PROTOCOLS FOR STRESSOR IDENTIFICATION
- TMDL APPLICATIONS -

By

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Abstract

The Virginia Department of Environmental Quality requested the Academic Advisory Committee (AAC) to provide guidance for stressor identification in biologically impaired streams. This report documents the stressor identification process used in Virginia's TMDL reports. The report concludes with a summary of the strengths and weaknesses of Virginia's TMDL reports and provides recommendations for improving application of the stressor identification procedures in future TMDL studies.

Introduction

A water body is designated as impaired when it does not support, or only partially supports, one or more of its designated uses. Section 303(d) of the Clean Water Act requires all states to establish total maximum daily loads (TMDLs) for impaired waters. The U.S. Environmental Protection Agency (EPA) has estimated that about half of the identified impaired U.S. water bodies do not adequately support aquatic life use (USEPA 2000). In Virginia, over 2,000 stream and river miles are listed as impaired for not adequately supporting the aquatic life use due to benthic degradation (VA-DEQ 2002).

Benthic degradation or impairment is particularly challenging during studies to develop TMDL endpoints because the causative pollutant(s) are not implicit in the listing as it is for pollutants governed by conventional water quality standards. Results of benthic surveys using biological assessment methods such as the Rapid Bioassessment Protocols (RBPII) Barbour et al. (1999) and the Virginia Stream Condition Index (VaSCI) (VA-DEQ, 2007a) do not directly identify the pollutant(s) that contribute to impairment. Establishing a linkage between the benthic condition and the specific pollutant(s) that cause impairment is necessary for developing a TMDL that addresses a benthic impairment. This linkage can be established by identifying critical stressors. For TMDL purposes, the term **"stressor"** means any factor that may negatively impact the benthic community population and diversity.

States are in various stages of integrating different levels of bioassessments into their water quality management programs. Most states use benthic macroinvertebrates with some combination of RBPII protocols and the multimetric approach as their primary bioassessment tool. Some states use multiple assemblages in their assessment to reduce uncertainty and some (e.g., Maine) are using multivariate approaches. Multivariate analysis typically involves selecting reference sites through clustering methods that group sites of similar macroinvertebrate composition. Details of state programs can be found on the USEPA's Website: http://www.epa.gov/owow/monitoring/newmon/bio/section4.htm.

Biological assessments are important for indicating impairments, particularly for those stressors for which water quality criteria have not yet been developed. However, biological assessments do not identify the cause or causes of the impairment. A reliable and efficient stressor identification process is needed to identify the causes of water quality violations with some degree of certainty. Furthermore, it is important to distinguish between natural and anthropogenic stressors. Natural stressors include but are not limited to high winds, low and high precipitation, frost action, snowfall and intense sunshine. Anthropogenic stressors are pollutants introduced into surface water from both point and nonpoint sources or from other human-induced changes in the environment that affect the biological stream community. TMDL studies are conducted only for streams where anthropogenic stressors are the suspected cause of the benthic impairments. However, hydraulic alterations, habitat changes and predation or competition by introduced species may also influence stream biota.

The USEPA has developed a Stressor Identification Guidance Document for TMDL purposes (USEPA 2000). Recently, the USEPA introduced an online stressor identification process: CADDIS (http://cfpub.epa.gov/caddis/) (USEPA 2007). The EPA's stressor identification process offers a means by which TMDL developers can more confidently identify the stressors causing the impairments. Higher levels of confidence in the stressor identification can be achieved through using data of high integrity and by incorporating the best professional judgment of a panel of experts in the field. The stressor identification team should have experience in multiple disciplines, exhibit willingness to carefully and critically think about the situation, and be persistent in finding the true cause of the biological impairment.

