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SENSITIVITY OF THE REFERENCE WATERSHED APPROACH IN BENTHIC TMDLS

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ABSTRACT

The Clean Water Act is the primary water quality legislation in the United States. The Act is designed to uphold the physical, chemical and biological integrity of the nation's waters. In Virginia, benthic macroinvertebrates are the primary indicator used to assess biological integrity. When the biota of a given waterbody is deemed impaired, the TMDL process is initiated. The primary stressors on the biota are then determined and the necessary reductions to those stressors are calculated. These stressors can come from either point or non-point source pollution.

In this paper, the reference watershed approach for benthic TMDLs is examined. Since the stressors causing the benthic impairments may not have state-mandated water quality standards, the TMDL goal is sometimes not obvious. A reference watershed that does not have a benthic impairment is chosen for comparison and the TMDL goal in the impaired watershed is the stressor load in the area-adjusted reference watershed. What are differences in stressor load reductions when different reference watersheds or different land use sources are used? These questions will be evaluated for the benthically impaired Stroubles Creek, in Montgomery County, Virginia using four reference watersheds and two land use sources for comparison.

KEYWORDS. TMDL, benthic, water quality, reference watershed

INTRODUCTION

The Clean Water Act and Virginia Water Quality Standards

In 1972, the United States Congress passed the Federal Water Pollution Control Act (PL92-500; USEPA, 2002), with the goal to "restore and maintain the chemical, physical, and biological

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integrity" of the Nation's waters (CWA Section 304a; USEPA, 2002). This act and subsequent amendments are collectively referred to as the Clean Water Act (CWA). The CWA requires states to develop water quality standards and to identify waters that do not meet state standards (CWA Section 303a; USEPA, 2002). The states are required to list waters that do not meet standards and to sponsor or conduct a study for each listed water to determine the target pollutant, the target pollutant load, and the necessary reductions in each pollutant needed to meet the applicable standard (CWA Section 303d; USEPA, 2002). Each TMDL study focuses on a single pollutant within a specific watershed and must take into account all non-point sources and permitted point sources of the pollutant.

The Commonwealth of Virginia has adopted both numeric and qualitative standards for water quality. Virginia has a narrative general standard for water quality, which reads as follows (9-VAC-25-260-20; Virginia General Assembly, 2002):

> *"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."*

The Virginia Department of Environmental Quality (DEQ) uses the benthic macroinvertebrate community to determine if Virginia's streams meet this general standard. A stream is designated as "benthically impaired" when comparison of the benthic macroinvertebrate community in that stream to the community in an unimpaired reference stream reveals an unhealthy macroinvertebrate community.

A TMDL study for a benthic impairment includes an analysis to determine the stressor(s), or cause(s), of the impairment. The goal of a benthic TMDL is to restore the benthic community to an unimpaired state by reducing stressors to levels in an unimpaired TMDL reference watershed.

The Benthic TMDL Process

Stressor Analysis

The process of developing a benthic TMDL differs from development of a TMDL for an impairment based on chemical water quality monitoring since a benthic impairment indicates a problem but does not identify the specific pollutants responsible for the impairment, as with chemical monitoring (USEPA, 2000). Sometimes the number and type of organisms present in an assemblage (the "metrics") can offer clues as to the cause of the impairment, but they are fairly general and do not reveal a definite answer. Therefore, physical and chemical water quality data must be analyzed in conjunction with the benthic metrics in order to identify the source of the impairment in a process called Stressor Analysis. Often, no single parameter is the obvious cause of the problem and best professional judgment is required. The identified stressors are then used as the basis for calculation of loads and load reductions within the TMDL.

Reference Watersheds and Stressor Modeling

Once the stressor(s) is identified, the target level of the stressor must be determined in order to remove the stress on the benthic community. Currently, benthic TMDLs in Virginia are developed using a reference watershed approach. In this method, an unimpaired TMDL reference watershed is located with similar characteristics (e.g. ecoregion, land use, climate) to the impaired watershed. The TMDL reference watershed does not need to be the same as the biomonitoring reference stream used to determine the impairment. The stressor loadings in the TMDL reference watershed establish the target level for the stressors in the impaired watershed. It is expected that if the stressor loads in the impaired watershed can be reduced to the levels in the TMDL reference watershed, then the benthic community in the impaired watershed will be restored. Each TMDL study includes a determination of the amount and percent of stressor reductions in the watershed needed to go from the existing load to the target TMDL load.

