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Linking Sediment with Biological Impairment in Virginia

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Abstract. *In Virginia, ecosystem integrity is essentially defined as support for the aquatic life designated use. Support for this use is monitored with EPA's Rapid Bioassessment Protocols for the benthic macroinvertebrate community. Specific biological metrics that link biological impairment with sediment or any other specific stressor do not exist. Therefore, the approach that is recommended by EPA and followed by Virginia, is to follow the Stressor Identification Guidance provided by EPA and perform this "weight-of-evidence" stressor analysis to determine the primary stressor responsible for the impairment. This paper summarizes the various types of evidence that have been used in previous biological (benthic) TMDLs in Virginia to identify sediment as the primary stressor and thus to provide the linkage between sediment and ecosystem integrity.*

Keywords. Biological impairment, ecosystem integrity, sediment, TMDL, weight-of-evidence.

Introduction

Biological communities are sensitive to a wide variety of pollutants and tend to be good integrators of recent past events and therefore tend to show changes in water quality that might be missed by ambient compliance monitoring performed bi-weekly or monthly by the state. Although biological assessments are useful for indicating changes in water quality, they are not as useful, by themselves, for diagnosing the pollutant(s) causing water quality impairment.

The U.S. Environmental Protection Agency (EPA) has developed a stressor identification protocol for diagnosing stressors associated with the impairments identified through biological assessments, referred to as a stressor analysis. There are essentially three outcomes from this procedure: a firm diagnosis where the evidence positively identifies a pollutant, one where the evidence shows positively that a given pollutant could not have caused the impairment, and a third where the evidence is mixed support in varying degrees for more than one pollutant. This third outcome is the most typical and relies on what is known as a weight-of-evidence approach to linking impairments and pollutant stressors. In this approach, all available data is evaluated for consistency with a menu of suspected pollutants or stressors in order to build a case for the most probable pollutant(s) in the watershed of concern.

Biological assessments in Virginia are conducted using EPA's Rapid Bioassessment Protocols (RBP II) with benthic macroinvertebrates. The weight-of-evidence approach has been used during the development of Total Maximum Daily Loads (TMDLs) in Virginia for waters that have been declared to be impaired based on these assessments.

Fine sediment, generally derived from soils and herein referred to simply as sediment, is a wide-ranging pollutant in surface waters and results partially from natural weathering processes, but is also greatly accelerated by human-induced activities in a watershed. Although sediment transport is a function of all streams, excessive sedimentation from human-induced activities creates an imbalance in the system that affects biological communities living in and around the stream. Excessive sedimentation can impair benthic communities by filling in the pores in gravel and cobble substrate, thereby eliminating macroinvertebrate habitat. Potential sources of human-induced sediment include agricultural, residential, and urban runoff, forestry and mining operations, runoff from abandoned mine land, construction sites, and in-stream disturbances. Loss of riparian vegetative cover is another major factor contributing to reduced habitat by increasing streamside temperatures, reducing allochthanous inputs, and increasing sediment delivery from surface runoff (EPA, 1999a).

Sediment has surfaced as one component of almost all biological impairments that have been listed in Virginia and, in most of the resulting TMDL studies, has been declared the most probable stressor. The evidence used to justify the selection of sediment within each stressor analysis has varied from watershed to watershed. This paper summarizes the evidence used in nine TMDLs that identified sediment as the most probable cause of their biological impairments (DEQ, 2007). The summary is then explored to look for patterns or trends that might provide useful support in stressor analyses for future TMDLs. The justifications for selection of sediment as the most probable stressor have evolved over time as new types of evidence were added and as more experience was gained with each new impaired watershed. Some types of evidence were very important in some watersheds and less persuasive in others. The expectation was that multiple lines of evidence would support the most probable stressor. In cases where no one stressor appeared to be dominant, however, sediment was preferably identified because of its all-encompassing relationship with available habitat and its association with other potential stressors. Additionally, by focusing on sediment as the most probable stressor in these uncertain cases, load reduction measures for sediment also reduce other potential stressors associated with sediment, such as nutrients and oxygen-demanding substances, improving the likelihood for restoration of aquatic life uses.