Stressor identification is a critical component for developing a TMDL report. Careful data mining and analysis during stressor identification can save significant time and resources in the long run. By using an appropriate stressor identification approach, TMDL developers are more likely to properly identify the true critical stressor(s). Targeting the wrong stressor may lead to implementing inappropriate and costly water quality control measures. A well-documented stressor identification process will increase support from watershed stakeholders during the TMDL implementation phase and will reduce possible legal challenges that may question the validity of a TMDL report. Furthermore, the stressor identification process can be used to either indicate where more data are needed or to show the cause of the impairment. If the causal stressor(s) cannot be determined with sufficient confidence, more data are needed. In these situations, the stressor identification process can be used to eliminate some potential stressors and, therefore, allow monitoring to be more targeted to the remaining potential stressors. A monitoring strategy should be developed that can generate conclusive evidence to support or refute the refined list of potential stressors. If the cause can be confidently identified, then the TMDL study should proceed by identifying the sources of the identified stressor(s), calculating the loads of the stressor(s), and determining the changes needed in the loads to meet water quality standards.

Review of Virginia's TMDL Reports that Address Biological Impairments

More than thirty TMDL reports have been developed for Virginia's biologically impaired waters (DEQ 2007b). In this paper, reports from 8 of these TMDL studies were reviewed to examine screening procedures for stressor identification, modes of analysis, and report organization and documentation. The TMDLs that were reviewed represent a variety of contractors and different regions of the state, and represent a variety of stressors. TMDL reports examined for this paper are:

1. Hunting Camp Creek (Bland County, Virginia)
2. Lewis Creek (Augusta County, Virginia)
3. Mill Creek (Shenandoah, Virginia)
4. Russell Prater Creek (Buchanan County -Dickenson County, Virginia)
5. South Run Watershed (Fauquier County- Prince William County, Virginia)
6. Spring Branch (Sussex County, Virginia)
7. Stroubles Creek (Montgomery County, Virginia)
8. Upper Roanoke River, Southwest Virginia

For all streams, the initial biological impairments were established by using RBPII, and the status of impairment was further verified for some streams using the VaSCI. All reviewed TMDLs claim to have followed the USEPA Stressor Identification Guidance (EPA 2000). Tables 1 through 8 provide a summary for each of the eight reviewed TMDL reports, including types of stressors considered, screening procedures, databases used, and the stressors identified. A summary of strengths and weaknesses of reviewed TMDL reports is provided in Table 9.

Table 1. Hunting Camp Creek

Stressor	**Screening Procedure**	**Criteria/Reference Database**	**Outcome**
Dissolved Oxygen	Field Measurements	VAWQS for Class VI waters	Eliminated
pH	Field Measurements	VAWQS for Class VI waters	Eliminated
Ammonia	Field Measurements	Acute/Chronic ammonia criteria of VAWQS	Eliminated
Organic Matter	Sampling, BOD5, Known sources, land use, maps and other.	BOD5 Detection Limit	Eliminated
Nutrients	Sampling	VA-DEQ 305(b) assessment criteria, for Nitrogen and Phosphorous	Eliminated
Toxics-water column	Sampling *P promelas* survival/growth and *C. dubia* survival/reproduction	VAWQS	Eliminated
Toxics-sediment	Sampling	EPA's PEC, VA-DEQ 305(b) assessment criteria for metals, pesticides or other constituents Consensus based screening values	Eliminated
Temperature	Field Measurements	VAWQS for Class VI waters	Unlikely Stressor
Sediment	TSS, Turbidity, Biomonitoring, land use	Taxa Richness, EPT Index	Most Probable Stressor

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration;
WQS: Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: Rapid Bioassessment Protocol; SCI: Stream Condition Index; EPTI- Ephemeroptera, Plecoptera, Trichoptera Index

