Total Maximum Daily Load Development for Lewis Creek General Standard (Benthic)

Prepared for
Virginia Department of Environmental Quality
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Lewis Creek Advisory Committee

City of Staunton Department of Public Works

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EXECUTIVE SUMMARY

Background and Applicable Standards

Lewis Creek was initially listed on the *1996 303(d) TMDL Priority List* for violations of the General Standard (benthic) based on monitoring performed. Lewis Creek had a rating of moderately impaired at biological monitoring station 1BLEW006.95. Lewis Creek was also listed as impaired on the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ & VADCR, 1998) and the *2002 303(d) Report on Impaired Waters* (VADEQ, 2002) with a rating of severely impaired at monitoring station 1BLEW006.95. Lewis Creek remained on the 2004 305(b)/303(d) Water Quality Assessment Integrated Report for a severely impaired rating at monitoring station 1BLEW006.95. Recent monitoring at station 1BLEW000.61 on Lewis Creek found moderately impaired conditions. Lewis Creek carries an agency watershed ID of VAV-B12R.

The General Standard is implemented by the Virginia Department of Environmental Quality (VADEQ) through application of the modified Rapid Bioassessment Protocol II (RBPII). Using the modified RBPII, the health of the benthic macro-invertebrate community is typically assessed through measurement of eight biometrics. Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, slightly impaired, moderately impaired, or severely impaired). Using this methodology, Lewis Creek was rated as severely impaired based on monitoring at 1BLEW006.95.

TMDL ENDPOINT: STRESSOR IDENTIFICATION

A Total Maximum Daily Load (TMDL) must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but generally do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (USEPA, 2000) was used to identify stressors affecting Lewis Creek. Chemical and physical monitoring data from VADEQ monitoring stations provided evidence to support or eliminate potential stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter.

The results of the stressor analysis for Lewis Creek are divided into three categories:

> **Non-Stressor(s)**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor(s)**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.
>
> **Most Probable Stressor(s)**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

The results indicate multiple stressors are affecting different reaches of Lewis Creek. Excessive levels of lead and total polycyclic aromatic hydrocarbons (PAHs) impact the urban area including monitoring station 1BLEW006.95. The lower portion of the watershed including monitoring station 1BLEW000.61 is impacted somewhat by excessive levels of lead and total PAHs but sediment deposition is the most serious problem at this monitoring station. Therefore there are three Most Probable Stressors in the Lewis Creek watershed; lead, total PAHs and sediment.

Sediment is delivered to Lewis Creek through surface runoff, streambank erosion, and natural erosive processes. During runoff events, sediment is transported to streams from land areas. Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Land disturbances from agriculture, industrial activity and construction (roads and buildings) accelerate erosion at varying degrees.

Sediment transport is a natural and continual process that is often accelerated by human activity. An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater, and construction stormwater discharge.

Lead is a naturally occurring compound in the watershed and is also transported to the stream by the sediment transport processes described above. In addition there are contaminated sites within the City of Staunton urban area that have historically had high levels of lead in both soil and ground water measurements. One of the most contaminated sites for lead was the former Klotz Courtyard. This site was a superfund project and 1,360 tons of lead contaminated soil was removed in 1996. The project was closed in 1997. Another site that has excessive levels of lead measured in soil samples is the former Staunton Metal Recyclers. This site has had very little remediation work done to it and probably is a continuing source of lead in the watershed.

Total PAHs are primarily the products of incomplete combustion of organic matter and are found in soot from vehicle exhaust, smoke, creosote, coal tar and asphalt. They also occur naturally in petroleum products. Total PAHS are also transported to the stream by the sediment transport processes described above. In addition there are contaminated sites within the City of Staunton urban area that have historically had excessive levels of total PAHs in soil and ground water samples. Direct contamination to Lewis Creek was also documented. Contamination was so severe at the former Beverly Exxon site that it was nominated for placement on USEPA’s National Priority List for superfund projects. However, at the request of the Governor of Virginia in 1996 it was removed and to date no remediation addressing the serious total PAH contamination has taken place. Columbia Gas, with property located adjacent to the former Beverly Exxon site, is participating in the VADEQ’s Voluntary Remediation Program (VRP) because of total PAH contamination on their site. Extensive remediation was accomplished in 2000 and 2002 and VADEQ is reviewing final reports to determine if additional work will be necessary.

Modeling Procedures

There are no existing in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Lewis

Creek watershed. The Upper Opequon Creek watershed was selected as the TMDL reference for Lewis Creek due to the similarity of the watershed characteristics. The TMDL sediment loads were defined as the modeled sediment load for existing conditions from the non-impaired upper Opequon Creek watershed, area-adjusted to the Lewis Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling between both the non-impaired creek and Lewis Creek.

A mass balance spreadsheet modeling approach was used in this study to develop benthic TMDLs for lead and total PAHs for the Lewis Creek watershed. The mass balance model was developed using sediment output from the GWLF modeling. The watershed was divided into three subwatersheds based on the location of monitoring performed during the TMDL study. Background contaminant loads from each subwatershed, a lumped contaminated site load, and downstream contaminant transport were considered in the mass balance model. Initial background loadings for lead and total PAHs were estimated for each subwatershed based on values published by Novotny and Olem (1994). These background loadings were then calibrated to match instream sediment contaminant concentrations. Background loadings from non-urban areas were calibrated to contaminant concentrations measured upstream of the City of Staunton (at station 1BLEW009.19). Background loadings in the urban area were calibrated to contaminant concentrations measured in Asylum Creek, located within subwatershed 2, but unaffected by contaminated sites. The lumped contaminated site load was then determined by balancing the mass necessary to match instream sediment contaminant concentrations measured at the outlet of subwatershed 2, the most contaminated station (1BLEW006.64). This mass balance provided the modeled existing conditions. To develop the TMDL, target instream sediment contaminant concentrations were set at the threshold effect concentration (TEC) for lead and total PAHs as published by MacDonald et al (2000). Loads were reduced to meet the TEC at the outlet of subwatershed 2. These reduced loads set the lead and total PAH TMDLs for Lewis Creek.

Existing Conditions

The sediment TMDL for Lewis Creek was defined by the average annual sediment load in metric tons per year (t/yr) from the area-adjusted Upper Opequon Creek. The sediment loads for existing conditions were calculated using the period of July 1992 through June 1997.

The sediment TMDL is composed of three components: waste load allocations (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), which was set to 10% for the sediment TMDL. The target sediment load (from area-adjusted Upper Opequon Creek) for Lewis Creek was 2,857 t/yr. The existing load from Lewis Creek was 6,742.96 t/yr. Table ES.1 summarizes the TMDL targets for Lewis Creek watershed.

Table ES.1 TMDL Sediment Targets for Lewis Creek Watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS	TMDL (t/yr)
Lewis Creek	40	2,857	322	3,218

The lead and total PAH TMDLs for Lewis Creek were defined by the average annual load in kilograms per year (kg/yr). The existing loads were determined by calculating the background loading in the three subareas and calibrating to monitored sediment concentrations at the outlet of subarea 2.

The lead and total PAH TMDLs are composed of three components: waste load allocations (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS). An implicit margin of safety was used for these parameters. The target lead and total PAH loads for Lewis Creek are 203,570 kg/yr. and 7,151 kg/yr. respectively. The existing lead load from Lewis Creek was 532,870 kg/yr. and the total PAH load was 28,015 kg/yr. Tables ES.2 and ES.3 summarizes the TMDL targets for the Lewis Creek watershed.

Table ES.2 TMDL Lead Targets for Lewis Creek Watershed.

Impairment	WLA (kg/yr)	LA (kg/yr)	MOS	TMDL (kg/yr)
Lewis Creek	0	203,570	*Implicit*	203,570

Table ES.3 TMDL Total PAH Targets for Lewis Creek Watershed.

Impairment	WLA (kg/yr)	LA (kg/yr)	MOS	TMDL (kg/yr)
Lewis Creek	0	7,151	*Implicit*	7,151

Load Allocation Scenarios

The next step in the sediment TMDL process was to reduce the various source loads to result in average annual sediment loads less than the target sediment TMDL load. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Allocations were developed at the outlet of Lewis Creek.

The final load allocation scenario for Lewis Creek required a 57% reduction in sediment. The sediment reduction will target loads from urban and agriculture land uses as well as stream bank erosion. No reductions to permitted sources were required.

Allocations for the lead and total PAH TMDLs were developed at the outlet of subwatershed 2. A 99% reduction for lead and total PAH was required for the combined contaminated sites in subwatershed 2. In addition a 3% reduction in lead and 16% reduction in total PAH were required from the background loads in subwatershed 2. The final load allocation scenarios for Lewis Creek required a 63% and 74% reduction in lead and total PAH, respectively.

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 Lewis Creek. The second step is to develop a

TMDL implementation plan (IP). The final step is to implement the TMDL IP and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency (EPA) 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. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. DEQ will rely on existing regulatory programs, such as the VADEQ Waste Program, Voluntary Remediation Program, Brownfields Program, Site Assessment Program, and Superfund Program, to address remediation at these sites and assist in implementing the lead and total PAH TMDLs.

It is anticipated that agricultural and urban runoff will be the initial target of implementation for sediment. A 35% reduction in erosion and sediment deposition from these areas can result in achieving nearly 50% of the required reduction in sediment.

The initial target of implementation for lead and Total PAH reductions will be to remediate the contaminated sites in the urban area that have not had any significant clean up work performed on their sites.

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

Public Participation

During development of the TMDL for Lewis Creek, public involvement was encouraged through two public meetings. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Lewis Creek TMDL were presented at the first of the public meeting held on January 24, 2005. Details of the pollutant sources and stressor identification were also presented at this meeting. Public understanding of and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. A local steering committee meeting was held on November 30, 2005 and the results of the sampling and stressor analysis were presented. A second local steering committee meeting was held on January 15, 2006 and the modeling approach as well as preliminary results were presented. The final model simulations and the TMDL load allocations were presented during the final public meeting on March 8, 2006. There was a 30-day public comment period after the final public meeting and two sets of written comments were received. VADEQ provided a written response to each of the comments. Watershed stakeholders will have the opportunity to participate in the development of the TMDL IP.

1. INTRODUCTION

1.1 Background

The United States Environmental Protection Agency's (EPA) document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA, 1991) states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs .*
>
> *. . . A TMDL, or total maximum daily load, is a tool for implementing State water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

Lewis Creek was initially listed on the *1996 303(d) TMDL Priority List* (VADEQ, 1996) for violations of the General Standard (benthic) based on monitoring performed. Lewis Creek had a rating of moderately impaired at biological monitoring station 1BLEW006.95. Lewis Creek was also listed as impaired on the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ & VADCR, 1998) and the *2002 303(d) Report on Impaired Waters* (VADEQ, 2002) with a rating of severely impaired at monitoring station 1BLEW006.95. Lewis Creek remained on the *2004 305(b)/303(d) Water Quality Assessment Integrated Report* (VADEQ, 2004) for a severely impaired rating at monitoring station 1BLEW006.95. Recent monitoring at station 1BLEW000.61 on Lewis Creek found moderately impaired conditions. Lewis Creek carries a Virginia Department of Environmental Quality (VADEQ) watershed ID of VAV-B12R.

The Lewis Creek watershed (within USGS Hydrologic Unit Code #0207005) is located in Virginia's Augsuta County and the city of Staunton (Figure 1.1). The impaired stream segment extends from river mile 9.55, just within the Staunton City limits, to its confluence with the Middle River near Verona. Lewis Creek flows into the Middle River.

Middle River flows into North River, which joins South River to form the South Fork of the Shenandoah River. The Shenandoah River drains to the Potomac River, which flows into the Chesapeake Bay. The land area of the Lewis Creek watershed is approximately 17,683 acres.

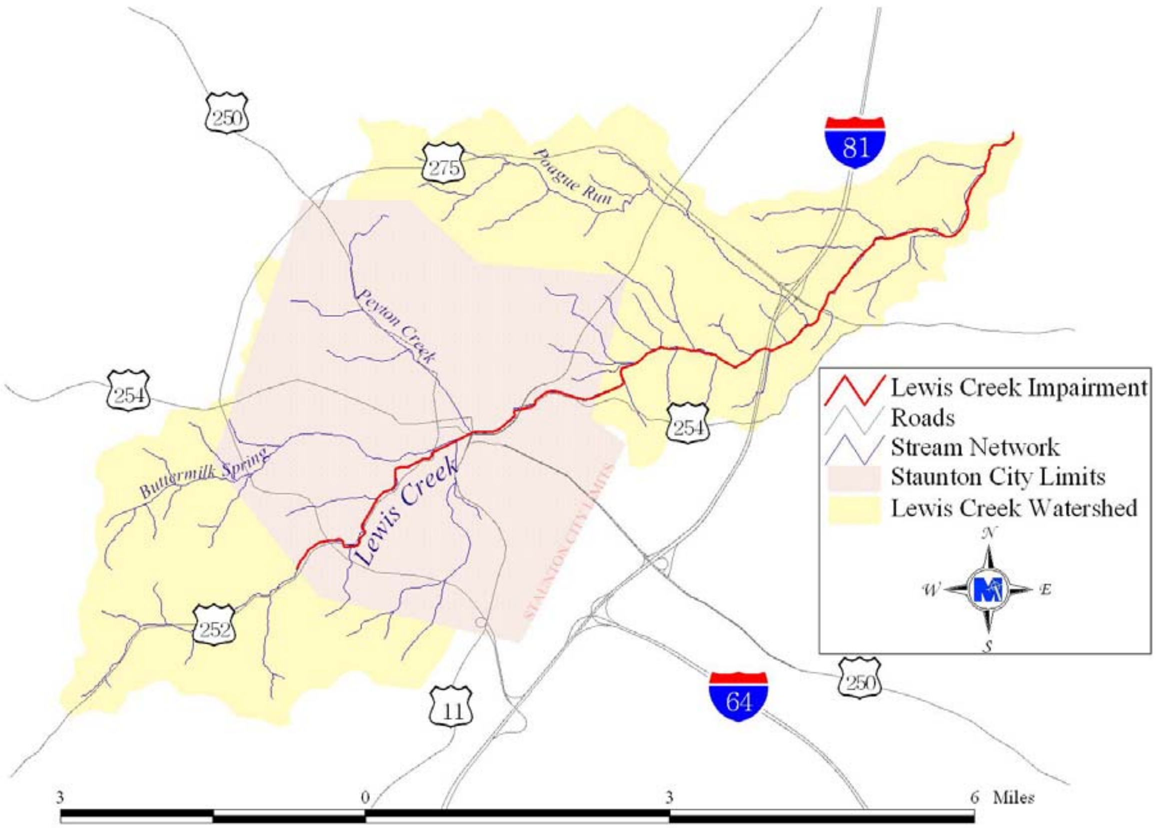

Figure 1.1 Location of the Lewis Creek watershed and impaired segment of Lewis Creek.

2. WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

Virginia state law 9VAC25-260-10 (Designation of uses) indicates:

A. *All state waters, including wetlands, 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.*

♦

D. *At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

♦

G. *The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*

1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*

2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*

6. *Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

2.2 Applicable Criterion for Benthic Impairment

Additionally, Virginia state law 9VAC25-260-20 defines the **General Standard** as:

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.*

2.3 Benthic Assessment

The General Standard is implemented by the VADEQ through application of the Rapid Bioassessment Protocol II (RBP II). Using the RBP II, the health of the benthic macroinvertebrate community is typically assessed through measurement of eight biometrics which measure different aspects of the community's overall health (Table 2.1). Surveys of the benthic macroinvertebrate community performed by the VADEQ are assessed at the family taxonomic level (Barbour, 1999). It is this bioassessment that is the endpoint for General Standard (benthic) impaired Total Maximum Daily Load (TMDL).

The VADEQ has three monitoring stations in the Lewis Creek watershed; a benthic monitoring station is located at river mile 6.95 off of Rt. 11 at the Virginia School for the Blind and Deaf. Lewis Creek was initially listed on the *1996 303(d) TMDL Priority List* as being partially supporting for aquatic life use. Lewis Creek was also listed as impaired on the *1998 303(d) Total Maximum Daily Load Priority List and Report*. Lewis Creek remained on the Virginia *2002 Section 303(d) Report on Impaired Waters* for violations of the General Standard (benthic) and on the *2004 305(b)/303(d) Water Quality Assessment Integrated Report* (VADEQ, 2004) based on monitoring performed at station 1BLEW006.95 (Figure 2.1). Benthic monitoring station 1BLEW006.95 is the long term station on Lewis Creek. 1BLEW000.61 was added later to better characterize the impairment and confirmed that the impairment extended to Middle River. Benthic monitoring station 1BLEW009.19 was added to determine conditions upstream of the City of Staunton. The RBP II scores for it have consistently indicated a slightly impaired condition.

Table 2.1 Components of the RBP II Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index	↓
Scraper to Filtering Collector Ratio	↑
EPT / Chironomid Ratio	↑
% Contribution of Dominant Family	↓
EPT Index	↑
Community Loss Index	↓
Shredder to Total Ratio	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases and a downward arrow indicates a negative response in benthic health when the associated biometric increases.

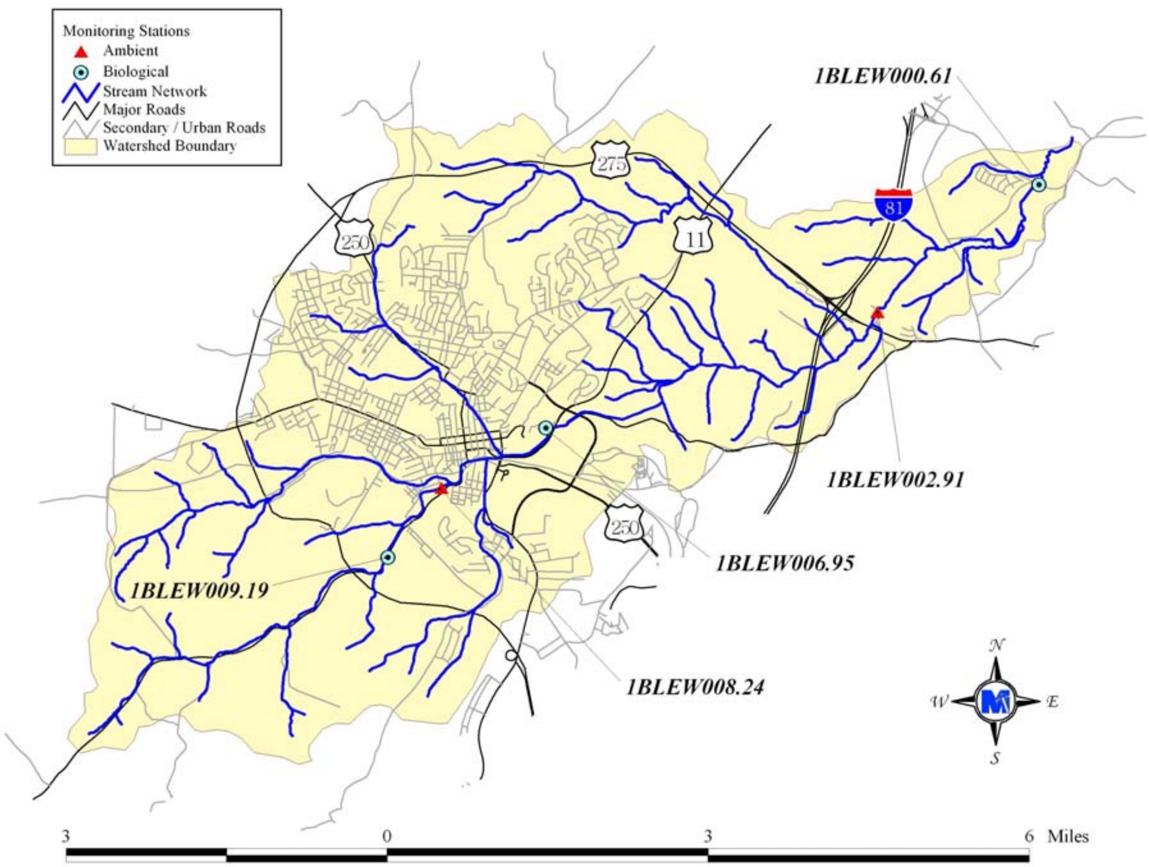

Figure 2.1 Location of VADEQ benthic monitoring stations in the Lewis Creek watershed.

Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.,* non-impaired, moderately impaired, or severely impaired).

RBP II benthic surveys were performed by the VADEQ at three monitoring stations, 1BLEW000.61 (May 2002 through May 2005), 1BLEW006.95 (October 1994 through May 2005) and 1BLEW009.19 (June 2004 through May 2005). The results of these surveys are presented in Tables 2.2, 2.3 and 2.4. The tables indicate moderate to severe impairment at stations 1BLEW000.61 and 1BLEW006.95 and slight impairment at 1BLEW009.19. The primary difference between Lewis Creek and the reference station was the absence of pollution-sensitive organisms such as mayflies, stoneflies and caddisflies. A Virginia Stream Condition Index (VASCI) was recently approved for use in Virginia and is being used on an interim basis to see if further calibration is necessary. Eight biometrics are obtained, with higher scores indicating a healthier benthic community. The advantage of the VASCI is that the score does not depend upon values from a reference station. The VASCI has an impairment threshold of 61.3 and the scores for the VADEQ surveys are presented in Tables 2.5, 2.6 and 2.7 and Figure 2.2.

Table 2.2 RBP II biological monitoring data for VADEQ station 1BLEW000.61.

	5/7/2002	11/1/2002	3/12/2003	10/24/2003	10/24/2003	6/2/2004	9/20/2004	5/4/2005
RBP II Metric	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
Taxa Richness	10	19	10	11	11	13	11	7
MFBI	5.26	5.59	5.68	5.74	5.75	5.58	6.11	5.73
SC/CF	0.00	0.38	1.25	0.05	0.00	0.57	0.15	2.00
EPT/Chi Abund	0.11	1.32	0.35	0.24	0.34	0.69	1.38	0.11
% Dominant	51.16	22.05	38.74	68.70	55.97	48.95	29.32	80.00
EPT Index	4	8	2	4	3	6	4	3
Comm. Loss Index	1.40	0.47	1.50	0.45	0.55	0.92	0.73	1.57
SH/Tot	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00
Biological Condition Score	10	22	16	14	12	14	22	14
% of Reference	21.74	47.83	36.36	30.43	26.09	31.82	50.00	33.33
Assessment	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**

Table 2.3 RBP II biological monitoring data for VADEQ station 1BLEW006.95.

	10/20/1994	5/16/1995	10/10/1995	6/3/1996	5/5/1997	9/18/1997	10/26/1999	4/11/2000
RBP II Metric	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
Taxa Richness	7	12	7	10	6	8	6	7
MFBI	6.02	6.11	6.28	6.69	6.26	6.64	5.77	6.11
SC/CF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EPT/Chi Abund	5.50	0.78	14.83	14.00	0.10	12.00	16.60	0.27
% Dominant	72.13	29.31	64.49	41.67	65.22	43.64	80.58	69.67
EPT Index	1	1	1	3	2	2	1	2
Comm. Loss Index	2.29	1.50	2.14	2.00	2.67	1.38	2.67	2.00
SH/Tot	0.00	0.01	0.00	0.01	0.00	0.02	0.02	0.01
Biological Condition Score	4	8	2	10	4	12	8	4
% of Reference	8.70	16.67	4.35	20.83	8.70	26.09	17.39	8.33
Assessment	**Severe**	**Severe**	**Severe**	**Moderate**	**Severe**	**Moderate**	**Severe**	**Severe**

Table 2.3 RBP II biological monitoring data for VADEQ station 1BLEW006.95. (cont.)

	10/16/2000	5/28/2002	11/1/2002	3/12/2003	10/24/2003	6/2/2004	9/20/2004	5/4/2005
RBP II Metric	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**	**Score**
Taxa Richness	10	9	7	10	11	10	9	8
MFBI	6.00	5.67	5.86	7.21	5.40	4.95	6.02	6.20
SC/CF	0.00	0.00	0.00	0.00	0.06	1.83	0.05	0.27
EPT/Chi Abund	1.80	1.21	7.23	0.71	1.12	1.44	10.25	0.22
% Dominant	45.05	30.91	74.19	55.91	32.08	32.56	74.77	64.46
EPT Index	2	3	2	3	5	2	2	2
Comm. Loss Index	1.30	1.22	1.71	1.50	0.45	1.20	0.89	1.38
SH/Tot	0.02	0.06	0.06	0.00	0.02	0.12	0.02	0.02
Biological Condition Score	10	12	8	8	18	28	22	12
% of Reference	21.74	26.09	17.39	18.18	39.13	63.64	50.00	28.57
Assessment	**Moderate**	**Moderate**	**Severe**	**Severe**	**Moderate**	**Slight**	**Moderate**	**Moderate**

Table 2.4 RBP II biological monitoring data for VADEQ station 1BLEW009.19.

	6/2/2004	9/20/2004	5/4/2005
RBP II Metric	**Score**	**Score**	**Score**
Taxa Richness	15	13	11
MFBI	4.80	4.55	3.74
SC/CF	3.29	1.59	7.29
EPT/Chi Abund	1.86	8.38	22.33
% Dominant	36.44	21.01	31.73
EPT Index	8	6	8
Comm. Loss Index	0.47	0.23	0.55
SH/Tot	0.02	0.02	0.00
Biological Condition Score	34	36	28
% of Reference	77.27	81.82	66.67
Assessment	**Slight**	**Slight**	**Slight**

Table 2.5 VASCI data for VADEQ station 1BLEW000.61.

VASCI Metric	05/07/02	11/01/02	03/12/03	10/24/03	06/02/04	09/20/04	05/04/05
Richness Score	45.45	86.36	45.45	50.00	59.09	50.00	31.82
EPT Score	36.36	72.73	18.18	36.36	54.55	36.36	27.27
%Ephem Score	6.32	43.67	7.35	7.47	26.24	22.08	9.06
%PT-H Score	4.36	4.42	0.00	0.00	5.89	0.00	0.00
%Scraper Score	58.76	33.02	69.75	12.31	14.66	7.28	14.34
%Chironomidae Score	48.84	77.95	81.98	31.30	51.05	70.68	20.00
%2Dom Score	19.02	82.94	62.40	27.54	51.46	62.93	16.03
%MFBI Score	69.65	64.84	63.59	62.64	64.99	57.16	62.75
VASCI Score	**36.10**	**58.24**	**43.59**	**28.45**	**40.99**	**38.31**	**22.66**

Table 2.6 VASCI data for VADEQ station 1BLEW006.95.

VASCI Metric	10/20/94	05/16/95	10/10/95	06/03/96	05/05/97	09/18/97	10/26/99	04/11/00
Richness Score	27.27	54.55	31.82	45.45	27.27	36.36	27.27	31.82
EPT Score	9.09	9.09	9.09	27.27	18.18	18.18	9.09	18.18
%Ephem Score	0.00	0.00	0.00	3.40	1.77	11.86	0.00	1.34
%PT-H Score	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
%Scraper Score	2.78	5.56	9.35	10.08	0.00	2.93	15.66	2.64
%Chironomidae Score	86.21	68.10	95.65	96.88	32.61	96.36	95.15	30.33
%2Dom Score	14.93	65.93	34.51	25.55	28.23	28.86	14.01	17.74
%MFBI Score	57.05	57.30	54.99	48.71	54.99	50.00	61.96	57.26
VASCI Score	**24.67**	**32.57**	**29.43**	**32.17**	**20.38**	**30.57**	**27.89**	**19.91**

Table 2.6 VASCI data for VADEQ station 1BLEW006.95 (cont.)

VASCI Metric	10/16/00	05/28/02	11/01/02	03/12/03	10/24/03	06/02/04	09/20/04	05/04/05
Richness Score	45.45	40.91	31.82	45.45	50.00	45.45	40.91	36.36
EPT Score	18.18	27.27	18.18	27.27	45.45	18.18	18.18	18.18
%Ephem Score	5.88	19.28	2.63	2.57	13.85	17.70	3.05	2.70
%PT-H Score	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
%Scraper Score	7.27	11.73	3.90	7.62	39.56	52.51	6.03	5.33
%Chironomidae Score	72.97	69.09	89.52	83.46	67.92	80.62	92.52	35.54
%2Dom Score	40.30	62.97	22.11	39.77	58.54	69.35	24.27	31.01
%MFBI Score	58.82	63.64	60.84	41.11	67.70	74.33	58.55	55.91
VASCI Score	**31.11**	**36.86**	**28.62**	**30.91**	**42.88**	**44.77**	**30.44**	**23.13**

Table 2.7 VASCI data for VADEQ station 1BLEW009.19.

VASCI Metric	06/02/04	09/20/04	05/04/05
Richness Score	68.18	59.09	50.00
EPT Score	72.73	54.55	72.73
%Ephem Score	31.80	67.17	87.84
%PT-H Score	4.76	14.16	13.50
%Scraper Score	76.54	62.35	79.09
%Chironomidae Score	82.20	93.28	97.12
%2Dom Score	66.04	88.52	74.93
%MFBI Score	76.52	80.20	92.05
VASCI Score	**59.85**	**64.91**	**70.91**

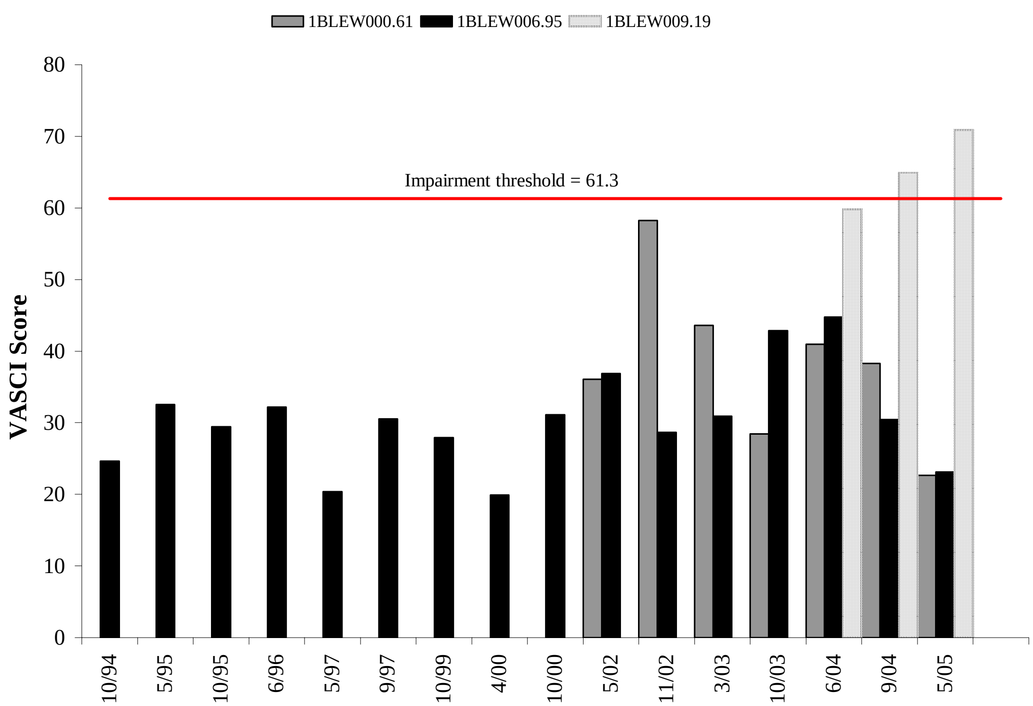

Figure 2.2 VASCI scores at VADEQ benthic monitoring stations on Lewis Creek.

2.4 Habitat Assessment

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.,* by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.,* due to land use changes in the watershed such as clearing large areas). Habitat assessment for Lewis Creek includes an analysis of habitat scores recorded by the VADEQ biologist.

2.4.1 Habitat Assessment at Biological Monitoring Stations

Habitat assessments are normally carried out as part of the benthic sampling. The overall habitat score is the sum of 10 individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score for a sampling site are shown in Table 2.8. Descriptions for each scoring category can be found in Appendix A (*Rapid Bioassessment Protocols for use in Streams and Wadeable Rivers: Second Edition*, 2000). Embeddedness is a measure of the extent to which the suitable riffle habitat is covered or sunken into sediment. The epifaunal substrate metric indicates the quantity and variety of natural structures in the stream, such as cobble, large rocks, fallen trees, branches, logs, etc. The pool sediment metric is the measurement of gravel, sand or fine sediment on the stream bottom. The channel flow status metric is a measure of how much of the stream channel is covered by water, and is particularly useful during periods of low flows. The most diverse high gradient streams have four distinct velocity/depth combinations (slow-deep, slow-shallow, fast-deep, and fast-shallow). Alteration is present when riprap or other forms of bank stabilization structures are present. Channel alteration can encourage scouring of the stream bottom. Riffles are the source of prime habitat in high gradient streams and, therefore, the more frequent they are the better the habitat. Bank stability is a measure of severity of bank erosion. Eroded banks indicate a problem with sediment movement into the stream. Bank vegetation is indicative of the type and quality of bank vegetation. Trees, for example, have root systems that can protect the bank from erosion. The lack of proper streambank vegetation is another indication of erosion potential. Riparian vegetation is a measure of the width of the natural riparian zone. A healthy riparian zone acts as a buffer for pollutants running off the land, helps prevent erosion, and provides habitat.

Table 2.8 Classification of habitat metrics based on score.

HABITAT METRIC	OPTIMAL	SUB-OPTIMAL	MARGINAL	POOR
Bank Stability	18 – 20	12 – 16	6 - 10	0 - 4
Bank Vegetation	18 – 20	12 – 16	6 - 10	0 - 4
Channel Alteration	16 – 20	11 – 15	6 - 10	0 - 5
Channel Flow	16 – 20	11 – 15	6 - 10	0 - 5
Embeddedness	16 – 20	11 – 15	6 - 10	0 - 5
Epifaunal Substrate	16 – 20	11 – 15	6 - 10	0 - 5
Pool Sediment	16 – 20	11 – 15	6 - 10	0 - 5
Riffles	16 – 20	11 – 15	6 - 10	0 - 5
Riparian Vegetation	18 – 20	12 – 16	6 - 10	0 - 4
Velocity	16 – 20	11 – 15	6 - 10	0 - 5
OVERALL SCORE	**166-200**	**113-153**	**60-100**	**0-47**

The VADEQ habitat assessments on Lewis Creek are displayed in Tables 2.9, 2.10 and 2.11. Two of the seven Embeddedness scores at 1BLEW000.61 were in the poor category and four had marginal ratings for embeddedness indicating that embeddedness is a significant problem at this benthic monitoring station. This means that the majority of the time the gravel and cobble in the riffle area is more than 75% surrounded by fine sediment. Pool Sediment scores were in the marginal category in four of the seven benthic surveys at 1BLEW000.61. Therefore the pool areas of the stream in the vicinity of this monitoring station were 30 – 50% covered with fine sediment. Four of the seven Bank Vegetation scores were in the marginal category indicating that only 50 - 70% of the stream bank has adequate vegetation to protect it during high stream flows. Riparian Vegetation scores were in the poor category for four surveys and marginal category for three. A poor score for this parameter indicates that there is little to no riparian vegetation due to human activities. Habitat scores at 1BLEW006.95 were much better for the Embeddedness and Pool Sediment parameters. Four Embeddedness scores were in the marginal category and one was in the poor category out of 16 total surveys. The average Embeddedness score was in the sub-optimal category. Four Pool Sediment scores were in the marginal category out of 16 surveys and the average score was in the sub-optimal category. Four of 16 Riparian Vegetation scores were in the poor category and eight were in the marginal category. The average Riparian Vegetation score was in the marginal category. Median Bank Stability scores were in the marginal category with one score in the poor category and four additional scores in the marginal category. Bank Stability is an indicator of how vulnerable the stream bank is to erosion. Marginal scores indicate that 30 – 60% of the stream bank is exposed and could potentially erode during high stream flows. Habitat scores were best at the most upstream benthic monitoring station 1BLEW009.19. Two out of three Riparian Vegetation scores were in the marginal category.

Table 2.9 Habitat scores for VADEQ monitoring station 1BLEW000.61 on Lewis Creek.

Habitat Metric	5/7/2002	11/1/2002	3/12/2003	10/24/2003	6/2/2004	9/20/2004	5/4/2005
Bank Stability	17	10	15	8	16	14	16
Bank Vegetation	13	8	7	0	14	16	10
Channel Alteration	14	13	12	15	12	14	16
Channel Flow	19	12	20	20	18	19	17
Embeddedness	9	3	9	7	5	10	12
Epifaunal Substrate	11	8	6	11	10	11	16
Pool Sediment	11	11	6	11	10	9	10
Riffles	13	12	14	10	15	16	12
Riparian Vegetation	2	7	3	0	6	6	2
Velocity	12	14	14	16	13	13	13
Total Score	**121**	**98**	**106**	**98**	**119**	**128**	**124**

Table 2.10 Habitat scores for VADEQ monitoring station 1BLEW006.95 on Lewis Creek.

Habitat Metric	10/20/1994	5/16/1995	10/10/1995	6/3/1996	5/5/1997	9/18/1997	10/26/1999	4/11/2000
Bank Stability	10	8	8	16	10	10	14	12
Bank Vegetation	10	8	10	14	10	6	17	7
Channel Alteration	12	12	12	16	10	14	10	12
Channel Flow	18	20	18	20	20	20	20	16
Embeddedness	10	14	10	12	12	12	12	2
Epifaunal Substrate	12	14	10	14	14	14	18	16
Pool Sediment	8	12	8	12	10	14	14	8
Riffles	10	14	14	14	12	14	18	16
Riparian Vegetation	6	4	2	6	0	4	10	12
Velocity	16	16	14	16	16	16	13	15
Total Score	**112**	**122**	**106**	**140**	**114**	**124**	**146**	**116**

Table 2.10 Habitat scores for VADEQ monitoring station 1BLEW006.95 on Lewis Creek (cont.)

Habitat Metric	10/16/2000	5/28/2002	11/1/2002	3/12/2003	10/24/2003	6/2/2004	9/20/2004	5/4/2005
Bank Stability	8	13	10	8	4	15	14	14
Bank Vegetation	17	14	15	18	17	18	15	18
Channel Alteration	7	14	8	17	9	6	10	6
Channel Flow	19	15	15	19	19	17	19	17
Embeddedness	13	10	8	16	12	14	12	11
Epifaunal Substrate	11	11	11	16	14	13	12	15
Pool Sediment	14	9	13	14	14	18	11	15
Riffles	16	16	17	12	13	18	13	16
Riparian Vegetation	6	11	8	7	6	9	10	9
Velocity	13	14	16	18	16	12	14	17
Total Score	**124**	**127**	**121**	**145**	**124**	**140**	**130**	**138**

Table 2.11 Habitat scores for VADEQ monitoring station 1BLEW009.19 on Lewis Creek.

Habitat Metric	6/2/2004	9/20/2004	5/4/2005
Bank Stability	17	18	14
Bank Vegetation	18	15	14
Channel Alteration	14	10	11
Channel Flow	18	18	19
Embeddedness	14	13	12
Epifaunal Substrate	17	16	18
Pool Sediment	15	11	14
Riffles	19	18	17
Riparian Vegetation	14	8	10
Velocity	9	14	14
Total Score	**155**	**141**	**143**

2.5 In-stream Water Quality Assessment

This section provides an inventory and analysis of available observed in-stream monitoring data throughout the Lewis Creek watershed. Sources of data and pertinent results are discussed. Routine ambient monitoring and special study data will be discussed separately.

2.5.1 Inventory of Water Quality Monitoring Data

The primary source of recent (1990 – 2004) water quality information for Lewis Creek is data collected at 1BLEW002.91. In addition some data has been collected at 1BLEW000.61, 1BLEW006.95, 1BLEW008.24 and 1BLEW009.19. The data is summarized in Tables 2.12 through 2.16.

Table 2.12 In-stream water quality data at 1BLEW000.61 (May 2002 – May 2005).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]
DO Probe, mg/L	11.18	10.35	15.70	8.90	2.50	6
Field pH, std units	8.02	8.20	8.40	7.20	0.45	7
Temp Celsius	12.26	11.90	17.10	6.60	4.57	7
Conductivity, μmhos/cm	607	619	701	438	85	7

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 2.13 In-stream water quality data at 1BLEW002.91(Jan. 1990 – May 2003).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]
BOD_5 DAY mg/L	1.70	1.35	5.00	1.00	0.90	50
CHLORIDE TOTAL mg/L	32.6	32	72.7	2.7	9.9	124
COD HI LEVEL mg/L	9.2	7.90	22.0	1.0	4.8	72
Conductivity, μmhos/cm	607.5	620.00	760.0	298.0	74.2	137
DO Probe, mg/L	10.69	10.50	15.80	7.40	1.87	137
Field pH, std units	8.11	8	9.40	6.20	0.42	137
FLUORIDE, TOTAL mg/L	0.1	0.14	0.2	0.1	0.0	11
NH3+NH4-N TOTAL mg/L	0.07	0.06	0.22	0.04	0.04	22
Nitrogen, Total Kjeldahl, mg/L	0.29	0.20	2.60	0.10	0.26	132
NO_2-N TOTAL mg/L	0.0	0	0.1	0.0	0.0	91
NO_3-N TOTAL mg/L	1.6	1.70	2.5	0.2	0.3	136
Phosphorus, Dissolved Ortho mg/L P	0.04	0.03	0.20	0.01	0.05	15
Phosphorus, Total Ortho mg/L P	0.03	0.02	0.14	0.01	0.02	100
Phosphorus, Total mg/L P	0.08	0.10	0.80	0.01	0.10	74
SILICA DISOLVED mg/L	7.6	8	10.7	4.0	1.9	24
Solids, Total dissolved, mg/L	366	368	423	334	19	22
Solids, Total inorganic suspended, mg/L	27.1	8.00	1,499	1.0	148.7	101
Solids, Total inorganic, mg/L	323.1	300.00	1,480	240.5	161.1	55
Solids, Total organic suspended, mg/L	4.8	3.00	108.0	1.0	13.0	69
Solids, Total organic, mg/L	86.5	82.00	170.0	39.0	21.8	55
Solids, Total suspended, mg/L	27.26	9.00	1,607	1.00	148.96	116
Solids, Total, mg/L	409.5	384.00	1,650	332.0	172.8	55
SULFATE SO4-TOT mg/L	21.9	21.60	39.6	11.2	5.7	124
Alkalinity as $CaCO_3$ mg/L	275.4	265.00	2,769	27.0	227.8	125
Temperature, Celsius	12.47	11.35	24.30	0.00	6.45	138
Hardness, Total as $CaCO_3$ mg/L	285.5	297.50	346.8	24.8	46.2	132
Total organic carbon, mg/L	2.8	2.30	12.0	0.7	1.8	64
Turbidity JKSN JTU	83.6	4.80	1,330	0.6	321.2	17
Turbidity TRBIDMTRHACH FTU	9.7	5.9	140.0	0.2	15.9	93
Turbidity FIELD NTU	10	6	88	1	18	25
Sediment Metals						
Aluminum SED mg/kg dry wgt	6,985	6,985	7,550	6,420	799	2
Arsenic SED mg/kg dry wgt	5	5	5	4	1	2
Chromium SED mg/kg dry wgt	20.7	21.00	23.0	18.2	2.4	3
Copper SED mg/kg dry wgt	37.0	41.00	45.0	25.0	10.6	3
Iron SED mg/kg dry wgt	19,650	19,650	20,500	18,800	1,202	2
Lead SED mg/kg dry wgt	69	68	77	62	7	3
Manganese SED mg/kg dry wgt	675	675	802	548	180	2
Nickel SED mg/kg dry wgt	13	12	16	12	2	3
Zinc SED mg/kg dry wgt	107.3	107.0	144.0	71.0	36.5	3

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 2.14 In-stream water quality data at 1BLEW006.95 (Oct. 1999 – May 2005).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]
DO Probe, mg/L	9.15	9.15	11.30	7.20	1.15	10
Field pH, std units	8.01	8.10	8.30	7.60	0.24	11
Temp, Celsius	14.21	13.50	20.20	9.80	3.44	11
Conductivity, μmhos/cm	579	614	725	449	90	11

[1]SD: standard deviation, [2]N: number of sample measurements.

Table 2.15 Single sample in-stream water quality data at 1BLEW008.24 (July 7, 2005).

Water Quality Constituent	Value
Conductivity, μmhos/cm	474
DO Probe, mg/L	8.18
Field pH, std units	7.85
NH3+NH4-N TOTAL mg/L	0.06
NO_2 and NO_3 N-TOTAL mg/L	1.59
Phosphorus, Total mg/L P	0.04
Solids, Total suspended, mg/L	19
Temperature, Celsius	17
Total Nitrogen as N mg/L	1.74
Turbidity LAB NTU	15

Table 2.16 In-stream water quality data at 1BLEW009.19 (June 2004 – Sept. 2004).

Water Quality Constituent	Mean	Median	Max	Min	SD[1]	N[2]
DO Probe, mg/L	9.4	9.4	10.0	8.8	0.85	2
Field pH, std units	8.15	8.15	8.3	8.0	0.21	2
Temp, Celsius	15.15	15.75	16.4	12.7	1.67	2
Conductivity, μmhos/cm	533	533	544	521	16.3	2

[1]SD: standard deviation, [2]N: number of sample measurements.

2.5.2 Fish Tissue and Sediment Results from Lewis Creek

VADEQ performed special fish tissue and sediment sampling at station 1BLEW005.24 in Lewis Creek on June 21, 2001. As a result, the Virginia Department of Health (VDH) issued a fish consumption advisory for Lewis Creek due to contamination from polychlorinated biphenyls (PCBs) (Table 2.17). The advisory extends from Rt. 252 south of Staunton downstream to the Middle River confluence at Laurel Hill. No other parameter exceeded a VDH action level. The sediment data is summarized in Tables

2.18 through 2.20. Additional information regarding the VDH ban can be found at http://www.vdh.state.va.us/HHControl/ShenandoahRiver.asp.

Table 2.17 Fish tissue sampling results for PCBs from 1BLEW005.24 on June 21, 2001.

Fish Species	VDH PCB action level (ppb[1] wet weight basis)	Value
White Sucker	50.00	108.24
White Sucker	50.00	84.27
Bluehead Chub	50.00	179.82

[1]ppb denotes parts per billion (aka - µg/kg or ng/g); wet weight basis, edible fillet.

Table 2.18 Sediment PCB and pesticide results generated from a VADEQ special study performed at Lewis Creek station 1BLEW005.24 on June 21, 2001.

Parameter	PEC[1] (µg/kg)	Value (µg/kg)
Total PCB[2]	676	209.71
Total[3] Chlordane	17.6	**118.32**
Sum DDE[4]	31.3	10.23
Sum DDD5	28	6.06
Sum DDT[6]	62.9	25.53
Total DDT[7]	572	41.83
Total BDE[8]	NA	7.07
OCDD[9]	NA	6.71

[1] PEC Probable Effect Concentration (MacDonald et al., 2000), [2] Total PCB denotes sum of polychlorinated biphenyl congeners, [3] Total Chlordane denotes sum of chlordane and breakdown products, [4] Sum DDE denotes sum of dichlorodiphenyl dichloroethylene isomers, [5]sum DDD denotes sum of dichlorodiphenyl dichloroethane isomers [6] Sum DDT denotes sum of dichlorodiphenyl trichloroethane isomers, [7] Total DDT denotes sum of isomers of DDE, DDD, and DDT, [8] BDE Total BDE denotes sum of polybrominated diphenyl ether congeners, [9] OCDD Octachlorodibenzodioxin, A bold number exceeds the PEC value, NA no PEC value has been established

Table 2.19 Sediment polycyclic aromatic hydrocarbon (PAH) results generated from a VADEQ special study performed at Lewis Creek station 1BLEW005.24 on June 21, 2001.

Parameter	PEC[1]/VA 99th Percentile* (mg/kg)	Value (mg/kg)
Total PAH[2]	22.8	16.509
High MW[3] PAH	NA	14.689
Low MW PAH	NA	1.820
Naphthalene	0.561	0.035
Naphthalene, 2-Methyl	0.083*	0.021
Naphthalene, 1-Methyl	NA	0.011
Biphenyl	NA	0.005
Naphthalene, D-Methyl	0.170*	0.015
Acenaphthylene	0.121*	0.026
Acenaphthene	NA	0.029
Naphthalene, T-Methyl	NA	0.010
Fluorine	0.536	0.053
Phenanthrene	1.170	**1.214**
Anthracene	0.845	0.232
PHH 1-Me	NA	0.168
Fluoranthene	2.230	**2.458**
Pyrene	1.520	**2.233**
ATH benz(a)	1.050	**1.223**
Chrysene	1.290	**1.377**
FTH benzo(b)	NA	1.297
FTH benzo(k)	NA	1.219
Pyrene benzo(e)	NA	1.020
Pyrene benzo(a)	1.450	1.311
Perylene	NA	0.379
Indeno[1,2,3-cd]pyrene	NA	0.954
Dibenz[a,h]anthracene	0.318*	0.289
Perylene benzo(ghi)	NA	0.930

[1] PEC Probable Effect Concentration (MacDonald et al., 2000), [2] PAH, Polycyclic aromatic hydrocarbon, also polynuclear aromatic hydrocarbons (PNAs), [3] MW Molecular Weight, A bold number exceeds the PEC value, NA no PEC value has been established

Table 2.20 Sediment metal results generated from a VADEQ special study performed at Lewis Creek station 1BLEW005.24 on June 21, 2001.

Metal	Consensus PEC[1] value (mg/kg)	Value (mg/kg)
Aluminum	NA	0.40
Silver	NA	0.27
Arsenic	33	5.5
Cadmium	4.98	0.44
Chromium	111	18
Copper	149	53.00
Mercury	1.06	**1.60**
Nickel	48.6	7.7
Lead	128	89.0
Antimony	NA	<0.5
Selenium	NA	<0.5
Thallium	NA	<0.3
Zinc	459	145.0

[1] PEC Probable Effect Concentration (MacDonald et al., 2000), NA no PEC value has been established, bold numbers exceed the PEC screening value.

2.5.3 Water-Column Toxicity Tests for Lewis Creek

Chronic toxicity tests using *Ceriodaphnia dubia* and *Pimephales promelas* (fathead minnow) were performed on Lewis Creek samples collected from 3/3/03 – 3/7/03 at station 1BLEW002.91. The initial sample was collected on 3/3/03 with renewals collected on 3/5 and 3/7. Hardness, alkalinity and dissolved oxygen concentrations ranged from 288 – 310 mg/L, 216 – 251 mg/L and 10.0 – 10.2 mg/L respectively. Tests were conducted as single concentration (no dilution series) tests on the ambient water. The tests included measuring survival and growth of fathead minnows and survival and reproduction of *Ceriodaphnia dubia*.

No effect on *Ceriodaphnia* survival was observed in Lewis Creek samples. *Ceriodaphnia* reproduction in the Lewis Creek sample was statistically different from the controls, indicating an adverse effect, but the EPA testing laboratory warned that those negative findings should be treated with some caution. While *Ceriodaphnia* reproduction in the sample (averaging 24.5) was significantly below control reproduction (31.1), it was still well above the minimum acceptable level for control treatments (15).

The results from the fathead minnow chronic test showed obvious toxicity in the Lewis Creek sample. There was a statistically significant reduction in fathead minnow survival, with 40% mortality observed in the Lewis Creek sample. It is interesting to note that no fathead minnow mortality was observed in the first two days of the test. Toxicity was observed only after renewal of the test with the first renewal sample. This indicates that toxicity in the water column may be intermittent. Unfortunately, no Toxicity Identification Evaluation (TIE) procedures were conducted on toxic Lewis Creek samples to identify the pollutant or class of chemicals causing the observed toxicity. However, based on this observed water column toxicity, follow-up analysis of water column samples under baseflow and stormflow were scheduled (section 2.5.4.2).

2.5.4 Special Sampling Data from Lewis Creek Collected by MapTech and VADEQ

A special monitoring program was developed by the VADEQ and MapTech to support the development of the TMDL by helping to identify the most probable stressor(s). The details for this monitoring program can be found in Appendix B – TMDL Development for Lewis Creek Watershed Quality Assurance Project Plan.

2.5.4.1 Lewis Creek Conductivity Sweep, April 12, 2005

Conductivity was measured at 13 sites on Lewis Creek. Depending on access, a measurement was made every one-half mile and in downtown Staunton at one-quarter mile intervals. Conductivity is a measure of the electrical potential in the stream. The more dissolved ions present in the water generally indicate high conductivity values. Conductivity can therefore be an indicator of polluted water entering the stream if there is a sudden spike in values. The results for Lewis Creek were fairly typical for an urban stream. There is an increase in values after the stream goes under buildings at the southern end of the city. This is most likely due to exfiltration from the city sewer system or illicit discharges to the stream. Figure 2.3 shows the results of the conductivity sweep. The x axis shows river miles with 0 being the confluence of Lewis Creek with the Middle River. The bolded area on the horizontal line indicates the City of Staunton corporate limits by river mile. Conductivity values slightly increase as Lewis Creek approaches the city and they increase in the downtown area where the stream goes under buildings. Values gradually begin falling as Lewis Creek leaves the city and confluences with the Middle River near Laurel Hill. Field pH measurements are shown on the right axis of Figure 2.3.

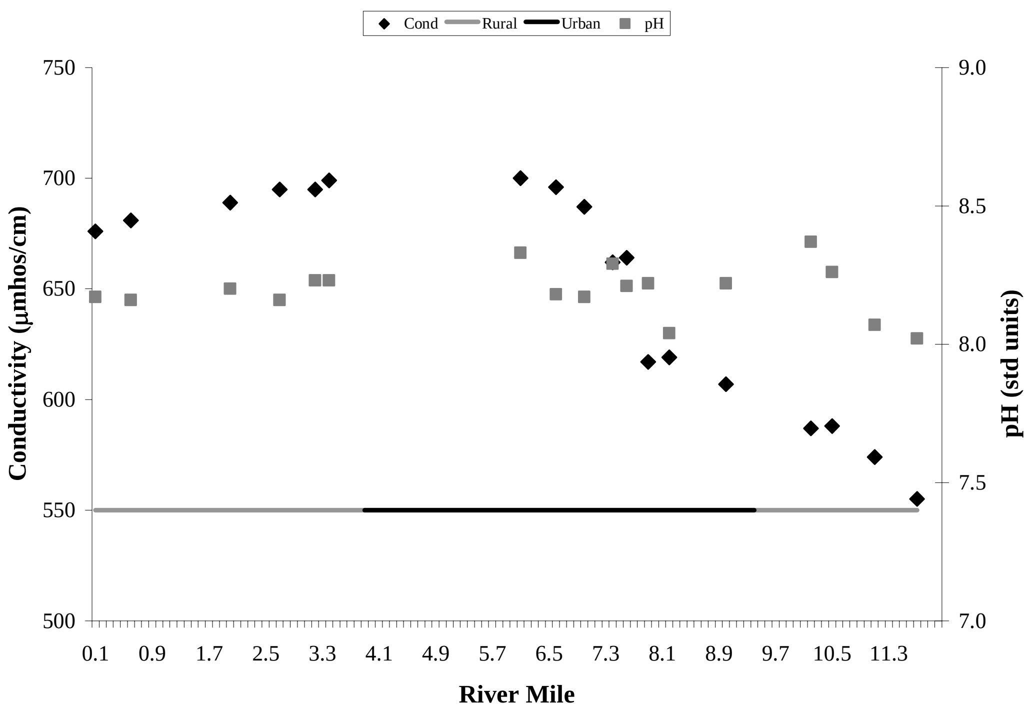

Figure 2.3 Conductivity sweep in Lewis Creek, April 12, 2005.

2.5.4.2 Lewis Creek Clean Metals Sampling, April 7 and May 24, 2005

Water column metals concentrations were sampled at the three benthic monitoring sites in Lewis Creek (1BLEW000.61, 1BLEW006.95 and 1BLEW009.19) using clean metals sampling procedures. Sampling was performed twice to capture metals concentrations during both dry and wet weather conditions. Tables 2.21 and 2.22 show the dissolved metals concentrations compared to the chronic water quality standard (WQS) and the total metals concentrations. The base flow sampling event (April 7, 2005) found metals concentrations to be fairly consistent among all three monitoring stations and concentrations were below chronic WQS. The storm flow sampling (May 24, 2005) results found metals concentrations somewhat higher than the dry weather concentrations but still well below chronic WQS. In addition, lead was measured above the minimum laboratory detection level at monitoring stations 1BLEW000.61 and 1BLEW006.95.

