Benthic TMDL for Stroubles Creek in Montgomery County, Virginia

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CHAPTER 1: EXECUTIVE SUMMARY

1.1. Background

Located in Montgomery County, Virginia, the Stroubles Creek watershed (VAW-N22R, HUC 05050001; approximately 6,119 acres) encompasses much of the town of Blacksburg. Stroubles Creek is a tributary of the New River, which flows north into the Kanawha River. The Kanawha flows into the Ohio River, which flows into the Mississippi River, which in turn discharges into the Gulf of Mexico.

Biological monitoring of Stroubles Creek over a period of 5 years has indicated that the waterbody did not support the "general standard" of water quality in Virginia. Along with a number of standards for specific pollutants, Virginia also has a general standard, which states that a waterbody must be free of pollutants or environmental stresses that substantially alter the aquatic biological community. Impairment is defined by two or more ratings (over the assessment period) of "moderate" or "severe" based on the Environmental Protection Agency's (EPA's) Rapid Bioassessment Protocol (RBP) II. Biomonitoring has been conducted on Stroubles Creek since 1994. Originally listed in 1996 with a benthic impairment, Stroubles Creek was also included on the 1998 and 2002 303(d) TMDL priority lists in Virginia. During the most recent assessment period (2002), Stroubles Creek's benthic community was monitored 9 times; each assessment received a "moderately impaired" rating. The overall rating for each of these assessment periods has consistently been "moderately impaired", leading to Stroubles Creek's placement on Virginia's 303(d) list of impaired water bodies with a benthic impairment. As such, it does not fully support the Clean Water Act's Aquatic Life Use. The impairment extends from the Duck Pond outlet downstream to its confluence with Walls Branch, for a total of 4.98 stream miles.

Physical and chemical monitoring of Stroubles Creek during the 2002 assessment period occurred at an ambient water quality monitoring station approximately five miles downstream from the biological monitoring station. Data collected from biomonitoring is used to determine the health of the benthic community, but does not identify the source(s) of stress on the community. In order to assist in the effort to discern what may be causing the benthic impairment, the EPA has outlined a stressor identification process. This process was used to identify key stressors. Organic matter, nutrients, and sediment were determined to be possible stressors, with a decision to use sediment as the surrogate of the compounding and interacting stressors found in the altered hydrology of this urbanized watershed. The TMDL was then developed for this stressor. Sediment sources were identified, a TMDL load calculated, a margin of safety applied, and load allocation scenarios were created.

In order to remedy the water quality impairment pertaining to the biological community, the Total Maximum Daily Load (TMDL) was developed to take into account all potential stressors and a margin of safety (MOS). A glossary of terms used in the development of this TMDL is listed in Appendix A.

1.2. Sources of Sediment

Sediment is delivered to the impaired segments of Stroubles Creek through the processes of surface runoff, channel and streambank erosion, and from point source inputs, as well as from background geologic processes. Natural sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, and urban land uses. During runoff events, sediment loading occurs from both pervious and impervious surfaces in the watershed. Streambank erosion is caused by reduction in riparian cover resulting in stream bank instability and increased runoff rates related to anthropogenic sources in the watershed. Animals grazing on pastures in riparian areas with access to streams also contribute to streambank erosion. Hardening of stream channels, as observed along much of Stroubles Creek and its tributaries, reduces upstream channel scour but increases scour downstream. Transport of sediment is further increased by increasing areas of imperviousness in a watershed from urban growth and development, which increase the flow volume and peak rates of surface runoff.

1.3. Modeling

Because Virginia has no numeric in-stream criteria for sediment, a "reference watershed" approach was used to define allowable TMDL loading rates in the impaired watershed. The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired.

The Toms Creek watershed was selected as the TMDL reference for Stroubles Creek. The TMDL sediment target load was defined as the modeled sediment load for existing conditions from the non-impaired Toms Creek watershed, area-adjusted to Stroubles Creek.

The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was selected for comparative modeling for both the impaired and reference watersheds in this TMDL study. Data to calibrate the GWLF model was not available, so the model was used with recommended model parameters for the land uses and conditions found in the Stroubles and Toms Creek watersheds.

1.4. Benthic TMDL for Sediment

The benthic TMDL for the Stroubles Creek watershed was developed using sediment as the pollutant and the Toms Creek watershed as the TMDL reference watershed. Toms Creek watershed is slightly smaller than the Stroubles Creek watershed by a factor of 1.194. In order to establish a common basis for comparing loads between these two watersheds, each land use category in Toms Creek watershed was increased by multiplying by this factor. This resulted in an area-adjusted Toms Creek watershed equal in size with the land area in the impaired Stroubles watershed (2,471.2 ha). The average annual sediment load in metric tons per year (t/yr) from the area-adjusted Toms Creek was used to define the TMDL sediment load for Stroubles Creek, as shown in Table 1.1. Loads were based on average annual sediment loads using the 10-yr period, January 1985 – December 1994, as representative of both wet and dry periods of precipitation.

Table 1.1. Stroubles TMDL - Existing Sediment Loads (t/yr)

Sediment Sources	Stroubles Creek (t/yr)	Stroubles Creek (t/ha)	Area-adjusted Toms Creek (t/yr)	Area-adjusted Toms Creek (t/ha)
High Till	434.4	46.08	62.7	60.48
Low Till	2,963.9	25.13	427.8	33.00
Pasture	366.5	0.73	702.1	1.42
Urban grasses	338.5	1.08	40.0	2.27
Hay	8.1	1.74	0.0	0.00
Forest	106.6	0.16	241.5	0.16
Transitional	110.8	6.09	0.0	0.00
Pervious Urban	95.1	0.24	280.3	0.76
Impervious Urban	22.4	0.05	56.4	0.52
Channel Erosion	1,845.9	0.75	334.8	0.14
MS4	421.8		0.0	
Permitted Point Sources	22.3		0.0	
Watershed Totals	**6,736.2**		**2,145.6**	
		Target Sediment TMDL Load =	**2,145.6**	**t/yr**
		10% MOS =	214.6	t/yr
		Load for Allocation =	**1,931.1**	**t/yr**

The benthic TMDL for Stroubles Creek is comprised of the three required TMDL load components – the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), each of which is quantified in Table 1.2. An explicit 10% margin of safety (MOS) was included in the calculation. The waste load allocation (WLA) included permitted TSS loads from all permitted dischargers.

Table 1.2. Stroubles Creek TMDL Sediment Goal

TMDL (t/yr)	WLA (t/yr)	LA (t/yr)	MOS (t/yr)
2,145.6	233.2	1,697.9	214.6
	VAR050441 - Litton Systems Inc Poly Scientific Div : 2.7 VAR050508 - VT - Central Heating Plt: 0.46 VAR10042 - VT - Dairy Science Center: 2.37 VAR10267 - VT - Campus: 15.43 VAR10275 - Hawthorne Ridge Town Houses: 0.77 VAR10282 - Carriage Court II: 0.54 VPG120011 - VT - Dairy Science Center: 0 MS4s (VAR040019, VAR040049, VAR040016): 210.88		

1.5. Projected Future Conditions

The Stroubles Creek watershed is experiencing urban development and growth, so changes in land use must be estimated for modeling future loads as part of the TMDL allocation procedure. A summary of the broad land use distributions for the entire Stroubles Creek watershed for existing and future scenarios is given in Table 1.3.

Table 1.3. Land Use Change Between Existing and Future Scenarios

	Existing	%Change	Future
Agriculture	25.7%	-5.9%	19.8%
Urban	46.6%	7.6%	54.1%
Forest	27.7%	-1.6%	26.1%

1.6. TMDL Reductions and Allocations

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories – agriculture, urban, and forestry – and then comparing category loads from the Stroubles Creek watershed to those of its area-adjusted reference watershed – Toms Creek – in Table 1.4.

Table 1.4. Categorized Sediment Loads for Stroubles Creek (t/yr)

Source Category	**Future** Stroubles Creek (t/yr)	**Reference** Toms Creek (t/yr)
Agriculture	3,469.1	1,192.6
Urban	623.7	376.7
Forestry	100.6	241.5
Channel Erosion	2,181.4	334.8
MS4	454.6	0.0
Point Sources	22.3	0.0
Total	**6,851.7**	**2,145.6**

This comparison shows that the annual average sediment loads from forestry are already lower from Stroubles Creek than from its reference. Individual point source loads have been permitted and, therefore, are not subject to reduction.

Equal percentage reductions were required from the two largest load categories – agriculture and channel erosion, as shown in Table 1.5. Since urban source loads were relatively smaller than the two largest load categories, the first alternative requires no reduction from the non-MS4 urban areas, while the second alternative applies the same percent reduction for both existing MS4 and "urban" source loads. These loads are listed separately, since MS4 loads are required to be included in the WLA portion of the TMDL. The projected increase in future sediment loads from MS4 areas was assumed to be mitigated by MS4 regulations requiring implementation of best management practices to reduce pollutants to the "maximum extent practicable". Note that high velocity urban runoff events and its accompanying channel erosion must be addressed prior to work on stream bank stabilization. The recommended TMDL allocation scenario is Alternative 2, as it requires reductions from all land use categories with loads greater than its reference watershed counterparts, and is consistent with previous interpretations of incorporating MS4 loads into the TMDL. Note that each allocation scenario is designed to meet a target load equal to the TMDL minus the margin of safety (MOS).

Table 1.5. TMDL Allocation Scenarios for Stroubles Creek

Source Category	Future Stroubles Creek (t/yr)	Stroubles Creek TMDL Sediment Load Allocations			
		TMDL Alternative 1		TMDL Alternative 2	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	3,469	**83%**	598	**77%**	803
Urban	624	0%	624	**54%**	289
Forestry	101	0%	101	0%	101
Channel Erosion	2,181	**83%**	376	**77%**	505
MS4*	455	**54%**	211	**54%**	211
Point Sources	22		22		22
Total	**6,852**		**1,931**		**1,931**

The TMDL to address the benthic impairment in Stroubles Creek is 2,145.6 t/yr of sediment and will require an overall reduction from projected future loads that includes the 10% margin of safety and is equal to 73% of the existing load.

1.7. Reasonable Assurance

Continued biological and chemical monitoring in the watershed by VADEQ, provisions of Virginia's WQMIRA (Water Quality Monitoring, Information, and Restoration Act of 1997) legislation requiring implementation of developed TMDLs, MS4 regulations on storm sewer discharges, and the potential of funding through Section 319 and USDA's CREP (Conservation Reserve Enhancement Program) programs all provide the basis for a reasonable assurance that this TMDL will be implemented.

Additionally, the Town of Blacksburg has taken steps to reduce its loading from sanitary sewer overflows, and is in the process of developing a regional plan for additional storm water detention on the Central Branch.

1.8. Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progress made. On October 17, 2002, the Virginia Tech TMDL group hosted the first public meeting in Squires Student Center on the Virginia Tech campus. The purpose of this meeting was threefold: to inform local citizens and stakeholders of the impairment, to explain the work that had been completed up to that point in identifying the benthic stressors, and to encourage the sharing of information about the watershed. Personnel from the Department of Environmental Quality (DEQ), the Department of Conservation and Recreation (DCR), and the Virginia Tech TMDL group presented information and data. Questions from the audience followed the presentations. The second and final public meeting was held on October 9, 2003 at Virginia Tech's Donaldson Brown Hotel and Continuing Education Center.

CHAPTER 2: INTRODUCTION

2.1. Background

2.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (USEPA, 1998; 40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant sources, and provides a framework for taking actions to restore water quality.

2.1.2. Impairment Listing

Stroubles Creek has been listed as impaired on Virginia's 1996, 1998, and 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ; 1997, 1998, 2002a) due to water quality violations of the General Standard (listed as a benthic impairment). The Virginia Department of Environmental Quality has delineated the impairment on Stroubles Creek. The impaired reach is 4.98 miles (8.02 km) in length, beginning at the headwaters of Stroubles Creek (Central Branch) and ending at the confluence of Stroubles Creek and Walls Branch, approximately 2.6 miles (4.2 km) miles downstream from the biological monitoring station. The Stroubles Creek benthic TMDL is targeted for completion in January 2004.

2.1.3. Watershed Location and Description

Stroubles Creek is a tributary of the New River (VAW-N22R, HUC 05050001). The headwaters of the creek originate in the eastern part of the town of Blacksburg, flowing in a generally southwestern direction, continuing into neighboring Montgomery County, Virginia. Stroubles Creek is formed from two main tributaries – Central Branch and Webb Branch – and receives flow from a number of other unnamed perennial streams. The two named tributaries flow into the Duck Pond on the Virginia Tech campus, with the main Stroubles Creek channel beginning at the pond's outfall. The watershed (Figure 2.1) contributing to the impaired section of Stroubles Creek (upstream of Wall's Branch) is 2,476 hectares (6,119 acres), oriented along a Northeast-Southwest axis. The watershed contains a significant urban area from the town of Blacksburg. Based on interpretations from aerial photographs (taken in 1998), approximately 46% of the land use in the watershed is urban and residential, while 28% is forested and 26% is agriculture. The urban and residential area is mainly in the Northeastern (upstream) section of the watershed; the forested area is mainly downstream, in the Southwestern corner.

Twelve miles from its headwaters, and 4.72 miles downstream from the impaired segment, Stroubles Creek enters the New River, which flows north to the Kanawha River. The Kanawha is a tributary of the Ohio River, which flows into the Mississippi River, with the Mississippi discharging into the Gulf of Mexico.

2.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to a violation of the general standard for water quality. A violation of this standard is assessed on the basis of measurements of the benthic macroinvertebrate community in the stream, with pollution impacts referred to as a benthic impairment. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia's waters.

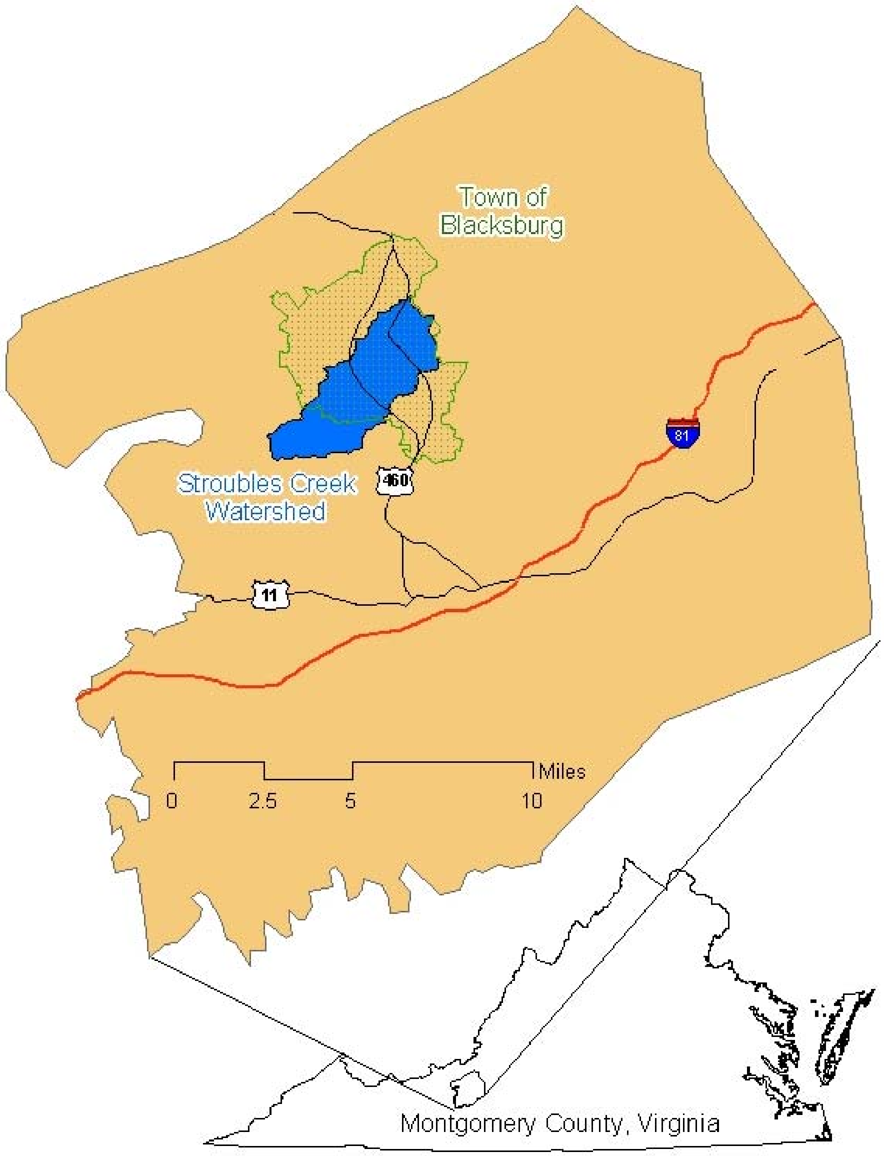

Figure 2.1. Location of Stroubles Creek watershed

2.2. Designated Uses and Applicable Water Quality Standards

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

"A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)" SWCB, 2003.

Stroubles Creek does not fully support the aquatic life designated use due to violations of the general (benthic) criteria listed below.

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

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

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2003.

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

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

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

CHAPTER 3: WATERSHED CHARACTERIZATION

3.1. Water Resources

The main branch of Stroubles Creek runs for 12 miles from the headwaters until it enters the New River. Stroubles Creek is perennial and generally has a trapezoidal channel cross-section, although the cross-sections change often due to the flashiness of the stream (Hoehn, et al., 1975).

3.2. Ecoregion

The Stroubles Creek watershed is located in the Central Appalachian Ridge and Valley Level III Ecoregion, and the Southern Limestone/Dolomite Valleys and Low Rolling Hills Level IV Ecoregion. The Central Appalachian Ridge and Valley Ecoregion is characterized by its generation from a variety of geological materials. This Level III Ecoregion has numerous springs and caves. The ridges tend to be forested, while limestone valleys are composed of rich agricultural land (USEPA, 2002). The Southern Limestone/Dolomite Valleys and Low Rolling Hills Level IV Ecoregion has fertile land and is primarily agricultural. Steeper areas have scattered forests composed mainly of oak trees. Streams tend to flow year-round and have gentle slopes and distinctive fish communities. The ecoregion is composed primarily of Appalachian Oak Forest (Woods et al., 1999).

3.3. Soils and Geology

The main general soil map units found in Stroubles Creek watershed are the Groseclose-Poplimento-Duffield and the Berks-Weikert associations. The Groseclose-Poplimento-Duffield soils (silty loam) are deep and well drained with clayey subsoil. These soil types are typically found on moderately dissected uplands. The Berks-Weikert soils (shaly silt loam) are moderately deep to shallow, well-drained soils with loamy subsoil. Berks-Weikert is typically found on mountains and highly dissected uplands. (In the case of Stroubles Creek, this soil is found on Price Mountain.) In upland areas, both of these soils are underlain by limestone bedrock (SCS, 1985).

3.4. Climate

The climate of the watershed is based on the meteorological observations made by the National Weather Service station in Blacksburg, Virginia. This station is located in the Corporate Research Center on the Virginia Tech campus. The station is located just south of the watershed boundary, but is only 1.27 miles from the centroid of the watershed. Average annual precipitation at the Blacksburg station is 40.43 inches with 52.6% of the precipitation occurring during the crop-growing season (May-October). Average annual snowfall is 23.1 inches with the highest snowfall occurring during January. Average annual daily temperature is 51.5°F. The highest average daily temperature of 71.2°F occurs in July while the lowest average daily temperature of 30.6°F occurs in January (SERCC, 2002).

3.5. Land Use

Land use for Stroubles Creek watershed was digitized and classified by the Virginia Department of Conservation and Recreation from 1998 digital ortho-photo quads. The main land use category in Stroubles Creek is urban/residential, comprising approximately 46% of the total watershed area. Forest, pasture, and cropland acreage accounts for about 28%, 21%, and 5% of the watershed area, respectively, as shown in Figure 3.1.