Table 2. Lewis Creek

Stressor	Screening Procedure	Criteria/Reference Database	Outcome
Clean Metals	Field Measurement	Detection Limit, VAWQS.	No action stated
Toxic- Water column	Bioassay with statistic significance	Statistical Analysis	Eliminated
Temperature	Field Measurement	VAWQS	Eliminated
Low D.O.	Field Measurement	VAWQS	Eliminated
pH	Field Measurement	Field pH WQS	Eliminated
Metals in water column	Sampling	WQS	Eliminated
Sediment-Pesticide	Sampling	measurable levels	Eliminated
Ammonia	Field Measurement	VAWQS	Eliminated
Chloride	Field Measurement	VAWQS Chronic	Eliminated
PCB	Fish Tissue Sample	CPEC VDH Action Level	Eliminated
Sulfate	Field Testing	90th Percentile Values From Reference Watershed	Eliminated
Chlordane	Sediment Sampling	PEC, Scientific Literature (Macdonald et al. 2001)	Eliminated
Conductivity	Sampling	90th Percentile Values from Reference Watershed, Scientific Literature	Possible Stressor
Toxic-sediment	Sediment Toxicity Tests with *C. tetans* on water column	Statistical Analysis, Benthic Habitat Abundance	Possible Stressor
Metals in sediment	Sampling	PEC, TEC Scientific Literature (Macdonald et al. 2001)	Possible Stressor (Pb, Hg)
Nutrients	Sampling	VADEQ Screening Value, PLE, Scientific Literature (Mills et. al. 1985), 90^{th} percentile from Reference Watershed,	Possible Stressor
Organic Matter	BOD_5, TOC, COD, TVSS, TKN, Possible Sources	90th Percentile from Reference Watershed	Possible Stressor
Hydraulic Modification	Stream flow Analysis	Embeddedness Score Embeddedness Category	Possible Stressor
Mercury	Fish Tissue Bioassay, sediment sampling, *C. tetans* toxicity testing, soil sampling, ultra trace method, Known Sources	PEC (Macdonald et al. 2001), Historical Information	Possible stressor
Sediment	Sampling, TSS, % of Haptobenthos, Sediment Modeling	Embeddedness Score Riparian Vegetation Score, 90^{th} Percentile from Reference Watershed	Most Probable Stressors
PAH	Sampling, Sediment Toxicity Analysis-survival and growth, Hazard Quotient, Known Sources,	PEC, TEC, Scientific Literature,(Macdonald et al. 2001), Historical, VA-DEQ 99^{th} Percentile for PAHs	Most Probable Stressors
Lead	Sediment Sampling, Dissolved Pb testing, Historical Analysis	PEC, Scientific Literature (Macdonald et. al. 2001), Chronic WQS, Historical Information.	Most Probable Stressors

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration; WQS: Water Quality Standards PLE: Problems Likely to Exist threshold; RBP: Rapid Bioassessment Protocol; SCI: Stream Condition Index

Table 3. Mill Creek

Stressor	Screening Procedure	Criteria/Reference Database	Outcome
Ammonia	Field Measurements	pH-and temperature dependent VAWQS.	Eliminated
pH	Field Measurements	Class V Maximum WQS range for pH	Eliminated
Temperature	Field Measurements	Class IV and Class V WQS maximum.	Eliminated
Toxics-Sediment	Sampling, testing	Consensus based sediment PEC values	Eliminated
Nutrients	Sampling, *Chironomidae* and *Hydropsychidae* percentages, visual observation, dissolved oxygen field testing and diurnal DO studies.	VAWQS for DO	Possible Stressor
Organic Matter	Visual observations, land usage, *Hydropsychidae* dominance, BOD5, COD, TKN and Low VSS, relation to nutrients	Scrapers to Collector-Filterers (SC/CF), Modified Family Biotic Index Metric	Possible Stressor
Sediment	Visual observations, land usage, aerial imagery, windshield survey	embeddedness category MAIS metrics, embeddedness score, in-stream sediment deposition score, RBII Metrics, SCI Metrics, % Haptobenthos	Most Probable Stressor

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration;
WQS: Water Quality Standards; PLE: Problems Likely to Exist threshold RBP;: Rapid Bioassessment Protocol; SCI: Stream Condition Index; MFBI: Modified Family Biotic Index