Table 2.21 Special study base flow clean metals data from Lewis Creek, April 7, 2005

Station ID	Metal	Dissolved Value (μg/L)	Chronic, WQS[1,2]	Total Value (μg/L)
1BLEW000.61	Aluminum, Dissolved	1.4	NA	
	Aluminum, Total		NA	218
	Antimony, Dissolved	<0.5	NA	
	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.3	150	
	Arsenic, Total		NA	0.4
	Barium, Dissolved	33	NA	
	Barium, Total		NA	37.1
	Beryllium, Dissolved	<0.1	NA	
	Beryllium, Total		NA	<0.1
	Cadmium, Dissolved	<0.1	2.78	
	Cadmium, Total		NA	<0.1
	Calcium, Dissolved	83	NA	
	Calcium, Total		NA	92.7
	Chromium, Dissolved	0.9	527.66	
	Chromium, Total		NA	0.7
	Copper, Dissolved	0.6	31.39	
	Copper, Total		NA	1.1
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	300
	Lead, Dissolved	<0.1	57.86	
	Lead, Total		NA	0.8
	Magnesium, Dissolved	22.5	NA	
	Magnesium, Total		NA	23.2
	Manganese, Dissolved	17.5	NA	
	Manganese, Total		NA	30.9
	Mercury, Dissolved	<0.0015	0.77	
	Mercury, Total		NA	0.0032
	Nickel, Dissolved	0.2	53.44	
	Nickel, Total		NA	0.5
	Selenium, Dissolved	<0.5	5	
	Selenium, Total		NA	0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<5
	Zinc, Dissolved	2.3	279.08	
	Zinc, Total		NA	2.4
1BLEW006.95	Aluminum, Dissolved	4.2	NA	
	Aluminum, Total		NA	153
	Antimony, Dissolved	<0.5	NA	

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

Table 2.21 Special study base flow clean metals data from Lewis Creek, April 7, 2005 (cont.).

Station ID	Metal	Dissolved Value (μg/L)	Chronic, WQS[1,2]	Total Value (μg/L)
1BLEW006.95	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.3	150	
	Arsenic, Total		NA	0.2
	Barium, Dissolved	30.3	NA	
	Barium, Total		NA	34.7
	Beryllium, Dissolved	<0.1	NA	
	Beryllium, Total		NA	<0.1
	Cadmium, Dissolved	<0.1	2.82	
	Cadmium, Total		NA	<0.1
	Calcium, Dissolved	75.3	NA	
	Calcium, Total		NA	84.6
	Chromium, Dissolved	0.8	534.54	
	Chromium, Total		NA	3.9
	Copper, Dissolved	0.6	31.82	
	Copper, Total		NA	1.1
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	191
	Lead, Dissolved	<0.1	59.03	
	Lead, Total		NA	1
	Magnesium, Dissolved	29.4	NA	
	Magnesium, Total		NA	28.3
	Manganese, Dissolved	6.5	NA	
	Manganese, Total		NA	15.6
	Mercury, Dissolved	<0.0015	0.77	
	Mercury, Total		NA	0.0038
	Nickel, Dissolved	0.3	54.16	
	Nickel, Total		NA	0.3
	Selenium, Dissolved	<0.5	5	
	Selenium, Total		NA	<0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<5
	Zinc, Dissolved	2.9	282.85	
	Zinc, Total		NA	6.7
1BLEW009.19	Aluminum, Dissolved	3.3	NA	
	Aluminum, Total		NA	520
	Antimony, Dissolved	<0.5	NA	
	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.3	150	

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

Table 2.21 Special study base flow clean metals data from Lewis Creek, April 7, 2005 (cont.).

Station ID	Metal	Dissolved Value (μg/L)	Chronic, WQS[1,2]	Total Value (μg/L)
1BLEW009.19	Arsenic, Total		NA	0.4
	Barium, Dissolved	26.2	NA	
	Barium, Total		NA	32
	Beryllium, Dissolved	<0.1	NA	
	Beryllium, Total		NA	<0.1
	Cadmium, Dissolved	<0.1	2.57	
	Cadmium, Total		NA	<0.1
	Calcium, Dissolved	65.9	NA	
	Calcium, Total		NA	73.4
	Chromium, Dissolved	0.5	485.93	
	Chromium, Total		NA	1.3
	Copper, Dissolved	0.4	28.80	
	Copper, Total		NA	0.8
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	518
	Lead, Dissolved	<0.1	50.90	
	Lead, Total		NA	0.9
	Magnesium, Dissolved	24.5	NA	
	Magnesium, Total		NA	28.4
	Manganese, Dissolved	11.5	NA	
	Manganese, Total		NA	38.5
	Mercury, Dissolved	<0.0015	0.77	
	Mercury, Total		NA	0.0028
	Nickel, Dissolved	0.2	49.08	
	Nickel, Total		NA	0.6
	Selenium, Dissolved	<0.5	5	
	Selenium, Total		NA	<0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<5
	Zinc, Dissolved	2.3	256.28	
	Zinc, Total		NA	2.9

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

Table 2.22 Special study storm flow clean metals from Lewis Creek, May 24, 2005

Station ID	Metal	Dissolved Value (μg/L)	Chronic WQS[1,2]	Total Value (μg/L)
1BLEW000.61	Aluminum, Dissolved	1.8	NA	
	Aluminum, Total		NA	230
	Antimony, Dissolved	<0.5	NA	
	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.4	150	
	Arsenic, Total		NA	0.3
	Barium, Dissolved	28.3	NA	
	Barium, Total		NA	26.5
	Beryllium, Dissolved	<0.1	NA	
	Cadmium, Dissolved	<0.1	2.11	
	Cadmium, Total		NA	<0.1
	Calcium, Dissolved	61.4	NA	
	Calcium, Total		NA	59.8
	Chromium, Dissolved	0.2	395.54	
	Chromium, Total		NA	2.3
	Copper, Dissolved	1	23.24	
	Copper, Total		NA	2
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	387
	Lead, Dissolved	0.1	36.97	
	Lead, Total		NA	2
	Magnesium, Dissolved	17.2	NA	
	Magnesium, Total		NA	16.4
	Manganese, Dissolved	19.2	NA	
	Manganese, Total		NA	33.4
	Mercury, Dissolved	<0.0015	0.77	
	Mercury, Total		NA	0.007
	Nickel, Dissolved	0.3	39.68	
	Nickel, Total		NA	0.6
	Selenium, Dissolved	<0.5	5	
	Selenium, Total		NA	<0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<0.1
	Zinc, Dissolved	1.2	207.13	
	Zinc, Total		NA	4.4

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

Table 2.22 Special study storm flow clean metals from Lewis Creek, May 24, 2005 (cont.).

Station ID	Metal	Dissolved Value (µg/L)	Chronic WQS[1,2]	Total Value (µg/L)
1BLEW006.95	Aluminum, Dissolved	3.9	NA	
	Aluminum, Total		NA	302
	Antimony, Dissolved	<0.5	NA	
	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.5	150	
	Arsenic, Total		NA	0.4
	Barium, Dissolved	30.1	NA	
	Barium, Total		NA	29
	Beryllium, Dissolved	<0.1	NA	
	Cadmium, Dissolved	<0.1	2.38	
	Cadmium, Total		NA	<0.1
	Calcium, Dissolved	69.6	NA	
	Calcium, Total		NA	64.7
	Chromium, Dissolved	0.4	447.69	
	Chromium, Total		NA	3.6
	Copper, Dissolved	4.6	26.44	
	Copper, Total		NA	10.9
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	407
	Lead, Dissolved	0.3	44.81	
	Lead, Total		NA	6.3
	Magnesium, Dissolved	22.3	NA	
	Magnesium, Total		NA	20.8
	Manganese, Dissolved	9.5	NA	
	Manganese, Total		NA	32.2
	Mercury, Dissolved	<0.0015	0.77	
	Mercury, Total		NA	14.6
	Nickel, Dissolved	0.3	45.10	
	Nickel, Total		NA	0.9
	Selenium, Dissolved	<0.5	5	
	Selenium, Total		NA	<0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<0.1
	Zinc, Dissolved	5.8	235.45	
	Zinc, Total		NA	15.5

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

Table 2.22 Special study storm flow clean metals from Lewis Creek, May 24, 2005 (cont.).

Station ID	Metal	Dissolved Value (µg/L)	Chronic WQS[1,2]	Total Value (µg/L)
1BLEW009.19	Aluminum, Dissolved	4.3	NA	
	Aluminum, Total		NA	900
	Antimony, Dissolved	<0.5	NA	
	Antimony, Total		NA	<0.5
	Arsenic, Dissolved	0.3	150	
	Arsenic, Total		NA	0.5
	Barium, Dissolved	24.2	NA	
	Barium, Total		NA	29.2
	Beryllium, Dissolved	<0.1	NA	
	Cadmium, Dissolved	<0.1	2.33	
	Cadmium, Total		NA	<0.1
1BLEW009.19	Calcium, Dissolved	59.7	NA	
	Calcium, Total		NA	64.2
	Chromium, Dissolved	0.2	439.09	
	Chromium, Total		NA	2.6
	Copper, Dissolved	0.6	25.91	
	Copper, Total		NA	1.7
	Iron, Dissolved	<50	NA	
	Iron, Total		NA	793
	Lead, Dissolved	<0.1	43.48	
	Lead, Total		NA	2.5
	Magnesium, Dissolved	23.1	NA	
	Magnesium, Total		NA	23.4
	Manganese, Dissolved	8.5	NA	
	Manganese, Total		NA	49.2
	Mercury, Dissolved	<1.5	NA	
	Mercury, Total		NA	9.2
	Nickel, Dissolved	0.3	44.21	
	Nickel, Total		NA	1.2
	Selenium, Dissolved	<0.5	NA	
	Selenium, Total		NA	<0.5
	Silver, Dissolved	<0.1	NA	
	Silver, Total		NA	<0.1
	Thallium, Dissolved	<0.1	NA	
	Thallium, Total		NA	<0.1
	Zinc, Dissolved	1.3	230.77	
	Zinc, Total		NA	8.4

[1] The water quality standard (WQS) is for the dissolved metal concentration and is calculated from the equation given in the standards using the measured hardness at the time of sample collection.
[2] The arsenic, mercury and selenium WQS are not calculated based upon hardness.
NA metal does not have a WQS or it could not be calculated.

2.5.4.3 Lewis Creek Sediment Sampling Sweep, May 2, 2005

On May 2, 2005 a sediment sampling sweep was performed in the Lewis Creek watershed. Seven sites were sampled on Lewis Creek and an additional six sites were sampled on tributaries to Lewis Creek (Table 2.23 and Figure 2.4). The purpose of the sampling was to confirm the high values found during the June 21, 2001 VADEQ sampling and to try and isolate spots in the watershed where sediment contaminants were highest.

Four categories of contaminants were sampled: pesticides, metals, PCBs and polycyclic aromatic hydrocarbons (PAHs). All pesticide values were below measurable levels (Table 2.24). Table 2.25 shows measured total PCB values that were above minimum detection. Tables 2.26 shows measured metals values. The only metal that exceeded a PEC level was lead at station 1BLEW006.64. PAHs were above laboratory accuracy levels at six of the 13 monitoring sites (Table 2.27). Fluoranthene and Pyrene exceeded the PEC value at one station, 1BLEW006.64. All other results were below the PEC or VA 99th percentile screening values. The toxicity of PAHs is additive (Swartz, 1999) and even though the majority of values were below toxic screening levels, there were enough compounds measured at some stations to potentially cause toxic conditions for the benthos.

One method to determine the combined toxicity potential is to calculate a hazard quotient. A hazard quotient is calculated by dividing the measured result by the PEC or screening value. Summing the results provides a hazard index and index values greater than 1.0 can indicate a potentially toxic situation, Table 2.28 (Ingersoll et. al., 2000). Four monitoring stations had hazard indexes that exceeded 1.0 (1BLEW000.61, 1BLEW005.68, 1BLEW006.64 and 1BPEY000.43).

Organic compounds such as PAHs preferentially bind to organic matter in sediment. They are much less likely to bind to sand and other inorganic matter in the sediment layer. Therefore, when comparing multiple monitoring sites it is important to remember that higher amounts of organic compounds at one site could be a function of much more organic matter being available at that site.

Considerable care was taken during the sediment sampling in Lewis Creek to get sediment of similar color and consistency at each site. TOC concentrations ranged from 14.82 to 46 g/kg (Table 2.29), however, differences in TOC levels among sites did not explain differences in PAH concentrations. Sites with PAH hazard indices >1 had TOC levels as low as 18.24 g/kg and as high as 45.17 g/kg.

Another consideration is particle size. Fine-grained organic sediments have more surface area and therefore more potential binding sites for organic compounds such as PAHs. Particle sizes at the 13 monitoring stations were examined and found to be consistent among all of the monitoring stations (Table 2.29).

Sediment quality guidelines are an area of continuing research and development. In an effort to focus agreement among various guidelines, MacDonald et al. (2000) developed consensus-based threshold effect concentrations (TECs) and probable effect concentrations (PECs). VADEQ uses PEC values as sediment screening guidelines. Using correlated sediment toxicity and sediment chemistry data, MacDonald demonstrated that most TECs provided an accurate basis for predicting the absence of toxicity, and PECs provided an accurate basis for predicting sediment toxicity. Therefore, values below TEC levels are not expected to cause toxicity, and values above PEC levels are expected to cause toxicity. In addition there are several PAH compounds that don't have PEC levels but VADEQ has established a 99^{th} percentile screening level for them. This screening value was treated in the same manner as a PEC screening value.

Table 2.23 Sediment sampling locations in the Lewis Creek watershed.

Station_ID	Map No	Location	Stream Name
1BLEW000.61	1	Rt. 612 bride near Laurel Hill	Lewis Creek
1BLEW002.91	2	Rt. 931 bridge	Lewis Creek
1BLEW004.01	3	I-81 bridge	Lewis Creek
1BLEW005.68	4	Above old Staunton STP	Lewis Creek
1BLEW006.64	5	Below Farrier Dauling	Lewis Creek
1BLEW006.95	6	Near Virginia School for the Deaf & Blind	Lewis Creek
1BLEW009.19	7	Rt. 252 south of Staunton	Lewis Creek
Tributaries			
1BPOG000.30	8	Near Holiday Inn	Poague Run
1BPOG002.00	9	Rt. 11 bridge	Poague Run
1BPEY000.43	10	New and Academy Streets	Peyton Creek
1BXEE000.10	11	Off Drury Street	Lewis Creek Unnamed Tributary
1BBMS000.25	12	Bridge Street bridge	Buttermilk Spring
1BBMS001.68	13	Rt. 703	Buttermilk Spring

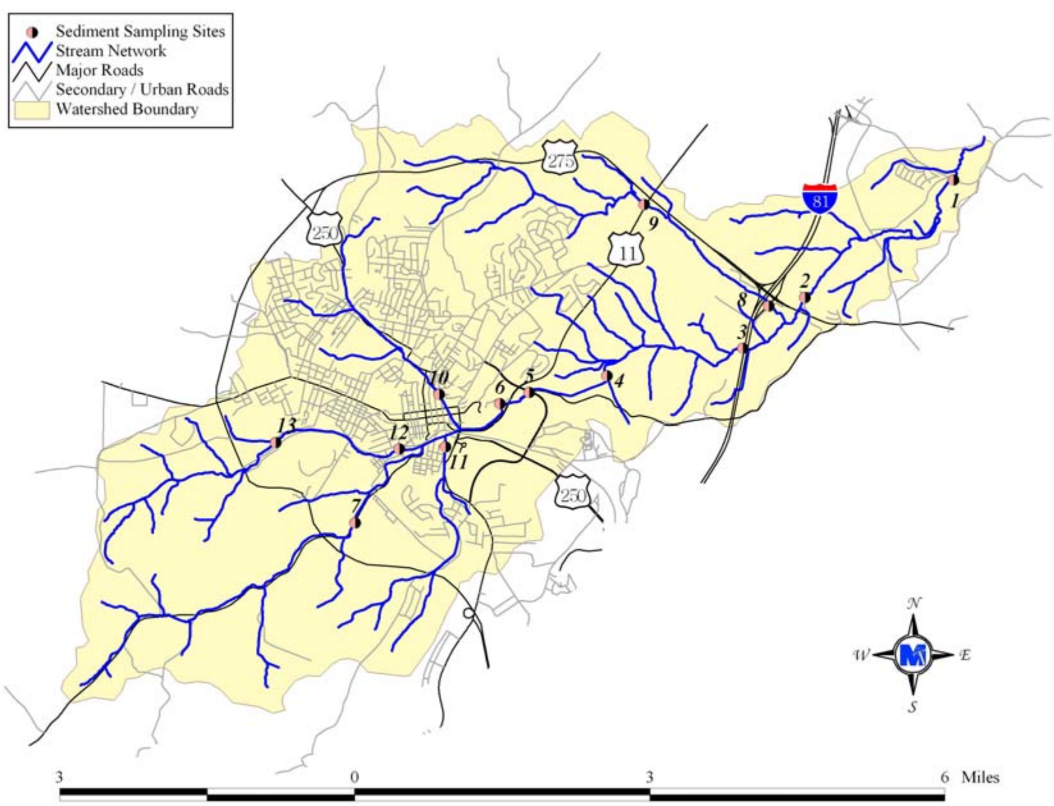

Figure 2.4 Sediment sampling sites in the Lewis Creek watershed, May 2, 2005.

Table 2.24 Sediment pesticides in sweep of Lewis Creek and major tributaries, May 2, 2005.

Pesticide (µg/kg)	1BLEW000.61	1BLEW002.91	1BLEW004.01	1BLEW005.68	1BLEW006.64	1BLEW006.95	1BLEW009.19
4,4' - DDT	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Aldrin	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
alpha-BHC	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Aroclor 1016	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1221	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1232	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1242	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1248	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1254	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
Aroclor 1260	< 8.56	< 8.12	< 7.48	< 19.0	< 12.8	< 10.4	< 8.72
beta-BHC	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Chlordane	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
4,4' - DDD	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
4,4' - DDE	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
delta-BHC	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Dieldrin	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Endosulfan I	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Endosulfan II	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Endosulfan Sulfate	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Endrin	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Endrin Aldehyde	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
gamma-BHC (Lindane)	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Heptachlor	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Heptachlor Epoxide	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Methoxychlor	< 0.856	< 0.812	< 0.748	< 0.760	< 1.28	< 1.04	< 0.872
Toxaphene	< 8.56	< 8.12	< 7.48	< 7.60	< 12.8	< 10.4	< 8.72

< Pesticide not detected in sample. The value shown is the minimum detection level.

Table 2.24 Sediment pesticides in sweep of Lewis Creek and major tributaries, May 2, 2005 (cont.).

Pesticide (µg /kg)	1BBMS000.25	1BBMS001.68	1BPEY000.43	1BPOG000.30	1BPOG002.00	1BXEE000.10
4,4' - DDT	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Aldrin	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
alpha-BHC	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Aroclor 1016	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1221	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1232	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1242	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1248	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1254	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
Aroclor 1260	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04
beta-BHC	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Chlordane	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
4,4' - DDD	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
4,4' - DDE	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
delta-BHC	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Dieldrin	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Endosulfan I	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Endosulfan II	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Endosulfan Sulfate	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Endrin	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Endrin Aldehyde	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
gamma-BHC (Lindane)	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Heptachlor	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Heptachlor Epoxide	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Methoxychlor	< 0.888	< 0.840	< 1.008	< 0.732	< 0.932	< 0.704
Toxaphene	< 8.88	< 8.40	< 10.08	< 7.32	< 9.32	< 7.04

< Pesticide not detected in sample. The value shown is the minimum detection level.

Table 2.25 Sediment Total PCBs in sweep of Lewis Creek and major tributaries, May 2, 2005.

Station	PEC[1] (mg/kg)	Total PCBs (mg/kg)
1BLEW000.61	0.676	0.023
1BLEW002.91	0.676	0.254
1BLEW004.01	0.676	0.057
1BLEW005.68	0.676	0.089
1BLEW006.64	0.676	0.061
1BLEW006.95	0.676	0.104
1BLEW009.19	0.676	0.009
Tributaries		
1BBMS000.25	0.676	0.079
1BBMS001.68	0.676	0.004
1BPEY000.43	0.676	0.033
1BPOG000.30	0.676	0.005
1BPOG002.00	0.676	0.012
1BXEE000.10	0.676	0.011

[1] PEC Probable Effect Concentration (MacDonald et al., 2000).

Table 2.26 Sediment metals (dry weight basis) values in sweep of Lewis Creek and major tributaries, May 2, 2005.

Metal (mg/kg)	1BLEW000.61	1BLEW002.91	1BLEW004.01	1BLEW005.68	1BLEW006.64	1BLEW006.95	1BLEW009.19	TEC[1] (mg/kg)	PEC[2] (mg/kg)
Aluminum	7,780	5,960	8,130	5,160	5,140	9,100	21,500	NA	NA
Antimony	<5	<5	<5	<5	<5	<5	<5	NA	NA
Arsenic	<5	5.06	5.95	5.92	6.38	7.94	7.06	9.79	33
Beryllium	<5	<5	<5	<5	<5	<5	<5	NA	NA
Cadmium	<1	<1	<1	<1	<1	<1	<1	0.99	4.98
Chromium	15.9	17.7	19.3	17.9	21.6	24.4	29.9	43.4	111
Copper	21.1	28.3	*32.5*	*39.5*	*46.8*	*56.9*	17.2	31.6	149
Iron	20,500	20,700	20,000	15,800	17,400	17,500	16,900	NA	NA
Lead	*45.1*	*76*	*80.7*	*95.2*	**172**	*113*	26.7	35.8	128
Manganese	779	634	673	525	443	671	691	NA	NA
Mercury, Total	0.16	0.14	*0.21*	*0.20*	*0.24*	*0.30*	<0.10	0.18	1.06
Nickel	15.5	15.2	17.6	15.8	15.5	17.6	21.5	22.7	48.6
Selenium	<1	<1	<1	<1	<1	<1	<1	NA	NA
Silver	<1	<1	<1	<1	<1	<1	<1	NA	NA
Thallium	<5	<5	<5	<5	<5	<5	<5	NA	NA
Zinc	85.4	104	*134*	*140*	*182*	*208*	68.1	121	459

[1] TEC Threshold Effect Concentration (MacDonald et al., 2000), [2]PEC Probable Effect Concentration (MacDonald et al., 2000). Concentrations in italics exceed the TEC value and bold concentrations exceed the PEC value.

Table 2.26 Sediment metals (dry weight basis) values in sweep of Lewis Creek and major tributaries, May 2, 2005 (cont.).

Metal (mg/kg)	1BBMS000.25	1BBMS001.68	1BPEY000.43	1BPOG000.30	1BPOG002.00	1BXEE000.10	TEC (mg/kg)	PEC (mg/kg)
Aluminum	10,300	7,300	10,900	10,900	5,980	7,300	NA	NA
Antimony	<5	<5	<5	<5	<5	<5	NA	NA
Arsenic	6.42	7.6	9.36	5.23	7.26	7.4	9.79	33
Beryllium	<5	<5	<5	<5	<5	<5	NA	NA
Cadmium	<1	<1	<1	<1	<1	<1	0.99	4.98
Chromium	22.0	18.2	28.8	22.3	16.6	19.9	43.4	111
Copper	24.9	9.46	*33.1*	13.1	11.5	15.5	31.6	149
Iron	13,500	14,400	17,100	27,300	17,200	14,500	NA	NA
Lead	*66.4*	27.1	*112*	21.4	25.9	*43.4*	35.8	128
Manganese	474	829	487	1,220	1,500	470	NA	NA
Mercury, Total	0.1	<0.1	0.13	<0.1	<0.1	<0.1	0.18	1.06
Nickel	15.9	10.1	19	16.5	11.3	15.7	22.7	48.6
Selenium	<1	<1	<1	<1	<1	<1	NA	NA
Silver	<1	<1	<1	<1	<1	<1	NA	NA
Thallium	<5	<5	<5	<5	<5	<5	NA	NA
Zinc	104	38.4	*172*	51.7	58	*123*	121	459

[1] TEC Threshold Effect Concentration (MacDonald et al., 2000), [2]PEC Probable Effect Concentration (MacDonald et al., 2000).
Concentrations in italics exceed the TEC value and bold concentrations exceed the PEC value.

Table 2.27 Sediment PAHs in sweep of Lewis Creek watershed, May 2, 2005.

PAH compound (mg/kg)	1BLEW000.61	1BLEW002.91	1BLEW004.01	1BLEW005.68	1BLEW006.64	1BLEW006.95	1BLEW009.19	TEC[1] (mg/kg)	PEC[2] (mg/kg)	VA 99th Percentile (mg/kg)**
Acenaphthene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	NA	NA	0.17
Acenaphthylene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	NA	NA	0.12
Anthracene	_0.178*_	<0.082	<0.150	<0.120	_0.221*_	<0.168	<0.086	0.057	0.85	
Benzo[a]anthracene	_0.708_	<0.082	<0.150	_0.668_	_1.010_	<0.168	<0.086	0.108	1.05	
Benzo[a]pyrene	_0.464_	<0.082	<0.150	_0.551_	_0.713_	<0.168	<0.086	0.150	1.45	
Benzo[b]fluoranthene	0.410	<0.082	<0.150	0.501	0.827	<0.168	<0.086	NA	NA	
Benzo[g,h,i]perylene	0.316*	<0.082	<0.150	0.377	0.515	<0.168	<0.086	NA	NA	
Benzo[k]fluoranthene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	NA	NA	
Chrysene	_0.738_	<0.082	<0.150	_0.774_	_1.170_	_0.192*_	<0.086	0.166	1.29	
Dibenz[a,h]anthracene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	0.033	NA	0.318
Fluoranthene	_1.440_	<0.082	<0.150	_1.540_	**2.300**	0.379*	<0.086	0.423	2.23	
Fluorene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	0.077	0.54	
Indeno[1,2,3-cd]pyrene	0.300*	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	NA	NA	
Naphthalene	<0.137	<0.082	<0.150	<0.120	<0.162	<0.168	<0.086	0.176	0.56	
Phenanthrene	_0.470_	<0.082	<0.150	0.555	_0.932_	<0.168	<0.086	0.204	1.17	
Pyrene	_1.250_	<0.082	<0.150	_1.220_	**1.930**	_0.312*_	<0.086	0.195	1.52	
TOTAL	_6.27_	0.00	0.00	_6.19_	_9.62_	0.88	0.00	1.61	22.80	NA

[1] TEC Threshold Effect Concentration (MacDonald et al., 2000), [2]PEC Probable Effect Concentration (MacDonald et al., 2000). Results indicated as "<" were not detected, the value shown is the minimum detection level. * Results are considered estimates. The compound was detected and measured, but the measured value was below the quantitation limit for the analysis. ** VA 99th percentile, Values in italics exceed the TEC value, bold values exceed a toxic screening level, NA not available.

Table 2.27 Sediment PAHs in sweep of Lewis Creek watershed, May 2, 2005 (cont.).

PAH compound (mg/kg)	1BPOG000.30	1BPOG002.00	1BXEE000.10	1BPEY000.43	1BBMS000.25	1BBMS001.68	TEC (mg/kg)	PEC (mg/kg)	VA 99th Percentile (mg/kg)**
Acenaphthene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	NA	NA	0.17
Acenaphthylene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	NA	NA	0.12
Anthracene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	0.057	0.85	
Benzo[a]anthracene	<0.146	<0.149	<0.168	*0.504*	<0.181	<0.084	0.108	1.05	
Benzo[a]pyrene	<0.146	<0.149	<0.168	*0.442*	<0.181	<0.084	0.150	1.45	
Benzo[b]fluoranthene	<0.146	<0.149	<0.168	0.520	<0.181	<0.084	NA	NA	
Benzo[g,h,i]perylene	<0.146	<0.149	<0.168	0.304*	<0.181	<0.084	NA	NA	
Benzo[k]fluoranthene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	NA	NA	
Chrysene	<0.146	<0.149	0.075	*0.805*	<0.181	<0.084	0.166	1.29	
Dibenz[a,h]anthracene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	0.033	NA	0.318
Fluoranthene	<0.146	<0.149	0.137	*1.630*	<0.181	<0.084	0.423	2.23	
Fluorene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	0.077	0.54	
Indeno[1,2,3-cd]pyrene	<0.146	<0.149	<0.168	0.298*	<0.181	<0.084	NA	NA	
Naphthalene	<0.146	<0.149	<0.168	<0.164	<0.181	<0.084	0.176	0.56	
Phenanthrene	<0.146	<0.149	<0.168	*0.601*	<0.181	<0.084	0.204	1.17	
Pyrene	<0.146	<0.149	0.114	*1.200*	<0.181	<0.084	0.195	1.52	
TOTAL	0.00	0.00	0.33	*6.30*	0.00	0.00	1.61	22.80	

[1] TEC Threshold Effect Concentration (MacDonald et al., 2000), [2]PEC Probable Effect Concentration (MacDonald et al., 2000). Results indicated as "<" were not detected, the value shown is the minimum detection level. * Results are considered estimates. The compound was detected and measured, but the measured value was below the quantitation limit for the analysis. ** VA 99th percentile, Values in italics exceed the TEC value, bold values exceed a toxic screening level, NA not available.

Table 2.28 Sediment PAHs hazard quotient* in sweep of Lewis Creek watershed, May 2, 2005.

PAH Compound (mg/kg)	PEC (mg/kg)	VA 99th Percentile (mg/kg)***	1BLEW000.61	1BLEW002.91	1BLEW004.01	1BLEW005.68	1BLEW006.64	1BLEW006.95	1BLEW009.19
Acenaphthene	NA	0.170	<	<	<	<	<	<	<
Acenaphthylene	NA	0.121	<	<	<	<	<	<	<
Anthracene	0.845		0.211	<	<	<	0.262	<	<
Benzo[a]anthracene	1.050		0.674	<	<	0.636	0.962	<	<
Benzo[a]pyrene	1.450		0.320	<	<	0.380	0.492	<	<
Benzo[b]fluoranthene	NA		<	<	<	<	<	<	<
Benzo[g,h,i]perylene	NA		<	<	<	<	<	<	<
Benzo[k]fluoranthene	NA		<	<	<	<	<	<	<
Chrysene	1.29		0.572	<	<	0.600	0.907	0.149	<
Dibenz[a,h]anthracene	0.32		<	<	<	<	<	<	<
Fluoranthene	2.23		0.646	<	<	0.691	1.031	0.170	<
Fluorene	0.54		<	<	<	<	<	<	<
Indeno[1,2,3-cd]pyrene	NA	0.318	0.207	<	<	<	<	<	<
Naphthalene	0.561		<	<	<	<	<	<	<
Phenanthrene	1.170		0.402	<	<	0.474	0.797	<	<
Pyrene	1.520		0.822	<	<	0.803	1.270	0.205	<
Hazard Index (sum of Hazard Quotients)**			**3.85**		0.00	**3.58**	**5.72**	0.52	0.00

*Hazard Quotients were calculated as the ratio of measured concentration to the PEC or state screening value for that compound. **Hazard Index was calculated as the sum of all hazard quotients for individual PAH compounds. Hazard Quotients or Hazard Indices that exceed 1.0 indicate that toxic effects on benthos are possible. Hazard ratios were not calculated for estimated values, A bold hazard index exceeds 1.0, PAH compounds exhibit similar exposure pathways and modes of action so are assumed to be additive in effect, *** VA 99th percentile screening value, < Acutal value not detected quotient could not be calculated, NA not available.

Table 2.28 Sediment PAHs hazard quotient* in sweep of Lewis Creek watershed, May 2, 2005 (cont.).

PAH Compound (mg/kg)	PEC (mg/kg)	VA 99th Percentile (mg/kg)***	1BPOG000.30	1BPOG002.00	1BXEE000.10	1BPEY000.43	1BBMS000.25	1BBMS001.68
Acenaphthene	NA	0.170	<	<	<	<	<	<
Acenaphthylene	NA	0.121	<	<	<	<	<	<
Anthracene	0.845	<	<	<	<	<	<	<
Benzo[a]anthracene	1.050	<	<	<	<	0.480	<	<
Benzo[a]pyrene	1.450	<	<	<	<	0.305	<	<
Benzo[b]fluoranthene	NA	<	<	<	<	<	<	<
Benzo[g,h,i]perylene	NA	<	<	<	<	<	<	<
Benzo[k]fluoranthene	NA	<	<	<	<	<	<	<
Chrysene	1.29	<	<	<	0.058	0.624	<	<
Dibenz[a,h]anthracene	0.32	<	<	<	<	<	<	<
Fluoranthene	2.23	<	<	<	0.061	0.731	<	<
Fluorene	0.54	<	<	<	<	<	<	<
Indeno[1,2,3-cd]pyrene	NA	0.318	<	<	<	<	<	<
Naphthalene	0.561	<	<	<	<	<	<	<
Phenanthrene	1.170	<	<	<	<	0.514	<	<
Pyrene	1.520	<	<	<	0.075	0.789	<	<
Hazard Index (sum of Hazard Quotients)**			0.00	0.00	0.20	**3.65**	0.00	0.00

*Hazard Quotients were calculated as the ratio of measured concentration to the PEC or state screening value for that compound. **Hazard Index was calculated as the sum of all hazard quotients for individual PAH compounds. Hazard Quotients or Hazard Indices that exceed 1.0 indicate that toxic effects on benthos are possible. Hazard ratios were not calculated for estimated values, A bold hazard index exceeds 1.0, PAH compounds exhibit similar exposure pathways and modes of action so are assumed to be additive in effect, *** VA 99th percentile screening value, < Acutal value not detected quotient could not be calculated, NA not available.

Table 2.29 Sediment total organic carbon and particle size in sweep of Lewis Creek watershed, May 2, 2005.

Station ID	%Sand	%Silt	%Clay	Total	TOC (g/kg)
1BLEW000.61	33	39	27	99	18.24
1BLEW002.91	51	29	20	100	17.53
1BLEW004.01	27	47	27	101	20.24
1BLEW005.68	33	42	24	99	27.25
1BLEW006.64	42	33	25	100	45.17
1BLEW006.95	17	48	35	100	46
1BLEW009.19	17	50	33	100	31.56
Tributaries					
1BBMS000.25	29	46	25	100	35.75
1BBMS001.68	42	36	22	100	28.66
1BPEY000.43	48	29	23	100	30.11
1BPOG000.30	39	36	25	100	14.82
1BPOG002.00	9	65	26	100	29.54
1BXEE000.10	37	39	24	100	17.16

TOC total organic carbon.

2.5.4.4 Follow-up Sediment Sampling at Four Monitoring Stations on Lewis Creek, October 5, 2005.

Follow-up sediment sampling for metals and PAHs was conducted at the three-benthic monitoring stations on Lewis Creek and station 1BLEW006.64 (where the highest PAH values were found in the May 2005 samples) on October 5, 2005. No individual constituents exceeded a toxic screening level but a hazard index of 1.0 was exceeded at monitoring stations 1BLEW006.64 and 1BLEW006.95. Tables 2.30 through 2.33 show the results of the metals and PAH data collected.

Additional sediment was collected at each of the four monitoring stations for sediment toxicity analysis. Biocoastal Analysts located in Gloucester, VA analyzed the sediment. The following tests were run on the collected samples:

10-day Survival and Growth with the amphipod *Hyalella azteca*

10-day Survival and Growth with the midge *Chironomus tentans*

There was no observed toxicity to *Hyalella azteca* in any of the Lewis Creek samples; however significant toxicity to *Chironomus tentans* was observed (Tables 2.34 and 2.35). There was a statistically significant reduction in survival of *Chironomus tentans* (*C.*

tentans) at monitoring station 1BLEW006.95 compared to the control and the upstream reference station, 1BLEW009.19. *C. tentans* survival at station 1BLEW006.95 was only 13% (or 87% mortality), indicating significant sediment toxicity. This finding is consistent with benthic monitoring results at this site that show severe to moderate impairment and very low abundance.

At station 1BLEW0006.1, *C. tentans* survival was significantly different from the laboratory control, but survival at this station was not statistically different from the upstream reference station (1BLEW009.19). At station 1BLEW006.64, *C. tentans* exhibited a statistically significant reduction in growth compared to the upstream reference (1BLEW009.19), but not compared to the laboratory control. These results confirm that all three downstream sediments exhibited some level of toxicity (survival or growth reductions) compared to control or reference sediment. It is likely that sediment toxicity is due to multiple stressors. Both stations (1BLEW006.64 and 1BLEW006.95) that showed toxicity compared to the reference had hazard quotients for PAHs greater than 1 in the October 5^{th} sampling. The most toxic station was 1BLEW006.95, where sediment lead levels were the highest. Sediment lead levels at 1BLEW006.95 were 125 mg/kg, just below the PEC value of 128 mg/kg, where toxic effects are likely. Sediment contamination levels at 1BLEW000.61 did not point to a specific stressor in the October 5^{th} sampling, however, it should be noted that the observed reduction in survival was statistically significant compared to the laboratory control, but not to the upstream reference, indicating that observed toxicity in this sample may be an artifact of testing. The absence of a statistically significant toxic impact on *Hyalella azteca* (*H. azteca*) is explained by differences in species sensitivities and is consistent with other studies that found *C. tentans* was more sensitive to PAH toxicity than *H. azteca* (Swartz, 1999).

Table 2.30 Sediment metals (dry weight basis) values in Lewis Creek, October 5, 2005.

Metal (mg/kg)	1BLEW000.61	1BLEW006.64	1BLEW006.95	1BLEW009.19	TEC[1] (mg/kg)	PEC[2] (mg/kg)
Aluminum	12,900	6,880	6,300	11,100	NA	NA
Antimony	<5	<5	<5	<5	NA	NA
Arsenic	<5	6.23	6.89	5.14	9.79	33
Beryllium	<5	<5	<5	<5	NA	NA
Cadmium	<1	<1	<1	<1	0.99	4.98
Chromium	17.7	19.9	21.8	20.6	43.4	111
Copper	23.8	*34.6*	*53.8*	12.1	31.6	149
Iron	19,500	15,200	15,300	14,900	NA	NA
Lead	*47.1*	*101*	*125*	19.6	35.8	128
Manganese	584	379	244	419	NA	NA
Mercury	*0.201*	*0.331*	*0.293*	<0.1	0.18	1.06
Nickel	17	14.6	15	14.6	22.7	48.6
Selenium	<1	<1	<1	<1	NA	NA
Silver	<1	<1	<1	<1	NA	NA
Thallium	<5	<5	<5	<5	NA	NA
Zinc	83.4	*125*	*178*	47.7	121	459

[1] TEC (MacDonald et al., 2000), [2]PEC (MacDonald et al., 2000). Concentrations in italics exceed the TEC value, < metal not detected, the value shown is the minimum detection level.

Table 2.31 Sediment PAHs in Lewis Creek, October 5, 2005.

PAH compound (mg/kg)	1BLEW000.61	1BLEW006.64	1BLEW006.95	1BLEW009.19	TEC[1] (mg/kg)	PEC[2] (mg/kg)	VA 99th Percentile (mg/kg)**
Acenaphthene	<0.076	<0.062	<0.076	<0.076	NA	NA	0.170
Acenaphthylene	<0.076	<0.062	<0.076	<0.076	NA	NA	0.121
Anthracene	<0.076	*0.167*	<0.076	<0.076	0.057	0.845	
Benzo[a]anthracene	<0.076	*0.573*	*0.208*	<0.076	0.108	1.050	
Benzo[a]pyrene	<0.076	*0.577*	*0.243*	<0.076	0.150	1.450	
Benzo[b]fluoranthene	<0.076	0.413	0.248	<0.076	NA	NA	
Benzo[g,h,i]perylene	<0.076	0.289	0.141*	<0.076	NA	NA	
Benzo[k]fluoranthene	<0.076	0.477	0.218	<0.076	NA	NA	
Chrysene	<0.076	*0.569*	*0.287*	<0.076	0.166	1.290	
Dibenz[a,h]anthracene	<0.076	*0.116**	<0.076	<0.076	0.033	NA	0.318
Fluoranthene	0.903*	*1.320*	*0.619*	<0.076	0.423	2.230	
Fluorene	<0.076	<0.062	<0.076	<0.076	0.077	0.536	
Indeno[1,2,3-cd]pyrene	<0.076	0.295	0.130*	<0.076	NA	NA	
Naphthalene	<0.076	<0.06	<0.076	<0.076	0.176	0.561	
Phenanthrene	<0.076	*0.428*	*0.241*	<0.076	0.204	1.170	
Pyrene	<0.076	*1.110*	*0.446*	<0.076	0.195	1.520	
Total	0.90	*6.33*	*2.78*	0.00	1.61	22.80	

[1] TEC (MacDonald et al., 2000), [2]PEC (MacDonald et al., 2000). Results indicated as "<" PAH compound not detected, the value shown is the minimum detection level. * Results are considered estimates. The compound was detected and measured, but the measured value was below the quantitation limit for the analysis. ** VA 99th percentile, Values in italics exceed the TEC value, bold values exceed the PEC or VA 99th percentile screening concentrations, NA not available.

Table 2.32 Sediment PAHs hazard quotients in Lewis Creek, October 5, 2005.

PAH Compound (mg/kg)	PEC (mg/kg)	VA 99th Percentile (mg/kg)***	1BLEW000.61	1BLEW006.64	1BLEW006.95	1BLEW009.19
Acenaphthene	NA	0.170	<	<	<	<
Acenaphthylene	NA	0.121	<	<	<	<
Anthracene	0.845		<	0.198	<	<
Benzo[a]anthracene	1.050		<	0.546	0.198	<
Benzo[a]pyrene	1.450		<	0.398	0.168	<
Benzo[b]fluoranthene	NA		<	<	<	<
Benzo[g,h,i]perylene	NA		<	<	<	<
Benzo[k]fluoranthene	NA		<	<	<	<
Chrysene	1.290		<	0.441	0.222	<
Dibenz[a,h]anthracene	NA	0.318	<	0.365		<
Fluoranthene	2.230		<	0.592	0.278	<
Fluorene	0.536		0.040	<	<	<
Indeno[1,2,3-cd]pyrene	NA		<	<	<	<
Naphthalene	0.561		<	<	<	<
Phenanthrene	1.170		<	0.366	0.206	<
Pyrene	1.520		<	0.730	0.293	<
Hazard Index (sum of Hazard Quotients)**			0.04	**3.64**	**1.37**	0.00

*Hazard Quotients were calculated as the ratio of measured concentration to the PEC or state screening value for that compound. **Hazard Index was calculated as the sum of all hazard quotients for individual PAH compounds. Hazard Quotients or Hazard Indices that exceed 1.0 indicate that toxic effects on benthos are possible. Hazard ratios were not calculated for estimated values, A bold hazard index exceeds 1.0, PAH compounds exhibit similar exposure pathways and modes of action so are assumed to be additive in effect, *** VA 99th percentile screening value, < Acutal value not detected quotient could not be calculated, NA not available.

Table 2.33 Sediment total organic carbon and particle size in sweep of Lewis Creek watershed, October 5, 2005.

Station ID	%Sand	%Silt	%Clay	Total	TOC (g/kg)
1BLEW000.61	17	44	39	100	24.48
1BLEW006.64	51	29	20	100	31.15
1BLEW006.95	35	38	26	99	51.27
1BLEW009.19	30	43	27	100	31.92

TOC total organic carbon.

Table 2.34 Whole sediment toxicity results for *C. tentans* (EPA 100.2).

Station	Survival (%)	Growth (weight in mg)
1BLEW000.61	60*	1.26
1BLEW006.64	75	0.907#
1BLEW006.95	13*#	1.44
1BLEW009.91	74	1.578
Control	85	1.108

* Significantly different (p=0.05) from control # Significantly different from station 1BLEW009.19

Table 2.35 Whole sediment toxicity results for *H.azteca* (EPA 100.1).

Station	Survival (%)	Growth (weight in mg)
1BLEW000.61	95	0.806
1BLEW006.64	94	0.84
1BLEW006.95	93	0.779
1BLEW009.91	93	0.635
Control	100	0.667

2.6 Known and Possible Sources of Contamination to Lewis Creek

The contaminants found in the sediments and fish of Lewis Creek are thought to be the combined result of general urban background sources (see Section 2.6.5) and specific contaminated sites that are a legacy of former industrial operations in the City of Staunton. Two of the former operations were coal gasification plants that operated from 1890 until the 1930s (The Brown's Directory of American Gas Companies). In addition, lead acid and metal recycling operations have caused contamination in Lewis Creek. The metal recycling operation is still in business but on a reduced scale. Another recycling operation, Shenandoah Recycling, Inc., is within a mile of Lewis Creek and handled hazardous waste. Fortunately, it was inspected and found to pose little, if any, threat to Lewis Creek. Since the late 1980s there have been numerous incidents of leaking petroleum storage tanks (LPST) in the vicinity of Lewis Creek and significant tributaries. Figures 2.5 and 2.6 show maps of Staunton and the location of the four industrial sites and LPSTs. Table 2.36 gives the map number and the site name. A brief description of these sources is presented in the following sections.

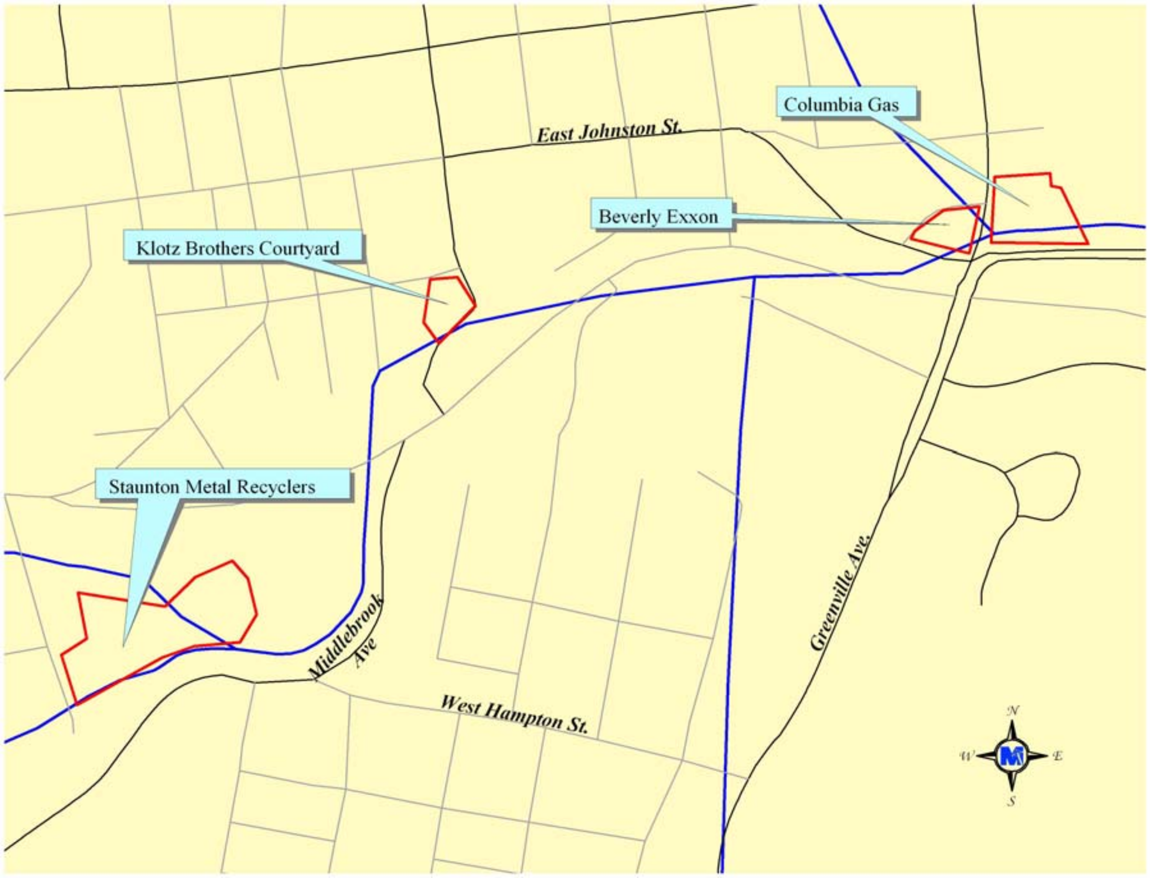

Figure 2.5 Map showing Staunton and four legacy industrial sites.

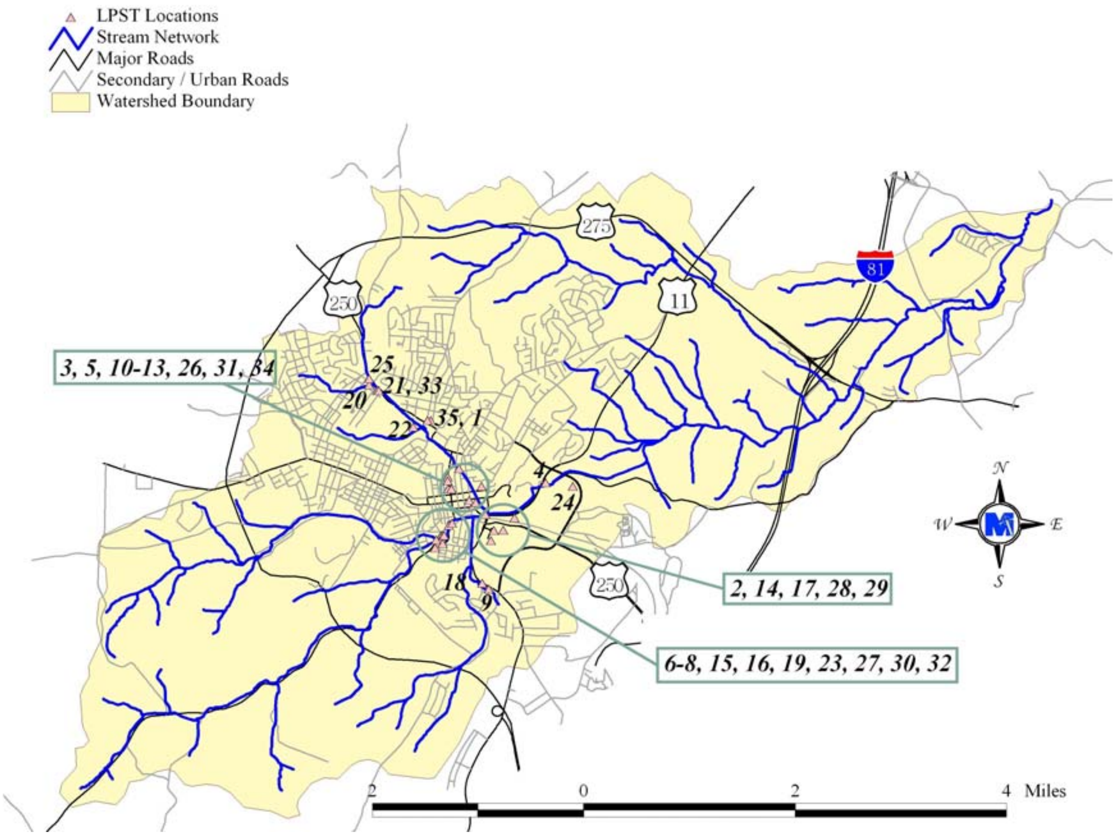

Figure 2.6 Map showing Staunton and the location of significant leaking petroleum storage tanks.

Table 2.36 Map numbers and site names for Staunton's leaking petroleum storage tanks.

Map Number	Site
1	Royal Station #4
2	Beverly Exxon
4	Moffett Paving Co.
5	C & P - Staunton
12	Mary Baldwin College
18	Etna Self Service
20	Quick-livick Inc
21	Lockridge Market
25	Churchville Avenue Citgo
22	National Guard Armory
13	Former Exxon Station
11	Ray Carr Tires-staunton
10	S & S Services And Repair
3	Johnson & New Parking
14	Little Oil Facility
6	Landes Wrecking Service
16	Fisher Oil Bulk Facility
19	Dull Oil Bulk Facility
23	CSX Tranportation Prop.
7	Vdot Csx Railroad Property
8	Ridenour Site
17	Western State Hospital
9	Maybush Village Amoco
15	Lewis Creek Discharge
24	Valley Feed Co
26	Staunton Abc Store
27	Guy C. Eavers Excavating Co.
28	Western State Hospital - Tank Wsh-9
29	Western State Hospital - Tank Wsh-16
30	Former Knopp Brothers
31	Shenandoah Shakespeare, Market St Playhouse
34	James Plecker Sinkhole - Staunton
33	Tastee Freeze
35	Kyles Amoco
32	C&O Flats Train Diesel Spill

2.6.1 New Life Recyclers (Formerly Staunton Metal Recyclers, Inc. and Klotz Brothers Junkyard)

From 1940 to1987, the Klotz Brothers Junkyard was a scrap metal recycling facility and tannery (Administrative Order by Consent, 1989) on a 2.5 acre site located off Bridge Street and primarily owned by CSX Transportation (formerly known as C & O Railroad). Staunton Metal Recyclers purchased the business on January 1, 1988. In 1991, the

Department of Waste Management (now VADEQ) conducted a screening site inspection of the property (DWM, 1991/1992). This study concluded that: 1) several heavy metals and organics were present at significant levels (greater than 3 times background) in soil and sediment; 2) contamination had migrated off site; and 3) soil and surface water are two of the major pathways of concern at the site.

As part of the 1991/1992 Screening Site Inspection, fifteen soil samples were collected including one upgradient background sample and one off-site downgradient sample to investigate off-site contaminant migration. Significant levels of 7 heavy metals and 21 organic contaminants were found in soil samples from the site (Table 2.37). A level for any given substance was considered significant if it measured at three times the background concentration. PCBs were detected in on-site soil at concentrations as high as 150 mg/kg, lead was detected as high as 3,020 mg/kg, and concentrations of PAHs were also high. In the off-site soil sample, antimony, cadmium, chromium, nickel, 2-butanone, bis(2-ethylhexyl)phthalate, and benzo(b)fluoranthene were found at significant levels, establishing off-site migration of contaminants. Appendix C shows the data collected from this inspection for lead and the 16 PAHs on the USEPA national priority list (NPL).

Table 2.37 Heavy metals and organic contaminants found at significant levels at the Klotz Brothers junkyard site.

Heavy Metals	Organic Contaminants
antimony	carbon disulfide, dibenzofuran, benzo(a)anthracene, phenanthrene, chrysene,
cadmium	tetrachloroethene, 2-butanone, di-n-butylphthalate, benzo(k)fluoranthene,
chromium	benzoic acid, 2-methylnaphthalene, benzo(b)fluoranthene, fluorine,
mercury	fluoranthene, benzo(a)pyrene, naphthalene, pyrene, aldrin, phenanthrene,
nickel	bis(2-ethylhexyl) phthalate, butylbenzylphthalate, PCBs; Aroclor-1016,
lead	Aroclor-1248, Aroclor-1254, Aroclor-1260
selenium	

The site is located in the 100-year flood plain, resulting in a high potential for contaminants at the site to flow into Lewis Creek. For example, Buttermilk Spring (a tributary to Lewis Creek) flows directly through the center of the site but is covered up with debris and is not visible. Sampling of sediment from Lewis Creek and Buttermilk Spring during the 1991/1992 screening site inspection confirmed that contaminants had migrated into these water bodies. Sediment samples contained significant levels of the following inorganics: cadmium, copper, lead, mercury, nickel, potassium, selenium, and silver. Organic analysis revealed significant levels of the following contaminants in sediment: toluene, pyrene, fluoranthene, benzo(k)fluoranthene, alpha-chlordane, dieldrin, di-n-octylphthalate, and PCBs.

Groundwater contamination is also likely according to information on soils underlying the site found in the Department of Waste Management (now VADEQ) Screening Site Inspection Report (DWM, 1991/1992). An approximately 49-feet thick, poorly sorted, fine-grained alluvium was found under the Klotz Brothers site, with a carbonate rock aquifer underlying the alluvium. The report also states that, because the alluvium is in hydraulic connection with the aquifer, there is a potential for groundwater contamination from the site.