Calculating the stressor loadings is accomplished using a computer model that can simulate the identified stressor.

TMDL Implementation

The TMDL process ends with a determination of necessary stressor reductions within the watershed. The implementation process then calculates how and where the reductions can be made most efficiently and effectively, and develops a plan to make the physical changes within the watershed necessary to achieve the reductions and restore the healthy benthic community.

Study Questions

For the Virginia reference watershed approach, only one watershed is used to determine the target stressor load. What differences in stressor loadings might result from the use of different reference watersheds? If the selection of reference watersheds results in widely differing target loads, the implications for the changes necessary in the impaired watershed could be significant. How should the benthic TMDL process handle these differences?

METHODS

Study Area

The research questions were studied on Stroubles Creek (VAW-N22R, HUC 05050001; 6,119 acres), which is located in Montgomery County, Virginia. Stroubles Creek watershed encompasses much of the town of Blacksburg and is in the Valley and Ridge ecoregion.

Biological monitoring of Stroubles Creek over a period of five years indicated that the waterbody does not support the general standard of water quality in Virginia. During this period, the Stroubles Creek benthic community was monitored nine times; each assessment received a moderately impaired rating, resulting in a violation of the general standard and Stroubles Creek was placed on Virginia's 2002 303(d) list of impaired water bodies for benthic impairment. The impairment starts at the headwaters and continues downstream for 7.28 stream miles.

Physical and chemical monitoring of Stroubles Creek occurred at an ambient water quality monitoring station five miles downstream of the biological monitoring station. The ambient water quality data does not clearly identify a single stressor affecting the benthic community. The Stressor Analysis indicates that the primary candidate stressors on its benthic community are sediment, nutrients, and organic matter, with sediment as the most probable stressor. Sediment was selected as the target pollutant for the Stroubles Creek TMDL.

Reference Watershed Selection

Four watersheds were chosen to serve as TMDL reference watersheds for this study, out of ten benthically unimpaired watersheds considered. Possible watersheds were chosen from watersheds in the Valley and Ridge ecoregion known to be benthically unimpaired and having adequate data for analysis. Table 1 shows the characteristics of Stroubles Creek and the four selected TMDL reference watersheds. Although none of the watersheds is a perfect match for Stroubles Creek, each shows enough similarity to serve as a TMDL reference watershed.

Table 1. TMDL Reference Watersheds.**

			NLCD Land Use Distribution			Non-Forested Soil Erodibility Factor				Census 2000	
CODE	WATERSHED	Area (ha)	% Urb	% For	% Agr	SSURGO	STATSGO	Slope (%)	Elev. (m)	Non-Sewered Population	(pop/ ha)
STE	**Stroubles Creek**	**2468**	**29%**	**39%**	**32%**	**0.34**	**0.31**	**3.94**	**641.0**	**11709**	**4.7443**
OPE	Upper Opequon Creek	15123	**5%**	**35%**	60%	0.31	0.30	**5.60**	224.1	**16322**	**1.0793**
HYS	Hays Creek	20801	0%	52%	48%	0.31	0.31	12.53	526.2	1600	0.0769
QAL	Upper Quail Run	349	**13%**	81%	7%	0.26	0.26	10.00	452.9	8	0.3668
TOM	Toms Creek	**2067**	**2%**	72%	**26%**	0.30	0.25	11.59	**688.8**	629	0.3043

**Highlighted in bold are some of the more successful matches.

Computer Modeling

The Generalized Watershed Loading Functions (GWLF) model (Haith et al., 1992) was chosen to estimate sediment loadings to Stroubles Creek and the reference watersheds. GWLF is a lumped-parameter, continuous simulation model with a daily time-step and monthly output. The

Virginia Tech TMDL Development Group has modified the GWLF model to improve its utility for TMDL development. Improvements included changes to output files to facilitate data processing, improved erosion and manure-month calculations, an allowance for variable urban sediment build-up rates, and incorporation of the AVGWLF (Evans et al., 2001) streambank erosion component.