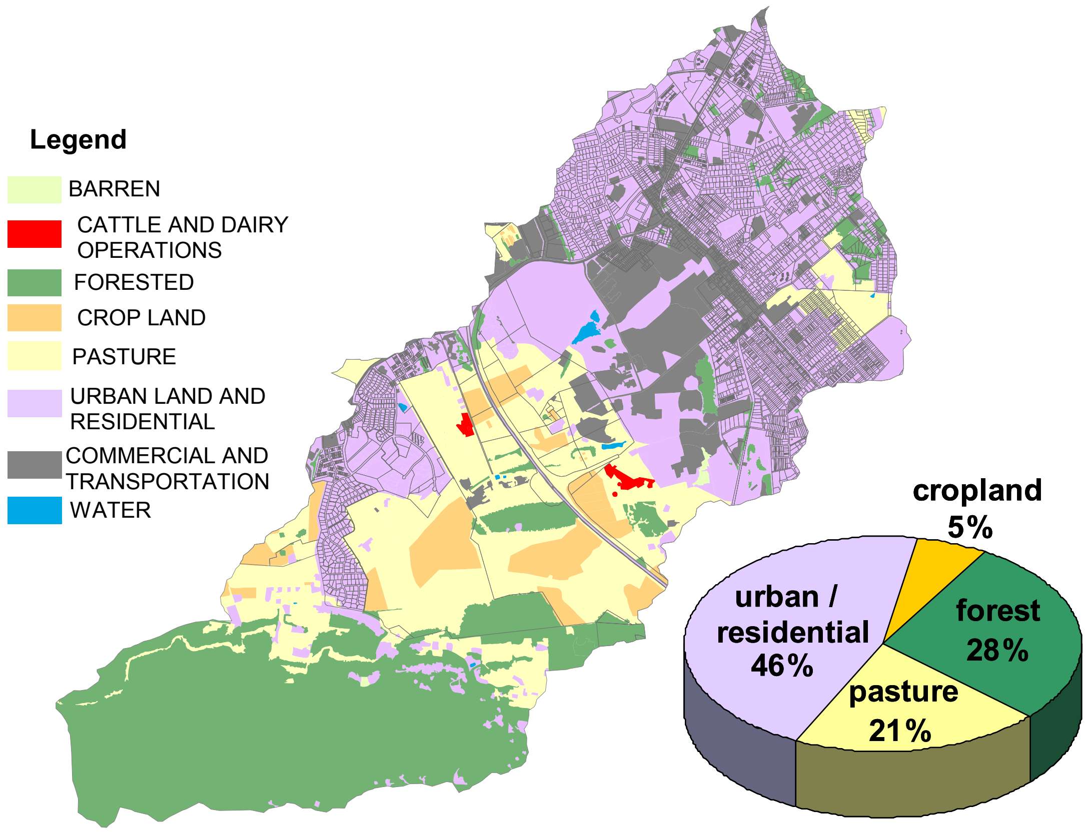

Figure 3.1. Land Use in Stroubles Creek Watershed

3.6. Future Land Use

The Stroubles Creek watershed is experiencing urban development and growth, so changes in land use must be estimated for modeling future loads as part of the TMDL allocation procedure. Future land use scenarios were created based on an analysis of trends between 2001 land use and future land use zoning projected to the year 2046 by the Town of Blacksburg, and a sub-watershed-by sub-watershed analysis of land use changes likely to occur in the foreseeable future.

The analysis of the Blacksburg data indicated a virtual elimination of forested and agricultural land by 2046 within the Blacksburg portion of the watershed, which was neither considered to be the intent of the planners, nor was consistent with the large tracts of university farmland which were not likely to change. The major trend from this analysis, however – that agricultural land would be shifting to urban residential, commercial and institutional uses – was consistent with that of a growing urban university community, as the one found in the Stroubles Creek watershed.

Within the context of this major trend, expected land use changes in the near future were identified within each sub-watershed. The sub-watershed specific land use changes can be found in Appendix B. On a watershed basis, the future scenario consisted of the changes shown in Table 3.1.

Table 3.1. Land use Change between Existing and Future Scenarios

	Existing	% Change	Future
Agriculture	25.7%	**-5.9%**	19.8%
Urban	46.6%	**7.5%**	54.1%
Forest	27.7%	**-1.6%**	26.1%

3.7. Water Quality Data

Virginia DEQ has monitored chemical water quality in the watershed since 1979. Ambient monitoring at station STE002.41 was performed quarterly from February 1994 through February 1999, bi-monthly from May 1999 through April 2001, and monthly from June 2001 through the present. Starting in July 2002 and continuing through the present, a new ambient water quality monitoring station, STE007.29, was established in the same location as the current biological monitoring station, and has been monitored on a monthly basis. The locations of these two stations are shown in Figure 3.2.

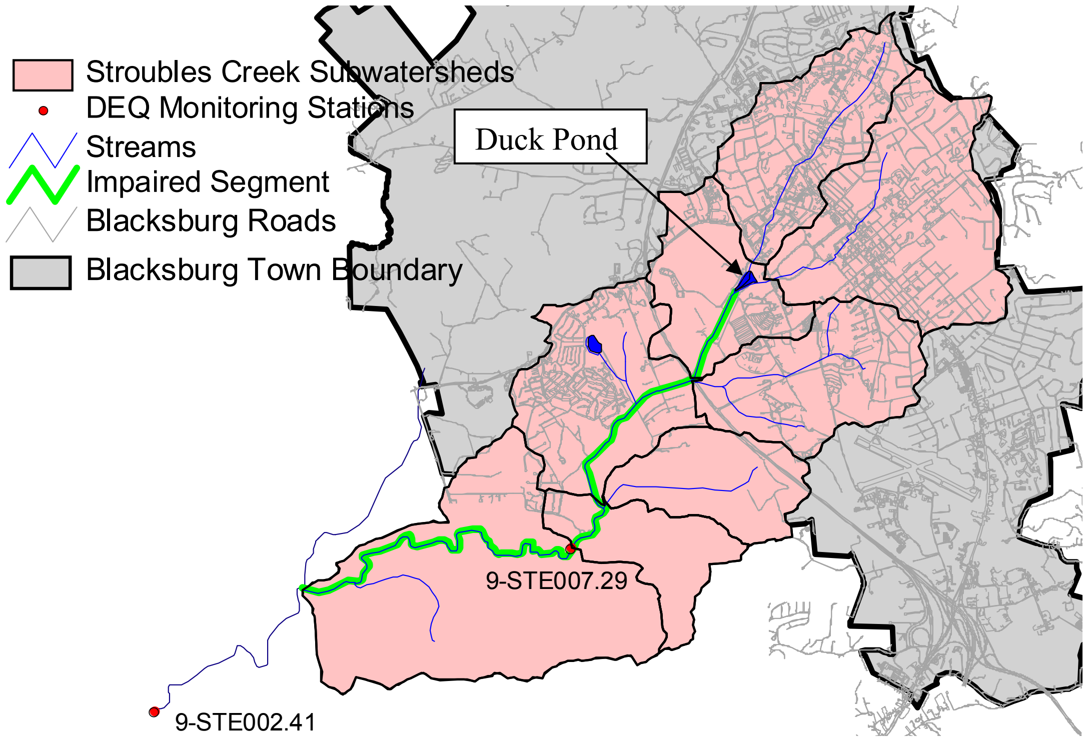

Figure 3.2. Stroubles Creek Monitoring Sites

3.8. Biological Monitoring Data

Biological communities have been monitored at STE007.29 annually or semi-annually from October 1994 through the present. Stroubles Creek was originally placed on the 303(d) list in 1996 based on 1 “moderately impaired” rating. For the 1998 and 2002 assessments, Stroubles Creek has also received an overall rating of “moderately impaired” based on 5 and 9 samples, respectively. As such, the Stroubles Creek watershed is not fully supportive of the Aquatic Life designated use. The VADEQ listed nonpoint source agricultural and urban pollution as the probable causes of the benthic impairment (VADEQ, 2002a).

The Rapid Bioassessment Protocol II (RBP II) is the official protocol used to assess compliance with the general standard in Virginia. The RBP II procedure evaluates the benthic macroinvertebrate community by comparing individual network biomonitoring stations with reference biomonitoring stations.

Reference biomonitoring stations have been identified by regional biologists that are both representative of regional physiographic and ecological conditions and have a healthy, unimpaired benthic community. Sinking Creek, located in Giles County, Virginia, was originally used as the reference watershed for Stroubles Creek. However, beginning in 2001, Toms Creek, located adjacent to Stroubles Creek on its northern boundary, was chosen as the new biological reference for Stroubles Creek (Devlin et al., 2003). This change was made by the DEQ regional biologist on the basis that the habitat and stream power in Stroubles Creek was more comparable to Toms Creek than it was with Sinking Creek. (Both Stroubles Creek and Toms Creek are second order streams, while Sinking Creek is a fourth order stream). Toms Creek is also much closer is size to that of Stroubles Creek. All of the nine assessments performed between June 1996 and November 2000 received a rating of "moderately" impaired, as shown in Table 3.2.

Table 3.2. RBP II Scores for Stroubles Creek (STE007.29)

RBP II (Scores calculated against a reference watershed.)

Sample Date	10/12/94	5/3/95	10/19/95	6/6/96	10/15/96	10/9/97	5/21/98	10/21/98	3/18/99	11/2/99	4/27/00	11/6/00	10/18/01	4/11/02	10/31/02	3/5/03	
Samp_ID	33	213	401	535	750	1035	1165	1351	1426	1463	1520	1553	1636	1672			**Ave.**
a. RBP II Metric Values																	
Taxa Richness	11	6	8	12	9	11	13	8	12	13	11	10	17	10	17	18	**12**
MFBI	5.61	5.81	6.36	5.48	5.49	5.42	5.44	6.19	7.69	5.47	6.06	5.97	5.79	5.39	5.81	5.54	**5.85**
SC/CF	0.14	0.15	0.03	1.00	0.14	0.43	0.57	0.03	0.70	0.55	0.21	0.02	0.30	1.03	0.62	0.2	**0.38**
EPT/Chi Abund	17.37	0.65	8.17	5.05	10.20	6.82	2.93	2.44	0.11	1.80	0.12	3.70	9.83	1.00	8.43	1.44	**5.00**
% Dominant	59.22	47.37	69.81	35.42	59.43	50.89	28.05	58.88	60.87	42.41	51.43	51.34	49.55	31.19	34.31	28.72	**47.43**
Dominant Species	Hydropsy	Chironon	Hydropsy	Elmidae	Hydropsy	Hydropsy	Simuliidae	Hydropsyc	Chironomi	Hydropsyc	Chironomi	Hydropsyc	Hydropsyc	Chironor	Hydropsy	Hydro/Chiro(A)	
EPT Index	3	1	1	2	3	5	4	3	4	5	3	4	5	3	6	4	**4**
Comm. Loss Index	0.64	2.50	1.38	0.83	0.78	0.73	0.69	1.25	1.00	0.69	1.27	1.30	0.29	1.20	0.35	0.44	**0.96**
SH/Tot	0.97	0.88	0.00	5.21	0.00	0.89	0.00	0.00	0.00	1.27	0.71	0.89	3.60	0.00	0	0.05	**0.90**
b. Reference Metric Values																	
Station_ID	SNK32	SNK212	SNK379	SNK536	SNK749	SNK1034	SNK1162	SNK1347	SNK1417	SNK1458	SNK1493	SNK1551	TOM1635	OM1673	TOM0257	TOM	
Reference Sample Date	10/12/94	5/19/95	11/12/95	6/6/96	10/15/96	10/14/97	5/21/98	10/21/98	3/11/99	11/2/99	4/27/00	11/6/00	10/18/01	4/11/02	10/31/02	3/5/03	**Ave.**
Reference Sample_ID	32	212	379	536	749	1034	1162	1347	1417	1458	1493	1551	1635	1673			
Taxa Richness	20	20	15	17	13	14	15	13	19	14	19	22	17	20	16	13	**17**
MFBI	3.57	3.15	3.28	3.81	3.76	3.50	3.78	3.17	3.62	3.39	3.69	3.52	4.34	4.90	4.44	4.44	**3.77**
SC/CF	0.81	1.07	0.35	1.05	1.16	0.57	0.22	3.14	0.71	0.79	0.46	0.86	0.57	0.50	0.86	0.33	**0.84**
EPT/Chi Abund	36.04	76.19	44.55	13.43	21.00	17.84	23.43	97.00	9.31	28.94	31.76	22.95	6.30	2.07	31.67	8.44	**29.43**
% Dominant	22.13	19.05	35.83	24.27	30.90	28.21	29.82	36.80	17.27	25.23	22.88	29.76	31.06	23.33	32.28	22.22	**26.94**
EPT Index	8	12	7	10	6	8	8	8	10	8	11	12	10	9	5	8	**9**
Comm. Loss Index																	
SH/Tot	4.10	2.72	3.33	2.91	0.00	0.64	1.75	0.00	2.16	7.21	5.08	2.42	4.55	0.02	0.03	0.06	**2.31**
Reference Biological Score	46	48	44	46	44	46	46	44	48	46	46	46	44	46	44	46	**46**
c. RBP II Metric Ratios																	
Taxa Richness	55.0	30.0	53.3	70.6	69.2	78.6	86.7	61.5	63.2	92.9	57.9	45.5	100.0	50.0	106.3	138.5	**72.4**
MFBI	63.5	54.2	51.6	69.5	68.5	64.6	69.5	51.2	47.1	61.9	60.8	59.0	74.9	90.9	76.4	80.1	**65.2**
SC/CF	17.2	14.2	7.7	95.0	12.3	76.1	261.9	0.9	98.0	69.3	45.8	2.3	53.0	206.0	72.1	60.6	**68.3**
EPT/Chi Abund	48.2	0.9	18.3	37.6	48.6	38.2	12.5	2.5	1.2	6.2	0.4	16.1	156.0	48.3	26.6	17.1	**29.9**
% Dominant	59.2	47.4	69.8	35.4	59.4	50.9	28.0	58.9	60.9	42.4	51.4	51.3	49.5	31.2	34.3	28.7	**47.4**
EPT Index	37.5	8.3	14.3	20.0	50.0	62.5	50.0	37.5	40.0	62.5	27.3	33.3	50.0	33.3	120.0	50.0	**43.5**
Comm. Loss Index	0.64	2.50	1.38	0.83	0.78	0.73	0.69	1.25	1.00	0.69	1.27	1.30	0.29	1.20	0.35	0.44	**0.96**
SH/Tot	23.7	32.2	0.0	178.8	0.0	139.3	0.0	0.0	0.0	17.6	14.0	36.9	79.2	0.0	0.0	83.3	**37.8**
d. RBP II Metric Scores																	
Taxa Richness	2	0	2	4	4	4	6	4	4	6	2	2	6	2	6	6	**3.8**
MFBI	2	2	2	2	2	2	2	2	0	2	2	2	4	6	4	4	**2.5**
SC/CF	0	0	0	6	0	6	6	0	6	6	4	0	6	6	6	6	**3.6**
EPT/Chi Abund	2	0	0	2	2	2	0	0	0	0	0	0	6	2	2	0	**1.1**
% Dominant	0	0	0	2	0	0	4	0	0	0	0	0	0	2	2	4	**0.9**
EPT Index	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	**0.4**
Comm. Loss Index	4	2	4	4	4	4	4	4	4	4	4	4	6	4	6	6	**4.3**
SH/Tot	2	2	0	6	0	6	0	0	0	0	0	4	6	0	0	6	**2.0**
Total RBP II Score	12	6	8	26	12	24	22	10	14	18	12	12	34	22	32	32	**18.5**
% of Reference	26.09	12.50	18.18	56.52	27.27	52.17	47.83	22.73	29.17	39.13	26.09	26.09	77.27	47.83	72.73	69.57	**40.7**
RBP II Assessment	**Moderate**	**Severe**	**st judgem**	**Slight**	**Moderate**	**st judgem**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Moderate**	**Slight**	**Moderat**	**Slight**	**Slight**	

The Macroinvertebrate Aggregated Index for Streams (MAIS) is a secondary index whose metrics are also calculated by VADEQ, but it is only used as a supplemental indicator of stream quality. The MAIS metrics were developed using data from the Central Appalachian Ridge and Valley ecoregion, and as such, are appropriate for use with Stroubles Creek watershed. Individual MAIS metrics are rated against a fixed scale rather than against those of a reference watershed, as in the RBP II index. The various metrics, some which duplicate those in the RBP II, along with their scores and final ratings, are given for each sample in Table 3.3.

Table 3.3. MAIS Assessment Results for Stroubles Creek

MAIS (Scores calculated against a fixed scale. Values indicating the best conditions are shown at the far right.)

a. MAIS Metric Values																		Best Score
Sample Date	10/12/94	5/3/95	10/19/95	6/6/96	10/15/96	10/9/97	5/21/98	10/21/98	3/18/99	11/2/99	4/27/00	11/6/00	10/18/01	4/11/02	10/31/02	3/5/03	**Ave.**	**Category**
% 5 Dominant	91.26	99.12		84.38	87.74	92.86	86.59	99.07	94.93	94.30	93.57	95.09	84.68	95.41	81.75	79.79	**90.70**	<79.13
MFBI	5.61	5.81		5.48	5.49	5.42	5.44	6.19	7.69	5.47	6.06	5.97	5.79	5.39	5.81	5.54	**5.81**	<4.22
% Haptobenthos	92.23	51.75		69.79	82.08	83.93	81.71	62.62	14.49	69.62	32.86	79.91	72.97	64.20	62.04	44.7	**64.33**	>83.26
EPT Index	3	1		2	3	5	4	3	4	5	3	4	5	3	6	4	**4**	>7
# Mayfly Taxa	2	0		0	1	3	2	2	3	3	2	1	4	1	4	2	**2**	>3
% Mayfly Abundance	8.74	0.00		0.00	2.83	9.82	4.88	2.80	2.90	3.16	2.86	2.68	3.60	0.92	8.03	11.7	**4.33**	>17.52
Simpson's Diversity Index	0.63	0.67		0.82	0.63	0.69	0.81	0.59	0.58	0.71	0.68	0.67	0.72	0.73	0.81	0.82	**0.70**	>0.823
# Intolerant Taxa	6	3		5	4	7	6	3	5	8	5	6	10	4	8	10	**6**	>9
% Scraper Abundance	9.71	6.14		39.58	11.32	22.32	30.49	1.87	0.72	1.90	0.00	0.00	2.70	1.83	5.11	6.38	**9.34**	>10.7
b. MAIS Scores																		
% 5 Dominant	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	**1.0**	
MFBI	0	0		1	1	1	1	0	0	1	0	0	0	1	0	1	**0.5**	
% Haptobenthos	2	0		1	1	1	1	1	0	1	0	1	1	1	1	0	**0.8**	
EPT Index	1	0		0	1	1	1	1	1	1	1	1	1	1	1	1	**0.9**	
# Mayfly Taxa	1	0		0	1	1	1	1	1	1	1	1	2	1	2	1	**1.0**	
% Mayfly Abundance	1	0		0	1	1	1	1	1	1	1	1	1	1	1	1	**0.9**	
Simpson's Diversity Index	0	1		1	0	1	1	0	0	1	1	1	1	1	1	1	**0.7**	
# Intolerant Taxa	1	1		1	1	1	1	1	1	1	1	1	2	1	1	2	**1.1**	
% Scraper Abundance	1	1		2	2	2	2	1	1	1	0	0	1	1	1	1	**1.1**	
Total MAIS Score	8	4	0	7	9	10	10	7	6	9	6	7	10	9	9	9	**7.5**	**18**
MAIS Assessment	**Poor**	**Very Poo**	**Very Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Very Poor**	**Poor**	**Very Poor**	**Poor**	**Poor**	**Poor**	**Poor**	**Poor**		**Best**

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling, beginning in 1994 for Stroubles, and beginning in 2001 for Toms Creek. The habitat parameter scores for Stroubles Creek are given in Table 3.4 and for Toms Creek in Table 3.5. Each of the 10 habitat parameters has a maximum score of 20 indicating the most desirable condition, and a score of 0 indicating the poorest habitat conditions. In 2000, two parameters were dropped from evaluation: graze and substrate. The Adjusted Scores, representing the score for each evaluation without graze and substrate, can be compared across dates. The blank columns represent an expected evaluation that was not performed.