Following the 1991/1992 screening site inspection, no further action was taken at the site. In 1999, Staunton Metal Recyclers, Inc. was issued a Virginia Pollutant Discharge Elimination System (VPDES) industrial stormwater permit for activities conducted on site. This permit contained requirements for a site stormwater pollution prevention plan and stormwater runoff monitoring. Stormwater runoff was monitored for seven metals and TSS, and quarterly monitoring reports were sent to VADEQ.

The data from stormwater monitoring is summarized in Table 2.38. Concentrations of TSS and metals were elevated in stormwater runoff from the site. In 2000, VADEQ personnel from the Valley Regional Office inspected Staunton Metal Recyclers, Inc. as a result of citizen complaints and a fire at the site. The unscheduled inspection was conducted on September 6, 2000 and a Notice of Violation (NOV) was eventually issued on January 8, 2001. Based on reports from the inspection, the site is a source of oil and hydraulic fluid, sediment, and metals.

On June 30, 2004, the industrial stormwater permit expired and was not reissued because Staunton Metal Recyclers was no longer in business. CSX Transportation Corporation still owns the majority of the site but metal recycling activities are no longer conducted on that portion of the site. A small portion of the original site is now owned by New Life Recyclers.

New Life Recyclers has not applied for an industrial stormwater permit to date, because they have certified no discharge from the site.

In the spring of 2005, AMEC Earth & Environmental, Inc. (AMEC) working on behalf of CSX Transportation performed some general site cleanup work. The following was done on the portion of the site owned by CSX.

1. Drum/container/waste disposal.
2. Scale pit sediment cleaning/disposal.
3. Can crusher foundation investigation and soil disposal.
4. Drainage channel inlet/outlet cleaning.

The can crusher investigation involved removing approximately 90 tons of badly stained soil from the immediate can crusher area. The disturbed area was approximately 40 feet long, 15 feet wide and 3.5 to 4.0 feet deep. The concrete slab used to crush the cans was destroyed and removed. Following removal of the soil, samples were collected from each of the four sidewalls, two from the bottom of the excavated area and one from a test pit. It is believed that most of the staining of the soil was from leaking hydraulic fluid from the crusher unit. This was noted in earlier inspection reports. Results from sidewall soil samples collected from the former can crushing area were similar to results from the 1991 site screening investigation, with many of the same contaminants present. PCB concentrations ranged as high as 15.74 mg/kg, lead was as high as 2,480 mg/kg, and total PAHs were as high as 44 mg/kg. A table of the lead and the NPL PAH data can be found in Appendix D. Figure 2.7 shows a picture of the cleaned up site from the east end of the CSX property looking west towards Bridge Street.

Table 2.38 Summary of VPDES stormwater runoff data from Staunton Metal Recyclers, Inc.

Date	Sample	Rainfall inches	Duration hrs	Runoff gallons	TSS mg/L	AL µg /L	Cd µg /L	Cr µg /L	Cu µg /L	Fe µg /L	Pb µg /L	Zn µg /L
7/19/2000	1	NA	NA	NA	74	793	<1	5	42	1,740	48	236
7/19/2000	2	NA	NA	NA	673	6,210	1	14	43	12,000	77	318
5/21/2001	1	0.44	18	700	250	570	2	5.6	10	600	11	36
5/21/2001	2	0.44	18	700	430	6,000	901	45	78	14,000	68	2,000
12/8/2001	1	1.2	10.3	3,345	23	230	<2	2	10	230	6.1	21
12/8/2001	2	1.2	10.3	3,345	350	9,500	<2	11	14	9,100	18	80
3/20/2002	1	1.25	6	6,212	14	83	<5	10	18	530	5	37
3/20/2002	2	1.25	6	6,212	350	12,000	6.5	33	54	12,000	430	1,000
6/27/2002	1	1.4	1.5	516	240	8,100	<5	15	57	6,900	78	360
6/27/2002	2	1.4	1.5	516	640	11,000	<5	20	200	10,000	200	440
9/26/2002	1	2.5	24	7,738	73	2,600	<5	10	30	2,600	40	120
9/26/2002	2	2.5	24	7,738	1,300	45,000	50	240	4,400	87,000	4,200	8,100

Figure 2.7 Former Staunton Metal Recyclers site looking west toward Bridge Street 11/30/2005).

2.6.2 The Klotz Brothers Courtyard

The Klotz Brothers courtyard site is located approximately 0.2 miles east of New Life Recyclers/CSX property that was the Klotz Brothers junkyard prior to 1988. This 0.12 acre site is on the northeast corner of Lewis Street and Middlebrook Avenue. The property was owned by the Klotz family since 1899 and was the site of a metal recycling business. Batteries were recycled from the early 1940s until 1977 by breaking them open in the courtyard, retrieving the lead plates, and pouring lead-contaminated acid directly onto the ground. At the time Lewis Creek flowed through a conduit underneath a storage building on the site. During a 1986 investigation by the Bureau of Hazardous Waste Management (BHWM), holes in the concrete floor of the storage building, directly over Lewis Creek, were discovered where broken batteries and other material were stored. There was no obvious evidence that battery fluids had been poured or otherwise leaked through the holes and into the creek.

In 1986, a water source (either an aquifer or a perched water table) was detected about 4 feet below the surface, indicating the potential for groundwater contamination. According to the *Preliminary Site Investigation of Klotz Brothers Courtyard* (VDWM, 1987), the water was checked with litmus paper and found to have a pH of 2. (Note: Litmus paper indicates only acidic (litmus is red) or basic (litmus is blue) conditions, not a specific pH. Presumably, the test paper was actually pH paper, a newer product than litmus paper that can reliably estimate pH.)

According to the borehole descriptions included in the preliminary site investigation (VDWM, 1987), orange/red clay was encountered at approximately 4 feet. Additional information was found in the Construction Closure Report (Hatcher-Sayre, 1997) describing the excavation of lead-contaminated soil from the old courtyard: "The vertical limits of excavation were defined by a noticeable clay layer that was encountered between depths of four feet and six feet". It seems clear that a clay layer did result in water perched below the Klotz Brothers site and that water was highly acidic and presumably heavily contaminated with lead.

The vertical and horizontal extent of the clay layer is not known, nor is the fate of acid/lead-contaminated water moving beyond the extent of the clay. The low pH of the water above the clay indicates that any acid-neutralizing carbonates in the soil had been consumed. Soil lead concentrations in the "courtyard" were found to range from 60 ppm - 39,600 ppm with an average of 10,430 ppm (> 1% lead in soil). The facility was listed as a Superfund site in 1986. The State Water Control Board ordered Klotz Brothers to lime the ground on the site in an effort to raise the pH and to plug the holes in the storage building in 1986.

Hatcher-Sayre, Inc. conducted drilling activities and soil and water testing in April 1988. Underlying the site is 3 feet to 8 feet of black granular fill with sand, cinders, metal scrap, brick, plastic, concrete, and other debris. In areas not filled, there is a 4 – 10 foot layer of black fat clay that appears to be native. The dolomitic Beekmantown Formation is encountered at approximately 16 – 23 feet below the surface. Groundwater at the site is under water table conditions and apparently fluctuates seasonally. It is thought that the box culvert, passing under the site, acts as a subsurface dam and results in temporary elevations in groundwater during extremely wet weather.

The revised work plan also reported results from analyses of groundwater samples taken from two monitoring wells (MW-1, MW-2) on-site and from stream water samples collected from Lewis Creek above and below the Klotz Brothers site (SW-above, SW-below). The results are displayed in Table 2.39 and the near-neutral values for pH indicate that the battery acid has been largely neutralized by contact with carbonate-containing soils, at least in the vicinity of the monitoring wells. The neutralization reaction would account for the high conductivity and for the fact that the lead is found primarily in particulate form.

Table 2.39 Analytical results from groundwater and surface water samples collected by Hatcher-Sayre, Inc. in April 1988.

	MW-1	MW-2	SW-above	SW-below
pH (std units)	6.8	6.9	8.4	8.4
Conductivity (μmho/cm)	1,600	1,800	410	430
Lead-unfiltered (μg/L)	180	110	< 50	< 50
Lead-filtered (μg/L)	< 50	< 50	< 50	< 50

In December 1996, 5,100 square feet (0.12 acres) of the courtyard were excavated to a depth 4-6 feet below the original surface and 1,360 tons of lead-contaminated material was disposed of by a transport, storage, and disposal (TSD) facility in Pennsylvania. The site was de-listed in 1997, with no further monitoring required, after the monitoring wells had been decommissioned in October 1996. It is not clear at this point if any lead that may be associated with this site is still impacting Lewis Creek. The water column metals' sampling done by MapTech and VADEQ in the spring of 2005 found lead below detection levels in the dry weather samples and lead was present in the wet weather samples but well below the hardness-based water quality standard. A table of the soil lead data collected by Hatcher and Sayre for the post closure report can be found in Appendix E.

2.6.3 Downtown Citgo (Formerly Beverly Exxon)

The SWCB (now VADEQ) actions at Beverly Exxon began with an underground LPST investigation late in 1989, although the problem was found to be a leaking distribution line rather than a leaking tank (Geotechnical & Environmental Services, 1990). The site was formerly a coal gasification plant and is presently the site of Downtown Citgo located on the west side of South Coalter Street. A coal gasification facility operated on the site from at least 1890 to the 1930s.

Additional information on the site history was found in the Expanded Site Inspection (ESI) Report (USEPA, 1997). Staunton Gas Light Company operated from at least 1894 through 1921 on parcels of land currently occupied by a service station and Commonwealth Gas. In 1921, the Staunton Gas Light Company was reorganized into the Staunton Gas Company, the Staunton Lighting Company, and the Citizens Gas Company. The Staunton Gas Company operated on the parcel of land currently occupied by a Citgo service station, and the Staunton Lighting Company and the Citizens Gas Company operated on the parcel of land now occupied by Columbia Gas. All three companies were coal gasification facilities. According to Radian Corporation, *Brown's Directory of American Gas Companies*, the coal gasification plant in Staunton operated from 1890 through 1930 as a coal gasification plant and from 1930 through 1940 as a water gasification plant. Water gas production refers to a process in which steam reacts with red-hot coal or coke to produce hydrogen and carbon monoxide, a combustible gas mixture used for heating and cooking until the 1950s.

Based on gas production records and estimates of coal tar production per unit of gas produced, the amount of coal tar generated was estimated at 950,000 gallons. The coal tar was generally stored on site and sold to the chemical industry for use as raw materials, however, during periods without a market for coal tar, the material was either discharged to a nearby surface water (such as Lewis Creek) or disposed of on site.

The site became a retail gasoline outlet in 1938 and, in October 1989, the Staunton Fire Department reported gasoline and a tar-like substance leaking into Lewis Creek through the stone retaining wall under the Greenville Avenue Bridge. The tar-like material in the stream was removed, and a valved pipe was installed through the retaining wall to recover the gasoline product. Approximately 350 gallons of product was recovered from the site. Line tightness testing revealed that the source of the gasoline was a leak in the gasoline dispensing lines. The lines were replaced and a leak detection system was installed. After laboratory analysis, the tar-like substance was found to contain mainly PAHs and was believed to be coal tar buried on site during the historic use of the site as a coal gasification facility. The buried coal tar had apparently been softened and partially dissolved by gasoline from the LPST and moved down-gradient to Lewis Creek. The primary route from the leaking hose to Lewis Creek was through coarse backfill around a storm sewer line, although the fill material allowed general down-gradient migration toward Lewis Creek.

The following summer, Geotechnical & Environmental Services (GES) conducted a site characterization to determine the full extent and impact of the gasoline release. GES installed four monitoring wells and conducted a soil gas probe investigation. During installation of two of the four wells, a black product was blown from the borehole by the drilling rig. A test pit was dug, and 6 inches of black product was found at the bottom of a void, believed to be a former containment structure. Black product was also observed floating on top of the groundwater. Due to the extent of the coal tar contamination, further investigation was referred to the State Superfund Program.

In 1992, the Virginia Department of Waste Management performed a screening site inspection. Groundwater, surface water, sediment, and a waste source sample were collected and analyzed. The inspection report concluded that groundwater contamination was extensive. Groundwater samples contained high levels of benzene, toluene, ethylbenzene, xylenes, numerous PAHs, arsenic, lead, zinc, and cyanide. The report concluded that migration of contamination can only be speculated to be happening since no samples were taken down-gradient or in the deeper aquifer. A table of the lead and the 16 NPL PAH data collected during this inspection can be found in Appendix F.

Surface water and sediment sampling revealed that a considerable amount of contamination was migrating from the site into the stream. Concentrations of individual

PAH compounds in sediment ranged as high as 140 mg/kg (phenanthrene). Even upstream sediment samples showed elevated PAH levels indicating that the extent of the contaminant migration was greater than initially thought. The report concluded that contamination had migrated to Lewis Creek, and the potential for future impact in Lewis Creek is high unless migration routes are controlled.

Following the Screening Site Inspection, EPA recommended listing the site on the National Priority List; however, the Commonwealth of Virginia did not support the listing. The State recommended that additional sampling be conducted before determining further action. EPA conducted a removal assessment at the Beverly Exxon site in 1994 and found no immediate threat from the coal tar or gasoline. In 1996 an Expanded Site Inspection was conducted by PRC Environmental Management, Inc. During sampling of monitoring well #3, up to 1.2 feet of a tar-like substance was again encountered floating on the water table. A black tar-like substance was also observed in sediment collected in Lewis Creek under the Greenville Avenue bridge. Based on analytical results from this Expanded Site Inspection, Environmental Resources Management, Inc. calculated a hazard ranking score (HRS) of 13.95 for the site. This score was not high enough to be considered for the NPL (listing on NPL required a minimum score of 28.5). It is important to note that this scoring result was based primarily on the fact that Lewis Creek is not an important sport fishery or a public water supply rather than a reflection of the severity of the contamination. State narrative water quality standards, such as the benthic standard for which this TMDL is being developed, were not considered in the assessment or scoring of the site. No pesticides were found in surface water samples and all metals' concentrations were below VADEQ water quality standards. Sediment samples indicated high concentrations of PAHs. The highest concentration was located adjacent to the Beverly Exxon site (71.08 mg/kg total PAHs). Sediment PAHs levels declined considerably upstream of the Beverly Exxon site. Downstream of both Beverly Exxon and Columbia Gas, total PAHs in sediment ranged from 0.96 mg/kg to 26.32 mg/kg. The only sediment metal to exceed its PEC screening value was lead. The highest sediment lead value was adjacent to the former Beverly Exxon site but concentrations exceeded the PEC upstream of this site. A table of the lead and 16 NPL PAH data collected and reported in the Expanded Site Inspection can be found in Appendix G. In November 2000, VADEQ was satisfied that the LPST problem was corrected and closed the case. To date, no remediation of the coal tar deposits has been conducted and EPA's Comprehensive Environmental Response, Compensation and Liability Information System (CERLIS) database lists the site as "no Further Remedial Action Planned."

2.6.4 Columbia Gas

Columbia Gas is located across the street from the former Beverly Exxon site on the east side of South Coalter Street. This property was also the site of a coal gasification facility that operated from the 1890s to the 1930s. Columbia Gas of Virginia, a NiSource Company (CGV), currently owns the property. In 1997, CGV requested that the VADEQ allow it to enter the Voluntary Remediation Program (VRP). The VADEQ accepted the request and CGV was assigned a VRP number of 00244. A site characterization report was prepared and submitted to the VADEQ in December 2002 by Environmental Resources Management (ERM).

ERM collected soils and groundwater data from the CGV site in October and November 1999. In surficial soil samples, semi-volatile organic compounds (SVOCs) (mainly PAHs) ranged from 1.3 mg/kg to 43.4 mg/kg. Lead values were high in one of the surficial soil samples. In subsurface soils, SVOCs ranged from non-detect to 967.1 mg/kg (at MW4). In groundwater, SVOCs ranged from non-detect to 7.74 mg/L (at MW4). The report also contained the sediment and water samples collected from Lewis Creek during the Enhanced Screening Site inspection of Beverly Exxon in October and November of 1996. A complete summary of analytical results for lead and the 16 NPL PAHs from this report can be found in Appendix H.

During the site characterization study an underground holder of a "tar by product" was identified on the CGV site near MW4 and in close proximity to Lewis Creek. Removal of this product began in December 1999. One thousand gallons of fuel oil was used to decrease the viscosity of the tar-like substance to make removal of it more successful. A vacuum truck removed 2,356 gallons of fuel oil and tar product. If one assumes that all 1,000 gallons of the fuel oil was removed, then 1,356 gallons of the tar product was also removed. The only material left in the holder was thick, solidified, tar-like material containing no liquid.

In April 2000, CGV discovered an intermittent sheen on the surface of Lewis Creek adjacent to its property. CGV removed all of the residual material in the holder described above and mitigated the source of the seeps. However, in June 2002 another sheen was discovered on Lewis Creek adjacent to the CGV property. CGV retained Earth Tech to remediate the cause of the sheen. Contaminated soil was discovered approximately four feet west of the south building at a depth of six feet. Soil was excavated to a depth of 13 feet where "clean" soil was found. Most importantly, in the process of soil removal a second coal tar brick container was discovered. This container was eight feet wide by four feet deep. The coal tar was removed by adding clean soil and approximately 1,500 pounds of portland cement and contaminated soil was excavated to a depth of 12 feet. A total of 145.3 tons of contaminated soil was removed from the site for treatment and disposal. An interceptor trench was constructed in the excavation that included a 12-inch sump well. Earth Tech gauged the sump well on two occasions (October 30, 2002 and November 4, 2002) to check for the presence of manufactured gas plant residuals with an oil/water interface probe. No measurable residuals were present in the well on either occasion but there was a slight sheen on the surface (Closure Report, November 2002). No visible sheens on Lewis Creek have been reported to the VADEQ since June 2002.

2.6.5 Background Urban Sources of PAHs and lead

PAHs are a group of chemicals that occur naturally in coal, crude oil, and gasoline. There are more than 100 different PAHs and there are numerous sources in the urban environment. The 16 NPL PAHs are generally the result of incomplete combustion of petroleum products or organic matter. Common sources are soot from vehicle emissions, atmospheric deposition, degradation of asphalt and asphalt sealants from roadways, parking lots and driveways, roofing tars, industrial emissions, creosote, tobacco products, residential wood burning and in any product containing coal tars such as some special-purpose skin creams and anti-dandruff shampoos. Combinations of these common background sources of PAHs are often a major source in urban streams (Stout, 2004).

An analysis of the PAH data collected by the VADEQ between 1995 and 2002 at 573 sites revealed that the result for the June 2001 sample on Lewis Creek was in the 99th percentile of data statewide, indicating that there are sources other than what are considered normal background in the Lewis Creek watershed. For example, the 16 NPL listed PAHs totaled 14.88 mg/L in the June 2001 sample collected in Lewis Creek. In contrast, a sample collected in Blacks Run (which runs through Harrisonburg, VA) on the same day was 5.3 mg/kg and a sample collected in August of 2001 from Abrams Creek (which runs through Winchester, VA) was 4.56 mg/kg. These results are more typical of background urban sources of PAHs in the northwestern portion of Virginia.

On March 2, 2006 MapTech and VADEQ performed a stream walk in various sections of Lewis Creek from river mile 7.35 upstream to river mile 8.59 looking for evidence of contamination from PAHs not associated with “normal” urban background sources. Several areas were found where there was evidence of current and past contamination. These areas are shown in Figures 2.8 – 2.11. Sheens on the surface of the water were observed in the Beverley Exxon and Columbia Gas area as well as the Staunton Metal Recyclers area when sediment deposits were disturbed. Additional evidence of current and past contamination was present under the Greenville Avenue bridge adjacent to the Beverley Exxon site. At this location, current seeps of an oily product and historical dried seeps of coal tar were observed.

Figure 2.8 **Seep located under Greenville Ave. Bridge adjacent to former Beverley Exxon site. Pipe shown in picture is believed to be pipe that was installed to recover gasoline free product from the site. Picture taken 3/2/06.**

Figure 2.9 Storm drain located under Greenville Ave. Bridge adjacent to former Beverley Exxon site. Tar-like material dripped and hardened from top of storm drain. Picture taken 3/2/06.

Figure 2.10 Sheen observed in Lewis Creek in front of retaining wall adjacent to Columbia Gas property. Sheen was observed when sediments near the retaining wall were disturbed. Picture taken 3/2/06.

Figure 2.11 Sheen observed from used boom still anchored to bank on Lewis Creek. Downstream of Staunton Metal Recyclers and Fisher Bulk Oil Facility. Picture taken 3/2/06.

Common background sources of lead in urban watersheds include atmospheric deposition, old paint from buildings prior to 1978, automobile exhaust prior to 1986 when leaded gas was used, plumbing in older homes where lead solder was used to seal the joints in the pipes, and wear and degradation of automotive components. Sediment lead concentrations range from 8 – 48 mg/L in Blacks Run and 23 – 50 mg/L in Abrams Creek, two typical urban streams in northwestern Virginia. During the May 2005 sediment sweep performed by MapTech and VADEQ a sediment lead concentration of 172 mg/L was found at station 1BLEW006.64. In comparison to the special sediment sampling for metals and other toxics collected from across Virginia by the VADEQ between 1995 and 2002 this value would rank in the 99th percentile. Clearly there are significant sources of lead in the Lewis Creek watershed other than normal urban background loads.

2.6.6 Leaking Petroleum Storage Tanks

The VADEQ administers a petroleum program that regulates above and below ground storage tanks. The first regulation impacting underground storage tanks was enacted in 1987. Regulations regarding above ground storage tanks had already been in place. The new underground storage tank regulations required owners to perform release detection tests on their tanks no later than December 22, 1993. As a result, many new cases were reported to VADEQ. Since 1987 there have been 35 petroleum storage tank related problems in the vicinity of Lewis Creek or a major tributary (Table 2.40 and Figure 2.6). All of these cases were closed when it was determined that the petroleum release posed no serious threat to public water supplies or surface waters. Petroleum products are minor sources of PAHs. The most common PAH found in petroleum products is naphthalene. The petroleum cases that appeared to have the most impact on Lewis Creek are discussed below:

The former Dull and former Fisher Oil bulk storage facilities were located on CSX Transportation property just north of the former Staunton Metal Recyclers site at the south end of the City of Staunton where they operated for over 50 years. There have been eight reported releases of petroleum products at these sites since 1989. A persistent sheen of oil was observed on Lewis Creek for three years (December 1994 through 1997). Both sites served as bulk storage for petroleum products and the primary causes of the contamination were sloppy handling, faulty valves, and spillage that occurred over the years. By way of example, in 1989 an above ground gasoline storage tank was overfilled by 200 gallons. The gasoline ended up in Lewis Creek, which was within 50 feet of the spill. A joint site characterization report was done in the mid 1990s to determine the extent of the contamination. Significant diesel fuel contamination was found in one monitoring well (MW3) on the Dull Oil site. At one point there was a free product thickness of 0.7 feet at the well surface. Over 16 gallons of free product was removed from the well in addition to 6,167 gallons of contaminated ground water. In addition, the concentration of lead in MW3 was 252 μg /L. Lewis Creek was sampled for dissolved-phase contamination on January 4, 2000 and March 8, 2000 and all values were below detection level. The visible sheen on Lewis Creek has not reappeared since 1997 and free product has been absent from MW3 since mid 1999. Oil absorbent booms and pads were installed in Lewis Creek on June 7, 1996 and removed on May 28, 1998. The last evidence of contamination on the boom and pads was on August 28, 1997. The Dull and Fisher petroleum site release cases were closed by the VADEQ in February 2000. In 2004, a new petroleum release case was opened at the former Fisher facility. During closure of the site, evidence of petroleum release was observed when distribution piping from the former above-ground storage tanks were excavated. The petroleum release contaminated soil in the vicinity of the former loading rack and distribution trenches. Groundwater was also contaminated, with 0.26 feet of free petroleum product observed in an existing monitoring well. A Corrective Action Plan for the site is currently being developed.

Table 2.40 VADEQ petroleum storage tank cases in the vicinity of Lewis Creek and tributaries

PC No	Site	Release Report	Map No
19890027	Royal Station #4	15-Jul-88	1
19900539	Beverly Exxon	30-Oct-90	2
19901579	Johnson & New Parking	14-May-90	3
19910111	Moffett Paving Co.	24-Jul-90	4
19910923	C & P – Staunton	2-Jan-91	5
19921181	Landes Wrecking Service	3-Jan-92	6
19921579	VDOT CSX Railroad Property	9-Mar-92	7
19922404	Ridenour Site	26-Jun-92	8
19931707	Maybush Village Amoco	8-Mar-93	9
19940081	S & S Services And Repair	19-Jul-93	10
19940082	Ray Carr Tires-Staunton	19-Jul-93	11
19941813	Mary Baldwin College	27-Jan-94	12
19954533	Former Exxon Station	28-Jul-94	13
19954599	Little Oil Facility	7-Oct-94	14
19954663	Lewis Creek Discharge	15-Dec-94	15
19954670	Fisher Oil Bulk Facility	29-Dec-94	16
19954763	Western State Hospital	27-Apr-95	17
19954810	Etna Self Service	14-Jun-95	18
19964751	Dull Oil Bulk Facility	19-Jul-95	19
19964804	Quick-livick Inc	17-Jan-96	20
19964869	Lockridge Market	23-May-96	21
19964870	National Guard Armory	4-Jun-96	22
19975104	CSX Tranportation Prop.	14-Mar-97	23
19985036	Valley Feed Co	24-Sep-97	24
19985105	Churchville Avenue Citgo	25-Feb-98	25
19985156	Staunton ABC Store	5-Jun-98	26
19995075	Guy C. Eavers Excavating Co.	2-Nov-98	27
19995107	Western State Hospital - Tank Wsh-9	3-Dec-98	28
19995108	Western State Hospital - Tank Wsh-16	3-Dec-98	29
19995210	Former Knopp Brothers	18-May-99	30
20006140	Shenandoah Shakespeare, Market St Playhouse	3-Apr-00	31
20016072	C&O Flats Train Diesel Spill	26-Oct-00	32
20016182	Tastee Freeze	29-Mar-01	33
20026042	James Plecker Sinkhole - Staunton	29-Oct-01	34
20026103	Kyles Amoco	20-May-02	35

2.7 VPDES Permits in the Lewis Creek Watershed

There are fifteen VPDES-permitted discharges in the Lewis Creek watershed. These are listed in Table 2.41 and shown in Figure 2.12. Nine of the permits fall under the VPDES general permit regulation and the remaining six construction stormwater permits are administered by the Department of Conservation and Recreation (VADCR). There are no individual VPDES-permitted discharges in the watershed. Municipal wastewater from the City is treated at the Middle River Regional Wastewater Treatment Facility (WWTF) east of Verona, and discharge is to the Middle River.

Table 2.41 VPDES permits in the Lewis Creek watershed.

Permit No	Map No.	Facility	Type	Nearest Stream
VAG110071	1	Transit Mixed Concrete	General - Mixed Concrete	Lewis Creek, U.T.
VAG110073	2	Augusta Blocks LLC	General - Mixed Concrete	Lewis Creek
VAG110073	3	Augusta Blocks LLC	General - Mixed Concrete	Lewis Creek
VAG840030	4	Appomattox Lime Co-Belmont Quarry & Staunton	General - Non Metallic Mining	Lewis Creek
VAR050826	5	Dixie Gas & Oil Corp Bulk Plant	Industrial Storm Water	Poague Run, U.T.
VAR050778	6	Augusta Blocks LLC	Industrial Storm Water	Lewis Creek
VAR051333	7	Ord's Auto Parts, LLC	Industrial Storm Water	Lewis Creek, UT
VAG401882	8	Weaver's Garage, Inc.	Single Family Residence	Poague Run, UT
VAG401072	9	Private Residence	Single Family Residence	Lewis Creek, U.T.
VAR100570	10	Project #0262-007-101,C502	Construction Storm Water	Lewis Creek
VAR103788	11	VDOT Verona Resid 0262-007-101,C503,B609,B61	Construction Storm Water	Lewis Creek
VAR101703	12	VDOT Verona Resid 0262-007-101,C503,B609,B61	Construction Storm Water	Lewis Creek
VAR102097	13	Disposal Area 2 - VDOT NFO 02262 007 101 C50	Construction Storm Water	Lewis Creek, U.T.
VAR103916	14	Triangle Services Retail Building - Staunton	Construction Storm Water	Lewis Creek
VAR104649	15	Harrington Place	Construction Storm Water	Lewis Creek UT

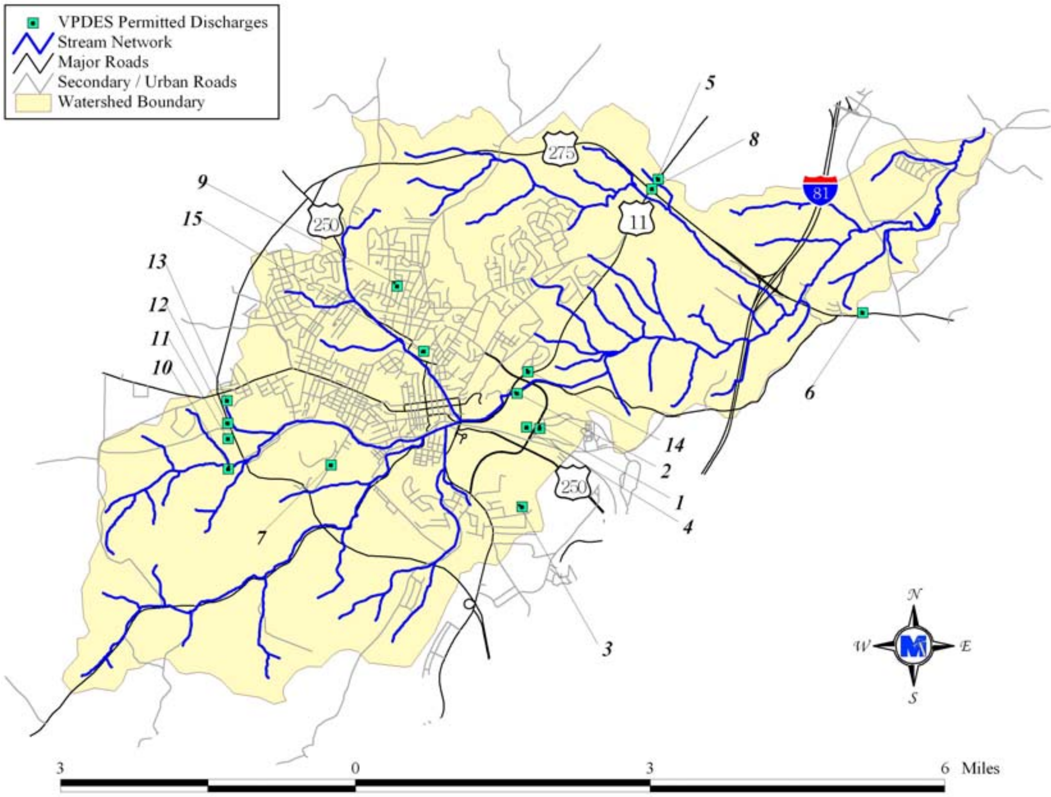

Figure 2.12 Permitted discharges in the Lewis Creek watershed.

3. TMDL ENDPOINT: STRESSOR IDENTIFICATION

3.1 Stressor Identification

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (USEPA, 2000) was used to separately identify the most probable stressor(s) for Lewis Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). There are no water quality standards or recommended screening levels for many of the water quality parameters sampled in the Lewis Creek watershed. For parameters without established water quality criteria or screening values, a comparison value will be used. Comparison values are 90th percentile values calculated from 14 monitoring stations on first and second order streams in the Potomac/Shenandoah River watershed. These stations were used as benthic reference stations or were otherwise found not to have a benthic impairment based on the most recent sampling results. These screening values were used to develop a list of possible stressors. For a parameter to become a probable stressor, additional information was required such as benthic habitat, metrics, and scientific references documenting problems for aquatic life. Graphs will be shown for parameters that exceeded a 90th percentile value in more than 10% of the samples collected within the impaired segment or if the parameter had extreme values. If a parameter does not exceed a water quality standard, screening value, or comparison value or does not have excessive values, median values will be shown for each monitoring station from downstream to upstream. Data for parameters with more than one but less than nine data points can be found summarized in section 2.5.1. The presence of nine values was selected as a cutoff in order to avoid using data from stations that were not sampled during different seasons of the year or different flow regimes in Lewis Creek. However, all data collected on Lewis Creek was carefully reviewed to ensure that it was consistent with expected values and to document any extreme values.

Land use data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity/total dissolved solids, temperature, and organic matter. In addition, because a substantial portion of the land area in the Lewis Creek watershed is impervious, hydraulic modification will be considered. It is understood that the EPA does not consider hydraulic modification to be a pollutant.

The results of the stressor analysis for Lewis Creek are divided into three categories:

Non-Stressor(s): Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors. A list of non-stressors can be found in Table 3.1.

Possible Stressor(s): Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors. A list of possible stressors can be found in Table 3.2.

Most Probable Stressor(s): The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s). A list of probable stressors can be found in Table 3.3.

3.2 Non-Stressors

Table 3.1 Non-Stressors in Lewis Creek.

Parameter	Location in Document
Temperature	section 3.2.1
Dissolved Oxygen	section 3.2.2
PH	section 3.2.3
Metals (except sediment lead and mercury)	section 3.2.4
Toxics (ammonia, chloride, sulfate, PCBs and pesticides)	section 3.2.5

3.2.1 Temperature

The maximum temperature recorded in Lewis Creek was 24.3^{o}C at VADEQ station 1BLEW002.91, which is well below the state standard of 31^{o}C for the mountain zone waters. Figures 3.1 and 3.2 show temperature measurements at 1BLEW002.91 and 1BLEW006.95. Temperature is considered a non-stressor.

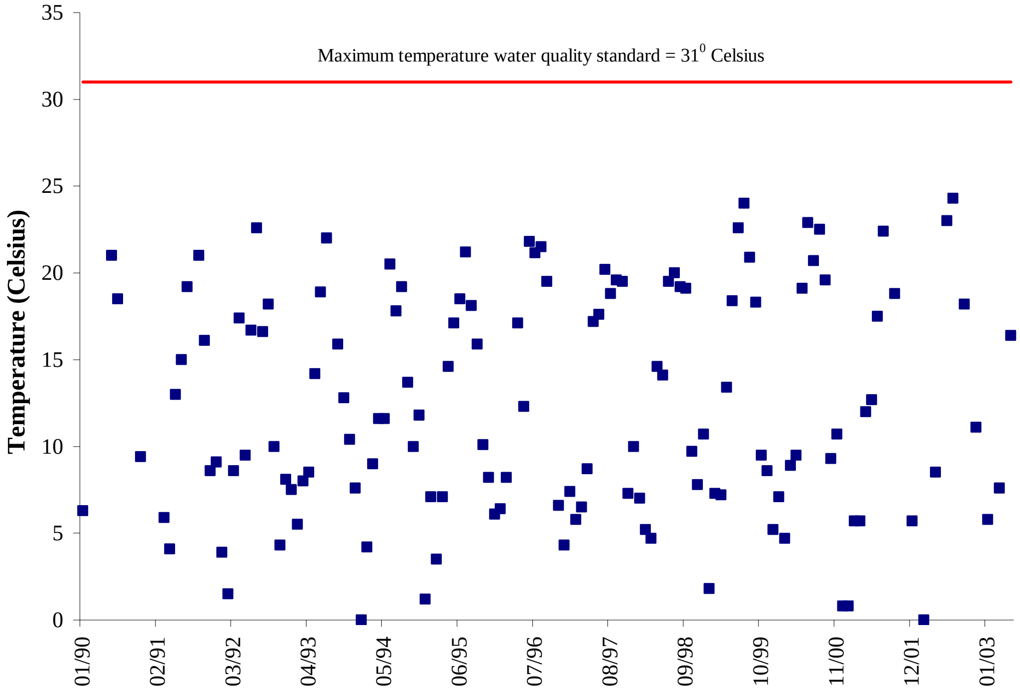

Figure 3.1 Temperature measurements at VADEQ station 1BLEW002.91.

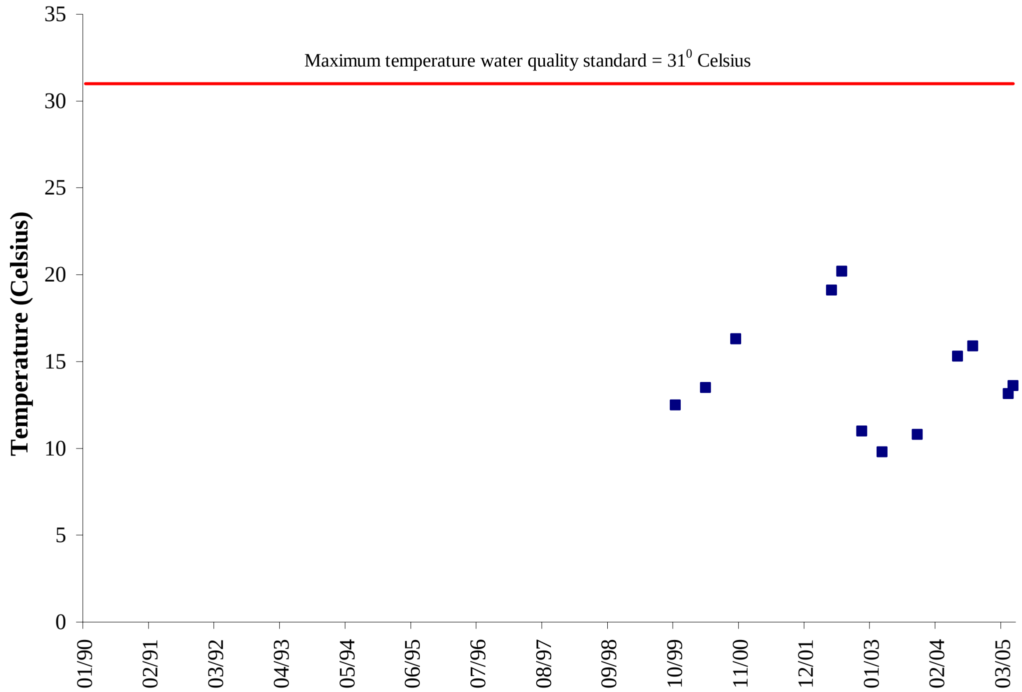

Figure 3.2 Temperature measurements at VADEQ station 1BLEW006.95.

3.2.2 Low dissolved oxygen

Not a single dissolved oxygen concentration was measured below the VADEQ minimum water quality standard at any of the monitoring stations on Lewis Creek. Figures 3.3 and 3.4 show dissolved oxygen concentrations measured at VADEQ monitoring stations 1BLEW002.91 and 1BLEW006.95. Low dissolved oxygen is considered a non-stressor.

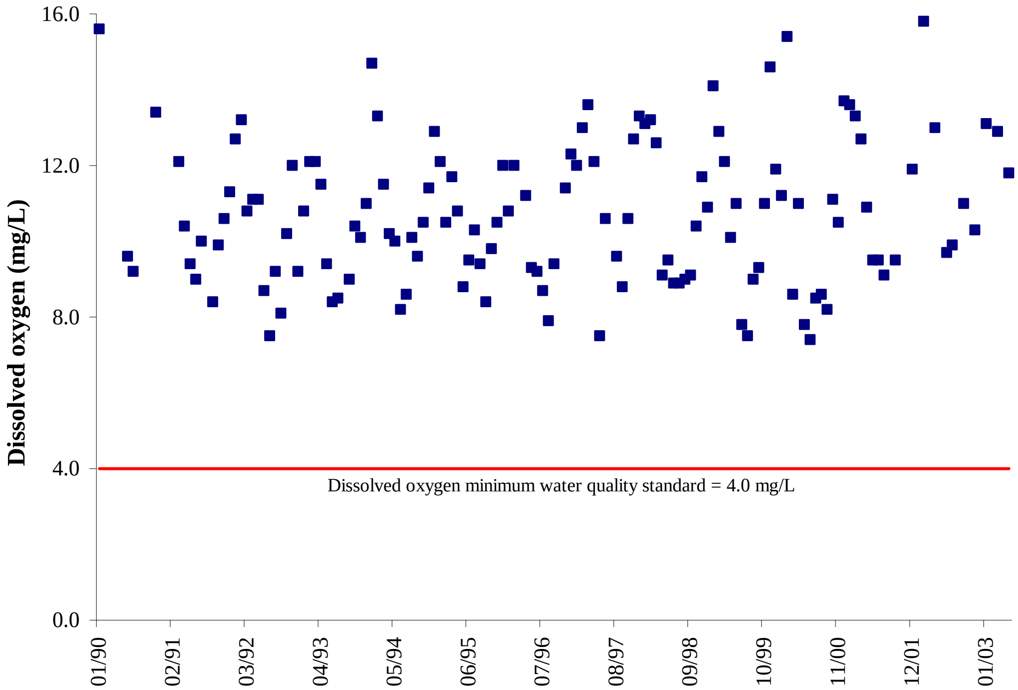

Figure 3.3 Dissolved oxygen measurements at VADEQ station 1BLEW002.91.

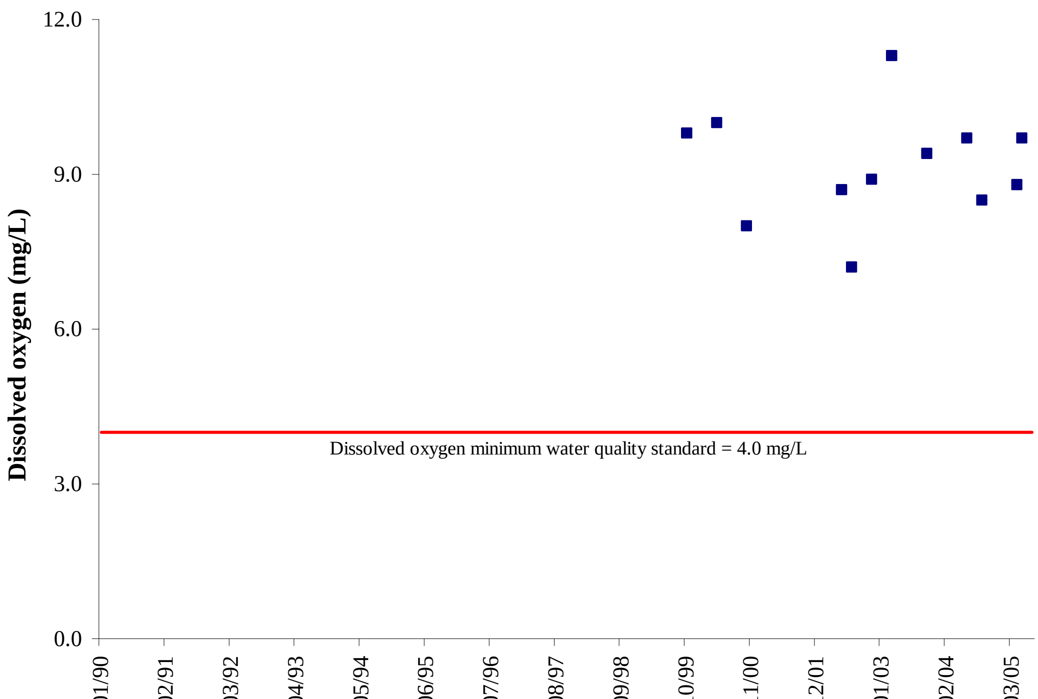

Figure 3.4 Dissolved oxygen measurements at VADEQ station 1BLEW006.95.

3.2.3 pH

Field pH values were within water quality standards everywhere pH was measured on Lewis Creek, with two exceptions in the early 1990s at station 1BLEW002.91. The minimum pH value measured was 6.2 std units. Field pH water quality standards (WQS) in the Shenandoah River Basin are 6.5 – 9.5 std units due to the prevalence of carbonate rock formations in the valley. A pH of 6.2 is not low enough to cause problems for the aquatic life in Lewis Creek. Field pH values are shown for VADEQ monitoring stations 1BLEW002.91 and 1BLEW006.95 in Figures 3.5 and 3.6

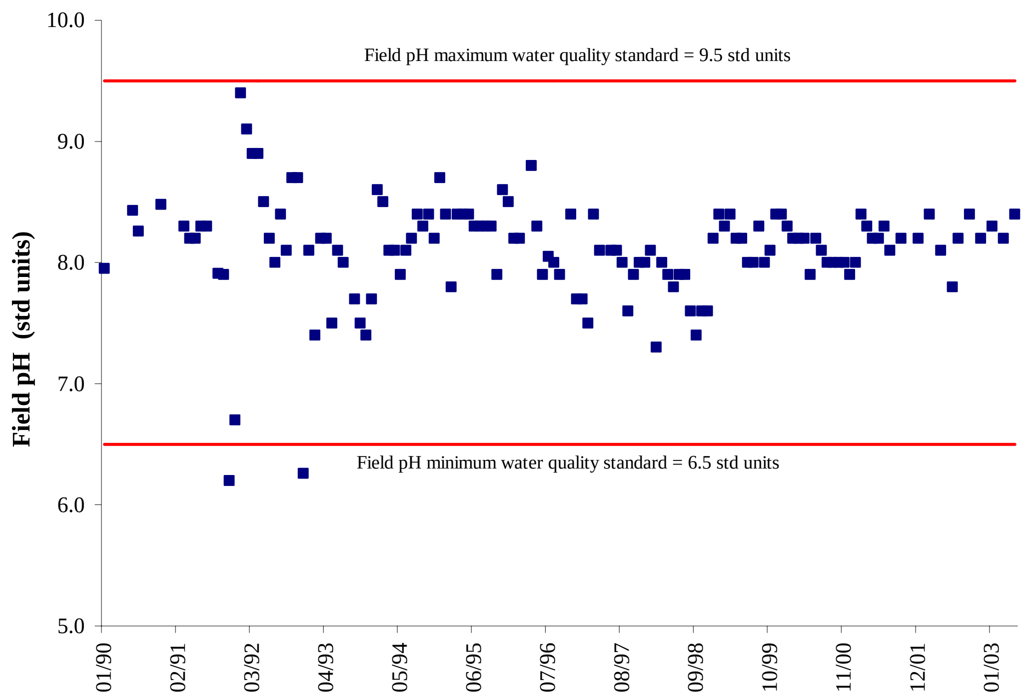

Figure 3.5 Field pH measurements at VADEQ station 1BLEW002.91.

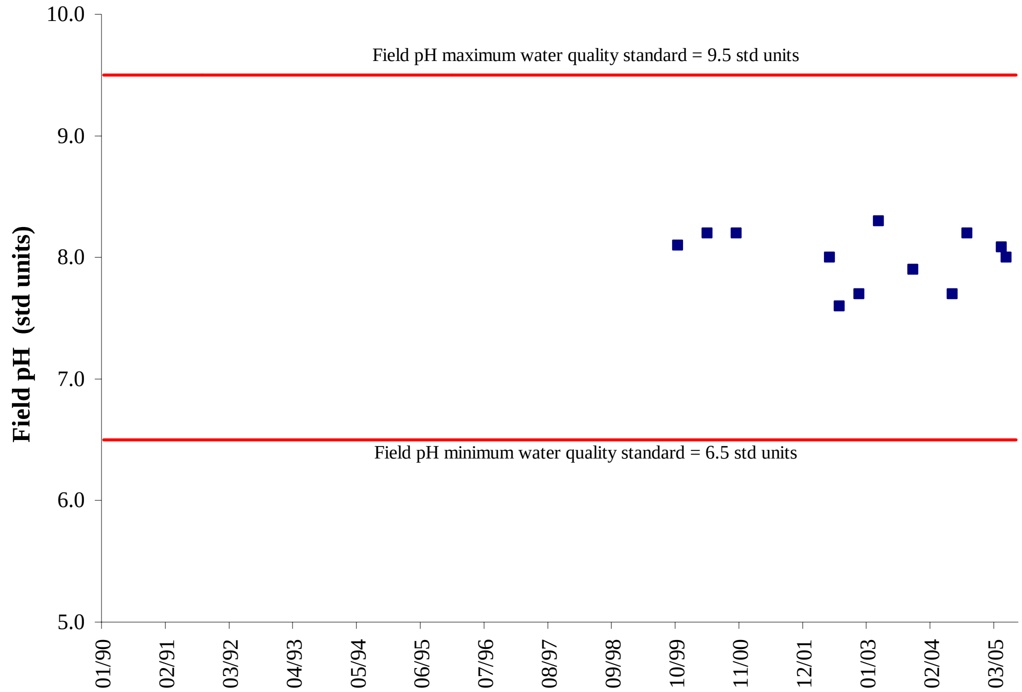

Figure 3.6 Field pH measurements at VADEQ station 1BLEW006.95.

3.2.4 Metals

This section will discuss VADEQ water quality monitoring for metals dissolved in the water column, metals in the sediment, and metals in fish tissue. Water column dissolved metals were sampled during a special study by VADEQ and MapTech at the three existing VADEQ benthic monitoring stations (1BLEW000.61, 1BLEW006.95 and 1BLEW009.19) on April 7, 2005 and May 24, 2005. All results were below the hardness-based water quality standard (Tables 2.21 and 2.22). Sediment metals samples were collected by VADEQ at station 1BLEW002.91 in July 1991, July 1996, and August 2000 and all values were below the Consensus Probable Effect Concentrations (PEC) (MacDonald et al, 2000). Special sediment monitoring done by VADEQ in conjunction with fish tissue sampling on June 21, 2001 at station 1BLEW005.24 found a mercury concentration of 1.60 mg/kg which exceeds the PEC value (1.06 mg/kg). The remaining metals were below the PEC value (Table 2.20). To confirm the 2001 findings and attempt to locate potential sources on Lewis Creek, a sediment sweep was done on May 2, 2005 at seven monitoring sites on Lewis Creek and six additional sites on significant tributaries. Mercury was found at six of the seven sites on Lewis Creek in addition to

Peyton Creek and Buttermilk Spring. Concentrations were generally about 10% of the PEC value (1.06 mg/kg). Mercury will be discussed further in the section on possible stressors (section 3.3). The remaining metals collected during the May 2, 2005 sediment sweep were below PEC values with the exception of lead at station 1BLEW006.64. Lead will be discussed in the section on probable stressors (section 3.4). Sediment sampling was performed again in October 2005 at the three benthic monitoring stations and station 1BLEW006.64. All metals concentrations were below PEC values although a lead concentration of 125 mg/kg was found at station 1BLEW006.95 (Table 2.32). The PEC value is 128 mg/kg. Metals, with the exception of lead and mercury, are considered non-stressors.

3.2.5 Toxic Contaminants

Water column and sediment toxicity tests indicated that toxicity was an issue impacting the benthic macroinvertebrate community in Lewis Creek. A water column bioassay conducted on March 4-7, 2003 on samples collected from 1BLEW002.91 concluded that there was a statistically significant reduction in fathead minnow survival (40% mortality). In addition, sediment toxicity tests from sediment collected on October 5, 2005 found a statistically significant reduction in the survival of *C. tentans* at monitoring station 1BLEW006.95 compared to the upstream control station, 1BLEW009.19. *C. tentans* also exhibited a statistically significant reduction in growth at monitoring station 1BLEW006.64 compared to station 1BLEW009.19 (section 2.5.4.4).

Total abundance figures from the benthic monitoring surveys at the three benthic monitoring stations on Lewis Creek also indicate a toxic substance(s) is impacting the benthic community. VADEQ benthic monitoring station 1BLEW006.95 averages 70% fewer total organisms than benthic monitoring station 1BLEW000.61 and 80% fewer than the upstream station, 1BLEW009.19. Some of this difference could be explained by the dislodging of benthic organisms and subsequent drifting downstream due to hydraulic modification (discussed in section 3.3.4). However, during the severe drought in 2002 the average difference in total abundance between benthic monitoring stations 1BLEW006.95 and 1BLEW000.61 was 70% fewer organisms. A review of the total habitat scores finds a similar conclusion. From 2002 through 2005 benthic monitoring station 1BLEW006.95 consistently had higher total habitat scores than benthic monitoring station 1BLEW000.61. It is logical to expect that the differences in total abundance figures would be much less given the fact that 1BLEW006.95 had higher total habitat scores. Additional supporting evidence can be found by examining the benthic assemblages from VADEQ monitoring stations 1BLEW000.61 and 1BLEW006.95. Chironomids comprised 42% of the total benthic assemblage at station 1BLEW000.61 and were the dominant family. The benthic assemblage at station 1BLEW006.95 indicated that chironomids were 25% of the total assemblage and were not the dominant family. These results are consistent with the conclusion that benthic macroinvertebrates at 1BLEW000.61 are primarily impaired by habitat conditions of excess sediment, while benthic macroinvertebrates at 1BLEW006.95 are primarily impaired by toxics. Clearly the sediment toxicity confirmed at this monitoring station is playing a prominent role in the reduced number of organisms found here, Figure 3.7.

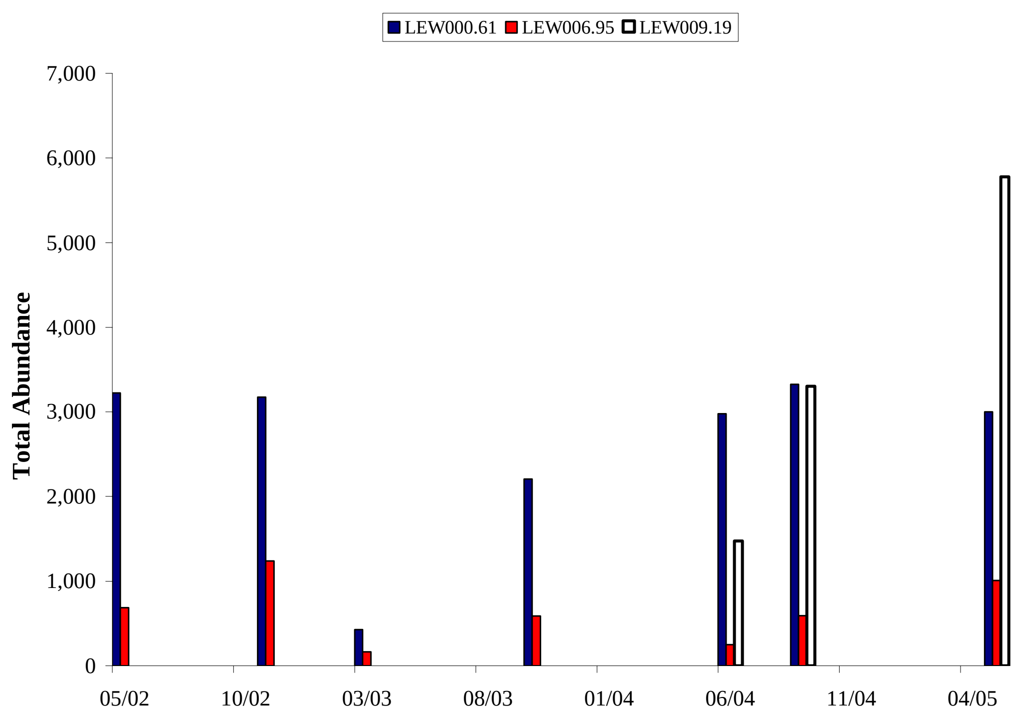

Figure 3.7 Total abundance numbers at the three VADEQ benthic monitoring stations on Lewis Creek.

While toxicity in general appears to be a major source of impairment in Lewis Creek, certain toxics could be ruled out and identified as non-stressors. Total ammonia

(NH_3/NH_4) concentrations were well below water quality standards at VADEQ monitoring station 1BLEW002.91 (Figure 3.8). Chloride concentrations were also well below the VADEQ chronic water quality standard of 230 mg/L (Figure 3.9). Sulfate concentrations were well below the 90th percentile screening value at VADEQ monitoring station 1BLEW002.91 (Figure 3.10). Fish tissue and sediment PCBs, organics, and pesticides were collected at VADEQ station 1BLEW005.24 on June 21, 2001. Analysis of the fish tissue indicated that PCBs exceeded the VDH action level of 50 µg/L. The specific results for the PCB concentrations can be found in Table 2.17 in section 2.5.2. A possible source for the PCBs is the old Staunton Metal Recyclers site on the south end of Staunton. PCBs were used in hydraulic fluid until the 1970s and old inspection reports noted considerable leakage from the hydraulic press at the can crusher area of the site. Additional sediment PCB sampling was done by the VADEQ and MapTech at 13 sites on Lewis Creek and significant tributaries on May 2, 2005. The results confirmed the findings of the June 21, 2001 sampling and all PCB values were below the established Consensus Probable Effect Concentration (MacDonald et al., 2000).

