [13]

3.5.3 Precipitation

Because precipitation infiltrates the regolith to recharge groundwater, the amount of precipitation is expected to control the TDS load by contributing to flow. To examine this relationship, rainfall data from a station 7 miles from the watershed was obtained and summed for the month, and for the four-day period preceding each sampling event (US Weather Station ID GHCND:USC00443640).

Among the samples there is a modest increase in median TDS load with rainfall volume in the first four and a half months wherein TDS rises with recent rainfall ("Early", **Figure 3.15**). However, in the last three sample dates ("Late"), the relationship disappeared. In this last period of sampling, the flow at most springs increased substantially despite the lack of recent rainfall.

Historically, monthly precipitation averages about the same from one month to the next (**Table 3.3**). However, during the six-month study period, monthly precipitation deviated widely from this pattern. Precipitation was markedly low in November and February, and high in September and January. Thus the amount of rainfall preceding sampling events was expected to be a factor in determining spring volume. To test this hypothesis, the rainfall in the four-day period prior to sampling was totaled for the two sampling events each month as were flow volume and load. Based on the recent monthly values listed in **Figure 3.15**, there is no obvious relationship between rainfall and spring volume in the study data.

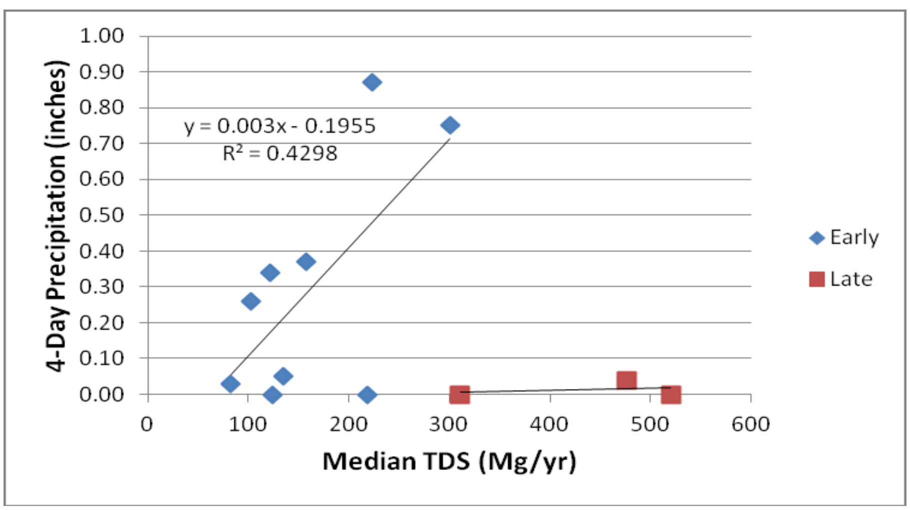


Figure 3.15 Sample date median TDS load and four-day precipitation separated into "Early" and "Late" sampling periods for monitored springs. [14]

13 From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].
14 TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined] and [Precip].

It is possible that precipitation is very local so that precipitation 7 miles distant is very different. It is also possible that spring flow is more dependent on deeper groundwater and little affected by local precipitation. On the other hand, our data set consists of only six data points collected over six months, which may be too few and in too short a period to elucidate any relationship. Whatever the case, there was a TDS load response to 4-day precipitation in the early part of the sampling period, but no evidence of direct precipitation impact on spring flow (**Figure 3.15**).

Table 3.3 Precipitation, spring flow, and TDS load over the study period.[15]

Sample Period	Precipitation				Spring Flow (cfs)	Median Month Spring Flow (cfs)	Median Monthly TDS Annual Load (Mg/yr)
	Historical Average (inch)	Observed (inch)	4-Day Prior to Sampling (inch)	Total 4-Day Prior to Sampling (inch)			
Early Sep. 2012			0.34		3.71		
Late Sep. 2012	3.14	6.47	0.00	0.34	3.05	3.38	2,879
Early Oct. 2012			0.37		2.08		
Late Oct. 2012	2.82	4.11	0.00	0.37	2.45	2.26	1,963
Early Nov. 2012			0.26		3.34		
Late Nov. 2012	2.91	0.71	0.05	0.31	2.81	3.08	2,569
Early Dec. 2012			0.75		4.14		
Late Dec. 2012	3.27	2.74	0.87	1.62	6.08	5.11	4,248
Early Jan. 2012			0.03		3.70		
Late Jan. 2013	3.19	5.92	0.00	0.03	6.86	5.28	3,879
Early Feb. 2012			0.00		14.84		
Late Feb. 2013	3.09	1.26	0.04	0.04	8.59	11.71	8,655
Total:	18.42	21.21	2.71	N/A	61.64	30.82	N/A

Note: Precipitation based on US Weather Station GHCND:USC00443640 about 7 miles east of study site.

3.6 TDS Load and Mine Springs

Of primary concern is the source of TDS in the mine springs. Although all nine springs are of interest, those of main concern are the dominant TDS sources. In **Figure 3.16**, blue arrows indicate the suspected direction of flow for each spring and, therefore, the immediate origin of TDS. The arrow width indicates its contribution to overall TDS load. The distribution of TDS load and flow between samples is highly variable based on the coefficient of variation of the data. Consequently, in comparisons of TDS load and spring volume, the median is used as the representative value instead of the mean.

15 Source: TDS v Flow with Totals and Averages_MJS_6.xlsx]Averages.

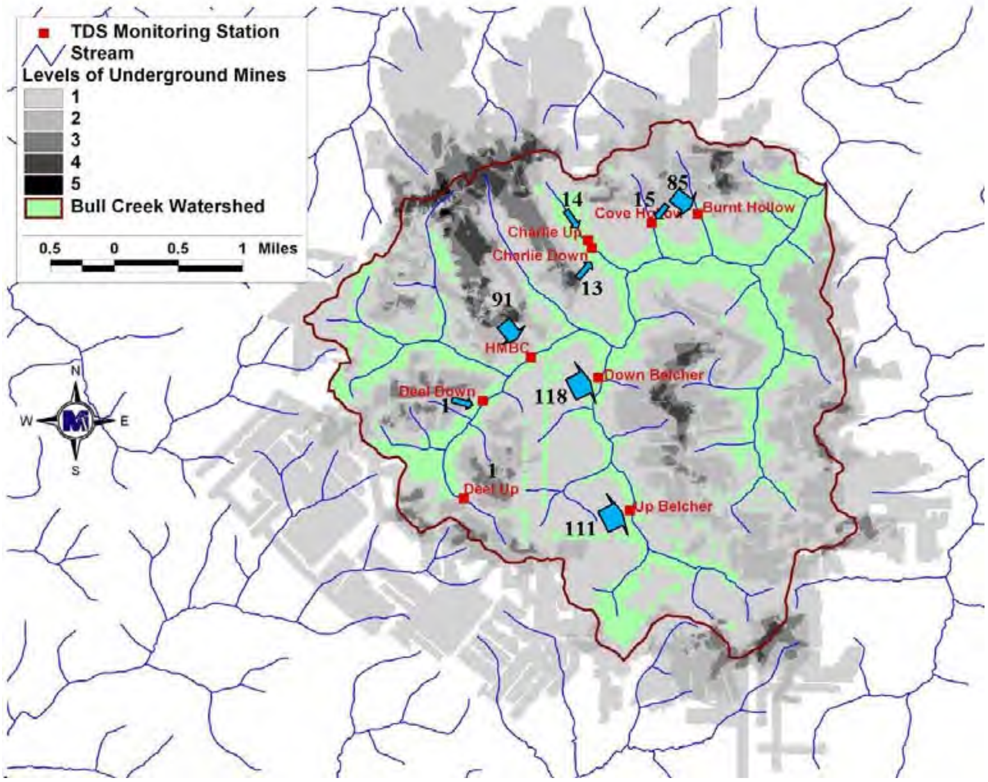


Figure 3.16 Relative Median TDS load and origin of spring flow.[16]

The Deel Up mine spring produces the smallest sample median TDS load (7 Mg/yr) over the sample period; about the same as Deel Down. Thus the Deel Up minimum was used as a base for comparing the loads indicated in **Figure 3.16**. Up Belcher and Down Belcher produce about equal TDS loads, over 100 times that at Deel Up (**Table 3.1**). Together they contribute 57% the TDS load in the watershed. Burnt Hollow and HMBC, also large sources, produce 85 and 91 times the load from Deel Up. Taken together, Up Belcher, Down Belcher, Burnt Hollow and HMBC (the dominant springs) account for 89% of the total TDS load. The remaining springs, Charlie Up, Charlie Down, and Cove Hollow, each produce about 14 times that from Deel Up. In summary, the mine springs that primarily determine the TDS load in the Bull Creek watershed are Up and Down Belcher, Burnt Hollow and HMBC.

3.7 Hydrologic Island

In the Bull Creek watershed, steep-sided hills are hydrologically isolated from one another by stream valleys into hydrologic islands. Groundwater accumulates in the hydrologic islands due to infiltration of rain that falls on the hill surfaces, and is released in springs. Because infiltration becomes groundwater,

16 From: DMME_TDS_Source_Arrows4.doc, *.pdf, *.png.

larger hill surfaces should accumulate more groundwater. Then the size of a hydrologic island footprint should be a factor in determining the volume of its springs.

The size of a hydrologic island in an un-mined watershed may be estimated through the topography (see **Figure 3.1 page 7)**. In the study area, although hill units may extend outside the Bull Creek watershed, the watershed divide is both an area of recharge for groundwater close to the surface, and a hydrologic divide. Surface groundwater within a watershed boundary tends to flow underground away from the divide towards the center of the watershed. Correspondingly, groundwater outside the boundary tends to flow in the opposite direction. Thus, hydrologic islands within the Bull Creek watershed operationally terminate at the watershed boundary. Where a spring emerges at the base of a hill, the hill system up-gradient is the spring's water source. i.e., its hydrologic island. **Figure 3.16** shows the inferred origin of the monitored springs in the Bull Creek watershed. **Figure 3.17** (page **23**) is a map of the hydrologic islands and their springs.

Mining complicates the consideration of groundwater availability and spring flow in a hydrologic island. As mentioned previously, abandoned coal mines can be reservoirs for groundwater. Coal mining in the Bull Creek watershed has been extensive, and at multiple levels where the topographic relief was sufficient to support it. These mine caverns are both conduits for rapid groundwater flow, and reservoirs for groundwater.

3.7.1 Functional Hydrologic Island

As mentioned earlier, in the study area groundwater tends to collect within hills above impermeable strata, and to behave separately from groundwater in adjoining hills. Consequently, it is useful to delineate hydrologically isolated hill systems in the watershed. This amounts to putting boundaries around the hills. Stream valleys are a logical indicator of the limits of hydrologic islands because that is where hill-derived groundwater discharges (Freeze & Cherry, 1979). However, if a stream is under-mined, it no longer forms a boundary. Consequently, the term "functional hydrologic island" is employed for hill systems that are separated by stream valleys but which share groundwater because the adjoining valleys are undermined. Functional hydrologic islands tend to be larger than "natural" hydrologic islands because mining has created underground conduits connecting two or more natural hydrologic islands into a functional whole. The proposed seven functional hydrologic islands with springs in the Bull Creek watershed are identified in **Figure 3.17**.

The hydrologic islands tend to be differently elongated. Elongated islands may generate higher TDS concentrations because the groundwater takes a longer mineral path. However, the length:width ratio was not examined in this study.

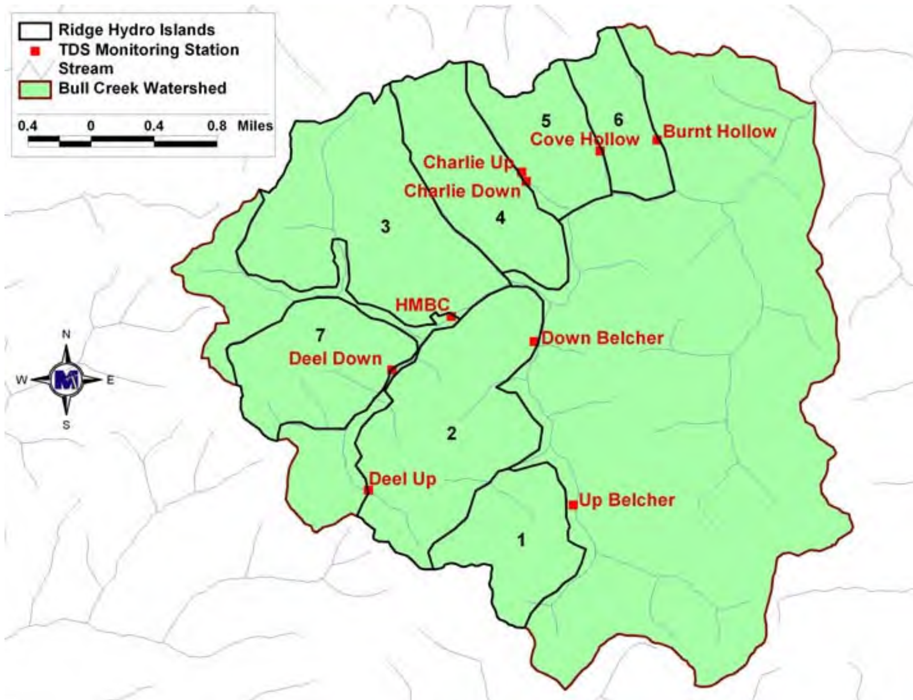


Figure 3.17 Functional hydrologic islands and mine springs in the Bull Cr. watershed.[17]

From a groundwater volume perspective, one important attribute of a functional hydrologic island is its surface area (**Table 3.4**). The surface area is the catchment for precipitation that recharges groundwater in the island. The surface area of the hydrologic island is taken to be its topographic footprint, the acres of land surface overshadowed by the hill when viewed from above. Admittedly, the surface area covers a three-dimensional bulge and so is larger than the footprint. Still, the footprint is likely to closely approximate the surface area since the islands are flat-topped and steep-sided. The relief of the island is the difference between the general elevation of the top, and the general elevation of the lowest part of the footprint.

17 Source: Hydro_Islands_v1.jpg

Table 3.4 Hydrologic island topography in the Bull Cr. watershed. [18]

Island No.	Island Foot-print (acre)	Top Elevation (ft)	Bottom Elevation (ft)	Relief (ft)	Standard Island Volume (10^9 ft^3)	Spring Elevation (ft)	"Spring Island" Relief (ft)	"Spring Island" Volume (10^9 ft^3)	Monitored Springs (dominant bolded)
1	359	2,172	1,427	745	12	1,377	795	12	**Up Belcher**
2	795	2,185	1,178	1,007	35	1232, 1567	953	33	**Down Belcher** + Deel Up
1+2	1154	2,185	1,178	1,007	51	1377, 1232, 1567	953	48	**Up Belcher + Down Belcher** + Deel Up
3	874	2,240	1,218	1,022	39	1261	979	37	**HMBC**
4	481	2,140	1,200	940	20	1309, 1293	847	18	0.5*Charlie Up + Charlie Down
5	324	2,095	1,065	1,030	15	1309	786	11	0.5*Charlie Up
6	244	2,085	1,035	1,050	11	1260, 1305	825	9	Cove Hollow + **Burnt Hollow**
7	444	2,207	1,312	895	17	1383	824	16	Deel Down
sum:	3,521				152			139	

Note: 1 acre = 43,560 square feet

The volume of the functional hydrologic island, "Standard Island Volume", in **Table 3** is calculated by multiplying the island footprint by its relief. Sometimes the lowest elevation of the island approximates that of the spring (**Table 3**). Because groundwater flows down the hydrologic gradient, the island volume above a spring or, "Spring Island Volume", is the more likely source of its groundwater. Then this volume is more likely to be related to spring flow volume and TDS concentration than the "Standard Island Volume". "Spring Island Volume" is based on the relief from the island top to the spring elevation. Where more than one spring emerges from the island, the lowest spring elevation is used in the volume estimate. Clearly, there are only minor differences between the standard island volume and the spring island volume. Consequently, for making other comparisons the standard island volume is used.

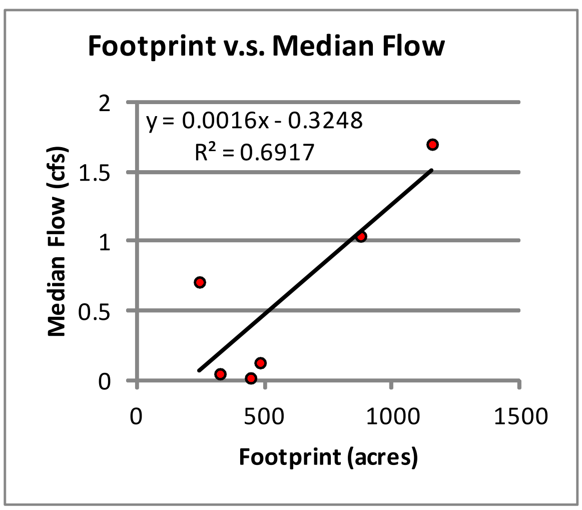
When all features of the Bull Creek hydrologic islands are compared to spring flow and to TDS concentration and load, island footprint stands out as the most consistently important (**Figure 3.18**). Footprint is correlated with spring flow volume and load; R^2 = .69 and .59, respectively.

18 Source: Hydrologic Island Vars v02.xlsx.

Table 3.5 Hydrologic island barriers, hydrology and TDS in the Bull Cr. watershed. [19]

Island No.	Largest Width of Valley Barrier (ft)	Smallest Width of Valley Barrier (ft)	Sum Medi-an Flow (cfs)	Flow-Weighted Median TDS Conc. (mg/L)	Flow-Weight. Median TDS Load (Mg/yr)[a]	Sum of Raw Median TDS Load (Mg/yr)	TDS Load Ratio[b]	Sum Mean TDS Load (Mg/yr)	Monitored Springs (dominant bolded)
1	339	339	0.83	1010	749	741	111	1,039	**Up Belcher**
2	678	678	0.87	1025	797	797	118 + 1	1,250	**Down Belcher** + Deel Up
1+2	678	678	1.70	1017	1546	1538	111+ 118+1	2,289	**Up Belcher + Down Belcher** + Deel Up
3	647	443	1.04	625	581	607	91	636	**HMBC**
4	990	628	0.13	1131	131	134	0.5*14 + 13	211	0.5*Charlie Up + Charlie Down
5	1102	452	0.05	502	22	47	0.5*14	83	0.5*Charlie Up
6	1498	370	0.71	1065	676	670	15 + 85	797	Cove Hollow + **Burnt Hollow**
7	647	629	0.02	475	8	8	1	17	Deel Down
Totals			**5.35**		**2,964**	**3,003**			

a product of Sum Median Flow and Flow-Weighted Median TDS Conc.
b ratio is based on "Sum of Raw Median TDS Load" divided by 7, that in Deel Up; **Table 3.1**.