Table 3.4. Habitat Evaluation Scores for Stroubles Creek

Habitat Evaluation Date Habitat Sample ID	10/12/94	5/3/95 STE193	10/19/95 STE365	6/6/96 STE482	10/15/96 STE659	10/9/97 STE903	5/21/98 STE1014	10/21/98	3/18/99 STE1249	11/2/99 STE1262	4/27/00	11/6/00 STE1306	10/18/01 STE1383	4/11/02	10/31/02	3/5/03	Ave.
ALTER	13	11	10	13	13	13	13	No	11	15	No	14	15	15	14	15	**13.2**
BANKS	9	9	14	12	12	13	16	Data	11	15	Data	11	20	5	11	8	**11.9**
BANKVEG	9	9	13	12	12	13	16	Collected	15	18	Collected	12	12	3	16	10	**12.1**
COVER	15	10	11	12	12	12	15		6	8		12	13				
EMBED	12	9	10	12	12	11	15		9	16		9	18	16	12	18	**12.8**
FLOW	14	15	15	16	16	18	18		16	18		13	17	19	20	20	**16.8**
GRAZE	14	8	9	13	13	14	13		9	11							
RIFFLES	16	14	15	16	16	12	18		17	15		16	18	16	17	20	**16.1**
RIPVEG	6	1	1	5	3	2	3		0	0		12	4	2	8	6	**3.8**
SEDIMENT	5	10	9	10	10	8	10		6	7		9	15	7	13	10	**9.2**
SUBSTRATE	15	12	13	12	12	13	17		11	9				13	17	12	**13.0**
VELOCITY	18	11	11	12	12	16	17		15	14		12	15	16	16	18	**14.5**
Total Habitat Score (12 metrics)	146	119	131	145	143	145	171		126	146		120	147	112	144	137	
Adjusted Score (10 metrics)	**117**	**99**	**109**	**120**	**118**	**118**	**141**		**106**	**126**		**120**	**147**	**112**	**144**	**137**	**122**

*ALTER = channel alterations; BANKS = bank stability; BANKVEG = bank vegetation; EMBED = embeddedness; FLOW = flow quantity; GRAZE = animal grazing in riparian area; RIFFLES = presence of riffles; RIPVEG = riparian vegetation; SEDIMENT = abundance of bottom sediment; SUBSTRATE = availability of firm, clean stream bottom surfaces; VELOCITY = velocity of flow.

Table 3.5. Habitat Evaluation Scores for Toms Creek

Habitat Evaluation Date HabSampID	04/11/02	10/31/02	03/05/03	Average
ALTER	16	17	15	16.0
BANKS	11	14	13	12.7
BANKVEG	11	15	14	13.3
EMBED	16	17	16	16.3
FLOW	15	20	20	18.3
RIFFLES	20	19	20	19.7
RIPVEG	6	8	4	6.0
SEDIMENT	12	9	12	11.0
SUBSTRATE	16	19	18	17.7
VELOCITY	16	20	20	18.7
Total Habitat Score	139	158	152	150

Virginia DEQ, with assistance from USEPA Region 3, is in the middle of a process to upgrade its biomonitoring and biological assessment methods to those currently recommended in the mid-Atlantic region. As part of this effort, a study has been performed to assist the agency to move from a paired-reference site approach to a regional reference condition approach, and has led to the development of a proposed stream condition index (SCI) for Virginia's non-coastal areas (Tetra Tech, 2002). This multimetric index is based on 8 biomonitoring metrics and has a scoring range of 0 – 100. The maximum score of 100 represents the best benthic community sites. Current proposed threshold criteria would define "unimpaired" sites as those with an SCI > 61.9 (the 10th percentile of all scores from 62 reference sites in Virginia), and "impaired" sites as those with an SCI < 56.3 (the 5th percentile). The average SCI score for Stroubles Creek, shown in Table 3.6, is consistent with that of an "impaired" site, and average SCI scores for both Sinking Creek and Toms Creek are consistent with those of "unimpaired" sites.

Table 3.6. Stream Condition Index

Station ID	Stream	No. of Samples	Stream Condition Index		
			Minimum	**Maximum**	**Average**
TMDL Station					
STE007.29	Stroubles Creek	16	21.8	51.2	37.9
Biological Reference Stations					
SNK012.06	Sinking Creek	14	61.7	83.3	72.3
TOM012.78	Toms Creek	4	61.9	70.0	67.1

CHAPTER 4: BENTHIC STRESSOR ANALYSIS

4.1. Introduction

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not implicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in EPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Stroubles Creek. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, and visual assessment of conditions in and along the stream corridor provided additional information to support or refute the candidacy of specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors considered in the following sections are temperature, pH, toxics, organic matter, nutrients, and sediment.

Since the impairment listing for Stroubles Creek was based on the benthic community samples from 1996 to 2000, data from this time period was included in this stressor analysis. As described previously, the historic ambient water quality monitoring station for chemical and physical data was located approximately five miles downstream from the benthic monitoring station, and so did not directly relate to stream conditions at the benthic station. Since mid-2002, an ambient water quality monitoring station has been included at the site of the benthic station. These recent data have also been included in this stressor analysis. Although the focus for this analysis was on the 1996-2000 assessment data, all available data for this stream was considered. In all charts, STE002.41 is the downstream ambient station; STE007.29 is the ambient/benthic station; and TOM012.78 is the biological reference station. Limits of detection are noted where applicable.

The results of the stressor analysis are divided into the following three categories:

- Non-Stressors: Those stressors with data indicating normal conditions, without violations of a governing standard, or without observable impacts usually associated with a specific stressor, were eliminated from the list of possible stressors.
- Possible Stressors: Those stressors with data indicating possible links, but with inconclusive data, were considered to be possible stressors.
- Most Probable Stressor(s): The stressor(s) with the most consistent data linking it with the poorer benthic metrics was considered to be the most probable stressor(s).

4.2. Eliminated Stressors

<u>Temperature</u>

Although the habitat evaluation indicated that some sections of Stroubles Creek have sparse riparian vegetation (Table 3.4), the water temperature appeared to fluctuate within normal bounds and has never exceeded Virginia's maximum water quality standard of 31°C for Class IV waters, as shown in Figure 4.1. Temperature, therefore, does not appear to be a stressor.

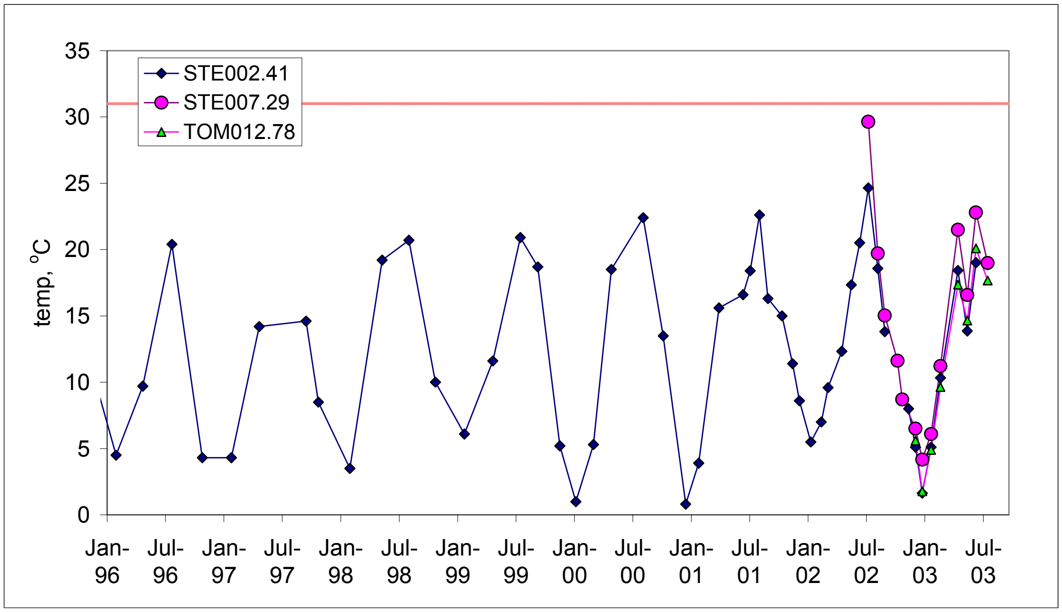

Figure 4.1. Water Temperature in Stroubles Creek

<u>pH</u>

All pH values fall between the Class IV water quality standard limits of 6.5 and 9.5, as shown in Figure 4.2. $CaCO_3$ concentrations (hardness) also appear fairly constant, and less than the maximum groundwater criteria of 300 mg/L for the Valley and Ridge physiographic region, as shown in Figure 4.3.

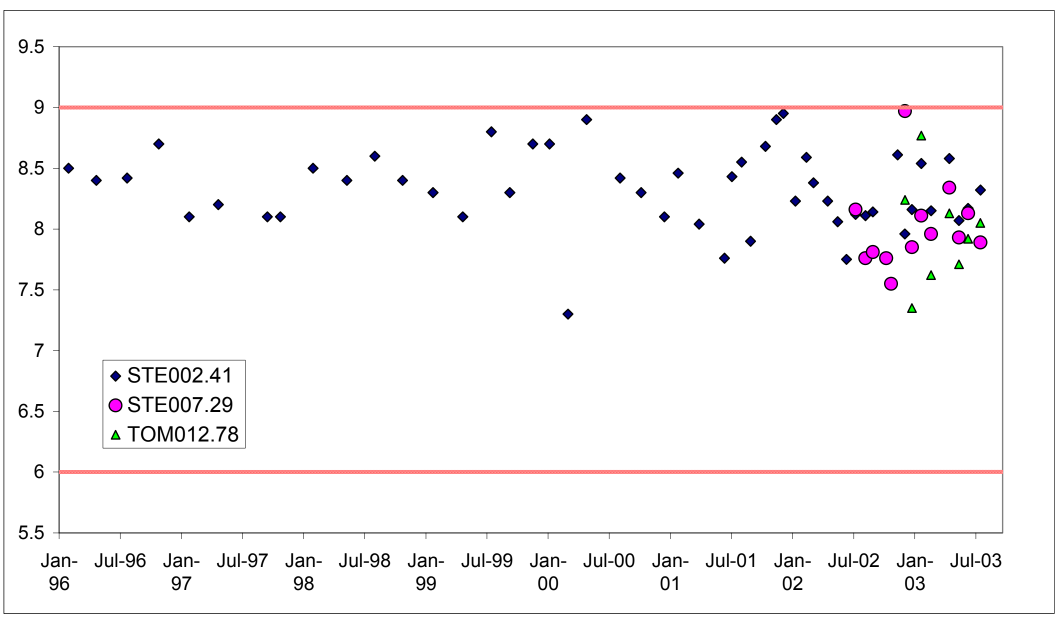

Figure 4.2. Field pH in Stroubles Creek

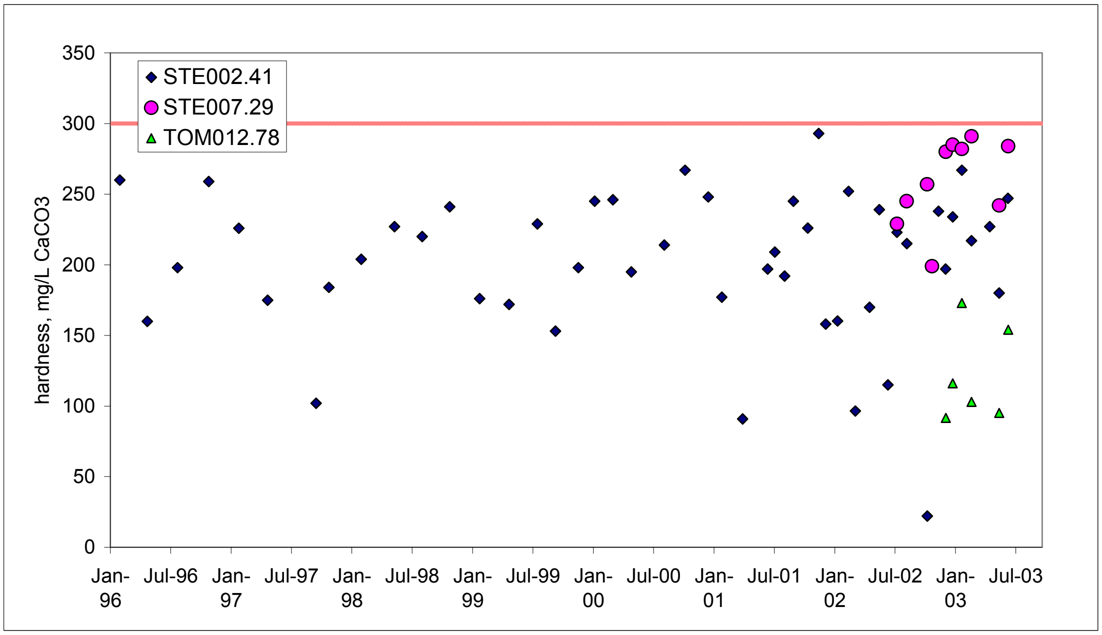

Figure 4.3. Hardness Concentration in Stroubles Creek

<u>Toxics</u>

There are no VPDES permits in Stroubles Creek watershed that might be sources of toxic substances. Although the Blacksburg municipal sewage treatment plant (STP) is located outside of the watershed, it has reported a number of incidences of sanitary sewer overflows over the past few years that might contain small amounts of household or industrial toxic wastes, from feeder lines in the watershed. No exceedences of DEQ's chronic and acute aquatic life criteria for ammonia have been recorded, and most measurements were at, or below, the minimum detection limit of 0.04 mg/L. One component of the benthic population known as shredders has traditionally been at very low levels in Stroubles Creek and could be a toxic effect, but is most probably the result of excessive sediment or lack of inputs of leaf litter due to reduced riparian canopy. In a 1992 county household water quality study, no samples had concentrations of toxics that exceeded the EPA health advisory levels or the maximum contaminant levels. Stream samples were also collected on November 4, 6, and 8, 2002 by Jason Hill and Mary Rummel (DEQ-WCRO) and submitted for chronic toxicity testing using the fathead minnow and Ceriodaphnia. Testing was conducted by the USEPA Wheeling Biology Group. The toxicity test results stated that "samples from Stroubles Creek did not have fathead minnow growth results which were statistically different from the laboratory Control but the difference may not be environmentally significant because the mean weight of the test fish was equivalent to that of the Controls in many other chronic tests…None of thesamples were toxic to daphnia" (EPA-Wheeling, 2003). Therefore toxicity was not apparent in these samples, and these test results support the other evidence that toxics are not a likely stressor.

4.3. Possible Stressors

Organic Matter

Organic matter can affect water quality in either the dissolved or particulate form. Dissolved organics would be reflected in increased concentrations of 5-day biological oxygen demand (BOD_5), while particulate organics may be reflected in increased levels of total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS). Decomposition of organic substances would result in decreased levels of measured dissolved oxygen (DO). On the particulate side, COD measurements (Figure 4.4) looked fairly typical, and most of the volatile suspended solids were near their minimum detection limit (MDL) of 3 mg/L.

On the dissolved side, all recent BOD measurements (Figure 4.5) have been near, or below, their MDL of 2 mg/L. Monthly ambient DO concentrations (Figure 4.6) are all above the minimum water quality standard of 5 mg/L. There was one parameter, however, that indicated dissolved organics were elevated – indirect measurements of dissolved volatile solids. Since most of the volatile suspended solids were near their MDL of 3 mg/L, the majority of the volatile solids (VS) shown in Figure 4.8, therefore, were in the dissolved form. The average VS concentrations at STE007.29 (99 mg/L) were almost twice as high as at the Toms Creek site, though these averages were from a limited number of samples.

One of the benthic metrics – the MFBI metric – had an average score of 5.81 (good condition < 4.22; poor condition > 5.56), indicating moderate levels of organic matter (Table 3.2). Additionally, *Hydropsychidae* and some *Chironimidae* - netspinners who thrive on particulate organic matter - were the dominant benthic species (Table 3.1), indicating that the organic matter load in Stroubles Creek has been sufficient to alter the benthic community (Devlin, 2003). Although at first glance these results appear to be inconsistent with the high water quality normally associated with high DO concentrations and low BOD, high organic matter loading does not always result in a DO or BOD impairment. Low DO and high BOD are not typically seen as a response to organic matter in flowing waters (with opportunities for re-aeration), as they are in reservoirs (Devlin, 2003).

Additional observations lend support to organic matter as a possible stressor. Recent reported multiple sanitary sewer overflows have increased organic loading around overflow areas. Documentation was unavailable to determine whether historical sanitary sewer overflows contributed to the original impairment in 1998. Additionally, the existence of town and campus runoff in the watershed should be an indication that pollution other than sediment may be impacting the stream. Urban runoff typically consists of fertilizers, pesticides, oils, grass clippings, etc. While sediment might settle out in the Duck Pond or other detention ponds, dissolved organics and suspended matter will tend to flow over the dams, especially during runoff events.