The special sediment sampling by VADEQ on June 21, 2001 at station 1BLEW005.24 found a chlordane concentration of 118.32 mg/kg (the PEC value is 17.6 mg/kg). However, the sediment sampling at 13 monitoring stations on Lewis Creek and tributaries on May 2, 2005 found chlordane below detection levels at every monitoring station. Toxics with the exceptions noted in Table 3.1 are considered non-stressors.

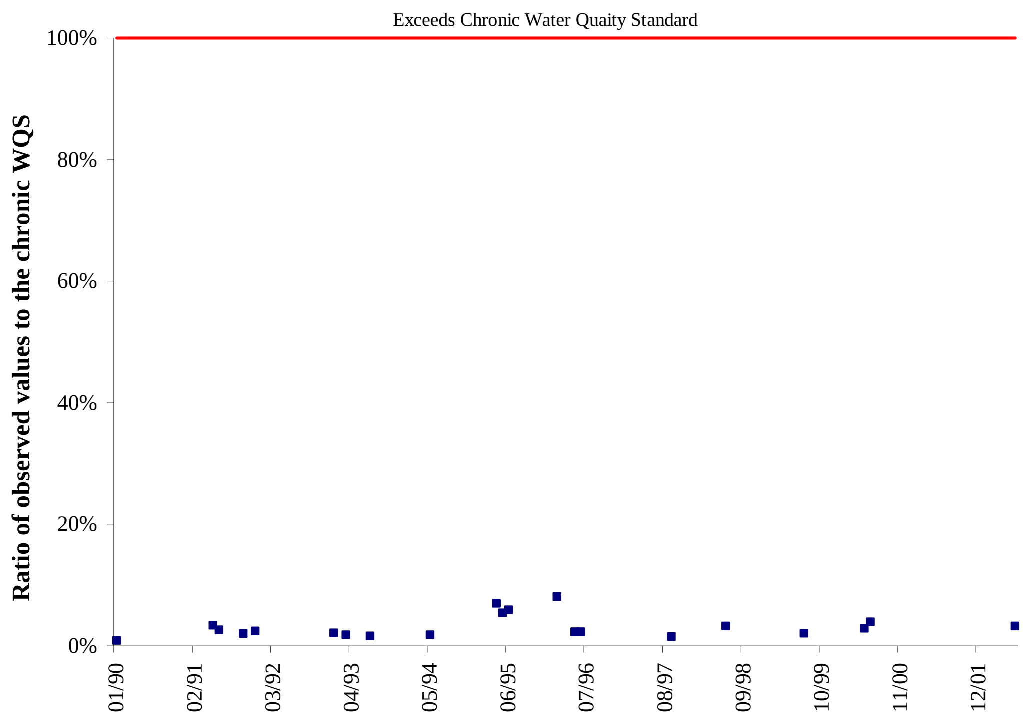

Figure 3.8 Total ammonia concentrations at VADEQ station 1BLEW002.91.

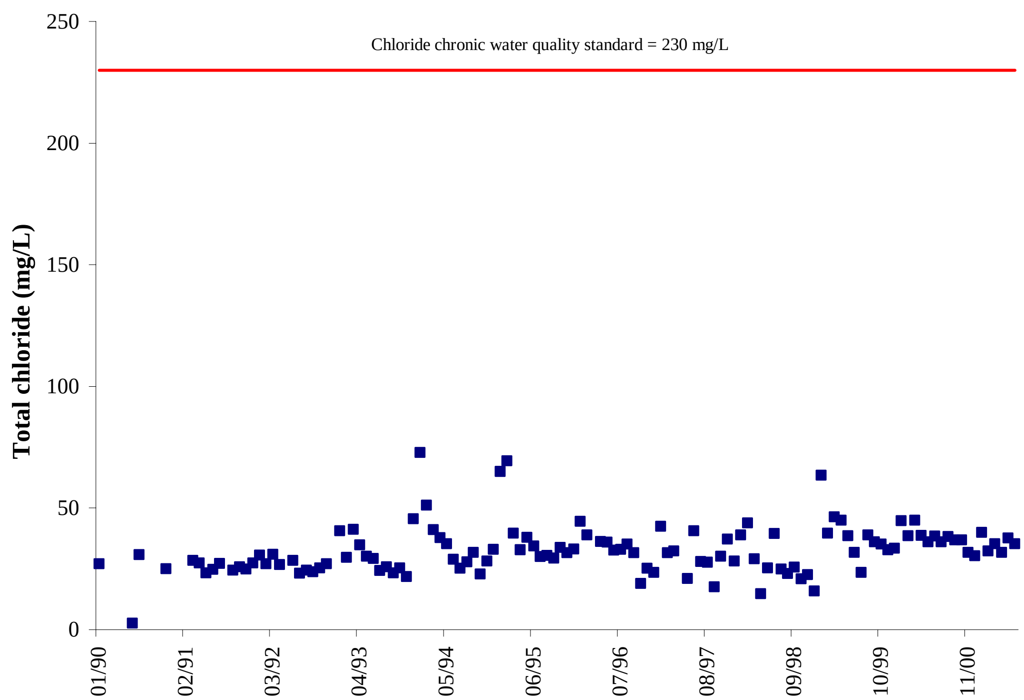

Figure 3.9 Total chloride concentrations at VADEQ station 1BLEW002.91.

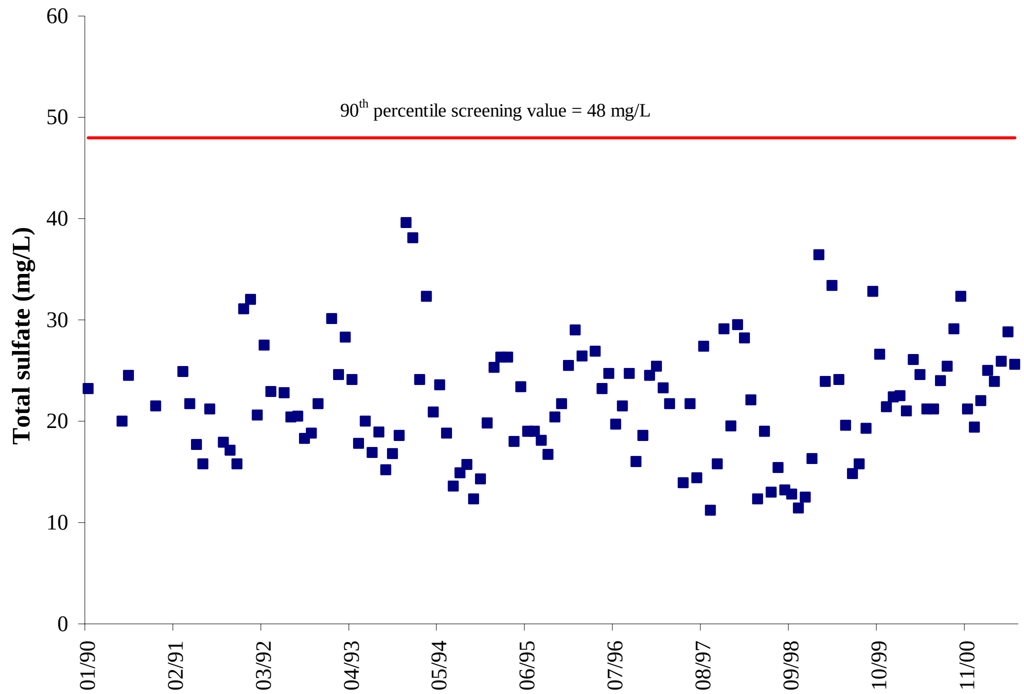

Figure 3.10 Sulfate concentrations at VADEQ station 1BLEW002.91.

3.3 Possible Stressors

Table 3.2 Possible stressors in Lewis Creek.

Parameter	Location in Document
Nutrients	section 3.3.1
Organic matter and nitrate nitrogen	section 3.3.2
Conductivity/Total dissolved solids	section 3.3.3
Hydraulic modification	section 3.3.4
Mercury	section 3.3.5

3.3.1 Nutrients

Median total phosphorus (TP) concentrations were very low at VADEQ monitoring station 1BLEW002.91; only one value out of 74 (1%) samples exceeded the VADEQ screening value of 0.2 mg/L (Figure 3.12). Nitrate-nitrogen (NO_3-N) concentrations were also low compared to the 90th percentile screening value of 2.0 mg/L. A more thorough examination of nutrients was performed to try and determine the potential for eutrophication from the existing data at VADEQ station 1BLEW002.91. The criteria used can be found in *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water* (Mills et al., 1985). This procedure determines the potential for eutrophication based on the concentrations of total phosphorus and total nitrogen. TP concentrations exceeded the Problem Likely to Exist (PLE) threshold 3% of the time, and TN exceeded it 100% of the time during the warm weather months. This analysis does not demonstrate that there is definitely a eutrophication problem in Lewis Creek, but it indicates that there is potential for a problem. Other critical factors are the amount of sunlight and the frequency of pools or slow moving areas in the stream. Therefore, nutrients (the nitrogen species, in particular) are considered possible stressors. A probable stressor designation is not warranted because total phosphorus is typically the nutrient that controls eutrophication in spite of high nitrogen concentrations. Controls on sediment and fecal coliform bacteria (from a previous TMDL) will reduce nitrogen concentrations concurrently. The potential sources for the high nitrogen concentrations are discussed in the following section.

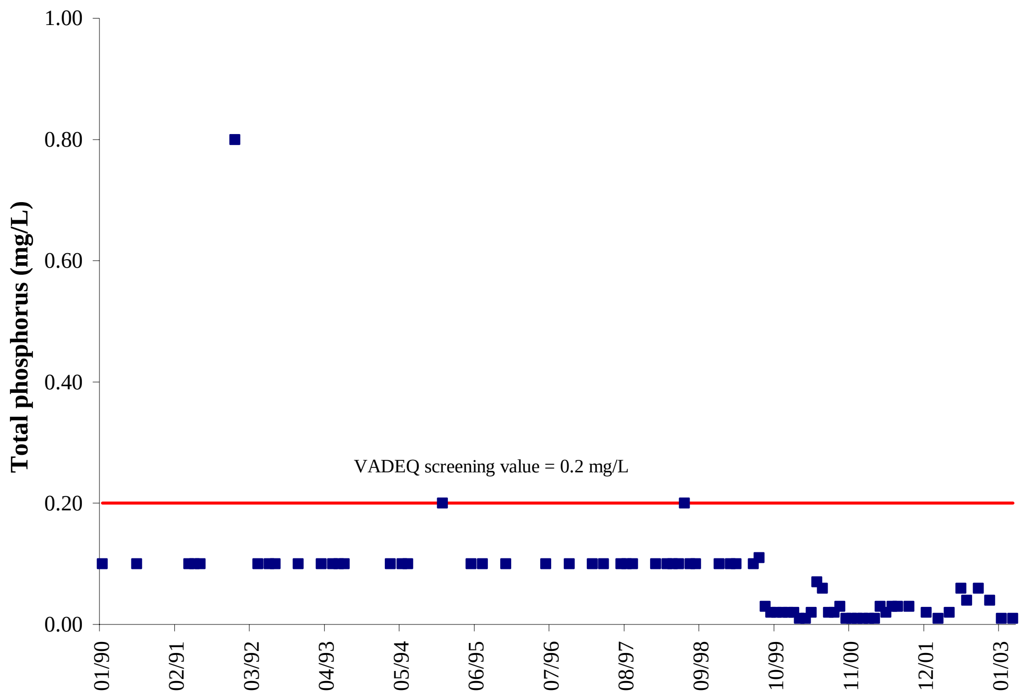

Figure 3.11 Total phosphorus concentrations at VADEQ station 1BLEW002.91.

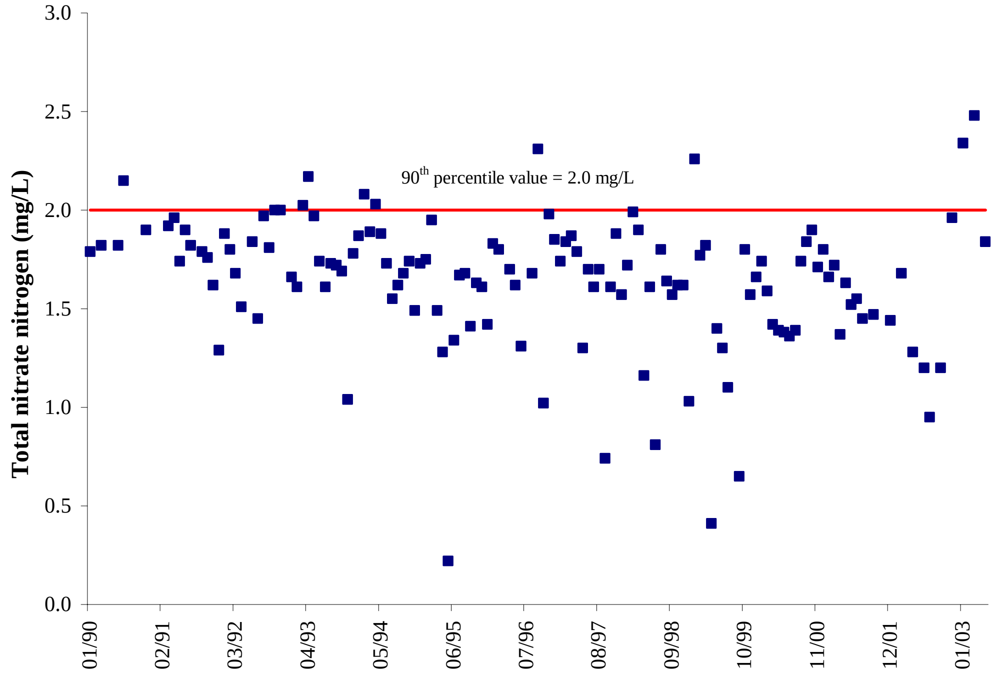

Figure 3.12 Nitrate-nitrogen concentrations at VADEQ station 1BLEW002.91.

3.3.2 Organic matter

Several different parameters were used to determine if organic matter in the stream was impacting the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) provides an indication of how much dissolved organic matter is present. Total organic carbon (TOC), chemical oxygen demand (COD), and total volatile solids (TVS, also called total organic solids) provide an indication of organic matter. The measure of total organic suspended solids (TVSS) provides an indication of particulate organic matter in a stream. Total Kjeldahl nitrogen (TKN) is a measure of the amount of organic nitrogen that is present. BOD_5 concentrations exceeded the 90th percentile screening value of 2.6 mg/L in eight of 49 (16%) samples at VADEQ monitoring station 1BLEW002.91 and a maximum value of 5.0 mg/L was reported in 1991 (Figure 3.13). TOC concentrations exceeded the 90th percentile screening value of 5.0 mg/L in seven of 63 (11%) samples at VADEQ monitoring station 1BLEW002.91 and a maximum value of 12.0 mg/L was reported in 1992 (Figure 3.14). COD concentrations exceeded the 90th percentile screening concentration of 14 mg/L in 10 of 71 (14%) samples, and the maximum concentration was 22 mg/L in 1996 (Figure 3.15). Only four out of 68 (6%)

TVSS concentrations exceeded the 90th percentile concentration (7.0 mg/L). However, there was a maximum value of 108 mg/L recorded in 1991 (Figure 3.16). TVS concentrations exceeded the 90th percentile concentration (75.0 mg/L) in 38 of 55 (69%) samples and the maximum concentration was 170 mg/L in 1991 (Figure 3.17). TKN concentrations exceeded the 90th percentile screening concentration (0.58 mg/L) in 9 of 131 (7%) and the maximum concentration was 2.6 mg/L in 1991 (Figure 3.18). Most of the parameters that are indicative of high organic matter reveal that it is elevated in Lewis Creek. The fact that most of the TVS concentrations exceeded the screening value (while very few of the TVSS concentrations did) indicates that most of the organic matter is dissolved. Based on the extremely high fecal coliform counts found in Lewis Creek (VADCR, 2004), it is likely that the source of the organic matter is from non-regulated sewage discharges, exfiltration, and overflows from the City of Staunton's sewage collection system in addition to animal waste inputs from the agricultural areas. These sources were addressed by the fecal coliform TMDL that was developed for Lewis Creek in the Middle River and Upper South River Watersheds. Therefore, organic matter is considered a possible stressor.

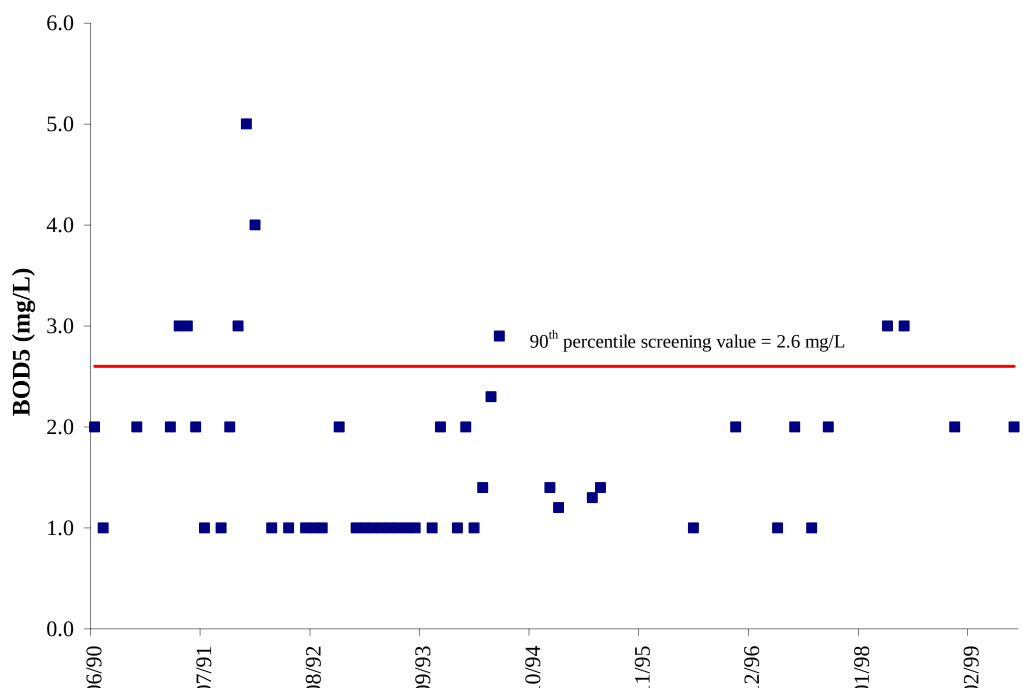

Figure 3.13 BOD$_5$ concentrations at VADEQ station 1BLEW002.91.

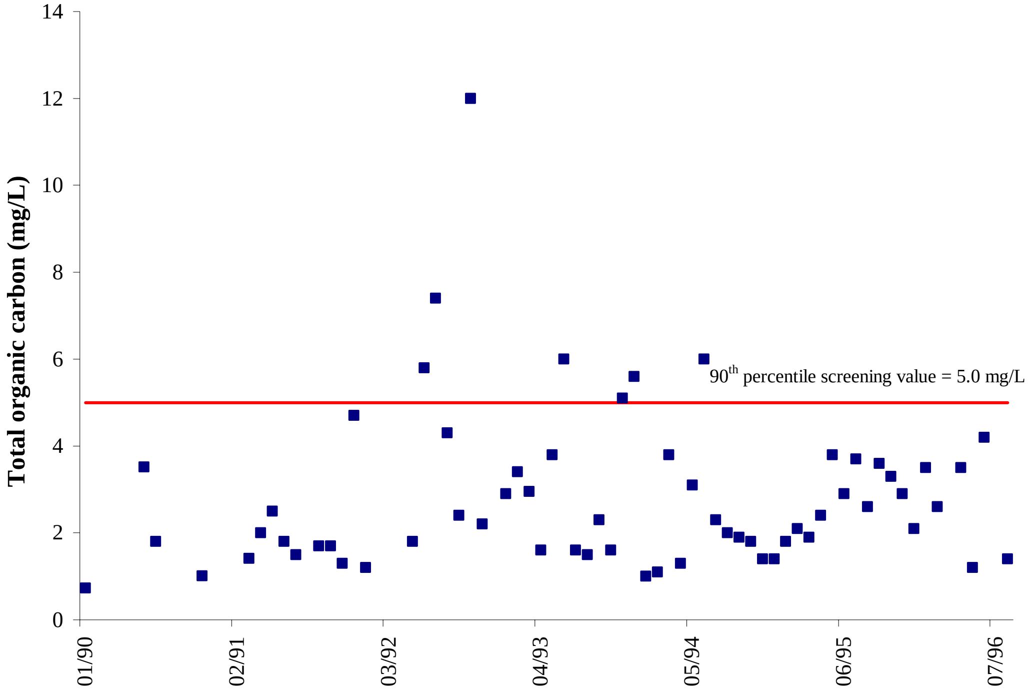

Figure 3.14 TOC concentrations at VADEQ station 1BLEW002.91.

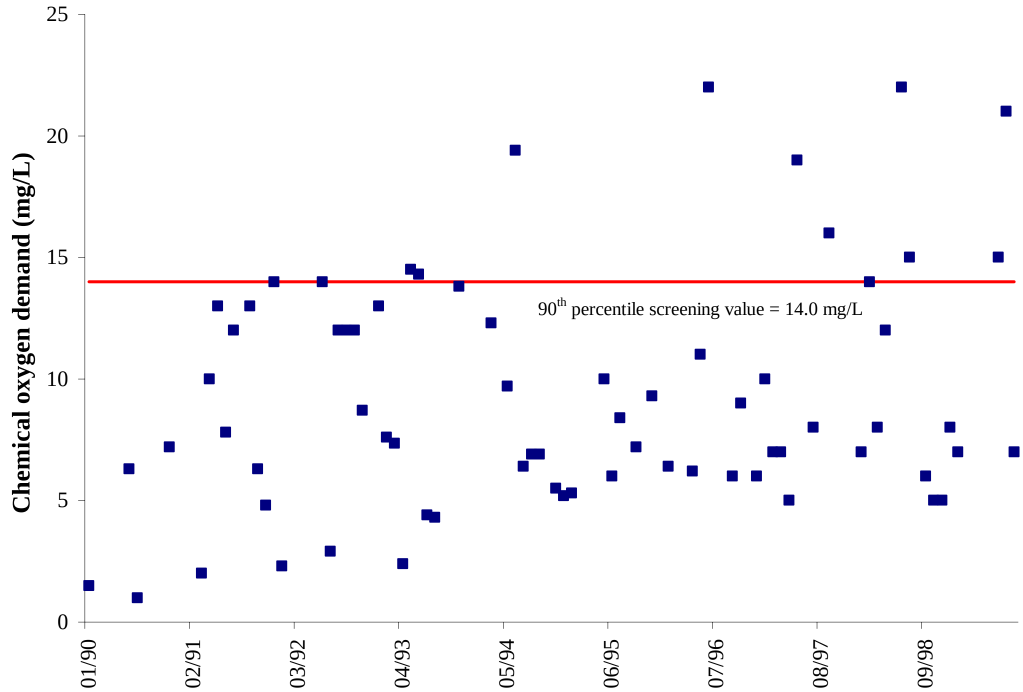

Figure 3.15 COD concentrations at VADEQ station 1BLEW002.91.

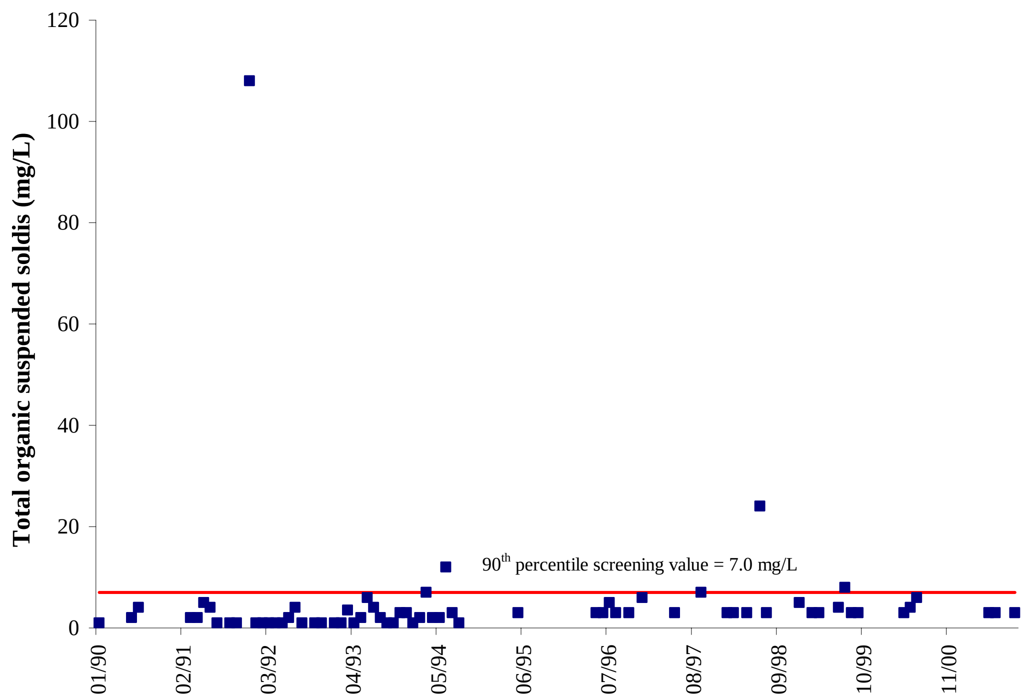

Figure 3.16 TVSS concentrations at VADEQ station 1BLEW002.91.

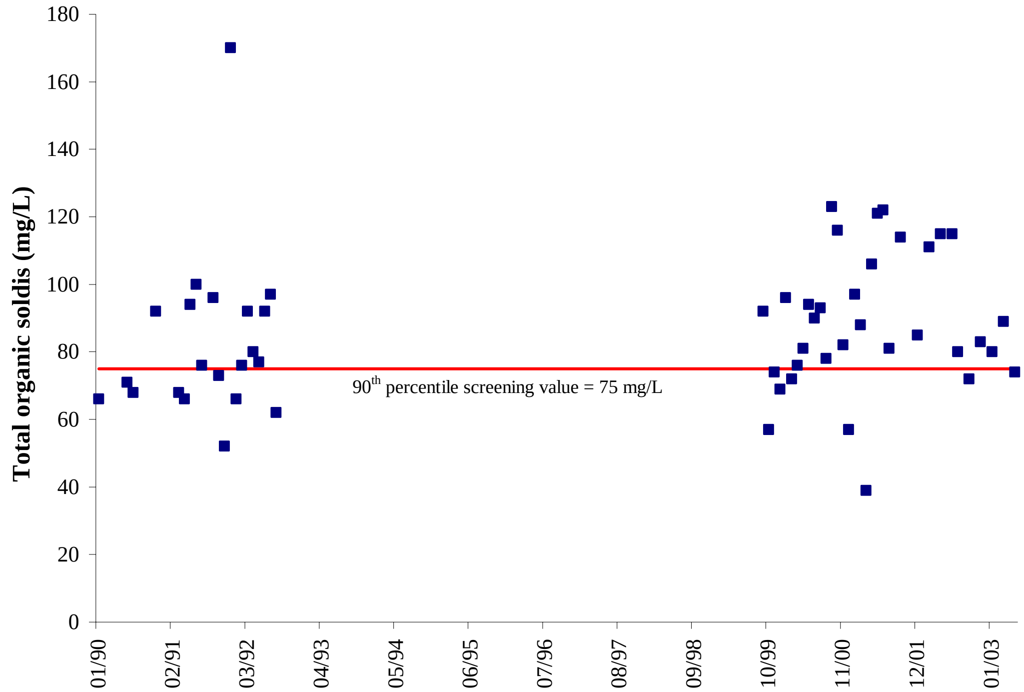

Figure 3.17 TVS concentrations at VADEQ station 1BLEW002.91.

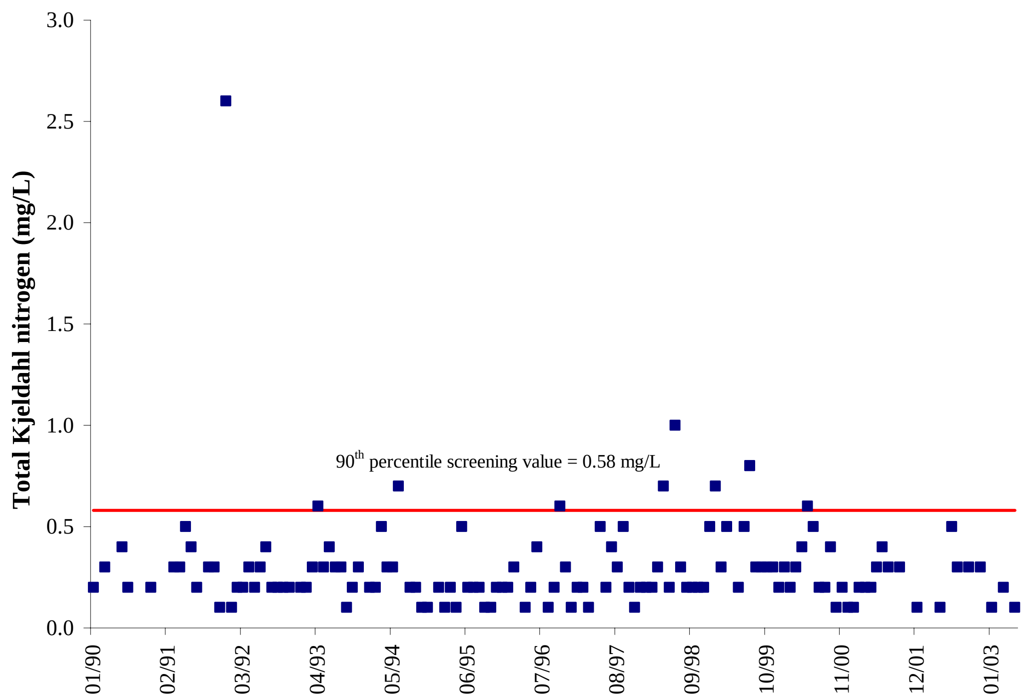

Figure 3.18 TKN concentrations at VADEQ station 1BLEW002.91.

3.3.3 Conductivity/Total dissolved solids

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. Total dissolved solids (TDS) is a measure of the concentration of dissolved salts plus dissolved metals, minerals, and organic matter and, therefore, there is often a direct correlation with conductivity. While the state of Virginia has no water quality standard for either conductivity or TDS, standards set by other states have values varying between 1,000 and 1,500.

The median conductivity value at monitoring station 1BLEW002.91 was 620 μmhos/cm and it exceeded the 90th percentile screening value of 574 μmhos/cm. Out of a total of 136 measurements, 115 (85%) exceeded the screening value. However, there were no extreme spikes and the measurements were fairly consistent (minimum 298 and maximum 760) (Figure 3.19).

The median TDS value was 368 mg/L and did not exceed 423 mg/L at VADEQ monitoring station 1BLEW002.91 (Figure 3.20). Only three out of 22 (14%) concentrations exceeded the 90th percentile screening value of 381 mg/L. A 2004 report by the Kentucky Department of Environmental Protection noted, “drastic reductions in mayflies at sites with conductivities generally above 500 μmhos/cm” (approximately 375 mg/L TDS) (Pond, 2004). This report was based on first and second order headwaters streams. However, there is no universal agreement on what concentration of TDS can impair a benthic community. After an exhaustive literature search, Kennedy (2002) reported that many authors have concluded that concentrations of 1,000 mg/L and higher could cause some type of stress to the benthic community. Conductivity/TDS are considered possible stressors because maximum TDS concentrations are below 500 mg/L.

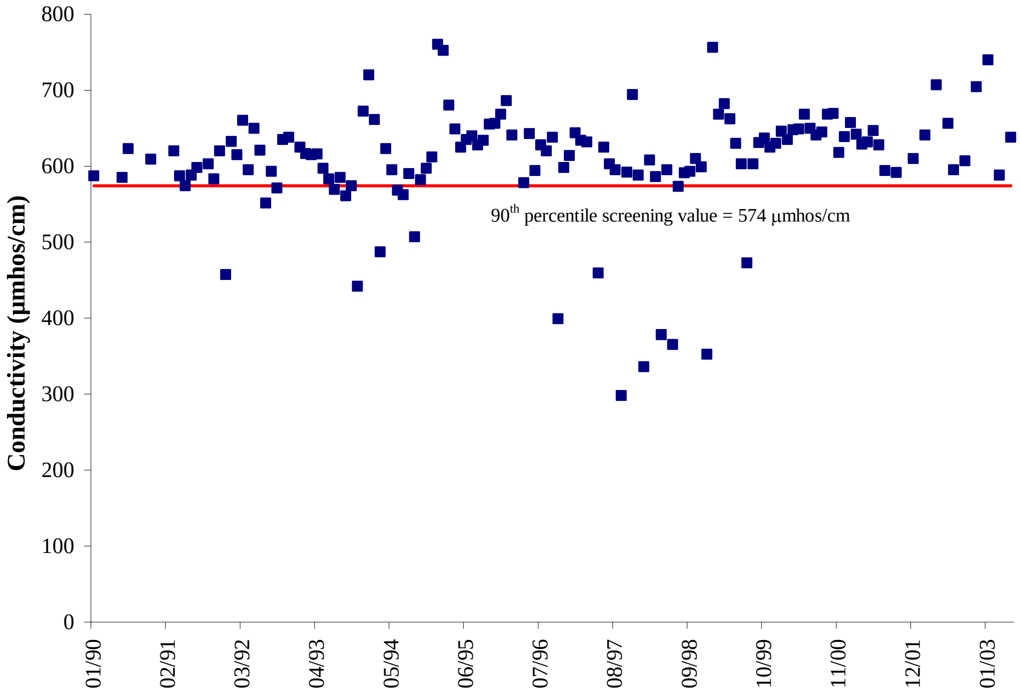

Figure 3.19 Conductivity measurements at VADEQ station 1BLEW002.91.

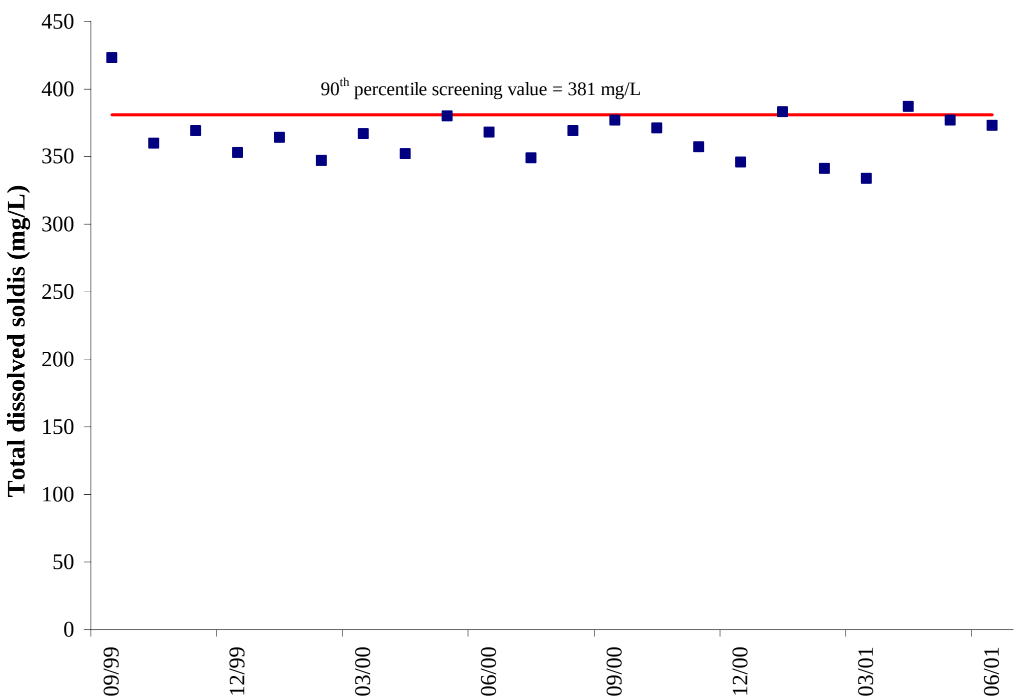

Figure 3.20 TDS concentrations at VADEQ station 1BLEW002.91.

3.3.4 Hydraulic Modification

When watersheds become more urbanized the percentage of impervious land area increases. Stormwater flows off impervious surfaces at much higher rates than from pervious land areas. In addition channelization and the armoring of the streambed and banks are also contributing factors. Therefore, larger volumes of water are delivered to streams in these watersheds in shorter time periods and the frequency of flash flooding is greatly increased. This can cause scouring of the stream bottom and a redistribution of the substrate, displacing the benthic macroinvertebrate fauna.

The displacement of habitat in the stream channel by flooding is one form of hydraulic modification. At the present time, the EPA does not consider this type of hydraulic modification a pollutant; as a result, pollutant allocations can't be established for it. It is necessary to discuss it because of its potential impact on the health of the benthic macroinvertebrate community. Figure 3.21 shows how urbanization affects the flow response to rainfall, as measured in Lewis Creek above the City of Staunton (where the degree of urbanization is very low) and downstream of the City. The large spikes in flow downstream of the City in response to rainfall events indicates that Lewis Creek has a high potential for hydraulic modifications that could negatively impact the benthic community.

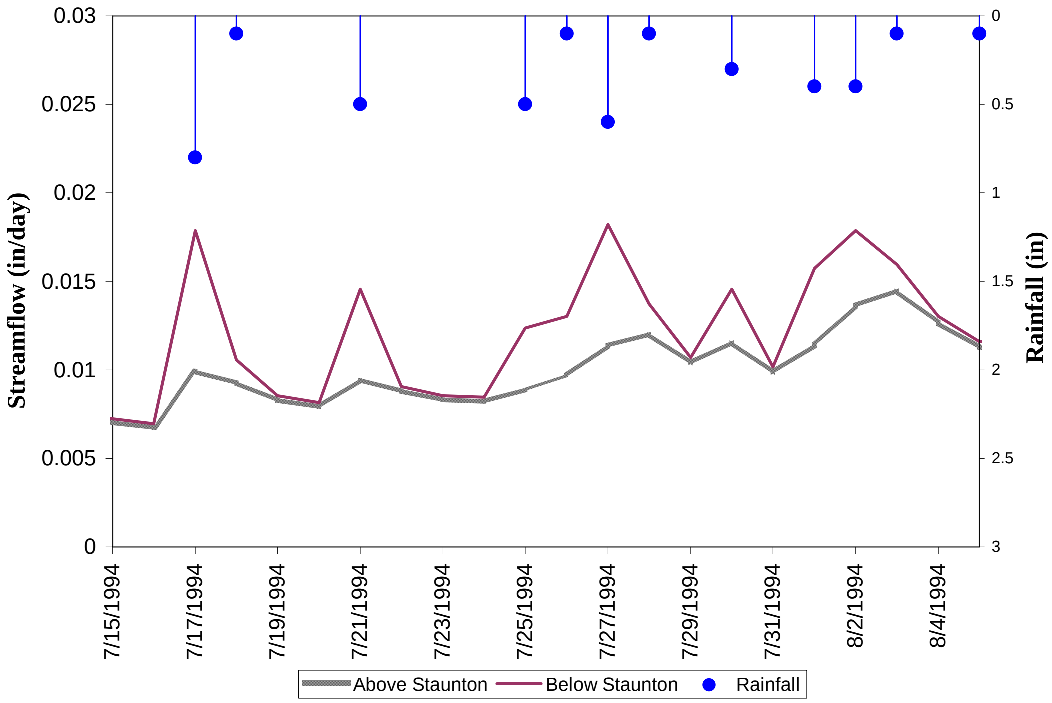

Figure 3.21 Stream flow response to rainfall in Lewis Creek above and below the City of Staunton.

The sediment modeling for Lewis Creek indicated that the watershed delivers a large amount of sediment to the stream. VADEQ benthic monitoring station 1BLEW006.95 is located at the southern end of the City and habitat scores indicative of sediment deposition (Embeddedness) are generally acceptable at this site. A closer inspection of Embeddedness scores reveals that during the recent drought years the average score was nine (marginal category); however, during 2003 and 2004 (years of above average rainfall and flash flooding in Staunton) the average score was 14, which is close to the optimal range. One conclusion that can be drawn from this is that, during periods of high rainfall and flash flooding, sediment is scoured from the riffle area at this monitoring station; during years of below normal rainfall, scouring is less frequent and sediment deposits can accumulate.

VADEQ benthic monitoring station 1BLEW000.61 is just over three miles downstream from the Staunton city limits and close to the confluence of Lewis Creek with Middle

River. The average Embeddedness score at this station was eight, signifying a marginal category and a very low score. Two of the seven scores fell into the ‘poor’ category. It is likely that the further the stream gets from the urban area and the closer to the mouth, flow velocities begin to decrease and the sediment load is deposited.

The data seem to confirm that hydraulic modification might be an issue at benthic monitoring station 1BLEW006.95. However, because hydraulic modification is not currently considered a pollutant by the EPA, TMDL allocations cannot be developed for it. In addition, until all of the pollutants discussed in the most probable stressor section are satisfactorily addressed, improvements in hydraulic condition alone may not improve benthic health. Nonetheless, plans to implement the Lewis Creek TMDL should consider practices that increase infiltration, reduce imperviousness, and slow runoff velocities. In addition to reducing the loads of most probable stressors (*e.g.*, sediment), such practices will reduce physical stresses from hydraulic modification.

3.3.5 Mercury

Mercury has been a concern in Lewis Creek because it was found in soil samples at the Staunton Metal Recyclers site and because 16 pounds of mercury could not be accounted for when City of Staunton’s former wastewater treatment plant (WWTP) was decommissioned in 1995. The WWTP was located downstream from the city in the vicinity of river mile 5.68 on Lewis Creek. The VADEQ performed fish tissue and sediment sampling at station 1BLEW005.24 in June 2001 just downstream from the former WWTP. The mercury concentration in the sediment was 1.6 mg/kg, which exceeds the PEC value of 1.06 mg/kg. The City of Staunton hired Environmental Investigations, Inc. to do a mercury sediment survey on Lewis Creek. On October 7th and 8th, 2004 10 sites on Lewis Creek were sampled for mercury; three of the sites were upstream of the WWTP. The majority of the results were below the minimum detection level (BDL) but one sample upstream of the former STP (near river mile 6.04) was 1.15 mg/kg, which exceeds the PEC level. The sediment sweep performed by MapTech and VADEQ on May 5, 2005 found mercury concentrations above the minimum detection level at six of the seven sites on Lewis Creek. However, the concentrations were very low, generally about 10% of the PEC value. The single site where mercury was not found was the control station upstream of the city (1BLEW009.19). Mercury was also found above the minimum detection level but at very low concentrations in Buttermilk Spring (1BBMS000.25) and Peyton Creek (1BPEY000.43). Results from the October 2005 follow up sediment sampling on four sites in Lewis Creek were similar, and no mercury was found at station 1BLEW009.19.

The majority of the mercury that is found in the aquatic environment is in an inorganic form and is not bioavailable and, therefore, does not harm aquatic life. The inorganic form of mercury can be converted to an organic or bioavailable form (referred to as methyl mercury) under favorable conditions. These conditions include an anaerobic environment, high nutrient concentrations, warm temperatures, and sulfur-oxidizing bacteria. The fish tissue sampling performed by VADEQ in June 2001 found mercury concentrations in the fish tissue to be BDL in two species and just above the minimum detection level in another species. This indicates that very little of the mercury in Lewis Creek is being converted to a bioavailable form.

MapTech and VADEQ performed clean metals sampling at three benthic monitoring stations in April and May 2005. The April sampling event was done when there had not been measurable rainfall for over a week. The May sampling was done during a measurable rainfall event. Methyl mercury was analyzed by the ultra trace method which can detect concentrations in the parts per trillion range (ng/L). Mercury was above the minimum detection level in the April samples at 1BLEW000.61 and 1BLEW006.95, but concentrations were well below the VADEQ WQS of 0.77 µg/L (Table 2.21). The May wet weather samples found mercury concentrations slightly higher at both monitoring stations but still well below the chronic WQS (Table 2.22). Concentrations at 1BLEW009.19 upstream from the city were BDL.

Possible sources of mercury in Lewis Creek are the abandoned WWTP downstream from the city and the former Staunton Metal Recyclers site at the southern end of the city. Soil concentrations of 16.4 mg/kg and 4.1 mg/kg were measured during a screening site investigation in 1991 and by AMEC, Inc. in 2004.

Total mercury was found above the PEC level on two occasions in sediment samples and sources of mercury exist in the watershed. However, in sediment samples that showed toxicity to *Chironomus tentans* in laboratory studies, mercury concentrations were 30% of PEC levels. Lead and total PAHs in those sediments were much higher with respect to their PEC levels and much more likely to have been the cause of the observed toxicity. Fish tissue samples collected in Lewis Creek show that the mercury contamination is not prevalent and significantly accumulating in the aquatic food web. Therefore, mercury is considered a possible stressor.

3.4 Probable Stressors

Table 3.3 Probable stressors in Lewis Creek.

Parameter	Location in Document
Sediment	section 3.4.1
Total PAHs	section 3.4.2
Lead	section 3.4.3

3.4.1 Sediment

Median Embeddedness habitat scores at VADEQ benthic monitoring station 1BLEW000.61 were in the marginal category. Out of the seven benthic surveys that have been performed by VADEQ at this monitoring station since 2002, two scores were in the 'poor' category. This metric provides an indication of how much fine sediment is surrounding the substrate in riffle areas and is one of the best indicators of sediment problems in riffle areas where the majority of the habitat is located. Marginal scores mean that 50 to 75% of the substrate in the riffle area is surrounded by fine sediment. Median Embeddedness habitat scores were in the sub-optimal category, which is considered acceptable, at VADEQ monitoring stations 1BLEW006.95 and 1BLEW009.19. The median Pool Sediment scores were in the same category as the Embeddedness scores at the three VADEQ benthic monitoring stations. Pool Sediment is a measure of the percentage of the stream bottom covered by sediment deposits in pool areas of the stream. Marginal Pool Sediment scores indicate that 30 – 50% of the stream bottom in pool areas is covered by sediment. The median Riparian Vegetation scores were in the marginal category at all three VADEQ benthic monitoring stations. This metric is important because it is a measure of the width of vegetation in the riparian zone. This vegetation helps filter both particulate and dissolved components that run off of the surrounding land during precipitation events. Marginal scores indicate a great deal of human impact in the riparian zone and the width of natural vegetation is only six to 12 meters.

Median total suspended solids (TSS) concentrations were very low but there was a spike of 1,067 mg/L (Figure 3.22). Neither the EPA nor the state of Virginia has a water quality standard for TSS; therefore, a 90th percentile screening value of 19 mg/L was used. Eighteen percent of the TSS values collected at 1BLEW002.91 exceeded the screening value. TSS concentrations are correlated with flow conditions. High concentrations typically reflect capturing high flow runoff events. These high values demonstrate that the stream is transporting significant amounts of sediment.

The %Haptobenthos metric which is part of the Macroinvertebrate Aggregated Index for Streams (MAIS) developed by Dr. Reese Voshell at Virginia Tech can be used as an indicator of excessive sediment at benthic monitoring stations. This metric was particularly low at VADEQ benthic monitoring station 1BLEW000.61 (30%). Haptobenthos are a functional group of benthic organisms that crawl and cling to rock surfaces and require a clean coarse substrate. Low percentages of organisms in the haptobenthos functional group indicate that sediment is covering and embedding bottom substrate and limiting the available suitable habitat for the organisms that require a clean coarse substrate (Voshell, 2002).

Sediment modeling for the Lewis Creek watershed found significantly more sediment being delivered to the downstream portion of the watershed than the middle (urban) and upstream portions. In addition the discussion on hydraulic modification in section 3.3.4 noted that during drought years embeddedness scores were lower (worse) at VADEQ monitoring station 1BLEW006.95 than during wetter years. In fact embeddeness scores at VADEQ monitoring station 1BLEW006.95 were about the same as the upstream non-impaired monitoring station, 1BLEW009.19. Overall embeddedness scores were lower at 1BLEW000.61 indicating that sediment is more of a problem in the downstream portions of the watershed where the stream is not impacted as much by hydraulic modification. Figure 3.23 shows embeddedness scores for the three VADEQ benthic monitoring stations in Lewis Creek.

Considering the low habitat embeddedness scores and low pool sediment scores at VADEQ monitoring station 1BLEW000.61, spikes in the TSS concentrations and the fact that the screening value was consistently exceeded, sediment is considered a probable stressor and will be one of the target pollutants used to address the benthic impairment in Lewis Creek.

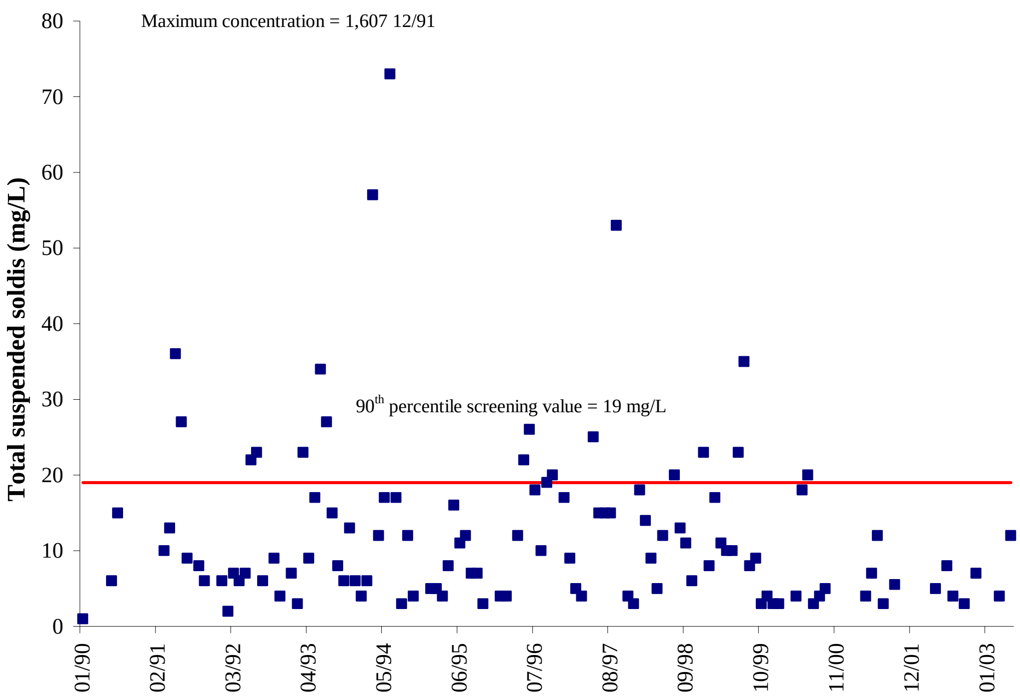

Figure 3.22 TSS concentrations at VADEQ station 1BLEW002.91.

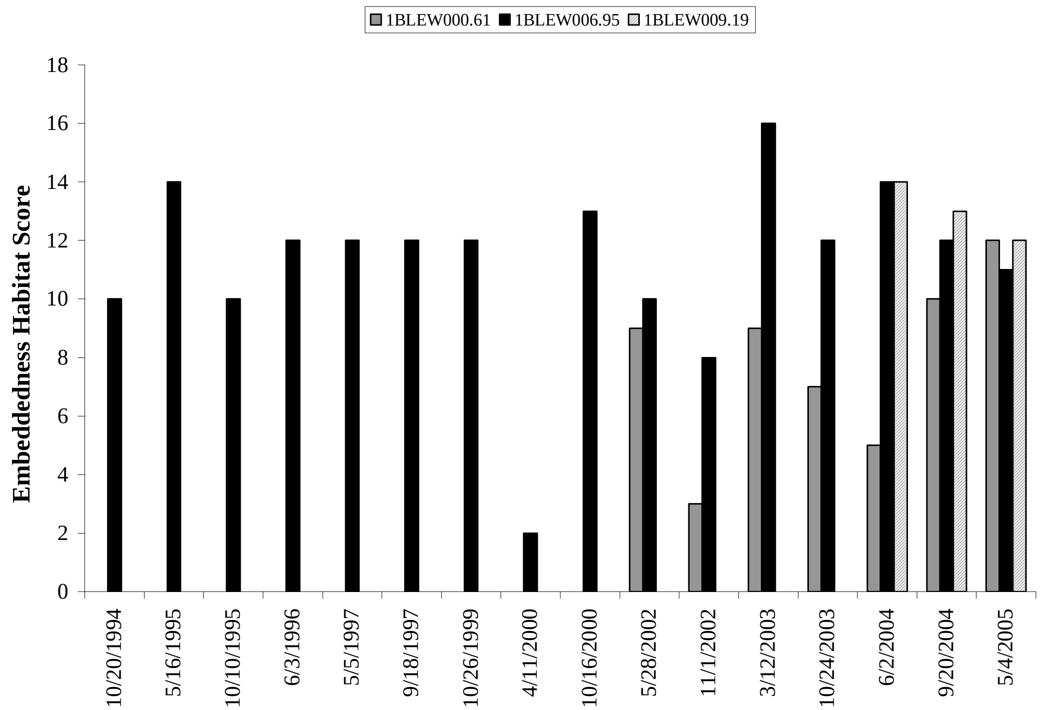

Figure 3.23 Embeddedness scores at three VADEQ monitoring stations on Lewis Creek.

3.4.2 Total PAHs (Polycyclic Aromatic Hydrocarbons)

PAHs are a group of chemicals that occur naturally in coal, crude oil, and gasoline. There are more than 100 different PAHs. PAHs generally occur as complex mixtures, not as single compounds. PAHs are also present in products made from fossil fuels, such as coal-tar pitch, creosote, and asphalt. When coal is converted to natural gas, PAHs can be released. Therefore, some coal-gasification sites may have elevated levels of PAHs. PAHs also can be released into the air during the incomplete burning of coal, oil, gas, or any organic substance. When the burning process is less efficient, more PAHs are given off. Forest fires and volcanoes can produce PAHs naturally. Once released into the aquatic environment, degradation by micro-organisms is often slow, leading to their accumulation in exposed sediments, soils, aquatic and terrestrial plants, fish, and invertebrates. In terms of human health, prolonged exposure to PAHs can have negative effects on individuals exposed to mixtures of PAHs. Many useful products such as mothballs, blacktop, and creosote wood preservatives contain PAHs. They are also found at low concentrations in some special-purpose skin creams and anti-dandruff shampoos that contain coal tars.

The 16 PAHs that are listed below are the most commonly sampled for the following reasons: there is more information available on these PAHs, they are suspected to be more harmful than some of the other PAHs, they exhibit harmful effects that are representative of the PAHs, there is a greater chance of exposure to these PAHs than to the others and, in relation to all of the PAHs analyzed. (Agency For Toxic Substances and Disease Registry, August 1995). Sixteen PAHs are currently identified on the USEPA National Priority List (NPL) hazardous waste list. The list is as follows:

Acenaphthene	benzo[b]fluoranthene	Fluoranthene
Acenaphthylene	benzo[g,h,i]perylene	Fluorene
Anthracene	benzo[j]fluoranthene	Indeno[1,2,3-c,d]pyrene
benz[a]anthracene	benzo[k]fluoranthene	Phenanthrene
Benzo[a]pyrene	chrysene	Pyrene
dibenz[a,h]anthracene		

High concentrations of several PAHs were found in a sediment sample taken by the VADEQ at station 1BLEW005.24 on June 21, 2001. Fluoranthene, phenanthrene, pyrene, benzoanthracene and chrysene all exceeded PEC concentrations developed for each compound (Table 2.19). The presence of these compounds is not surprising given the surrounding urban land use, the documented contamination at individual sites and documentation that waste coal tar buried on these sites has migrated to Lewis Creek (see sections 2.7.3 and 2.7.4). Table 3.4 shows the maximum reported concentrations, the date of collection, and pertinent comments.

Table 3.4 Maximum total PAH data from three sources in the Lewis Creek watershed.