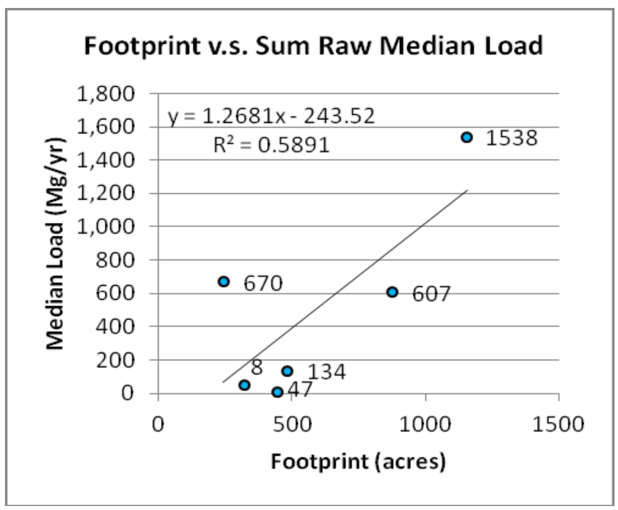


Figure 3.18 Hydrologic island footprint relationship to spring flow (left) and TDS load (right).[20]

19 Source: Hydrologic Island Vars v02.xlsx, and TDS v Flow with Totals and a

3.7.2 Barriers to Groundwater Flow

Stream beds are very permeable and, when undisturbed, are zones where groundwater emerges from rocks below the stream bed and from surrounding hills. Thus these depressions in the ground surface delimit hydrologic islands and represent barriers to horizontal groundwater movement. Further, the broader the un-mined area under a stream valley, the greater barrier it presents. These barriers are shaded green in **Figure 3.19** where the average boundary width is indicated at critical points. The largest and smallest boundary widths proximate to the spring in a hydrologic island are listed in **Table 3.5**. Although perennial streams in the watershed have been undisturbed by mining, most intermittent streams have been under-mined. Under-mined streams are shown in **Figure 3.19** as blue lines.

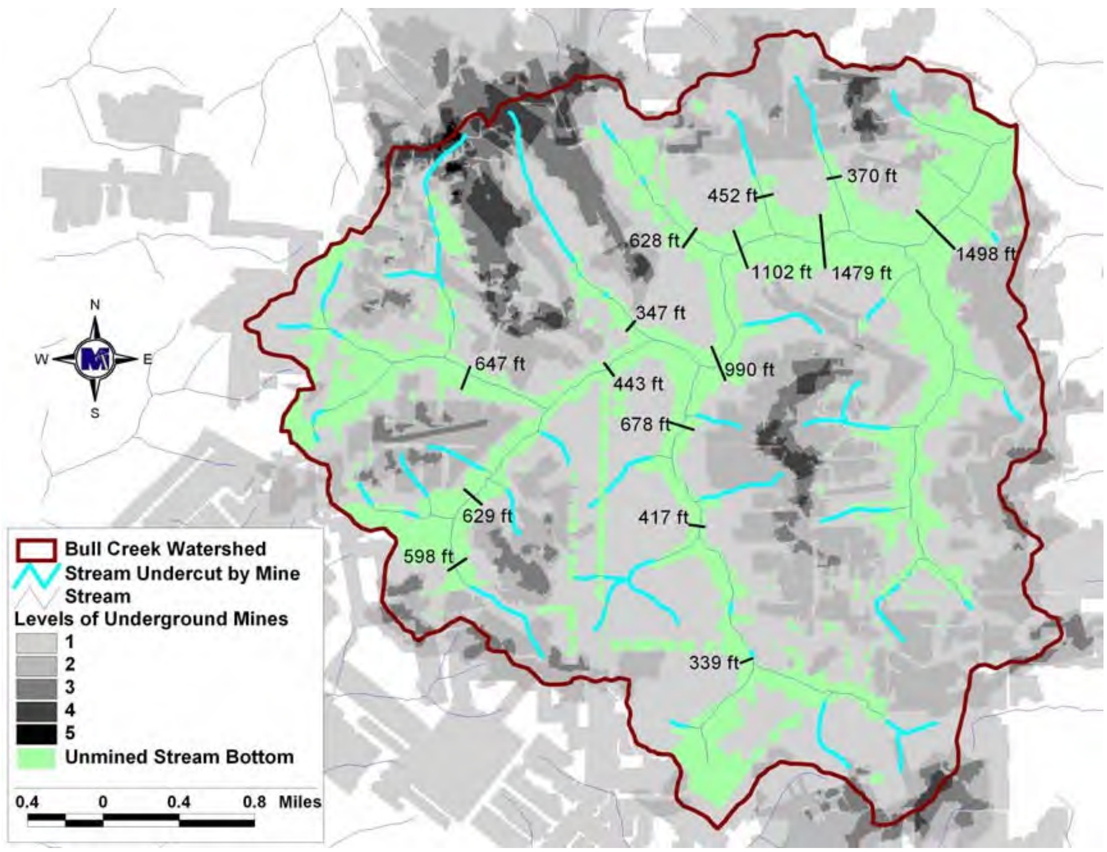


Figure 3.19 Hydrologic buffers (green) and under-mined headwater streams (cyan).

Under-mined streams may reverse their operation by acting as recharge zones where precipitation and overland flow move downward to groundwater. For this reason they are not thought to define the periphery of functionally hydrologic islands from a groundwater perspective. The stream barriers and

20 Source: Graphs Island Dimensions vs Load.xls.

under-mined streams in **Figure 3.19** were considered when delimiting the hydrologic islands in **Figure 3.17**.

3.7.3 Hydrologic Islands and Springs

Islands #1 and #2 are considered one unit, “#1 +#2”, because of the undermining of the intermittent stream valley between them. It has by far the largest footprint and hill volume in the Bull Creek watershed (**Table 3.4**). Consequently, as expected, it yields the largest volume of spring (1.70 cfs) and the largest median TDS load (1,546 Mg/yr). Next in footprint size and hill volume is hydrologic island #3 which has the second highest flow and produces the third highest TDS load. Hydrologic island #3 is associated with the HMBC spring in which TDS and flow are significantly affected by the AML on the hill surface. There is a stream valley between hydrologic islands #3 and #4 that has been undermined for more than half its length. If, as this suggests, the two islands are a single functional unit, that would help explain the volume of flow in HMBC. Following island #3 in size of footprint and hill volume is island #4 from which issue Charlie Up and Charlie Down springs. Although its TDS concentration is the second highest of the islands, its spring flow volume is low. Thus it produces only moderate TDS load.

Among the smaller islands, the leader in TDS load is #6 with the greatest relief of all hydrologic islands. Its footprint and volume are smaller than in units #5 and #7. But its spring volume far exceeds that of islands #4, #5, or #7. Thus it produces one of the top TDS loads through dominant spring Burnt Hollow, and moderate spring Cove Hollow. It is also possible that hydrologic islands #6 and #5 are a functional unit because the stream valley between them has been partially undermined. Small hydrologic islands #5 and #7 contribute only minor TDS loads through springs Charlie Up and Deel Down, respectively. Island #7 has the smallest footprint, and its spring Deel Down is located well above most other springs which may explain the small TDS load. In conclusion, the hydrologic footprint appears to be a reasonable determinant of the volume of spring flow and thereby TDS load.

Table 3.6 Regression of spring flow and TDS load against island footprint.[21]

Parameter	Estimate	Std. Error	p (t-value)
Median Flow, intercept a	-0.3248	0.3553	0.412
“ “, slope b	0.0016	0.0005	0.040
Sum Raw Median Load, intercept a	-243.5	354.5	0.530
“ “, slope b	1.268	0.530	0.075

The statistical relationship of island footprint to spring flow volume and to TDS load is tabled above. Neither intercept is significant. The probabilities for the slopes are marginal principally because of the

21 Source: Graphs Island Dimensions vs Load.xls.

high leverage of island #6; its load and flow are higher than predicted by the regressions. This suggests that the footprint of island #6 is underestimated. Given the statistical improvement of the results when island #6 is removed, the models in **Table 3.6** will be used in a later section to predict spring flow and load in the South Fork Pound watershed. In conclusion, hydrologic footprint appears to be a reasonable determinant of the volume of spring flow and thereby TDS load.

3.8 Mining Extent

The Department of Mines, Minerals and Energy provided ArcView shape files for mine floor space in and near the Bull Creek watershed. ArcView was used to measure the aerial extent of the mining.

It has been noted earlier that the Bull Creek watershed has been mined extensively. To provide some organization to the mining data, the study area was divided into mine units that appeared unconnected. Essentially, the five units are outlined in **Figure 3.20** in red are separate mainly because they are unconnected by mine galleries.

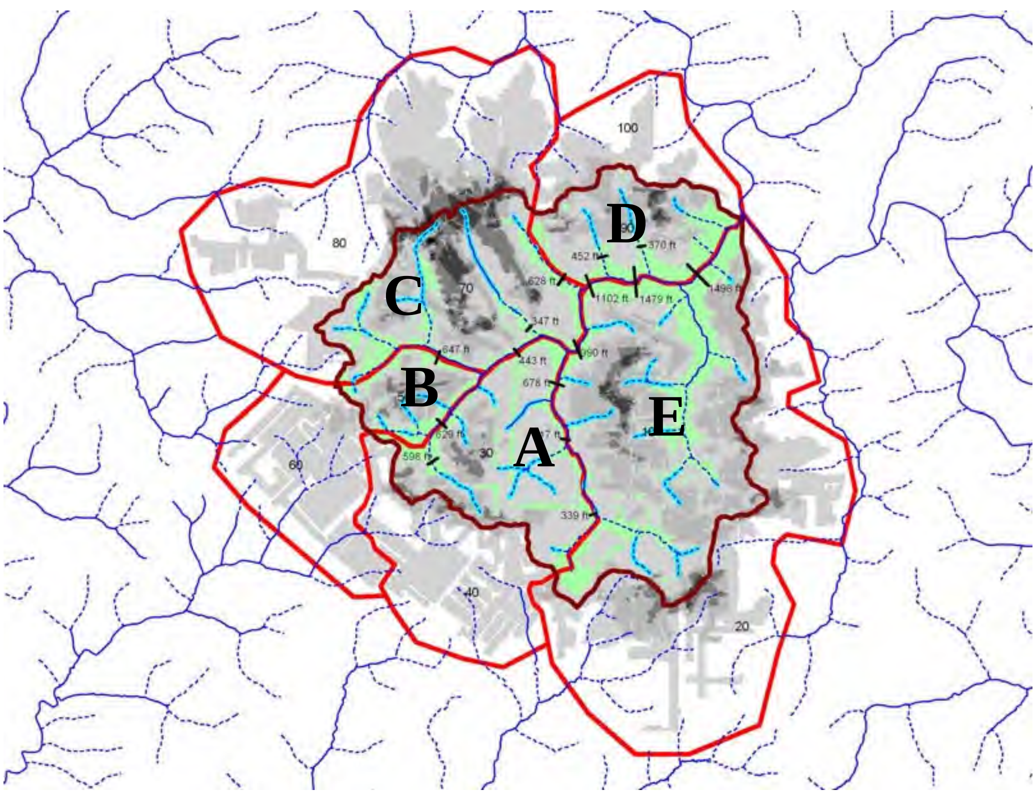


Figure 3.20 Mine units in the Bull Creek watershed area.

While units A, B and E exhibit no obvious connection to other mined areas, areas C and D do have a few connections to bordering mine units. Mined subareas within the individual units have been mined at two or more levels, have multiple connections, and thereby are likely to share groundwater. Then, for purposes of analysis, the five units may be considered separate sources of mine water. Each unit also extends beyond the Bull Creek watershed boundary. Because groundwater, especially surface groundwater, tends to flow from the highlands towards streams that feed the watershed outlet (Freeze & Cherry 1979), it is reasonable to distinguish the mined area inside the watershed from that outside. The mining characteristics of these mined areas are listed in **Table 3.7**.

Two measures of mining were expected to be useful in terms of predicting groundwater quality and quantity, mine footprint and total mine floor. Looking down on the land surface, the area that has been mined is referred to as the "mined footprint". This area together with the un-mined footprint equals the area of the mine unit.

Because mines tend to collect and transport groundwater, areas with multiple mine levels should be better collectors and conduits of groundwater. Consequently, the total mine floor in a unit was measured. This is the "Total Mine Floor" value in **Table 3.7**. Also, the mine floor within the watershed is presented separate from that outside because the watershed boundary is a groundwater hydrologic divide.

It is believed that the sampled springs originate from mines. In attempting to relate mine parameters to the TDS in a spring, there is no tie between mine and spring elevation except that the spring is reported to originate in a mine. Thus the elevation of a spring and its groundwater source could vary from the level of the lowest mine, to the highest. Despite this uncoupling, the general relationship between spring TDS and mine footprint or floor space should be detectable.

3.8.1 Impact on Flow

Mining techniques that open passages in hills make them more porous to groundwater. Thus mine caverns may serve as reservoirs for groundwater. Mining impacts hills in three dimensions. But, because mine galleries tend to be a consistent height, mine floor space is a good yardstick of mining extent. Then mine floor space summed across all levels in a hill system, should reflect the potential size of the groundwater reservoir.

Mine interconnections provide conduits for groundwater movement between mine cells. Then, extensively mined hills are expected to produce larger volume springs. As discussed earlier, spring volume is the primary factor controlling TDS load in mine springs. Then the impacts of mine parameters on TDS concentration are likely to produce only minor changes in TDS load. The impacts of mining on TDS are discussed next.

Table 3.7 Watershed footprint, mine extent, and spring characteristics in the Bull Creek watershed. [22]

Mine Area	Location With Respect to Bull Cr. Watershed	Mined Footprint (ac)	Un-Mined Footprint (ac)	Total Footprint (ac)	Mined Levels	Total Mine Floor (ac)	% of Footprint Mined [a]	Ratio Mine Floor to Footprint [b]	Sum Median Spring Flow (cfs)	Sum Median TDS Load (Mg/yr)	Monitored Spring
A	inside	1115	345	1460	3	1464	76%	1.0	1.70	1,538	Deel Up + **Up Belcher + Down Belcher**
	outside	855	534	1389	3	948	62%	0.7			none
	total	1970	879	2849		2412	69%	0.8			
B	inside	315	152	467	3	546	67%	1.2	0.02	8	Deel Down
	outside	777	544	1322	2	813	59%	0.6			none
	total	1092	696	1788		1359	61%	0.8			
C	inside	1359	365	1724	5	2534	79%	1.5	1.17	741	0.5*Charlie Up+Charlie D+**HMBC**
	outside	1513	1844	3357	5	1982	45%	0.6			none
	total	2872	2209	5081		4516	57%	0.9			
D	inside	705	289	994	4	1097	71%	1.1	0.76	717	0.5*Charlie Up+Cove Ho+**Burnt Ho**
	outside	373	527	900	3	426	41%	0.5			none
	total	1078	815	1894		1523	57%	0.8			
E	inside	2331	755	3086	4	3671	76%	1.2	NA	NA	none
	outside	1443	1790	3233	4	2001	45%	0.6			none
	total	3774	2544	6318		5672	60%	0.9			
Totals	inside	5,825	1,906	7731		9,312	75%	1.2			
	outside	4,961	5,239	10201		6,170	49%	0.6			
	total	10,786	7,143	17930		15,482	60%	0.9			

a .. = 100% * mined Footprint / Total Footprint; implies the percent of area mined.
b .. = Total Mine Floor / Total Footprint; implies the extent of mining in the hill; e.g., 1.5 indicates mining has removed an area equal to 1 ½ times the footprint.

3.8.2 Impact on TDS Concentration

Because mine galleries tend to be a fixed height, the groundwater exposure to minerals in mines should be a linear function of mine floor space. The larger the mined floor space the greater the exposure. Then the amount of mine floor in a hill should relate to the TDS concentration. **Table 3.7** lists the mine floor space for each of the five mined units in the Bull Creek watershed. A larger reservoir may lead to longer

22 From Mine Footprint Vars v02.xls.

groundwater detention time which should result in higher TDS concentration. However, in hills made porous by mining, the water detention time is reduced leading to lower TDS concentration in the groundwater. Therefore, mining may increase or decrease TDS concentration.

3.8.3 Mine Footprint

While the amount of mine floor in a hill system relates to the groundwater volume of a hill system, the footprint still has some attraction. The percent mined footprint (as a % of total footprint) suggests the extent of mining across the hill system. Mining could be extensive, even at several levels, but be restricted to only a portion of the system.

The principal mining factors controlling groundwater and TDS are expected to be those within the Bull Creek watershed because groundwater moves from the watershed boundary downhill. However, mining just outside the watershed boundary, especially if extensive, may modify groundwater volume or TDS in the watershed. Consequently, an estimate was made of the mine footprint and mine floor of the extent of mines in and around Bull Creek watershed (**Table 3.7**).

3.8.4 Mine Units

Mine unit A seems unique in that more than 50% of it has been mined primarily at one level compared to units C and E which have been mined at multiple levels. Mine unit A is the same as hydrologic island #1+#2. Mine Unit A has the highest spring volume among the four mined areas with springs. Therefore, it yields the highest TDS load. Dominant springs Up Belcher and Down Belcher are the contributors. Unit A's mined footprint and total footprint are the second largest of the four mined areas with springs. It also has the second largest mine floor.

Mine unit B has the smallest total footprint inside the watershed, and, as might be expected, the smallest mined footprint. It has by far the smallest mined floor space and the smallest percent of mined footprint to total footprint (67%). Consequently, its spring Deel Down has the lowest TDS load of all mine units with springs. Unit B covers the same area within the Bull Creek watershed that hydrologic island #7 covers.

Unit C, of the spring-monitored units, has the most extensive total footprint, mine footprint, and number of mine floors. Consequently, unit C has one of the highest spring volumes and TDS loads, although these measures are only about half the values in unit A. Its springs include dominant spring HMBC and moderate volume springs Charlie Up and Charlie Down. Unit C covers the same area within the watershed as hydrologic islands #3 and #4 combined.

Mine unit D has a mined and total footprint more than half the size of A, and produces about half the TDS load. The ratio of mined footprint to total footprint in D is also smaller; 71% versus 76% while its ratio of mine floor to footprint is slightly larger. Unit D covers, within the watershed, the same area as hydrologic islands #5 and #6.

Mine unit E is the largest in the study area. But it lacks monitored springs and so provides no indication of the relationship between mine features and spring water quality or quantity.

Based on the above discussion, for predicting TDS load or spring volume, mine parameters appear useful measures for distinguishing mine units. The identified mine units appear to have reasonable boundaries but there does not appear to be a relationship to TDS load or flow volume for the measured mine parameters. Perhaps because of the small number of units for comparison there is not a clear relationship between the examined parameters and TDS load and flow volume as there was for hydrologic island footprint. As an example of the lack of relationship, mine unit loads are graphed against mine floor area in **Figure 3.21**. The R-squared coefficient of 0.13 suggests there is no clear relationship. The spread of data points suggests much more data are needed to determine whether any relationship exists.