Table 4. Russell Prater Creek

Stressor	**Screening Procedure**	**Criteria/Reference Database**	**Outcome**
Metals	Sampling Benthic Surveys	90^{th} percentile from Reference Watershed, Scientific Literature (Soucek, 2001; Merricks, 2003)	Eliminated
Temperature	Field Measurement	VAWQS	Eliminated
Alkalinity	Field Measurement	90^{th} Percentile from Reference Watershed	Eliminated
pH	Field Measurement	VAWQS	Possible Stressor
Sulfate	Sulfate Concentrations (no specifics)	90^{th} Percentile from Reference Watershed, Scientific Literature (Merricks 2003)	Possible Stressor
Sediment	Sampling	90^{th} Percentile from Reference Watershed screening values, embeddedness score, Sediment Deposition Score, Habitat Metrics	Most Probable Stressor
Conductivity/ Total Dissolved Solids	Field Measurements	90^{th} Percentile from Reference Watershed, statistical analysis, Scientific Literature (Merricks, 2003; KanCRN, 2004)	Most Probable Stressor

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WQS: Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: rapid Bioassessment Protocol;
SCI: Stream Condition Index

Table 5. South Run Watershed

Stressor	Screening Procedure	Criteria/Reference Database	Outcome
pH	Field Measurement	VAWQS for Class III waters	Eliminated
Temperature	Field Measurement	VAWQS for Class III waters	Eliminated
Organic Chemicals-dissolved	Sampling, Fish tissue sampling	VAWQS-Acute or chronic criteria, Risk based Fish Tissue Screening Value	Eliminated
Organic Chemicals-Sediment	Sampling	DEQ 2006 assessment guidance memorandum	Eliminated
Metals- water column	Sampling, Fish tissue sampling, known sources	VAWQS- Acute or Chronic criteria, risk based fish tissue screening value	Eliminated
Toxicity-Ammonia	Sampling, chronic toxicity testing (mortality and reproduction) on fathead minnows and *C, dubia.* Growth testing on fathead minnows	Statistical Analysis	Eliminated
Dissolved Oxygen	Ambient data, Diurnal D.O. field measureement	VAWQS - minimum Standard	Non-stressor
Nutrient Nitrogen/Phosphorus	Diurnal DO monitoring, known and potential sources, biological field notes, total phosphorus andTotal Nitrogen sample analyses	Total Phosphorus median from the 2005 VA-DEQ nutrient criteria report, VADEQ reference values, EPT scores, MFBI scores, N/P ratio	Most probable Stressor (phosphorus)

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration; WQS: Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: Rapid Bioassessment Protocol; SCI: Stream Condition Index

Table 6. Spring Branch

Stressor	Screening Procedure	Criteria/Reference Database	Outcome
Temperature	Field Measurement	VAWQS	Eliminated
Organic Matter	BOD5, TKN	BOD5 and TKN background values for swamp-like streams	Possible Stressor
Sediment	Value for Habitat, TSS	None	Possible Stressor
Toxics	Sampling, Fathead minnow Acute and chronic effects, groundwater contamination	Acute/Chronic WQS, Virginia Groundwater Standard, MCL for chloroform	Possible Stressor
pH	Field Measurements, eutrophication of Bryant Pond, Dissolved Oxygen measurements	Class VII WQS	Most Probable Stressor
Nutrients	Dissolved Oxygen field measurements, algal growth in Bryant Pond, possible and known nutrient/dissolved oxygen violation sources, TP concentrations, Nitrite-nitrate-nitrogen concentrations	Class VII WQS for D.O., VADEQ Screening level, USEPA screening level, maximum concentrations, PLE, SPP threshold, State 99th and Coastal Plain Streams 100th percentiles for TP, Scientific Literature (Mills et al., 1985, VA-DEQ 2004a, Miltner and Ranking,1988, Sheeder and Evans 2004) RBII Index Scores	Most Probable Stressor
Dissolved Oxygen	D.O. field measurements, algal growth in Bryant Pond, possible and known nutrient/dissolved oxygen violation sources, nutrient sources	Class VII WQS for D.O.	Most Probable Stressor