Site	Date	Soil (mg/kg)	Lewis Creek Sediment (mg/kg)	Ground Water (μg /L)	Surface Water (μg /L)	Comments
Staunton Metal Recyclers (Klotz Brothers Junkyard)	1991	19.22	4.5	NA	NA	SSI by VDWM., 5/8/1991
Staunton Metal Recyclers (Klotz Brothers Junkyard)	2005	44.34	NA	NA	NA	Data from AMEC consulting, 12/2004 - 1/2005.
Beverly Exxon (Currently Downtown Citgo)	1996	NA	71.08*	267,500**	NA	From Hazard Ranking Report, 1997
Columbia Gas	1999	117.23	71.08*	7,510	NA	From Final SCR report. Data prior to 2002 site remediation work. Sediment value from upstream of CGV and Beverly Exxon.

* Data collected in 1996 and is the same data for both sites, ** 14.5 inches of free phase product was on top of the surface of this well. The total PAH concentration of the free phase product was 44,290,000 μg /L.

In order to confirm the extent of the problem, MapTech and VADEQ performed a sediment sweep on May 2, 2005 on 13 sites on Lewis Creek and significant tributaries (Table 2.26). The results confirmed the presence of high concentrations of PAH compounds in the sediment at three sites on Lewis Creek and one site on the Peyton Creek tributary (Table 2.29). Follow up sediment sampling was performed again on October 5, 2005 at the three benthic monitoring stations on Lewis Creek and station 1BLEW006.64. Additional sediment was collected for a sediment toxicity analysis at each station. The results of the sediment testing again confirmed the presence of high PAH concentrations in the sediment at two of the four stations on Lewis Creek, 1BLEW006.64 and 1BLEW006.95 (Table 2.34). More importantly, the sediment toxicity results indicated a statistically significant reduction in survival at stations

1BLEW000.61 and 1BLEW006.95 and a statistically significant reduction in growth at station 1BLEW006.64 (see section 2.5.4.4).

The observed toxicity may in part be explained by PAHs which toxicologically are additive (Swartz, 1999) and, even though the majority of the individual values were below PEC screening levels, there were enough compounds measured to have the potential for an additive effect. Not taken into account are the PAHs that were excluded from the analysis but yet may be present in the sediment and thus contributing to the observed effects. One method to determine the combined toxicity potential is to calculate a hazard quotient. A hazard quotient is calculated by dividing the measured result by the PEC or screening value and summing the results for all of the measured PAHs. Values greater than 1.0 can indicate a potentially toxic condition. Tables 2.30 and 2.35 show the stations where hazard quotients exceeded 1.0 in the May 2nd and Oct 5th sample results.

PAH concentrations in sediment are typically derived from three sources: naturally occurring in fossil fuels (petrogenic), those that result from the burning of organic matter or combustion (pyrogenic), and the transformation of precursors in the environment by rapid biological/chemical processes (biogenic PAH). PAHs resulting from the biogenic processes usually do not contribute nearly as much to the total mass of PAH in the sediment as the inputs from anthropogenic sources. It is possible to look at the ratios of various PAH compounds in the sediment to distinguish between petrogenic and pyrogenic sources (Neff et al., 2004). This is important because Lewis Creek has historically had both petrogenic and pyrogenic sources of PAHs contribute directly to the stream (section 2.6). One technique is to look at the ratio of phenanthrene and anthracene (PH/AN). Pyrogenic sources typically have ratios less than 5 while petrogenic sources are usually greater than 5. Similarly the ratio of fluoranthene to pyrene (FL/PY) is usually just below or greater than one (1) if the source is pyrogenic but, if it is substantially less than one, then the source is usually petrogenic (Neff et al., 2004). Table 3.5 provides examples of these two ratios from various sources and the average from the 2005 Lewis Creek sediments. The ratios for the Lewis Creek sediments clearly fall into the pyrogenic sources category and most closely match coal tar. PAH compound ratios are not a definitive indicator of sources, but are an additional diagnostic tool useful in narrowing potential sources. Therefore, the primary sources of PAHs in the Lewis Creek watershed sediments are most likely not from leaking petroleum storage tanks even though they may still contribute to the total loading measured in the stream. When the total PAH result from the VADEQ June 2001 sample is compared to the 2005 results for Lewis Creek there appears to be a decrease in concentrations (Figure 3.24). The red line in Figure 3.24 is the threshold effect concentration (TEC) and no adverse impacts on the benthic community are expected at concentrations below this level (MacDonald et al, 2000). This might be partially explained by the site remediation work done by Columbia Gas in 2002. Based on the sediment toxicity results, total PAH concentrations exceeding established hazard quotient guidelines and known sources in the watershed, total PAHs are considered probable stressors.

Table 3.5 Ratios of PAH isomers from various sources and the 2005 Lewis Creek watershed sediments

Source	PH/AN Ratio	FL/PY Ratio
PYROGENIC SOURCES[1]		
Auto exhaust soot	1.79	0.9
Highway dust	4.7	1.4
Urban Runoff	0.56-1.47	0.23-1.07
Coal tar	3.11	1.29
PETROGENIC SOURCES[1]		
No. 2 Fuel Oil & Diesel Fuel	>800*	0.38
No 4 Fuel Oil	11.8	0.16
Road paving asphalt	20	<0.11*
LEWIS CREEK WATERSHED SEDIMENTS		
Average of 2005 Sediment Results	3.14	1.24

[1]Source Neff et. al, 2004, *Anthracene or fluoranthene concentration was below detection limit

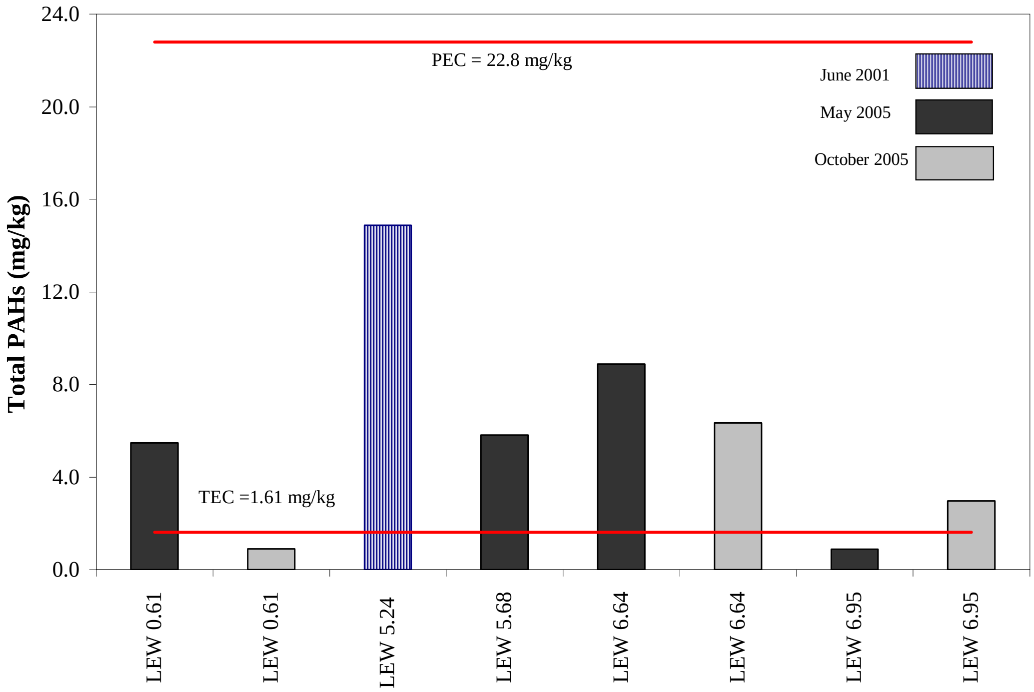

Figure 3.24 Total PAH concentrations in Lewis Creek sediment collected 6/2001, 5/2005, and 10/2005.

3.4.3 Lead

Sediment lead concentrations in Lewis Creek are high and concentrations steadily increase from downstream to upstream but drop sharply upstream of Staunton at VADEQ monitoring station 1BLEW009.19. Figure 3.25 shows the results of sediment lead collected in June 2001, May 2005, and October 2005. Concentrations are plotted against the PEC value of 128 mg/kg developed for lead (impacts to the aquatic biota can be expected when concentrations exceed the PEC). Also shown is the TEC (35.8 mg/kg) and concentrations below this value cannot be expected to adversely impact the aquatic biota (MacDonald et. al, 2000). The VADEQ has a hardness-based water quality standard for dissolved lead. (The standard is based on a formula dependent on the hardness value for the sample.) MapTech and VADEQ sampled Lewis Creek twice in 2005, once during base flow conditions and once during wet weather conditions at each of the three benthic monitoring stations. Dissolved lead was not found in the base flow sample collected in April 2005. However, concentrations above the minimum detection level were found in the wet weather sample collected in May 2005 at 1BLEW000.61 and

1BLEW006.95 (Table 2.22). These concentrations were well below the calculated chronic water quality standard.

Four significant sources of lead in the Lewis Creek watershed were discussed in section 2.6: Staunton Metal Recyclers (formerly Klotz Brothers Junkyard), Klotz Brothers Courtyard, Beverly Exxon, and Columbia Gas. Metals data has been collected from these four sites at various times since the late 1980s. Table 3.6 shows the maximum reported concentrations, the date of collection, and pertinent comments. It is important to note that in most cases, if remediation took place, it was preceded by data collection. Some data was collected following soil removal at the Klotz Brothers Courtyard site. The data seemed to confirm that lead had not migrated to adjacent property owners. No further data is available from the Columbia Gas site following remediation in 2002. Natural lead concentrations in soil vary from 30 – 700 mg/kg (Hatcher and Sayre, 1997). Soils data is available from three of the four sources discussed in section 2.6. It is clear from the soils values reported above that extremely high lead concentrations are present at every site that reported data, with the exception of the Klotz Brothers Courtyard site following Superfund remediation. Based on the fact that sediment lead exceeded a PEC level in Lewis Creek, a sediment sample indicating toxicity to *Chironomous Tentans* and the fact that there are unremediated sources that have significant amounts of lead in soil and/or ground water, lead is considered a probable stressor.

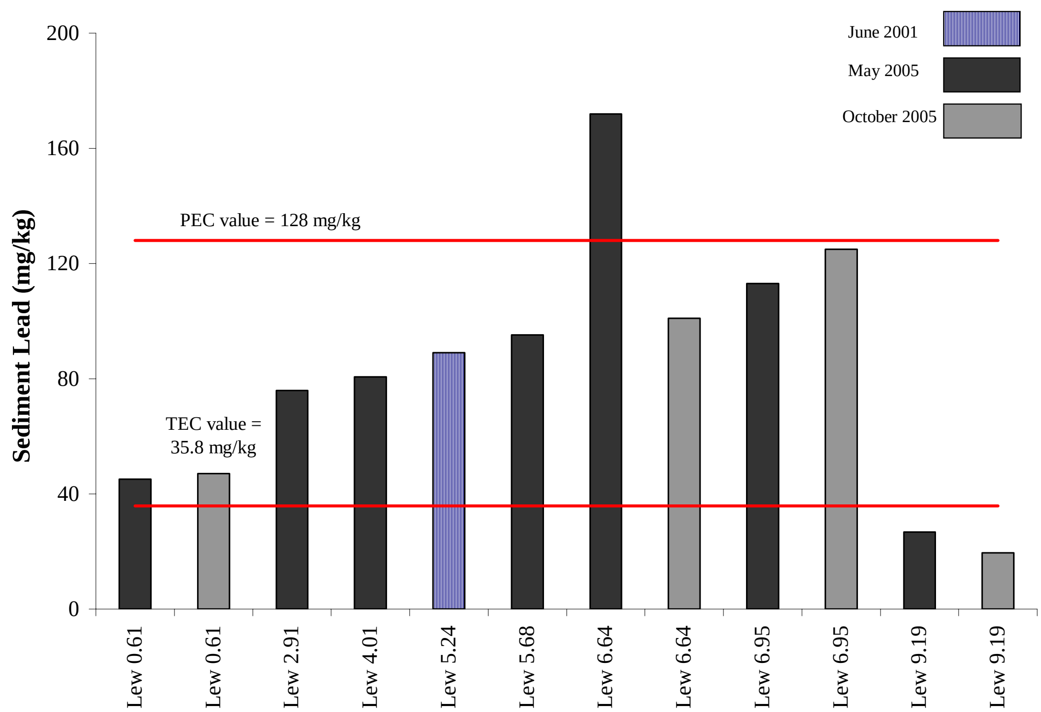

Figure 3.25 Lead concentrations in Lewis Creek sediment collected 6/2001, 5/2005 and 10/2005.

Table 3.6 Maximum lead data from four sources in the Lewis Creek watershed.

Site	Date	Soil (mg/kg)	Lewis Creek Sediment (mg/kg)	Ground Water (μg /L)	Surface Water (μg /L)	Comments
Staunton Metal Recyclers (Klotz Brothers Junkyard)	1991	3,020L	28.9	NA	9.0	SSI by VDWM., 5/8/1991
Staunton Metal Recyclers (Klotz Brothers Junkyard)	2005	2,480	NA	NA	NA	Data from AMEC consulting, 12/2004 – 1/2005.
Klotz Brothers Courtyard	1987	39,600	NA	NA	NA	Site inspection by VDWM, 1987
Klotz Brothers Courtyard (post remediation)	1996	472	NA	<50	<20	Hatcher and Sayre closure report, 1997
Beverly Exxon (Currently Downtown Citgo)	1996	NA	240*	448	ND	From Hazard Ranking Report, 1997
Columbia Gas	1999	3,200	230	76	B	From Final SCR report. Data prior to 2002 site remediation work. Sediment value from upstream of CGV and Beverly Exxon.

*Lab spike recovery not within control limits. Sample had low bias actual value expected to be higher, ND Not Detected, B Compound detected but there was sample blank interference, NA Not available, L Reported value low actual value is higher.

3.5 Summary

There are three probable stressors impacting Lewis Creek: sediment, lead and total PAHs. Habitat assessment scores, specific benthic metrics (%Haptobenthos), sediment modeling, comparisons to reference watersheds and visual observations point toward excessive sedimentation as one probable stressor. Evidence from sediment toxicity tests, high sediment concentrations in relation to PEC values and significant historical sources suggest that sediment toxicity from PAHs and lead is a probable stressor. These three stresssors may be exerting varying levels of influence throughout the impaired reach of Lewis Creek. Sediment toxicity due to PAHs and lead appear to exert more influence near downtown Staunton (station 1BLEW006.95) and decreases in influence downstream as the distance from primary PAH and lead sources increases. Habitat stress due to excessive sedimentation appears to increase downstream (station 1BLEW000.61) and decrease upstream, where hydraulic condition scours and flush the stream bottom. To address the benthic impairment in Lewis Creek, each of these probable stressors will be addressed by developing TMDLs for sediment, total PAHs in sediment and lead in sediment.

3.6 Trend and Seasonal Analyses

In order to improve the TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on water quality parameters that were identified as possible or probable stressors. A Seasonal Kendall Test (Gilbert, 1987) was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in dissolved oxygen levels during a particular season or month. A seasonal analysis of water chemistry results was conducted using the Mood's Median Test (Minitab, 1995). This test was used to compare median values of water quality in each season.

Only VADEQ monitoring station 1BLEW002.91 had enough data to perform trend and seasonality analyses. The results of the Seasonal Kendall Test used to detect long-term trends are shown in Table 3.7. The results of the Mood's Median Test for water quality data from Lewis Creek are shown in Tables 3.8 through 3.12. Values in seasons with the same median group letter are not significantly different from each other at a 95% significance level. For example, if winter and spring are in median group "B", they are not significantly different from each other.

Table 3.7 Trend Analysis results for water quality data at VADEQ monitoring station 1BLEW002.91 in Lewis Creek.

Water Quality Constituent	Trend
BOD_5	No Trend
Conductivity	3.400 µmhos/year
NO_3-N, Total	-0.023
Total Organic Solids	1.333
Total Organic Carbon	No Trend
Total dissolved solids (TDS)	--
Total kjeldahl nitrogen (TKN)	No Trend
Total Suspended Solids	-0.400

"--": insufficient data. Trend values equal slope from the Seasonal Kendall Test. Positive values indicate an increase. Negative values indicate a decrease over time.

Table 3.8 Summary of Mood's Median Test on Conductivity at 1BLEW002.91.

Season	Mean	Min	Max	Median Group	
Winter	639.11	336.00	760.00		B
Spring	602.72	365.00	707.00	A	B
Summer	588.29	298.00	668.00	A	
Fall	599.33	352.00	704.50	A	B

Table 3.9 Summary of Mood's Median Test on NO_3-N at station 1BLEW002.91.

Season	Mean	Min	Max	Median Group	
Winter	1.82	1.37	2.48		B
Spring	1.51	0.22	2.17	A	
Summer	1.58	0.65	2.31	A	
Fall	1.65	1.02	2.00	A	B

Table 3.10 Summary of Mood's Median Test on BOD_5 at station 1BLEW002.91.

Season	Mean	Min	Max	Median Group	
Winter	1.47	1.00	4.00	A	B
Spring	1.90	1.00	3.00	A	B
Summer	1.18	1.00	2.00	A	
Fall	2.24	1.00	5.00		B

Table 3.11 Summary of Mood's Median Test on TSS at station 1BLEW002.91.

Season	Mean	Min	Max	Median Group	
Winter	9.26	1.00	57.00	A	
Spring	19.97	4.00	155.00		B
Summer	12.80	3.00	53.00	A	B
Fall	92.00	3.00	1607.00	A	

Table 3.12 Summary of Mood's Median Test on TKN at station 1BLEW002.91.

Season	Mean	Min	Max	Median Group	
Winter	0.24	0.10	0.70	A	
Spring	0.38	0.10	1.00		B
Summer	0.27	0.10	0.80	A	
Fall	0.29	0.10	2.60	A	

3.7 Reference Watershed Selection

A reference watershed approach was used to estimate the necessary load reductions that are needed to restore a healthy aquatic community and allow the streams in the Lewis Creek watershed to achieve their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar attributes, land use, soils, stream characteristics (*e.g.*, stream order, corridor, slope), area (not to be less than half, or more than twice, the size of the impaired watershed), and is in the same ecoregion as the impaired watershed. The modeling process uses load rates in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current load rates and determine what reductions are necessary to meet the load rates of the non-impaired watershed.

A total of six potential reference watersheds from the Appalachians ecoregion were selected for analysis that would lead to the selection of a reference watershed for the Lewis Creek sediment TMDL (Figure 3.26). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, land use, soils, slope, stream order, watershed size). Based on these comparisons, and after conferring with state and regional VADEQ personnel, the Upper Opequon Creek watershed (located in Frederick County) was selected as the reference watershed for Lewis Creek. Tables 3.13 and 3.14 show Lewis Creek and the potential reference streams along with the information used to compare them.

The Upper Opequon Creek watershed was the best fit based on land use, erodibility, soils and slope.

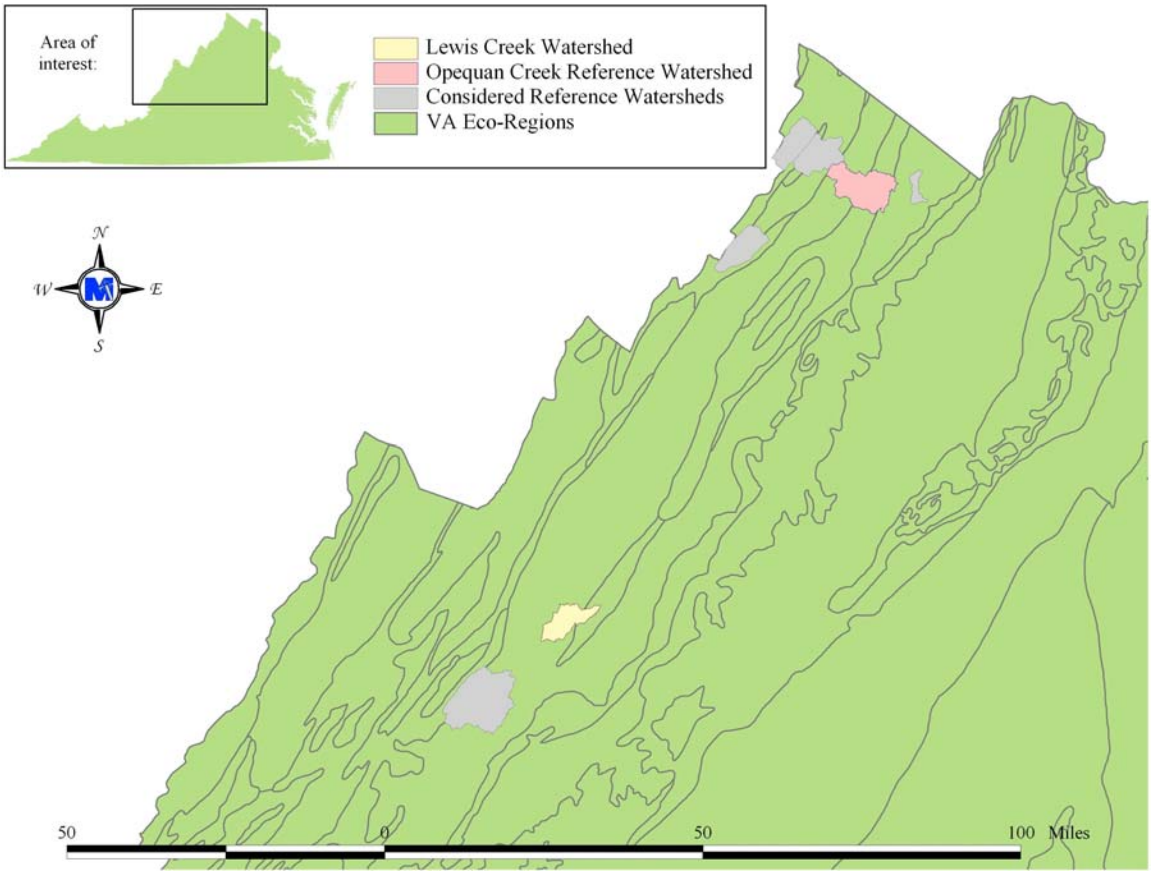

Figure 3.26 Location of selected and potential reference watersheds.

Table 3.13 **Reference watershed selection for Lewis Creek – Part 1.**

Watershed	Lewis Creek	Upper Opequon Creek	Hays Creek	Chapel Run	Hogue Creek
Station		1AOPE036.13	2-HYS001.41	1BCPL000.95	1AHOC006.23
Area (acres)	17,683.2000	33,128.11	50,858.62	4,760.00	21,083.45
Stream Order	2	2	4	1	3
Land Use (acres):					
11 - Open Water	39.81	129.88	20.02	7.12	85.84
21 - Low Intensity Residential	3,053.64	1,253.61	62.71	2.67	91.18
22 - High Intensity Residential	30.91	130.32	0.00	0.00	0.00
23 - Commercial/Industrial/Transportation	656.27	351.82	4.23	0.00	81.62
31 - Bare Rock/Sand/Clay	0.00	0.00	0.00	0.00	0.00
32 - Quarries/Strip Mines/Gravel Pits	0.00	6.67	0.00	0.00	10.67
33 - Transitional	78.95	430.77	33.14	1.11	124.98
41 - Deciduous Forest	2,973.80	7,214.55	20,544.83	599.12	15,210.59
42 - Evergreen Forest	384.29	532.40	1,738.87	43.14	338.03
43 - Mixed Forest	1,651.91	3,231.99	4,106.21	608.68	1,519.37
81 - Pasture/Hay	8,291.81	18,074.97	23,514.18	3,391.89	3,458.83
82 - Row Crops	439.67	1,598.76	809.05	89.18	146.78
85 - Urban/Recreational Grasses	69.61	86.06	0.00	0.00	0.00
91 - Woody Wetlands	0.45	43.81	1.33	2.22	8.01
92 - Emergent Herbaceous Wetlands	10.90	42.03	27.35	16.46	8.01
Slope (degrees):					
(Area Weighted Value)	5.93	3.57	9.98	2.61	8.49
Aspect (degrees)					
(Area Weighted Value)	175.5806	165.57	184.02	17588.49%	17875.84%

Table 3.13 Reference watershed selection for Lewis Creek – Part 1 (cont.).

Watershed	Lewis Creek	Upper Opequon Creek	Hays Creek	Chapel Run	Hogue Creek
Soils MUID (%):					
VA001	10.70%	0.00%	2.09%	0.00%	0.00%
VA002	16.70%	21.47%	0.00%	19.49%	0.11%
VA003	69.50%	0.00%	86.60%	0.00%	27.08%
VA004	3.10%	0.00%	0.00%	0.00%	0.00%
VA005	0.00%	0.00%	8.28%	0.00%	7.54%
VA016	0.00%	0.00%	3.04%	0.00%	0.00%
VA066	0.00%	51.78%	0.00%	0.00%	62.68%
VA069	0.00%	26.75%	0.00%	80.51%	2.58%
Soil Characteristics					
Hydrologic Group (avg):	2.3789	2.6998	2.2302	2.2859	2.666
Erodibility Kffactor (weighted value)	0.2513	0.2479	0.2554	0.2846	0.2394
Available Water Capacity (weighted value)	0.1244	0.1048	0.1325	0.1539	0.096
Unsat SMC	3.4594	3.1388	3.5026	4.0486	2.8657
EcoRegion % (IV)					
Northern Limestone/Dolomite Valleys	82.60%	50.38%	0.00%	100.00%	25.92%
Northern Sandstone Ridges	0.00%	0.00%	8.90%	0.00%	10.67%
Northern Shale Valleys	17.40%	49.62%	91.10%	0.00%	63.41%

Table 3.13 Reference watershed selection for Lewis Creek - Part II.

Watershed	Lewis Creek	Back Creek	Cedar Creek
Station		1ABAR046.01	1BCDR027.54
Area (acres)	17,683.2000	17,367.69	19,019.94
Stream Order	2	2	2
Land Use (acres):			
Open Water	39.81	110.31	12.90
Low Intensity Residential	3,053.64	54.26	9.79
High Intensity Residential	30.91	1.56	0.00
Commercial/Industrial/Transportation	656.27	30.69	0.00
Bare Rock/Sand/Clay	0.00	0.00	0.00
Quarries/Strip Mines/Gravel Pits	0.00	188.36	0.00
Transitional	78.95	34.25	47.81
Deciduous Forest	2,973.80	13,638.96	14,794.94
Evergreen Forest	384.29	234.40	290.44
Mixed Forest	1,651.91	1,558.51	2,462.30
Pasture/Hay	8,291.81	1,399.06	1,303.21
Row Crops	439.67	105.64	85.62
Urban/Recreational Grasses	69.61	0.00	0.00
Woody Wetlands	0.45	4.89	0.22
Emergent Herbaceous Wetlands	10.90	8.23	2.89
Slope (degrees) (Area Weighted Value):	5.93	10.81	12.48
Aspect (degrees) (Area Weighted Value)	175.5806	211.09	17518.20%
Soils MUID (%):			
VA001	10.70%	0.00%	0.00%
VA002	16.70%	0.00%	0.00%
VA003	69.50%	10.26%	0.00%
VA004	3.10%	0.00%	0.00%
VA005	0.00%	22.79%	80.37%
VA016	0.00%	0.00%	0.00%
VA066	0.00%	66.95%	19.63%
VA069	0.00%	0.00%	0.00%
Soil Characteristics:			
Hydrologic Group (avg):	2.3789	2.7553	2.6287
Erodibility Kffactor	0.2513	0.2257	0.1959
Available Water Capacity	0.1244	0.0843	0.0825
Unsat SMC	3.4594	2.4975	1.8753
EcoRegion % (IV)			
Northern Limestone/Dolomite Valleys	82.60%	0.00%	0.00%
Northern Sandstone Ridges		41.34%	59.00%
Northern Shale Valleys		58.66%	41.00%

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Lewis Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration, and model application for sediment are discussed.

4.1 Sediment GWLF Model

4.1.1 Modeling Framework Selection - GWLF

A reference watershed approach was used in this study to develop a benthic TMDL for sediment for the Lewis Creek watershed. As noted in Chapter 3, sediment was identified as a probable stressor for Lewis Creek. A watershed model was used to simulate sediment loads from potential sources in Lewis Creek and the Opequon Creek reference watershed. The model used in this study was the *Visual Basic™* version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow et al., 2002 and BSE, 2003. A numeric endpoint was based on an unit-area loading rate calculated for the respective reference watershed. The TMDL was then developed for the impaired watershed based on this endpoint and the results from load allocation scenarios. All sediment loads are in metric tons per year (Mg/yr or t/yr).

The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungaged watersheds. It was chosen for this study as the model framework for simulating sediment. GWLF is a continuous simulation spatially lumped model that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model can simulate dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources of pollution. The model considers flow input from both surface and groundwater. Land use classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, stream-bank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. Runoff is simulated based on the Soil Conservation Service's Curve Number Method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1983; Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of the runoff.

For execution, GWLF uses three input files for weather, transport, and nutrient loads. The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in April and ending in September. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types, but does include urban sediment buildup rates.

4.1.2 Model Setup

Watershed data needed to run GWLF used in this study were generated using Geographical Information System (GIS) spatial coverage, local weather data, streamflow data, literature values, and other data. Watershed boundaries for the impaired stream segment and the selected reference watershed were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The reference watershed outlet for Upper Opequon Creek was located at biological monitoring station 1AOPE036.13. For TMDL development, the total area for the Upper Opequon Creek reference watershed was equated with the area of the Lewis Creek watershed. To accomplish this, the area of land use categories in the Upper Opequon Creek reference watershed was proportionally decreased based on the percentage of land use distribution. As a result, the watershed area for Upper Opequon Creek was decreased to be equal to the watershed area for the Lewis Creek watershed.

The GWLF model was developed to simulate runoff, sediment and nutrients in ungaged watersheds based on landscape conditions such as land use/landcover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept to estimate runoff and sediment from different pervious areas in the watershed (Li, 1975; England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by land use activity (*e.g.*, farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses land use categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil land use topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the effect of varying soil-topographic conditions by land use entities. A description of model parameters is given in section 4.1.2.1 followed by a description of how parameters and other data were calculated and/or assembled.

4.1.2.1 Description of Model Input Parameters

The following description of GWLF model input parameters was taken from *Benthic TMDL for Stroubles Creek in Montgomery County, Virginia* (BSE, 2003).

Hydrologic Parameters

Watershed-Related Parameter Descriptions

- *<u>Unsaturated Soil Moisture Capacity (SMC):</u> The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*

- *<u>Recession Coefficient (/day):</u> 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.*

- *<u>Seepage Coefficient (/day):</u> The seepage coefficient represents the amount of flow lost as seepage to deep storage.*

Running the model for a 12-month period prior to the chosen period during which loads were calculated, initialized the following parameters.

- *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 and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar-year basis.*

- *ET_CV: Composite evapo-transpiration 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 a regional coefficient used in Richardson's equation for calculating daily 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.*

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 and Wischmeier and Smith (1978), and Hession et al.*

- *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, 2002)

- *% Developed land: percentage of the watershed with urban-related land uses - defined as all land…*

- *Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*

- *Stream length: calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*

- *Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling in meters. ``*

4.1.2.2 Streamflow and Weather Data

The Upper Opequon Creek GWLF model was calibrated for hydrology using observed flow data from USGS station #01615000 Opequon Creek near Berryville, VA. The Lewis Creek GWLF model was calibrated for hydrology using output from the calibrated HSPF model used during the Middle River TMDL development (VADCR, 2003). Daily precipitation and temperature data were obtained from National Climatic Data Center (NCDC) weather stations in Virginia (Table 4.1).

Table 4.1 Weather stations used in GWLF models for Lewis Creek and Upper Opequon Creek.

Watershed	Weather Stations (station_id, location, Thiessen weights)	Data Type	Data Period
Lewis Creek	Station id: 448062 Location: Staunton Sewage Treatment Plant Thiessen weight: 1	Daily Precipitation & Temperature	4/1/1992–3/31/1998
Upper Opequon Creek	Station id: 449186 Location: Winchester 7 SE Thiessen weight: 0.3322; Station id: 449181 Location: Winchester Winc Thiessen weight: 0.6604; Station id: 440670 Location: Berryville Thiessen weights: 0.0074	Daily Precipitation & Temperature	4/1/1992–3/31/1998

4.1.2.3 Land use/landcover classes

Land use classes are used as the basic response unit for performing runoff and erosion calculations and summarizing sediment transport. The National Land Cover Data (NLCD) produced cooperatively between USGS and EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA).

Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital land use coverage was developed identifying up to 21 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources (when available) including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc-second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data.

The land area of the Lewis Creek watershed is approximately 17,561 acres, with pasture/hay and forest accounting for the majority of the watershed (Table 4.2). Approximate proportions of specific land uses are 47% pasture/hay, 29% forest, urban land uses 22%, and others accounting for the remaining 2%.

Table 4.2 Land use and area of Lewis Creek watershed.

Land use	Acreage
Commercial	652.63
Forest	5,010.16
High Intensity Residential (HIR)	30.91
Industrial sites:	
Klotz Brothers Courtyard (KBC)	0.59
Beverly Exxon (BE)	0.47
Columbia Gas (CG)	1.16
Staunton Metal Recyclers (SMR)	3.31
Low Intensity Residential (LIR)	3,035.12
Pasture/Hay	8,188.37
Row Crops	435.37
Transitional	80.09
Urban Grass	71.93
Water	39.81
Wetland	11.34
Total	**17,561.2**

The land use types were grouped into 17 categories based on similarities in hydrologic features (Table 4.3) and pollution source type. Urban land use categories (residential, commercial, and the industrial sites) were further subdivided into a pervious (PER) and an impervious (IMP) component. The percentage of impervious and pervious area was assigned from data provided in VADCR's online 2004 NPS assessment database (VADCR, 2004).

Table 4.3 Land use categories for the Lewis Creek watershed.

TMDL Land use Categories	**Pervious / Impervious (Percentage)**	**Land use Classifications** (MRLC Class No. where applicable)
Commercial	Pervious (50%) Impervious (50%)	Commercial/Industrial/Transportation (23)
Transitional	Pervious (100%)	Transitional (33)
Low Intensity Residential (LIR)	Pervious (75%) Impervious (25%)	Low Intensity Residential (21)
High Intensity Residential (HIR)	Pervious (60%) Impervious (40%)	High Intensity Residential (22)
Forest	Pervious (100%)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Pasture Improved	Pervious (100%)	Pasture/Hay (81)
Pasture Unimproved	Pervious (100%)	Pasture/Hay (81)
Pasture Overgrazed	Pervious (100%)	Pasture/Hay (81)
Hay	Pervious (100%)	Pasture/Hay (81)
Row Crops High Tillage	Pervious (100%)	Row Crops (82)
Row Crops Low Tillage	Pervious (100%)	Row Crops (82)
Klotz Brothers Courtyard (KBC)	Impervious (100%)	Delineated from aerial photos and site maps
Beverly Exxon (BE)	Impervious (100%)	Delineated from aerial photos and site maps
Columbia Gas (CG)	Pervious (30%) Impervious (70%)	Delineated from aerial photos and site maps
Staunton Metal Recyclers (SMR)	Pervious (90%) Impervious (10%)	Delineated from aerial photos and site maps
Water	Pervious (100%)	Open Water (11)
Wetlands	Pervious (100%)	Woody Wetlands (91) Emergent Herbaceous Wetland (92)

The pasture/hay category was subdivided into four sub-categories: hay, improved pasture, overgrazed pasture, and unimproved pasture. The percentage of the pasture/hay acreage that was assigned to each category was based on field observations and VADCR's online 2004 NPS assessment database (VADCR, 2004). Cropland was also sub-divided into two sub-categories: low tillage and high tillage. The percentage assigned to each cropland sub-category was obtained from VADCR's online database (VADCR, 2004). Each of the four industrial sites were assigned separate land uses. The land area draining to these sites were delineated. The land uses in these drainage areas were assigned unique names.

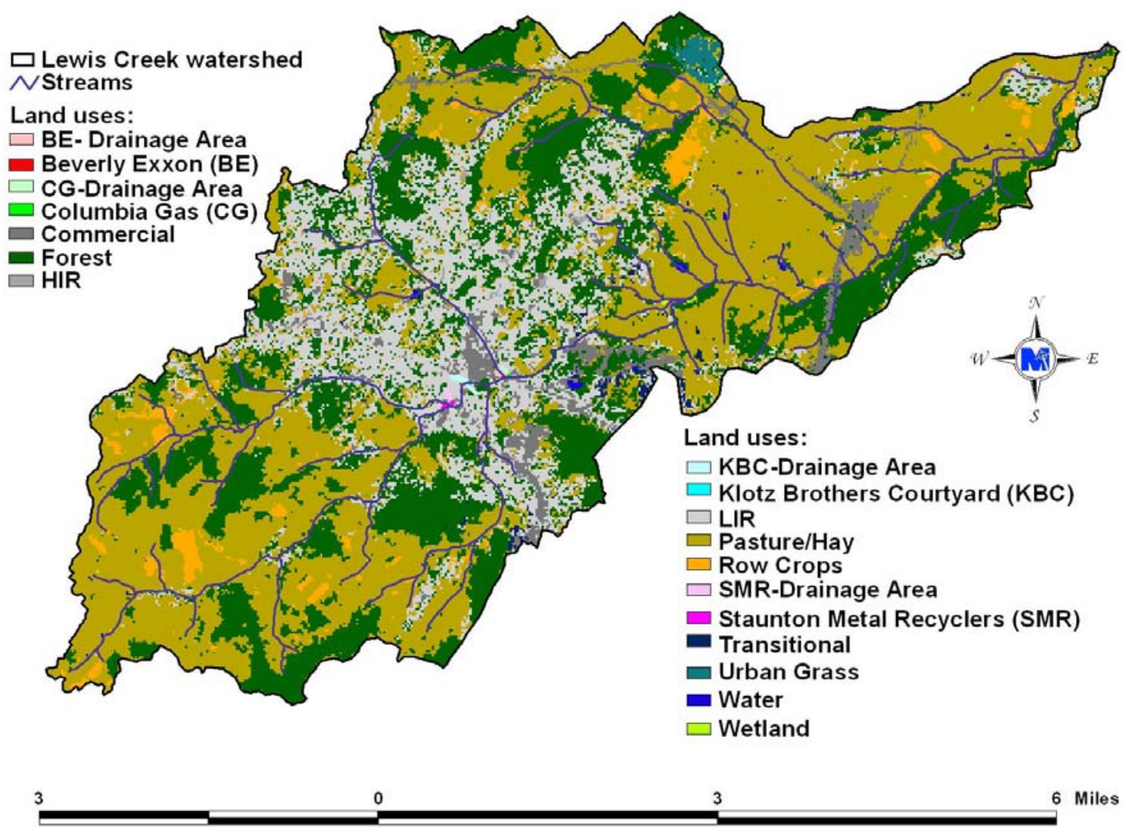

Figure 4.1 Land uses in the Lewis Creek watershed.

The weighted C-factor for each land use category was estimated following guidelines given in Wischmeier and Smith (1978), GWLF User's Manual (Haith et al., 1992), and Kleene (1995).

Table 4.4 Land use distributions for Lewis Creek and reference watershed Upper Opequon Creek.

Sediment Source	Lewis Creek (ha)	Upper Opequon Creek (ha)
Pervious Area:		
Water	16.11	64.89
LIR	921.22	374.09
HIR	7.51	24.35
Commercial	132.06	69.98
Transitional	32.41	174.15
Quarries	0.00	25.38
Forest	2,027.58	5,132.36
Pasture Improved	785.72	1,593.32
Pasture Unimproved	785.72	1,593.32
Pasture Overgrazed	785.72	1,593.32
Hay	932.66	3,457.63
Row Crops High Tillage	35.86	392.60
Row Crops Low Tillage	140.33	301.04
Urban Grass	29.11	34.83
Wetland	4.59	38.43
Staunton Metal Recyclers (SMR)	1.21	
Klotz Brothers Courtyard (KBC)	0.07	
Beverly Exxon (BE)	0.12	
Columbia Gas (CG)	0.40	
Impervious Area:		
LIR	307.07	124.70
HIR	5.00	16.24
Commercial	132.06	69.98
Staunton Metal Recyclers (SMR)	0.13	
Klotz Brothers Courtyard (KBC)	0.24	
Beverly Exxon (BE)	0.19	
Columbia Gas (CG)	0.33	
Total	**7,082.98**	**15,080.63**

4.1.2.4 Sediment Parameters

Sediment parameters include USLE parameters K, LS, C, and P, sediment delivery ratio, and buildup and loss function for impervious surfaces. The product of the USLE parameters, KLSCP, is entered as input to GWLF. The Kf factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. Soils data for Lewis Creek and Upper Opequon Creek watersheds were obtained from the State Soil Geographic (STATSGO) database for Virginia (NRCS, 2004). The area-weighted Kf-factor by land use category was calculated using GIS procedures. Land slope was calculated from USGS Digital Elevation Models (DEMs) using GIS techniques. The length-of-slope was based on VirGIS procedures given in VirGIS Interim Reports (Shanholtz et al., 1988). The VirGIS length-of-slope values were developed in cooperation with local SCS Office personnel for much of Virginia. The area-weighted slope and length-of-slope were calculated by land use category using GIS procedures. The area-weighted LS factor was calculated for each land use category using procedures recommended by Wischmeier and Smith (1978). The average soil solum thickness and corresponding available soil moisture capacity were obtained from soils data and used to estimate the unsaturated soil moisture capacity.

4.1.2.5 Pervious and Impervious Surfaces

Each urban area was sub-divided into pervious areas (USLE sediment algorithm applies) and impervious areas (where an exponential buildup-washoff algorithm applies). The percentage of pervious and impervious area was calculated from data obtained from VADCR’s 2004 NPS assessment database (VADCR, 2004).

Daily sediment build-up rate on impervious surfaces (which represents the daily amount of dry deposition from the air on days without rainfall) was assigned using GWLF manual (Haith et al. 1992) guidance.

4.1.2.6 Sediment Delivery Ratio

The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratios for impaired and reference watersheds were calculated as an inverse function of watershed size (Evans et al., 2001).

4.1.2.7 SCS Runoff Curve Number

The runoff curve number is a function of soil type, antecedent moisture conditions, and cover and management practices. The runoff potential of a specific soil type is indexed by the Soil Hydrologic Group (HG) code. Each soil-mapping unit is assigned HG codes that range in increasing runoff potential from A to D. The soil HG code was given a numerical value of 1 to 4 to index HG codes A to D, respectively. An area-weighted average HG code was calculated for each land use/land cover from soil survey data using GIS techniques. Runoff curve numbers (CN) for soil HG codes A to D were assigned to each land use/land cover condition for antecedent moisture condition II following GWLF guidance documents and SCS, 1986 recommended procedures. The runoff CN for each land use/land cover condition was then adjusted based on the numerical area-weighted soil HG codes.

4.1.2.8 Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of streams, total length of natural stream channel, percent-developed land, mean stream depth, watershed soil erodibility, watershed average slope, land use, and watershed area. Stream length, watershed land use, slope, and soils were all obtained from GIS maps of the watersheds.

4.1.2.9 Evapotranspiration Cover Coefficients

Evapotranspiration (ET) cover coefficients are entered by month. Monthly ET cover coefficients were assigned each land use/land cover condition (from MRLC classification) following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each sediment source class.

4.1.3 Source Representation

The source area identified as the primary contributor to sediment loading in the Lewis Creek watershed involves surface runoff. The sediment process is a continual process but is often accelerated by human activity. An objective of the TMDL process is to minimize the acceleration process. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

4.1.3.1 Surface Runoff

During runoff events (natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.*, forest, agricultural fields, lawns, etc.). Rainfall intensity, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, mining operations, timber harvesting, and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by various factors (*e.g.*, the deposition from wind erosion and vehicular traffic).

4.1.3.2 Point Sources

VPDES point sources were identified in the Lewis Creek watershed with discharge specifics listed in Table 4.5. Permitted load was calculated as the maximum annual modeled runoff times a maximum TSS concentration.

Table 4.5 VPDES point source facilities and permitted TSS loads from the Lewis Creek watershed.

Lewis Creek Point Sources		Existing Conditions			
VPDES ID	**Name**	**Permit Discharge (MGD)**	**Disturbed Area (ha)**	**Conc. (mg/L)**	**TSS (t/yr)**
Mixed Concrete General Permit					
VAG110073	Augusta Blocks LLC		3.17	50	0.13
VAR050778	Augusta Blocks LLC	0.039		30	1.62
VAG110071	Transit Mixed Concrete		1.62	38	0.08
Non Metallic Mining General Permit					
VAG840030	Appomattox Lime Co-Belmont Quarry & Staunton Lime		1.74	50	0.07
VAG840030	Appomattox Lime Co-Belmont Quarry & Staunton Lime	0.76		30	31.52
Industrial Stormwater General Permit					
VAR050826	Dixie Gas & Oil Corp Bulk Plant		2.63	50	0.11
VAR051333	Ord's Auto Parts, LLC		70.82	50	2.94
Single Family Home Sewage Treatment Permit					
VAG401882	Weaver's Garage, Inc.	0.001		30	0.04
VAG401072	Residence	0.001		30	0.04
Construction Stormwater Permit					
VAR100570	Project #0262-007-101,C502		28.33	50	1.18
VAR103788/VAR101703	VDOT Verona Resid 0262-007-101,C503, B609,B614,B615		45.33	50	1.88
VAR102097	Disposal Area 2 - VDOT NFO 02262 007 101 C503		3.52	50	0.15
VAR103916	Triangle Services Retail Building - Staunton		0.93	50	0.04
VAR104649	Harrington Place		1.94	50	0.08
Total					**39.88**

4.1.4 Stream Characteristics

The GWLF model does not support in-stream flow routing. An empirical relationship developed by Evans et al., 2001 and modified by BSE, 2003 requires total watershed stream length of the natural channel and the average mean depth for making estimates of channel erosion. This calculation excludes the non-erosive hardened and piped sections of a stream.

4.1.5 Selection of Representative Modeling Period

Selection of the calibration period was based on two factors: availability of data and the need to represent critical hydrological conditions. Mean daily discharge at USGS Gaging Station #01625000 (Middle River at Grottoes) was available from October 1970 to September 2000. The modeling period was selected to include the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Middle and South River segments (including Lewis Creek) on the *1998 303(d) Total Maximum Daily Load Priority List and Report*.

The mean daily flow and precipitation for each season were calculated for the period October 1970 through September 2000. This resulted in 30 observations of mean flow and precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The representative period was chosen such that the mean and variance of each season in the modeled period was not significantly different from the historical data (Table 4.6, Figures 4.2 and 4.3).

Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for hydrologic calibration was 10/1/1992 to 9/30/1997.

Table 4.6 Comparison of modeled period to historical records.

	Mean Flow (cfs)				Precipitation (in/day)			
	Fall	**Winter**	**Summer**	**Spring**	**Fall**	**Winter**	**Summer**	**Spring**
	Historical Record (1971 - 2000)							
Mean	304	548	392	198	0.096	0.093	0.111	0.118
Variance	47,275	86,384	31,314	18,500	0.002	0.002	0.001	0.002
	Calibration Time Period (10/92-9/97)							
Mean	208	799	529	107	0.093	0.123	0.114	0.127
Variance	27,672	74,689	9,551	71,502	0.001	0.002	0.004	0.004
	p-values							
Mean	0.131	0.034	0.008	0.230	0.430	0.061	0.456	0.392
Variance	0.324	0.504	0.128	0.012	0.298	0.558	0.044	0.058

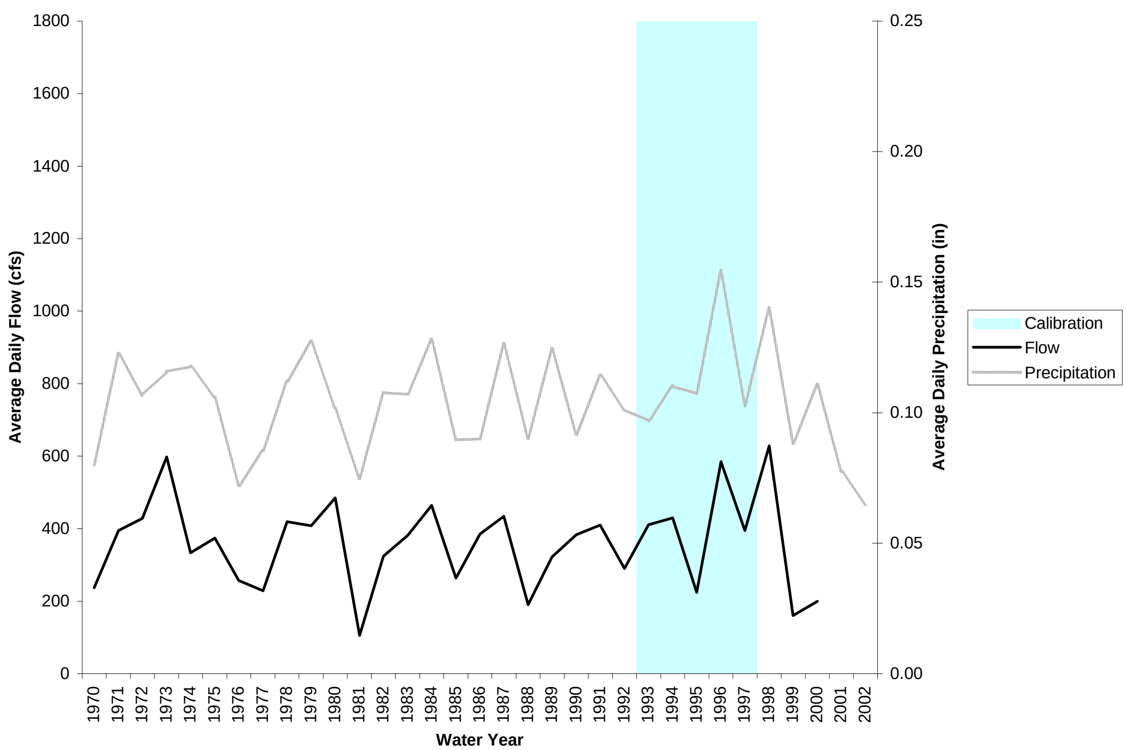

Figure 4.2 Hydrologic calibration and validation periods compared to annual flow and precipitation records.

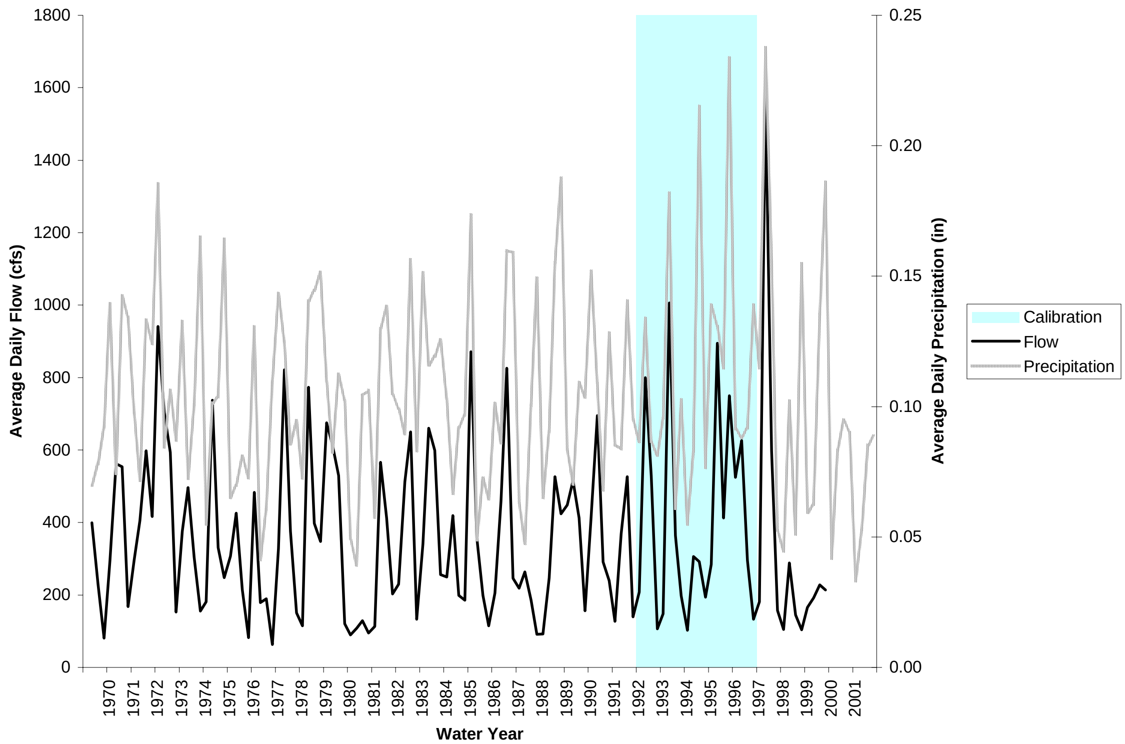

Figure 4.3 Hydrologic calibration and validation periods compared to seasonal flow and precipitation records.

4.1.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.*, seasonal and spatial variability of crop cover conditions, runoff curve number, etc.). Sensitivity analyses were run on the runoff curve number (CN) and the combined erosion factor (KLSCP), which combines the effects of soil erodibility, land slope, land cover, and management practices (Table 4.8). For a given simulation, the model parameters in Table 4.7 were set at the base value except for the parameter being evaluated. The parameters were adjusted to -10% and 10% of the base value. Results are listed in Table 4.8. The results show that while CN changes have a large impact on runoff and sediment load, the KLSCP factor only impacts sediment load. The results tend to reiterate the need to carefully evaluate conditions in the watershed and follow a systematic protocol in establishing values for model parameters.

Table 4.7 Base watershed parameter values (area-weighted) used to determine hydrologic and sediment response for Lewis Creek.

Sediment Source	Lewis Creek CN	Lewis Creek KLSCP
Pervious Area:		
Water	100.00	0.00000
LIR	64.60	0.00703
HIR	63.34	0.00564
Commercial	67.38	0.00240
Transitional	86.17	0.15759
Forest	60.06	0.00008
Pasture/Hay	65.57	0.05232
Pasture Improved	66.63	0.00624
Pasture Unimproved	73.33	0.03603
Pasture Overgrazed	82.03	0.07205
Hay	63.63	0.00624
Row Crops High Tillage	79.96	0.23697
Row Crops Low Tillage	76.74	0.09293
Urban Grass	64.26	0.00004
Wetland	67.39	0.00177
Staunton Metal Recyclers (SMR)	63.34	0.00070
Klotz Brothers Courtyard (KBC)	63.34	0.00090
Beverly Exxon (BE)	63.34	0.00273
Columbia Gas (CG)	72.56	0.00093
Impervious Area:		
LIR	98.00	0.00701
HIR	98.00	0.00564
Commercial	98.00	0.00240
Staunton Metal Recyclers (SMR)	98.00	0.00070
Klotz Brothers Courtyard (KBC)	98.00	0.00090
Beverly Exxon (BE)	98.00	0.00273
Columbia Gas (CG)	98.00	0.00093

Table 4.8 Sensitivity of model response to changes in selected parameters.

Model Parameter	Parameter Change (%)	Total Runoff Volume (%)	Total Sediment Load (%)
CN	10	6.24	12.42
CN	-10	-4.68	-15.46
KLSCP	10	0	9.21
KLSCP	-10	0	-9.21

4.1.7 Model Calibration Processes

Although the GWLF model was originally developed for use in ungaged watersheds, calibration was performed to ensure that hydrology was being simulated accurately. This process was necessary to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soils, land use, and topographic data. Parameters that can be adjusted during calibration included the recession constant, the evapotranspiration cover coefficients, the unsaturated soil moisture storage, and the seepage coefficient.

Streamflow in Lewis Creek is not continuously monitored; therefore, the hydrology component of the model was calibrated based on output for Lewis Creek from the calibrated HSPF model for the larger Middle River watershed (calibrated at USGS gage #01625000). The Upper Opequon Creek model was calibrated using data from USGS station #01615000 at the outlet.

Model calibrations were considered very good for total runoff volume. Monthly fluctuations were variable but were still reasonably good considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.*, Tetra Tech, 2001 and BSE, 2003). The final calibration results for Lewis Creek are given in Figures 4.4 and 4.5 with accuracy of fit statistics given in Table 4.9. The final calibration results for Opequon Creek are given in Figures 4.6 and 4.7 with accuracy of fit statistics also given in Table 4.9.