A geographic information system (ArcMap 8.2 by ESRI) was used to develop the parameters for modeling the sediment loading in the watersheds. Slope was obtained from digital elevation maps and soil data from SSURGO and STATSGO databases were used to obtain the hydrologic soil group, K-factor (soil erodibility), and available water capacity. Stream length was based on the U.S. Census Bureau Census 2000 TIGER/Line Hydrography files.

Land use was obtained for each watershed from the National Land Cover Dataset (NLCD), which provides 1992 land use information in raster format (30m resolution). For three of the watersheds, digitized polygons around different land coverages were obtained from Digital Orthphoto Quarter Quads (DOQQs) developed from 1997 and 1998 aerial photographs. The land uses from each of these sources were transformed into 17 land use categories for use in GWLF. Land use parameters were obtained from TR-55 (USDA, 1986), the GWLF User's Manual (Haith, et al., 1992), or best professional judgment.

Post-processing of the model results was done in spreadsheets. The goals of computer modeling in a TMDL study are to define the point source (WLA) and non-point source (LA) loads for existing and/or future conditions, and to identify alternative scenarios for reducing the WLA and/or LA loads to meet the target TMDL load. Equation 1 defines the various load components that must be met by each TMDL allocation scenario.

$$TMDL = WLA + LA + MOS \qquad \text{Equation 1}$$

where TMDL = total allowable daily load
WLA = waste load allocation (point sources)
LA = load allocation (non-point sources)
MOS = margin of safety (typically 5 to 10% of TMDL)

Since the target TMDL load and the MOS are amounts determined by each TMDL reference watershed, the modeled loads from the impaired Stroubles Creek watershed must equal the TMDL minus the MOS in comparison with each potential TMDL reference watershed. An MOS of 10% was used for this study. The reduction needed in Stroubles Creek to meet the TMDL is the difference between the Stroubles Creek sediment load and the reference watershed TMDL minus the MOS.

RESULTS AND DISCUSSION

Loads from each source were calculated for each reference watershed and for Stroubles Creek (see Table 2). Existing waste load allocation (WLA) and load allocation (LA) loads were calculated, along with the percent reduction required from the existing loads in Stroubles Creek, for each of the potential TMDL reference watersheds (see Table 1). LA loads were assumed to be zero for this study. These loads were calculated as the 10-year average annual sediment loads from each watershed, adjusted to be equal in size to the Stroubles Creek watershed.

Table 2. Area-adjusted 10-year average annual sediment loads by source area and for total watershed area.**

Surface Runoff Sources	STEn (t/yr)	HYSn (t/yr)	OPEn (t/yr)	QALn (t/yr)	TOMn (t/yr)	STEd (t/yr)	OPEd (t/yr)	QALd (t/yr)
High Till	274.4	529.0	1721.9	255.5	325.6	947.9	1733.2	0.0
Low Till	1905.9	1264.1	581.2	113.7	2261.7	403.3	585.0	0.0
Pasture	492.0	2054.1	1831.9	600.1	719.1	99.9	446.8	23.1
Urban grasses	46.0	0.0	7.5	0.0	0.0	30.4	77.8	120.1
Hay	12.5	1250.3	695.7	92.5	18.5	3.2	152.9	0.0
Forest	29.1	83.6	49.6	7.3	96.8	61.9	48.1	324.9
Transitional	472.0	85.5	394.2	216.6	291.8	103.3	264.6	0.0
Pervious Urban	90.5	1.5	23.4	196.0	13.7	52.7	36.0	436.8
Impervious Urban	27.7	0.1	5.3	10.1	2.4	86.9	27.8	27.5
Channel Erosion	3,679.5	632.5	1,601.8	3,256.2	279.6	4,064.8	1,389.1	5,725.6
Watershed Totals	7,029.5	5,900.8	6,912.5	4,748.1	4,009.3	5,854.3	4,761.4	6,658.1
**The three letter codes refer to the watersheds (see Table 1); n = NLCD, d = DOQQ; t = metric tons.								