Stressor Analysis

Once the TMDL process begins in a watershed with a declared biological impairment, the pollutant, or stressor, must then be identified before sources and loads can be quantified. The stressor analysis is conducted to identify one or more plausible stressor(s) that was coincident in time and space with the reported biological impacts. The stressor may be something that either directly affected the benthic community or indirectly affected its habitat. A list of candidate stressors was developed and evaluated with available data to determine the pollutant(s) responsible for the benthic impairment in each watershed. The potential biological stressors considered varied somewhat from watershed to watershed, but generally included ammonia, pH, temperature, dissolved oxygen (DO), toxics, nutrients, organic matter, and sediment. In areas with active mining, impacts from combinations of total dissolved solids, conductivity, and sulfates have also been considered. While TMDLs are required for pollutants, they are not specifically required for “pollution” – man-made or man-induced alteration of the chemical, physical, biological and radiological integrity of water (EPA, 1999b) – situations where there is no identifiable pollutant. Some instances of “pollution”, such as habitat degradation or severely altered hydrology, however, may have measurable characteristics that can be associated with specific pollutants such as sediment.

Data Available for Analysis

The information generally available in Virginia for the stressor analysis includes data from the Virginia Department of Environmental Quality (DEQ) biological sampling, habitat assessment, and ambient water quality sampling programs. Available data was reviewed not only for the impaired segment, but also for any upstream or near downstream stations. While DEQ typically reports individual RBP II ratings for each sample together with individual biological metric scores and ratings, the actual taxa counts and distribution can also provide additional information that is useful for diagnosis. Data were also obtained from DEQ for all National Pollution Discharge Elimination System (NPDES) permits in the watershed and consisted of available permit details, monthly discharge monitoring reports (DMRs) reported by the discharger, and sampling inspection reports (SIRs) reported by DEQ inspectors. DEQ also provided information for a variety of other permits, including stormwater permits for construction sites, municipal separate storm sewer system (MS4) stormwater permits, confined animal operation permits (CAFOs), and general permits for domestic sewage discharge. Additionally, DEQ monitoring data was available at some sites from periodic sediment sampling for metals and toxic substances, diurnal DO tests, relative bed stability analyses, and tests for chronic toxicity. Data from DEQ and the Virginia Department of Conservation and Recreation (DCR) that appear in the biennial 305(b) and 303(d) reports to EPA and Congress were reviewed for monitored exceedences and for simulated nonpoint source (NPS) pollutant load ratings for each 14-digit watershed in the state. DCR’s database of installed agricultural cost-shared best management practices (BMPs) were also reviewed for all NPS-dominated watersheds to see what management measures had already been installed. In areas of the state where mining occurred, the Virginia Division of Mines, Minerals, and Energy (DMME) provided additional information on mining permits and required monitoring data upstream and downstream of the sites. In areas with mining prior to the enactment of the 1977 Surface Mine Reclamation Act, U.S. Geological Survey (USGS) 7.5-minute topographic maps provided useful information in helping to assess abandoned mine land (AML) features.

In some watersheds, additional monitoring data was available from universities; from federal agencies, such as USGS or the Tennessee Valley Authority; or from local watershed volunteer groups such as the Friends of the North Fork of the Shenandoah River and Izaac Walton League “Save Our Streams” (SOS) groups. Although volunteer monitoring data in the past have been considered only as supplemental to DEQ data, volunteer groups have been getting quality assurance/quality control (QA/QC) plans approved by the state, and their data is now accepted for use in the biennial assessments. One major strength of the volunteer data is that, with the generally small amount of DEQ monitoring data available, it can be used to give a glimpse of conditions at other times and locations around the watershed. Along with the monitored water quality parameters, volunteer data tend to include additional types of visual assessments, which are useful in providing perspective to the DEQ ambient data set.