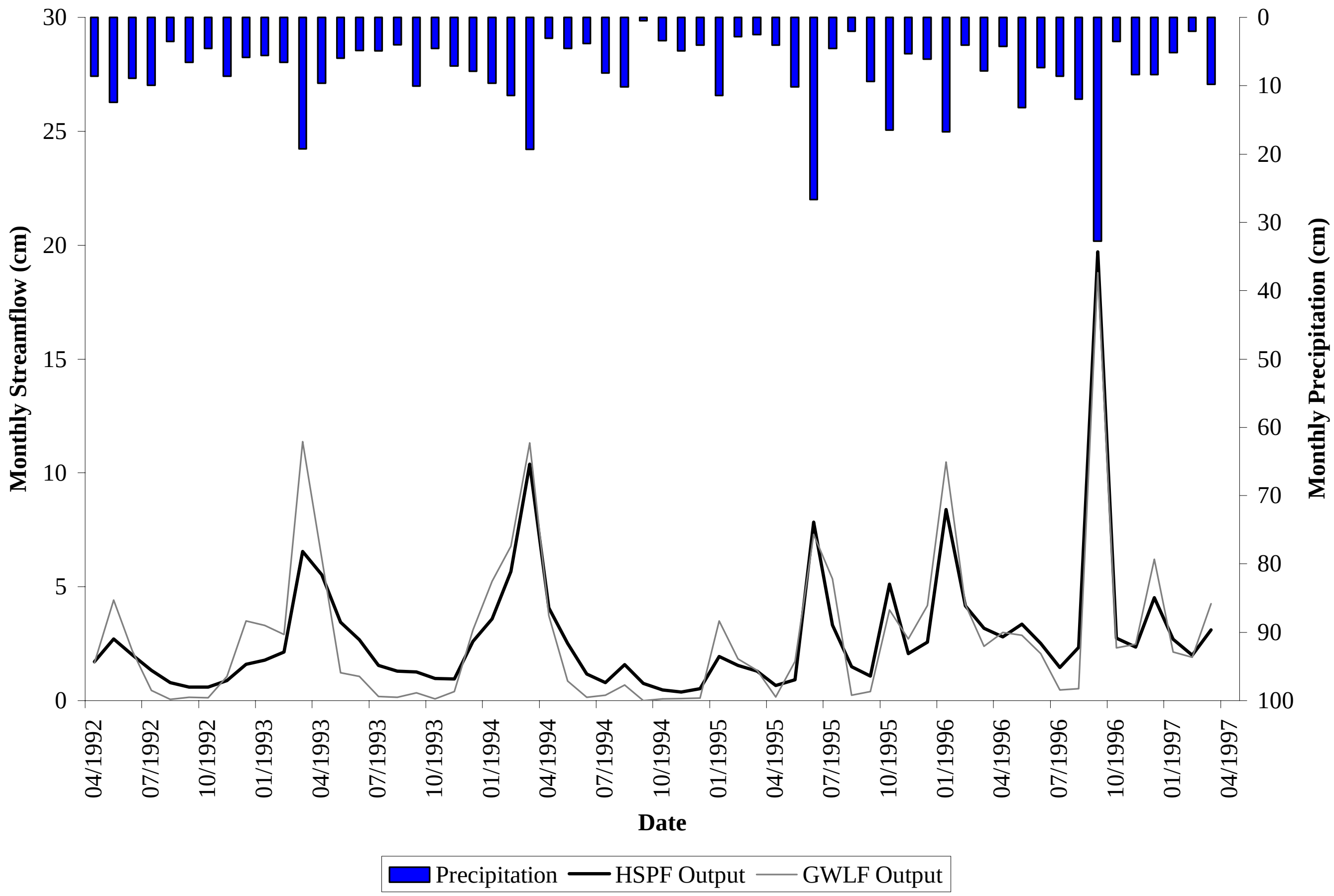

Figure 4.4 **Comparison of GWLF simulated streamflow and HSPF simulated streamflow for Lewis Creek watershed.**

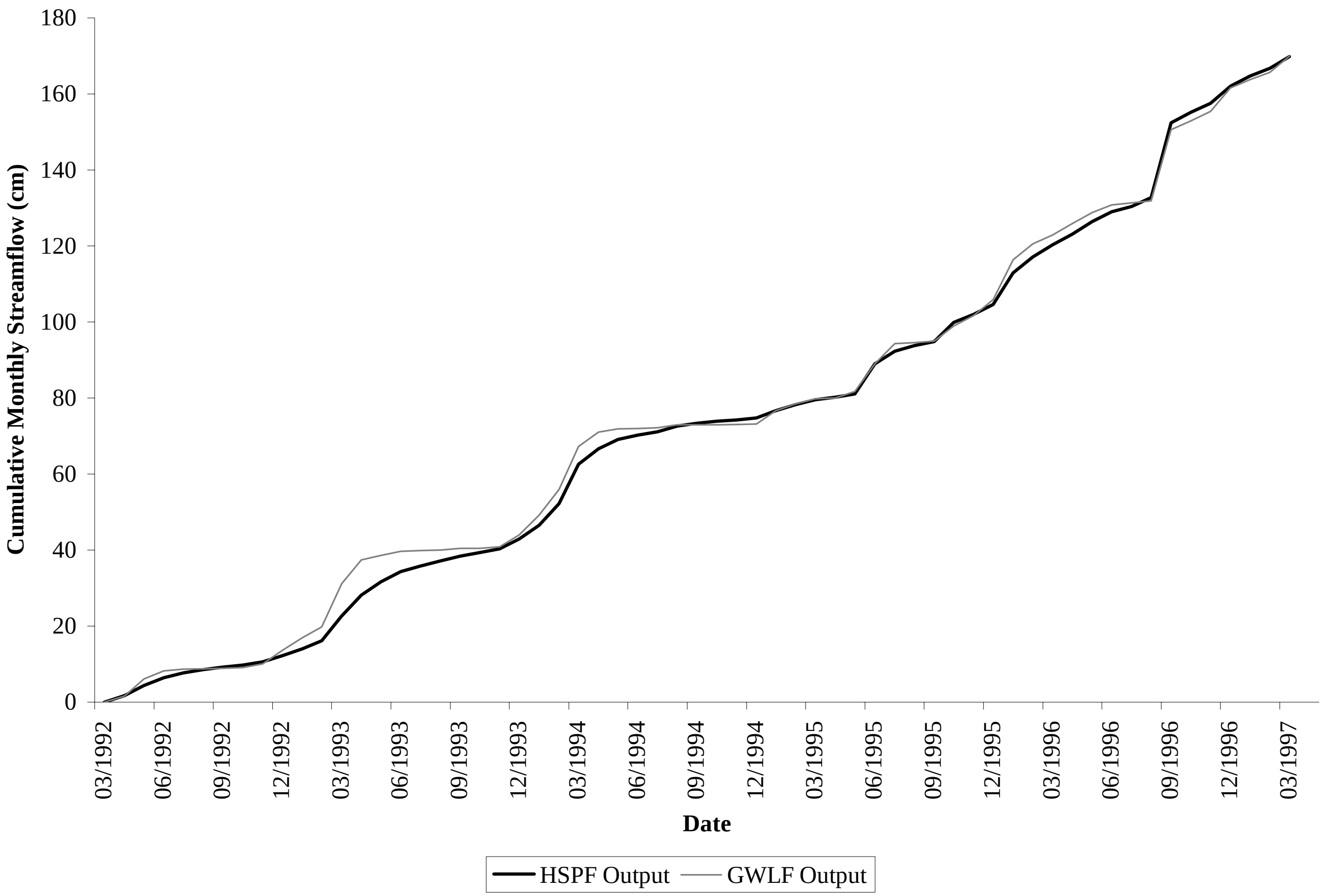

Figure 4.5 Comparison of cumulative monthly streamflow from GWLF and HSPF for Lewis Creek watershed.

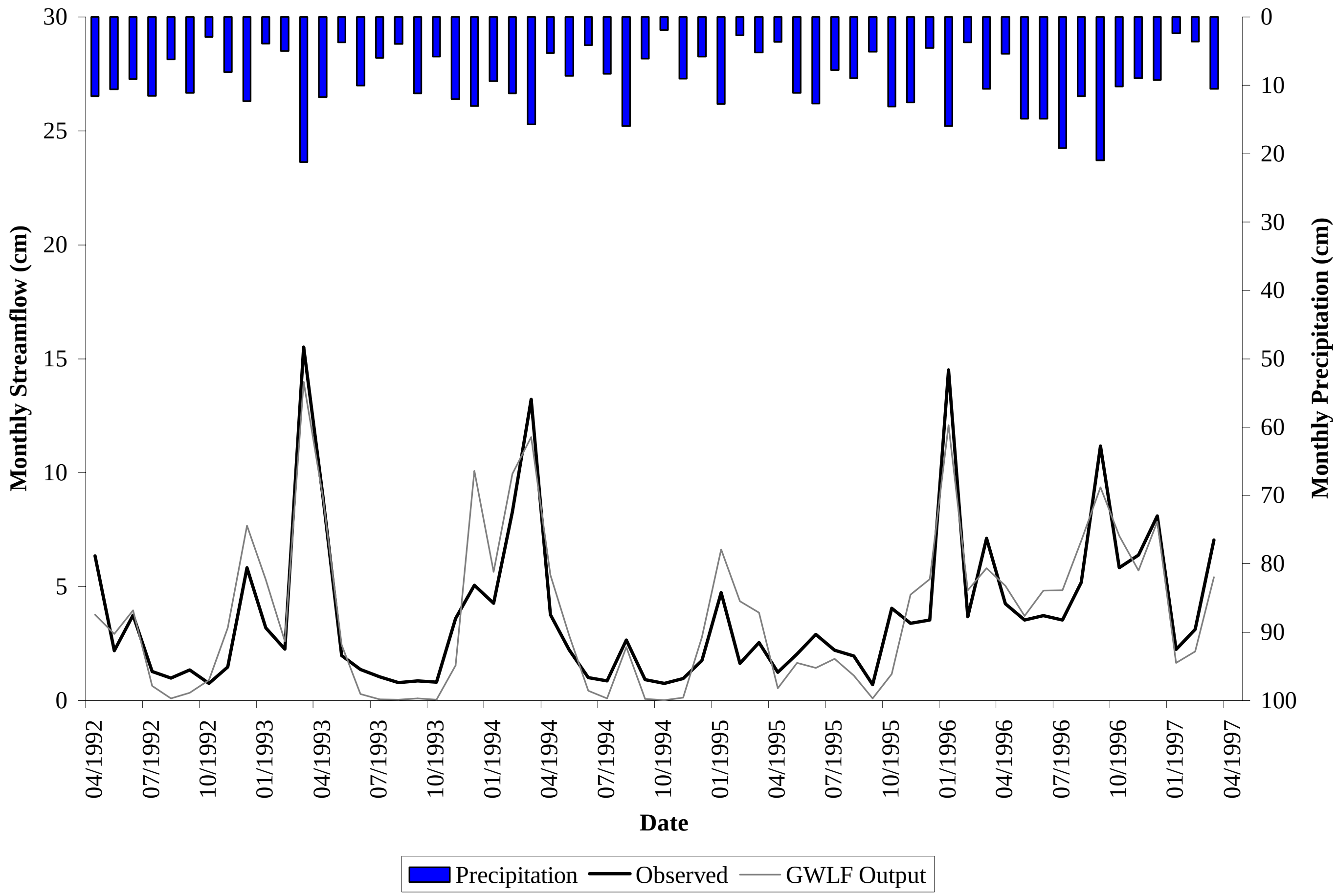

Figure 4.6 **Comparison of GWLF simulated streamflow and Observed streamflow for Upper Opequon Creek watershed.**

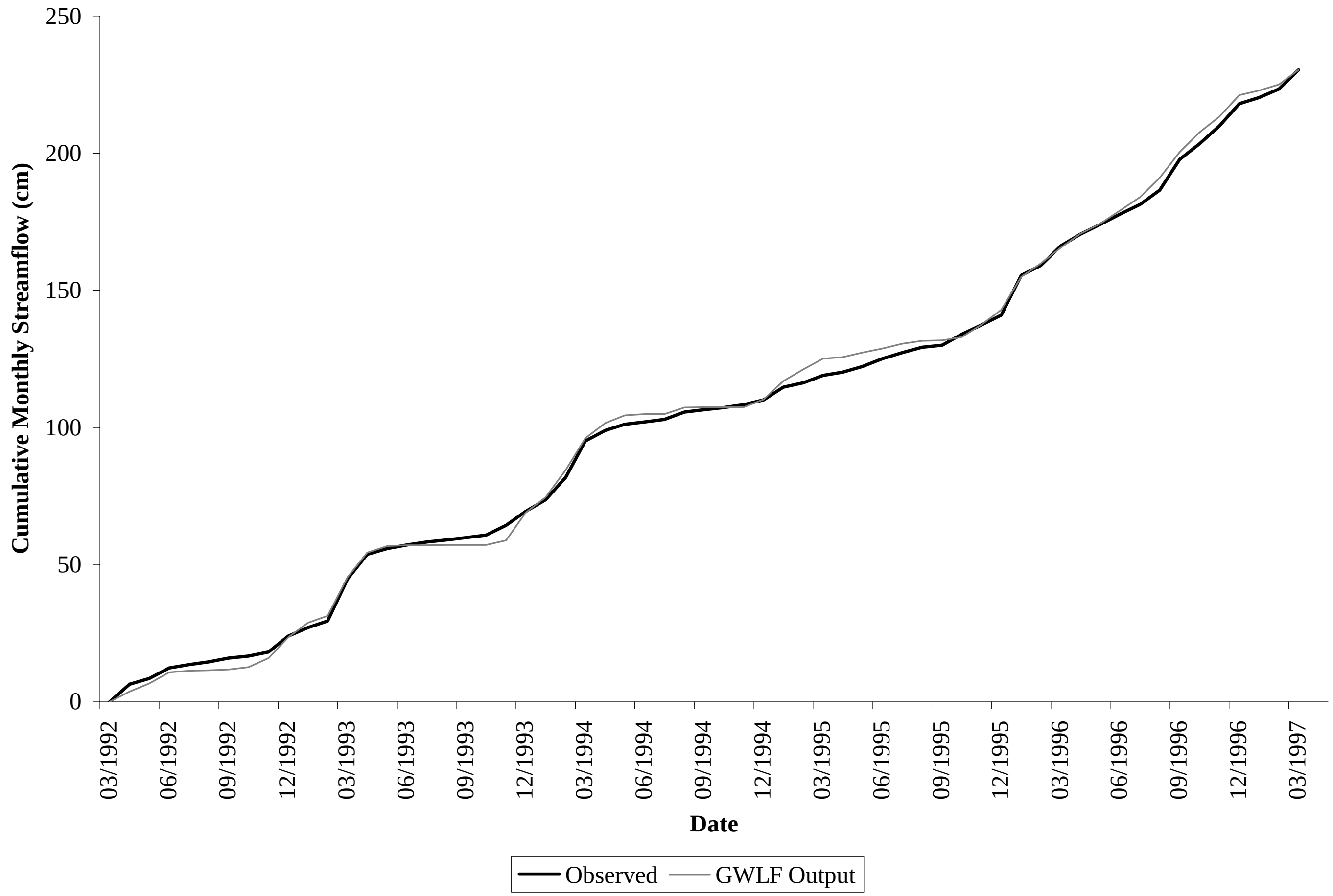

Figure 4.7 Comparison of cumulative monthly streamflow from GWLF and Observed for Upper Opequon Creek watershed.

Table 4.9 GWLF flow calibration statistics.

Watersheds	Simulation Period	R^2 (Correlation value)	Total Volume Error (Sim-Obs)
Lewis Creek	4/1/1992 – 3/1/1997	0.938	0.060
Upper Opequon Creek	4/1/1992 – 3/1/1997	0.909	0.005

4.1.8 Existing Conditions

A listing of parameters from the GWLF transport input files that were finalized during hydrologic calibration for conditions existing at the time of impairment are given in Tables 4.10 through 4.13. Watershed parameters for Lewis Creek and reference watershed Opequon Creek are given in Table 4.10. Monthly evaporation cover coefficients are listed in Table 4.11.

Table 4.10 Lewis Creek and reference watershed Upper Opequon Creek GWLF watershed parameters for existing conditions.

GWLF Watershed Parameter	Units	Lewis Creek	Upper Opequon Creek
Recession Coefficient	Day^{-1}	0.0655	0.0655
Seepage Coefficient	Day^{-1}	0.322	0.02
Sediment Delivery Ratio	---	0.1398	0.1174
Unsaturated Water Capacity	(cm)	13	13
Erosivity Coefficient (Apr-Sep)	---	0.31	0.31
Erosivity Coefficient (Oct-Mar)	---	0.12	0.12
Fraction of developed land	---	0.275	0.0487
Livestock density	(AU/ac)	0.0176	0.198
Area-weighted soil erodibility	---	0.257	0.217
Area weighted runoff curve number	---	68.94	74.58
Total Stream Length	(m)	96,450	32,429
Mean channel depth	(m)	0.792	0.975

Table 4.11 Lewis Creek and reference watershed Upper Opequon Creek GWLF monthly evaporation cover coefficients for existing conditions.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
ET_CV	0.82	0.83	0.85	0.85	0.85	0.77	0.76	0.75	0.75	0.75	0.77	0.8

Table 4.12 lists the area-weighted USLE erosion parameter and runoff curve number by land use erosion source areas for Lewis Creek and the reference watershed Upper Opequon Creek. The area adjustment for the reference watershed is listed in Table 4.13.

Table 4.12 Lewis Creek and reference watershed Upper Opequon Creek GWLF land use parameters for existing conditions.

Sediment Source	Lewis Creek		Upper Opequon Creek	
	CN	**KLSCP**	**CN**	**KLSCP**
Pervious Area:				
Water	100.00	0.00000	100.00	0.00000
LIR	64.60	0.00703	72.56	0.00140
HIR	63.34	0.00564	72.56	0.00071
Commercial	67.38	0.00240	72.56	0.00078
Transitional	86.17	0.15759	87.56	0.06602
Quarries			87.56	0.37490
Forest	60.06	0.00008	68.34	0.00004
Pasture/Hay	65.57	0.05232		
Pasture Improved	66.63	0.00624	72.56	0.00212
Pasture Unimproved	73.33	0.03603	77.89	0.01222
Pasture Overgrazed	82.03	0.07205	85.23	0.02444
Hay	63.63	0.00624	69.56	0.00212
Row Crops High Tillage	79.96	0.23697	82.45	0.05991
Row Crops Low Tillage	76.74	0.09293	80.23	0.02349
Urban Grass	64.26	0.00004	72.56	0.00306
Wetland	67.39	0.00177	68.95	0.00002
Staunton Metal Recyclers (SMR)	63.34	0.00070		
Klotz Brothers Courtyard (KBC)	63.34	0.00090		
Beverly Exxon (BE)	63.34	0.00273		
Columbia Gas (CG)	72.56	0.00093		
Impervious Area:				
LIR	98.00	0.00701	98.00	0.00140
HIR	98.00	0.00564	98.00	0.00071
Commercial	98.00	0.00240	98.00	0.00078
Staunton Metal Recyclers (SMR)	98.00	0.00070		
Klotz Brothers Courtyard (KBC)	98.00	0.00090		
Beverly Exxon (BE)	98.00	0.00273		
Columbia Gas (CG)	98.00	0.00093		

Table 4.13 Land use area for Lewis Creek reference watershed Upper Opequon Creek.

Sediment Source	Lewis Creek (ha)	Upper Opequon Creek (ha)	Upper Opequon Creek (Area-Adjusted) (ha)
Pervious Area:			
Water	16.11	64.89	30.48
LIR	921.22	374.09	175.71
HIR	7.51	24.35	11.44
Commercial	132.06	69.98	32.87
Transitional	32.41	174.15	81.80
Quarries		25.38	11.92
Forest	2,027.58	5,132.36	2,410.59
Pasture/Hay	0.16		
Pasture Improved	785.72	1,593.32	748.36
Pasture Unimproved	785.72	1,593.32	748.36
Pasture Overgrazed	785.72	1,593.32	748.36
Hay	932.66	3,457.63	1,623.99
Row Crops High Tillage	35.86	392.60	184.40
Row Crops Low Tillage	140.33	301.04	141.39
Urban Grass	29.11	34.83	16.36
Wetland	4.59	38.43	18.05
Staunton Metal Recyclers (SMR)	1.21		
Klotz Brothers Courtyard (KBC)	0.00		
Beverly Exxon (BE)	0.00		
Columbia Gas (CG)	0.14		
Impervious Area:			
LIR	307.07	124.70	58.57
HIR	5.00	16.24	7.63
Commercial	132.06	69.98	32.87
Staunton Metal Recyclers (SMR)	0.13		
Klotz Brothers Courtyard (KBC)	0.24		
Beverly Exxon (BE)	0.19		
Columbia Gas (CG)	0.33		
Total	**7,083.14**	**15,080.63**	**7,083.14**

The sediment loads existing at the time of impairment were modeled for Lewis Creek and the reference watershed Upper Opequon Creek (Table 4.14). The existing condition for the Lewis Creek watershed is the combined sediment load, which compares to the target TMDL load under existing conditions for the area-adjusted reference watershed Upper Opequon Creek.

Table 4.14 Existing sediment loads for Lewis Creek and reference watershed Upper Opequon Creek.

Sediment Source	Lewis Creek		Opequon Creek (Area-Adjusted)	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area:				
Water	0.00		0.00	
LIR	231.52	2.01	9.08	0.05
HIR	1.48	0.36	0.30	0.03
Commercial	12.46	0.60	0.95	0.03
Transitional	281.95	22.65	283.78	3.47
Quarries			234.85	19.70
Forest	4.82	0.01	3.32	0.001
Pasture/Hay	0.31	4.09		
Pasture Improved	183.06	0.70	58.58	0.08
Pasture Unimproved	1,241.17	4.78	412.77	0.55
Pasture Overgrazed	2,955.02	11.49	935.88	1.25
Hay	198.84	0.63	122.79	0.08
Row Crops High Tillage	435.99	35.16	533.74	2.89
Row Crops Low Tillage	623.87	12.81	158.21	1.12
Urban Grass	0.04	0.00	1.85	0.11
Wetland	0.32	0.09	0.01	0.001
Staunton Metal Recyclers (SMR)	0.03			
Klotz Brothers Courtyard (KBC)	0.00			
Beverly Exxon (BE)	0.00			
Columbia Gas (CG)	0.00			
Impervious Area:				
LIR	59.67	1.36	12.45	0.21
HIR	0.97	0.39	1.62	0.21
Commercial	25.66	1.37	6.99	0.21
Staunton Metal Recyclers (SMR)	0.03	0.20		
Klotz Brothers Courtyard (KBC)	0.05	0.19		
Beverly Exxon (BE)	0.04	0.19		
Columbia Gas (CG)	0.06	0.20		
Streambank Erosion	444.89		354.39	
Straight Pipes	0.83		0.00	
Point Sources	39.88		86.87	
Total	**6,742.96**		**3,218.45**	

4.2 Lead and Total PAHs Mass Balance Model

4.2.1 Modeling Framework Selection – Mass Balance

A mass balance spreadsheet modeling approach was used in this study to develop benthic TMDLs for lead and total Polycyclic Aromatic Hydrocarbons (PAHs) for the Lewis Creek watershed. As noted in Chapter 3, lead and total PAHs were also identified as probable stressors for Lewis Creek. The mass balance model was developed using sediment output from the GWLF modeling described in section 4.1. The watershed was divided into three subwatersheds based on the location of monitoring performed during the TMDL study. Background loadings for lead and total PAHs were developed for each subwatershed based on values published by Novotny and Olem (1994). A numeric endpoint was based on published threshold effect concentrations (TEC) for lead and total PAHs (McDonald et al, 2000). The TMDLs were then developed for the impaired watershed based on these endpoints. The background loadings for subwatersheds 1 and 2 were combined and calibrated to the monitoring station at the outlet of subwatershed 2 because this was the monitoring station with the highest lead and total PAH sediment concentrations. A lumped contamination load was determined by calibrating the background loads to the highest concentrations in the sediment. All lead and total PAH loads are in kilograms per year (kg/yr).

4.2.2 Model Setup – Mass Balance

Background loadings for lead and total PAHs were determined by using sediment output for pervious and impervious areas from the GWLF modeling described above. The three subwatershed boundaries were delineated at the sediment monitoring stations used in October 2005 by VADEQ and MapTech using GIS techniques (Figure 4.8). Subwatershed 1 was the upper and smallest subwatershed and the outlet was VADEQ benthic monitoring station 1BLEW009.19. This subwatershed was considered the background subwatershed because it consists of very light residential and agricultural land uses. Subwatershed 2 primarily consisted of the urban area of the City of Staunton. The outlet chosen for this subwatershed was VADEQ monitoring station 1BLEW006.64 because this station had the highest sediment load of lead and total PAHs. Subwatershed 2 contains the four known contaminated industrial sites. Subwatershed 3 contains the remainder of the watershed downstream to the confluence with Middle River. There are no known sources of contamination in this subwatershed. Background contaminant loads from each subwatershed, a lumped contaminated site load, and downstream contaminant transport were considered in the mass balance model. Initial background loadings for lead and total PAHs were estimated for each subwatershed based on values published by Novotny and Olem (1994). These background loadings were then calibrated to match instream sediment contaminant concentrations. Background loadings from non-urban areas were calibrated to contaminant concentrations measured upstream of the City of Staunton (at station 1BLEW009.19). Background loadings in the urban area were calibrated to contaminant concentrations measured in Asylum Creek, located within subwatershed 2, but unaffected by contaminated sites. The lumped contaminated site load was then determined by balancing the mass necessary to match instream sediment contaminant concentrations measured at the outlet of subwatershed 2, the most contaminated station (1BLEW006.64). This mass balance provided the modeled existing conditions. To develop the TMDL, target instream sediment contaminant concentrations were set at the threshold effect concentration (TEC) for lead and total PAHs as published by MacDonald et al (2000). Loads were reduced to meet the TEC at the outlet of subwatershed 2. These reduced loads set the lead and total PAH TMDLs for Lewis Creek.

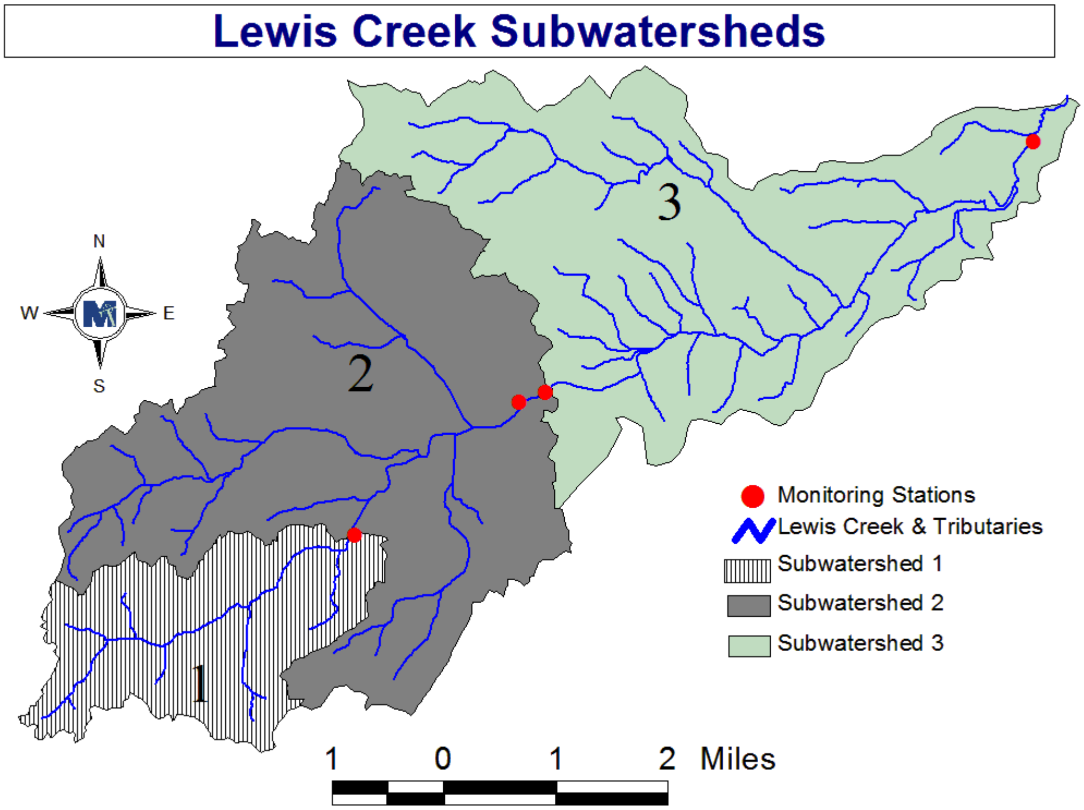

Figure 4.8 Subwatersheds in the Lewis Creek watershed.

4.2.2.1 Background Values – Mass Balance

4.2.2.1.1 Lead

An initial background lead concentration of 161 µg/L was used for the impervious areas in subwatersheds 1 and 3. This was the lowest figure in the range for urban impervious runoff provided by Novtony and Olem (1994). Background loads for both the impervious and pervious areas were then calibrated to a sediment concentration of 23.15 mg/kg found at VADEQ monitoring station 1BLEW009.19.

A background lead concentration of 182.5 µg/L was used for the impervious areas in subwatershed 2 (the midpoint of the range found in Novtony and Olem, 1994). The background load was calibrated to a sediment concentration of 43 mg/kg found at VADEQ monitoring station 1BXEE000.10 on Aslyum Creek. The drainage area of this creek is mostly urban, but known contaminated industrial sites are not present within this portion of the watershed.

4.2.2.1.2 Total PAHs

An initial background total PAH concentration of 0.27 kg/km^2 was used for the impervious areas in subwatersheds 1 and 3. This figure was for light residential areas and provided by Novtony and Olem (1994). Background loads for subwatershed 1 for both the impervious and pervious areas were then calibrated to the sediment concentration of 0.605 mg/kg found at VADEQ monitoring station 1BLEW009.19. A background total PAH concentration of 0.57 kg/km^2 was used for the impervious areas in subwatershed 2. This figure was for dense residential and commercial areas and provided by Novotny and Olem (1994). The background load was calibrated to a sediment concentration of 1.265 mg/kg calculated at VADEQ monitoring station 1BXEE000.10 on Asylum Creek.

4.2.2.2 Model Calibration Processes - Mass Balance

Background sediment and pollutant loads were determined for subwatersheds 1 and 2 the mass balance model was calibrated to the average sediment concentrations of 136.5 mg/kg (lead) and 7.99 mg/kg (total PAHs) found at VADEQ monitoring station 1BLEW006.64. The combined loading from all contaminated sites was used as the calibration parameter to balance the pollutant mass necessary to match sediment concentrations at 1BLEW006.64. The process was the same for both lead and total PAHs. The following expression shows the calculations used to calibrate the mass balance model:

$$(L_{B1} + L_{B2} + L_C)/(S_1 + S_2) = C_{6.64}$$

L_{B1} and L_{B2} represent the background pollutant loads from subwatersheds 1 and 2 and L_C represents the contaminated site pollutant load. S_1 and S_2 represent the sediment loads from subwatersheds 1 and 2 and $C_{6.64}$ represents the sediment contaminant concentration at VADEQ monitoring station 1BLEW006.64.

Tables 4.15 and 4.16 show the existing loadings calculated for lead and total PAHs in the Lewis Creek watershed.

Table 4.15 Existing lead sediment loads for the Lewis Creek watershed.

Source	Lewis Creek (kg/yr)	Percentage (%)
Subwatershed 1 Background	29,442	6
Subwatershed 2 Background	86,720	16
Contaminated Sites	330,203	62
Subwatershed 3 Background	86,506	16
Total	**532,871**	**100**

Table 4.16 Existing total PAH sediment loads for the Lewis Creek watershed.

Source	Lewis Creek (kg/yr)	Percentage (%)
Subwatershed 1 Background	769	3
Subwatershed 2 Background	5,119	18
Contaminated Sites	20,239	72
Subwatershed 3 Background	1,887	7
Total	**28,014**	**100**

4.2.3 Modeling Endpoints - Mass Balance

4.2.3.1 Lead

The sediment threshold effect concentration (TEC) of 35.8 mg/kg was used as the lead endpoint for the model to determine the necessary allocations (MacDonald et al., 2000). The TEC value is the concentration below which no impact to the benthic community is expected. Allocations were developed to meet the sediment concentration of 35.8 mg/kg at the VADEQ monitoring station 1BLEW006.64 at the outlet of subwatershed 2.

4.2.3.2 Total PAHs

The sediment TEC value of 1.61 mg/kg was used as the total PAH endpoint for the model to determine the necessary allocations (MacDonald et al., 2000). Allocations were developed to meet the target total PAH sediment concentration of 1.61 mg/kg at the VADEQ monitoring station 1BLEW006.64 at the outlet of subwatershed 2.

5. ALLOCATION

Total Maximum Daily Loads consist of waste load allocations (WLAs, permitted point sources) and load allocations (LAs, nonpoint sources), including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for uncertainties in the process. The definition is typically denoted by the expression:

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

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For sediment, the TMDL is expressed in terms of annual load in metric tons per year (Mg/yr or t/yr). For lead and PAHs, the TMDLs are expressed in terms of annual load in kilograms per year (kg/yr).

5.1 Sediment TMDL

This section describes the development of a TMDL for sediment for Lewis Creek using a reference watershed approach. The model was run over the period of 4/1/1992 to 3/1/1998 for sediment modeling for Lewis Creek. The target sediment TMDL load for Lewis Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Upper Opequon Creek watershed under existing conditions minus a 10% MOS.

5.1.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, an MOS was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. For example, the extrapolation from a reference watershed to an impaired watershed.

An MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The MOS for the Lewis Creek sediment TMDL was explicitly express as 10% of the area-adjusted reference watershed load (321.85 t/yr).

5.1.2 Future Land Development Considerations

A review of the Staunton City and Augusta County Comprehensive Plans (City of Staunton; 2006; Augusta County, 2006) indicated that commercial, industrial, and residential land uses are expected to increase over the next 20 years. Based on the estimates in the Augusta County Comprehensive Plan, 7 acres will become commercial area, and 191 acres will become low intensity residential area in the Lewis Creek watershed. The Staunton City Comprehensive Plan shows an estimated 827 acres will become commercial area, 653 acres will become low intensity residential are, and 415 acres will become medium intensity residential are in the Lewis Creek watershed. These land use changes were assumed to come from forest, pasture, and cropland.

This future scenario was run with the GWLF model. The resulting sediment load (Table 5.1) was 1,686.86 t/yr less than the sediment load from the existing land use scenario (Table 4.15); therefore the final sediment TMDL was calculated using the existing scenario. The explanation for these results is the high percentage of unimproved and overgrazed pasture in the watershed. These land uses delivered the most sediment. Substituting the pasture for impervious land use in the future and the resulting increase in channel erosion is offset by a greater reduction in sediment delivered from the land.

Table 5.1 Future sediment loads for the impaired and area-adjusted reference watersheds.

Sediment Source	Lewis Creek		Upper Opequon Creek (Area-Adjusted)	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area:				
Water	0.00		0.00	
LIR	390.38	2.01	9.08	0.05
MIR	77.37	0.28		
HIR	1.48	0.36	0.30	0.03
Commercial	51.82	0.59	0.95	0.03
Transitional	281.95	22.65	283.78	3.47
Quarries	0.00		234.85	19.70
Forest	2.98	0.01	3.32	0.001
Pasture/Hay	0.31	4.09		
Pasture Improved	113.32	0.70	58.58	0.08
Pasture Unimproved	768.32	4.78	412.77	0.55
Pasture Overgrazed	1,829.25	11.49	935.88	1.25
Hay	123.09	0.63	122.79	0.08
Row Crops High Tillage	269.89	35.16	533.74	2.89
Row Crops Low Tillage	386.20	12.81	158.21	1.12
Urban Grass	0.04	0.00	1.85	0.11
Wetland	0.32	0.09	0.01	0.001
Staunton Metal Recyclers (SMR)	0.03	0.02		
Klotz Brothers Courtyard (KBC)	0.00			
Beverly Exxon (BE)	0.00			
Columbia Gas (CG)	0.01	0.04		
Impervious Area:				
LIR	100.67	1.36	12.45	0.21
MIR	26.21	0.19		
HIR	0.97	0.39	1.62	0.21
Commercial	106.69	1.37	6.99	0.21
Staunton Metal Recyclers (SMR)	0.03	0.20		
Klotz Brothers Courtyard (KBC)	0.05	0.19		
Beverly Exxon (BE)	0.04	0.19		
Columbia Gas (CG)	0.06	0.20		
Streambank Erosion	821.63		354.39	
Straight Pipes	0.83		0.00	
Point Sources	39.88		86.87	
Total	**5,393.78**		**3,218.45**	

5.1.3 Final Sediment TMDL

The target TMDL load for Lewis Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Upper Opequon Creek watershed under existing conditions. To reach the target goal (2,896.61 t/yr), three different scenarios were run with GWLF (Table 5.2). Sediment loads from straight pipes were reduced 100% in all scenarios because straight pipes are illegal and should be removed for health implications because they are a source of human pathogens. Scenario 1 shows a 42% reduction to sediment loads from pervious and impervious low intensity residential, high intensity residential and commercial, a 74% reduction from transitional, a 75% reduction from unimproved and overgrazed pasture, a 60% reduction from high tillage row cropland and a 20% reduction from streambank erosion. Scenario 2 shows an 83% reduction to loads from unimproved and overgrazed pasture, a 63% reduction from high tillage row cropland, and a 20% reduction from streambank erosion. Scenario 3 shows a 76% reduction from transitional, a 78% reduction from unimproved and overgrazed pasture, a 62% reduction from high tillage row cropland and a 20% reduction from streambank erosion. All three scenarios meet the TMDL goal at a total sediment load reduction of 57.04%. Scenario 1 was chosen to use for the final TMDL.

Table 5.2 Final TMDL allocation scenario for the impaired watershed.

Sediment Source	Lewis Existing Loads t/yr	Scenario 1 Reductions (Final) (%)	Scenario 1 Allocated Loads t/yr	Scenario 2 Reductions (%)	Scenario 2 Loads t/yr	Scenario 3 Reductions (%)	Scenario 3 Loads t/yr
Pervious Area:							
Water	0.00	0	0.00	0	0.00	0	0.00
LIR	231.52	42	134.28	0	231.52	0	231.52
HIR	1.48	42	0.86	0	1.48	0	1.48
Commercial	12.46	42	7.23	0	12.46	0	12.46
Transitional	281.95	74	73.31	0	281.95	76	67.67
Forest	4.82	0	4.82	0	4.82	0	4.82
Pasture/Hay	0.31	0	0.31	0	0.31	0	0.31
Pasture Improved	183.06	0	183.06	0	183.06	0	183.06
Pasture Unimproved	1,241.17	75	310.29	83	211.00	78	273.06
Pasture Overgrazed	2,955.02	75	738.75	83	502.35	78	650.10
Hay	198.84	0	198.84	0	198.84	0	198.84
Row Crops High Tillage	435.99	60	174.40	63	161.32	62	165.68
Row Crops Low Tillage	623.87	0	623.87	0	623.87	0	623.87
Urban Grass	0.04	0	0.04	0	0.04	0	0.04
Wetland	0.32	0	0.32	0	0.32	0	0.32
Staunton Metal Recyclers (SMR)	0.03	0	0.03	0	0.03	0	0.03
Klotz Brothers Courtyard (KBC)	0.00	0	0.00	0	0.00	0	0.00
Beverly Exxon (BE)	0.00	0	0.00	0	0.00	0	0.00
Columbia Gas (CG)	0.00	0	0.00	0	0.00	0	0.00
Impervious Area:							
LIR	59.67	42	34.61	0	59.67	0	59.67
HIR	0.97	42	0.56	0	0.97	0	0.97
Commercial	25.66	42	14.88	0	25.66	0	25.66
Staunton Metal Recyclers (SMR)	0.03	0	0.03	0	0.03	0	0.03
Klotz Brothers Courtyard (KBC)	0.05	0	0.05	0	0.05	0	0.05
Beverly Exxon (BE)	0.04	0	0.04	0	0.04	0	0.04
Columbia Gas (CG)	0.06	0	0.06	0	0.06	0	0.06
Streambank Erosion	444.89	20	355.91	20	355.91	20	355.91
Straight Pipes	0.83	100	0.00	100	0.00	100	0.00
Point Sources:	39.85	0	39.85	0	39.85	0	39.85
Total	**6,742.96**	**57.04**	**2,896.44**	**57.06**	**2,895.65**	**57.06**	**2,895.54**

The sediment TMDL for Lewis Creek includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point source discharges. The LA was calculated as the target TMDL load minus the WLA load minus the MOS (Table 5.3).

Table 5.3 TMDL targets for the impaired watershed.

Impairment	WLA (t/yr)	LA (t/yr)	MOS (t/yr)	TMDL (t/yr)
Lewis Creek	40	2,857	322	3,218

The reductions required to meet the TMDL were based on existing conditions. The final overall sediment load reduction required for Lewis Creek is 57.04% (Table 5.4).

Table 5.4 Required reductions for the impaired watershed.

Load Summary	Lewis Creek	Reductions Required	
	(t/yr)	(t/yr)	(% of existing load)
Existing Sediment Loads	6,743	3,846	57.04
Target Modeling Load	2,897		

5.2 Lead TMDL

5.2.1 Scenario Development

The allocation scenario was modeled using sediment output from GWLF and a mass balance spreadsheet. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard.

5.2.2 Lead Wasteload Allocations

In the Lewis Creek watershed there are currently no permitted point sources for lead.

5.2.3 Lead Load Allocations

Load allocations to nonpoint/nonpermitted sources were divided into combined background loads from land uses and a combined contaminated site load. The combined contaminated site load represents the four sites in subwatershed 2 that have a history of lead related water quality issues.

In the first allocation scenario, the contaminated sites load was reduced by 99%; however, this scenario failed to reduce lead to the target concentration. Therefore a slight reduction to the background load in subwatershed 2 was required. The development of the allocation scenario was an iterative process that required an assessment of source reductions against the water quality target. Table 5.5 shows the final TMDL load for the lead impairment. The TMDL requires a slight reduction in background loadings from the urbanized area in subwatershed 2. It is likely that this can be accomplished by urban BMPs that will be implemented to meet sediment and bacteria reductions called for in concurrent and prior TMDLs.

Table 5.5 Average annual lead loads (kg/yr) modeled after TMDL allocation in the Lewis Creek impairment.

Source	Lead (kg/yr)	Reductions% (Final)	Allocation (kg/yr)
Subwatershed 1 Background	29,442	0	29,442
Subwatershed 2 Background	86,720	3	84,321
Contaminated Sites	330,203	99	3,302
Subwatershed 3 Background	86,506	0	86,506
Total	**532,871**	**62**	**203,571**

Lead concentrations were calculated and loads were adjusted until the sediment lead endpoint was met (Table 5.6).

Table 5.6 Lead TMDL for Lewis Creek.

Impairment	WLA (kg/yr)	LA (kg/yr)	MOS	TMDL (kg/yr)
Lewis Creek	0	203,570	*Implicit*	203,570

5.3 Total PAH TMDL

5.3.1 Scenario Development

The allocation scenario was modeled using sediment output from GWLF and a mass balance spreadsheet. By adopting an implicit MOS in estimating the loads in the watershed, it is ensured that the recommended reductions will in fact succeed in meeting the water quality standard.

5.3.2 Total PAH Wasteload Allocations

In the Lewis Creek watershed there are currently no permitted point sources for total PAHs.

5.3.3 Total PAH Load Allocations

Load allocations to nonpoint/nonpermitted sources are divided into combined background loads from land uses and a combined contaminated site load. The combined contaminated site load represents the three sites in subwatershed 2 that have had a history of total PAHs related water quality issues.

In the first allocation scenario, the contaminated sites loading was reduced by 99%; however, this scenario failed to reduce lead to the target concentration. Therefore a 16% reduction to the background load in subwatershed 2 was required. The development of the allocation scenario was an iterative process that required an assessment of source reductions against the water quality target. Table 5.7 shows the final TMDL load for the total PAH impairment. The TMDL requires a reduction in background loadings from the urbanized area in subwatershed 2.

Table 5.7 Average annual total PAH loads (kg/yr) modeled after TMDL allocation in the Lewis Creek impairment.

Source	Total PAH (kg/yr)	Reductions (Final)	Allocation (kg/yr)
Subwatershed 1 Background	769	0	769
Subwatershed 2 Background	5,119	16	4,293
Contaminated Sites	20,239	99	202
Subwatershed 3 Background	1,887	0	1,887
Total	**28,014**	**74**	**7,151**

Total PAH concentrations were calculated and loads were adjusted until the total PAH endpoint was met (Table 5.8).

Table 5.8 Total PAHs TMDL for Lewis Creek.

Impairment	**WLA** (kg/yr)	**LA** (kg/yr)	**MOS**	**TMDL** (kg/yr)
Lewis Creek	0	7,151	*Implicit*	7,151

6. IMPLEMENTATION

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream (see section 6.4.2). For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES) and National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR ' 122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of 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 *Guidance Manual for Total Maximum Daily Load Implementation Plans*, published in July 2003 and available upon request from VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends for the required BMPs to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement. 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.

6.2 Stage 1 Scenarios

Implementation of BMPs in the watershed 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.

6.2.1 Stage 1 Scenario – Sediment

The stage 1 scenario presented in Table 6.1 shows that half of the required reduction can be achieved by 35% reductions from the significant urban and agricultural land uses and a 20% reduction in stream bank erosion.

Table 6.1 Sediment Stage 1 scenario for the Lewis Creek impairment.

Sediment Source	Lewis Existing Loads	Stage 1 Reductions	Stage 1 Allocated Loads
	t/yr	(%)	t/yr
Pervious Area:			
Water	0.00	0	0.00
LIR	231.52	35	150.49
HIR	1.48	35	0.96
Commercial	12.46	35	8.10
Transitional	281.95	35	183.27
Forest	4.82	0	4.82
Pasture/Hay	0.31	0	0.31
Pasture Improved	183.06	0	183.06
Pasture Unimproved	1,241.17	35	806.76
Pasture Overgrazed	2,955.02	35	1,920.76
Hay	198.84	0	198.84
Row Crops High Tillage	435.99	35	283.40
Row Crops Low Tillage	623.87	0	623.87
Urban Grass	0.04	0	0.04
Wetland	0.32	0	0.32
Staunton Metal Recyclers (SMR)	0.03	0	0.03
Klotz Brothers Courtyard (KBC)	0.00	0	0.00
Beverly Exxon (BE)	0.00	0	0.00
Columbia Gas (CG)	0.00	0	0.00
Impervious Area:			
LIR	59.67	35	38.78
HIR	0.97	35	0.63
Commercial	25.66	35	16.68
Staunton Metal Recyclers (SMR)	0.03	0	0.03
Klotz Brothers Courtyard (KBC)	0.05	0	0.05
Beverly Exxon (BE)	0.04	0	0.04
Columbia Gas (CG)	0.06	0	0.06
Streambank Erosion	444.89	20	355.91
Straight Pipes	0.83	100	0.00
Point Sources:	0.00	0	0.00
VAG110073	0.13	0	0.13
VAG110071	0.08	0	0.08
VAR050778	1.62	0	1.62
VAG840030	31.60	0	31.60
VAR050826	0.11	0	0.11
VAR051333	2.94	0	2.94

Table 6.1 Sediment Stage 1 scenario for the Lewis Creek impairment (cont.).

Sediment Source	Lewis Existing Loads	Stage 1 Reductions	Stage 1 Allocated Loads
VAR100570	1.18	0	1.18
VAR103788/VAR101703	1.88	0	1.88
VAR102097	0.15	0	0.15
VAR103916	0.04	0	0.04
VAR104649	0.08	0	0.08
VAG401882	0.04	0	0.04
VAG401072	0.04	0	0.04
Total	**6,742.96**	**28.56**	**4,817.10**

6.2.2 Stage 1 Scenario – Lead and Total PAHs

There are four sites in the City of Staunton that have been and some may still be sources of significant pollution in Lewis Creek. The sites were described in detail in section 2.6. There was not enough data currently available from each of these sites to make accurate individual pollutant load allocations for them. In addition, some of the sites have been completely or partially remediated and current post-remediation data were not available. To provide an indication of how these sites might be prioritized in terms of implementation an attempt was made to estimate the possible ranges of pollutant loading from the sites. Available soil and groundwater data from each site (Appendices D-H) were used in combination with sediment and groundwater flux estimates from the GWLF model. Possible maximum loads were calculated using the highest measured values from the site and possible minimum values were calculated using the lowest measured values from the site. In some cases, where specific data was not available for a site, estimates were made from other nearby data. Tables 6.2 and 6.3 show the results of these calculations. It should be noted that these possible ranges are intended only for the purposes of prioritizing site remediation efforts. In some cases, the available data used in this exercise is not recent and does not reflect previous remediation efforts at the sites. Updated site characterization studies should be carried out at these sites as the next step in implementing this TMDL. DEQ and EPA are actively initiating follow-up site characterization at Beverley Exxon, Columbia Gas, and Staunton Metal Recyclers. The sites in the tables are ordered based upon the amount of remediation that has been completed (from least to most). The former Klotz Courtyard was a superfund site and 1,360 tons of contaminated soil was removed in 1996. The case was closed in 1997 and it is considered fully remediated. Therefore the quantity of lead contributed from this site is probably similar to the value in the minimum column. Columbia Gas is in the VADEQ Voluntary Remediation Program (VRP) and significant remediation has taken place at their site in 2000 and 2002. The VADEQ is reviewing a site characterization report to determine if additional work will be necessary. Therefore the quantity of pollutants contributed from this site is likely to be similar to the figures in the minimum column. Gasoline that leaked from underground lines at the former Beverly Exxon site was removed and the leaking petroleum storage tank case was closed in 2000 but the coal tar residue that was discovered on the site has never been cleaned up in spite of significant contamination at the site and in Lewis Creek. Therefore the quantity of pollutants contributed by this site is likely to be closer to the figures in the maximum column. Very little remediation has been performed at the former Staunton Metal Recyclers site. In 2005 discolored soil from leaking hydraulic fluid around the former metal press was removed but earlier reports noted that the entire site should be considered contaminated. Therefore pollutants contributed from this site are probably similar to the figures in the maximum column.

Stage 1 implementation efforts should address the contamination at the two sites where very little remediation work has occurred (former Staunton Metal Recycling site and former Beverly Exxon site) because they are probably the most significant contributors of lead and total PAHs to the watershed. To ensure that implementation of this TMDL occurs, DEQ will rely on existing regulatory programs to address these sites. The DEQ Site Assessment Program has requested that USEPA reopen the Beverly Exxon site case and perform additional site characterization work. USEPA has agreed and site investigations are planned for Sping 2006. The DEQ Waste Program will oversee negotiations with CSX, the owner of the former Staunton Metal Recycling site, to further investigate and remediate that site. Based on the owner's wishes, this site might also be eligible for participation in the VRP or Brownfields Programs. The Columbia Gas site is currently participating in the VRP Program, and activities at that site will continue under VRP Program review. DEQ has recently commented on the site characterization report and requested additional information and characterization. Columbia Gas is actively responding to those requests.

Remediation at these contaminated sites will likely reduce the bulk of lead and PAH loads to Lewis Creek, however, it may be possible that other significant sources exist in the watershed. Following Stage I Implementation that addresses these identified contaminated sites, it may be necessary for additional watershed source characterization work to identify other potential sources if contaminant levels have not been reduced to TMDL goals.

Table 6.2 Possible ranges of lead loadings from four contaminated sites in the Lewis Creek watershed.

Site	Max (kg/yr)	Min (kg/yr)
Former Staunton Metal Recycling	215,331	257
Former Beverly Exxon	240	235
Columbia Gas	1,264	430
Former Klotz Courtyard	290,000	31
Totals	506,835	953

Table 6.3 Possible ranges of total PAH loadings from three contaminated sites in the Lewis Creek watershed.

Site*	Max (kg/yr)	Min (kg/yr)
Former Beverly Exxon	1,313,148	2,079
Former Staunton Metal Recycling	613	38
Columbia Gas	9,027	73
Totals	1,322,788	2,190

*Klotz courtyard was not a significant source of total PAHs.

6.3 Ongoing Restoration Efforts

Implementation of this TMDL will contribute to ongoing water quality improvement efforts aimed at restoring water quality in Virginia’s streams.

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with Guidance Memo No. 03-2004 (VADEQ, 2003), during periods of reduced resources, monitoring can be temporarily discontinued until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or when deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station(s) (1BLEW006.95 and 1BLEW000.61). At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30th of each year.

VADEQ staff, in cooperation with VADCR staff, the IP Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining water quality standards, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request that the monitoring managers in each regional office increase the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent upon staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

To demonstrate that water quality standards are being met in watersheds where corrective actions have taken place (whether or not a TMDL or IP has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (total suspended solids, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

6.4.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA 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. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the SWCB 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. EPA outlines the minimum elements of an approvable implementation plan in its 1999 *Guidance for Water Quality-Based Decisions: The TMDL Process*. The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES 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 permitted sources are not usually addressed during the development of a TMDL implementation plan. However, the NPDES permits which cover the municipal separate storm sewer systems (MS4s) are expected to be included in TMDL implementation plans. For the implementation of the TMDL's LA component, a TMDL implementation plan addressing the WQMIRA requirements, at a minimum, will be developed.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the state's Water Quality Management Plans (WQMPs).

The WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin. VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the SWCB for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as is the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf.

6.4.3 Stormwater Permits

VADEQ and VADCR coordinate separate State programs that regulate the management of pollutants carried by stormwater runoff. VADEQ regulates stormwater discharges associated with "industrial activities", while VADCR regulates stormwater discharges from construction sites and from MS4s.

EPA approved VADCR's VPDES stormwater program on December 30, 2004. VADCR's regulations became effective on January 29, 2005. VADEQ is no longer the regulatory agency responsible for administration and enforcement of the VPDES, MS4, and construction stormwater permitting programs. More information is available on VADCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp.

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is VADCR's Virginia Stormwater Management Program (VSMP) Permit Regulation (4 VAC 50-60-10 et. seq). Section 4VAC 50-60-380 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when: (2) Numeric effluent limitations are infeasible…"

For MS4/VSMP general permits, the Commonwealth expects the permittee to specifically address the TMDL wasteload allocations for stormwater through the implementation of programmatic BMPs. BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Office of Water, 2002).

If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL wasteload allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit.

Wasteload allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed in TMDL implementation plans. An IP will identify types of corrective actions and strategies to obtain the wasteload allocation for the pollutant causing the water quality impairment. Permittees need to participate in the development of TMDL IPs since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL.

Additional information on Virginia's Stormwater Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm.

6.4.4 Implementation Funding Sources

Cooperating agencies, organizations, and stakeholders must identify potential funding sources available for implementation during the development of the IP in accordance with the *Guidance Manual for Total Maximum Daily Load Implementation Plans*. Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia

Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits, and landowner contributions. The *Guidance Manual for Total Maximum Daily Load Implementation Plans* 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.

Funding for remediation of PAHs and lead at contaminated sites will depend upon the DEQ or EPA programs responsible for overseeing the cleanup efforts. Under some programs, responsible parties fund remediation actions, and under other programs (EPA Superfund Program or DEQ Petroleum Program) designated state or federal funding is utilized.

6.4.5 Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, the current designated use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of the contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10).

This, and other, information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic sources identified in the TMDL. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 6.2 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable BMPs can be identified, a UAA may be initiated with the goal of re-designating the stream for a more appropriate use.

7. PUBLIC PARTICIPATION

The development of the Lewis Creek TMDL greatly benefited from public involvement. Table 7.1 details the public participation throughout the project. The first Local Steering Committee meeting took place on November 30, 2005 at Staunton City Hall, Staunton. VA. There were 28 people in attendance, including 14 landowners, 4 city representatives, 2 consultants, 1 media personnel, 6 agency representatives and 1 MapTech staff. The meeting was publicized in the *Staunton News Leader*. The second Local Steering Committee meeting took place on January 15, 2006 and was attended by 10 people.