Table 3. Watershed total sediment loads and corresponding TMDL figures and percent reduction required.

	STEn (Mg/yr)	HYSn (Mg/yr)	OPEn (Mg/yr)	QALn (Mg/yr)	TOMn (Mg/yr)	STEd (Mg/yr)	OPEd (Mg/yr)	QALd (Mg/yr)
Watershed Totals (Mg/yr)	7,029.5	5,900.8	6,912.5	4,748.1	4,009.3	5,854.3	4,761.4	6,658.1
Potential TMDL =		**5,900.8**	**6,912.5**	**4,748.1**	**4,009.3**		**4,761.4**	**6,658.1**
10% MOS =		**590.1**	**691.2**	**474.8**	**400.9**		**476.1**	**665.8**
WLA =		0.0	0.0	0.0	0.0		0.0	0.0
LA =		5,310.7	6,221.2	4,273.3	3,608.4		4,285.3	5,992.3
Reduction Needed =		1,718.8	808.3	2,756.2	3,421.1		1,569.1	-138.0
% of Existing Load =		**24.5%**	**11.5%**	**39.2%**	**48.7%**		**26.8%**	**-2.4%**

Considerable variability of required reductions between reference watersheds is evident in the results shown in Table 3. In the Quail Run-DOQQ case, the TMDL load (the sediment load minus the MOS) is greater than the load in Stroubles Creek. The highest required reductions are based on Tom's Creek, 48.7%. The variability among these reductions should raise concern with the reference watershed approach. Choice of the one reference watershed used in a benthic TMDL is fairly subjective, with the consultant preparing the TMDL using best professional judgment in comparing watershed characteristics such as those listed in Table 1. These results show, however, that two reference watersheds with reasonably good similarity to an impaired watershed can require very different sediment load reductions. The difference in implementation strategy between an 11.5% reduction, as required by Upper Opequon, and a 48.7% reduction, as required by Tom's Creek, may be significant.

In addition to variability among reference watersheds, there is variability in results depending on which land use source is used.

SUMMARY AND CONCLUSION

Using a reference watershed to determine pollutant reductions for benthically impaired watersheds requires best professional judgment to determine which one reference watershed is most similar to the impaired watershed. Observation of the modeling results for sediment loading in the impaired Stroubles Creek watershed and in four potential TMDL reference watersheds revealed that the choice of the TMDL reference watershed can have considerable effect on the required load reduction.

In addition, different land use sources can produce different load reduction requirements. Care should be taken to use the most current and accurate land use available so that the load requirements are based on the best data available.

Further Research

Due to potential differences in TMDL results based on different reference watersheds, it would be beneficial to utilize an approach that does not rely on a reference watershed or to develop a more analytical means for reference watershed selection. A regression model approach has been developed that links water quality measurements with the metrics of the benthic community (Frondorf, 2001). This model includes both chemical measurements, such as pH and dissolved oxygen, and physical measurements, such as percent-pasture and embeddedness. How does a TMDL developed using these regression equations, which do not require a reference watershed, compare with the reference watershed approach? Can the regression model indicate if certain watershed characteristics should be more heavily weighted when choosing a reference watershed? An additional approach to discerning the best reference watershed to use in a TMDL study may be to examine the loads based on source area. As seen in Table 2, the proportion of the load coming from a given source area varies among watersheds. It may be beneficial to choose for reference a watershed that has similar load proportions to the impaired watershed.

A second issue revolves around the model chosen to analyze the stressor loadings into the waterbody. Since different models require different data and model processes differently, how would TMDLs vary if different models were used to calculate loadings? What effect would these differences have on the TMDL results and on TMDL implementation?

Finally, the effectiveness of implementation measures chosen to meet the reductions called for in a TMDL should be examined. If significant differences in load reductions greatly affect choices made in implementation, then the choice of reference watershed is indeed important. Implementation in Virginia is approached in phases. Throughout each phase, the stream is monitored to see if the benthic community is recovering. When the benthic community is restored, implementation is ceased, regardless of the stressor reductions achieved. Further study on the success of implementation and the corresponding reductions would allow a better understanding of the correlation between stressor reduction and benthic restoration.

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