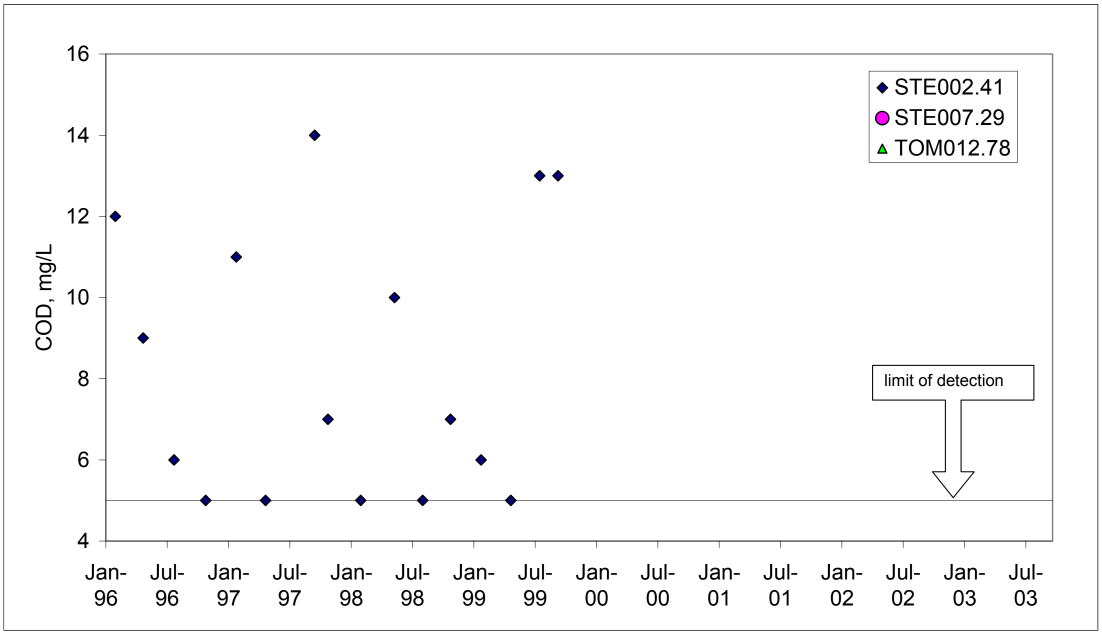

Figure 4.4. COD Concentration in Stroubles Creek

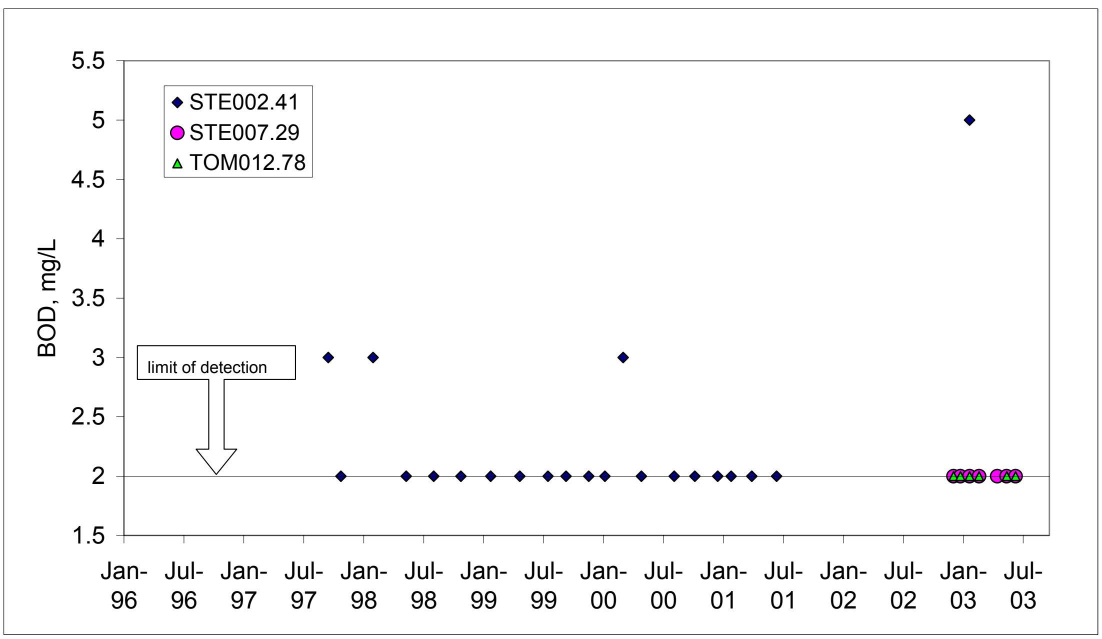

Figure 4.5. BOD (5-day) Concentration in Stroubles Creek

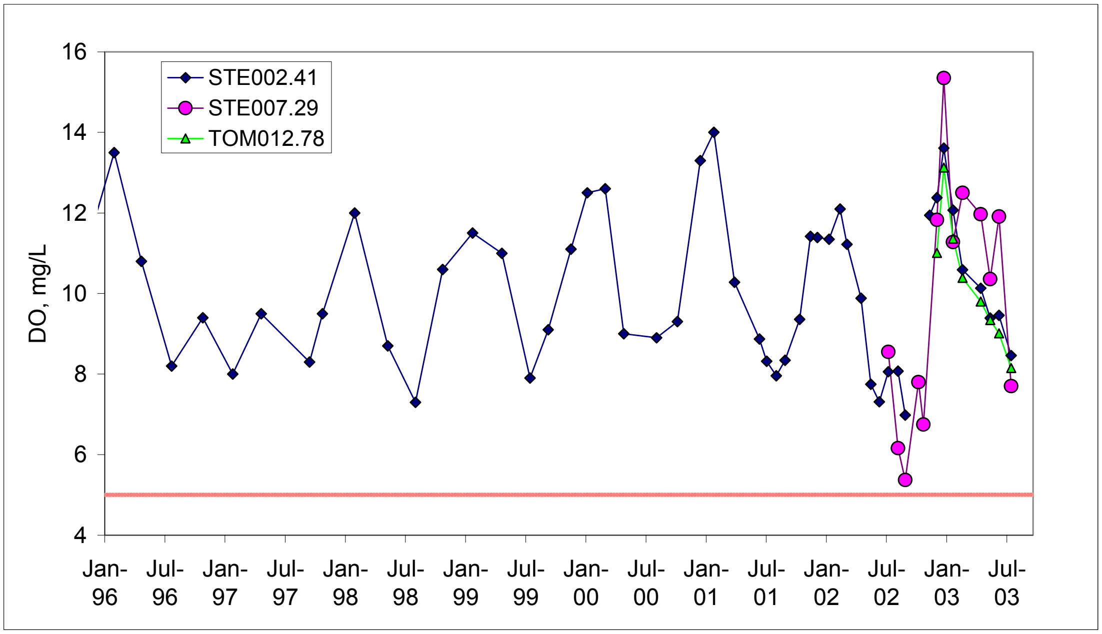

Figure 4.6. Monthly Dissolved Oxygen Concentration in Stroubles Creek

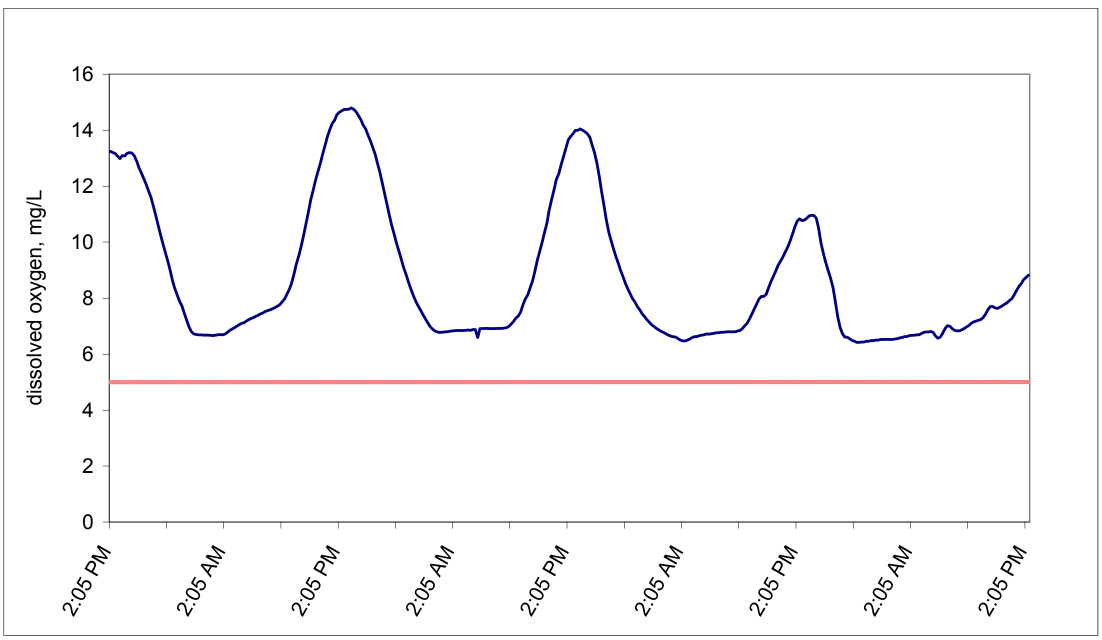

Figure 4.7. Diurnal Dissolved Oxygen Concentration in Stroubles Creek

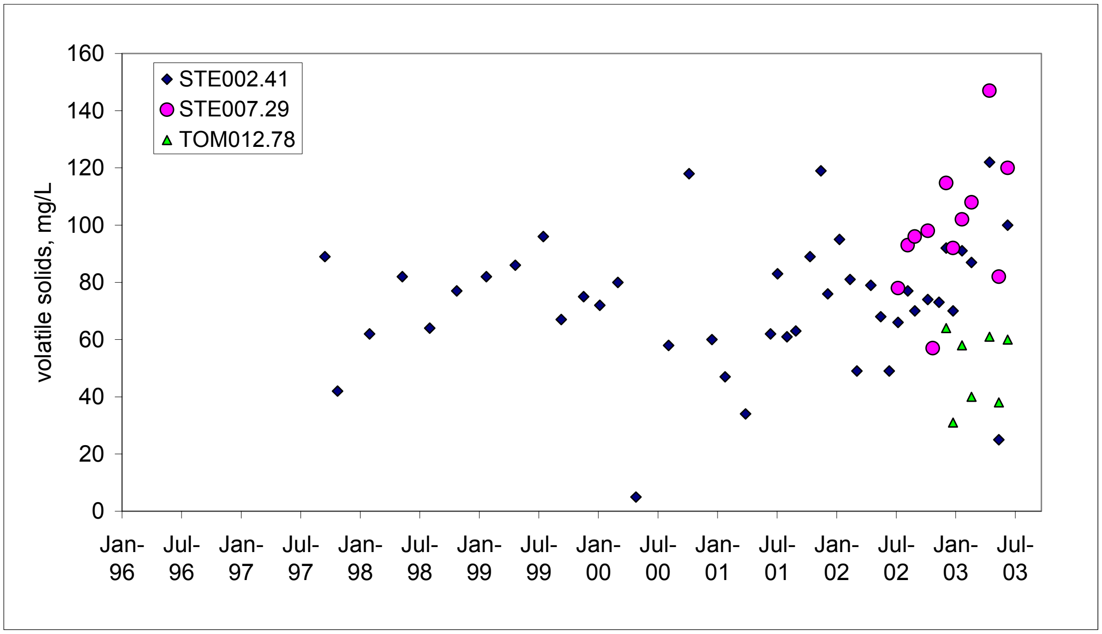

Figure 4.8. Volatile Solids Concentration in Stroubles Creek

<u>Nutrients</u>

Two metrics described in the organic matter section – high MFBI scores and dominance of *Hydropsychidae* and *Chironimidae* (Table 3.2) – also indicate that nutrients might be a stressor. Stroubles Creek benthic samples also have an abundance of chironomids, which often accompany nutrient enrichment.

In addition, the downstream station (STE002.41) reported 5-yr average dissolved N and P concentrations well above levels needed for eutrophic growth, with P being the limiting nutrient, as shown in Figures 4.9 and 4.10. Recent data collected at the ambient station co-located with the benthic site (STE007.29) has shown that nutrient levels are even greater further upstream in the watershed, and slime and algae growth have been observed in the stream.

According to the Ohio EPA (1999), "wooded riparian buffers are a vital functional component of the stream ecotone and instrumental in the detention, removal and assimilation of nutrients from or by the water column". The Riparian Vegetation habitat score for Stroubles Creek, shown earlier in Table 3.4, is the lowest (average 3.8 out of 20) of all habitat assessment parameters. In streams

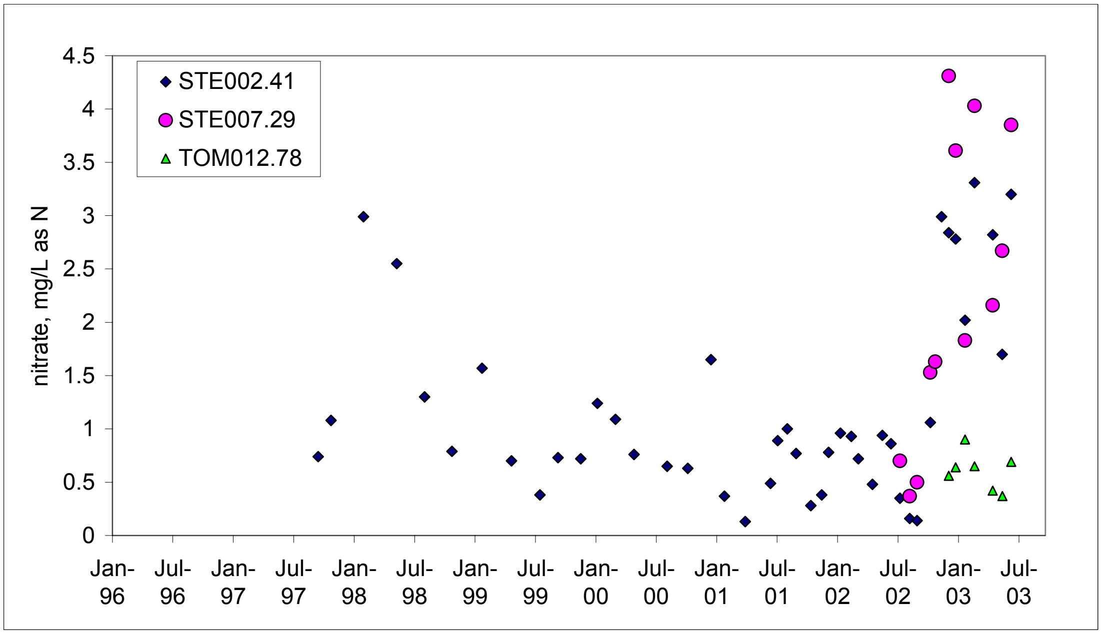

Figure 4.9. Nitrate (NO_3-N) Concentration in Stroubles Creek

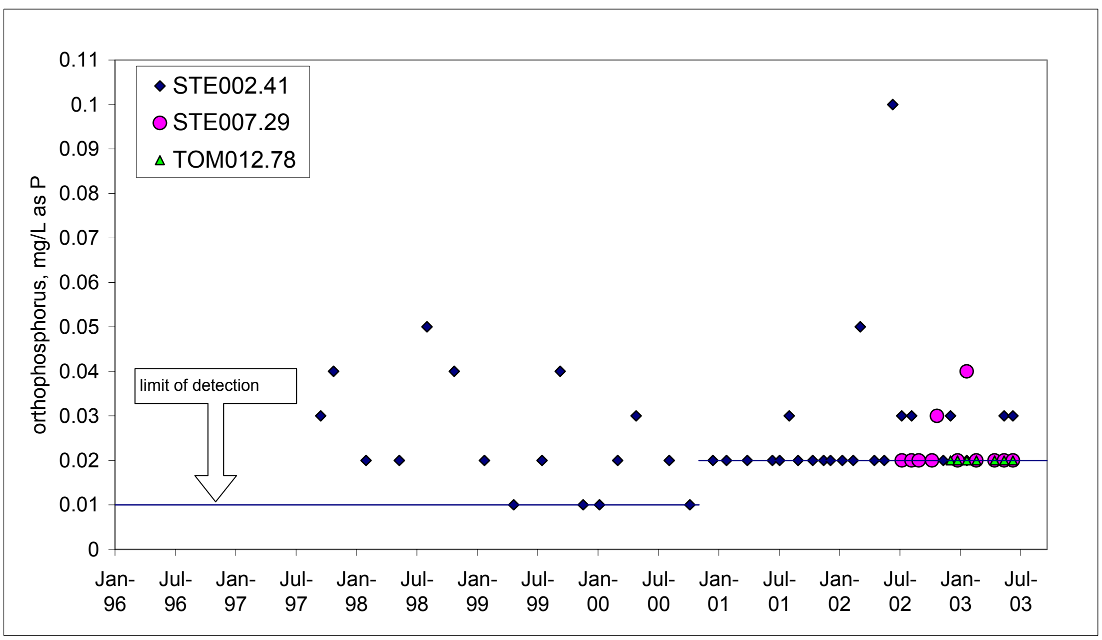

Figure 4.10. Orthophosphorus (PO_4-P) Concentration in Stroubles Creek

with open canopies and enough nutrients for eutrophic conditions, primary production can be so high that the benthic community shifts to one that resembles organic pollution (Voshell et al., 2003). In the early stages of eutrophication, there is an increase in the organisms that feed on algae (scrapers, e.g. *Elmidae*) and suspended fine detritus (collector-filterers, e.g. *Hydropsychidae*). In later stages of eutrophication, organisms that feed on fine detritus in sediment (burrowers/collector-gatherers, e.g. *Chironomidae*) will be dominant (Voshell et al., 2003). Stroubles Creek has a benthic community that resembles an intermediate stage of eutrophication (Devlin, 2003).

The elevated nutrient levels, well above the N and P eutrophic sufficiency levels of 0.3 mg/L and 0.01 mg/L respectively, combined with the open canopy surrounding most of Stroubles headwaters, to facilitate primary production that is higher than normal for a second order stream. This condition will cause a shift in the autochthonous (produced within the stream) food supply, resulting in an altered benthic community (Devlin, 2003).

Fish community data collected by the Virginia Tech Chapter of the American Fisheries Society (VT AFS) also support the position that Stroubles Creek is nutrient enriched. The poor riparian canopy, together with nutrients from upstream sources in Stroubles, produce an environment conducive to algal growth which can alter both fish and macroinvertebrate communities (Devlin, 2002). The VT AFS Chapter data show that Central Stonerollers make up approximately 40 – 60% of the fish community (Benson et al., 2000; Murphy, 2002). This species is an herbivore that quickly and efficiently dominates an ecosystem when a plant/algae food source is readily available. Bluehead Chubs (insectivore/omnivore) account for another 25% of the community. The Index of Biotic Integrity (IBI) scores for 1999 were in the poor-to-fair range indicating a stressed community.

A study by Woodside (1988) attributed the majority of the nutrients and organic matter (OM) entering the Duck Pond from Webb Branch, to town and campus runoff, with resident ducks and geese being only a minor contributor. He cites the Central Branch (under the Drill Field) as a contributor of large amounts of allochthanous OM, mostly in the form of leaves and plant debris. The Duck Pond and other basins in the watershed trap sediment and attached pollutants coming from upstream urban runoff, as is shown by its current need for dredging and its eutrophic nature. However, not all nutrients and other pollutants will be captured in these relatively shallow ponds, especially during major runoff events. Frequent algal blooms will result in increased organic matter levels downstream.

Despite all of these supportive observations, dissolved phosphorus concentrations tend to hover around its MDL of 0.01 or 0.02 mg/L, and no measurements of total phosphorus have exceeded DEQ's threatened water threshhold of 0.2 mg/L. Low DO measurements, generally expected to accompany elevated levels of nutrients, also have not been reported. However, there does not need to be a DO or BOD impact in flowing waters for an impact from nutrient enrichment to exist. In fact, subtle increases in nutrients will stimulate algae and macrophyte production which, in turn leads to increased DO. As long as stream flow is constant and temperatures are not excessively high, decaying organic matter will not necessarily cause a severe depletion of DO (Devlin, 2003). This effect is illustrated by the recent diurnal dissolved oxygen measurements shown in Figure 4.11, where the larger diurnal fluctuations in Stroubles Creek indicate increased productivity, possibly from higher nutrient levels, than at the neighboring Toms Creek station. Nutrients were, therefore, considered to be a possible stressor.

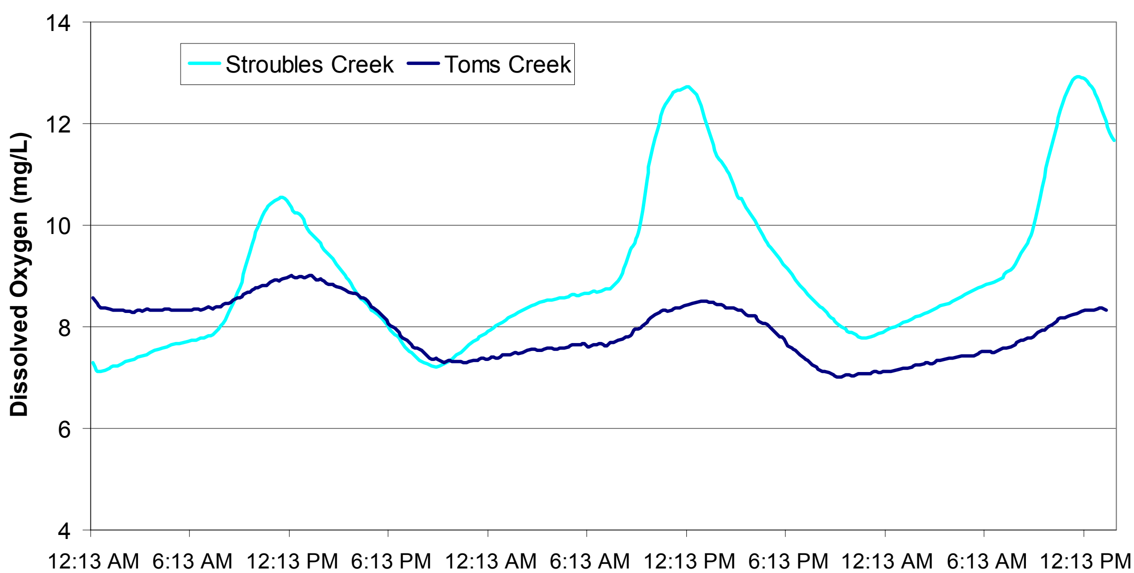

Figure 4.11. Diurnal DO, September 9-11, 2003

Sediment

Several factors provide evidence of excessive sediment loadings into Stroubles Creek. First, Stroubles Creek received repeated low habitat scores for bank stability, in-stream sediment deposition, and riparian vegetation (Table 3.4). Low scores in these three habitat indicators correlate with sediment deposition or the possibility for sediment production due to an unstable channel. In addition, the impervious urban area has been estimated as 17.7% of the entire watershed. One effect of this imperviousness is that a stream will widen its banks or downcut the stream bed (or both) in order to accommodate the higher stream velocity, energy, and flashiness during storms caused by increased runoff volumes due to reduced infiltration in the impervious areas. Studies have shown that increasing impervious area in a watershed above 12-15% is consistently correlated with a decline in benthic macroinvertebrate diversity (Schueler, 1994). In addition to impervious area in the watershed, there is significant construction activity on the Virginia Tech campus and in the town of Blacksburg that can contribute to sediment loading. A stretch of stream between the Duck Pond and the downstream benthic monitoring station has been degraded due to livestock access.