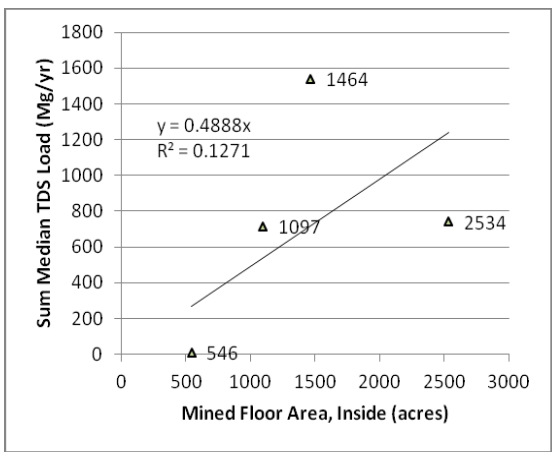


Figure 3.21 Relationship between mine floor and TDS load in the Bull Cr. watershed. [23]

23 Source: Mine_param_totals.xls[Totals].

4. South Fork Pound River Watershed and Monitoring

Water quality data have been collected since about 1995 in the South Fork Pound watershed. Samples have been collected in-stream (**Figure 4.1**) as well at National Pollutant Discharge Elimination System (NPDES) outfalls associated with mining (**Figure 4.13**). These data are discussed in the following sections. Following that, hydrologic islands and mining activities are detailed.

4.1 In-stream Water Quality, S. F. Pound

The TDS load at the final S. F. Pound watershed outlet originates primarily in the upper watershed. It can be traced up the mainstem of the river in which the load remains approximately constant from the outlet across the lower watershed and halfway up the upper watershed. Thus, although the outlet has a TDS load of 29.4 $*10^6$ kg/yr (station #12), half way up the upper watershed it is 28.3$*10^6$ kg/yr (station #27); about the same (**Table 4.1**). Over that distance the stream volume decreases by one third and the TDS concentration correspondingly increases upstream. That the source of TDS is not in the lower watershed is supported by noting that the TDS concentration at station #14, which drains the southeast quarter of the lower watershed is 424 mg/L.

4.1.1 Mainstem

Generally, the mainstem in the lower watershed has about 28% higher flow than the upper watershed because of its larger catchment (comparing stations #12 and #37). But the TDS concentration is about 25% lower. Thus, the TDS load at the outlet of the lower watershed is only slightly larger than in the upper watershed. The differences in potential loads from the two parts of the S. F. Pound River watershed contrast more when normalized to 11,000 gpm, the flow at the outlet. The normalized loads emphasize the TDS strength of mainstem streams in the upper watershed.

4.1.2 Intermittent streams

Intermittent streams in the lower watershed on average have TDS concentration medians ranging from freshwater range to dilute mine water; 236 - 958 mg/L. This is expected because there is very little mining in the area so that few mineral-rich discharges are available to add TDS. On the other hand, intermittent streams in the upper watershed are fed by many mineral-rich discharges regularly generating high TDS concentrations. Based on 2012-2013 data, the TDS concentration median range is 1,189 – 3,265 mg/L. The difference in tributary TDS strength is especially evident when the TDS load is normalized to a flow of 11,000 gpm as provided in **Table 4.1**.

It is worth noting that a tributary in the lower watershed contains less than 4% the TDS load of the mainstem, while a tributary in the upper watershed contains up to 14% of the mainstem load.

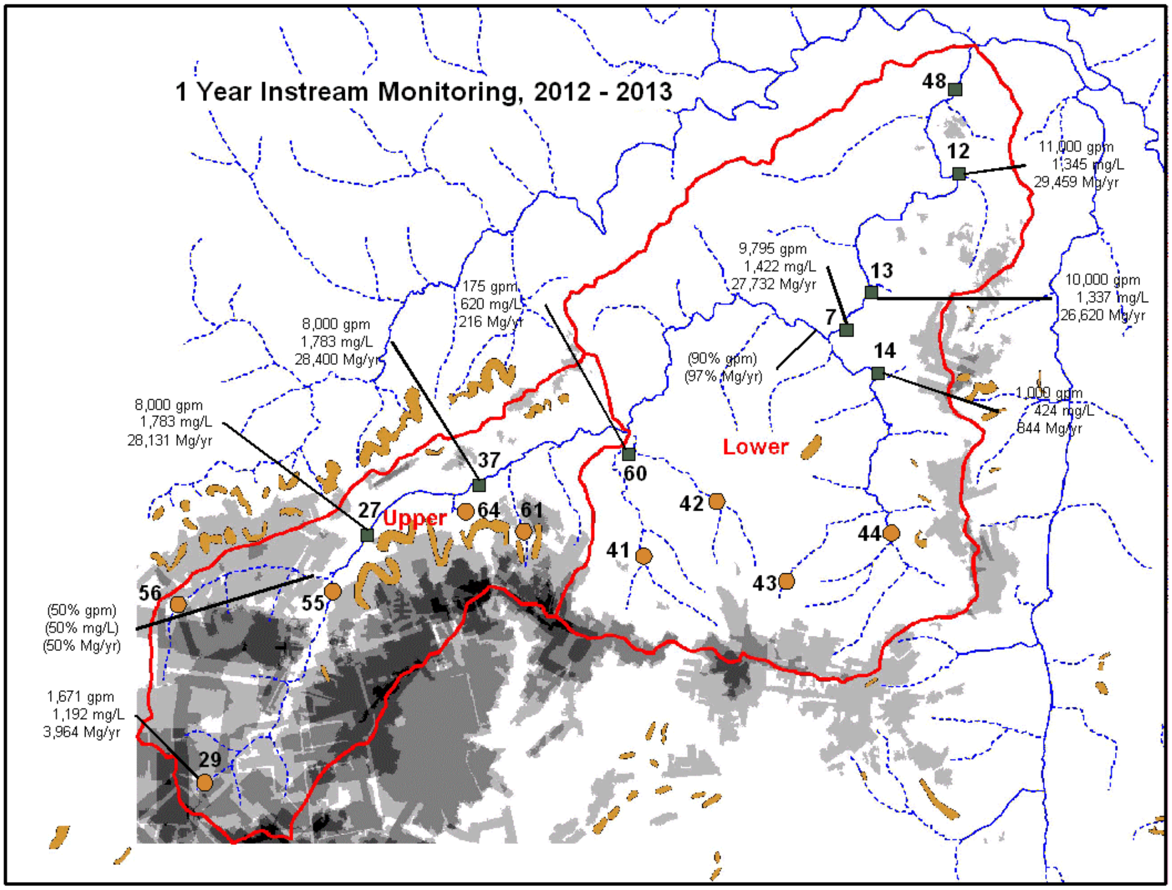


Figure 4.1 In-stream median TDS, TDS load (Mg/yr), and stream flow for one year in the S.F. Pound River watershed. Squares mark perennial streams and circles mark intermittent stream stations.[24]

4.2 Seasonality

A comparison of mainstem flow seasonality was attempted for 2009-2013 (**Figure 4.2)**. Of note is the disparity between the median flow at station 12 of 25,500 gpm for the period and 11,000 gpm for the current year. The period of record flow is double that predicted from feeder stations 13, 7, and 37 for the same period and so is erroneous. This means the TDS loads would be over-estimated as well. Consequently, flow was examined for station 7 a few miles upstream. In both the lower and upper watersheds, mainstem flow is somewhat lower during the growing season (**Figure 4.2**). At the same

24 Source: SFP_Monitoring_v4.png; SFP_Monitoring_v4.vsd.

time, TDS load tends to be higher during the growing season in both watersheds (Figure 4.3).

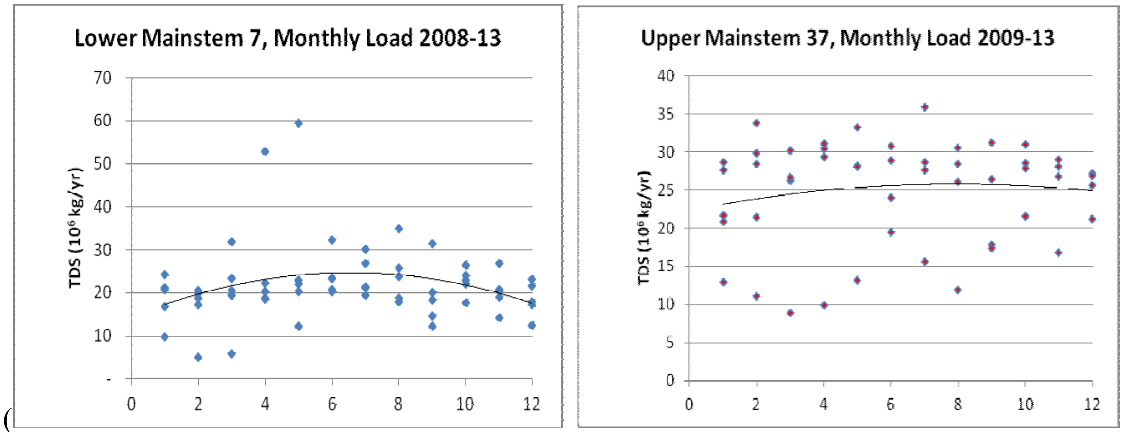


Table 4.1 In-stream water quality over the recent 12 months as mapped in Figure 4.1 for the S. F. Pound River watershed.[25]

Watershed	Map No.	DMME MpNo	Median Flow (gpm)	Median TDS conc. (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period
Perennial							
Lower, mainstem*	**12**	0007245	**11,000**	**1,345**	29.394	29.4	2012-13
" "	**13**	0007246	**10,000**	1,337	26.563	29.2	2012-13
" "	**7**	0006928	**9,795**	1,422	27.673	31.1	2012-13
" " , tributary	**14**	0007696	1,000	424	0.842	9.3	2012-13
Upper, mainstem	**37**	3420109	8,000	**1,783**	28.339	39.0	2012-13
" "	**27**	3420066	8,000	**1,766**	28.069	38.6	2012-13
Intermittent							
Lower, tributary	**60**	3420267	175	620	0.216	13.5	2012-13
" "	**44**	3420178	**450**	498	0.445	10.9	2012-13
" "	**43**	3420177	38	958	0.072	20.9	2012-13
" "	**42**	3420176	5	236	0.002	5.2	2012-13
" "	**41**	3420175	75	834	0.124	18.2	2012-13
Upper, tributary	**61**	3420268	43	**2,843**	0.243	62.1	2012-13
" "	**64**	3420271	30	**3,265**	0.195	71.4	2012-13
" "	**55**	3420257	**500**	736	0.731	16.1	1995**
" "	**56**	3420258	88	551	0.096	12.0	1995**
" "	**29**	3420085	**1,671**	**1,192**	3.957	26.1	2012-13
" "	**39**	3420111	1,685	1,189	3.980	26.0	2012-13

* ..outlet of the S. F. Pound watershed.

25 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[tab: Instream Extracted].

** .. no more recent data. TDS concentrations from this period are substantially lower than in 2012-13.

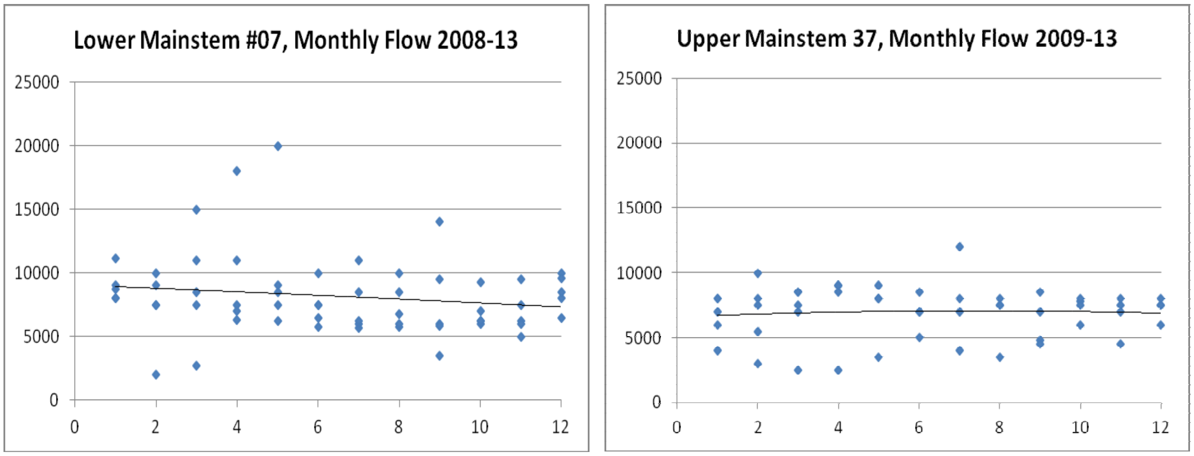


Figure 4.2 Monthly flow (gpm) in the lower (station 07) and upper (station 37) S. F. Pound. [26]

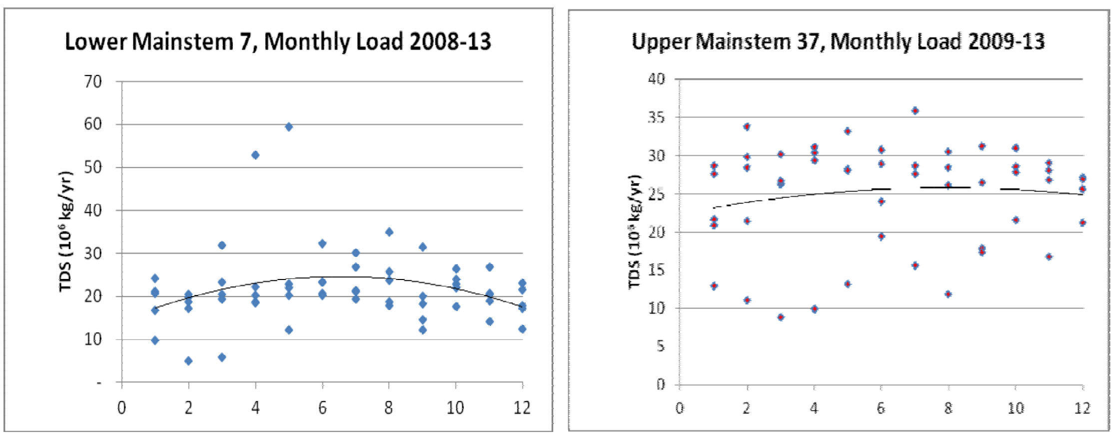


Figure 4.3 Monthly TDS Load (10^6 kg/yr) in the lower and upper S. F. Pound.

Based on the most recent year's data, mainstem flow in the upper watershed tends to fluctuate around a median flow of 8,000 gpm (stations 37 and 27; **Figure 4.4**). Meanwhile, tributary flow tends to be low in the growing season and high from November through March (stations 64 and 61; **Figure 4.4**).

26 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

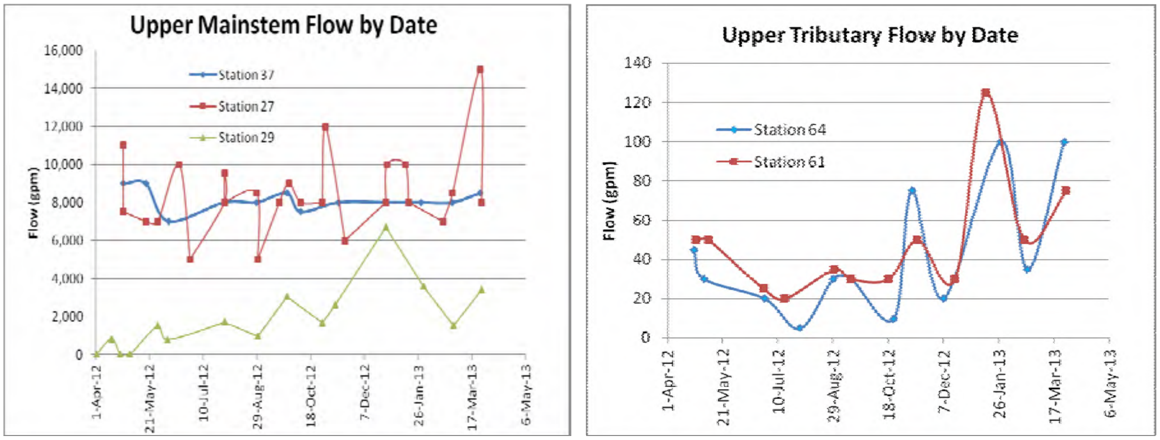
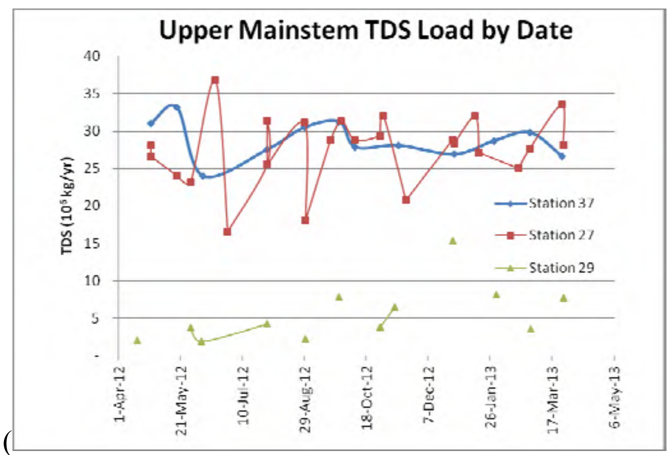


Figure 4.4 Mainstem and tributary flow (gpm) in the upper S. F. Pound. [27]

Based on recent data, mainstem TDS concentration and load also fluctuate around the median in the mainstem (**Figure 4.5**). However, tributary stream TDS concentration is highest in the growing season, and as much as double that in the mainstem. While TDS load tends to fluctuate about the median in the mainstem, tributary TDS load is highest when the flow is high from November through March (



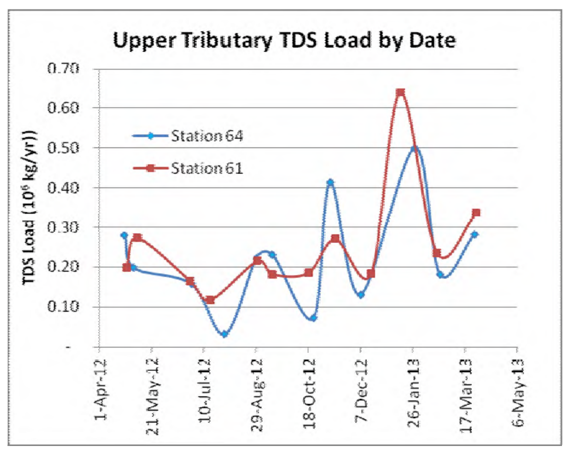


Figure 4.6). The seasonal tributary TDS load pattern is similar to that for Bull Cr. watershed springs.

In the upper watershed, the great difference in mainstem and tributary loads and the difference in seasonality indicates that tributary TDS-loading of the mainstem is diluted by substantial runoff and other low-TDS sources in the upper S. F. Pound watershed.

27 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_Extracted].