Table 7.1 Public participation during TMDL development for the Lewis Creek watershed.

Date	Location	Attendance[1]	Type
1/24/05	Staunton City Hall Staunton, VA	51	1st public
11/30/05	Staunton City Hall Staunton, VA	28	TAC meeting
1/15/06	Staunton City Hall Staunton, VA	10	2nd TAC meeting
3/8/06	Staunton City Hall Staunton, VA	26	Final public

[1]The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

The first public meeting was held at the Staunton City Hall in Staunton, Virginia on January 24, 2005; 51 people attended, including 43 stakeholders, 2 consultants, and 6 agency representatives.

The final public meeting was held at the Staunton City Hall in Staunton, Virginia on March 8, 2006. Twenty-six people attended, including watershed citizens, agency representatives from VADEQ and VADCR, and consultants. The meeting was publicized with notices in the *Virginia Register* and on the VADEQ website. There was a

30-day public comment period after the final public meeting and two sets of written comments were received. VADEQ provided a written response to each of the comments.

Public participation during the implementation plan development process will include the formation of a stakeholders' committee as well as open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the express purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from the Department of Environmental Quality, Department of Conservation and Recreation, Department of Health, local agricultural community, local residents, and local governments. This committee will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity*. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

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

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota.

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

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

Cause. 1. That which produces an effect (a general definition).

2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition).[2]

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to* *restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition**. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also **Respiration.

***Designated uses.** Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

***Dilution.** The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

***Direct runoff.** Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

***Discharge.** Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

***Discharge Monitoring Report (DMR).** Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

***Discharge permits (under NPDES)**. A permit issued by the EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

***Dispersion**. The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

***Diurnal.** Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

***Domestic wastewater.** Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

***Drainage basin.** A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. 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 (9VAC25-260-20). (4)

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph*. A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle*. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

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.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Improved pasture. Pasture that is sown with a mixture of introduced grasses and legumes and fertilized on a regular basis. Such pastures, if well managed, are much more productive than native pastures, which may consist of native shrubs, grasses, weeds, with or without a tree canopy. The most highly managed pastures may produce more than 20 times the dry matter and protein per hectare than unimproved pastures.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

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 (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by the EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

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

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that 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.*

Numeric targets*. A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff*. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

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.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

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.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works*. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period*. The time allowed for the public to express its views and concerns regarding action by the EPA or states (e.g., a* Federal Register *notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity*. Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration*. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone*. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient*. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

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

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquatic systems as a result of erosion.

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

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.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor.

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 mL geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff*. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

Surface area*. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water*. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

***Technology-based standards**. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

***Topography.** The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

***Total Maximum Daily Load (TMDL).** The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) 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.*

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to remediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

***Transport of pollutants (in water).** Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

***Tributary.** A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

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 processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' 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 (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also Domestic wastewater.*

Wastewater treatment*. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality*. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation 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.*

WQIA. Water Quality Improvement Act.

APPENDIX A

Habitat Scoring Descriptions

Rapid Bioassessment Protocols For Use in Streams and Wadeable Rivers: Second Edition

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1. Epifaunal Substrate/ Available Cover **(high and low gradient)**	Greater than 70% (50% for low gradient streams) of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient).	40-70% (30-50% for low gradient streams) mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% (10-30% for low gradient streams) mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% (10% for low gradient streams) stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
2.a Embeddedness **(high gradient)**	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
3a. Velocity/ Depth Regimes **(high gradient)**	All 4 velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (slow is <0.3 m/s, deep is >0.5 m)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/ depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
4. Sediment Deposition **(high and low gradient)**	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
5. Channel Flow Status **(high and low gradient)**	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
6. Channel Alteration **(high and low gradient)**	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
7a. Frequency of Riffles (or bends) **(high gradient)**	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
8. Bank Stability (score each bank) **Note: determine left or right side by facing downstream** **(high and low gradient)**	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion.	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
9. Vegetative Protection (score each bank) **Note: determine left or right side by facing downstream.** **(high and low gradient)**	More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
10. Riparian Vegetative Zone Width (score each bank riparian zone) **(high and low gradient)**	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12-18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

APPENDIX B

TMDL Development for Lewis Creek Watershed

Quality Assurance Project Plan

TMDL Development for Lewis Creek Watershed

Quality Assurance Project Plan

Submitted to:

Virginia Department of Environmental Quality
Office of Water Quality Programs
P. O. Box 10009
Richmond, Virginia 23240-0009

Under Contract Number: 11139

Submitted by:

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Effective Period February 2005 to June 2005

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A1 Approval Page
TMDL Development for Lewis Creek Watershed

Virginia Department of Environmental Quality

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Note: The Project Quality Assurance Officer will secure written documentation (such as the letter in Appendix D) from each sub-tier project participant (*e.g.*, subcontractors, other units of government, laboratories) stating the organization's awareness of and commitment to requirements contained in this quality assurance project plan and any amendments or revisions to this plan. The Project Quality Assurance Officer will maintain the documentation as part of the project's quality assurance records, and will ensure that the document is available for review.

A2 Table of Contents

A3 Distribution List

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Note: The Project Quality Assurance Officer will provide copies of this project plan and any amendments or revisions of this plan to each sub-tier project participant, *e.g.*, subcontractors, other units of government, laboratories. The Project Quality Assurance Officer will document receipt of the plan by sub-tier participants and maintain this documentation as part of the project's quality assurance records. This documentation will be available for review.

List of Acronyms

AVSSEM	Acid Volatile Simultaneous Extraction of Metals
CAR	Corrective Action Request
CFR	Code of Federal Regulations
COC	Chain of Custody
DCLS	Division of Consolidated Laboratory Services
DL	Detection Level
EPA	Environmental Protection Agency
ES&C	Environmental Services and Consulting, LLC
GC/MS	Gas Chromatography/Mass Spectrometry
GPS	Global Positioning System
LCS	Laboratory Control Standard
LCSD	Laboratory Control Standard Duplicates
LUST	Leaking Underground Storage Tank
MS	Matrix Spikes
MSD	Matrix Spike Duplicate
NOV	Notice of Violation
NPS	Nonpoint Source Pollution
PAH	Polyaromatic hydrocarbons
PCB	Polychlorinated Biphenyls
PEC	Probable Effects Concentrations
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAM/QAP	Quality Assurance Manual/Quality Assurance Plan
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QAS	Quality Assurance Specialist
R	Percent Recovery
RL	Reporting Limit
RPD	Relative Percent Deviation
SA	Spike Added
SI	International System of Units
SOP	Standard Operating Procedure
SR	Observed Spiked Sample Concentration
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TOM	Task Order Manager
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality

A4 Project/Task Organization

Virginia Department of Environmental Quality
Robert Brent
VADEQ, Task Order Manager

The Task Order Manager (TOM) is responsible for managing the project for the Virginia Department of Environmental Quality (VADEQ). Reviews project progress.

James Kern
MapTech, Inc., Project Manager

The Project Manager is responsible for ensuring that tasks and other requirements in the contract are executed on time and with the quality assurance/quality control requirements in the system as defined by the contract and in the project QAPP, assessing the quality of subcontractor/participant work, submitting accurate and timely deliverables to the VADEQ TOM, and coordinating attendance at conference calls, training, meetings, and related project activities with VADEQ. Responsible for verifying that the QAPP is distributed and followed by the MapTech team (including all subcontractors) and that the project is producing data of known and acceptable quality. Responsible for ensuring adequate training and supervision of all activities involved in generating analytical and field data, including the facilitation of audits and the implementation, documentation, verification and reporting of corrective actions.

Phillip McClellan
MapTech, Inc., Project Quality Assurance Officer

The Project QAO is responsible for coordinating development and implementation of the project's QA program. The Project QAO is responsible for writing and maintaining QAPPs, and maintaining records of QAPP distribution, including appendices and amendments. The Project QAO ensures that the data collected for the project is of known and acceptable quality and adheres to the specifications of the QAPP. The Project QAO is responsible for maintaining written records of sub-tier commitment to requirements specified in this QAPP. The Project QAO is responsible for identifying, receiving, and maintaining project quality assurance records. The Project QAO is responsible for compiling and submitting the Quality Assurance (QA) report. The Project QAO is responsible for coordinating with the VADEQ Quality Assurance Specialist (QAS) to resolve QA-related issues. The Project QAO notifies the Project Manager and VADEQ TOM of particular circumstances that may adversely affect the quality of data. The Project QAO coordinates the research and review of technical QA material and data related to water quality monitoring system design and analytical techniques. Also conducts assessments of participating organizations during the life of the project as noted in Section C1. Implements or ensures implementation of corrective actions needed to resolve nonconformance noted during assessments.

Karen Kline
MapTech, Inc., Technical Coordinator, Data Manager

The Technical Coordinator assists the Project Manager in ensuring that tasks and other requirements in the contract are executed on time and with the quality assurance/ quality control requirements in the system as defined by the contract and in the project QAPP.

The Data Manager is responsible for the acquisition, verification, and transfer of data to VADEQ, oversees data management for the study, and performs data quality assurances prior to transfer of data to VADEQ. The Data Manager is responsible for transferring data to VADEQ in the acceptable format. Ensures that the data review checklist is completed and data submitted with appropriate codes and data. Provides the point of contact for the VADEQ TOM to resolve issues related to the data and assumes responsibility for the correction of any data errors.

Division of Consolidated Laboratory Services (DCLS)
Naomi Roadcap, Metals & Radiochemistry Group Manager

Environmental Services and Consulting, LLC (ES&C)
Nicole L. Martin, Laboratory Manager

ProChem Analytical, Inc.
Royal Carson, Laboratory Director

The Laboratory Manager is responsible for supervision of laboratory personnel involved in generating analytical data for the project. Responsible for ensuring that laboratory personnel involved in generating analytical data have adequate training and a thorough knowledge of the QAPP and all standard operating procedures (SOPs) specific to the analyses or task performed and/or supervised. Responsible for oversight of all laboratory operations ensuring that all quality assurance/quality control (QA/QC) requirements are met, documentation related to the analysis is complete and adequately maintained, and that results are reported accurately. Responsible for ensuring that corrective actions are implemented, documented, reported and verified. Monitors the implementation of the Quality Assurance Manual/Quality Assurance Plan (QAM/QAP) within the laboratory to ensure complete compliance with QA data quality objectives as defined by the contract and in the QAPP. Conducts in-house audits to ensure compliance with written SOPs and to identify potential problems.

Division of Consolidated Laboratory Services
Rebecca Perdue, Laboratory Quality Assurance/Safety Training

Environmental Services and Consulting, LLC (ES&C)
Stuart R. Lynde, Laboratory Quality Assurance Officer

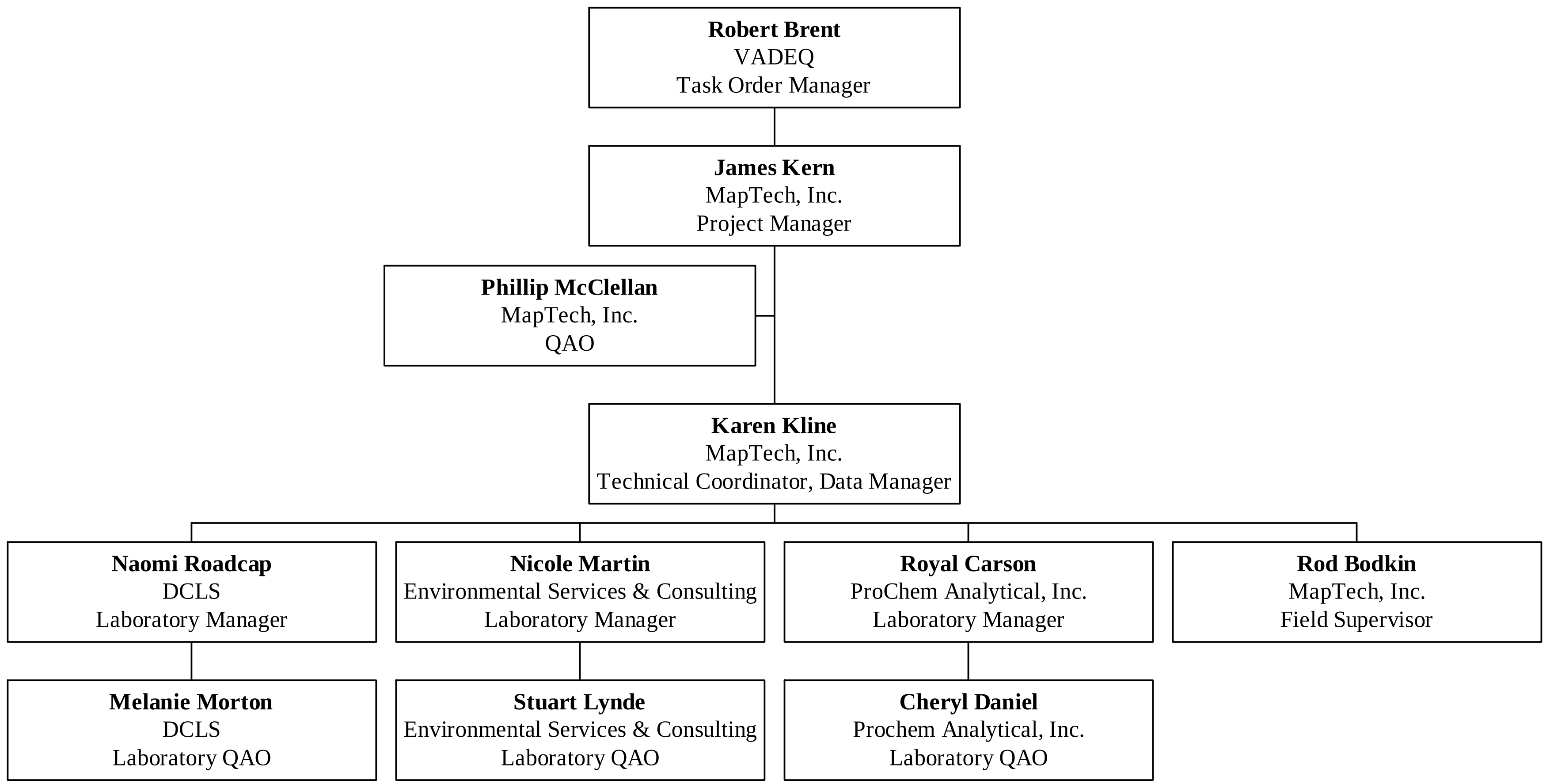
ProChem Analytical, Inc.
Cheryl Daniel, Laboratory Quality Assurance Officer

The Laboratory QAO is responsible for supervising and verifying all aspects of QA/QC in the laboratory. Performs validation and verification of data before the report is sent to the contractor. Ensures that all QA reviews are conducted in a timely manner from real-time review at the bench during analysis to final pass-off of data to the QAO. Ensures that all QA reviews are conducted in a timely manner from real-time review at the bench during analysis to final pass-off of data to the QAO.

Rod Bodkin
MapTech, Field Supervisor

The Field Supervisor is responsible for supervising all aspects of the sampling and measurement of surface waters and other parameters in the field. Responsible for the acquisition of water samples and field data measurements in a timely manner that meet the quality objectives specified in Section A7 (Table A.1 and Table A.2), as well as the requirements of Sections B1 through B8. The Field Supervisor is responsible for field scheduling, staffing, and ensuring that the staff is appropriately trained. The Field Supervisor also reports status, problems, and progress to the Project Manager.

Figure A.1 Organization chart.



A5 Problem Definition

Project Description

The New River Highlands RC&D and MapTech, Inc. are leading an effort for the VADEQ to assess the water quality of Lewis Creek (Figure A.2). The segment first appeared on Virginia*'s 1996 303(d) TMDL Priority List* for violation of the General Standard (benthic). This project will result in establishing the Total Maximum Daily Load (TMDL) for the given constituent and the impairment.

Background

The Lewis Creek impairment extends from river mile 9.55, just south of the City of Staunton, to its confluence with the Middle River near Verona. The Lewis Creek Watershed and the impaired segment of Lewis Creek are shown in Figure A.2. The cause for listing is both the General Standard (benthic) and the Fecal Coliform Standard. During the 2002 assessment period, Station 1BLEW006.95 had a rating of severely impaired based on assessment of the benthic macroinvertebrate community, and Station 1BLEW002.91 had 25 fecal coliform violations out of 58 samples. Also at Station 1BLEW002.91, a single sediment sample exceeded the screening value for polychlorinated biphenyls (PCBs) resulting in a threatened waters designation. In the *2004 Virginia Water Quality Assessment 305(b)/303(d) Integrated Report*, levels of PCBs in two different species of fish exceeded the water quality standard.

The Virginia Department of Environmental Quality (VADEQ) reports that the primary source of fecal coliform bacteria and the problems with the benthic community are due to nonpoint source (NPS) pollution from urban and rural runoff. The source of the sediment PCBs is reported as unknown. There are three known sources of industrial contaminants to Lewis Creek, including a former Superfund site, a leaking underground storage tank (LUST) site, and a metal recycling facility that has received a Notice of Violation (NOV) from VADEQ for improper control of storm water runoff. Sediment levels of chlordane, mercury and polyaromatic hydrocarbons (PAHs) exceed Probable Effects Concentrations (PEC), and fish taken from Lewis Creek exceed VADEQ screening levels for PCBs. As a result of these findings, the General Standard (benthic) TMDL development was not undertaken as part of a previous TMDL development contract for the Middle and Upper South River watersheds. However, stressor identification was carried out and recommendations made for additional monitoring to support development of a TMDL for the general quality impairment. These results are detailed in a report to Virginia Department of Conservation and Recreation (VADCR) entitled *Stressor Identification and Source Assessment to Support the General Standard Total Maximum Daily Load Development for Lewis Creek (VADCR, 2004).*

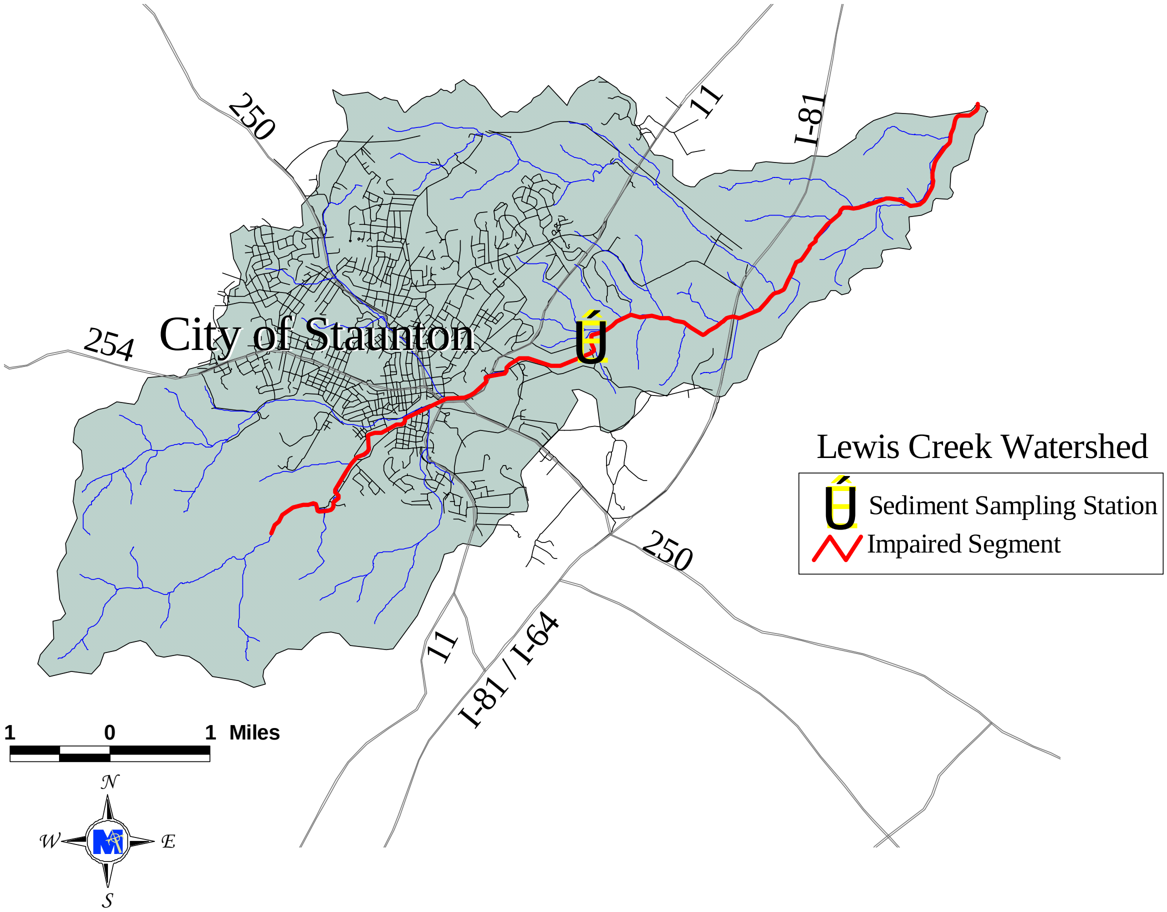


Figure A.2 The Lewis Creek Watershed with impaired segment highlighted.

Primary Stressors
The primary stressors on aquatic life that were identified during stressor identification include:

1) hydraulic modifications of Lewis Creek in downtown Staunton that result in more effective flushing of macroinvertebrates to Middle River; and

2) a presence of toxic substances, including both metals (lead, mercury, and zinc) and organics (chlordane, PCBs, and PAHs), that have been found in sediments and fish tissue from Lewis Creek and thought to be a legacy of past industrial operations.

In addition, based on meetings with VADEQ central and regional office personnel, sediment is considered a stressor for the lower Lewis Creek just upstream of the confluence with Middle River.

The principal objective of this project is to develop a TMDL for Lewis Creek. Because of the numbers of industrial activities (active and inactive) that have operated within the Lewis Creek drainage area over the past century with little data to characterize pollutant loads currently reaching Lewis Creek, additional information must be gathered to determine if existing pollutants reported in the stream are legacy or if various pollutants continue to be delivered to Lewis Creek through storm water runoff, seeps, etc. The first phase of this project, therefore, addresses data collection and gathering essential information to attain a better understanding of the current dynamics of the system, to establish whether or not pollutants are a legacy issue, and to support TMDL development. The second phase will include the integration of studies to date into the development of a TMDL.

A6 Project/Task Description and Schedule

The work to be performed and the project schedule are described in the work plan (Appendix A).

Revisions to the QAPP

Until the work described is completed, this QAPP shall be revised as necessary and reissued within 120 days of significant changes. The last approved versions of QAPPs shall remain in effect until revised versions have been fully approved; the revision must be submitted to the VADEQ for approval before the last approved version has expired.

A7 Quality Objectives and Criteria

The project objective is to collect data that complies with VADEQ rules for surface water quality monitoring programs, which may be used to support decisions related to TMDL development, stream standards modifications, permit decisions, and water quality assessments.

Specific objectives:

Data collection and information gathering essential to attain a better understanding of the current dynamics of the system, to establish whether or not pollutants are a legacy issue and to support TMDL development.

Develop information necessary to support modeling and assessment activities required to allocate pollutant loadings for all stream segments where water quality standards are not being met.

Perform the modeling and assessment activities necessary to allocate the loadings of the constituents of concern for all stream segments where water quality standards are not being met.

Document, compile, and summarize technical analyses in reports to the VADEQ.

An intensive assessment of the waterbody will be conducted to achieve the water quality data objectives. This project will include the assessment of historical water quality data and the collection of sediment and soil samples. The measurement of performance criteria to support the project objective is specified in Tables A.1, A.2 and A.3.

Table A.1 Data quality objectives for sediment and soil samples.

PARAMETER	UNITS	METHOD TYPE	METHOD[1]	PRECISION of Laboratory Duplicates (RPD)	ACCURACY of Matrix Spikes % Recovery	Detection Level (DL)	REPORTING LIMIT (RL)	Laboratory Performing Analysis
PAH	µg/L	Capillary Column GC/MS	SW-846 8270C[2]	± 25 %	30 - 140 %	0.067 mg/kg	0.200 mg/kg	ProChem Analytical
PCB	µg/L	GC	SW-846 8082[2]	± 25 %	20 - 130 %	0.0523 mg/kg	0.261 mg/kg	ProChem Analytical
Individual Congener	µg/L	GC	SW-846 8082[2]	± 20 %	70 - 130 %	0.00125 mg/kg	0.00125 mg/kg	Northeast Analytical
Organochlorine Pesticide	µg/L	Capillary Column GC/MS	SW-846 8081A[2]	± 50 %	30 - 130 %	0.0017 mg/kg	0.0050 mg/kg	ProChem Analytical
AVSSEM	µmole/g	Flame AA	SM3111B	± 20 %	80 – 120 %	*	*	DCLS
Metals	µg/g	ICP-MS	SW-846 3015A/6020	± 20 %	70 – 130 %	*	*	DCLS
Hg	µg/g	Cold Vapor AA	EPA 245.1/ SW-846 3015	± 20 %	70 – 130 %	*	*	DCLS
Particle Size Distribution	% Sand, Silt & Clay	Gravimetric	Applied Marine Research Lab	± 20 %	N/A	*	*	DCLS
TOC	mg/Kg	High Temperature Combustion	SM 18th ed. 5310B	± 20 %	N/A	*	*	DCLS

[1] (NEI, 2005)
[2] Refer to Appendix B for Methods

* Data to be provided by VADEQ and DCLS

Table A.2 Data quality objectives for sediment toxicity.

PARAMETER	UNITS	METHOD TYPE	METHOD	ENDPOINTS	RECOVERY RATE	MINIMUM SURVIVAL IN CONTROL SEDIMENT	ACCEPANCE RATE IN REFERENCE TESTS
Sediment Toxicity	Number of organisms	*Hyalella azteca*	EPA 100.1	Survival & Growth (length or dry weight)	≥ 90 %	80 %	≥ 95 %
Sediment Toxicity	Number of organisms	*Chironomus tentans*	EPA 100.2	Survival & Growth (ash-free dry weight)	≥ 90 %	70 %	≥ 95 %

Table A.3 Data quality objectives for water quality samples.

PARAMETER	UNITS	7.1.1.1.1 METHOD TYPE	METHOD[1]	PRECISION of Laboratory Duplicates (RPD)	ACCURACY of Matrix Spikes % Recovery	Laboratory Performing Analysis
Conductivity	μS/cm	Multiparameter Probe	EPA 120.1	N/A	N/A	Field
PH	pH units	Multiparameter Probe	EPA 150.1	N/A	N/A	Field
Clean Metals	μg/L	Total Trace Elements	SOP#200011[2]	*	*	DCLS
		Dissolved Trace Elements		*	*	
		Total Filterable Solids		*	*	
		Total Non-Filterable Solids		*	*	
		Voltatile Non-Filterable Solids		*	*	
		Fixed Non-Filterable Solids		*	*	

[1] (NEI, 2005)
[2] Refer to SOP for Clean Metals Sampling in Sampling Plan (VADEQ, 2001)

* Data to be provided by VADEQ and DCLS

<u>Accuracy and Precision</u>
Accuracy is a statistical measurement of correctness and includes components of systemic error. The precision of laboratory data is a measure of the reproducibility of a result when an analysis is repeated. Approximately five percent of the samples will be duplicated as a measure of accuracy and precision. Agreement should be at least 95% or higher.

<u>Representativeness</u>
Representativeness is a measure of how accurately a monitoring program reflects the actual conditions. The representativeness of the data is dependent on 1) the sampling locations, 2) the number of samples collected, 3) the number of years and seasons when sampling is performed, and 4) the sampling procedures. Representativeness will be determined by treating all samples of in the same fashion.

<u>Comparability</u>
Standard Operating Procedures (SOPs) and EPA approved methods will be followed both in the field and laboratory in order to ensure comparability of project data. A detailed description of the SOPs and methods are presented in the sampling plan. Sample blanks and duplicates will be utilized in both sampling and analysis phases to facilitate use of QA procedures in the laboratory to ensure a high quality product. All data collected will be reported using the standardized metric International System of Units (SI). These techniques combined with requirements for containers, sample preservation, and holding times will yield a reasonable assurance of achieving the required confidence levels in the sampling phase.

<u>Completeness</u>
The completeness of the data is basically a relationship of how much of the data is available for use compared to the total potential data. Ideally, 100% of the data should be available. However, the possibility of unavailable data due to accidents, insufficient sample volume, broken or lost samples, etc., is to be expected. Therefore, it will be a general goal of the project(s) that 90% data completion is achieved.

A8 Special Training/Certifications

No special certifications are required for this project. Field personnel must be trained in sediment sample collection, soil sample collection, water-quality sampling operations, record management, quality assurance procedures, and vehicle operations. The field supervisor, Rod Bodkin, has adequate experience with the fieldwork. Mr. Bodkin will be collecting samples, and will train the field technician accompanying him.

Laboratory personnel must be trained in analytical methods, record management, and quality control procedures. The laboratory manager(s) will be conducting the laboratory work and will train the laboratory technician(s).

A9 Documents and Records

The field data sheets, chain of custody (COC) forms (see sampling plan), and bottle labels will be completed on-site at the time of sampling. Collectors will report the date and time of sample collection, the name and number of the site, weather conditions, water temperature, and their name on the COC forms. The COC forms will accompany the samples to the lab and in the shipments to the laboratories.

The laboratory technicians will use laboratory data sheets on which they will record the date and time of the analyses. The laboratory manager will enter the data into a database and send to the data manager.

Additional information on record keeping specific to the individual laboratory is available upon request. The documents that describe, specify, report, or certify activities, requirements, procedures, or results for this project, and the items and materials that furnish objective evidence of the quality of items or activities, are listed below.

Document/Record	**Location**	**Retention**	**Form**
QAPP, amendments, and appendices	MapTech	5 years	Paper
Field notebooks or field data sheets	MapTech	5 years	Paper
Field equipment calibration/maintenance logs	MapTech	5 years	Paper
Chain of custody records	MapTech	5 years	Paper
Field SOPs	MapTech	5 years	Paper
Field corrective action documentation	MapTech	5 years	Paper
Laboratory QA manuals	Labs	5 years	Paper
Laboratory SOPs	Labs	5 years	Paper
Laboratory instrument performance	Labs	5 years	Paper
Laboratory data reports	Labs	5 years	Paper
Laboratory data verification for integrity, precision, accuracy and validation	Labs	5 years	Paper
Laboratory equipment maintenance logs	Labs	5 years	Paper
Laboratory calibration records	Labs	5 years	Electronic
Laboratory corrective action documentation	Labs	5 years	Paper
Project data verification/validation	MapTech	5 years	Paper/Electronic
Progress reports/final report/data	MapTech	3 years	Paper/Electronic

References

EPA 2000. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated \
Contaminants with Freshwater Invertebrates. 2nd ed. EPA-600/R-99/064. Washington, D.C.: United States Environmental Protection Agency.

National Environmental Methods Index. Available at: www.nemi.gov. Accessed January 1-31, 2005.

VADCR. 2004. *Stressor Identification and Source Assessment to Support the General Standard Total Maximum Daily Load Development for Lewis Creek.* April 2004.

VADEQ. 2001. *Standard Operating Procedures for Clean Metals Sampling*. Revision no.20001105. Richmond, VA: Virginia Department of Environmental Quality.

B1 Sampling Process Design

Data collection and analysis will follow standard VADEQ and EPA accepted methods. A Global Positioning System (GPS) will be used to identify sample locations. The basic monitoring tasks include:

- The identification of present and former industrial sites along the downtown segment of Lewis Creek including the closed landfill. Surface conditions will be characterized and pollutant delivery pathways to Lewis Creek and/or tributaries will be identified.
- MapTech will measure conductivity and pH at regular intervals from the confluence of Lewis Creek with Middle River to the Lewis Creek headwaters (Figure B1). Samples will be collected at ½- mile intervals from the confluence with Middle River upstream to VADEQ benthic monitoring stations. Sampling will proceed at ¼- mile intervals or at shorter intervals as data suggest to better define the pollutant source(s) until one mile upstream of the Klotz Brothers Courtyard. To the extent possible, conductivity monitoring will be conducted on a cloudy day, to minimize variation due to temperature changes.
- MapTech will collect seven sediment samples at each of the 13 monitoring stations (Figure B1). These 13 monitoring stations include the three benthic monitoring stations, as well as ambient and fish-tissue stations established by VADEQ.
- MapTech will collect one base flow, dry weather conditions, water column sample and one storm flow, wet weather conditions, water column sample at each biological monitoring site (Figure B1) for analysis of clean metals. A storm event is defined as 1/4" or greater rainfall within a 24-hour period.
- After sediment analysis is completed and interpreted, one sediment sample will be collected from the station with the worst sediment toxicity conditions. A second sample will be collected at the most “pristine” upstream station and used as a control. The location of these samples will be confirmed with a GPS unit.
- MapTech will collect up to ten (10) soil samples at strategically located sites to define both background conditions and existing conditions from potential source areas. The samples will be analyzed for metals, semi-volatiles, PCBs, and pesticides. The exact number of samples and type of analysis will not be known until the dominant stressor(s) is identified.

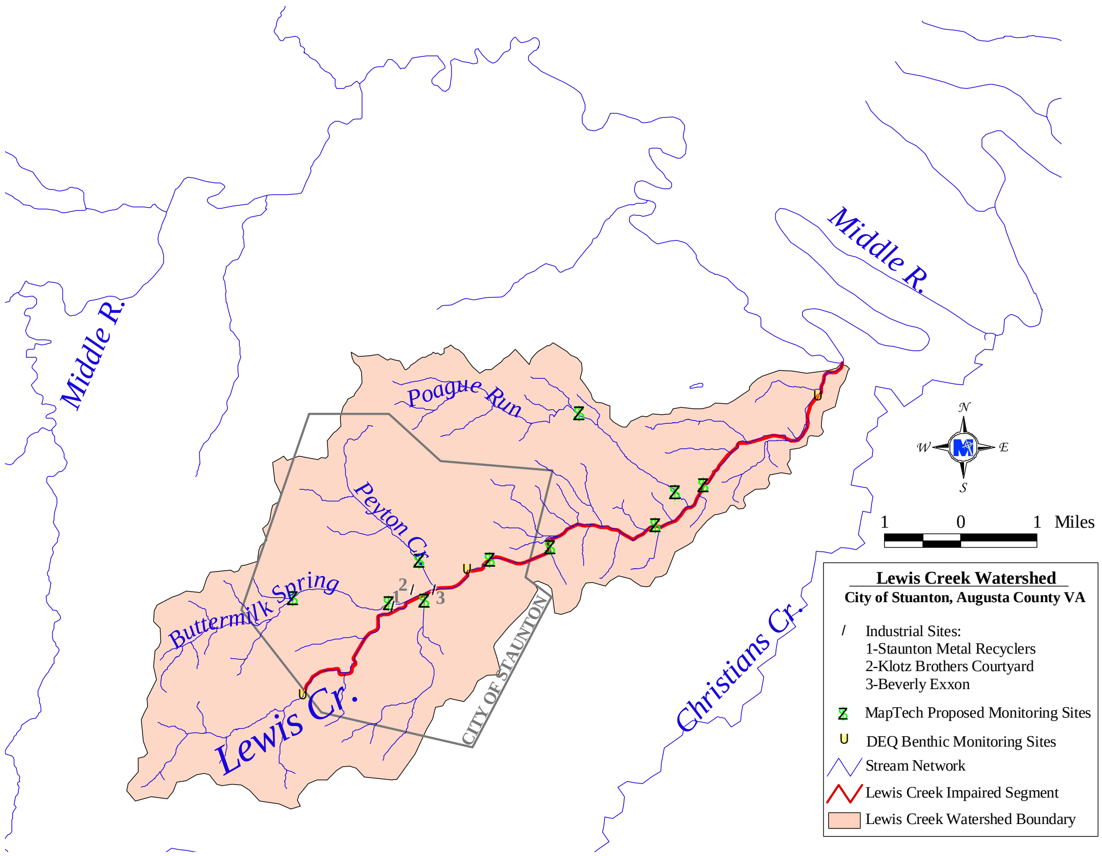


Figure B.1 Lewis Creek and tributaries with proposed monitoring stations.

B2 Sampling Methods Requirements

Sediment Sampling

MapTech will follow the field sampling procedures for field and conventional chemical parameters documented in the *Standard Operating Procedures Manual for the Department of Environmental Quality; Office of Water Quality Monitoring and Assessment* (2003).

Site Selection

Fine-grained sediment (silt + clay) is responsible for a significant proportion of the annual transport of metals, phosphorus, chlorinated pesticides and many industrial compounds such as polynuclear aromatic hydrocarbons and polychlorinated biphenyls (Ongley, 2001). An ideal sampling site should possess the characteristics conducive to deposited fine sediment. Characteristics of a potential sampling site are in areas where the movement of water is slow, along the inner side of bends or eddies.

Field Sampling Procedures

The procedures used for sediment collection depend on the setting (*e.g.,* the depth of the stream and the depth of sediment) and on the specific analysis of the sample. Depending on the analysis, a collection procedure will be utilized. For this project, due to the variety of the parameters being sampled, many different collection procedures are required. The protocols in the sampling plan are for wadeable, shallow waters. In the case of depths that are unwadeable, the Alternative Sediment Sampling Method (documented in the sampling plan) should be followed.

Table B.1 shows each constituent to be analyzed along with the corresponding collection method, sample volume, and holding time. One sample will be collected for each analyte being tested at each monitoring site. These samples will be collected in separate containers. This ensures that the proper equipment and sampling methods are used for each analyte.

Water Sampling

MapTech will collect one base flow water column sample and one storm flow water column sample at each biological monitoring site for analysis of clean metals. Each of the three benthic monitoring stations will follow the clean metals sampling method.

MapTech will measure conductivity and pH at regular intervals from the confluence of Lewis Creek with Middle River to the Lewis Creek headwaters. Conductivity and pH measurements will be collected in the field using a multi-parameter probe. Refer to the sampling plan for the detailed procedures.

Table B.1 Field sampling and handling procedures.

Parameter	Matrix	Container	Preservation Requirement[1]	Sample Volume[1]	Holding Time[1]
Sediment Metals	sediment	Glass Bottle with Teflon-lined lid	4 °C	8 oz	14 days
AVSSEM	sediment	Glass Bottle with Teflon-lined lid	4 °C	8 oz.	14 days
Particle Size	sediment	Glass Bottle with Teflon-lined lid	4 °C	8 oz	14 days
TOC	sediment	Glass Bottle with Teflon-lined lid	4 °C	8 oz.	14 days
PAH	sediment & soil	Glass Bottle with Teflon-lined lid	4 °C	8 oz	14 days
PCB	sediment & soil	Glass Bottle with Teflon-lined lid	4 °C	8 oz	14 days
Organochlorine Pesticides	sediment & soil	Glass Bottle with Teflon-lined lid	4 °C	8 oz.	14 days
Clean Metals	water	[2]	[2]	[2]	[2]

[1] (NEI, 2005)
[2] Refer to SOP for Clean Metals Sampling (VADEQ, 2001)

Sampling Methods and Equipment

Detailed procedures for collecting sediment, soil, and water samples for metal and organic analyses are in the sampling plan.

Processes to Prevent Cross Contamination

Decontamination procedures prior to and during field sampling, as outlined the sampling plan, prevent cross-contamination of samples. These include such things as direct collection into sample containers, when possible, clean sampling techniques for metals, and certified containers for organics. Field quality control (QC) samples as discussed in Section B5 are collected to verify that cross-contamination has not occurred.

Documentation of Field Sampling Activities

Field sampling activities are documented on field data sheets as presented in the sampling plan. Sample collection records, pH, and conductivity are part of the field data record. For all visits, station ID, location, sampling time, date, depth and sample collector's name/signature are recorded. Values for all measured field parameters are recorded. Detailed observational data are recorded including water appearance, weather, biological activity, stream uses, unusual odors, specific sample information, missing parameters (*i.e.*, items that were to have been sampled that day, but weren't), days since last significant rainfall, and flow severity.

Recording Data

For the purposes of this section and subsequent sections, all field and laboratory personnel follow these basic rules for recording information:

1. Legible writing in indelible, waterproof ink with no modifications, write-overs or cross-outs;
2. Correction of errors with a single line followed by an initial and date;
3. Close-outs on incomplete pages with an initialed and dated diagonal line.

Deviations from Sampling Method Requirements or Sample Design, and Corrective Action

Examples of deviations from sampling method requirements or sample design include, but are not limited to, such things as inadequate sample volume due to spillage or container leaks, failure to preserve samples appropriately, contamination of a sample bottle during collection, storage temperature and holding time exceedance, sampling at the wrong site, etc. Any deviations will invalidate resulting data. Corrective action should include that samples are to be discarded and re-collected. It is the responsibility of the field supervisor to ensure that the actions and resolutions to the problems are documented and that records are maintained in accordance with this QAPP.

B3 Sample Handling and Custody Procedures

The sample handling and custody section is adapted from "Section VI: Sample Identification and Corrective Action" of the *SOP Manual* (VADEQ 2003).

Chain-of-Custody

Proper sample handling and custody procedures ensure the custody and integrity of samples beginning at the time of sampling and continuing through transport, sample receipt, preparation, and analysis.

A sample is in custody if it is in actual physical possession or in a secured area that is restricted to authorized personnel. The COC form is used to document sample handling during transfer from the field to the laboratory, and among contractors. The following list of items should be included on the COC form and match the form in the sampling plan:

1. date and time of collection,
2. site identification,
3. sample matrix,
4. number of containers,
5. field treatments (preservative used or if the sample was filtered),
6. analyses required,
7. name of collector,
8. custody transfer signatures and dates and time of transfer,
9. name of laboratory admitting the sample, and

10. bill of lading (if applicable).

Field Data Sheet

A field data sheet is required to be carried in the field by the sampler for each run. Make entries in the field data sheet for all the field parameters. The field data sheet is included in the sampling plan.

Sample Label

The label should be placed on the glass sample bottles or placed on a label that is then attached to the sample containers. Samples are labeled with an indelible, waterproof marker. Label information includes the site identification, the date and time of sampling, sample type (*e.g.,* conventional water parameters, organics) and the preservative added, if applicable.

Sample Handling

Samples are collected in the field and stored in coolers and preserved on ice at 4˚C. Samples are delivered to water quality laboratory in coolers with COC forms attached. The laboratory staff examines each sample container for anomalies and ensures that all container information matches the information on the appropriate field data sheet. If the information is present and correct, the laboratory staff will receive the samples by signing the field data sheet "received by" block. At this instant, the samples become the responsibility of the water quality laboratory.

Failures in Chain-of-Custody and Corrective Action

All failures associated with chain-of-custody procedures are immediately reported to the project manager. These include such items as delays in transfer, resulting in holding time violations; violations of sample preservation requirements; incomplete documentation, including signatures; possible tampering of samples; broken or spilled samples, etc. The project manager, in consultation with the QAO, will determine if the procedural violation may have compromised the validity of the resulting data. Any failures that have reasonable potential to compromise data validity will invalidate data, and the sampling event should be repeated. The resolution of the situation will be reported to VADEQ in the monthly progress report. Corrective action reports will be maintained by the QAO.

B4 Analytical Methods Requirements

The analytical methods are listed in Table A.1 of Section A7. Copies of laboratory SOPs are retained by each laboratory and are available for review by VADEQ. Laboratory SOPs are consistent with EPA requirements, as specified in the method.

Standards Traceability

All standards used in the laboratory are traceable to certified reference materials. Standards preparation is fully documented and maintained in a standards log book. Each documentation includes information concerning the standard identification, starting materials (including concentration, amount used, and lot number), date prepared, expiration date, and preparer's initials or signature. The reagent bottle has to be labeled in a way that will trace the reagent back to preparation.

Failures in Measurement Systems and Corrective Actions

Failures in field and laboratory measurement systems involve, but are not limited to, such things as instrument malfunctions, failures in calibration, blank contamination, quality control samples outside QAPP defined limits, etc. In many cases, the field technician or laboratory analyst will be able to correct the problem. If the problem is resolvable by the field technician or laboratory analyst, then they will document the problem on the field data sheet or laboratory record and complete the analysis. If the problem is not resolvable, then it is conveyed to the Laboratory Supervisor, who will make the determination and notify the project QAO. If the analytical system failure may compromise the sample results, the resulting data will not be reported to VADEQ as part of this study. The nature and disposition of the problem is reported on the data report, which is sent to the Project Manager. The Project Manager will include this information on the monthly report, which is sent to VADEQ.

B5 Quality Assurance Control Requirements

The quality control requirements for sampling follow the procedures in Section III, Part B of the SOP Manual for VADEQ (VADEQ, 2003).

Equipment Blanks

1. Equipment blanks test for carry over contamination between sampling sites. Equipment blanks are samples generated from the sampling equipment in use.
2. The equipment blank may be performed in the field between stations.
3. One (1) equipment blank needs to be collected on each run where sediment sampling is being performed.
4. Analyte-free water is run through the sampling equipment and then poured into the respective sampling containers, preserved identically as samples normally being collected, and then sent to the lab to determine if there is possible contamination from the sampling equipment.
5. If the equipment blank results are three times above the method detection limits, the data is suspect and will be removed from the database by the QAO.

Duplicate Samples

1. Four percent of the sediment samples collected will be field duplicates.
2. The duplicate samples will be collected from one location as one sample of sufficient volume to homogenize and split it into two aliquots for analysis.
3. Duplicate samples will be collected and handled in accordance with procedures in the sampling plan.
4. The station in which duplicate samples will be collected will be chosen randomly.

Field Blanks - Field blanks consist of analyte-free de-ionized water that is taken to the field and transferred to the appropriate container in precisely the same manner as a sample during the course of a sampling event. They are used to assess the contamination from field sources such as airborne materials, containers, and preservatives. The analysis of field blanks should yield values less than the Method Detection Limit (MDL). When target analyte concentrations are high, blank values should be less then 5% of the lowest value of the batch. Thirteen field blanks will be collected, one at each monitoring station.

Field duplicates - A field duplicate is defined as a second sample (or measurement) from the same location, collected in immediate succession, using identical techniques. This applies to all cases of routine surface water collection procedures, including in-stream grab samples, bucket grab samples (*e.g.,* from bridges), pumps, and other water sampling devices. Duplicate samples are sealed, handled, stored, shipped, and analyzed in the same manner as the primary sample. Precision of duplicate results is calculated by the relative percent deviation (RPD) as defined by 100 times the difference (range) of each duplicate set, divided by the average value (mean) of the set. For duplicate results, X_1 and X_2, the RPD is calculated from the following equation:

$$\mathbf{RPD = \{ (X_1 - X_2)/ (X_1+X_2)/2 \}* 100}$$

Field duplicates will be collected at a frequency of 4% or greater.

Laboratory Measurement Quality Control Requirements and Acceptability Criteria

Detailed laboratory QC requirements are contained within each individual method and Laboratory Quality Assurance Manuals. The minimum requirements that all participants abide by are stated below. Lab QC sample results are reported with the data report (Section C2).

Laboratory duplicate - Laboratory duplicates are used to assess precision. A laboratory duplicate is prepared by splitting aliquots of a single sample (or a matrix spike or a laboratory control standard) in the laboratory. Both samples are carried through the entire preparation and analytical process. Laboratory duplicates are analyzed on 10% of samples analyzed. Acceptability criteria are outlined in Table A.1 of Section A7.

Precision is calculated by the relative percent deviation (RPD) of duplicate results as defined by 100 times the difference (range) of each duplicate set, divided by the average value (mean) of the set. For duplicate results, X_1 and X_2, the RPD is calculated from the following equation:

$$\mathbf{RPD = \{ (X_1 - X_2)/ (X_1+X_2)/2 \}* 100}$$

A duplicate is considered to be a special type of laboratory duplicate and applies when samples are run in the field as well as in the laboratory. Duplicate analyses are performed on samples from the sample bottle on a 10% basis. Calculating the logarithm of each result and determining the range of each pair evaluate results of duplicates. Precision limits for analyses are defined in Table A.1.

Performance limits and control charts are used to determine the acceptability of duplicate analyses.

<u>Laboratory Control Standard (LCS) and Laboratory Control Standard Duplicates (LCSDs)</u>- A laboratory control sample is analyte-free water spiked with the analyte of interest prepared from standardized reference material. A laboratory control sample duplicate is a second LCS prepared in the same manner. The LCS and LCSD are generally spiked into laboratory pure water at a level less than or equal to the mid-point of the calibration curve for each analyte. The LCS and LCSD are carried through the complete preparation and analytical process. The LCS is used to document the accuracy of the method due to the analytical process. LCSs/LCSDs are generally run at a rate of one each per batch. Acceptability criteria are laboratory specific and usually based on results of past laboratory data (*i.e.,* control charts). LCSs/LCSDs are routinely incorporated into the analysis program. The analysis of LCSs is a measure of accuracy and is calculated by Percent Recovery (%R). Percent Recovery is defined as 100 times the observed concentration, divided by the true concentration of the spike.

The formula used to calculate percent recovery, where %R is percent recovery, SR is the observed spiked sample concentration, and SA is the spike added:

$$\mathbf{\%R = [SR/SA] * 100}$$

<u>Matrix spikes (MS) and matrix spike duplicates</u>- A matrix spike is an aliquot of sample spiked with a known concentration of the analyte of interest. A matrix spike duplicate (MSD) is a second matrix spike prepared in exactly the same way. Percent recovery of the known concentration of added analyte is used to assess accuracy of the analytical process. The spiking occurs prior to sample preparation and analysis. Matrix spike samples and matrix spike duplicates are routinely prepared and analyzed at a rate of 10% of samples processed. The MS is spiked at a level less than or equal to the midpoint of the calibration or analysis range for each analyte. The MS is used to document the accuracy of a method due to the sample matrix and not to control the analytical process. Acceptability criteria are outlined in Table A.1 of Section A7 and are calculated by Percent Recovery. Percent Recovery (%R) is defined as 100 times the observed concentration, minus the sample concentration, divided by the true concentration of the spike. Acceptance criteria are defined in Table A.1 of Section A7.

The formula used to calculate percent recovery, where %R is percent recovery, SSR is the observed spiked sample concentration, SR is the sample concentration, and SA is the spike added is:

$$\%R = [(SSR - SR)/SA] * 100$$

Method Blank- A method blank is an analyte-free matrix to which all reagents are added in the same volumes or proportions as used in the sample processing and analyzed with each batch. The method blank is carried through the complete sample preparation and analytical procedure. The method blank is used to document contamination from the analytical process. The analysis of method blanks should yield values less than the method detection limit. For very high-level analyses, blank value should be less than 5% of the lowest value of the batch.

Additional method specific QC requirements - Additional QC samples are run (*e.g.*, surrogates, internal standards, continuing calibration samples, interference check samples) as specified in the methods. The requirements for these samples, their acceptance criteria, and corrective actions are method-specific.

Failures in Quality Control and Corrective Action

The Project Manager, in consultation with the QAO, evaluates sampling QC excursions. In that differences in field duplicate sample results are used to assess the entire sampling process, including environmental variability, the arbitrary rejection of results based on pre-determined limits is not practical. Therefore, the professional judgment of the Project Manager and the QAO will be relied upon in evaluating results. Rejecting sample results based on wide variability is a possibility. Field blank values exceeding the acceptability criteria may automatically invalidate the sample, especially in cases where high blank values may be indicative of contamination, which may be causal in putting a value above the standard. Notations of field duplicate excursions and blank contamination are noted in the quarterly report and the final QC Report.

Corrective action will involve identification of the cause of the failure where possible. Response actions will typically include re-analysis of questionable samples. In some cases, a site may have to be re-sampled to achieve project goals.
The laboratory staff evaluates laboratory measurement quality control failures. The disposition of such failures and conveyance to VADEQ are discussed above under the heading of Failures in Measurement Systems and Corrective Actions in Section B4: Analytical Methods Requirements.

B6 Instrument/Equipment Testing, Inspection and Maintenance Requirements

Sampling equipment testing and maintenance requirements are detailed in the sampling plan.

B7 Instrument Calibration and Frequency

Detailed laboratory calibrations are contained within the QAM(s). The laboratory QAM identifies all tools, gauges, instruments, and other sampling, measuring, and test equipment used for data collection activities affecting quality that must be controlled and, at specified periods, calibrated to maintain bias within specified limits. Calibration records are maintained and are available for inspection by the laboratory. The equipment requiring periodic calibrations includes, but is not limited to, thermometers, pH meters, balances, incubators, and analytical instruments.

B8 Inspection/Acceptance Requirement for Supplies and Consumables

All new batches of field and laboratory supplies are inspected and tested before use to ensure that they are adequate and not contaminated.

B9 Non-Measurement Data (Data Acquisition Requirements)

The MapTech team will not collect non-measurement data as a part of this work plan. Only data collected directly under this QAPP will be submitted to VADEQ. All data collected under this QAPP will comply with all requirements of the project and the QAPP.

B10 Data Management

Data Management Protocols are addressed in the Data Management Plan (Appendix C).

References

Ongley, E. 2001. Sediment measurements. In *Water Quality Monitoring: a Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*, 315-333. London: Spon Press.

VADEQ. 2001. *Standard Operating Procedures for Clean Metals Sampling*. Revision no.20001105. Richmond, VA: Virginia Department of Environmental Quality.

VADEQ. 2003. *Standard Operating Procedures Manual for the Department of Environmental Quality; Office of Water Quality Monitoring and Assessment.* Revision no.10. Richmond, VA: Virginia Department of Environmental Quality.

C1 Assessments and Response Actions

The following table presents types of assessments and response action for data collection activities applicable to the QAPP.

Table C.1 Assessments and response actions.

Assessment Activity	Approximate Schedule	Responsible Party	Scope	Response Requirements
Status Monitoring Oversight, etc.	Continuous	Project Manager	Monitoring of the project status and records to ensure requirements are being fulfilled. Monitoring and review of contract laboratory's performance and data quality	Report to VADEQ in Monthly Report. Ensure project requirements are being fulfilled.
Laboratory Inspections	Dates to be determined by Laboratory QAO	Laboratory QAO	Analytical and quality control procedures employed at the laboratory	Implements corrective action. Report sent to Project Manager

Corrective Action

The Project Manager is responsible for implementing and tracking corrective action procedures as a result of audit findings. Records of audit findings and corrective actions are maintained by both the laboratory and project Quality Assurance Officers.

C2 Reports to Management

Laboratory Data Reports

Laboratory data reports contain the results of all specified QC measures listed in section B5 including, but not limited to, equipment blanks, filter and reagent blanks, field blanks, laboratory duplicates, laboratory control standards, calibrations, and matrix spikes. This information is reviewed by the QAO and compared to the pre-specified acceptance criteria to determine acceptability of data before forwarding to the Project Manager. This information is available for inspection by the DEQ.

Reports to VADEQ Project Management

The Monthly Progress Report summarizes MapTech, Inc. activities for each task; reports problems, delays, and corrective actions; and outlines the status of each task's deliverables.

D1 Data Review, Validation, Verification Requirements

For the purposes of this document, verification means the processes taken to determine compliance of data with project requirements, including documentation and technical criteria. Validation means those processes taken independently of the data-generation processes to determine the usability of data for its intended use(s). Integrity means the processes taken to ensure that no falsified data will be reported.

All data obtained from field and laboratory measurements will be reviewed and verified for conformance to project requirements, and then validated against the data quality objectives, which are listed in Section A7. Only those data, which are supported by appropriate quality control data and meet the data quality objectives defined for this project, will be considered acceptable.

The procedures for verification and validation of data are described in Section D2 below. The Field Supervisor is responsible for ensuring that field data are properly reviewed and verified for integrity. The Laboratory Managers are responsible for ensuring that laboratory data are scientifically valid, defensible, of acceptable precision and accuracy, and reviewed for integrity. The Data Manager will be responsible for ensuring that all data are properly reviewed and verified, and submitted in the required format to the project database. The QAO is responsible for validating the data. The Project Manager, with the concurrence of the QAO, is responsible for validating that all data to be reported meet the objectives of the project and are suitable for reporting to VADEQ.

D2 Validation and Verification Methods

All data will be verified to ensure that they are representative of the samples analyzed and locations where measurements were made, and that the data and associated quality control data conform to project specifications. The staff and management of the respective field, laboratory, and data management tasks are responsible for the integrity, validation and verification of the data each task generates or handles throughout each process. The field and laboratory tasks ensure the verification of raw data, electronically generated data, and data on chain-of-custody forms and hard copy output from instruments.