One metric from the macroinvertebrate sampling also suggests sediment as a probable stressor. *Chironimidae* were one of two dominant species in six of the seven spring benthic macroinvertebrate samples. This family is quite diverse in their living habits, with some attaching their tube retreats on vegetation as well as hard substrates. Regardless of the substrate, however, their dominance will be linked to an abundant food source. According to Voshell (2002), "most Chironomids consume the organic component of the fine sediment in which they live or which surrounds their tube when attached to firm substrates." Therefore, high proportions of *Chironomidae* are linked to an adequate/abundant source of organic matter, which may also be indicative of elevated levels of fine sediment. However, not all *Chironomidae* require fine sediment substrate to exist in a stream.

A study by Knocke in the spring of 1985 at 15 sites in the Duck Pond drainage area showed suspended solids concentrations typically less than 10 mg/L during dry weather, but greater than 1,000 mg/L during the one storm event monitored. Though a minimal amount of storm data are available, they do support the case for significant sediment loading during storm events. An estimate of sediment deposition in the upper and lower Duck Ponds provides further evidence of large sediment loads from the watershed, most probably during these large runoff events. Knocke (1985) estimated sediment deposition in the Duck Ponds as 2 to 6 inches/year (0.05 – 0.15 m/yr), based on its dredging history. Hoehn and Woodside (1988) list the surface areas of the upper and lower Duck Ponds as 29,469 m^2, which translates into a total sediment volume of 1,473 – 4,420 m^3/yr. Assuming a bulk density of 1500 kg/m^3, this amounts to a total of 2,209 – 6,630 t/yr. If we further assume a trapping efficiency of 50% for the ponds, this leads to an estimated range of sediment loading entering the Duck Ponds between 4,418 and 13,260 t/yr, and a sediment loading to the downstream benthic community of half that amount.

Some metrics indicate that sediment may not be a stressor on Stroubles Creek. For example, *Hydropsychidae* and *Elmidae* were dominant in some of the samples, neither of which can tolerate high sediment loads. *Hydropsychidae* dominated all fall samples and three of the spring samples. The retreats they construct on rocks and other hard substrate are built so that food (detritus, algae, and other seston) will be filtered out of the current and collect in the net at the back of the retreat. When the fine sediment load is high, these retreats are dislodged from the substrate or buried in the sediment which interferes with feeding (Lemly, 1982). Riffle beetles (*Elmidae*) are the second most abundant taxa in four samples and dominant in one, suggesting high primary production. Similar to *Hydropsychidae*, Elmids feed on algae, periphyton, and detritus. Their primary habitat is cobble and gravel substrate. They are clingers and are adapted to living on substrates covered with periphyton and algae rather than fine sediments. *Hydropsychidae* and *Elmidae* would probably not be dominant if sediments were having a large impact.

Sediment is also not supported as a stressor by embeddedness and substrate – two of the habitat assessment metrics most related to the impact of sediment on the riffle-run habitat. Average scores of 12.8 and 13.0 out of 20 for these 2 metrics, respectively, indicate that sediment has only a slight impact on the benthic habitat. Additionally, the "%Haptobenthos" metric scores were moderate, indicating only slight reductions in availability of the clean, coarse substrate used as attachment sites by these organisms. Furthermore, the Central Stonerollers, which do not inhabit heavily silted streams, make up approximately 40 – 60% of the fish community (Benson, 1999; Murphy, 2002).

Therefore, although evidence is mixed in support of sediment, sufficient information is available to show that sediment does contribute to the stress on the benthic macroinvertebrates in Stroubles Creek.

4.4. Most Probable Stressor

Sediment was initially identified as the most probable stressor for Stroubles Creek, as presented at the first public meeting. Confidence was somewhat limited in this assessment, since the available benthic and chemical monitoring data were not collected at the same site, but were separated by about 5 miles of stream that constituted a recovery zone. Further concerns raised at the public meeting by the regional biologist eventually led to an additional 6 months of monitoring with both benthic and chemical sampling at the same site – station STE007.29, the existing benthic station. After analyzing the data collected at this site, together with the previous data, no single unambiguous stressor emerged during the stressor analysis. As discussed in the previous section, three stressors – nutrients, organics, and sediment – showed potential impacts.

After further discussion with state DCR and DEQ personnel, and with the regional biologist and TMDL coordinator, a decision was made to use sediment as the representative stressor around which to develop a staged implementation TMDL to address the benthic impairment in Stroubles Creek. Sediment was chosen based on the following rationale:

- Impacts from the three possible stressors – nutrients, organic matter, and sediment – are inter-connected.
- Best management practices employed to control sediment would result in decreases in the other possible stressors as well. Best management practices that might be used during implementation include those that would address the open canopy, streambank stability, riparian buffer zones, urban and construction runoff, livestock access to the stream, and runoff from agricultural fields. Additionally, BMPs that would decrease stream power and erosive energy, e.g. those that increase infiltration and delay runoff from impervious areas during peak runoff events, might also be appropriate. Some examples of the synergistic reductions from sediment BMPs are:
    - Reducing livestock access to stream also reduces inputs of organic manure and nutrients
    - Increasing riparian buffers and tree canopy reduces inputs of nutrients as they replace heavily fertilized riparian urban lawns
    - Delaying runoff from impervious areas would allow not only sediment, but also suspended organic matter and attached nutrients to settle out prior to entering the stream.
- The ultimate criteria for judging the success of the TMDL will be the restoration of the benthic community itself. The staged implementation approach may include combinations of the above categories of BMPs in order to address all three possible stressors. As implementation proceeds, progress will be monitored, and the effectiveness of the implementation strategy will be evaluated.

CHAPTER 5: THE REFERENCE WATERSHED MODELING APPROACH

5.1. Introduction

Because Virginia has no numeric in-stream criteria for the pollutant of concern, a "reference watershed" approach was used to set allowable loading rates in the impaired watershed.

The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. This reference watershed may or may not be the same as the biological reference watershed (i.e., the watershed used for determining comparative biological metric scores in the RBP II process). The reference watershed is selected on the basis of similarity of land use, topography, ecology, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment.

The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization of the reference and TMDL watersheds, definition of the TMDL endpoint using modeled output from the reference watershed, and development of alternative TMDL reduction (allocation) scenarios.

5.2. TMDL Reference Watershed Selection

5.2.1. Comparison of Potential Watersheds

The initial list of potential reference watersheds was composed of all watersheds currently used as biological references by the Valley Region DEQ office; the watershed used as biological reference for Stroubles Creek; the two watersheds most recently used as sediment reference watersheds for the Blacks

Run and Cooks Creek watershed TMDLs; one watershed considered, but never used, as a biological reference for Stroubles Creek; and a new proposed watershed adjacent to Stroubles Creek. Because sediment was identified as the primary pollutant responsible for the benthic impairment, the comparison of watershed characteristics focused, not only on geological and ecological similarities, but also on sediment-generating characteristics. Only minor differences exist among the eco-region classifications for all of the potential reference watersheds. All watersheds are in the same Central Appalachian Ridges and Valleys Level III Ecoregion. Stroubles Creek and the two Toms Creek watersheds, defined by station IDs TOM002.19 and TOM012.78, are predominantly in the Southern Limestone/Dolomite Valleys and Low Rolling Hills Level IV Ecoregion, while all other watersheds are in the Northern Limestone/Dolomite Valleys Level IV Ecoregion.

Table 5.1 compares the various physical and sediment-related characteristics of the potential reference watersheds to the characteristics of the impaired watershed. The characteristics chosen to be representative of sediment generation were land use distribution, non-forested average soil erodibility, and average non-forested % slope. The K-factor was used to represent soil erodibility in the watersheds, and was calculated as an area-weighted average of the soil K-factors in the watershed.

Table 5.1. Comparison of Physical and Sediment-Related Characteristics

STATIONID	WATERSHED	Area (ha)	Landuse Distribution %Urb	%For	%Agr	Non-Forested Soil Erodibility Factor SSURGO	STATSGO	Slope (%)	Elevation (meters)	Census 2000 Non-Sewered Population	(pop/ha)
STE007.29	Stroubles Creek	2,468	29%	39%	32%	0.34	0.31	3.94	641.0	11,709	4.74
OPE034.53	Opequon Creek	15,123	5%	35%	60%	0.31	0.30	5.60	224.1	16,322	1.08
STC000.72	Strait Creek	672	0%	71%	29%	NA	0.24	18.50	988.3	57	0.08
STY004.24	Stony Creek	19,768	1%	87%	12%	0.26	0.27	11.67	507.7	2,126	0.11
BLP000.79	Bullpasture River	28,495	0%	81%	18%	NA	0.25	7.73	794.6	527	0.02
CWP050.66	Cowpasture River	56,604	0%	86%	14%	NA	0.26	13.81	748.4	994	0.02
HYS001.41	Hays Creek	20,801	0%	52%	48%	0.31	0.31	12.53	526.2	1,600	0.08
JKS067.00	Jackson River	31,429	0%	81%	19%	NA	0.26	13.93	848.7	705	0.02
TOM002.19	Toms Creek	9,070	3%	70%	28%	0.31	0.30	12.92	662.7	0	0.00
SNK012.06	Sinking Creek	12,860	0%	62%	38%	NA	0.30	18.24	771.6	928	0.07
TOM012.78	Toms Creek	2,067	2%	72%	26%	0.30	0.25	11.59	688.8	629	0.30
QAL005.18	Quail Run	349	13%	81%	7%	0.26	0.26	10.00	452.9	8	0.02

- Characteristics of the Impaired watershed
- Closest matching characteristics of the candidate reference watersheds

5.2.2. TMDL Reference Watershed Selection

Based on the information presented in the previous two sections, the smaller Toms Creek watershed (TOM012.78) was selected as the reference watershed for Stroubles Creek. Land use distribution and Level IV Ecoregion were considered the most important characteristics considered in this selection, as Toms Creek has a significant urban component while comprised predominantly of agricultural land uses, and is adjacent to Stroubles Creek with the same predominant sub-ecoregion classification. Toms Creek watershed is also comparable in size to Stroubles Creek. Other characteristics - K-factors, slope, and elevation, were comparable to those of Stroubles Creek.

5.3. TMDL Modeling Target Loads

The reference watershed approach for Stroubles Creek uses the sediment loading rate in the non-impaired Toms Creek watershed as the TMDL target endpoint for Stroubles Creek. Reductions from various sources will be specified in the alternative TMDL scenarios that will achieve the TMDL target within the impaired Stroubles Creek watershed. Reductions in sediment load to levels found in the reference watershed are expected to allow benthic conditions to return to a non-impaired state.

CHAPTER 6: MODELING PROCESS FOR TMDL DEVELOPMENT

6.1. Source Assessment of Sediment

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

6.1.1. Surface Runoff

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

6.1.2. Channel and Streambank Erosion

Pasture areas accessible to streams are often associated with sediment loading through the activity of livestock on their streambanks. Livestock hooves on streambanks detach clumps of soil, and push the loosened soil downslope and into streams adjacent to these areas, delivering sediment to the stream independent of runoff events. Impervious areas tend to increase the percentage of rainfall that runs off the land surface leading to larger volumes of runoff with higher peak flows and greater channel erosion potential. For the future scenario, livestock numbers and access to streams were reduced in proportion to the decreases in pasture areas in each sub-watershed.

6.1.3. Point Source TSS Loads

Fine sediment is included in total suspended solids (TSS) loads that are permitted for various facilities with industrial and construction VPDES permits around the watershed. Additionally, three MS4 permits have recently been issued in the watershed. These permits are designed to reduce nonpoint source pollution of urban stormwater runoff from the MS4 areas and to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, although no numerical limits for any specific water quality parameter are stipulated in these permits. "Small municipal separate storm sewer systems owners/operators must reduce pollutants in their storm water discharges to the maximum extent practicable to protect water quality. Small municipal separate storm sewer systems permits require the owner/operator to develop a storm water management program designed to prevent harmful pollutants from being washed by storm water runoff into the municipal separate storm sewer systems (or from being dumped directly into the municipal separate storm sewer systems) and then discharged from the municipal separate storm sewer systems into local waterbodies" (http://www.deq.state.va.us/water/bmps.html). The MS4 permits blur the lines that have traditionally distinguished point and nonpoint sources of pollution. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). Sediment loads modeled from industrial permitted dischargers, transitional (construction sites), and stormwater runoff from the MS4 areas are also included in the wasteload allocation (WLA) component of the TMDL, in compliance with 40 CFR §130.2(h).

6.2. GWLF Model Description

The Generalized Watershed Loading Functions (GWLF) model was developed for use in ungaged watersheds (Haith et al., 1992), and was chosen for the modeling required for the Stroubles Creek TMDL. The loading functions, upon which the model is based, are compromises between the empiricism of export coefficients and the complexity of chemical simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff and sediment, dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater, and nutrient inputs from septic systems. The hydrology in the model is simulated with a daily water balance procedure that takes into consideration types of storages within the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986). Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans (2002) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model.

The GWLF model operates on three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains primarily input data related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Visual Basic™ version of GWLF with modifications for use with ArcView was used in this study (Evans et al., 2001). Additional modifications were made to the model to allow for variable inputs and outputs of sediment buildup and washoff from impervious surfaces and to allow for load summarization on a calendar year basis. The following modifications were made to the Penn State Visual Basic version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Although the model runs begin in April per the design constraints of the GWLF model, the model was recoded to output data beginning with the following January for summary on a calendar basis.
- Urban sediment washoff was added as a variable input to replace an erroneous formula that calculated USLE erosion from impervious areas.
- A constant was added to groundwater flow in order to match minimum baseflows from the Chesapeake Bay Watershed Model during the statewide nonpoint source assessment for Virginia (Yagow, 2002).

- An automatically calculated correction factor was incorporated to account for differences between calculations of watershed total sediment yield and summations of sediment yield from individual land uses.

6.3. Supplemental Post-Model Processing

After modeling was performed on individual and cumulative sub-watersheds, and total watersheds, the model output was post-processed in an Excel™ spreadsheet to summarize the modeling results and to account for two additional conditions. These two conditions were the existing levels of agricultural best management practices (BMPs) and sediment detention within the various sub-watersheds of Stroubles Creek watershed.

The effect of installed agricultural BMPs was based on the Virginia Department of Conservation and Recreation's State Cost-Share Database. This database tracks the implementation of BMPs within each state HUP watershed. These data are then used by EPA's Chesapeake Bay Program to calculate sediment reduction and pass-through fractions of the sediment load from each land use in each HUP for use with the Chesapeake Bay model and with the Virginia 2002 Statewide NPS Pollution Assessment (Yagow et al., 2002). Since Stroubles Creek lies within the N22 watershed, the sediment pass-through fractions for each land use category within N22 were related to, and applied to, the modeled land use categories used for this TMDL study. Modeled sediment loads within each land use category were then multiplied by their respective pass-through fractions to simulate the reduced loads resulting from existing BMPs.

Sediment detention in the Virginia Tech Duck Ponds and the Virginia Tech stormwater detention ponds were modeled by estimating the proportion of each land use category above ponds and detention basins and applying a 50% reduction to sediment loads from surface runoff and from channel erosion upstream from the ponds and detention basins.

6.4. Input Data Requirements

6.4.1. Climate Data

Hourly precipitation and temperature data were obtained for the National Weather Service station closest to both watersheds - Blacksburg (440766) - as shown in Figure 6.1. The periodic record was edited by filling missing records and distributing missing distributions based on available records from surrounding stations. The hourly precipitation data was summed as daily totals, and hourly temperature transformed to a daily average, with each converted to metric units, cm and °C, respectively, for use with the GWLF model.

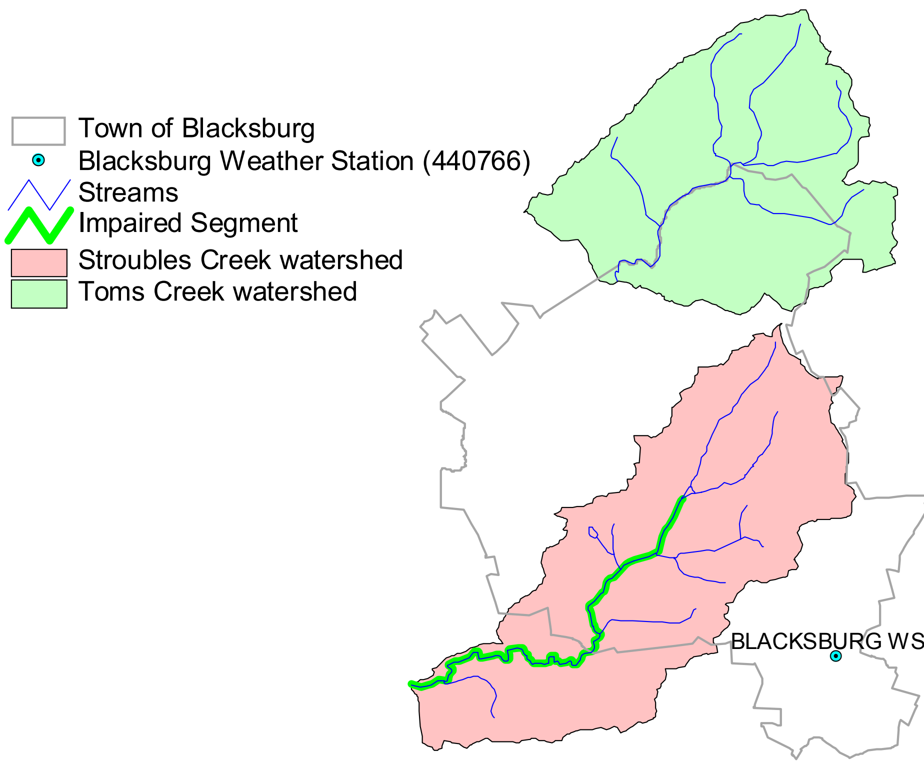

Figure 6.1. Location of Watersheds and NWS Weather Station

6.4.2. Land Use

Digital land use for both Stroubles Creek and Toms Creek were developed from 1998 digital ortho-photo quarter quads. The Stroubles Creek layer was developed and interpreted by the Virginia Department of Conservation and Recreation (DCR), while Toms Creek was digitized and interpreted by the

Virginia Tech Biological Systems Engineering Department (BSE) and reviewed by DCR to assure consistency in interpretation. The 22 original interpreted land uses were categorized for use with the GWLF model, as shown in Table 6.1. The 13 land use categories and their distribution within the Stroubles Creek and Toms Creek watersheds are shown in Table 6.2.