Recently available 1:200 and 1:400 Virginia Base Mapping Program (VBMP, 2002) aerial imagery was also useful in assessing riparian vegetation and potential livestock impacts in the riparian zone prior to watershed visits.

Evidence Used to Evaluate Sediment as a Stressor

A variety of measures were used to assess the relative importance of sediment as a stressor during the stressor analysis within each TMDL watershed. These measures are described in Table 1. The evidence evaluated for sediment included several biological metrics, habitat metrics, in-stream measurements, volunteer monitoring data, site visit observations and general land use information, and other miscellaneous items.

Since biomonitoring data served as the basis for assessment of each aquatic life use impairment, these data were available from fall and spring samples taken over a period of up to five years for any given 305(b) biennial assessment period. The primary biological metric used to indicate potential impact from sediment was “%haptobenthos.” Where these functional groups of clingers and sprawlers were minimal or absent and toxicity was ruled out, sediment was considered to be a plausible source of stress. Although fish inventories were not available at all sites, where they were available, the presence of silt intolerant species was seen as a sign that sediment impacts were minimal, or at least, not extreme. Individual biological metric values and scores and total sample scores were also reviewed with respect to land use management changes coincident with the samples to see if associations could be identified and related to any major shifts in biological metrics.

Habitat assessment metrics specific to sediment were an additional source of evidence evaluated to assess the role of sediment in the benthic impairment in each watershed. In fact, poor scores for two or more of these metrics were typically seen as necessary, though not sufficient, evidence for declaring sediment as a stressor. These metrics are qualitative in nature and the nature of their evaluation must be kept in mind during the analyses. Although the habitat assessment is conducted in a stream reach near the benthic sample collection site, it is possible in mixed land use watersheds that upstream hydrologic modifications might be driving biological changes rather than human activities within the immediate stream reach. Another consideration in reviewing the metrics over time was to check for changes in the biologist performing the assessments at a given station and for changes in the reference site used for RBP scoring, as these may lead to significant changes in the metric scores from sample to sample that have nothing to do with conditions at an individual site.

In-stream sediment concentrations, generally reported as total suspended solids (TSS), would at first glance appear to be a primary source of information for proving sediment impact in a watershed. Unfortunately, most monitoring is performed during ambient (baseflow) conditions, and since most sediment loads arise from nonpoint sources (NPS) during storm runoff, the only sediment impacts likely to be noticed in the ambient data set are typically minor and related to point sources. Under these conditions, TSS is also more likely to consist of organic solids than sediment. Where stormflow samples have been collected, larger concentrations are generally observed and can be used as positive evidence of sediment loading in a watershed.

If data from an upstream station or from prior sampling at the same station prior to major changes in a watershed are available, these may also be useful in assessing the feasibility of sediment as a likely source of stress in the immediate stream reach. The relative bed stability (RBS) measurement – not a sediment concentration, but an estimate of the sediment size distribution in the stream bottom – can be useful in discriminating between natural and human-induced sedimentation (Kaufmann et al., 1999).

Land use and other human-induced changes are very dynamic and can change dramatically from year to year in some watersheds, while they remain fairly constant in others. Land uses and their distribution were essential watershed characteristics assessed as potential sources of all pollutants, including sediment. Spatial geographic information system (GIS) data – interpreted from satellite imagery or digitized from aerial photography – was an initial starting point for assessment of potential sources of sediment. All imagery, however, is recorded at a specific point in time, and watershed visits and meetings with a local technical advisory committee were essential for assessing current conditions, and especially to more closely check on the condition of the riparian zone throughout each watershed. In 2002, the Commonwealth of Virginia contracted to have the state flown and captured land use variably at resolutions of 1:200 or 1:400, which has proven to be a tremendous resource (VGIN, 2002). With imagery at this resolution, it was possible to inspect the riparian corridor in great detail, as many more parts of the watershed were visible for scrutiny than just those visible from the road during a windshield survey. It also allowed us to highlight and focus on particular areas of concern, making the use of time spent in the field more productive. A variety of conditions and land uses known to increase sediment loading were assessed both from spatial land use data and during watershed visits. Once again, this information provided indirect evidence of probable cause and was used to support evidence provided by benthic or habitat metrics in developing the weight-of-evidence case for sediment as a stressor.