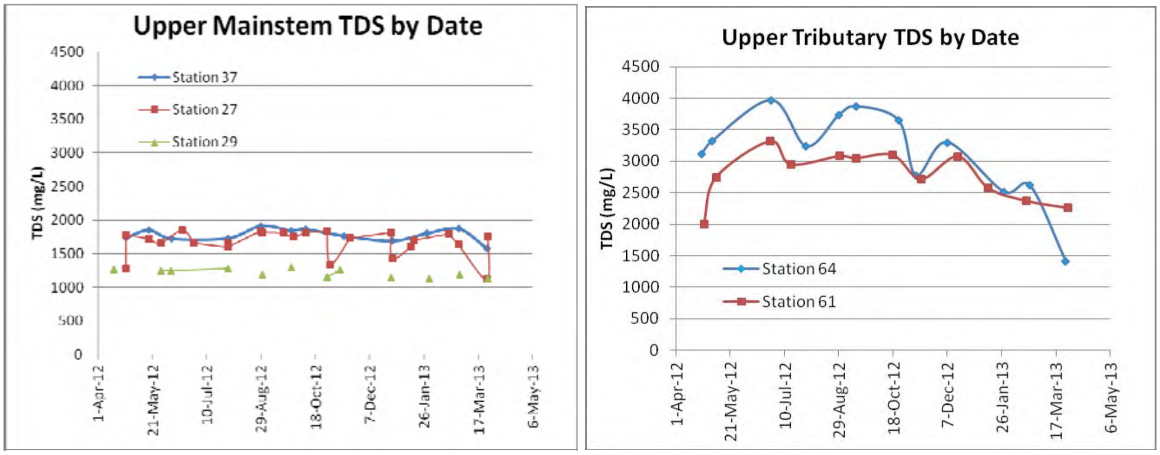


Figure 4.5 **Mainstem and tributary TDS concentration (mg/L) in the upper S. F. Pound.** [28]

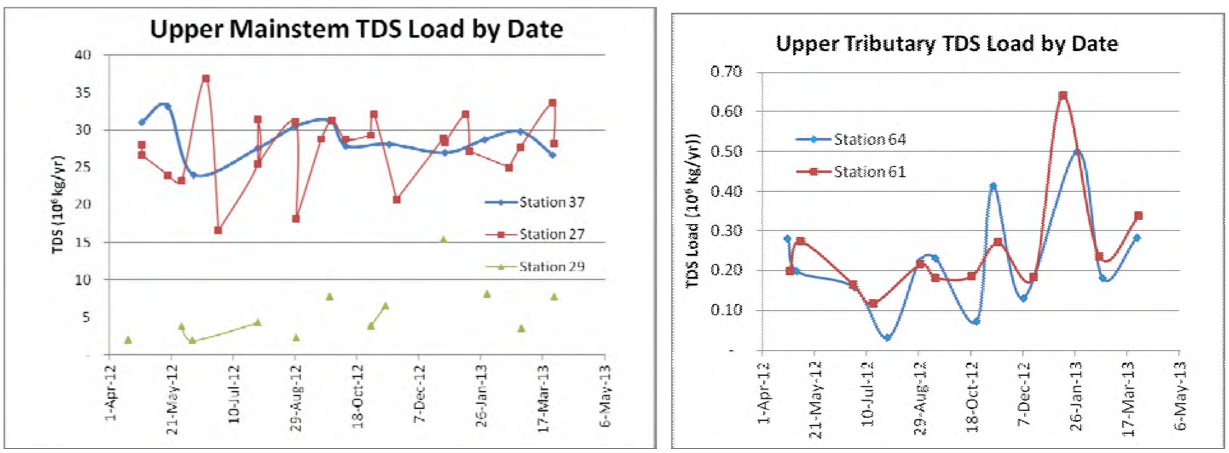


Figure 4.6 **Mainstem and tributary TDS load (10^6 kg/yr) in the upper S. F. Pound.** [29]

4.3 In-stream Historical Patterns, S. F. Pound

In-stream water quality data for the S. F. Pound mainstem and tributaries have been collected since 1995. A few stations have been monitored continuously over that period. The recent conditions of TDS concentration, TDS load and flow are indicated in **Figure 4.1**.

Near the outlet of the S. F. Pound watershed is in-stream station 48. Because it was only monitored from 1995 through 2005, the data for station 7 has been added to complete the TDS record through 2013 although there is a 2006 gap. Note that the data for station 7 has not been adjusted to account for the smaller catchment at station 7.

28 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_Extracted].
29 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

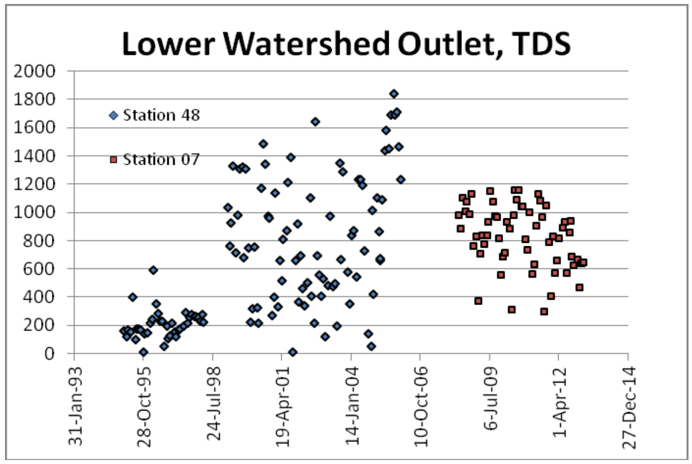


Figure 4.7 In-stream TDS concentration (mg/L) at the S. F. Pound River watershed outlet.[30]

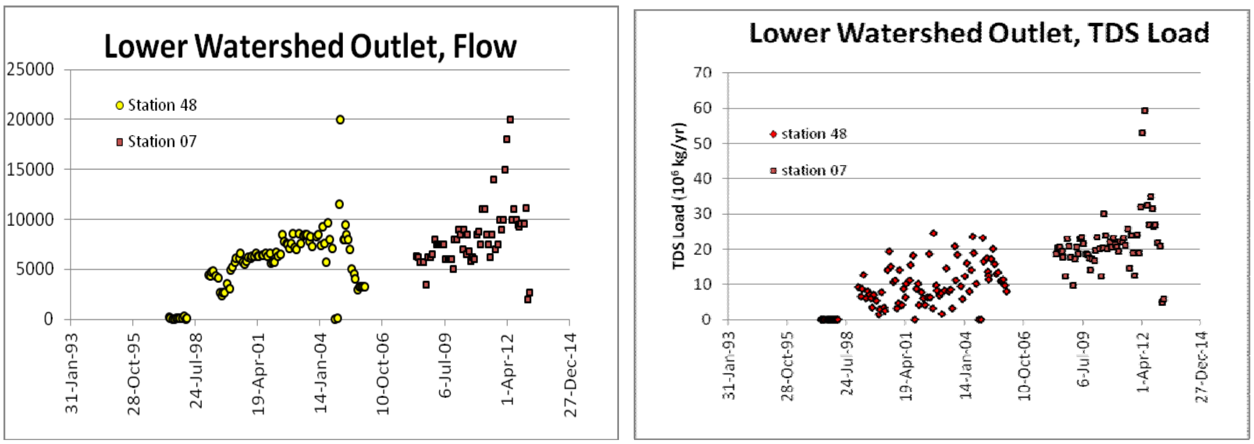


Figure 4.8 In-stream flow (gpm) and TDS load (10^6 kg/yr) at the S. F. Pound River watershed outlet.[31]

At station #48/#07, the TDS concentration abruptly rose 600 mg/L in early 1998 and became more variable (**Figure 4.7**). The early TDS concentration was often typical of freshwater, while after 1997 the TDS was mainly in the range expected of mine discharge waters (>620 mg/L). Meanwhile, the flow gradually doubled over the 1998 to 2005 period. The TDS load abruptly increased in 1998 and continued an upward trend through 2013 (**Figure 4.8**).

In the upper watershed, which today is extensively mined, the water quality record is presented for station #37, which is very similar for station #27 located 1.4 miles upstream. The data suggests that the TDS concentration has been steadily increasing from 1995 to 2013 (**Figure 4.9**). TDS variability also appears to have reduced as the concentration became consistently high. A second-order polynomial is used to track the TDS concentration trend.

30 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].
31 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

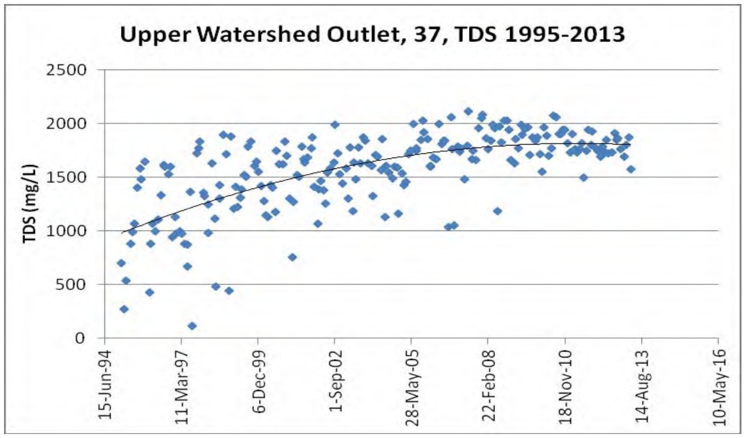


Figure 4.9 In-stream TDS (mg/L) near the outlet of the upper S. F. Pound R. watershed. [32]

The flow volume at station #37 follows a rollercoaster pattern (**Figure 4.10**, left). It began low in 1995, rose to average 4,000 in 1999, dropped to about 3,000 gpm for about 6 years, and rose to about 7,500 gpm in 2009 to 2013. Because TDS load is strongly controlled by flow, it demonstrated a similar pattern starting at a low of about 2 x 10^6 kg/yr in 1995 and reached about 35 x 10^6 kg/yr recently. It is possible that the flow pattern is an artifact of a change in the method of flow measurement method. Nonetheless, the recent flows and TDS values are thought to be dependable, and the increasing trend in TDS concentration is consistent. The overall increase in TDS concentration and load is corresponds with increased mine activity, as evidenced by aerial photography.

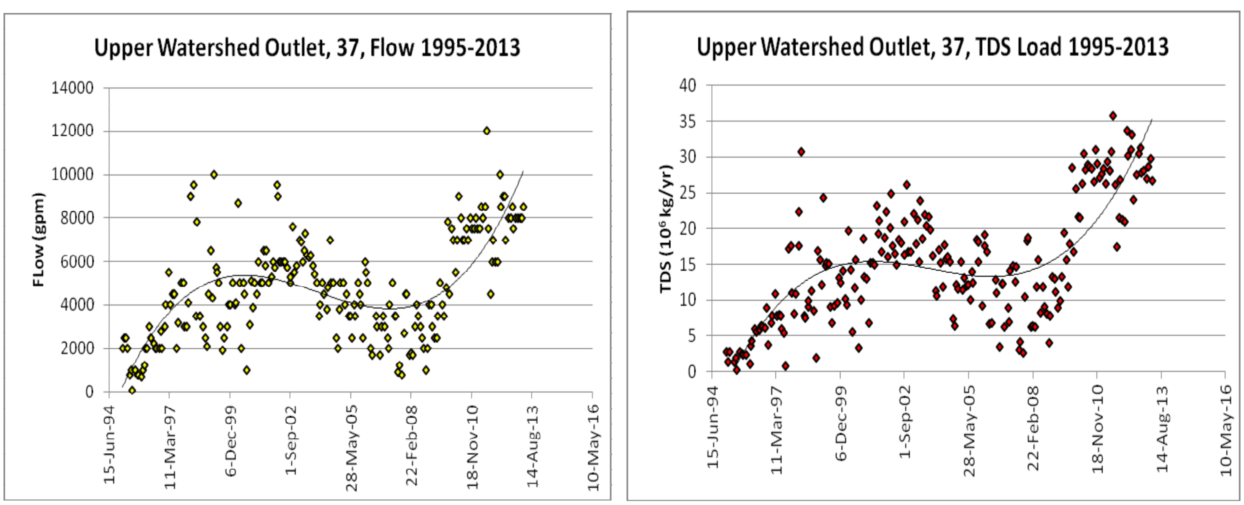


Figure 4.10 In-stream flow (gpm) and TDS load (10^6 Mg/yr) near the outlet of the upper S. F. Pound River watershed.

To confirm that much of the TDS in the mainstem originates in the upper S. F. Pound watershed, the water quality is examined for tributaries in the watershed. Tributary station 42 in the upper part of the

32 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

lower watershed is used as the example. The TDS concentration was initially somewhat variable in the 1990s but became relatively stable through the present at about 236 mg/L; a freshwater concentration. Tributary flow has been a relatively low 5 gpm and, consequently, the TDS load has been a fraction of the mainstem. Finally, normalized to the watershed outlet flow, the TDS load strength is well below that of the outlet. The same low strength applies to the other lower watershed tributaries for which there are data (**Table 4.1**). The reverse is true of upper watershed tributaries, which have TDS load strengths equal to, or exceeding the load of the watershed outlet.

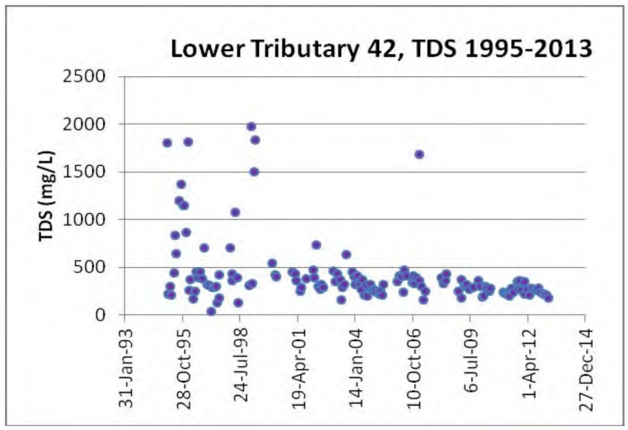


Figure 4.11 Tributary TDS (mg/L) in the lower S. F. Pound River watershed (1995-2013). [33]

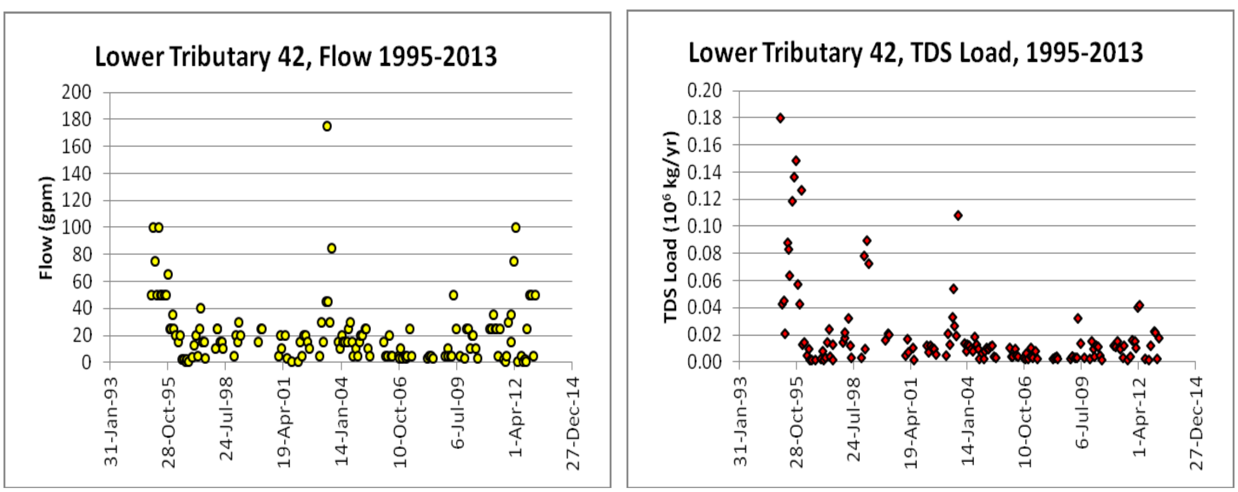


Figure 4.12 Tributary flow (gpm) and TDS load (10^6 Mg/yr) in the lower S. F. Pound River watershed.

33 Source: DMME SFPound IS and NP data 7_26_13_CDF.xls[Instream_WQ_Data].

4.4 Mining NPDES Permitted Discharges, S. F. Pound

There are water quality records for many NPDES permitted discharges in the watershed (Appendix A, **Figure)**. However, only twelve have been monitored for flow and TDS. The characteristics of these discharges for the most recent 12 months are presented in **Table 4.2** and **Figure 4.13**. The data for stations 82 and 34 is viewed with caution because the record period is earlier.

Table 4.2 NPDES discharge over the recent 12 months in the S. F. Pound River watershed.[34]

Map No.	DMME MpNo	Median Flow (gpm)	Median TDS (mg/L)	Median TDS Load (10^6 kg /yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period	Notes
Lower Watershed:							
12	0006925	30	405	0.024	8.9	2012-2013	
64	3470158	50	778	0.077	17.0	2012-2013	
20	2670086	100	1,202	0.239	26.3	2012-2013	
89	3470291	100	**2,098**	0.417	45.9	2012-2013	
Upper Watershed:							
92	3470294	**554**	**2,006**	**2.208**	43.8	2012-2013	compare IS#37
85	3470287	**554**	**2,016**	**2.219**	44.1	2012-2013	adjacent to #92
84	3470286	25	1,744	0.087	38.1	2012-2013	compare IS#27
86	3470288	52	**2,328**	0.241	50.9	2012-2013	
91	3470293	52	**2,322**	0.240	50.7	2012-2013	adjacent to #86
82	3470259	**700**	928	**1.291**	20.3	**2009-**	
35	3470069	63	1,771	0.222	38.7	2012-2013	adjacent to #82
34	3470068	100	1,272	0.253	27.8	**2009-**	near #82

* .. no more recent data.

NPDES discharges in the lower watershed, based on recent monitoring, exhibit a range of TDS concentration from freshwater to mine water quality. Meanwhile, discharges in the upper watershed exhibit TDS in the mine water range; all exceed a median of 1,700 mg/L. The individual TDS loads are small compared to the load at the S. F. Pound outlet, 29.4 x 10^6 kg/yr, because the flows are relatively small. However, when normalized to the flow at the outlet, especially the discharges in the upper watershed exhibit larger TDS strength than the mainstem outlet. This indicates that these small discharges, if representative of a larger contributing area, can significantly raise the TDS load in area streams.