Table 6.1. Consolidation of VADCR Land Use Categories for Stroubles Creek

TMDL Land Use Categories	Pervious/Impervious (percentage)	VADCR Land Use Categories
Cropland	Pervious (100%)	Cropland (211)
Pasture 1	Pervious (100%)	Improved pasture (2121) Orchards (22)
Pasture 2	Pervious (100%)	Unimproved pasture (2122)
Pasture 3	Pervious (100%)	Overgrazed pasture (2123)
Urban Grass	Pervious (100%)	Open urban (18)
Hay	Pervious (100%)	Rotational Hay (2114)
Forest	Pervious (100%)	Forest (4)
Transitional	Pervious (100%)	Barren (7) Urban transition (16) Harvested forest (44) Confined cattle (231)
Low Density Residential (LDR)	Pervious (88%) Impervious (12%)	LDR (111) Wooded residential (118)
Medium Density Residential (MDR)	Pervious (70%) Impervious (30%)	MDR (112) Mobile homes (115) Farmstead (241) Dairy Waste Facilities (242)
High Density Residential (HDR)	Pervious (35%) Impervious (65%)	HDR (113)
Commercial	Pervious (21%) Impervious (79%)	Commercial (12) Industrial (13) Transportation/Utilities (14)

Table 6.2. Land Use Distribution in Stroubles Creek and Toms Creek Watersheds (ha)

Land Use Category	STE1	STE2	STE3	STE4	STE5	STE6	STE7	STE8	Stroubles Creek Total	Toms Creek Total	Toms Creek Area Adjusted
	Stroubles Creek Sub-watersheds										
Hi Till cropland	0.9	0.3	4.0	2.0	1.2	0.0	0.0	1.1	9.4	0.9	1.0
Low Till cropland	11.0	3.9	50.0	24.6	14.5	0.0	0.0	13.9	117.9	10.9	13.0
Pasture, improved	68.8	54.8	87.3	125.3	45.7	46.1	0.0	41.9	469.8	331.2	395.4
Pasture, unimproved	2.5	1.4	0.0	0.5	5.4	0.2	0.0	4.3	14.2	69.5	83.0
Pasture, overgrazed	0.2	0.5	0.0	8.7	8.7	0.0	0.0	1.3	19.4	12.8	15.2
Urban grass	1.2	0.6	1.3	55.1	64.5	63.9	41.8	84.5	312.9	14.8	17.6
Hay	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	4.7	0.0	0.0
Forest	504.8	76.8	37.9	8.7	20.3	25.1	5.1	5.6	684.4	1227.6	1465.4
Transitional	0.9	3.2	0.5	2.1	7.1	3.1	1.2	0.0	18.2	0.0	0.0
LDR - pervious	12.1	8.9	0.4	1.1	2.5	10.8	12.5	0.8	49.1	253.3	302.3
MDR - pervious	11.5	4.9	0.5	14.6	28.2	118.0	65.6	2.9	246.2	48.0	57.3
HDR - pervious	0.0	0.0	0.0	15.1	4.4	11.5	18.3	1.1	50.3	0.0	0.0
Commercial - pervious	0.0	0.0	0.5	3.5	9.7	18.2	14.3	10.3	56.5	9.7	11.6
LDR - impervious	1.7	1.2	0.1	0.1	0.3	1.5	1.7	0.1	6.7	34.5	41.2
MDR - impervious	4.9	2.1	0.2	6.3	12.1	50.6	28.1	1.2	105.5	20.6	24.6
HDR - impervious	0.0	0.0	0.0	28.1	8.2	21.3	33.9	2.0	93.5	0.0	0.0
Commercial - impervious	0.0	0.0	1.8	13.2	36.7	68.4	53.9	38.6	212.6	36.5	43.6
Total Area	**620.5**	**158.6**	**184.4**	**309.0**	**274.2**	**438.5**	**276.5**	**209.4**	**2,471.2**	**2,070.1**	**2,471.2**

6.4.3. Hydrologic Parameters

A long-term record of flow was not available for Stroubles Creek, Toms Creek, or any comparably-sized watershed in the area. Therefore, GWLF modeling was performed without attempting to calibrate hydrologic parameters. All parameters were evaluated in a consistent manner between the two watersheds, in order to ensure their comparability for the reference watershed approach. The GWLF parameter values were evaluated from a combination of GWLF user manual guidance, AVGWLF procedures, procedures developed during the 2002 statewide NPS pollution assessment (Yagow et al., 2002), and professional judgment. Parameters were generally evaluated using GWLF manual guidance, except where noted otherwise. Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file.

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated

by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph.
- Seepage coefficient (day-1): The seepage coefficient represents the amount of flow lost as seepage to deep storage.

The following parameters were initialized by running the model for a 9-month period prior to the chosen period during which loads were calculated:
- 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 is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

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

6.4.4. Sediment Parameters

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

Land Use-Related Parameter Descriptions
- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.

- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997).
- 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 in MDR, HDR, and COM land uses, as well as the imperviouos portions of LDR.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- 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.

6.5. Accounting for Sediment Pollutant Sources

6.5.1. Surface Runoff

Pervious area sediment loads were modeled explicitly in the GWLF model using sediment detachment, a modified USLE erosion algorithm, and a sediment delivery ratio to calculate edge-of-watershed loads, reported on a monthly basis by land use. Impervious area sediment loads were modeled explicitly in the GWLF model using an exponential buildup-washoff algorithm.

6.5.2. Channel and Streambank Erosion

Streambank erosion was modeled explicitly within the GWLF model using a modification of the routine included in the AVGWLF adaptation of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of: percentage developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, streamflow volume, and total stream length in the watershed.

6.5.3. Point Source

There are 2 permitted industrial stormwater dischargers, 4 construction permit dischargers, and 1 concentrated animal feeding operation (CAFO) in

Stroubles Creek watershed and none in Toms Creek, as shown in Table 6.3. There were no single family homes permitted under the 1000-gpd general permit in the watershed. Permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/L. Modeled runoff for industrial stormwater dischargers was calculated by multiplying the maximum annual modeled runoff depth for commercial pervious land uses (17.84 cm) and for commercial impervious land uses (90.90 cm) by their respective percentages (21% pervious, 79% impervious) for an average annual runoff depth for commercial areas (75.56 cm); the modeled runoff for construction areas used the average annual modeled runoff depth for transitional land uses (38.08 cm). Future loads for the MS4 permits were calculated in aggregate from impervious area loads within the portion of the watershed within the Town of Blacksburg. Existing loads were modeled as if the MS4 permits and any accompanying BMPs were not active. A baseline load from the MS4 area, however, was calculated for existing conditions. The future load was calculated assuming that the future load, including any increases from increased impervious area, would be reduced to 50% of the baseline load through the use of urban runoff BMPs.

Table 6.3. TSS Loads from Permitted Dischargers in Stroubles Creek

Stroubles Creek Point Sources		Existing Conditions			Future Conditions
VPDES ID	**Name**	**Max. Annual Runoff (cm)**	**Conc. (mg/L)**	**TSS (t/yr)**	**TSS (t/yr)**
Industrial Stormwater					
VAR050441	Litton Systems Inc Poly Scientific Div	75.56	100	2.70	2.70
VAR050508	VT - Central Heating Plt	75.56	100	0.46	0.46
Construction Permits					
VAR10042	VT - Dairy Science Center	38.08	100	2.37	2.37
VAR10267	VT - Campus	38.08	100	15.43	15.43
VAR10275	Hawthorne Ridge Town Houses	38.08	100	0.77	0.77
VAR10282	Carriage Court II	38.08	100	0.54	0.54
CAFO Permit					
VPG120011	VT - Dairy Science Center			0.00	0.00
MS4 Permits					
VAR040019	Town of Blacksburg				
VAR040049	Virginia Tech			421.77	210.88
VAR040016	VDOT - Blacksburg Area				
Point Source Totals				**444.05**	**233.2**

6.6. Accounting for Critical Conditions and Seasonal Variations

6.6.1. Critical Conditions

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

6.6.2. Seasonal Variability

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

6.7. GWLF Model Parameters

The Generalized Watershed Loading Functions (GWLF) model was developed for use in ungaged watersheds (Haith et al., 1992), although hydrologic calibration has been recommended where observed flow data is available. However, since observed flow data was not available at either Stroubles Creek or its reference watershed – Toms Creek – hydrologic calibration was not performed. Therefore, the GWLF model parameters were evaluated using GWLF user manual guidance and professional judgment. Since the reference watershed approach produces relative loads generated by the impaired and TMDL reference watersheds, the evaluation of each parameter was performed in the same manner for both watersheds to ensure the comparability of the model outputs.

A complete listing of all GWLF parameter values evaluated for the GWLF transport file for both watersheds under existing conditions are shown in Tables 6.4 – 6.6. Table 6.4 lists the various watershed-wide parameters and their values, Table 6.5 shows the evapotranspiration coefficients, and Table 6.6 shows the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP quotient for erosion modeling.

Table 6.4. GWLF Watershed Parameters

GWLF Watershed Parameters	units	STE1x	STE2x	STE3	STE4x	STE5	STE6	STE7	STE8x	Toms Creek Area-adjusted
recession coefficient	(day^{-1})	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
seepage coefficient	(day^{-1})	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
sediment delivery ratio		0.1665	0.1738	0.1954	0.1780	0.1942	0.1920	0.1942	0.1855	0.1665
unsaturated water capacity	(cm)	13.08	13.33	15.94	12.95	12.42	10.17	13.34	11.75	13.27
erosivity coefficient (Nov - Apr)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
erosivity coefficient (growing season)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
% developed land	(%)	36.5	46.7	2.5	56.0	38.7	69.9	80.9	67.1	7.2
no. of livestock	(AU)	415	384	108	236	92	24	0	34	550
area-weighted soil erodibility		0.306	0.330	0.327	0.338	0.329	0.325	0.362	0.340	0.265
area-weighted runoff curve number		79.58	81.84	76.40	83.18	82.56	83.79	86.38	84.63	74.88
total stream length**	(m)	18584.7	12850.4	1861.6	10119.2	2121.6	807.4	1729.8	4439.7	21088.6
stream length with livestock access	(m)	4364.22	4364.22	1592.76	2204.29	0	0	0	0	0

** total stream length was reduced by the length of channelized sections of the stream for the purposes of estimating channel erosion.

Table 6.5. GWLF Monthly Evapo-Transpiration Cover Coefficients

Watershed	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
STE1x	0.821	0.824	0.826	**0.826**	0.826	0.822	0.794	0.766	0.754	**0.746**	0.786	0.813
STE2x	0.768	0.770	0.771	**0.771**	0.771	0.769	0.751	0.734	0.727	**0.722**	0.746	0.763
STE3	0.976	0.984	0.987	**0.987**	0.987	0.978	0.917	0.855	0.828	**0.811**	0.899	0.959
STE4x	0.723	0.724	0.724	**0.724**	0.724	0.723	0.713	0.704	0.700	**0.697**	0.711	0.720
STE5	0.770	0.772	0.773	**0.773**	0.773	0.771	0.754	0.737	0.730	**0.725**	0.749	0.765
STE6	0.671	0.672	0.672	**0.672**	0.672	0.671	0.667	0.663	0.662	**0.660**	0.666	0.670
STE7	0.571	0.571	0.571	**0.571**	0.571	0.571	0.570	0.569	0.568	**0.568**	0.570	0.571
STE8x	0.670	0.671	0.671	**0.671**	0.671	0.670	0.665	0.659	0.657	**0.656**	0.663	0.668
TOMadj	0.948	0.954	0.956	**0.956**	0.956	0.950	0.907	0.865	0.847	**0.835**	0.895	0.936

* July values represent the maximum composite ET coefficients during the growing season.

** Jan values represent the minimum composite ET coefficients during the dormant season.

Table 6.6. GWLF Land Use Parameters – Existing Conditions

	STE1x		STE2x		STE3		STE4x		STE5		STE6		STE7		STE8x		Toms Creek Area-adjusted	
Landuse	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
Hitill	0.8565	86.7	0.8625	86.7	0.9764	86.8	0.7702	86.5	1.1119	87.6	0.0000	86.8	1.3620	86.8	0.6763	87.6	1.1158	87.6
Lotill	0.4596	85.1	0.4669	85.1	0.5248	85.2	0.4210	85.0	0.6408	86.0	0.0000	85.2	0.8756	85.2	0.3561	86.0	0.5960	86.0
Pasture 1	0.0084	71.8	0.0083	71.8	0.0111	72.2	0.0072	71.3	0.0060	73.4	0.0112	72.1	0.0000	72.2	0.0105	72.7	0.0123	73.4
Pasture 2	0.0617	78.2	0.0423	78.4	0.0000	77.6	0.0326	78.3	0.0302	78.5	0.3169	77.6	0.0000	77.6	0.0424	78.5	0.0691	78.5
Pasture 3	0.1773	84.7	0.1790	84.7	0.0000	85.0	0.1707	84.7	0.1801	85.7	0.0000	85.0	0.0000	85.0	0.1004	85.7	0.3042	85.7
Uran grass	0.0339	76.9	0.0334	76.9	0.0177	76.7	0.0333	76.9	0.0267	77.8	0.0436	76.7	0.0465	76.7	0.0000	77.2	0.0583	77.8
Hay	0.0258	77.8	0.0356	77.8	0.0000	76.7	0.0377	77.8	0.0395	77.8	0.0000	76.7	0.0000	76.7	0.0000	0.0	0.0000	77.8
Forest	0.0061	71.3	0.0026	71.7	0.0014	71.2	0.0020	71.3	0.0012	72.4	0.0035	71.1	0.0023	71.2	0.0029	71.3	0.0077	72.4
Transitional	0.6132	90.5	0.5838	90.5	0.1464	90.3	0.6093	90.5	0.5811	90.9	1.0294	90.3	0.6796	90.3	0.9330	90.3	0.0000	90.9
LDR-pervious	0.0145	77.8	0.0128	77.8	0.0028	77.6	0.0109	77.6	0.0046	78.5	0.0137	77.6	0.0110	77.6	0.0119	77.6	0.0191	78.5
MDR-pervious	0.0081	77.6	0.0082	77.6	0.0108	77.6	0.0081	77.6	0.0055	78.5	0.0088	77.6	0.0085	77.6	0.0086	77.6	0.0164	78.5
HDR-pervious	0.0088	77.1	0.0088	77.1	0.0000	77.6	0.0088	77.1	0.0074	78.5	0.0087	77.6	0.0087	77.6	0.0088	77.6	0.0000	78.5
Com-pervious	0.0046	77.8	0.0047	77.8	0.0043	77.6	0.0049	77.8	0.0056	78.5	0.0036	77.6	0.0057	77.6	0.0047	77.8	0.0138	78.5
LDR-impervious	0.0000	91.6	0.0000	91.6	0.0000	91.6	0.0000	91.6	0.0000	91.8	0.0000	91.5	0.0000	91.6	0.0000	91.6	0.0000	91.8
MDR-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
HDR-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Com-impervious	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

CHAPTER 7: THE BENTHIC TMDL FOR SEDIMENT

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1994).

7.1. Background

The benthic TMDL for sediment was developed using a reference watershed approach. The GWLF model was run for existing conditions over the 10-yr period of January 1984 – December 1994. This period was chosen to include a variety of hydrologic conditions that included both wet and dry years. Since different size watersheds would be expected to produce different size sediment loads, the area of the impaired watershed was adjusted to the area of the impaired watershed by multiplying the ratio of the watershed areas times the area of each land use in the impaired watershed, so that model output was compared between two equal-sized watersheds. The average annual sediment load (t/yr) from Toms Creek (the TMDL reference watershed), area-adjusted to the impaired watershed, was then used to define the TMDL sediment load for the impaired Stroubles Creek watershed.

In order to provide more information on the spatial variability of the sediment loads for the implementation phase, the entire Stroubles Creek watershed was subdivided into 8 sub-watersheds, as shown in Figure 7.1. Modeling was performed on these 8 sub-watersheds plus the area-adjusted Toms Creek watershed. The TMDL reference watershed was modeled as a single watershed. The increased spatial variability of sediment sources by land use and sub-area in the impaired watershed is important when defining where and how reductions are made for the allocation scenarios and during future planning for implementation of control measures.

Of the 8 sub-watersheds in the Stroubles Creek watershed, 4 sub-watersheds originate with headwater segments, while the remaining 4 downstream sub-watersheds receive flow and sediment from one or more upstream sub-watersheds. Because the GWLF model was not designed to model downstream subwatersheds independently, each downstream watershed was modeled to include all of its upstream drainage. Spreadsheet accounting was then used to subtract loads from upstream segments and to account for differences in the GWLF area-based sediment delivery ratio between the entire watershed and smaller upstream subwatersheds, thereby apportioning watershed sediment loads among the various subwatersheds. In order to focus on the comparison between the impaired and reference watershed, all loads in the following discussion are reported only as watershed totals for the impaired Stroubles Creek watershed and its area-adjusted TMDL reference watershed – Toms Creek. Details on model parameter inputs and sediment loads for all of the individual subwatersheds are given in Appendix C.

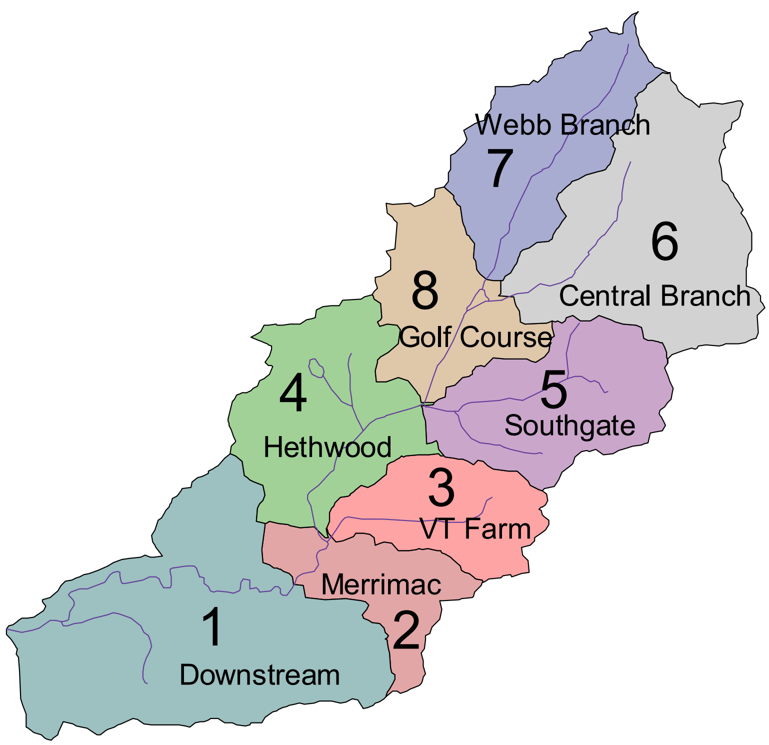

Figure 7.1. GWLF Modeling Subwatersheds for Stroubles Creek

7.2. The Stroubles Creek Benthic TMDL

The benthic TMDL for the Stroubles Creek watershed was developed using sediment as the pollutant and a reference watershed approach, with Toms Creek watershed as the TMDL reference watershed. Since Toms Creek watershed was slightly smaller than the Stroubles Creek watershed, the area of each land use in the Toms Creek watershed was increased in proportion to the ratio of the area of the impaired watershed to that of the TMDL reference watershed (x 1.194), as detailed in Table 6.2. This resulted in an area-adjusted Toms Creek watershed equal in size with the land area in the impaired Stroubles Creek watershed (2,471 ha).

The existing sediment loads were modeled for each watershed and are listed in Table 7.1 by sediment source as average annual (t/yr) and unit-area (t/ha) loads. The target TMDL sediment load in Stroubles Creek – 2,145.6 t/yr - was defined as the average annual sediment load for the area-adjusted Toms Creek watershed under existing conditions.

Table 7.1. Existing Sediment Loads (t/yr)

Sediment Sources	Stroubles Creek (t/yr)	Stroubles Creek (t/ha)	Area-adjusted Toms Creek (t/yr)	Area-adjusted Toms Creek (t/ha)
High Till	434.4	46.08	62.7	60.48
Low Till	2,963.9	25.13	427.8	33.00
Pasture	366.5	0.73	702.1	1.42
Urban grasses	338.5	1.08	40.0	2.27
Hay	8.1	1.74	0.0	0.00
Forest	106.6	0.16	241.5	0.16
Transitional	110.8	6.09	0.0	0.00
Pervious Urban	95.1	0.24	280.3	0.76
Impervious Urban	22.4	0.05	56.4	0.52
Channel Erosion	1,845.9	0.75	334.8	0.14
MS4	421.8		0.0	
Permitted Point Sources	22.3		0.0	
Watershed Totals	**6,736.2**		**2,145.6**	
Target Sediment TMDL Load =			**2,145.6**	**t/yr**
10% MOS =			214.6	t/yr
Load for Allocation =			**1,931.1**	**t/yr**

The benthic TMDL for Stroubles Creek is comprised of three required load components – the waste load allocation (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), as shown in Table 7.2.

Table 7.2. Stroubles Creek TMDL Sediment Load

TMDL (t/yr)	**WLA (t/yr)**	**LA (t/yr)**	**MOS (t/yr)**
2,145.6	233.2	1,697.9	214.6
	VAR050441 - Litton Systems Inc Poly Scientific Div : 2.7 VAR050508 - VT - Central Heating Plt: 0.46 VAR10042 - VT - Dairy Science Center: 2.37 VAR10267 - VT - Campus: 15.43 VAR10275 - Hawthorne Ridge Town Houses: 0.77 VAR10282 - Carriage Court II: 0.54 VPG120011 - VT - Dairy Science Center: 0 MS4s (VAR040019, VAR040049, VAR040016): 210.88		

The margin of safety (MOS) was explicitly defined as 10% of the calculated TMDL to reflect the relative uncertainty associated with benthic impairments. The waste load allocation (WLA) was calculated as half of the modeled sediment load from impervious land uses within MS4 permit areas, plus loads from specific industrial stormwater and construction permits. The MS4 loads were calculated for existing conditions and assumed to represent loads prior to implementation of MS4 regulations. The load allocation (LA) – the allowable sediment load from nonpoint sources – was calculated as the target TMDL load minus the MOS minus the WLA. Since the MOS is excluded from allocation, the target load for modeling purposes in Stroubles Creek becomes the TMDL minus the MOS (1,931.1 t/yr).