Verification, validation and integrity review of data will be performed using self-assessments and peer review, as appropriate to the project task, followed by technical review by the manager of the task. The data to be verified (listed by task in Table D.1) are evaluated against project specifications (Section A7) and are checked for errors, especially errors in transcription, calculations, and data input. Potential outliers are identified by examination for unreasonable data, or identified using computer-based statistical software. If a question arises or an error or potential outlier is identified, the manager of the task responsible for generating the data is contacted to resolve the issue. Issues that can be corrected are then corrected and documented, either electronically or by initialing and dating the associated paperwork. If an issue cannot be corrected, the task manager consults with higher-level project management to establish the appropriate course of action, or the data associated with the issue are rejected.

The Project Manager and QAO are each responsible for validating that the verified data are scientifically valid, defensible, of known precision, accuracy, and integrity, meet the data quality objectives of the project, and are reportable to VADEQ. One element of the validation process involves evaluating the data again for anomalies. The QAO or Project Manager may designate other experienced water quality experts familiar with the water bodies under investigation to perform this evaluation. Any suspected errors or anomalous data must be addressed by the manager of the task associated with the data before data validation can be completed.

Table D.1 Data verification procedures.

Data to be Verified	**Field Task**	**Laboratory Task**	**Data Manager Task**
Sample documentation complete; samples labeled, sites identified	✓	✓	
Field QC samples collected for all analytes	✓		
Standards and reagents traceable	✓	✓	
Chain of custody complete/acceptable	✓	✓	
Sample preservation and handling acceptable	✓	✓	
Holding times not exceeded	✓	✓	
Collection, preparation and analysis techniques consistent with SOPs and QAPP	✓	✓	✓
Field documentation (*e.g.*, biological, stream habitat) complete	✓		
Instrument calibration data complete	✓	✓	
Sediment records complete	✓	✓	
QC samples analyzed at required frequencies	✓	✓	✓
QC results meet performance and program specifications	✓	✓	✓
Analytical sensitivity consistent with QAPP	✓	✓	✓
Results, calculations, transcriptions checked	✓	✓	
Laboratory bench-level review performed		✓	
All laboratory samples analyzed for all parameters		✓	
Corollary data agree	✓	✓	✓
Nonconforming activities documented	✓	✓	✓
Outliers confirmed and documented; reasonableness check performed			✓
Dates formatted correctly			✓
Depth reported correctly			✓

Appendix A: Work Plan

Table 1. Lewis Creek TMDL project timetable.

Milestone	Target Completion (time from award)
QAPP Development	**3 weeks**
Data Collection/Laboratory Analysis	
Location of industrial sites and land fills, site conditions, flow pathways	**4 weeks**
Conductivity Analysis- Field work and interpretation	**4 weeks**
Collection of sediment samples	**4 weeks**
Collection of baseflow water column samples	**6 weeks**
Collection of storm flow water column samples	**6 weeks**
Laboratory Analysis by ProCHEM and delivery of results to MapTech	**8 weeks**
Laboratory Analysis by DCLS and delivery of results to MapTech	**8 weeks**
Analysis of results to determine station for toxicity testing	**8 weeks**
Collection of sediment samples for toxicity testing	**9 weeks**
Toxicity testing by Environmental Services Consulting and delivery of results to MapTech.	**11 weeks**
Analysis of new data/interpretation of results/TMDL targets	**12 weeks**
Draft report of analysis/interpretation of results/presentation to VADEQ	**13 weeks**
Revision of document as may be required by VADEQ and submittal to EPA for review	**14 weeks**
Revision of document as may be required by EPA/VADEQ	**16 weeks**
Approval to move forward with TMDL from EPA/VADEQ	**16 weeks**
Collection of soil samples as needed based on technical approach	**18 weeks**
Laboratory Analysis by DCLS and delivery to MapTech	**20 weeks**
Laboratory Analysis by ProCHEM and delivery to MapTech	**20 weeks**
TMDL Development	
Completion of Chapters 1, 2, and 3 and delivery to VADEQ	**16 weeks**
First Public meeting	**17 weeks**
Model development	**20 weeks**
Model calibration/validation	**22 weeks**
TMDL allocations	**23 weeks**
Draft TMDL report to VADEQ	**24 weeks**
Revision of document as may be required by VADEQ and submittal to EPA for review	**26 weeks**
Revision of document as may be required by EPA/VADEQ	**28 weeks**

Appendix B: Laboratory Methods

Attachment 1: SW-846 Method 8270C (PAH)[1]

Attachment 2: SW-846 Method 8082C (PCB)[1]

Attachment 3: SW-846 Method 8081A (Organochlorine Pesticide)[1]

Attachment 4: EPA Method 100.1

Attachment 5: EPA Method 100.2

[1]Attachment 1, 2, and 3 contain methods from the EPA publication SW-846, entitled *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*. These methods are from SW-846 are followed by ProChem Analytical, Inc. The laboratory methods included in appendix B-1 are Method 8270C (PAH), Method 8082 (PCB), and Method 8081A (Organochlorine Pesticide).

SW-846 Manual: Test Methods for Evaluating Solid Waste, Physical/Chemical Methods.
Available at: http://www.epa.gov/epaoswer/hazwaste/test/main.htm. Accessed 2 February 2005.

Appendix C: Data Management

Personnel –
Field crews for the Lewis Creek TMDL Project will follow protocols that ensure that the MapTech team database maintains its integrity and usefulness. The project team responsible for data management will be Dr. James Kern, Project Manager, Dr. Karen Kline, Data Manager, and Mr. Rod Bodkin, Field Supervisor. The database manager will review all data reports submitted from the Field Supervisor and will forward the reports to the Quality Assurance Officer, Mr. Phillip McClellan, with his evaluation of said reports. Should any items of concern occur, Mr. Phillip McClellan will notify the applicable Field Supervisor and Laboratory Quality Assurance Officer and verify that transcription errors were not made and ensure that all necessary corrective actions have been taken in reassessing samples that may have been affected by non-compliance in quality control.

System Design – Hardware and Software Requirements –
The data generated is stored in Microsoft Access. All data will be backed up to a CD.

Data Management Implementation –
Field data collected at the time of the sampling event is logged by the field technicians, along with notes on sampling conditions in field logs or on field data sheets. The field log/sheet is the responsibility of the field technicians, and is transported with the sample to the laboratory. The field technician logs the sample in a Microsoft Access Lab Samples Database. Each sample is assigned a separate and distinct sample number. A chain of custody also accompanies the sample. The field technician must review the chain of custody to verify that it is filled out correctly and completely. Laboratory technicians in the laboratory take receipt of the sample, review the chain of custody, and begin analysis.

The Laboratory QAO for each laboratory supervises the laboratory and reviews the report that is generated when all analyses are complete. The report is reviewed to see that all necessary information is included and that the data quality objectives have been met. When the report is complete, the Laboratory QAO signs the report. A hard copy is kept on file. If the Laboratory QAO feels that there has been an error or finds that information is missing, the report is returned to the analyst for review and tracking to correct the error and generate a corrected copy. The QAO analyzes the data for quality assurance and provides it to the data manager. The Project Manager is responsible for transmittal of the data to VADEQ from the data manager in the required format.

Laboratories –
The laboratory manager or quality assurance officer of the laboratory will provide hard copy data of the analysis in report form to the Data Manager for QA/QC. These reports will contain the results of all specified quality control measures listed in section B5 including, but not limited to, equipment blanks, filter and reagent blanks, field blanks, laboratory duplicates, laboratory control standards, calibration, and matrix spikes.

Quality Assurance/Control –
See Section D of the QAPP.

Migration/Transfer –
As data is generated in the field as well as from laboratory procedures, it is input onto the appropriate field and laboratory logs. Data generated in the laboratory will be entered into the database and sent to the Data Manager.

Backup/Disaster Recovery -
The Project Manager for the project coordinates with the Data Manager on the scheduling of backups. The Data Manager coordinates the backup of the database.

Archives/Data Retention –
Complete original data sets are archived on CD-ROM and retained on-site by the MapTech team for a retention period specified in the original QAPP. The project Data Manager is responsible for producing the CD-ROM copies, which are made as necessary.

Appendix D: Example Letter to Document Adherence to QAPP

Example letter to document adherence to the QAPP

TO: *(name)*
(organization)

FROM: *(name)*
(organization)

Please sign and return this form by (*date*) to:

(*address)*

I acknowledge receipt of the referenced document(s). I understand the document(s) describe quality assurance, quality control, and other technical activities that must be implemented to ensure the results of work performed will satisfy stated performance criteria.

______________________________ ______________________

Signature Date

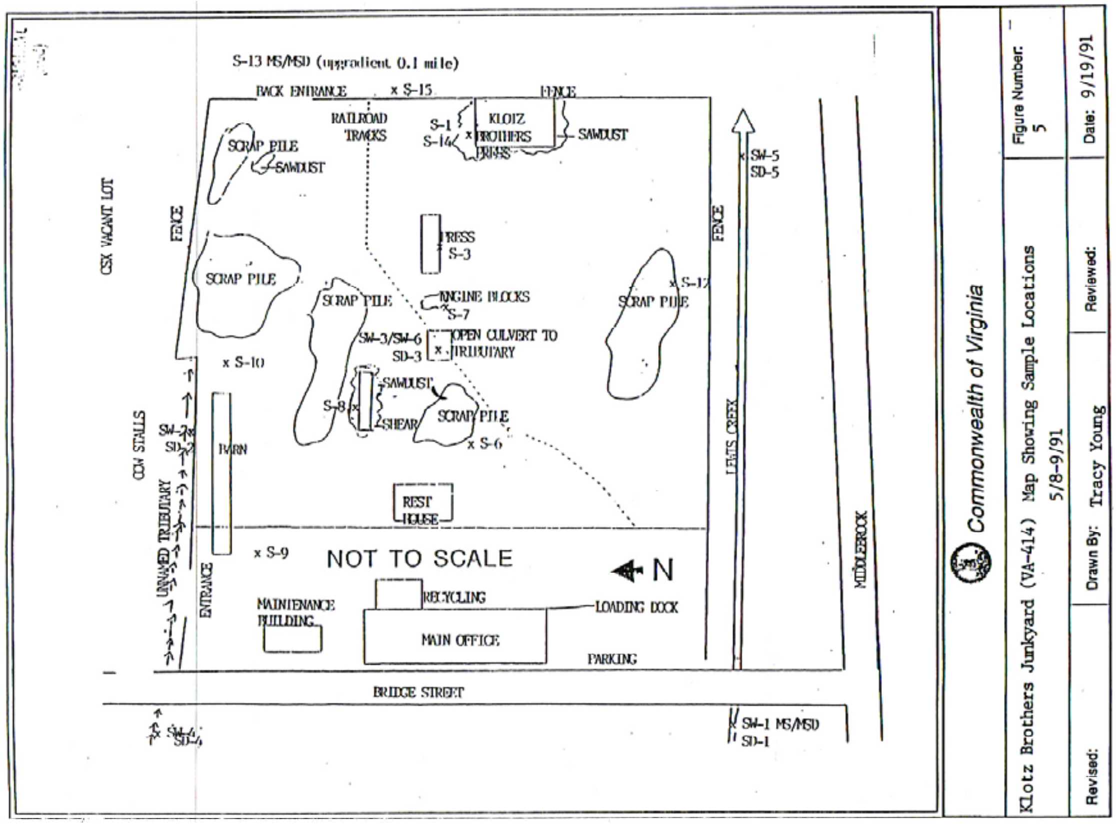
APPENDIX C

Appendix C-1

Screening Site Inspection Virginia Department of Waste Management

November 21, 1991

Site Map



Appendix C-2

Surface Water Data

Parameter	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6
Lead (μg /L)	2.9B	9	7.4	3.2B	6.2B	7.6

B Not detected substantially above the level reported in laboratory or field blanks.

Appendix C-3

Soils Data

Parameter (mg/kg)	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-10	S-11
Lead	217	171	3,020L	50.8	28.9	102	760	1620	224	1,010	
Polycyclic Aromatic Hydrocarbons											
Acenaphthene	<	<	<	<	<	<	<	<	<	<	<
Acenaphthylene	<	<	<	<	<	<	<	<	<	<	<
Anthracene	<	<	<	<	<	<	<	<	<	<	<
Benzo(a)anthracene	<	0.29J	0.12J	0.43J	<	0.25J	1.4J	<	<	1.00J	<
Benzo(a)pyrene	<	0.29J	0.092J	0.34J	<	0.077J	0.910J	<	<	<	<
Benzo(b)fluoranthene	<	0.42J	0.14J	0.49J	<	0.20J	1.60J	<	<	1.80J	<
Benzo(g,h)perylene	<	<	<	0.32J	<	<	<	<	<	<	<
Benzo(k)fluoranthene	<	0.37J	0.14J	0.40J	0.096J	0.17J	1.70J	<	<	<	<
Chrysene	<	0.41J	0.14J	0.54J	<	0.37J	1.70J	<	<	<	<
Dibenz(a,h)anthracene	<	<	<	<	<	<	<	<	<	<	<
Fluoranthene	<	0.77J	0.76J	0.74J	0.13J	0.250J	2.30J	<	1.10J	2.40J	<
Fluorene	<	<	<	<	<	0.093J	<	<	<	<	<
indeno(1,2,3-cd)pyrene	<	<	<	0.29J	<	<	<	<	<	<	<
Naphthalene	<	<	<	<	<	1.40J	<	<	<	<	<
Phenanthrene	0.730J	0.37J	0.13J	0.31J	<	1.40J	<	<	<	0.180J	<
Pyrene	1.00J	0.83J	1.50J	0.86J	0.11J	0.37J	3.5J	<	<	3.50J	<
Total PAHs	1.73J	3.75J	3.02J	4.72J	0.336J	4.58J	13.11J	<	1.10J	8.88J	<

Soils Data continued

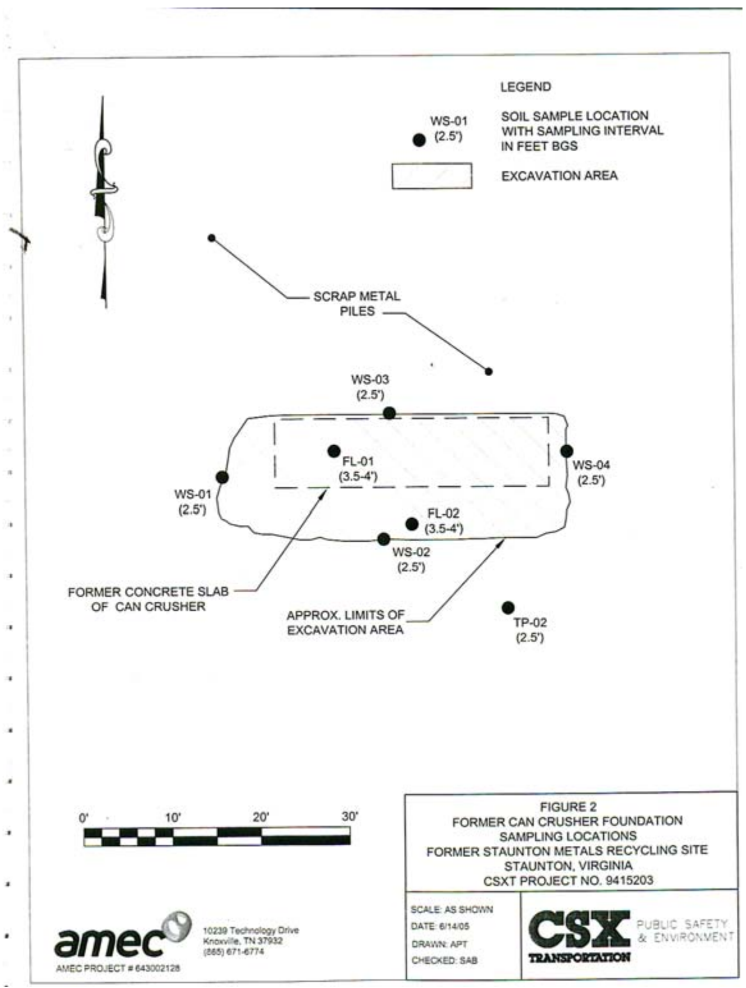
Parameter (mg/kg)	S-12	S-13	S-14	S-15
Lead	354	349		164
Polycyclic Aromatic Hydrocarbons				
Acenaphthene	<	<	<	<
Acenaphthylene	<	<	<	<
Anthracene	<	<	<	<
Benzo(a)anthracene	<	<	<	<
Benzo(a)pyrene	<	<	<	<
Benzo(b)fluoranthene	<	1.10J	<	0.68J
Benzo(g,h)perylene	<	<	<	<
Benzo(k)fluoranthene	0.89J	<	<	<
Chrysene	1.3J	<	<	<
Dibenz(a,h)anthracene	<	<	<	<
Fluoranthene	2.00J	<	1.40J	
Fluorene	<	<	<	<
indeno(1,2,3-cd)pyrene	<	<	<	<
Naphthalene	<	<	<	<
Phenanthrene	0.860J	<	0.78J	<
Pyrene	2.80J	<	1.50J	<
Total PAHs	7.85J	1.10J	3.68J	0.68J

APPENDIX D

Appendix D-1

Sub-surface soil samples from former can crushing area from AMEC, Inc. July 8, 2005. Data collected from former can crusher foundation area.

Site Map



Appendix D-2

AMEC, Inc. Sub-Surface Soils Data

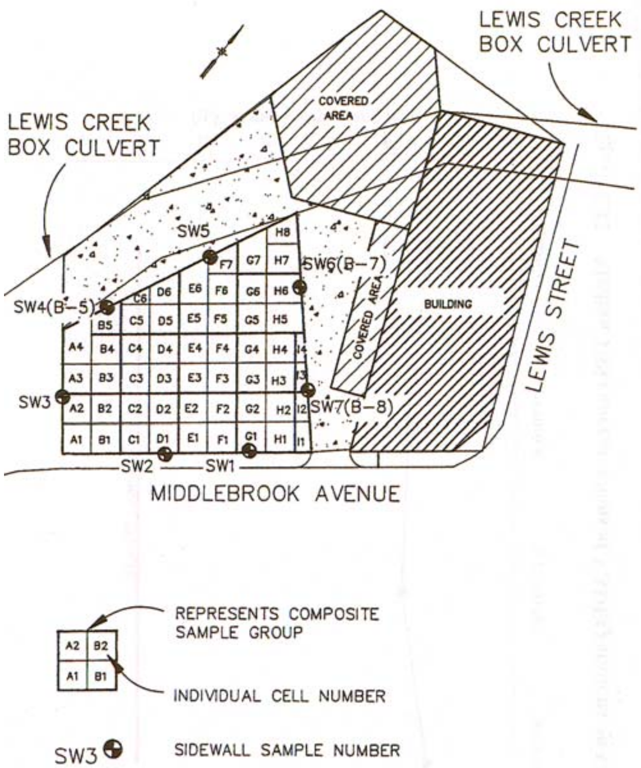
Parameter (mg/kg)	WS-01 (2.51)	WS-02 (2.51)	WS-03 (2.51)	WS-04 (2.51)	FL-01 (3.5-4')	FL-02 (3.5-41)	TP-02 (2.51)
Lead	1,940	1,010	2,480	789	48	44	329
Polycyclic Aromatic Hydrocarbons							
Acenaphthene	1.12	0.0866 J	0.743 J	<0.150	<0.0410	<0.0410	<0.760
Acenaphthylene	0.0978 J	0.112J	0.220 J	<0.150	<0.0410	<0.0410	<0.760
Anthracene	1.97	0.211	0.823	<0.150	<0.0410	<0.0410	<0.760
Benzo(a)anthracene	3.8	0.319	1.56	0.290 J	0.0731 J	0.0892 J	<0.760
Benzo(a)pyrene	3.42	0.321	1.47	0.348 J	0.0808 J	0.1 06 J	<0.760
Benzo(b)fluoranthene	4.32	0.682	2.09	0.546 J	0.1 23 J	0.1 39 J	<0.760
Benzo(g,h,i)perylene	1.93	0.263	1	0.296 J	<0.0810	<0.0820	<1 .500
Benzo(k)fluoranthene	1.49	0.140 J	0.717 J	0.169 J	0.0428 J	0.0442 J	<0.760
Butyl benzyl phthalate	<0.20	<0.094	<0.390	0.378 J	<0.100	<0.100	<1.900
Chrysene	3.86	0.545	1.9	0.382 J	0.0945 J	0.119J	<0.760
Fluoranthene	7.46	0.524	3.81	0.682 J	0.142 J	0.239	<0.760
Fluorene	0.914	0.910 J	0.673 J	<0.150	<0.0410	<0.0410	<0.760
lndeno(1 ,2,3-cd)pyrene	2.04	0.28	1.05	<0.290	<0.0810	<0.0820	<1.500
Naphthalene	0.244 J	0.293	0.307 J	<0.150	<0.0410	<0.0410	<0.760
Phenanthrene	5.4	0.485	3.19	0.491 J	0.0923 J	0.205	<0.760
Phenol	<0.08	<0.04	0.308 J	<0.150	<0.0410	<0.0410	<0.760
Pyrene	6.27	0.624	3.8	0.844	0.1 54 J	0.208	<1.500
Total PAHs	44.34	5.68	23.66	4.43	0.80	1.15	0.00

J Estimated concentration; compound detected below quantitation limit, < Below minimum detection level.

APPENDIX E

Construction Closure Report, Klotz Brothers Courtyard Site, Hatcher-Sayre, Inc. January 1997

Site Map



DESCRIPTION	DATE COLLECTED	TOTAL LEAD
SIDEWALL 1	12/16/96	280.0 PPM
SIDEWALL 2	12/16/96	235.0 PPM
SIDEWALL 3	12/11/96	57.8 PPM
SIDEWALL 4	8/8/96	472.0 PPM
SIDEWALL 5	12/16/96	51.6 PPM
SIDEWALL 6	8/8/96	469.0 PPM
SIDEWALL 7	8/8/96	392.0 PPM
A,B,1,2	12/11/96	37.4 PPM
A,B,3,4,5	12/11/96	64.8 PPM
C,D,1,2	12/11/96	302.0 PPM
C,D,3,4	12/11/96	149.0 PPM
C,D,5,6	12/13/96	37.0 PPM
E,F,1,2	12/13/96	107.0 PPM
E,F,3,4	12/16/96	118.0 PPM
E,F,5,6,7	12/16/96	128.0 PPM
G,H,1,2	12/13/96	219.0 PPM
G,H,3,4	12/17/96	110.0 PPM
G,H,5,6	12/17/96	80.1 PPM
G,H,7,8	12/17/96	68.1 PPM
I,1,2	12/13/96	86.7 PPM
I,3,4	12/17/96	67.0 PPM

AVERAGE CELL DEPTH FEET BELOW GRADE

ROW \ COLUMN	1	2	3	4	5	6	7	8
A	4.6	5.1	5.7	6.2	NA	NA	NA	NA
B	5.0	4.7	5.3	5.4	5.5	NA	NA	NA
C	4.5	4.9	4.5	4.7	6.0	6.0	NA	NA
D	3.6	3.7	3.7	4.2	6.0	6.0	NA	NA
E	4.4	4.5	4.1	4.5	4.8	4.6	NA	NA
F	4.3	4.6	4.9	4.1	4.2	4.9	4.6	NA
G	4.2	4.4	4.2	4.7	4.6	4.7	4.9	NA
H	4.6	4.5	4.4	4.2	4.3	4.6	5.0	4.9
I	4.8	4.8	4.0	3.9	NA	NA	NA	NA

HATCHER-SAYRE, INC.

FIGURE 5
KLOTZ BROTHERS, INC.
CONFIRMATION SOIL SAMPLING PLAN
STAUNTON, VIRGINIA

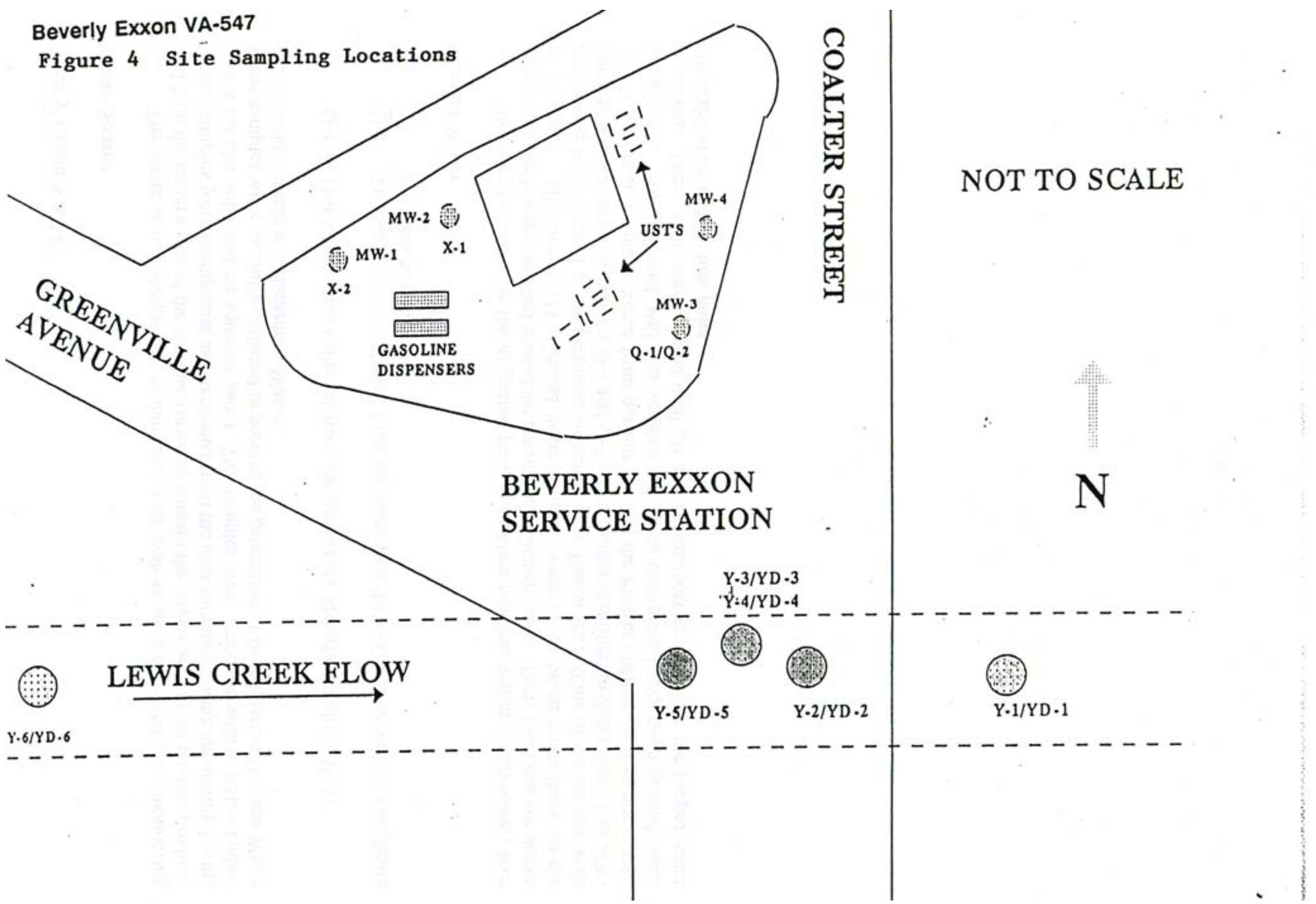
JOB #: 0042-001
SCALE: 1" = 30'
DRAWN BY: M.C.W.
JAN. 1997

APPENDIX F

Appendix F-1

Screening Site Inspection, Department of Environmental Quality, December 5, 1992

Site Map



Appendix F-2

Sampling Sites

TABLE 1: SAMPLING LOCATIONS

Sample Number	Sample Type	Location	Date Sampled
Q-1	Multiphase	Waste Source	4/29/92
Q-2	Multiphase	Waste Source Duplicate	4/29/92
X-1	Water	Northwest On-Site Well	Not taken
X-2	Water	Western On-Site Well	4/29/92
X-3	Water	Background 450 Feet Northwest	4/29/92
Y-1	Water	Lewis Creek after Bridge	4/28/92
Y-2	Water	Downstream from Point of Entry	4/28/92
Y-3	Water	Point of Entry	4/28/92
Y-4	Water	Point of Entry Duplicate	4/28/92
Y-5	Water	Upstream from Point of Entry	4/28/92
Y-6	Water	Upstream of Beverly Exxon	4/29/92
YD-1	Sediment	Soil Sediment Sample of Y-1	4/28/92
YD-2	Sediment	Soil Sediment Sample of Y-2	4/28/92
YD-3	Sediment	Soil Sediment Sample of Y-3	4/28/92
YD-4	Sediment	Soil Sediment Sample of Y-4	4/28/92
YD-5	Sediment	Soil Sediment Sample of Y-5	4/28/92
YD-6	Sediment	Soil Sediment Sample of Y-6	4/29/92

Appendix F-3

Surface Water Data

Parameter (mg/L)	Y-1	Y-2	Y-3	Y-4	Y-5	Y-6
Lead	0.038	0.017	0.014	0.023	0.009	0.002
Polycyclic Aromatic Hydrocarbons						
Acenapthylene	<	<	0.007	0.008	<	<
Acenaphthene	<	<	0.009	0.041	<	<
Fluorene	<	<	0.017	0.054	<	<
Phenanthrene	<	<	0.077	0.11	<	<
Anthracene	<	<	0.032	0.045	<	<
Fluoranthene	<	<	0.1	0.11	<	<
Pyrene	<	<	0.16	0.15	<	<
Benzo(a)anthracene	<	<	0.078	0.088	<	<
Chrysene	<	<	0.065	0.054	<	<
Benzo(b)fluoranthene	<	<	0.088	0.089	<	<
Benzo(k)fluoranthene	<	<	0.088	0.089	<	<
Benzo(a)pyrene	<	<	0.058	0.054	<	<
Indeno(l ,2,3-cd)pyrene	<	<	0.034	0.024	<	<
Dibenz(a,h)anthracene	<	<	0.015	0.012	<	<
Benzo(g,h,i)perylene	<	<	0.042	0.033	<	<
Total PAHs			0.87	0.961		

Appendix F-4

Lewis Creek Sediment Data

Parameter (mg/kg)	YD-1	YD-2	YD-3	YD-4	YD-5	YD-6
Lead	366	55.8	289	139	532	246
Polycyclic Aromatic Hydrocarbons						
Acenaphthenc	0.06	0.11	17.00	25.00	0.23	<
Acenapthylene	<	0.06	6.80	9.40	<	<
Anthracene	0.04	0.38	18.00	24.00	0.49	0.05
Benzo(a)anthracene	0.12	0.66	32.00	88.00	1.70	0.24
Benzo(a)pyrene	0.11	0.58	19.00	24.00	1.30	0.21
Benzo(b)fluoranthene	0.12	0.48	44.00	66.00	1.80	0.22
Benzo(g,h,i)perylene	0.10	0.30	9.30	16.00	1.30	0.16
Benzo(k)fluoranthene	0.10	0.57	44.00	66.00	1.30	0.24
Chrysene	0.13	0.64	29.00	45.00	3.10	0.28
Dibenz(a,h)anthracene	0.03	0.12	3.80	6.40	0.77	0.08
Fluoranthene	0.28	1.10	55.00	87.00	2.50	0.60
Fluorene	0.03	0.22	28.00	45.00	0.25	<
Indeno(l ,2,3-cd)pyrenc	0.03	0.37	8.90	14.00	1.30	0.16
Naphthalene	<	0.03	82.00	110.00	0.06	<
Phenanthrene	0.16	1.30	87.00	140.00	3.50	0.31
Pyrene	0.28	1.50	62.00	96.00	4.70	0.49
Total PAHs	1.59	8.42	545.80	861.80	24.30	3.04

< Concentration below minimum detection level.

Appendix F-5

Ground Water Data

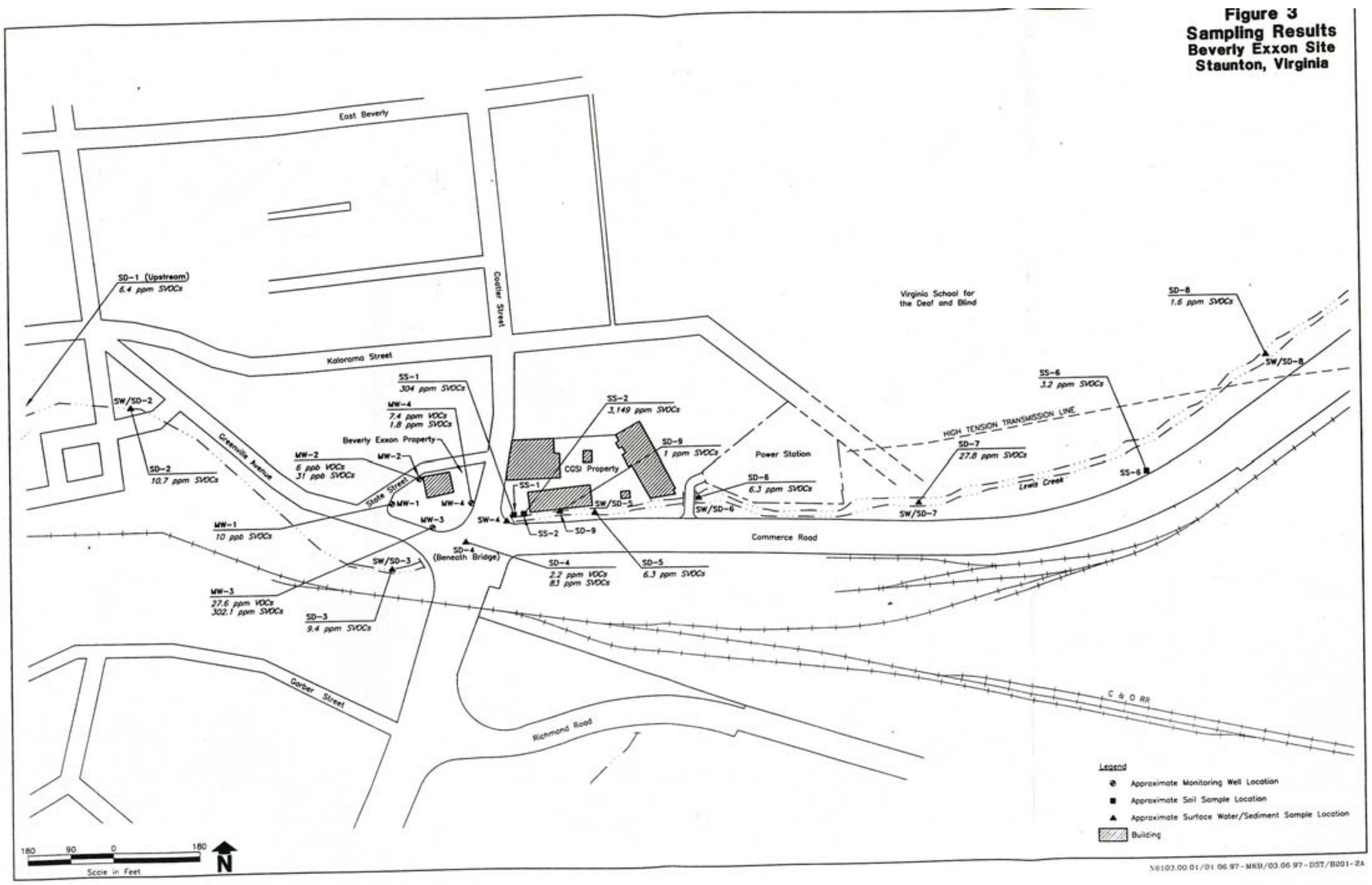
Parameter (mg/L)	X-2	X-3	X-4
Lead	0.02	0.05	0.00

APPENDIX G

Appendix G-1

Hazard Ranking System (HRS) Scoring Package, May 6, 1997 by ERM, Inc. (Note: Samples were split with the Expanded Site Inspection performed by EPA at the same time.

Site Map



Appendix G-2

Surface Water Data

Parameter (mg/L)	**SW-1**	**SW-2**	**SW-3**	**SW-4**	**SW-5**	**SW-6**	**SW-7**	**SW-8**
Lead	<	<	<	0.002B	0.003B	<	<	<

< Compound not detected, B Compound identified but concentration unknown due to blank contamination interference

Appendix G-3

Ground Water Data

Parameter (mg/L)	MW-1	MW-2	MW-3	MW-3 (Oil)*	MW-4
Lead	0.033	0.058	0.369	0.005	0.448
Polycyclic Aromatic Hydrocarbons					
Acenaphthene	0.004J	0.010J	16	3,200	0.094J
Acenaphthylene	<	0.003J	2.4J	540J	0.013J
Anthracene	<	<	15	2,700	0.06
Benzo[a]anthracene	<	<	18	3,100	0.073
Benzo[a]pyrene	<	0.001J	16	2,700	0.052
Benzo[b]fluoranthene	<	<	7.9J	1,500J	0.043J
Benzo[g,h,i]perylene	<	0.003J	9.30	600J	0.029J
Benzo[k]fluoranthene	<	<	6.3J	1,600J	0.04J
Chrysene	<	<	0	3,000	0.072
Dibenz[a,h]anthracene	<	<	5.4J	320J	0.012J
Fluoranthene	0.001J	0.001J	21	3,700	0.17
Fluorene	<	<	15	2,600	0.08
Indeno[1,2,3-cd]pyrene	<	0.002	8.2	630J	0.024J
Naphthalene	<	0.002J	28	4,600	0.15
Phenanthrene	0.001J	0.001J	48	8,400	0.21
Pyrene	0.002J	0.001J	33	5,100	0.17
Total PAHs	0.008	0.024	250	44,290	1.292

* There was approximately 18” of free product on top of the water in well 3. This substance was analyzed separately from the water sample taken from the well, J Estimated concentration; compound detected below quantitation limit, < Below minimum detection level.

Appendix G-4

Soils Data*

Parameter (mg/kg)	SS-1	SS-2	SS-6
Lead	0.053NL	0.136NL	0.216NL
Polycyclic Aromatic Hydrocarbons			
Acenaphthene	1.2J	<	<
Acenaphthylene	4.0J	13.0J	<
Anthracene	11	100	0.19J
Benzo[a]anthracene	28	250	0.31J
Benzo[a]pyrene	27	230	0.36J
Benzo[b]fluoranthene	30	270	0.37J
Benzo[g,h,i]perylene	19	140	<
Benzo[k]fluoranthene	14.0J	120J	0.31J
Chrysene	27	230	0.35J
Dibenz[a,h]anthracene	8.2	67J	<
Fluoranthene	51	500	0.50J
Fluorene	2.2J	22.0J	<
Indeno[1,2,3-cd]pyrene	24	200	0.12J
Naphthalene	1.10J	12.0J	<
Phenanthrene	30	370	0.19J
Pyrene	0.051	510	0.43J
Total PAHs	277.8	3,034.0	3.1

* Soils data was collected from the Columbia Gas property, J Estimated concentration; compound detected below quantitation limit, L Sample has a low bias, actual value is expected to be higher, < Below minimum detection level.

Appendix G-5

Lewis Creek Sediment Data

Parameter (mg/kg)	SD-1*	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9
Lead	118NL	230NL	86.7NL	240NL	74NL	154NL	154NL	19.2NL	34.5NL
Polycyclic Aromatic Hydrocarbons									
Acenaphthene	<	0.130J	<	3.50J	<	0.10J	0.22J	0.53J	0.12J
Acenaphthylene	<	0.072J	<		<	<	<	<	<
Anthracene	0.11J	0.28J	0.12J	3.5L	0.23J	0.15J	0.73J	<	0.061J
Benzo[a]anthracene	0.45J	0.72	0.82	5.00	0.52J	0.39J	2.2J	<	0.06
Benzo[a]pyrene	0.54J	0.52	0.84J	3.80	0.62J	0.4J	1.80	0.86J	<
Benzo[b]fluoranthene	0.64J	0.75	1.10	3.1L	0.60J	0.39J	3.10	0.096J	<
Benzo[g,h,I]perylene	0.23J	0.26J	0.30J	1.7JL	0.22J	0.19J	0.73J	<	<
Benzo[k]fluoranthene	0.43J	0.66J	0.73J	2.4JL	0.56J	0.32J	1.8J	0.13J	<
Chrysene	0.66J	0.83	1.10	4.60	0.66J	0.46J	2.70	0.12J	0.062J
Dibenz[a,h]anthracene	<	0.15J	<	0.44JL	<	0.068J	0.16J	<	<
Fluoranthene	<	1.40	1.50	12.0L	1.00	0.99	4.60	0.22J	0.19J
Fluorene	<	0.18J	<	5.3L	<	0.094J	0.28J	<	0.11J
Indeno[1,2,3-cd]pyrene	0.30J	0.38J	0.42J	2.1J	0.30J	0.26J	1.10	<	<
Naphthalene	<	0.092J	<	0.64JL	<	<	<	<	<
Phenanthrene	0.65J	1.40	0.72J	12.0L	0.55J	0.64	3.20	0.12J	0.11J
Pyrene	0.93J	1.80	1.30	11.0J	0.85J	1.20	3.70	0.17J	0.24J
Total PAHs	4.94	9.624	8.95	71.08	6.11	5.652	26.32	2.246	0.96

* Site above Klotz Courtyard but below Staunton Metal Recyclers, J Estimated value, compound detected below quantitation limit, N Lab spike recovery was not within control limits, L Sample has a low bias, actual value is expected to be higher, < Compound not detected. This data is identical to the data reported in the Columbia Gas Closure Report.

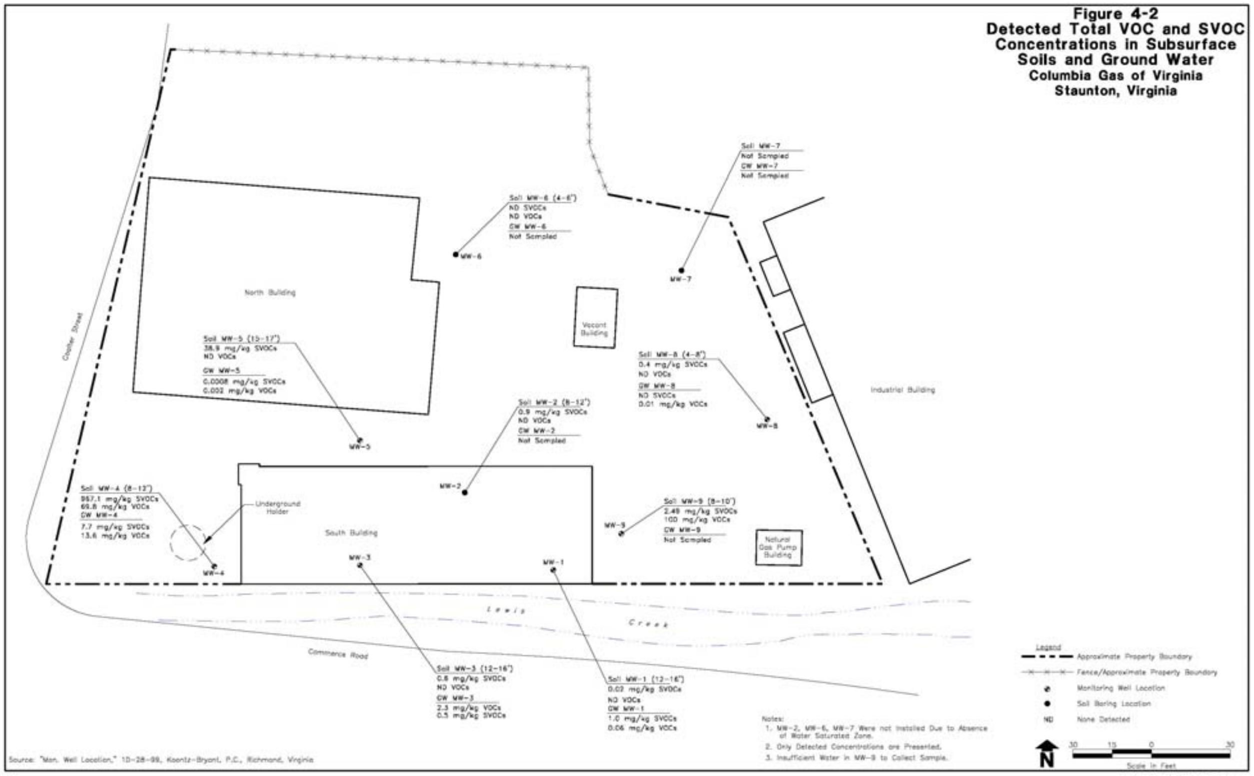
APPENDIX H

Appendix H-1

Closure Report for Coal Tar Seep Remediation. Columbia Gas of Virginia December 31, 2002

Environmental Resources Management

Ground Water Sampling Site Map



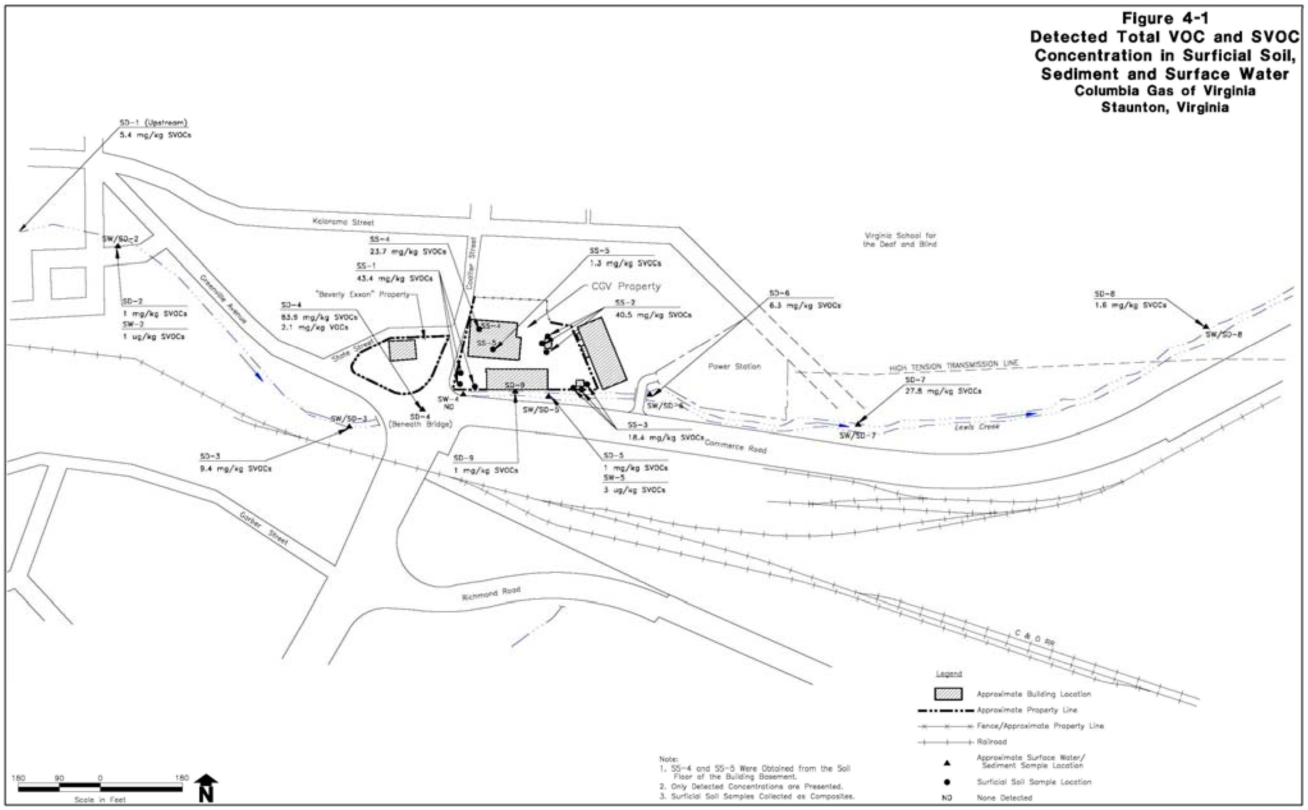
Appendix H-2

Ground Water Data

Parameter (mg/kg)	MW-I	MW-3	MW-4	MW-5	MW-8
Lead	< 0.005	0.076	< 0.005	< 0.005	< 0.005
Polycyclic Aromatic Hydrocarbons					
Acenaphthene	0.11	0.07	0.16	< 0.0002	< 0.0002
Acenaphthylene	< 0.008	0.03	0.11	< 0.0002	< 0.0002
Anthracene	< 0.008	0.01	< 0.080	< 0.0002	< 0.0002
Benzo[a]anthracene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Benzo[a]pyrene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Benzo[b]fluoranthene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Benzo[g,h,i]perylene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Benzo[k]fluoranthene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Chrysene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Dibenz[a,h]anthracene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Fluoranthene	< 0.008	0.01	< 0.080	0.0003	< 0.0002
Fluorene	0.02	0.07	< 0.080	< 0.0002	< 0.0002
Indeno[1,2,3-cd]pyrene	< 0.008	< 0.004	< 0.080	< 0.0002	< 0.0002
Naphthalene	0.74	< 0.004	6.60	< 0.0002	< 0.0002
Phenanthrene	0.03	0.08	0.16	< 0.0002	< 0.0002
Pyrene	< 0.008	0.02	< 0.080	0.0003	< 0.0002
Total PAHs	0.90	0.29	7.03	0.0006	0.00

Appendix H-3

Surface Water, Sediment & Soils Sampling Site Map



Appendix H-4

Surface Water Data

Parameter (mg/kg)	SW-1	SW-2	SW-3	SW-4	SW-5	SW-6	SW-7	SW-8
Lead	< 1.7	< 1.7	< 1.7	1.9	2.6	< 1.7	< 1.7	< 1.7

< Concentration below minimum detection level.

Appendix H-5

Soils Data

Parameter (mg/kg)	SS-1	SS-2	SS-3	SS-4	SS-5
Lead	470	3,200	160	420	270
Polycyclic Aromatic Hydrocarbons					
Acenaphthene	< 0.16	< 0.16	67	94	< 0.009
Acenaphthylene	0.92	0.78	0.31	0.48	< 0.009
Anthracene	0.66	0.5	0.28	0.28	0.013
Benzo[a]anthracene	4	4	1	2	0.13
Benzo[a]pyrene	4	3	2	2	0.17
Benzo[b]fluoranthene	3	3	1	2	0.16
Benzo[g,h,i]perylene	3	3	2	2	0.12
Benzo[k]fluoranthene	4	4	1	1.6	0.14
Chrysene	4	4	1.3	2	0.12
Dibenz[a,h]anthracene	0.8	0.73	0.33	0.41	0.053
Fluoranthene	6	6	3	3	0.096
Fluorene	0.19	0.18	0.1	0.14	< 0.009
Indeno[1,2,3-cd]pyrene	2	2	1	1	0.11
Naphthalene	< 0.16	< 0.16	< 0.043	0.42	< 0.009
Phenanthrene	3	2	1	2	0.039
Pyrene	9	8	3	4.4	0.11
Total PAHs	43.37	37.49	18.39	17.42	1.26

Appendix H-6

Sub-Surface Soils Data

Parameter (mg/kg)	MW-1 12-16'	MW-2 8-12'	MW-3 12-16'	MW-4 8-12'	MW-5 15-17'	MW-6 4-6'	MW-8 4-8'	MW-8 DUP 4-8'	MW-9 8-10'
Lead	36	24	29	150	28	23	36	47	39
Polycyclic Aromatic Hydrocarbons									
Acenaphthene	< 0.009	< 0.008	0.05	86.00	0.09	< 0.009	< 0.008	< 0.008	< 0.016
Acenaphthylene	< 0.009	0.01	0.01	12.00	0.52	< 0.009	< 0.008	< 0.008	< 0.016
Anthracene	< 0.009	0.02	0.02	52.00	1.20	< 0.009	< 0.008	< 0.008	< 0.016
Benzo[a]anthracene	< 0.009	0.09	0.04	33.00	3.00	< 0.009	0.05	0.02	< 0.016
Benzo[a]pyrene	< 0.009	0.10	0.02	31.00	2.80	< 0.009	0.03	0.01	< 0.016
Benzo[b]fluoranthene	< 0.009	0.11	0.02	20.00	2.20	< 0.009	0.04	0.02	< 0.016
Benzo[g,h,i]perylene	0.02	0.06	0.01	14.00	1.90	< 0.009	0.03	0.01	< 0.016
Benzo[k]fluoranthene	< 0.009	0.06	0.02	17.00	2.60	< 0.009	0.04	0.02	< 0.016
Chrysene	< 0.009	0.08	0.03	28.00	2.70	< 0.009	0.04	0.01	< 0.016
Dibenz[a,h]anthracene	< 0.009	0.01	< 0.008	3.40	0.41	< 0.009	0.01	< 0.008	< 0.016
Fluoranthene	< 0.009	0.12	0.11	80.00	7.40	< 0.009	0.08	0.03	< 0.016
Fluorene	< 0.009	< 8.2	0.03	58.00	0.34	< 0.009	< 0.008	< 0.008	< 0.016
Indeno[1,2,3-cd]pyrene	< 0.009	0.06	0.00	8.70	1.40	< 0.009	0.03	0.01	< 0.016
Naphthalene	< 0.009	0.01	0.01	150.00	0.00	< 0.009	< 0.008	< 0.008	0.64
Phenanthrene	< 0.009	0.06	0.06	180.00	3.90	< 0.009	0.02	0.01	< 0.016
Pyrene	< 0.009	0.11	0.16	120.00	8.30	< 0.009	0.07	0.03	< 0.016
Total PAHs	0.02	0.90	0.58	893.10	38.76	0.00	0.44	0.15	0.64

Appendix H-7

Lewis Creek Sediment Data

Parameter (mg/kg)	SD-1*	SD-2**	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9
Lead	119	230	86.7	240	74	154	154	19.2	34.5
Polycyclic Aromatic Hydrocarbons									
Acenaphthene	< 1.0	0.13	< 0.002	3.5	< 0.009	0.1	0.22	0.53	0.12
Acenaphthylene	< 1.0	0.072	< 0.009	< 2.50	< 0.009	< 0.005	< 930	< 0.008	< 0.004
Anthracene	0.11	0.28	0.12	3.5	0.23	0.15	0.73	< 0.008	0.061
Benzo[a]anthracene	0.45	0.72	0.82	5	0.52	0.39	2.2	< 0.008	0.063
Benzo[a]pyrene	0.54	0.52	0.84	3.8	0.62	0.4	1.8	0.086	< 0.004
Benzo[b]fluoranthene	0.64	0.75	1.1	3.1	0.6	0.39	3.1	0.096	< 0.004
Benzo[g,h,i]perylene	0.23	0.26	0.3	1.7	0.22	0.19	0.73	< 0.008	< 0.004
Benzo[k]fluoranthene	0.43	0.66	0.73	2.4	0.56	0.32	1.8	0.13	< 0.004
Chrysene	0.66	0.83	1.1	4.6	0.66	0.46	2.7	0.12	0.062
Dibenz[a,h]anthracene	< 1.0	0.15	< 0.009	0.44	< 870	0.068	0.16	< 0.008	< 0.004
Fluoranthene	< 1.0	1.4	1.5	12	1	0.99	4.6	0.22	0.19
Fluorene	< 1.0	0.18	< 0.009	5.3	< 0.009	0.094	0.28	< 0.008	0.11
Indeno[1,2,3-cd]pyrene	0.3	0.38	0.42	2.1	0.3	0.26	1.1	< 0.008	< 0.004
Naphthalene	<	0.092J	<	0.64JL	<	<	<	<	<
Phenanthrene	0.65	1.4	0.72	12	0.55	0.64	3.2	0.12	0.11
Pyrene	0.93	1.8	1.3	11	0.85	1.2	3.7	0.17	0.24
Total PAHs	4.94	9.62	8.95	71.08	6.11	5.65	26.32	1.47	0.96

*SD-1 is above Klotz Courtyard but below Stn Metal Recyclers, ** SD-2 is above Beverly Exxon but below Klotz Courtyard. This table is identical to the sediment data reported for the Beverly Exxon Enhanced Screening Report.