Other information evaluated included knowledge about upstream impairments, particularly those already having TMDLs developed for sediment, and modeled sediment loads. Virginia performs simulations of sediment and nutrient loads by watershed as part of its biennial NPS pollution assessment for the 305(b) report. These relative modeled pollutant loads, together with additional evaluative data, were used to rank watersheds for agricultural, urban, and forestry sources of nitrogen, phosphorus, and sediment, as well as for riverine impairments evaluated within the stream channel and riparian corridor. Monitoring or modeling performed as part of TMDL development for each watershed may also highlight localized sediment source areas that dominate an otherwise stable watershed.

Table 1. Descriptions of Data Types used as Evidence.

Type of Evidence	Description
%haptobenthos	Percentage of a benthic macroinvertebrate sample composed of clingers and sprawlers that require a clean, coarse, firm substrate. Low numbers may indicate heavy sedimentation (Smith and Voshell, 1997).
Presence of silt intolerant fish species	Grazing species, such as central stonerollers, do not inhabit heavily silted streams, as they require hard surfaces from which to scrape algae and the availability of pebbled substrate for forming spawning nests.
RBP II Habitat metrics	Each metric rated from 0-20: with 0-5 indicating poor habitat, 6-10 marginal habitat, 11-15 sub-optimal habitat, and 16-20 optimal habitat (Barbour et al., 1999).
Bank stability	Evaluates the condition of stream banks for signs of erosion.
Embeddedness	Evaluates the extent to which rocks are covered with silt, sand, or mud on the stream bottom.
Epifaunal substrate	The variety of natural structures and features available for refuge or feeding, and as sites for spawning and nursery functions.
Riparian vegetation	The extent, type, and degree of vegetation coverage within the riparian zone.
Sediment deposition	Evaluates the amount of sediment accumulated in pools and deposited in point bars. Large amounts tend to indicate an unstable and changing environment.
Channel alterations	Evaluates large-scale changes in the shape and sinuosity of the stream channel usually associated with increased scouring.
Total Habitat Score	An aggregate score from 10 metrics, each with a maximum score of 20; optimal range is 160-200.
Ambient TSS	Monitored total suspended solids (TSS) data generally collected during baseflow conditions on a bi-weekly or monthly basis.
Runoff TSS	Monitored stormflow data that would be more representative of nonpoint source (NPS) runoff contributions of sediment.
PS TSS	Point source (PS) discharger effluent sampled concentrations as part of NPDES permit compliance monitoring.
Upstream monitoring	Where available, this data can help isolate or delimit potential major sediment sources.
Relative bed stability	A procedure to measure the likelihood of changes in stream bed composition due to upstream hydrological changes. Can be used to separate human-induced from natural sediment problems (Kaufmann et al., 1999). Logarithm of RBS (LRBS) < -1 indicates excessive sedimentation, and > 1 indicates a sediment starved stream.

Table 1 (cont.). Descriptions of Data Types used as Evidence.

Type of Evidence	Description
Impervious Area %	Estimated from landuse and aerial imagery – high percentages are associated with faster runoff response and larger storm peaks.
Upstream sediment TMDLs	Downstream sediment problems are often related to sediment problems farther upstream that may propagate downstream, even though surface runoff from the immediate segment produces minimal sediment loading.
Biennial State NPS Sediment Rating	These simulated sediment load ratings may provide supplemental support for sediment and potential source areas that are not evident in available monitored data.
High resolution aerial imagery	1:400 or better imagery allows viewing areas not readily accessible by roads and can save time by identifying a limited number of specific areas requiring ground-truthing during watershed visits.
Impairment severity	RBP II rating categories based on the chosen suite of metrics and a reference non-impaired site. Ratings are NI – non-impaired, SI – slightly impaired, MI – moderately impaired, and VI – severely impaired.