34 DMME SFPound IS and NP data 7_26_13_CDF.xls[NPDES Extracted].

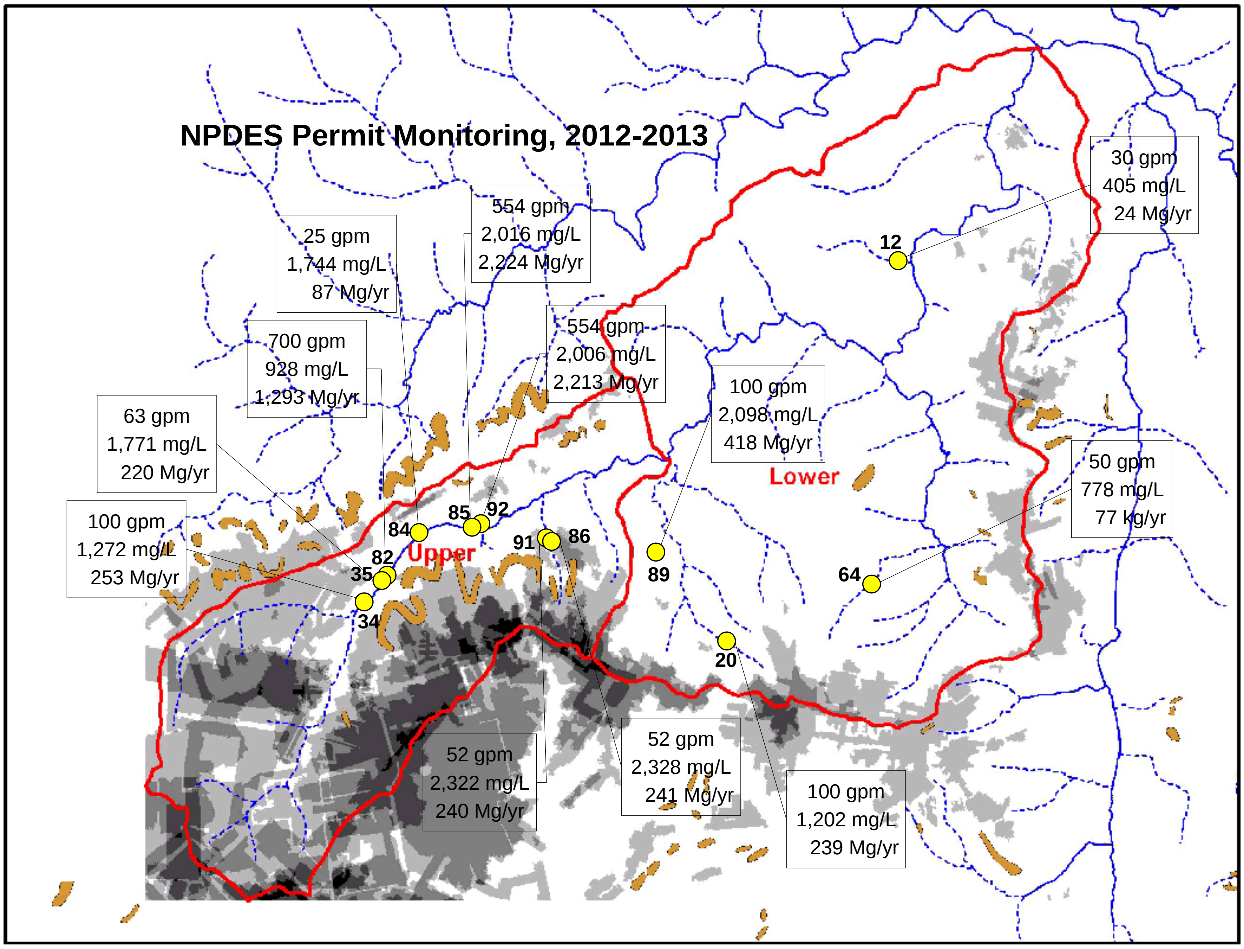


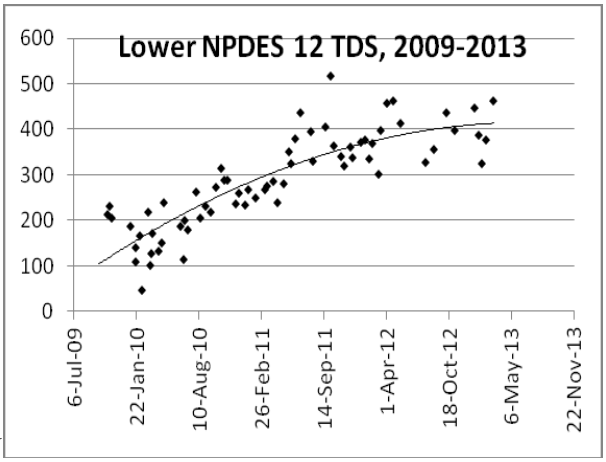
Figure 4.13 NPDES discharge median TDS (mg/L), TDS load (10^3 Mg/yr), and stream flow (gpm) for one year in the S. F. Pound River watershed.[35]

NPDES discharges 12, 91 and 92 were chosen for detailing water quantity and TDS changes over time because discharge 12 is in the lower watershed and 91 and 92 are in the upper watershed. They were all sampled in 2012 and 2013, but their records began at different times with the earliest record being from NPDES station 92. Presumably the record start date is the date permitted mining began above each discharge.

35 Source: SFP_NPDES_v5.vsd

TDS Loads in Bull and Pound Watersheds

In the lower watershed, from 2009 to 2013, flow was variable at NPDES 12 (**Figure 4.14**) while TDS



concentration exhibited the same upward trend (

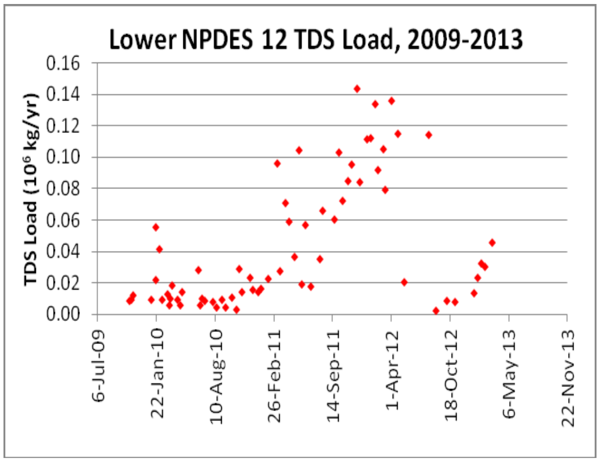


Figure 4.15, left) observed in the mainstem of the upper watershed (**Figure 4.19**). TDS load had a median of 0.024 x 10^6 kg/yr r and varied with flow being highest in 2011 and early 2012.

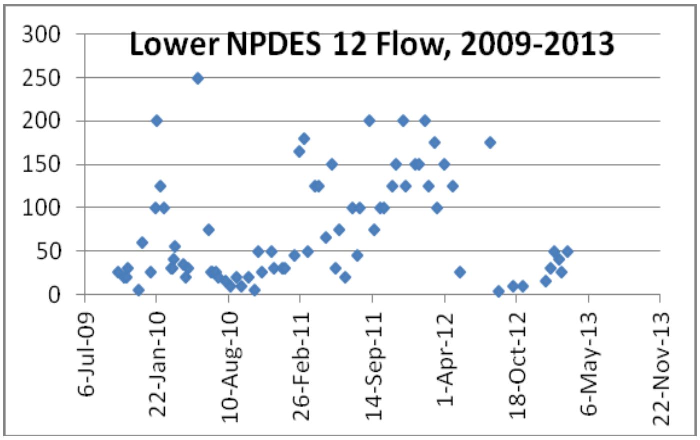


Figure 4.14 NPDES #12 flow (gpm**) in the lower watershed from 2009 to 2013.** [36]

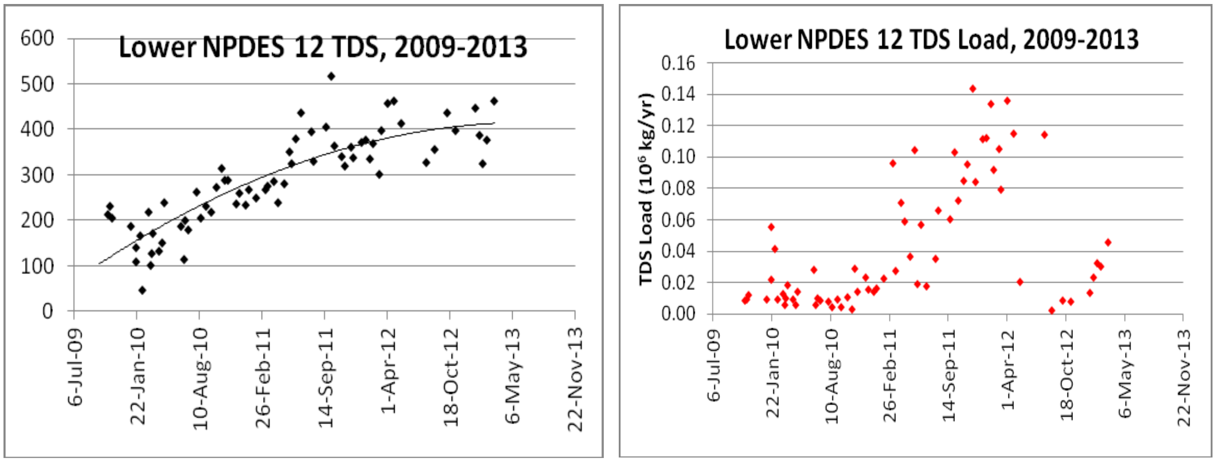


Figure 4.15 NPDES #12 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the lower watershed. [37]

In the upper watershed at NPDES 92 where the record is longer, the discharge flow trended upward over the period (**Figure 4.16**) as did the TDS load reaching a median of 2.208 x 10^6 kg/yr in the most recent 12 months (**Figure 4.17**). The reason for the increase compared to NPDES 12 is partly the much larger median TDS concentration, 2,006 mg/L, but especially the flow, which was 18 times larger.

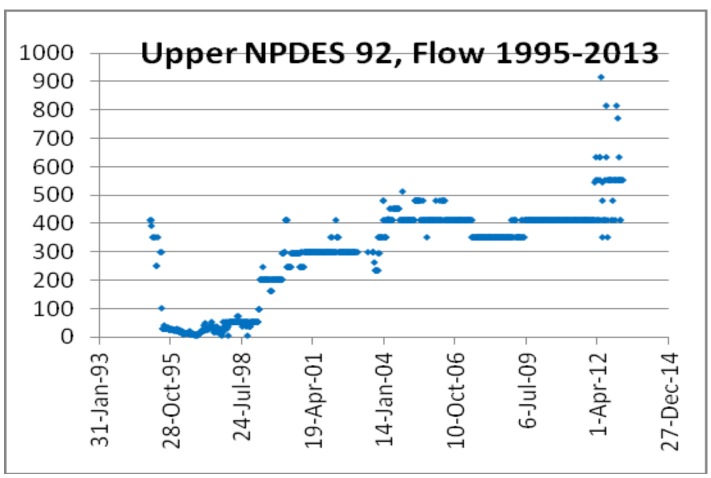


Figure 4.16 NPDES #92 flow (gpm) in the upper watershed from 1995 to 2013. [38]

36 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].
37 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].
38 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].

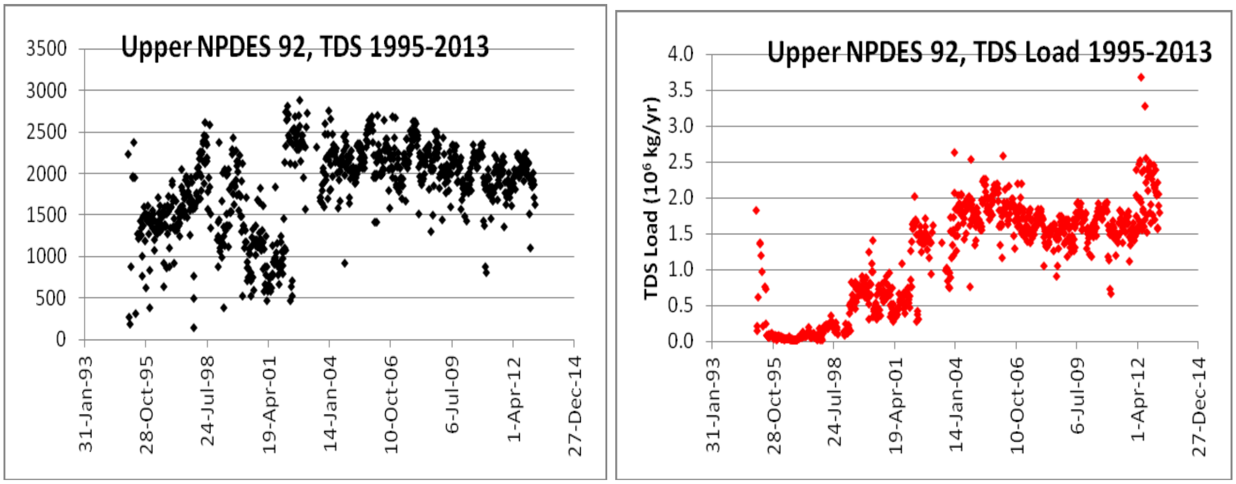


Figure 4.17 NPDES #92 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the upper watershed.

NPDES 91 had one-tenth the flow of NPDES 92 (**Figure 4.18**), and consequently had one-tenth the TDS load. The recent TDS concentration median was somewhat larger; 2,333 mg/L (**Figure 4.19**). Over the period of record, the TDS concentrations in both NPDES 91 and NPDES 92 appear lower before about the year 2002 and higher thereafter.

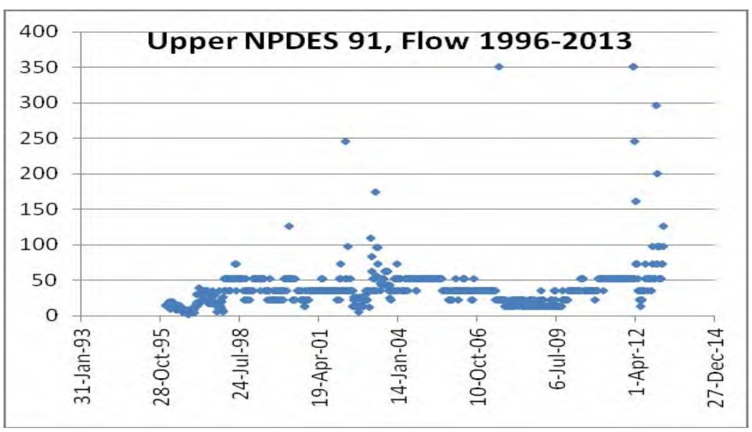


Figure 4.18 NPDES #91 flow (gpm**) in the upper watershed from 1996 to 2013.** [39]

39 Source: DMME SFPound IS and NP data 7_26_13_CDF_NPDES.xls[tab: NPDES WQData].

TDS Loads in Bull and Pound Watersheds

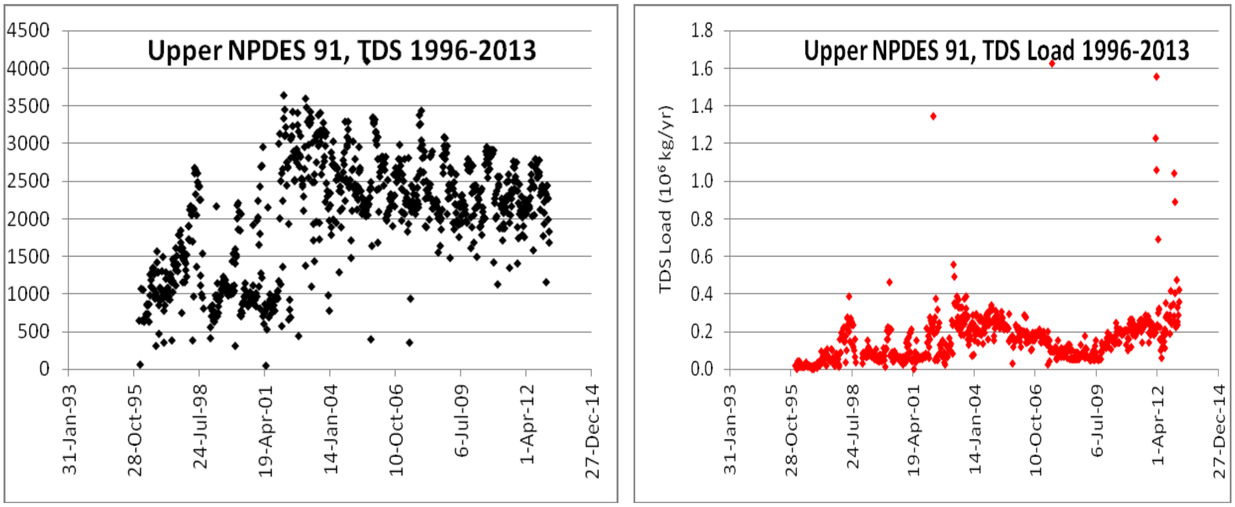


Figure 4.19 NPDES #91 TDS concentration (mg/L, left) and load (10^6 kg/yr, right) in the upper watershed.

4.5 Mining Extent, S. F. Pound

The Department of Mines, Minerals and Energy provided ArcView® shape files for mine floor space in and near the S.F. Pound River watershed. ArcView® was used to measure the aerial extent of the mining.

For purposes of analysis, the South Fork Pound River (S. F. Pound) watershed was divided hydrologically into topographically upper and lower components (**Figure 4.20**). The major difference is the upper watershed is extensively mined while the lower watershed is mined very little. Mining in the lower watershed is principally along the watershed boundary and then mainly one level deep. Below-ground mining in the upper watershed is up to four levels deep, and the area has been surface-mined as well. Because underground mining characteristics in the upper watershed in the S. F. Pound are very similar to those in the Bull Cr. watershed, relationships found in the Bull Creek watershed should apply to the upper watershed as well.

Table 4.3 Watershed footprint and mine extent in the S. F. Pound River watershed.[40]

	Upper Watershed				Lower Watershed				Total	
Number of Mine Levels	**Mined Foot-print (acres)**	**Total Mine Floor (acres)** [a]	**% of Water-shed Mined**	**Ratio Mine Floor to Water-shed**	**Mined Foot-print (acres)**	**Total Mine Floor (acres)** [a]	**% of Water-shed Mined**	**Ratio Mine Floor to Water-shed**	**Mined Foot-print (acres)**	**Total Mine Floor (acres)**
0 (area	1,297	0			6,821	0			8,118	0

40 Source: Mine_param_totals.xls[Totals].

unmined)										
1	1,258	1,258			459	459			1,717	1,717
2	727	1,454			100	200			827	1,654
3	509	1,526			18	54			527	1,580
4	58	234			2	7			60	241
Mine Footprint	**2,552[b]**		**66%**		**578[b]**		**8%**		**3,130[b]**	
Total Mine Floor		**4,472**		**1.2**		**720**		**0.1**		**5,191**
Watershed Area	**3,849[c]**				**7,399[c]**				**11,189[c]**	

a .. = Number of Mine Levels multiplied by Mined Footprint.
b .. Total of footprint in Levels 1 – 4.
c .. sum of “0 (area unmined)” and “Mine Footprint”.

The S. F. Pound River watershed totals 11,189 acres, which is 31% larger than the 7,731 acres in the Bull Creek watershed (compare **Table 3.7** and **Table 4.3**). However, the upper S. F. Pound watershed has a footprint of 3,849 acres; half the size of the Bull Creek watershed.