Because of expected future growth in the watershed, TMDL modeling for the allocation runs was performed using the future land use scenario for Stroubles Creek. The projected future sediment loads in Stroubles Creek watershed by land use category and subwatershed are shown in Table 7.3.

Table 7.3. Projected Future Sediment Loads (t/yr)

Sediment Sources	Stroubles Creek (t/yr)	Stroubles Creek (t/ha)	Area-adjusted Toms Creek (t/yr)	Area-adjusted Toms Creek (t/ha)
High Till	401.6	46.06	62.7	60.48
Low Till	2,735.0	25.07	427.8	33.00
Pasture	324.5	0.89	702.1	1.42
Urban grasses	331.3	1.09	40.0	2.27
Hay	8.1	1.73	0.0	0.00
Forest	100.6	0.16	241.5	0.16
Transitional	110.6	6.08	0.0	0.00
Pervious Urban	150.9	0.29	280.3	0.76
Impervious Urban	30.9	0.06	56.4	0.52
Channel Erosion	2,181.4	0.88	334.8	0.14
MS4	454.6		0.0	
Permitted Point Sources	22.3		0.0	
Watershed Totals	**6,851.7**		**2,145.6**	

The reductions required to meet the TMDL from future conditions in Stroubles Creek are summarized in Table 7.4.

Table 7.4. Summary of Required Reductions for Stroubles Creek

Load Summary	Stroubles Creek (t/yr)	Reductions Required (t/yr)	Reductions Required (% of Existing Load)
Projected Future Load	6,829.4	4,898.4	73.0%
Existing Load	6,713.9	4,782.9	71.2%
TMDL	2,145.6		
Target Modeling Load	1,931.1		

TMDL allocation scenarios were developed by consolidating nonpoint source loads into 3 categories – agriculture, urban, and forestry – and then comparing category loads from the Stroubles Creek watershed to those of its area-adjusted reference watershed – Toms Creek in Table 7.5. This comparison shows that the annual average sediment loads from forestry are already lower from Stroubles Creek than from its reference. Point sources are not subject to reduction.

Table 7.5. Categorized Sediment Loads for Stroubles Creek (t/yr)

Source Category	Future Stroubles Creek (t/yr)	Reference Toms Creek (t/yr)
Agriculture	3,469.1	1,192.6
Urban	623.7	376.7
Forestry	100.6	241.5
Channel Erosion	2,181.4	334.8
MS4	454.6	0.0
Point Sources	22.3	0.0
Total	**6,851.7**	**2,145.6**

Existing MS4 loads were assumed to represent loads generated in areas covered by the MS4 permits prior to implementation of the Phase II MS4 regulations. The allocated MS4 load was based on the assumption that implementation of BMPs under the MS4 regulations to the "maximum extent practicable" would reduce existing loads by 50% and prevent any increases in the projected future scenario in Table 7.3. Equal percentage reductions were required from the two largest load categories – agriculture and channel erosion. Since urban source loads were relatively smaller than the two largest load categories, the first alternative requires no reduction from the non-MS4 urban areas, while the second alternative applies the same percent reduction for both existing MS4 and "urban" source loads. These loads are listed separately, since MS4 loads are required to be included in the WLA portion of the TMDL. The recommended TMDL allocation scenario is Alternative 2, as it requires reductions from all land use categories with loads greater than its reference watershed counterparts, and is consistent with previous interpretations of incorporating MS4 loads into the TMDL.

Table 7.6. TMDL Allocation Scenarios for Stroubles Creek

Source Category	Future Stroubles Creek (t/yr)	Stroubles Creek TMDL Sediment Load Allocations			
		TMDL Alternative 1		TMDL Alternative 2	
		(% reduction)	(t/yr)	(% reduction)	(t/yr)
Agriculture	3,469	**83%**	598	**77%**	803
Urban	624	0%	624	**54%**	289
Forestry	101	0%	101	0%	101
Channel Erosion	2,181	**83%**	376	**77%**	505
MS4*	455	**54%**	211	**54%**	211
Point Sources	22		22		22
Total	**6,852**		**1,931**		**1,931**

7.3. Summary

The benthic TMDL for Stroubles Creek was achieved through sediment reductions from the two major source categories – "agriculture" and "channel erosion", with equal reductions required from the both the non-MS4 and MS4 "urban areas. The TMDL to address the benthic impairment in Stroubles Creek is 2,145.6 t/yr of sediment and will require an overall reduction from projected future loads equal to 73% of the existing load. From the two alternative scenarios, Alternative 2 was recommended because it required reductions from all land use categories with loads greater than its reference watershed counterparts, and is consistent with previous interpretations of incorporating MS4 loads into the TMDL. The majority of additional sediment generated by future land use changes is likely to be due to increased total and peak runoff from an increasing amount of impervious area that can affect both surface erosion and channel erosion. Much of this increase in runoff and sediment load is expected to be attenuated through compliance with the new MS4 discharge regulations that should accompany future development. The impacts of future development and the MS4 regulations will be documented through DEQ's continuing biological and ambient water quality monitoring, and should be taken into consideration during development of implementation plans for Stroubles Creek.

Stroubles Creek watershed used the Toms Creek watershed upstream from Deerfield Drive as its TMDL reference watershed. The TMDL to address the benthic impairment was developed to meet the existing sediment load from the Toms Creek watershed, after it was area-adjusted to the impaired Stroubles Creek watershed. The TMDL was developed to take into account all major sediment sources in the watershed from both point and nonpoint sources, and to consider future land use changes. The sediment loads were averaged over a 10-year period to take into account both wet and dry periods, and the model inputs took into consideration seasonal variations and critical conditions related to sediment loading. The allocated loads were 10% less than the calculated TMDL to account for the required margin of safety.

CHAPTER 8: BENTHIC TMDL IMPLEMENTATION

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

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

8.1. Staged Implementation

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Among the 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.

8.2. Link to Ongoing Restoration Efforts

The Town of Blacksburg has taken a number of steps to address its sanitary sewer overflows, which will also remove one possible source of stress on the benthic community. A plan has been approved to build a new sewer line to the Toms Creek area. This new sewer line will divert flow from the North Main section of the sanitary sewer currently experiencing the overflows. Additionally, an Inflow and Infiltration (I&I) program has been undertaken to reduce non-sanitary and illegal connections to the sewer that tend to exacerbate the problem. As part of the I&I program, an in-sewer monitoring system is being installed to monitor progress in reducing I&I, and to facilitate better management of storm surges until the I&I can be reduced.

8.3. Reasonable Assurance for Implementation

8.3.1. Follow-Up Monitoring

VADEQ will continue sampling at the established biological monitoring stations (STE007.29 and TOM012.78) in accordance with its biological monitoring program. VADEQ will continue to use data from these monitoring stations and related ambient monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

8.3.2. 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. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

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

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

8.3.3. Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for storm water 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,…”.

Part of the Stroubles Creek watershed is covered by Phase II VPDES permits VAR040019, VAR040049, and VAR040016 for the small municipal separate storm sewer systems (MS4s) owned by the Town of Blacksburg, Virginia Tech and the VDOT-Blacksburg Area, respectively. All of these permits were issued on December 9, 2002. The effective dates of coverage are April 14, 2003, July 9, 2003, and April 14, 2003, respectively. The permits state, under Part II.A., that the “permittee must develop, implement, and enforce a storm water management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law.”

The permit also contains a TMDL clause that states: “If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of storm water discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Storm Water Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL.”

For MS4/VPDES general permits, DEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. DEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. Any changes to the TMDL resulting from water quality standards changes on Stroubles Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase II program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html .

8.3.4. Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement Program (CREP) and the Environmental Quality Incentive Program (EQIP), the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

CHAPTER 9: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progess made. On October 17, 2002, the Virginia Tech TMDL group hosted the first public meeting in Squires Student Center on the Virginia Tech campus, with approximately 56 people in attendance. The purpose of this meeting was threefold: to inform local citizens and stakeholders of the impairment, to explain the work that had been completed up to that point in identifying the benthic stressors, and to encourage the sharing of information about the watershed. Personnel from the Department of Environmental Quality (DEQ), the Department of Conservation and Recreation (DCR), and the Virginia Tech TMDL group presented information and data. Questions from the audience followed the presentations. The second and final public meeting was held on October 9, 2003 at Virginia Tech's Donaldson Brown Hotel and Continuing Education Center. Approximately 36 people attended the final meeting. Copies of the presentation materials were available for public distribution at the meeting.

CHAPTER 10: REFERENCES

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APPENDIX A.Glossary of Terms

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

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

Ambient Water Quality
Level of water quality constituents collected as part of a routine monitoring program.

Ammonia (NH_3)
An inorganic nitrogen compound.

Aquatic Ecosystem
The living and nonliving components of a water body, i.e. its physical, chemical, and biological components.

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

Benthic Macroinvertebrates
Organisms living in or on the bottom of a waterbody that are visible without a microscope ("macro-") and lack backbones ("invertebrates"). Benthic macroinvertebrates include larval or nymph forms for insects (e.g. stoneflies, mayflies, etc.), crustaceans (e.g. crayfish), snails, mussels, clams, worms, and leeches.

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

Bioassessment
The process of evaluating the algal, benthic macroinvertebrate, and/or fish communities to determine whether a water body suppors the state-defined designated use for aquatic life.

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.

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

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

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

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

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

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

Hydrology

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

Load allocation (LA)

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

Margin of Safety (MOS)

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

Metrics

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

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 sampling and measurement to determine the physical, chemical, and biological status of a particular media like air, soil, or water.

Nitrate (NO_3^-)

An inorganic nitrogen compound. Nitrate may be naturally present in water, but high concentrations are most likely due to fertilizer runoff, livestock facilities, sanitary wastewater discharges, and/or atmospheric deposition (dissolved in precipitation).

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

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

Organic Matter
Plant and animal residues, or substances made by living organisms.

Orthophosphate (PO_4^{-3})
Often referred to simply as phosphate. Most phosphorus exists in water in this form. Plants use orthophosphate as a phosphorus source. Like nitrates, phosphate in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

pH
A numerical measure of acidity or alkalinity. The pH scale ranges from 1 (acidic) to 14 (alkaline). A pH of 7 is neutral.

Phosphorus
An essential nutrient to the growth of organisms. In excessive amounts, phosphorous contributes 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.

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.

Public Comment Period
The time allowed for the public to express its views and concerns regarding action proposed by a state or federal agency.

Rapid Bioassessment Protocol (RBP)

A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualititative assessment of their habitat. RBP 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.

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.

Reference Site

A benchmark against which that water quality in a specific watershed is compared; for example, a biological evaluation in the watershed would be compared with that from a reference site (unimpaired) to determine the level of impairment.

Riparian

Pertaining to the banks of a river, stream, pond, lake, etc., as well as to the plant and animal communities along such bodies of water.

Runoff

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

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.

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.

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

In this context, any person or organization with a vested interest in TMDL development and implementation in a specific watershed.

Stressor

Any substance or condition that adversely impacts the aquatic ecosystem.

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.

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

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 imparied water meeting water quality standards and achieving a "fully supporting" use support status.

Urban Runoff

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

Validation (of a model)

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

Wasteload allocation (WLA)

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

Water quality standard

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

Watershed

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

Many of the glossary terms are taken from:

Benham, Brian, Kevin Brannan, Theo Dillaha, Saied Mostaghimi, and Gene Yagow. 2002. TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Virginia Cooperative Extension. Publication Number 442-758. Virginia Tech. Blacksburg, Virginia.

APPENDIX B. Future Land Use Estimation for Stroubles Creek Subwatersheds

The following assessment was made on a subwatershed by subwatershed basis, while following the overall trend implied by existing and future zoning plans for the Town of Blacksburg showing agricultural land uses decreasing, and urban land uses increasing. The assessed percent changes were then made to the individual land use categories by subwatershed to arrive at estimates for the future scenario, while holding individual subwatershed acreages constant.

Existing Landuse

		Stroubles Creek Sub-watersheds								Landuse
		STE1	STE2	STE3	STE4	STE5	STE6	STE7	STE8	Totals
	cropland	11.9	4.2	54.0	26.6	15.7	0.0	0.0	15.0	127.3
	pasture/hay	71.5	56.6	87.3	134.5	64.4	46.3	0.0	47.4	508.1
urbg	urban grass	1.2	0.6	1.3	55.1	64.5	63.9	41.8	84.5	312.9
	forest	504.8	76.8	37.9	8.7	20.3	25.1	5.1	5.6	684.4
	transitional	0.9	3.2	0.5	2.1	7.1	3.1	1.2	0.0	18.2
LDR	Low Density Residential	13.8	10.1	0.5	1.2	2.8	12.3	14.2	0.9	55.8
MDR	Medium Density Residential	16.5	7.1	0.7	20.9	40.3	168.6	93.7	4.1	351.8
HDR	High Density Residential	0.0	0.0	0.0	43.2	12.6	32.7	52.2	3.0	143.8
COMM	Commercial/Industrial	0.0	0.0	2.2	16.7	46.4	86.6	68.3	48.8	269.1
	Sub-watershed Totals	620.5	158.6	184.4	309.0	274.2	438.5	276.5	209.4	2,471.2

- Land uses losing acreage in Future Scenario

Assessing Change

Sub-watershed	From	% change	To
STE1	pasture	20	MDR
	pasture	20	LDR
	forest	5	LDR
STE2	cropland	100	MDR
	pasture	20	LDR
	forest	10	LDR
STE3	cropland	10	LDR
	pasture	10	LDR
STE4	pasture	10	urbg
	pasture	20	MDR
	pasture	10	HDR

Sub-watershed	From	% change	To
STE5	pasture	10	COMM
	forest	10	COMM
STE6	pasture	10	LDR
	pasture	25	MDR
	pasture	5	COMM
	forest	10	LDR
	forest	10	MDR
STE7	urbg	10	HDR
	LDR	20	MDR
	LDR	10	COMM
STE8	urbg	20	COMM
	pasture	20	MDR
	pasture	20	COMM

Future Landuse Scenario

		Stroubles Creek Sub-watersheds								Landuse	
		STE1	STE2	STE3	STE4	STE5	STE6	STE7	STE8	Totals	% Change
	cropland	11.9	0.0	48.6	26.6	15.7	0.0	0.0	15.0	117.8	-7.5%
	pasture/hay	44.0	45.6	78.6	84.4	59.9	27.8	0.0	30.7	371.0	-27.0%
urbg	urban grass	1.2	0.6	1.3	67.6	64.5	63.9	37.6	67.6	304.3	-2.7%
	forest	479.6	69.1	37.9	8.7	18.3	20.1	5.1	5.6	644.4	-5.8%
	transitional	0.9	3.2	0.5	2.1	7.1	3.1	1.2	0.0	18.2	0.0%
LDR	Low Density Residential	52.8	28.8	14.6	1.2	2.8	19.4	9.9	0.9	130.4	133.7%
MDR	Medium Density Residential	30.2	11.2	0.7	46.0	40.3	182.6	96.5	12.5	420.0	19.4%
HDR	High Density Residential	0.0	0.0	0.0	55.7	12.6	32.7	56.4	3.0	160.5	11.6%
COMM	Commercial/Industrial	0.0	0.0	2.2	16.7	53.0	88.9	69.7	74.1	304.7	13.2%
	Sub-watershed Totals	620.5	158.6	184.4	309.0	274.2	438.5	276.5	209.4	2,471.2	

- Land uses gaining acreage in Future Scenario

Overall Change

	Existing	Future	**% Change**
Agriculture	25.7%	19.8%	**-5.9%**
Urban	46.6%	54.1%	**7.6%**
Forest	27.7%	26.1%	**-1.6%**

APPENDIX C. Subwatershed Model Inputs and Sediment Loads

Table C.1. Subwatershed Land Use Distributions – Existing and Future Scenarios

ID#	ANCODE	Watershed Description	hit	lot	pa1	pa2	pa3	urbg	orch	for	tran	L-pur	M-pur	H-pur	Com-pur	L-imp	M-imp	H-imp	Com-imp	Water	Land_ha
	Existing Scenario																				
600	STEwall	Stroubles Creek upstream from Wall Branch	9.4	117.9	469.8	14.2	19.4	312.9	4.7	684.4	18.2	49.1	246.2	50.3	56.5	6.7	105.5	93.5	212.6	5.0	2,471.2
603	TOMdo	Toms Creek at Deerfield Drive	0.9	10.9	331.2	69.5	12.8	14.8	0.0	1227.6	0.0	253.3	48.0	0.0	9.7	34.5	20.6	0.0	36.5	2.0	2,070.1
6001	STE1	Stroubles Downstream segment nr. outlet	0.9	11.0	68.8	2.5	0.2	1.2	0.0	504.8	0.9	12.1	11.5	0.0	0.0	1.7	4.9	0.0	0.0	0.0	620.5
6002	STE2	Stroubles segment nr. Merrimac	0.3	3.9	54.8	1.4	0.5	0.6	0.0	76.8	3.2	8.9	4.9	0.0	0.0	1.2	2.1	0.0	0.0	0.2	158.6
6003	STE3	Stroubles trib nr. SE VT farm	4.0	50.0	87.3	0.0	0.0	1.3	0.0	37.9	0.5	0.4	0.5	0.0	0.5	0.1	0.2	0.0	1.8	0.0	184.4
6004	STE4	Stroubles segment nr. Hethwood	2.0	24.6	125.3	0.5	8.7	55.1	0.0	8.7	2.1	1.1	14.6	15.1	3.5	0.1	6.3	28.1	13.2	0.7	309.0
6005	STE5	Stroubles trib nr. VetMed and Southgate	1.2	14.5	45.7	5.4	8.7	64.5	4.7	20.3	7.1	2.5	28.2	4.4	9.7	0.3	12.1	8.2	36.7	0.9	274.2
6006	STE6	Central Branch	0.0	0.0	46.1	0.2	0.0	63.9	0.0	25.1	3.1	10.8	118.0	11.5	18.2	1.5	50.6	21.3	68.4	0.2	438.5
6007	STE7	Webb Branch	0.0	0.0	0.0	0.0	0.0	41.8	0.0	5.1	1.2	12.5	65.6	18.3	14.3	1.7	28.1	33.9	53.9	0.0	276.5
6008	STE8	Stroubles segment nr. Golf Course	1.1	13.9	41.9	4.3	1.3	84.5	0.0	5.6	0.0	0.8	2.9	1.1	10.3	0.1	1.2	2.0	38.6	3.1	209.4
6031	TOMadj	Toms Creek area-adjusted to Stroubles	1.0	13.0	395.4	83.0	15.2	17.6	0.0	1465.4	0.0	302.3	57.3	0.0	11.6	41.2	24.6	0.0	43.6	2.0	2,471.2
6101	STE1x	Cumulative Stroubles Creek to outlet	9.4	117.9	469.8	14.2	19.4	312.9	4.7	684.4	18.2	49.1	246.2	50.3	56.5	6.7	105.5	93.5	212.6	5.0	2,471.2
6102	STE2x	Cumulative Stroubles to STE1 outlet	8.5	106.9	401.0	11.7	19.1	311.6	4.7	179.5	17.3	37.0	234.7	50.3	56.5	5.0	100.6	93.5	212.6	5.0	1,850.7
6104	STE4x	Cumulative Stroubles to STE4 outlet	4.2	53.0	258.9	10.4	18.7	309.8	4.7	64.9	13.5	27.7	229.3	50.3	56.0	3.8	98.3	93.5	210.8	4.8	1,507.7
6108	STE8x	Cumulative Stroubles to STE8 outlet	1.1	13.9	88.0	4.5	1.3	190.2	0.0	35.8	4.4	24.1	186.5	30.8	42.8	3.3	79.9	57.2	160.9	3.2	924.4
	Future Scenario																				
6201	STE1f	STE1 future scenario	0.9	11.0	41.3	2.5	0.2	1.2	0.0	479.6	0.9	46.4	21.2	0.0	0.0	6.3	9.1	0.0	0.0	3.06	620.5
6202	STE2f	STE2 future scenario	0.0	0.0	43.8	1.4	0.5	0.6	0.0	69.1	3.2	25.3	7.9	0.0	0.0	3.5	3.4	0.0	0.0	3.06	158.6
6203	STE3f	STE3 future scenario	3.6	45.0	78.6	0.0	0.0	1.3	0.0	37.9	0.5	12.8	0.5	0.0	0.5	1.8	0.2	0.0	1.8	5.06	184.4
6204	STE4f	STE4 future scenario	2.0	24.6	75.2	0.5	8.7	67.6	0.0	8.7	2.1	1.1	32.2	19.5	3.5	0.1	13.8	36.2	13.2	10.07	309.0
6205	STE5f	STE5 future scenario	1.2	14.5	41.1	5.4	8.7	64.5	4.7	18.3	7.1	2.5	28.2	4.4	11.1	0.3	12.1	8.2	41.9	15.04	274.2
6206	STE6f	STE6 future scenario	0.0	0.0	27.7	0.2	0.0	63.9	0.0	20.1	3.1	17.1	127.8	11.5	18.7	2.3	54.8	21.3	70.2	19.85	438.5
6207	STE7f	STE7 future scenario	0.0	0.0	0.0	0.0	0.0	37.6	0.0	5.1	1.2	8.7	67.6	19.7	14.6	1.2	29.0	36.6	55.0	23.09	276.5
6208	STE8f	STE8 future scenario	1.1	13.9	25.1	4.3	1.3	67.6	0.0	5.6	0.0	0.8	8.7	1.1	15.6	0.1	3.7	2.0	58.5	26.15	209.4
6211	STE1xf	STE1x future scenario	8.7	109.1	332.7	14.2	19.4	304.3	4.7	644.4	18.2	114.8	294.0	56.2	64.0	15.7	126.0	104.3	240.7	29.22	2,471.2
6212	STE2xf	STE2x future scenario	7.8	98.1	291.5	11.7	19.1	303.1	4.7	164.8	17.3	68.4	272.8	56.2	64.0	9.3	116.9	104.3	240.7	34.28	1,850.7
6214	STE4xf	STE4x future scenario	4.2	53.0	169.1	10.4	18.7	301.2	4.7	57.8	13.5	30.2	264.5	56.2	63.5	4.1	113.4	104.3	238.9	44.35	1,507.7
6218	STE8xf	STE8x future scenario	1.1	13.9	52.8	4.5	1.3	169.1	0.0	30.8	4.4	26.6	204.1	32.2	48.9	3.6	87.5	59.9	183.8	59.40	924.4