Justifications Used to Support the Determination of Sediment

The evidence from the nine TMDL watersheds is summarized in Table 2. Table 2 also includes the relative impairment ratings from the RBP II procedure to lend some perspective on the degree of impairment; the slighter the impairment, the more difficult the task to identify a unique stressor(s). Determination of the most probable stressor was not a straight-forward procedure, but relied on a considerable amount of professional judgment. The weight-of-evidence approach was not merely one of tallying metric scores or the number of supportive lines of evidence, but also considered relative strength amongst all possible stressors, the degree of impairment, and trends over time. The following are descriptions of the major pieces of evidence used to support the selection of sediment in each of the nine watersheds referenced in Table 2.

The main evidence for sediment in the dominantly agricultural Linville Creek included poor scores for %haptobenthos, repeated low average habitat ratings for five sediment metrics, and observed damage to streambanks from livestock trampling. In the primarily urban Abrams Creek watershed, %haptobenthos scores were poor with low habitat scores for riparian vegetation and embeddedness, observed livestock trampling of streambanks in one section, and channelization of one tributary through the City of Winchester. Lower Opequon Creek exhibited similar low scores of %haptobenthos and low habitat scores for available substrate and embeddedness, and was downstream from Abrams Creek which also has a sediment problem. Toms Brook had moderate to low scores for embeddedness and received discharge from a small wastewater treatment plant with periodic system upsets that may have contributed to one precipitous drop in %haptobenthos observed in one of the samples. This appeared to be a fairly minor impairment and all of the evidence supporting any stressor was minimal. Sediment was used in lieu of any other explanatory parameters.

Stroubles Creek was a mixed land use watershed with a considerable impervious area, sediment accumulation documented from a dredged pond, observed livestock trampling of streambanks, and channelization of upstream tributaries in the urban portion, supported by low habitat scores for three habitat metrics related to sediment. Mossy Creek had a very slight impairment with monitored data showing elevated sediment concentrations during runoff events, some areas with livestock access to streams. Although habitat metrics and overall scores were quite good, there was a slightly decreasing trend that could be attributed to sediment. North River also exhibited a fairly minor impairment that was related to several upstream TMDL segments where sediment was the identified stressor. While %haptobenthos and several habitat metrics were poor, they were improving in a manner that was consistent with partial implementation of BMPs in the upstream TMDL watersheds. This segment was reclassified as "impaired, but not requiring a TMDL" because a simulation of full implementation in the upstream segments showed sediment loads comparable to non-impaired watersheds (Benham et al., 2005).

The impairment in Mill Creek appeared to be highly influenced by one tributary that showed extremely poor %haptobenthos and habitat sediment metrics along with highly denuded and eroding streambanks due to livestock access. High resolution aerial photography was used to extensively identify problem areas for presentation during discussions with the local watershed advisory group. The last watershed – Lick Creek – was in a mining area with most roads, residences, and businesses located in the narrow valley riparian corridors. Poor %haptobenthos scores, many poor habitat sediment metrics and observed riparian conditions supported sediment as one of the most probable stressors. Since mined areas are required to monitor extensively, monitored data was also available to document large stormflow concentrations of sediment.

As can be seen from the above discussion, many different combinations of evidence were used to arrive at a determination of sediment as the most probable stressor in these watersheds.

Table 2. Summary of Evidence Used to Evaluate Sediment as a Biological Stressor.