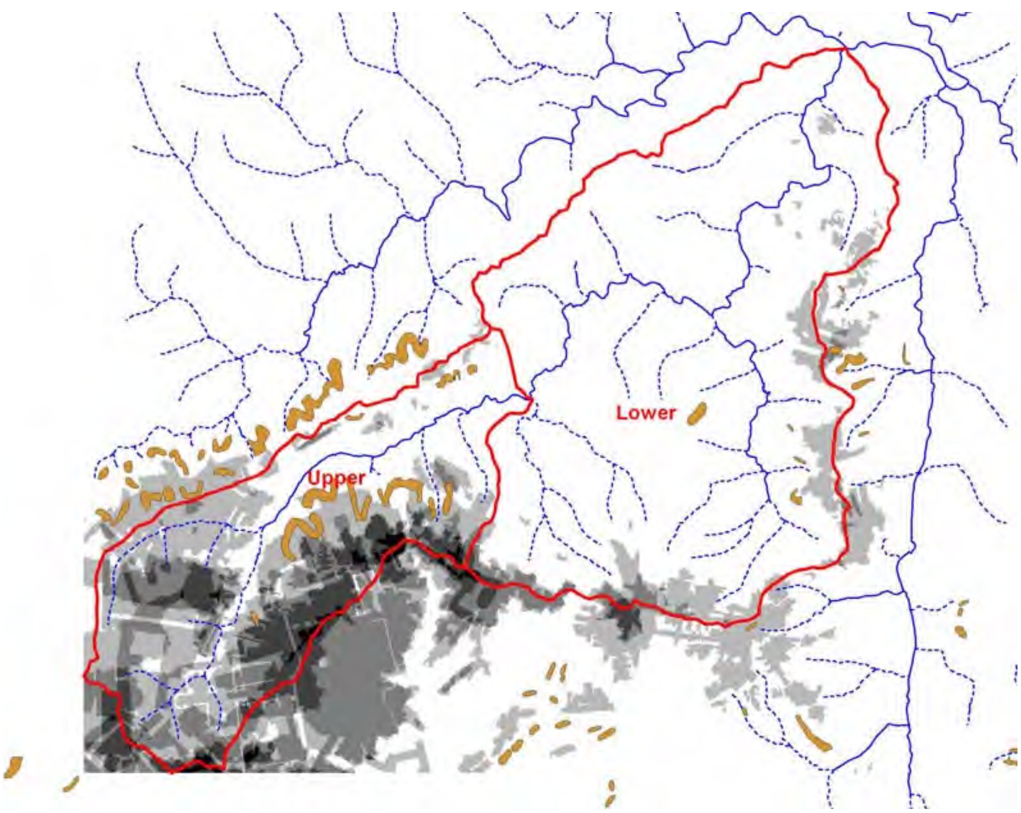


Figure 4.20 Underground and surface mining in the S. F. Pound River watershed.[41]

4.6 Hydrologic Islands, S. F. Pound

The upper watershed of the S. F. Pound watershed appears to consist of five hydrologic islands (**Figure 4.21**). The measures for the hydrologic islands are presented in **Table 4.4**. As in the Bull Creek watershed, the hill units were divided based on suspected contiguity of underground mine drainage. For example, the S. F. Pound mainstem has not been undermined for most of its length and so divides the area into two parts. Island #8 is essentially un-mined. Island #9 has been thoroughly mined at one level. Islands #10, 11 and 12 have been extensively mined underground, but islands #11 and #12 also contain prominent abandoned surface mines.

41 Source: SFP_Monitoring.vsd.

Table 4.4 Hydrologic island topography in the upper S. F. Pound River watershed.[42]

Island	Island Footprint (acres)	Top Elevation (ft)	Bottom Elevation (ft)	Relief (ft)	Standard Island Volume (10^9 ft^3)	Mine Footprint (acres)
#8	571	2200	1800	400	10	66
#9	213	2600	2000	600	6	165
#10	1,013	3600	2000	1,600	71	891
#11	1,438	3600	1850	1,750	110	1,189
#12	613	2700	1750	950	25	242
Sum:	3,849	3600	1750	1,850	221	2,552

Note: 1 acre = 43,560 square feet

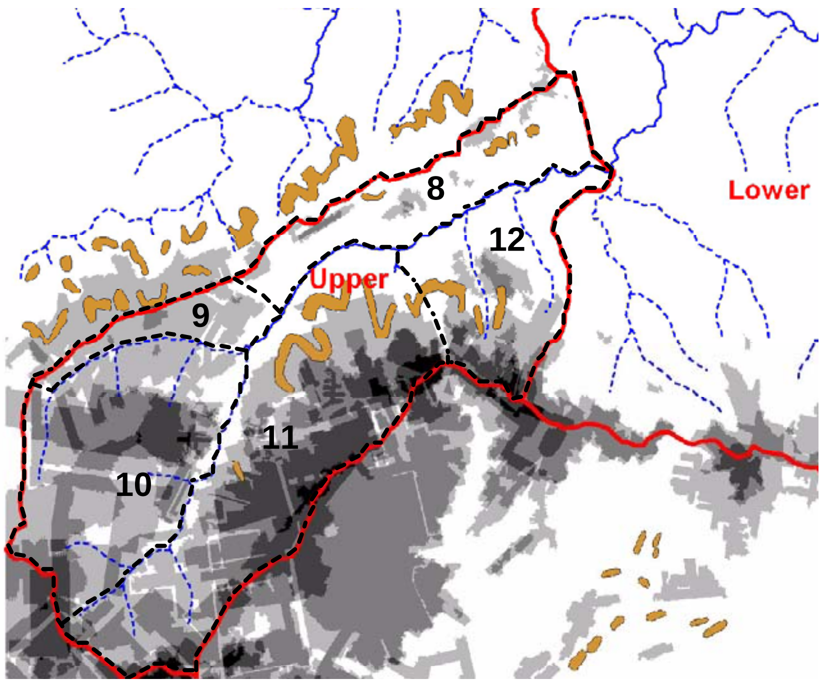


Figure 4.21 Hydrologic islands in the upper S. F. Pound River watershed.[43]

4.1 Comparison of Bull Creek and S. F. Pound Watersheds

4.1.1 Hydrologic Island Relationships

Relationships were developed in the Bull Creek watershed between hydrologic island footprint and spring flow/TDS load (**Figure 3.18**). They are used here to estimate the flow and TDS load of springs in the four most extensively mined hydrologic islands, #9 through #12, in the upper S. F. Pound watershed

42 Source: SFP_Island Dimensions_8_23_13.xls.
43 Source: SFP_Islands v2.vsd.

(**Table 4.5**). In the S. F. Pound, island #8 has very little mining and should produce low-TDS springs. The spring discharge in Bull Cr. island #7 with similar island parameters approximates its load and flow.

Table 4.5 Comparison of hydrologic islands.[44]

Watershed and Island	Foot-print (acre)	Relief (ft)	Island Volume ($x10^9$ ft^3)	Mining	Median Spring Flow (gpm)	Median TDS conc. (mg/L)	Median TDS Load (Mg/yr)	*Load x Flow* Median TDS Load (Mg/yr)
S.F. Pound #8	571	400	10	minimal	**0.02**	*475*	**8**	
Bull Cr. #1+2	1,154	1,007	51	UG	1.70	1,017	1,538[a]	1,382[e]
S.F. Pound #9	213	600	6	UG	**0.02±0.53**[b]	*(1,511)*[d]	**27**[c]	*45*[e]
S.F. Pound #10	1,013	1,600	71	UG	**1.30±0.54**[b]	*(897)*[d]	**1,042**[c]	*1,062*[e]
Bull Cr. #3	874	1,022	39	UG+Surf.	1.04	625	607[a]	858[e]
S.F. Pound #11	1,438	1,750	110	UG+Surf.	**1.98±0.69**[b]	*(893)*[d]	**1,580**[c]	*944*[f]
S.F. Pound #12	613	950	25	UG+Surf.	**0.66±0.49**[b]	*(905)*[d]	**534**[c]	*432*[f]

a .. Sum of Raw Median TDS load; **Table 3.5**.
UG, UG+Surf. .. underground mining, and underground plus surface mining.
b .. Estimated Median Flow (**gpm**) = 0.0016*(footprint acres) – 0.3248, 95% C.I.; **Figure 3.18**.
c .. Estimated Median TDS Load (Mg/yr) = 1.2681*(footprint acres) – 243.52; **Figure 3.18**.
d .. Back-calculated: Median TDS concentration (mg/L) = footprint est. Median TDS Load (Mg/yr) / (footprint est. flow*0.8935911).
e .. Estimated using non-HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 794.45*(Footprint est. flow, **gpm***0.8935911); **Figure 3.9**.
f .. Estimated using HMBC *Load x Flow* relationship: Median Load (Mg/yr) = 387.62*(Footprint est. flow, **gpm***0.8935911); **Figure 3.9**.
Load x Flow Median TDS Load .. The TDS load based on the basic flow-dependent load relationship for all non-HMBC springs presented in **Figure 3.9**.

Hydrologic island #1+2 from the Bull Creek watershed has been extensively mined underground matching the nature of mining in S. F. Pound islands #9 and #10. Island #10 is similar in footprint size to #1+2 while #9 is much smaller. But their footprints are in the Bull Cr. range developed to predict flow and TDS load. However, the S. F. Pound hydrologic islands have greater relief and therefore have about 40% larger hill volume than the Bull Creek islands. This suggests they could have larger groundwater reservoirs although no significant relationship was found between hill volume and flow in Bull Cr. Still spring volume, and TDS load which is proportional to flow, may be somewhat under-predicted in these taller islands.

44 SFP_Island Dimensions_8_23_13.xls

Bull Creek island #3 is slightly larger than island #12, and about 60% the size of island #11. However, the flow and load predictions should be reasonable because the S. F. Pound islands are within the island footprint range used to develop the relationships. However, as was noted for the HMBC spring in Bull Creek, abandoned surface mine features tend to produce substantially lower TDS concentrations and higher flows than areas that have only been mined underground. Thus, although the predicted flow volume may be under estimated for any springs in islands #11 and #12, the TDS load yield is still expected to be reasonable.

The "Load x Flow" estimate of load presented in the last column of **Table 4.5** is a separate estimate of the loads. This is the predicted load based upon the Bull Cr. spring volume dependence on TDS load in **Figure 3.9** on **page 14**. In the table, this separate estimate for Bull Cr. #1+2 and S. F. Pound #9 and #10 is based on the load from all non-HMBC springs. For the remaining islands the HMBC spring relationship is used. Upon comparing the values, the island-estimated load for S. F. Pound #11 appears somewhat over-estimated.

4.1.2 Mining Relationships

Relationships were developed in the Bull Creek watershed between hydrologic island footprint and flow/TDS load (**Figure 3.18**). Because the upper S. F. Pound watershed has essentially the same characteristics as the Bull Cr. watershed, the hydrologic island relationships from Bull Cr. are used here to estimate the flow and TDS load in the upper S. F. Pound watershed and the entire Bull Creek watershed (**Table 4.6**).

Table 4.6 Comparison of mining in the Bull Cr. and S. F. Pound River watersheds and estimated spring TDS load in the upper S. F. Pound watershed.

Watershed	Footprint Area (acres)	% of Footprint Mined	Mine Levels	Ratio of Mine Floor to Footprint	Spring Median Flow (gpm)	Spring Median TDS (mg/L)	Spring Median TDS Load (Mg/yr)
Bull Creek[1]	7,731	75%	4	1.2	12.045[a]	*(794)*[c]	9,560[b]
Unit A, inside	1,460	76%	3	1.0	1.70	1,017	1,538
S.F. Pound[2]	11,189	28%		0.5	NA	NA	NA
Lower Watershed	7,399	8%		0.1	NA	NA	NA
Upper Watershed	3,849	66%		1.2	5.834[a]	*(795)*[c]	4,637[b]

a .. Estimated from hydrologic island relationship: median flow (**gpm**) = 0.0016 *Footprint (acres) – 0.3248.
b .. Estimated from hydrologic island relationship: median TDS load (Mg/yr) = 1.2681*Footprint (acres) – 243.52.
c .. Estimated from estimated median TDS load (Mg/yr) divided by (median flow (**gpm**) * 0.8935911).
1 .. Footprint and mine information from **Table 3.7**.
2 .. Footprint and mine information from **Table 4.3**.

4.1.3 Water Quality Relationships

In the following **Table 4.7**, water quality and quantity in the S. F. Pound mainstem and tributaries are presented for comparison to values in NPDES discharges and dominant Bull Cr. watershed springs. While tributary loads tend to be one 100^{th} the size of mainstem loads, NPDES loads can be as much as one 10^{th} the size of mainstem loads. Meanwhile, mine spring loads are miniscule compared to mainstem loads.

Table 4.7 Comparison of water quality and discharge over the recent 12 months.[45]

Watershed	Map No. NPDES No., or Spring	Median Flow (gpm)	Median TDS (mg/L)	Median TDS Load (10^6 kg/yr)	TDS Load Normalized to 11,000 gpm (10^6 kg/yr)	Sample Period
SFP, Lower, mainstem[a]	**12**	**11,000**	**1,345**	29.394	29.4	2012-13
SFP, Upper, mainstem[a]	**37**	8,000	**1,783**	28.339	39.0	2012-13
SFP, Lower, tributary[a]	**60**	175	620	0.216	13.5	2012-13
SFP, Upper, tributary[a]	**61**	43	**2,843**	0.243	62.1	2012-13
SFP., Lower[b]	NPDES **20**	100	1,202	0.239	26.3	2012-13
SFP., Upper[b]	NPDES **85**	**554**	**2,016**	2.219	44.1	2012-13
Bull Cr.[c]	DownBelcher	0.85	1,035	0.002	22.6	2012-13
Bull Cr. [c]	HMBC	1.04	625	0.001	13.7	2012-13

a .. **Table 4.1** page 35.
b .. **Table 4.2** page 42.
c .. **Table 3.1** page 13.

45 DMME SFPound IS and NP data 7_26_13_CDF.xls[NPDES Extracted].

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Appendix A. Data Tables

Table A. 1 Spring TDS, flow, and physical data by sample date in the Bull Cr. watershed.[46]

Observations							Spring Statistics								
Seq	Site	Date	TDS Concen-tration (mg/L)	Flow (gpm)	TDS Load (kg/yr)	4-day total Ppt (in)	Mean TDS conc. (mg/L)	Median TDS conc. (mg/L)	Mean TDS Load (Mg/yr)	Median TDS Load ($x10^6$ Mg/yr)	Median TDS Load Ratio	Elevation (feet)	Mean Flow (gpm)	Median Flow (gpm)	Median TDS Load ($x10^6$ Mg/yr)
1	HMBC	9/11/2012	754	1.36	913,629	0.34									913.6
2	HMBC	9/25/2012	703	0.66	413,980	0									414.0
3	HMBC	10/8/2012	715	0.63	400,601	0.37									400.6
4	HMBC	10/23/2012	595	0.70	372,712	0									372.7
5	HMBC	11/15/2012	621	0.70	390,109	0.26									390.1
6	HMBC	11/28/2012	671	1.08	648,167	0.05									648.2
7	HMBC	12/13/2012	687	1.00	616,353	0.75									616.4
8	HMBC	12/28/2012	628	0.98	547,146	0.87									547.1
9	HMBC	1/10/2013	597	1.12	596,957	0.03									597.0
10	HMBC	1/24/2013	527	1.78	840,126	0									840.1
11	HMBC	2/7/2013	484	2.66	1,148,282	0									1148.3
12	HMBC	2/21/2013	546	1.54	749,415	0.04	627	625	636	607	91	1261	1.18	1.04	749.4
13	DeelUp	9/11/2012	603	0.03	15,087	0.34									15.1
14	DeelUp	9/25/2012	634	0.01	3,399	0									3.4
15	DeelUp	10/8/2012	560	0.04	20,016	0.37									20.0

[46] From TDS v Flow with Totals and Averages_MJS_6.xlsx[Combined].

16	DeelUp	10/23/2012	627	0.00	2,241	0									2.2
17	DeelUp	11/15/2012	372	0.02	5,319	0.26									5.3
18	DeelUp	11/28/2012	603	0.01	5,927	0.05									5.3
19	DeelUp	12/13/2012	650	0.01	3,485	0.75									5.9
20	DeelUp	12/28/2012	476	0.01	4,679	0.87									3.5
21	DeelUp	1/10/2013	558	0.02	7,479	0.03									4.7
22	DeelUp	1/24/2013	498	0.05	22,250	0									7.5
23	DeelUp	2/7/2013	520	0.03	15,334	0									22.3
24	DeelUp	2/21/2013	601	0.04	23,093	0.04	559	581	11	7	1	1567	0.02	0.02	15.3
25	DeelDown	9/11/2012	537	0.00	2,159	0.34									23.1
26	DeelDown	9/25/2012	519	0.01	5,426	0									2.2
27	DeelDown	10/8/2012	544	0.01	5,833	0.37									5.4
28	DeelDown	10/23/2012	536	0.01	4,311	0									5.8
29	DeelDown	11/15/2012	396	0.01	3,892	0.26									4.3
30	DeelDown	11/28/2012	503	0.01	4,944	0.05									3.9
31	DeelDown	12/13/2012	516	0.03	15,677	0.75									4.9
32	DeelDown	12/28/2012	300	0.07	19,838	0.87									15.7
33	DeelDown	1/10/2013	382	0.03	10,241	0.03									19.8
34	DeelDown	1/24/2013	309	0.11	29,545	0									10.2
35	DeelDown	2/7/2013	371	0.13	44,424	0									29.5
36	DeelDown	2/21/2013	446	0.13	53,405	0.04	447	475	17	8	1	1383	0.05	0.02	44.4
37	BurntHollow	9/11/2012	1,070	0.54	515,361	0.34									515.4
38	BurntHollow	9/25/2012	1,100	0.60	585,838	0									585.8
39	BurntHollow	10/8/2012	1,130	0.47	476,606	0.37									476.6
40	BurntHollow	10/23/2012	1,120	0.37	371,305	0									371.3
41	BurntHollow	11/15/2012	1,060	0.91	865,747	0.26									865.7

42	BurntHollow	11/28/2012	1,100	0.56	552,418	0.05									552.4
43	BurntHollow	12/13/2012	1,120	0.41	414,340	0.75									414.3
44	BurntHollow	12/28/2012	998	0.62	552,027	0.87									552.0
45	BurntHollow	1/10/2013	1,050	0.89	831,308	0.03									831.3
46	BurntHollow	1/24/2013	888	0.89	703,842	0									703.8
47	BurntHollow	2/7/2013	954	1.28	1,093,739	0									1093.7
48	BurntHollow	2/21/2013	1,010	1.39	1,250,000	0.04	1,050	1,065	684	569	85	1305	0.74	0.61	1250.0
49	CharlieUp	9/11/2012	1,060	0.13	121,242	0.34									121.2
50	CharlieUp	9/25/2012	1,080	0.07	65,625	0									65.6
51	CharlieUp	10/8/2012	1,130	0.02	23,224	0.37									23.2
52	CharlieUp	10/23/2012	1,070	0.03	25,816	0									25.8
53	CharlieUp	11/15/2012	958	0.01	9,417	0.26									9.4
54	CharlieUp	11/28/2012	1,060	0.01	11,366	0.05									11.4
55	CharlieUp	12/13/2012	1,050	0.16	145,432	0.75									145.4
56	CharlieUp	12/28/2012	934	0.27	223,677	0.87									223.7
57	CharlieUp	1/10/2013	953	0.06	52,799	0.03									52.8
58	CharlieUp	1/24/2013	772	0.45	310,434	0									310.4
59	CharlieUp	2/7/2013	866	0.67	520,027	0									520.0
60	CharlieUp	2/21/2013	946	0.56	475,925	0.04	990	1,004	165	93	14	1309	0.20	0.10	475.9
61	CharlieDown	9/11/2012	1,320	0.09	110,877	0.34									110.9
62	CharlieDown	9/25/2012	1,420	0.07	91,361	0									91.4
63	CharlieDown	10/8/2012	1,430	0.12	157,174	0.37									157.2
64	CharlieDown	10/23/2012	1,450	0.06	73,855	0									73.9
65	CharlieDown	11/15/2012	1,170	0.02	15,683	0.26									15.7
66	CharlieDown	11/28/2012	1,250	0.06	63,668	0.05									63.7
67	CharlieDown	12/13/2012	1,330	0.25	300,684	0.75									300.7