Table C.2. Average Slope (%) by Land Use and Subwatershed

ID#	ANCODE	Watershed Description	Hi-Till	Lo-Till	Pasture 1	Pasture 2	Pasture 3	Urban grass	Hay	Forest	Transitional	LDR	MDR	HDR	Commercial
600	STEwall	Stroubles Creek upstream from Wall Branch	6.183	6.183	7.914	11.167	6.524	6.608	7.108	22.276	8.613	10.626	6.417	6.529	5.566
603	TOMdo	Toms Creek at Deerfield Drive	7.626	7.626	9.488	11.447	9.748	8.880	0.000	24.020	0.000	15.039	10.177	0.000	11.537
6001	STE1	Stroubles Downstream segment nr. outlet	5.765	5.765	10.403	24.950	5.269	25.092	0.000	26.151	19.488	14.852	5.791	0.000	0.000
6002	STE2	Stroubles segment nr. Merrimac	5.341	5.341	10.937	20.900	17.822	22.087	0.000	16.000	10.524	14.360	9.473	0.000	0.000
6003	STE3	Stroubles trib nr. SE VT farm	6.877	6.877	8.469	0.000	0.000	6.249	0.000	7.147	4.298	3.244	7.146	0.000	6.777
6004	STE4	Stroubles segment nr. Hethwood	4.881	4.881	5.784	3.398	6.921	6.300	0.000	5.270	4.372	4.321	5.708	7.006	4.962
6005	STE5	Stroubles trib nr. VetMed and Southgate	7.691	7.691	5.491	6.264	5.988	5.828	7.108	6.138	7.157	4.206	4.675	5.477	5.850
6006	STE6	Central Branch	0.000	0.000	10.459	23.812	0.000	7.700	0.000	12.163	10.873	9.080	7.008	6.642	5.490
6007	STE7	Webb Branch	8.839	8.839	0.000	0.000	0.000	7.243	0.000	9.482	8.250	7.732	6.261	6.281	5.921
6008	STE8	Stroubles segment nr. Golf Course	4.966	4.966	4.844	6.707	3.750	5.918	0.000	6.156	0.000	3.759	3.292	7.240	5.091
6031	TOMadj	Toms Creek area-adjusted to Stroubles	7.626	7.626	9.488	11.447	9.748	8.880	0.000	24.020	0.000	15.039	10.177	0.000	11.537

Table C.3. Average Soil Erodibility (K-factor) by Land Use and Subwatershed

ID#	ANCODE	Watershed Description	Hi-Till	Lo-Till	Pasture 1	Pasture 2	Pasture 3	Urban grass	Hay	Forest	Transitional	LDR	MDR	HDR	Commercial
600	STEwall	Stroubles Creek upstream from Wall Branch	0.369	0.369	0.307	0.285	0.328	0.338	0.353	0.244	0.335	0.284	0.363	0.378	0.270
603	TOMdo	Toms Creek at Deerfield Drive	0.371	0.371	0.348	0.328	0.332	0.343	0.000	0.232	0.000	0.256	0.341	0.000	0.315
6001	STE1	Stroubles Downstream segment nr. outlet	0.374	0.374	0.291	0.179	0.192	0.218	0.000	0.220	0.217	0.230	0.355	0.000	0.000
6002	STE2	Stroubles segment nr. Merrimac	0.371	0.371	0.258	0.194	0.192	0.263	0.000	0.260	0.231	0.222	0.301	0.000	0.000
6003	STE3	Stroubles trib nr. SE VT farm	0.369	0.369	0.304	0.000	0.000	0.170	0.000	0.315	0.205	0.375	0.375	0.000	0.170
6004	STE4	Stroubles segment nr. Hethwood	0.364	0.364	0.294	0.165	0.284	0.350	0.000	0.339	0.359	0.369	0.367	0.361	0.351
6005	STE5	Stroubles trib nr. VetMed and Southgate	0.366	0.366	0.328	0.319	0.368	0.316	0.353	0.351	0.369	0.389	0.360	0.400	0.270
6006	STE6	Central Branch	0.000	0.000	0.406	0.375	0.000	0.315	0.000	0.401	0.387	0.380	0.350	0.365	0.209
6007	STE7	Webb Branch	0.375	0.375	0.000	0.000	0.000	0.367	0.000	0.363	0.376	0.380	0.389	0.398	0.290
6008	STE8	Stroubles segment nr. Golf Course	0.376	0.376	0.319	0.345	0.424	0.359	0.000	0.372	0.000	0.361	0.427	0.383	0.311
6031	TOMadj	Toms Creek area-adjusted to Stroubles	0.371	0.371	0.348	0.328	0.332	0.343	0.000	0.232	0.000	0.256	0.341	0.000	0.315

Table C.4. Hydrologic Soil Group (HSG) Distribution by Subwatershed

ID#	ANCODE	Watershed Description	Area (Sq.k	HSG= A (%)	HSG=B (%)	HSG=C (%)	HSG=D (%)
600	STEwall	Stroubles Creek upstream from Wall Branch	24.712	3	35	47	16
603	TOMdo	Toms Creek at Deerfield Drive	20.701	3	4	76	16
6001	STE1	Stroubles Downstream segment nr. outlet	6.205	0	17	78	5
6002	STE2	Stroubles segment nr. Merrimac	1.586	0	5.7	91.8	2.5
6003	STE3	Stroubles trib nr. SE VT farm	1.844	0	14.6	84.3	1.2
6004	STE4	Stroubles segment nr. Hethwood	3.090	3	35	47	16
6005	STE5	Stroubles trib nr. VetMed and Southgate	2.742	3	4	76	16
6006	STE6	Central Branch	4.385	0	17	78	5
6007	STE7	Webb Branch	2.765	0	14.6	84.3	1.2
6008	STE8	Stroubles segment nr. Golf Course	2.094	2.9	4.3	76.2	16.5
6031	TOMadj	Toms Creek area-adjusted to Stroubles	24.712	3	4	76	16

Table C.5. Channel Erosion Parameters

ID#	ANCODE	developed land (%)	beef and dairy* (AU)	animal density (AU/ac.)	area-weighted CN	area-weighted KF	aFactor	Stream Length (meters) livestock access	total length	hardened length	adjusted length
	Existing Conditions										
600	STEwall	31.211	550	0.0901	76.72	0.252	**0.0001450**	4,364.2	22,974.0	4389.3	**18,584.7**
603	TOMdo	7.211	461	0.0901	74.88	0.252	**0.0000274**	0.0	17,665.6	0.0	**17,665.6**
6001	STE1	2.920	50	0.0326	72.09	0.231	**0.0000001**	0.0	5,734.3	0.0	**5,734.3**
6002	STE2	5.224	50	0.1276	74.62	0.254	**0.0000198**	567.2	869.5	0.0	**869.5**
6003	STE3	1.605	120	0.2634	76.24	0.321	**0.0000507**	1,592.8	1,861.6	0.0	**1,861.6**
6004	STE4	26.203	175	0.2292	77.29	0.274	**0.0001413**	2,204.3	3,780.9	223.0	**3,557.9**
6005	STE5	36.339	100	0.1476	82.06	0.266	**0.0002042**	0.0	3,720.9	1599.3	**2,121.6**
6006	STE6	65.988	40	0.0369	83.18	0.236	**0.0003246**	0.0	2,092.8	1285.4	**807.4**
6007	STE7	78.052	0	0.0000	86.05	0.215	**0.0003811**	0.0	2,877.8	1148.0	**1,729.8**
6008	STE8	26.789	15	0.0290	81.50	0.280	**0.0001616**	0.0	2,036.2	133.6	**1,902.6**
6031	TOMadj	7.211	550	0.0901	74.88	0.252	**0.0000274**	0.0	21,088.6	0.0	**21,088.6**
6101	STE1x	31.211	550	0.0901	78.65	0.252	**0.0001547**	4,364.2	22,974.0	4389.3	**18,584.7**
6102	STE2x	40.697	500	0.1093	80.84	0.259	**0.0002127**	4,364.2	17,239.7	4389.3	**12,850.4**
6104	STE4x	49.209	330	0.0886	82.06	0.251	**0.0002529**	2,204.3	14,508.5	4389.3	**10,119.2**
6108	STE8x	60.718	55	0.0241	83.66	0.240	**0.0003046**	0.0	7,006.7	2567.0	**4,439.7**
	Future Scenario										
600	STEwall	36.451	415	0.0680	77.73	0.243	**0.0001687**	4,364.2	22,974.0	4389.3	**18,584.7**
603	TOMdo	7.211	461	0.0901	74.88	0.252	**0.0000274**	0.0	17,665.6	0.0	**17,665.6**
6001	STE1	5.891	31	0.0201	72.83	0.228	**0.0000001**	0.0	5,734.3	0.0	**5,734.3**
6002	STE2	9.259	40	0.1029	75.42	0.243	**0.0000351**	567.2	869.5	0.0	**869.5**
6003	STE3	2.525	108	0.2370	76.40	0.321	**0.0000548**	1,592.8	1,861.6	0.0	**1,861.6**
6004	STE4	38.371	110	0.1438	79.38	0.266	**0.0002000**	2,204.3	3,780.9	223.0	**3,557.9**
6005	STE5	38.746	92	0.1363	82.56	0.259	**0.0002138**	0.0	3,720.9	1599.3	**2,121.6**
6006	STE6	69.909	24	0.0222	83.79	0.228	**0.0003407**	0.0	2,092.8	1285.4	**807.4**
6007	STE7	80.918	0	0.0000	86.38	0.209	**0.0003928**	0.0	2,877.8	1148.0	**1,729.8**
6008	STE8	42.854	10	0.0188	84.07	0.245	**0.0002285**	0.0	2,036.2	133.6	**1,902.6**
6031	TOMadj	7.211	550	0.0901	74.88	0.252	**0.0000274**	0.0	21,088.6	0.0	**21,088.6**
6101	STE1x	36.451	415	0.0680	79.58	0.243	**0.0001779**	4,364.2	22,974.0	4389.3	**18,584.7**
6102	STE2x	46.698	384	0.0840	81.84	0.249	**0.0002388**	4,364.2	17,239.7	4389.3	**12,850.4**
6104	STE4x	56.039	236	0.0633	83.18	0.240	**0.0002827**	2,204.3	14,508.5	4389.3	**10,119.2**
6108	STE8x	67.074	34	0.0148	84.63	0.226	**0.0003309**	0.0	7,006.7	2567.0	**4,439.7**

* No. of Beef and Dairy reduced by the % of pasture reduced by accompanying buildout.

Table C.6. Other GWLF Land use-Specific Parameters

Land Use	Description	Runoff Curve Numbers HSG=A	HSG=B	HSG=C	HSG=D	C-factor	ET Cover Coefficient (dormant)	(growing)	Sediment Buildup (kg/ha-day)
Hi-Till	S. Mtn&Valley (Region 2)	70.9	80.6	87.8	91.1	0.352	0.40	1.00	
Lo-Till	S. Mtn&Valley (Region 2)	69.3	79.1	86.3	89.4	0.155	0.55	1.00	
pasture1	pasture, good or improved	39	61	74	80	0.003	1.00	1.00	
pasture2	pasture, fair or unimproved	49	69	79	84	0.013	1.00	1.00	
pasture3	pasture, poor or overgrazed	68	79	86	89	0.071	1.00	1.00	
TOMn urban	close-seeded…,contour, good	55	69	78	83	0.013	1.00	1.00	
orchard	orchard, fair, 20-40% canopy	43	65	76	82	0.001	0.30	1.00	
forest	woods, fair	36	60	73	79	0.0005	0.51	1.00	
transitional	fallow, bare soil	77	86	91	94	0.175	0.30	0.30	
LDR-pur	low intensity residential, 88% pervious	46	65	77	82	0.003	1.00	1.00	1.30
MDR-pur	med intensity residential, 70% pervious	57	72	81	86	0.003	1.00	1.00	1.10
HDR-pur	high intensity residential, 35% pervious	77	85	90	92	0.003	1.00	1.00	2.20
Com-pur	high intensity commercial, 21% pervious	85	90	92	94	0.003	1.00	1.00	0.80
LDR-imp	low intensity residential, 12% impervious	76	85	89	91		0.00	0.00	2.50
MDR-imp	med intensity residential, 30% impervious	98	98	98	98		0.00	0.00	6.20
HDR-imp	high intensity residential, 65% impervious	98	98	98	98		0.00	0.00	3.90
Com-imp	high intensity commercial, 79% impervious	98	98	98	98		0.00	0.00	2.80

Table C.7. Sediment Loads by Subwatershed – Stroubles Creek and Area-adjusted Toms Creek

	Existing Scenario Sediment Loads (t/yr)									Toms Creek Area-adjusted	Stroubles Creek
Landuse	**STE1x**	**STE2x**	**STE3**	**STE4x**	**STE5**	**STE6**	**STE7**	**STE8**	**TOMdo**	**TOMadj**	**STEsdr***
Hi-Till	37.7	8.1	209.4	70.2	69.0	0.0	0.1	39.8	54.0	62.7	434.4
Lo-Till	262.4	49.5	1,436.5	472.0	471.2	0.0	0.5	271.7	368.5	427.8	2,963.9
pasture1	32.1	25.5	32.7	26.4	7.8	14.9	0.0	6.4	175.1	203.3	145.7
pasture2	14.4	6.6	0.0	-0.2	4.9	0.6	0.0	6.7	218.4	253.6	33.0
pasture3	1.5	11.6	0.0	84.1	83.5	0.0	0.0	7.1	211.2	245.2	187.8
urban grass	7.7	5.3	0.9	78.1	39.4	52.1	36.7	118.3	34.4	40.0	338.5
orchard	0.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	8.1
forest	91.7	10.0	1.9	0.1	0.8	1.6	0.2	0.3	208.0	241.5	106.6
transitional	51.9	57.7	0.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	110.8
LDR-pur	9.3	6.9	0.1	0.3	0.3	3.1	2.9	0.2	203.6	236.4	23.1
MDR-pur	3.8	2.7	0.2	4.7	3.6	22.6	12.1	0.8	31.0	36.0	50.6
HDR-pur	0.1	0.0	0.0	6.0	0.7	2.1	3.5	0.6	0.0	0.0	13.0
Com-pur	0.0	0.0	0.1	1.0	1.4	1.6	1.9	2.5	6.8	7.9	8.4
LDR-imp	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	8.6	10.2	0.6
MDR-imp	9.0	3.0	0.0	0.0	0.0	0.3	0.0	0.0	21.5	25.7	12.4
HDR-imp	2.4	0.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.5
Com-imp	4.0	1.6	0.1	0.0	0.0	0.2	0.0	0.0	17.2	20.6	5.8
Chan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MS4	317.2	211.8	11.2	788.7	56.8	38.6	79.1	342.6	252.2	334.8	1,845.9
PS	4.2	30.1	3.9	62.6	140.2	106.3	50.4	24.1	0.0	0.0	421.8
Total	**850.0**	**431.6**	**1,697.2**	**1,593.9**	**887.8**	**245.2**	**187.4**	**821.0**	**1,810.6**	**2,145.6**	**6,713.9**

	Future Scenario Sediment Loads (t/yr)										
Landuse	**STE1xf**	**STE2xf**	**STE3f**	**STE4xf**	**STE5f**	**STE6f**	**STE7f**	**STE8f**	**TOMdo**	**TOMadj**	**STEsdr***
Hi-Till	37.6	-3.4	188.5	70.1	69.0	0.0	0.1	39.8	54.0	62.7	401.6
Lo-Till	255.7	-27.7	1,292.7	471.3	470.9	0.0	0.5	271.5	368.5	427.8	2,735.0
pasture1	19.4	20.1	29.4	15.5	6.7	8.9	0.0	3.8	175.1	203.3	103.9
pasture2	14.4	6.6	0.0	-0.2	4.9	0.6	0.0	6.7	218.4	253.6	33.0
pasture3	1.5	11.5	0.0	84.0	83.5	0.0	0.0	7.1	211.2	245.2	187.6
urban grass	7.7	5.0	0.9	98.9	39.4	52.1	33.0	94.3	34.4	40.0	331.3
orchard	0.0	0.0	0.0	0.0	8.1	0.0	0.0	0.0	0.0	0.0	8.1
forest	87.2	8.9	1.9	0.1	0.7	1.3	0.2	0.3	208.0	241.5	100.6
transitional	51.8	57.6	0.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	110.6
LDR-pur	34.1	19.2	1.7	0.3	0.3	4.9	2.1	0.1	203.6	236.4	62.6
MDR-pur	6.6	4.3	0.2	9.0	3.6	24.5	12.5	2.4	31.0	36.0	63.1
HDR-pur	0.1	0.0	0.0	7.8	0.7	2.1	3.8	0.6	0.0	0.0	15.1
Com-pur	0.0	0.0	0.1	1.0	1.7	1.6	1.9	3.8	6.8	7.9	10.1
LDR-imp	1.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	8.6	10.2	2.2
MDR-imp	13.8	4.1	0.0	0.0	0.0	0.4	0.0	0.0	21.5	25.7	18.3
HDR-imp	2.7	1.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	3.9
Com-imp	4.5	1.8	0.1	0.0	0.0	0.2	0.0	0.0	17.2	20.6	6.6
Chan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MS4	409.8	245.3	12.1	935.5	60.3	40.9	82.4	395.1	252.2	334.8	2,181.4
PS	4.6	30.9	4.2	77.3	142.1	108.6	51.7	35.1	0.0	0.0	454.6
Total	**953.0**	**386.0**	**1,532.1**	**1,770.6**	**891.8**	**247.3**	**188.1**	**860.5**	**1,810.6**	**2,145.6**	**6,829.4**