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration; WQS:
Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: rapid Bioassessment Protocol; SCI: Stream Condition

Table 7. Stroubles Creek

Stressor	Screening Procedure	Criteria/ Reference Database	Outcome
Temperature	Field Measurements	VA Maximum WQS for Class IV waters.	Eliminated
pH	Field measurements, CaCO3 measurements	VA Maximum WQS for Class IV waters, CaCO3 maximum groundwater criteria.	Eliminated
Toxics	Sampling, Field Measurements, known sources, household water quality study, fathead minnow and *Ceriodaphnia* chronic toxicity testing, Known sources	DEQ Chronic/acute criteria, minimum detection limits, previous studies, EPA maximum contaminant level, statistical analysis	Eliminated
Organic Matter	BOD5, Total Organic Carbon, Chemical Oxygen Demand, Volatile Solids, Dissolved Oxygen, known sources and events, dominance of *Hydropsychidae* and *Chironimidae* ,comparison to Tom's Creek	Minimum detection limits, minimum WQS, MFBI scores , Benthic Metrics	Possible
Nutrients	dominance of *Hydropsychidae* and *Chironimidae*, sampling, known sources, Diurnal Dissolved Oxygen measurements	American Fisheries Society data, DEQ's Threatened Water Threshold, Scientific Literature (Ohio EPA, 1999; Voshell et al., 2003;Devlin, 2003; Devlin, 2002, Benson et al., 2000; Murphy 2002), Biological Integrity Scores, Habitat Scores, MFBI Scores, Riparian Vegetation Scores, Previous Studies (Woodside 1988)	Possible Stressor
Sediment	Percentage of impervious surfaces, land use, *Chironomidae* prevalence	Scientific Literature (Schueler, 1994; Voshell, 2002; Lemly 1982; Benson, 1999; Murphy, 2002) Habitat scores, previous studies (Knocke, 1985, Hoehn and Woodside, 1988)	Possible/most Probable Stressor

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration;
WQS: Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: rapid Bioassessment Protocol;
SCI: Stream Condition Index

Table 8. Upper Roanoke

Stressor	**Screening Procedure**	**Criteria/ Reference Database**	**Outcome**
Dissolved Oxygen	Field Diurnal Measurements	Minimum Concentration WQS	Eliminated
pH	Field Measurements	Class IV WQS	Eliminated
Temperature	Field Measurements	Class IV WQS	Eliminated
Nutrients	Sampling, Nitrogen concentrations, phosphorous concentrations, Chlorophyll A concentrations, D.O. concentrations	Scientific Literature (Dodds, et al. 2002)	Eliminated
Metals	Sampling, *Ceriodaphia* survival/reproduction, fathead minnow growth/survival, toxicity testing	VAWQS, statistical analysis, Consensus Based Screening Value (VA-DEQ 2004b)	Possible Stressor
Organics	Sampling, *Ceriodaphia* survival/reproduction, fathead minnow growth/survival toxicity testing	VAWQS, statistical analysis	Possible Stressor
Toxics	Sampling, *Ceriodaphia* survival/reproduction, fathead minnow growth/survival, toxicity testing	VAWQS, statistical analysis, personal communications (Hill 2004)	Possible Stressor
Sediment	Historical data, impervious areas, land use	Fact sheet (VA-DEQ, 2004), previous studies on the Roanoke River, Habitat Scores, Riparian Vegetation Scores	Most Probable Stressor

PEC: Probable Effect Concentration; TEC: Threshold Effect Concentration; CPEC: Census Probable Effect Concentration; WQS:
Water Quality Standards; PLE: Problems Likely to Exist threshold; RBP: Rapid Bioassessment Protocol; SCI: Stream Condition Index