68	CharlieDown	12/28/2012	1,100	0.15	145,477	0.87									145.5
69	CharlieDown	1/10/2013	1,100	0.08	82,568	0.03									82.6
70	CharlieDown	1/24/2013	876	0.08	63,406	0									63.4
71	CharlieDown	2/7/2013	1,060	0.43	405,404	0									405.4
72	CharlieDown	2/21/2013	1,100	0.03	32,437	0.04	1,217	1,210	129	87	13	1293	0.12	0.08	32.4
73	UpBelcher	9/11/2012	970	0.89	769,704	0.34									769.7
74	UpBelcher	9/25/2012	1,050	0.64	600,493	0									600.5
75	UpBelcher	10/8/2012	1,090	0.30	291,230	0.37									291.2
76	UpBelcher	10/23/2012	1,030	0.62	571,568	0									571.6
77	UpBelcher	11/15/2012	1,020	0.78	711,853	0.26									711.9
78	UpBelcher	11/28/2012	1,040	0.71	661,686	0.05									661.7
79	UpBelcher	12/13/2012	1,060	0.93	876,166	0.75									876.2
80	UpBelcher	12/28/2012	976	2.13	1,856,796	0.87									1856.8
81	UpBelcher	1/10/2013	1,000	0.66	588,877	0.03									588.9
82	UpBelcher	1/24/2013	921	2.16	1,774,382	0									1774.4
83	UpBelcher	2/7/2013	887	2.57	2,037,814	0									2037.8
84	UpBelcher	2/21/2013	924	2.09	1,728,144	0.04	997	1,010	1,039	741	111	1377	1.21	0.83	1728.1
85	DownBelcher	9/11/2012	960	0.58	494,120	0.34									494.1
86	DownBelcher	9/25/2012	1,070	0.87	831,844	0									831.8
87	DownBelcher	10/8/2012	1,080	0.38	364,800	0.37									364.8
88	DownBelcher	10/23/2012	1,090	0.45	438,306	0									438.3
89	DownBelcher	11/15/2012	1,050	0.78	728,098	0.26									728.1
90	DownBelcher	11/28/2012	1,080	0.23	221,968	0.05									222.0
91	DownBelcher	12/13/2012	1,070	1.25	1,199,003	0.75									1199.0
92	DownBelcher	12/28/2012	884	1.78	1,402,924	0.87									1402.9
93	DownBelcher	1/10/2013	1,020	0.82	748,311	0.03									748.3

94	DownBelcher	1/24/2013	896	1.24	990,413	0								990.4
95	DownBelcher	2/7/2013	855	6.81	5,201,451	0								5201.5
96	DownBelcher	2/21/2013	928	2.71	2,245,616	0.04	999	1,035	1,239	790	118	1232	1.49	0.85	2245.6
97	CoveHollow	9/11/2012	1,080	0.10	94,578	0.34								94.6
98	CoveHollow	9/25/2012	1,080	0.13	123,530	0								123.5
99	CoveHollow	10/8/2012	1,180	0.10	108,607	0.37								108.6
100	CoveHollow	10/23/2012	1,190	0.21	217,992	0								218.0
101	CoveHollow	11/15/2012	1,010	0.11	101,986	0.26								102.0
102	CoveHollow	11/28/2012	1,130	0.13	135,308	0.05								135.3
103	CoveHollow	12/13/2012	1,140	0.10	100,851	0.75								100.9
104	CoveHollow	12/28/2012	1,010	0.08	72,202	0.87								72.2
105	CoveHollow	1/10/2013	1,050	0.03	23,457	0.03								23.5
106	CoveHollow	1/24/2013	879	0.11	82,474	0								82.5
107	CoveHollow	2/7/2013	907	0.26	206,674	0								206.7
108	CoveHollow	2/21/2013	986	0.09	79,297	0.04	1,054	1,065	112	101	15	1260	0.12	0.10	79.3
		maximum:	1,450	6.81	5,201,451	0.87	1217.2	1210.00	1238.9	790.08	118	1,567	1.49	1.04	5,201.5
		minimum:	300	0.00	2,159	0.00	446.58	474.50	10.69	6.70	1	1,232	0.02	0.02	2.2
		average:	882	0.57	448,038	0.23	882.10	896.50	448.04	333.69		1,332	0.57	0.41	448.0
		median:	959.00	0.24	219,979.8	0.05	997.33	1010.00	165.42	101.42			0.203	0.104	220.0

Note: To calculate TDS load in Megagrams/year (Mg/yr) from mg/L***gpm**, multiply 0.8935911 times the product of TDS (mg/L) and flow (**gpm**). Multiply Mg/yr by 1,000 to convert to kg/yr. Source: TDS v Flow with Totals and Averages_MJS_6.xlsx.

Table A. 2 Spring TDS concentration (mg/L) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median TDS Conc. (mg/L)	Average TDS Conc. (mg/L)
9/11/2012	1080	960	970	1320	1060	1070	537	603	754	970.0	928.2
9/25/2012	1080	1070	1050	1420	1080	1100	519	634	703	1070.0	961.8
10/8/2012	1180	1080	1090	1430	1130	1130	544	560	715	1090.0	984.3
10/23/2012	1190	1090	1030	1450	1070	1120	536	627	595	1070.0	967.6
11/15/2012	1010	1050	1020	1170	958	1060	396	372	621	1010.0	850.8
11/28/2012	1130	1080	1040	1250	1060	1100	503	603	671	1060.0	937.4
12/13/2012	1140	1070	1060	1330	1050	1120	516	650	687	1060.0	958.1
12/28/2012	1010	884	976	1100	934	998	300	476	628	934.0	811.8
1/10/2013	1050	1020	1000	1100	953	1050	382	558	597	1000.0	856.7
1/24/2013	879	896	921	876	772	888	309	498	527	876.0	729.6
2/7/2013	907	855	887	1060	866	954	371	520	484	866.0	767.1
2/21/2013	986	928	924	1100	946	1010	446	601	546	928.0	831.9
Average:	**1053.5**	**998.6**	**997.3**	**1217.2**	**989.9**	**1050.0**	**446.6**	**558.5**	**627.3**		**882.1**
Minimum:	**879**	**855**	**887**	**876**	**772**	**888**	**300**	**372**	**484**	**866**	**729.6**
Maximum:	**1190**	**1090**	**1090**	**1450**	**1130**	**1130**	**544**	**650**	**754**	**1090**	**984.3**
Median:	**1065.0**	**1035.0**	**1010.0**	**1210.0**	**1004.0**	**1065.0**	**474.5**	**580.5**	**624.5**	**1005.0**	**892.4**

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 3 Bull Cr. spring flow volume (gpm) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median Flow (gpm)	Average Flow (gpm)	Total Flow (gpm)	Median Monthly Total Flow (gpm)
9/11/2012	0.098	0.576	0.888	0.094	0.128	0.539	0.005	0.028	1.356	0.128	0.412	3.71	
9/25/2012	0.128	0.870	0.640	0.072	0.068	0.596	0.012	0.006	0.659	0.128	0.339	3.05	3.38
10/8/2012	0.103	0.378	0.299	0.123	0.023	0.472	0.012	0.040	0.627	0.123	0.231	2.08	
10/23/2012	0.205	0.450	0.621	0.057	0.027	0.371	0.009	0.004	0.701	0.205	0.272	2.45	2.26
11/15/2012	0.113	0.776	0.781	0.015	0.011	0.914	0.011	0.016	0.703	0.113	0.371	3.34	
11/28/2012	0.134	0.230	0.712	0.057	0.012	0.562	0.011	0.011	1.081	0.134	0.312	2.81	3.08
12/13/2012	0.099	1.254	0.925	0.253	0.155	0.414	0.034	0.006	1.004	0.253	0.460	4.14	
12/28/2012	0.080	1.776	2.129	0.148	0.268	0.619	0.074	0.011	0.975	0.268	0.676	6.08	5.11
1/10/2013	0.025	0.821	0.659	0.084	0.062	0.886	0.030	0.015	1.119	0.084	0.411	3.70	
1/24/2013	0.105	1.237	2.156	0.081	0.450	0.887	0.107	0.050	1.784	0.450	0.762	6.86	5.28
2/7/2013	0.255	6.808	2.571	0.428	0.672	1.283	0.134	0.033	2.655	0.672	1.649	14.84	
2/21/2013	0.090	2.708	2.093	0.033	0.563	1.385	0.134	0.043	1.536	0.563	0.954	8.59	11.71
Average:	**0.120**	**1.490**	**1.206**	**0.120**	**0.203**	**0.744**	**0.048**	**0.022**	**1.183**	**0.203**	**0.571**	**5.14**	**5.14**
Minimum:	**0.025**	**0.230**	**0.299**	**0.015**	**0.011**	**0.371**	**0.005**	**0.004**	**0.627**	**0.025**	**0.025**	**0.025**	**2.26**
Maximum:	**0.255**	**6.808**	**2.571**	**0.428**	**0.672**	**1.385**	**0.134**	**0.050**	**2.655**	**0.672**	**0.672**	**0.672**	**11.71**
Median:	**0.104**	**0.846**	**0.835**	**0.083**	**0.098**	**0.608**	**0.021**	**0.016**	**1.043**	**0.170**	**0.412**	**3.706**	**4.25**

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 4 Bull Cr. spring TDS load (Mg/yr) by sample date in the Bull Cr. watershed.

Date	Cove Hollow	Down Belcher	Up Belcher	Charlie Down	Charlie Up	Burnt Hollow	Deel Down	Deel Up	HMBC	Median Load (Mg/yr)	Ave. Load (Mg/yr)	Sum Median Load (Mg/yr)	Obser-ved 4-day Ppt (inch)
9/11/2012	95	494	770	111	121	515	2	15	914	121	337	3,037	0.34
9/25/2012	124	832	601	91	66	586	5	3	414	124	302	2,722	0.00
10/8/2012	109	365	291	157	23	477	6	20	401	157	205	1,848	0.37
10/23/2012	218	438	572	74	26	371	4	2	373	218	231	2,078	0.00
11/15/2012	102	728	712	16	9	866	4	5	390	102	315	2,832	0.26
11/28/2012	135	222	662	64	11	552	5	6	648	135	256	2,306	0.05
12/13/2012	101	1,199	876	301	145	414	16	3	616	301	408	3,672	0.75
12/28/2012	72	1,403	1,857	145	224	552	20	5	547	224	536	4,825	0.87
1/10/2013	23	748	589	83	53	831	10	7	597	83	327	2,942	0.03
1/24/2013	82	990	1,774	63	310	704	30	22	840	310	535	4,817	0.00
2/7/2013	207	5,202	2,038	405	520	1,094	44	15	1,148	520	1,186	10,673	0.00
2/21/2013	79	2,246	1,728	32	476	1,250	53	23	749	476	737	6,637	0.04
Median:	**101**	**790**	**741**	**87**	**93**	**569**	**8**	**7**	**607**			**2,989**	
percent:	**3.4%**	**26.3%**	**24.7%**	**2.9%**	**3.1%**	**19.0%**	**0.3%**	**0.2%**	**20.2%**	**100.0%**		**100%**	
minimum:	**23**	**222**	**291**	**16**	**9**	**371**	**2**	**2**	**373**			**1,848**	
maximum:	**218**	**5,202**	**2,038**	**405**	**520**	**1,250**	**53**	**23**	**1,148**			**10,673**	

Source: TDS_Monitoring_Analysis_v02_MJS.xls.

Table A. 5 Mined footprint, mine floor, and un-mined footprint (acres) in the Bull Cr. watershed.

Mine Unit	Un-Mined Inside	Mined Footprint Inside	Mined Footprint Outside	Mined Footprint Total	Mined Floor Inside	Mined Floor Outside	Mined Floor Total	Mined + Un-Mined Footprint Inside
A	344.6	1,114.9	855.4	1,970.3	1,464.0	948.2	2,412.2	1,459.5
B	152.0	314.7	777.2	1,091.9	545.9	813.5	1,359.4	466.7
C	364.7	1,359.5	1,512.6	2,872.1	2,534.1	1,982.4	4,516.5	1,724.2
D	288.8	705.4	372.9	1,078.3	1,097.2	425.8	1,523.1	994.2
E	754.6	2,331.2	1,443.0	3,774.2	3,670.8	2,000.9	5,671.7	3,085.8

Note: footprint units are acres.
Source: Mine_param_totals.xls[Totals].

Table A. 6 Mine parameters in the Bull Cr. watershed.

Mine Area	Location Respect to Bull Cr Watershed	Mined Footprint (acres)	Un-Mined Footprint (acres)	Total Footprint (ac)	Mined Levels	Total Mine Floor (acres)	Percent of Footprint Mined	Ratio Mine Floor to Footprint	Median Spring Flow (gpm)	Sum Median Spring Flow (gpm)	Median TDS Load (Mg/yr)	Flow-Weighted Med.TDS Load (Mg/yr)	Sum Median TDS Load (Mg/yr)	Monitored Spring
A	inside	1115	345	1460	3	1464	76%	1.0	0.02+0.83 +0.85	1.7	7 + 741 + 790	757	1,538	Deel Up + Up Belcher + Down Belcher
	outside	855	534	1389	3	948	62%	0.7						none
	total	1970	879	2849		2412	69%	0.8						
B	inside	315	152	467	3	546	67%	1.2	0.02	0.02	8	8	8	Deel Down
	outside	777	544	1322	2	813	59%	0.6						none
	total	1092	696	1788		1359	61%	0.8						
C	inside	1359	365	1724	5	2534	79%	1.5	0.5*0.1+ 0.08+1.04	1.17	0.5*93 + 87 + 607	548	740	0.5*Charlie Up+Charlie Down + HMBC
	outside	1513	1844	3357	5	1982	45%	0.6						none
	total	2872	2209	5081		4516	57%	0.9						
D	inside	705	289	994	4	1097	71%	1.1	0.5*0.1+ 0.1+0.61	0.76	0.5*93+ 101+569	473	716	0.5*Charlie Up + Cove Hollow + Burnt Ho
	outside	373	527	900	3	426	41%	0.5						none
	total	1078	815	1894		1523	57%	0.8						
E	inside	2331	755	3086	4	3671	76%	1.2	NA	NA	NA	NA	NA	none
	outside	1443	1790	3233	4	2001	45%	0.6						none
	total	3774	2544	6318		5672	60%	0.9						
Total	inside	5825	1906	7731		9312	75%	1.2						
	outside	4961	5239	10201		6170	49%	0.6						
	total	10786	7143	17930		15482	60%	0.9						

Source: Mine Footprint Vars v02.xls.

Table A. 7 Hydrologic island parameters and related spring data in the Bull Cr. watershed.

Island #	Foot-print (acre)	Foot-print Top Eleva-tion (ft)	Foot-print Bottom Elevation (ft)	Island Relief (ft)	Standard Island Volume (10^9 ft^3)	Spring Eleva-tion (ft)	Spring Island Relief (ft)	Spring Island Volume (ft^3)	Largest Width of Valley Barrier (ft)	Small-est Width of Valley Barrier (ft)	Median Flow (gpm)	Sum Med. Flow (gpm)	Flow-Weigh-ted Med. TDS Conc. (mg/L)	Flow-Weight Median TDS Load (Mg/yr)	Sum of Raw Median TDS Load (Mg/yr)	Associated Spring (dominant bolded)
1	359	2,172	1,427	745	12	1,377	795	12	339	339	0.83	0.83	1010	749	741	**Up Belcher**
2	795	2,185	1,178	1,007	35	1232, 1567	953	33	678	678	0.85+0.02	0.87	1025	797	797	**Down Belcher** + Deel Up
1+2	1154	2,185	1,178	1,007	51	1377, 1232, 1567	953	48	678	678	0.83+0.85+0.02	1.70	1017	1546	1538	**Up Belcher** + **Down Belcher** + Deel Up
3	874	2,240	1,218	1,022	39	1261	979	37	647	443	1.04	1.04	625	581	607	**HMBC**
4	481	2,140	1,200	940	20	1309, 1293	847	18	990	628	0.5*0.1 + 0.08	0.13	1131	131	134	0.5*Charlie Up + Charlie Down
5	324	2,095	1,065	1,030	15	1309	786	11	1102	452	0.5*0.1	0.05	502	22	47	0.5*Charlie Up
6	244	2,085	1,035	1,050	11	1260, 1305	825	9	1498	370	0.1+0.61	0.71	1065	676	670	Cove Hollow + **Burnt Hollow**
7	444	2,207	1,312	895	17	1383	824	16	647	629	0.02	0.02	475	8	8	Deel Down
sum:	3521				152			139				5.35		2,964	3003	

Source: Hydrologic Island Vars v02.xlsx.

Table A. 8 In-stream water quality stations data summary in the South Fork Pound watershed.

MapTech Map No.	Row Labels	Count of WtTds	Count of WtFlow	Count of WtPh	Average of WtTds (mg/L)	Average of WtFlow (gpm)	Average of WtPh (SU)	Average TDS Load (106 kg/yr)
1	0003655		26			922		
2	0003656		26			1543		
3	0003657		26			2477		
4	0004380	46	32	46	1138	5751	7.7	13.00
5	0004381	46	32	46	1112	6248	7.6	13.80
6	0005063	53	59	53	1786	591	7.7	2.10
7	0006928	60	60	60	1385	8148	7.7	22.42
8	0006929	60	60	60	1354	9743	7.7	26.21
9	0006930	59	60	59	309	188	7.1	0.12
10	0006931	60	60	60	1344	8519	7.7	22.75
11	0007244	56	64	64	1196	23407	8.0	55.62
12	0007245	56	64	64	1261	23627	7.8	59.19
13	0007246	56	64	64	1258	24561	7.8	61.39
14	0007696	15	15	15	425	2360	7.6	1.99
15	0007697	15	15	15	440	116	7.2	0.10
18	2620125	12	219	12	716	973	7.3	1.38
19	2620126	220	220	220	1558	4699	7.9	14.55
25	3420040	10	10	10	930	2115	7.7	3.91
26	3420065	12	12	12	774	988	7.5	1.52
27	3420066	728	770	729	1441	4220	7.8	12.08
28	3420084	200	220	200	1394	3185	7.8	8.82
29	3420085	185	232	185	881	1056	7.5	1.85
31	3420091	40	41	41	916	4902	7.7	8.92
32	3420092	41	41	41	983	6376	7.7	12.45
33	3420095	122	85	123	845	5542	7.5	9.30
34	3420096	124	96	125	894	5283	7.5	9.38
35	3420103	3		3	525		7.2	
36	3420104	3		3	497		7.3	
37	3420109	218	222	220	1570	4678	7.9	14.59
38	3420110	194	214	194	1408	3180	7.8	8.90
39	3420111	357	433	358	893	1037	7.5	1.84
41	3420175	214	219	214	1048	57	6.8	0.12
42	3420176	145	219	145	417	14	5.9	0.01
43	3420177	117	219	117	923	30	7.4	0.06
44	3420178	218	219	218	713	240	7.3	0.34
47	3420193	122	84	122	788	7981	7.5	12.49
48	3420194	122	95	122	638	5532	7.5	7.01
49	3420216	9	9	9	592	97	7.4	0.11

50	3420217	9	9	9	723	1133	7.5	1.63
51	3420244	131	120	131	598	1845	7.4	2.19
52	3420245	131	120	131	603	2081	7.4	2.49
55	3420257	12	12	12	774	988	7.5	1.52
56	3420258	12	12	12	630	94	7.5	0.12
57	3420263	119	96	121	529	4464	7.4	4.69
58	3420265	200	220	200	1394	3212	7.8	8.90
60	3420267	204	219	204	555	2123	7.2	2.34
61	3420268	218	220	218	2009	18	7.1	0.07
62	3420269	75	220	75	1517	3	6.6	0.01
63	3420270	294	296	294	1955	14	7.1	0.05
64	3420271	294	295	294	1953	17	7.2	0.07
65	3420272	295	295	295	1746	45	7.6	0.16
66	3420313	10	12	10	29	4	0.8	0.00
67	3420320	91	57	92	688	3498	7.5	4.78
68	3420321	96	68	96	524	4119	7.4	4.29
69	3420322	93	68	93	542	4665	7.4	5.02

Source: DMME SFPound IS and NP data 7_26_13_MJS_JDB.xls[Instream WQ Data]

Table A. 9 Mine floor and mine footprint for mine units in the Bull Cr. watershed.