Types of Evidence		TMDL Watersheds								
		Linville Creek	Abrams Creek	Lower Opequon Creek	Toms Brook	Stroubles Creek	Mossy Creek	North River	Mill Creek (Crooked Run)~	Lick Creek
Benthic Macroinvertebrate Metric Ratings										
	%Haptobenthos	Poor	Fair	Fair	Fair ↓ Poor	Fair		Poor ↑	Good (Poor)	Poor
	Presence of silt intolerant fish species?					Yes			No	Yes
Habitat Metric Ratings										
	Bank stability	Poor				Fair		Poor ↑		Poor
	Embededdness	Poor	Poor	Poor	Poor – Fair	Fair	Good ↓	Poor ↑	(Poor)	Fair
	Epifaunal substrate	Poor		Poor		Fair				V. Good
	Riparian vegetation	V. Poor	V. Poor			V. Poor		Poor ↑	Poor (Poor)	Poor
	Sediment deposition in point bars					Poor	Poor		(Poor)	Poor
	Channel alterations						Poor			
	Average Total Habitat Score (out of 200)	103	133	125	152 ↑	122	158 ↓	151 ↑	159 (127)	123 ↑
TSS Measurements										
	Ambient	Low	Low	Low	Low		Low-Med	Low-Med	Low	Low
	Runoff					Yes	Yes			Yes
	PS		Yes	Yes	Yes			Yes	Yes	Yes ↑
	Upstream									Yes
	Relative Bed Stability (LRBS)					0.22			0.56	
Volunteer Monitoring Data										
	Observations						Fines deposition, stream bank erosion			
	Overall stream quality (ecological conditions)						Good			Acceptable

~ Crooked Run was a tributary within the Mill Creek watershed that had been monitored only recently and so had not been listed separately as an impaired segment in the most recent 305(b) report.

Table 2 (cont.). Summary of Evidence Used to Evaluate Sediment as a Biological Stressor.

Types of Evidence		TMDL Watersheds								
		Linville Creek	Abrams Creek	Lower Opequon Creek	Toms Brook	Stroubles Creek	Mossy Creek	North River	Mill Creek (Crooked Run)	Lick Creek
Visual Site Observations										
	construction sites?		Yes	Yes		Yes		Yes		
	forest harvesting?									Yes
	clean-till farming?									
	livestock access + trampled streambanks?	Yes	Yes	Yes		Yes	Yes		Yes	
	mining?									Yes
	stream dredging?									Yes
	unpaved roads?									Yes
	channel armoring?		Yes			Yes				Yes
	channel alterations?					Yes				Yes
	sediment accumulation in ponds?					Yes				Yes
	stream bank erosion?					Yes	Yes			Yes
	Impervious area %		21%	6.60%		18%		1.40%	0.50%	
Other										
	Upstream Sediment TMDL(s)?			Yes				Yes		
	Biennial State NPS Sediment Rating					M		H→M	L	H
	Localized Sediment Source Areas?							Yes	Yes	Yes
	High resolution aerial photographs								Yes	
Impairment Severity		**SI - MI**	**MI**	**SI - MI**	**SI - MI**	**MI**	**SI - MI ↓**	**SI ↑**	**SI - MI ↑**	**MI - VI**

Summary and Conclusions

The procedures included in the stressor analyses of these nine watersheds evolved over time and were greatly influenced by the available data sources which varied from watershed to watershed. However, even with this great variability, there were some general similarities in our analyses as follows:

- Habitat metrics often offered initial evidence for sediment from the available data
- Ambient TSS rarely provided useful support, unless point source related
- Upland sediment sources were often directly related to land uses and their management
- Windshield tours were essential to confirm sediment impacts
- The representativeness of the monitoring site and stream reach, and verification of the continuity of reference sites and monitors used for the biological and habitat metrics were essential to ensure proper interpretation of the metrics over time.

While easily quantifiable measurements of sediment load are not generally available in TMDL watersheds, there are a variety of types of evidence than can be used to support the case for sediment as the most probable stressor, as discussed in this paper. Because of the inherent uncertainties in these procedures, therefore, it is recommended that stressor analyses pointing toward sediment always be used in conjunction with an adaptive approach to implementation.

Biological and habitat monitoring should be used during implementation to see if targeted management practices are having the desired effect (EPA, 1999a). Monitoring to evaluate sediment during runoff events or streambank and bed load erosion is seldom economically feasible, unless performed in conjunction with funded research. Sediment monitoring in any case is still only a surrogate, as only biological monitoring will show when water quality is improving and the aquatic life uses are restored.

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