Table 9. Strength and Weakness of the Reviewed TMDL Reports*

TMDL Report	Strength	Weakness
Hunting Camp Creek	The report fully discusses the importance of stressor analysis; describes adequately soils and land use in the watershed.	Naming of stressor categories is different from other TMDL reports; Anthropogenic sources of sediment not fully discussed; historical sources of nickel contamination are not explored; the results of sediment toxicity testing are incomplete; toxic categories are not provided.
Lewis Creek	Fully describes various causes and types of stressors; testing methods described well.	The report is disorganized and difficult to read; the rationale for using 90^{th} percentile is not fully explained; the reasoning behind the choice of TDS as a stressor is not clear; graphs and calculation methods are not fully explained. Major citation ((Macdonald et al. 2001) not listed.
Mill Creek	The report is well organized; it is understandable by a wide cross-section of stakeholders.	The statement for identifying sediment as the most probable stressor is not fully described.
Russell Prater Creek	The report is organized well, clear and concise; uses very effective visual charts.	Describing mining history in the area will enhance the report; some categories of stressors not provided; the justification for selection of reference watershed is not fully described.
South Run Watershed	The summary of water quality data is very clear and easy to understand; the usage of VA-DEQ and EPA memos and notes are used effectively to reinforce conclusions.	No citations of scientific literature; the use of 99^{th} percentile value is not fully described; description of stressors and identification process is not fully explained.
Spring Branch	Historical aspects of stressor identification process are described well; stressor section is clear and informative; issues related to algal blooms are described well	Nutrients and DO lumped together including some non-scientific assumption for relationship between DO and nutrients; lack of explanation about value of "habitat" in sediment section; adequate explanation or justification for using percentile value is not provided.
Stroubles Creek Watershed	The stressors section and categories are neatly structured; nutrients and effects are described well; land use issues are described well; large number of supporting reference literature is provided	Screening methods is not fully addressed; databases are not adequately described; written more in format of a research paper than for diverse stakeholder group.
Upper Roanoke	None	DO, pH and temperature lumped together; no definitive databases or standards provided; toxics section is confusing; no mention of sampling or measurements.

* Note: For some TMDL studies (e.g. Mills Creek) more details for the stressor analysis are provided in a separate document. The TMDL report may contain only highlights of the stressor analysis document.

Recommendations

Further review of the TMDL reports (Tables 1 through 8) revealed some strengths and weaknesses of each report (Table 9). This review shows that the process and protocols for stressor identification are inconsistently applied among TMDL developers. The consistency among applications could be improved by developing a template to provide more structure to the stressor identification process in future TMDL reports. To develop a template, we recommend that guidelines be developed by VA-DEQ that include the following important factors, that can be assessed in cooperation with existing TMDL contractors and developers used by the state:

1. The stressor identification process should follow the USEPA guidelines, though flexibility should be allowed in this very complex process.
2. A checklist should be compiled that includes all potential stressors previously identified for Virginia (This should be considered a starting list, with other site-specific potential stressors added as needed).
3. Under each potential stressor, a list should be compiled of all data sources that are applicable to this stressor, fully acknowledging that data availability varies greatly from watershed to watershed.
4. Also, under each stressor, a list should be provided of any relevant standards, criteria, screening values, or other reference values that have been used, or might prove useful, in evaluating observed data for any given stressor.
5. Sufficient justification should be provided for the rationale used in selection of the most probable stressor(s), and developed in cooperation with a local watershed technical advisory committee and DEQ.
6. A detailed explanation of the stressor identification process should be presented to the local TAC for their discussion and concurrence and presented either as a separate Stressor Analysis report or as an appendix to the full report, while a summary of major points in the process should be included in the TMDL study report and presented in layman's terms at public meetings. It is important for the TMDL developers to effectively communicate with the stakeholders the reasoning for choosing or eliminating each potential stressor. Therefore, proper documentation is a major component of the report.

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