Value	Location	Mine Unit	Count (of 100 sq.ft. blocks)	Mine Footprint (sq.ft.)	Floor Multiplier	Mine Floor (sq.ft.)
30	Inside	A	150116	0	0	0
31	Inside	A	360988	36098800	100	36098800
32	Inside	A	97300	9730000	200	19460000
33	Inside	A	27375	2737500	300	8212500
40	Outside	A	232560	0	0	0
41	Outside	A	337581	33758100	100	33758100
42	Outside	A	29569	2956900	200	5913800
43	Outside	A	5441	544100	300	1632300
50	Inside	B	66220	0	0	0
51	Inside	B	52388	5238800	100	5238800
52	Inside	B	68669	6866900	200	13733800
53	Inside	B	16029	1602900	300	4808700
60	Outside	B	237151	0	0	0
61	Outside	B	322719	32271900	100	32271900
62	Outside	B	15818	1581800	200	3163600
70	Inside	C	158879	0	0	0
71	Inside	C	290896	29089600	100	29089600
72	Inside	C	147024	14702400	200	29404800
73	Inside	C	100087	10008700	300	30026100
74	Inside	C	52288	5228800	400	20915200
75	Inside	C	1899	189900	500	949500
80	Outside	C	803344	0	0	0
81	Outside	C	527201	52720100	100	52720100
82	Outside	C	76653	7665300	200	15330600
83	Outside	C	38479	3847900	300	11543700
84	Outside	C	15214	1521400	400	6085600
85	Outside	C	1343	134300	500	671500
90	Inside	D	125815	0	0	0
91	Inside	D	163772	16377200	100	16377200
92	Inside	D	121670	12167000	200	24334000
93	Inside	D	16467	1646700	300	4940100
94	Inside	D	5362	536200	400	2144800

100	Outside	D	229385	0	0	0
101	Outside	D	140234	14023400	100	14023400
102	Outside	D	21364	2136400	200	4272800
103	Outside	D	841	84100	300	252300
10	Inside	E	328718	0	0	0
11	Inside	E	514399	51439900	100	51,439,900
12	Inside	E	435852	43585200	200	87170400
13	Inside	E	47984	4798400	300	14395200
14	Inside	E	17240	1724000	400	6896000
20	Outside	E	779528	0	0	0
21	Outside	E	431236	43123600	100	43123600
22	Outside	E	154456	15445600	200	30891200
23	Outside	E	40095	4009500	300	12028500
24	Outside	E	2789	278900	400	1115600

Source: Mine_param_totals.xls[Raw].

Definitions:

count = The number of 100 sqft units at this level

value = Area (first digit) plus number of mine levels (second digit);
e.g., mine levels = 0 (none), 1 (one level), 2 (2 levels), etc.

location= Inside or outside of the Bull Cr. watershed

floor multiplier = Number by which Count is multiplied to get total mine floor
e.g., 400 means the area is 4 floors deep

footprint = The sqft of ground area that has N levels of mine
e.g., area 10 has 32,871,800 sqft of area un-mined and 51,439,900 sqft mined at 1 level only.
Multiply footprint by N levels to obtain total mine floor across N levels;
e.g., multiply footprint at level 3 to obtain total mine floor in the 3 levels.

mine floor = The mine floor space at N levels summed.
Equals the mine footprint at level N multiplied by N.

Table A. 10 S. F. Pound NPDES discharge stations and data summary.[47]

MapTech Map No.	Row Labels	Count of WtTds	Count of WtFlow	Count of WtPh	Average of WtTds (mg/L)	Average of WtFlow (gpm)	Average of WtPh (SU)	Average TDS Load (106 kg/yr)
1	0003655		26			922		
1	0000261		206			0		0
2	0001239		426			0		0
5	0001737	2	337	12	1687	48	7.15	0.16
7	0004373		64			0		0.00
8	0004374		73	1		0	6.70	0.00
9	0005182	1	233	10	156	0	7.12	0.00
10	0005819	1	24	2	728	1	6.75	0.00
12	0006925	68	91	76	289	62	7.23	0.04
13	0006926		27			0		0.00
14	0006927		25			0		0.00
15	0007240	1	84	1	376	2	7.70	0.00
16	0007241		84			0		0.00
17	0007242		84			0		0.00
20	2670086	98	453	432	1098	42	7.06	0.09
25	3470010		9			0		0.00
26	3470011		10	7		4	6.23	
31	3470054		25	21		29	7.14	
32	3470055		25	10		7	7.20	
34	3470068	32	386	388	1283	54	7.50	0.14
35	3470069	100	439	350	1466	35	7.52	0.10
36	3470072		270	55		2	7.41	
37	3470100		25			0		0.00
38	3470101		25			0		0.00
39	3470102		25			0		0.00
61	3470155		310			0		0.00
62	3470156		284			0		0.00
63	3470157		284			0		0.00
64	3470158	23	438	198	755	21	7.68	0.03
65	3470159		310			0		0.00
66	3470160		310			0		0.00
67	3470161		263	4		0	7.40	0.00
69	3470189		236	85		4	7.33	
70	3470190		223	67		5	7.23	
71	3470199		270	2		0	7.50	0.00
79	3470248		224	192		22	7.51	
82	3470259	32	296	286	1069	308	7.43	0.65
83	3470264		181	107		13	7.39	

47 DMME SFPound IS and NP data 7_26_13_CDF.xls.

84	3470286	79	443	246	1548	7	7.35	0.02
85	3470287	99	439	433	2003	295	7.69	1.17
86	3470288	101	441	424	2237	38	7.26	0.17
87	3470289	4	366	216	627	12	7.29	0.01
88	3470290		432	37		2	7.22	
89	3470291	87	442	432	1392	69	6.95	0.19
91	3470293	860	872	872	2029	38	6.96	0.15
92	3470294	875	890	890	1832	301	7.68	1.10
93	3470318		194	28		7	6.52	
94	3470319		192	150		36	7.13	
95	3470326		172	36		2	7.17	
96	3470327		181	23		1	6.87	
133	3481220		10	2		1	6.75	
134	3481221		10	5		5	6.58	
152	3482127		19	19		149	7.29	
154	3482129		17			0		0.00
159	3484551		19			0		0.00
160	3485964		101	101		1179	7.51	

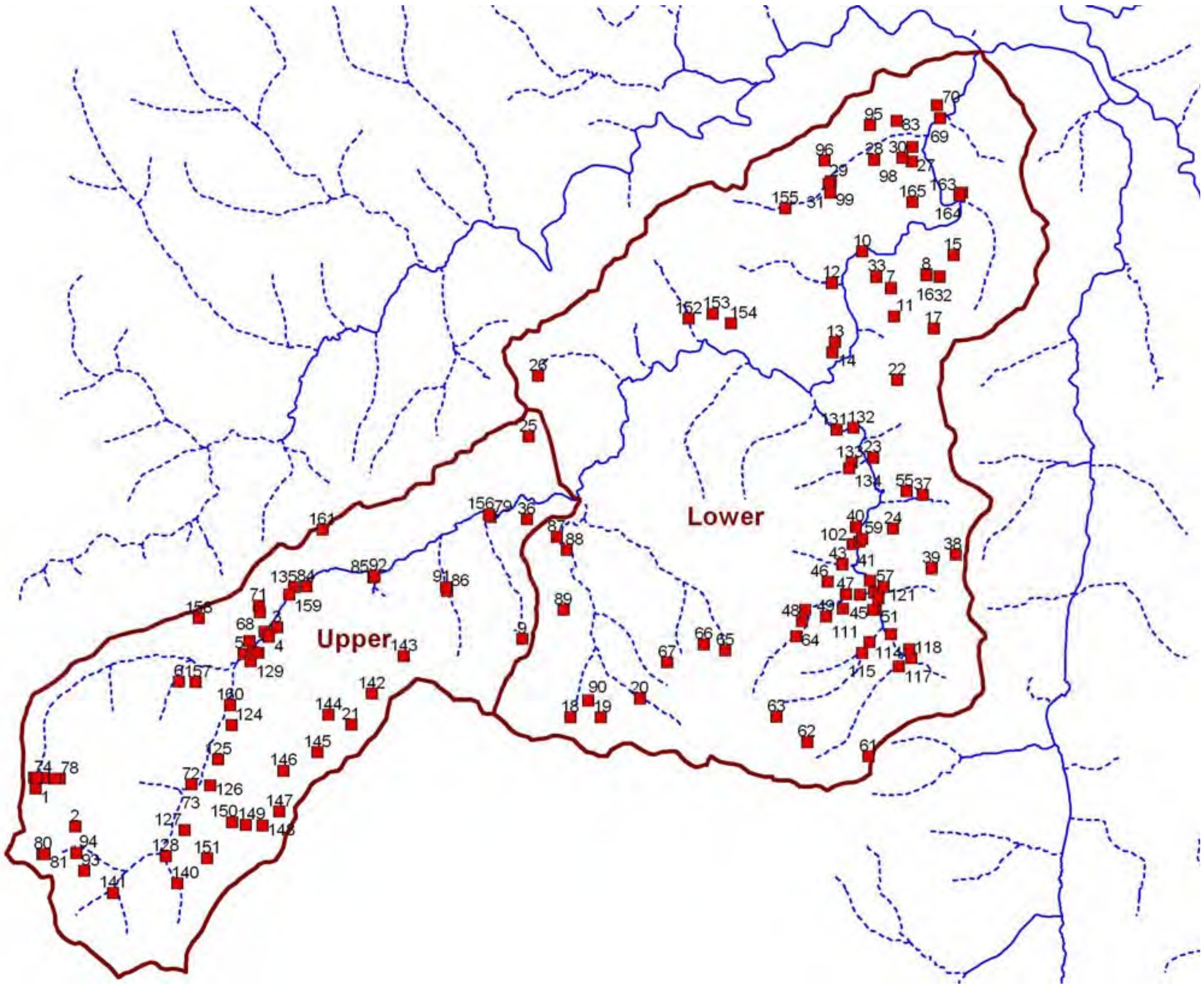

Figure A.1 NPDES monitoring stations in the S. F. Pound River watershed.[48]

[48] Source: SFP_NPDES_Mon_v1.png.

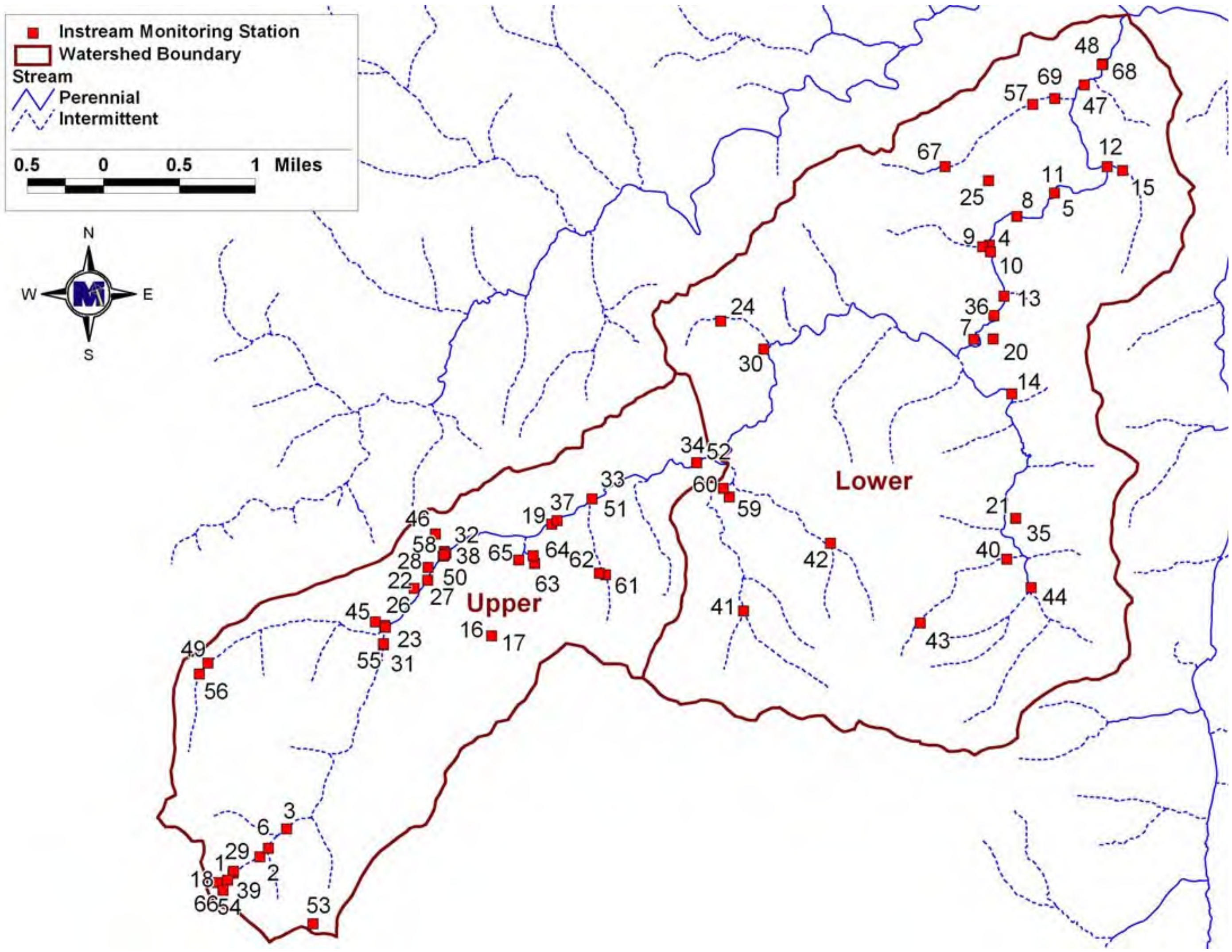

Figure A.2 In-stream water quality monitoring stations in the S. F. Pound River watershed.[49]

49 Source: SFP_Instream_mon_v1.jpg

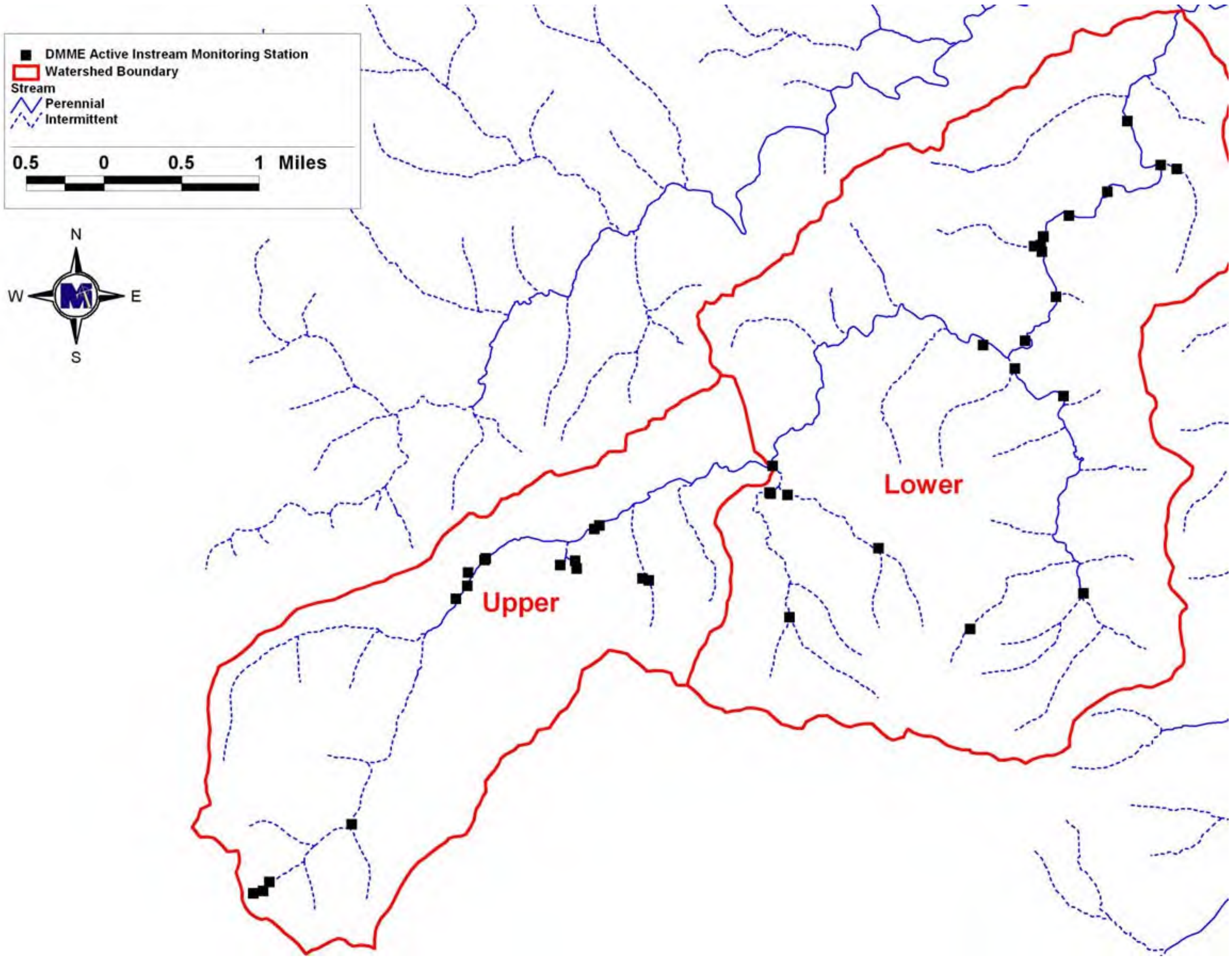

Figure A.3 Recent in-stream water quality sampling stations in the S. F. Pound River watershed.