A "WATERSHED APPROACH" TO TMDL DEVELOPMENT

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Abstract. The State of Minnesota, in an effort to streamline the identification of impaired waters and subsequent TMDL development, has developed a watershed approach to condition monitoring and assessment similar to other states such as Ohio and Indiana. The watershed approach uses intensive biological monitoring (fish and macroinvertebrates) to determine biologically impaired stream reaches. Follow up water quality monitoring in the identified impaired reaches is then used to identify the cause of the impairment through a stressor identification process. The idea behind the watershed approach is to identify all of the impairments at once providing an opportunity to address the impairments through a coordinated TMDL process.

Although the "Watershed Approach" provides a focused framework for the identification of impaired waters and TMDLs, this approach is highly dependent on the development of biological indices for the evaluation of biological communities. These indices require a significant investment in time and resources to develop. Furthermore, the results of the Stressor Identification process routinely results in identifying stressors such as lack of habitat or altered hydrology not easily addressed in the TMDL framework. As a result, a large amount of creativity is required in the development of these TMDLs.

This paper will review the "Watershed Approach" using several examples where the process has been applied in Minnesota. The authors will review the necessary scientific information required for this approach, identify the strengths and weaknesses, and outline how this approach may be applicable to Southeast US watersheds.

INTRODUCTION

The basis of the Environmental Protection Agency's Total Maximum Daily Load (TMDL) program is the protection of designated beneficial uses of the nation's water bodies. The most ubiquitous beneficial use is aquatic life. Past approaches to protecting aquatic life focused on developing water quality standards thought to be protective of aquatic organisms, however there was no direct measure of the health of the biological community.

Relatively new approaches are currently being applied that directly address the biological community and attempt to identify and remedy those factors limiting the health of the biological community.

The basis of these new approaches includes the development of an Index of Biological Integrity (IBI) to directly measure the health of the biological community managers intend to protect (Ohio EPA 1987, USEPA 1996). An IBI develops an index to measure the health of the biological community based on a number of metrics easily measured in biological surveys. Each metric in the IBI denotes a quantifiable attribute of a biological community that changes in a predictable way. Metrics include measures such as species richness and composition, trophic composition and reproductive function, and abundance and condition. The metrics are then compared to a range of reference values to characterize the biological integrity of a site. Most IBIs in rivers and streams have used fish and macroinvertebrate communities.

The State of Minnesota has been working toward establishing statewide IBIs by major river basin for both fish and macroinvertebrates in warm and coldwater streams. These IBIs are integral to the Stressor Identification (SI) process that is the basis for the watershed approach for developing TMDLs. The watershed approach focuses on the biologically impaired reaches in an effort to determine and remedy the factors causing the impairment.

STRESSOR IDENTIFICATION

Identification of the stressors impairing a biological community is accomplished through a weight-of-evidence approach (USEPA 2000). USEPA has developed a process where the candidate causes are listed, evidence for those causes is evaluated, and then the supported probable causes are identified. EPA maintains an online tool to support the SI process called the Causal Analysis/Diagnosis Decision Information System (CADDIS; USEPA 2007).

Although the SI process focuses managers on those factors causing biological impairment, many of the stressors are not easily addressed in the TMDL framework. Incorporation of nontraditional parameters in the TMDL requires come creativity in the development of targets and endpoints. Many TMDL developers have applied traditional TMDL parameters as surrogates; however this approach does not get directly to the cause of the impairment. For example, many TMDLs have addressed embeddedness through the development of sediment allocations. Sediment TMDLs only address suspended particles and do not address bedload which is likely the primary driver for embeddedness. Consequently, the TMDL may miss the actual cause of the impairment.

In an attempt to address these short-comings and streamline the TMDL process, the State of Minnesota developed a “Watershed Approach” for developing TMDLs. The watershed approach uses intensive biological monitoring (fish and macroinvertebrates) to determine biologically impaired stream reaches. Follow up water quality and geomorphologic monitoring in the identified impaired reaches is then used to identify the cause of the impairment through a stressor identification process. The idea behind the watershed approach is to identify all of the impairments at once providing an opportunity to address the impairments through a coordinated TMDL process.

WATERSHED APPROACH

The watershed approach includes a four step process for assessment of a watershed. The four steps include intensive monitoring, stressor identification, development of the TMDL, and implementation planning.

Intensive Monitoring. The first step in developing TMDLs on a watershed wide basis is intensive monitoring of the watershed including biological and chemical parameters. The purpose of the watershed wide monitoring is to determine the overall health of the watershed, identify currently impaired water bodies, and identify waters in need of protection to prevent impairment (MPCA 2009). A major component of the watershed monitoring is biological monitoring to identify impaired biological communities. Follow-up monitoring is then conducted in the biologically impaired reaches to assist in the stressor identification process.

Intensive monitoring is conducted on a major watershed basis (8-digit HUC) with intermediate (11 digit HUC) and minor (14 digit HUC) watersheds sampled along with the outlet of the major watershed. Water chemistry and biological communities are monitored at the 8 and 11 digit HUC scale with just biological monitoring occurring down to the 14 digit HUC scale. Biological monitoring includes habitat and geomorphologic assessments at those sites (MPCA undated; MPCA 2002a). Follow up monitoring occurs in each of the reaches determined to be biologically impaired to identify the source and cause of impairment.

Identification of the impaired reaches relies heavily upon the development and application of a statewide IBI for both cold and warm water streams. The State of Minnesota has invested heavily in the development of IBIs for both fish and macroinvertebrates including intensive biological monitoring and metric development (MPCA 2002b, MPCA 2004).

Stressor Identification. Once all of the biologically impaired reaches have been identified and follow up data have been collected, the data need to be assessed to identify the causal factors limiting the biological communities. In Minnesota, this is accomplished through the use of EPA’s SI process or CADDIS, an on-line causal analysis system (Figure 2).

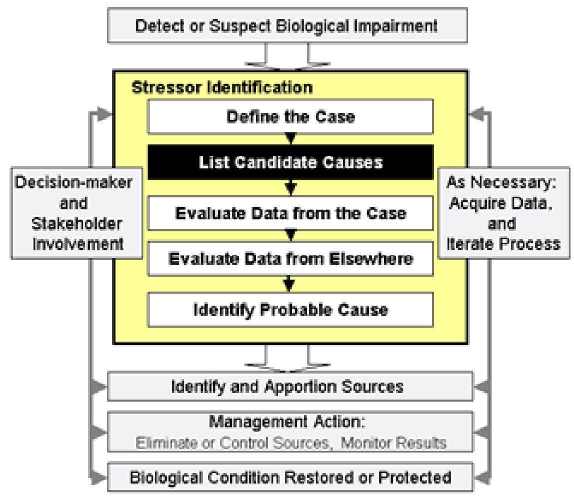

Figure 1. Stressor identification process (EPA 2007).

TMDL Development. Upon completion of the SI process, TMDLs need to be developed for those parameters identified as stressors of the biological communities. The process is relatively straightforward for traditional TMDL parameters such as dissolved oxygen, nutrients, toxics, and turbidity. Typical approaches for these parameters can range from simple load duration curves to complex models such as SWAT and HSPF. Application of the TMDL framework to nontraditional parameters such as habitat loss, barriers, and hydrologic alteration require the developer to establish benchmarks for these parameters.

Implementation Planning. The ultimate objective through the entire process is to develop an understanding of stressors to eliminate through watershed management and restoration. The data generated throughout the process are focused on understanding the cause of the biological impairment and development of projects to address the underlying causes.

CASE STUDIES

Site Description. Two watersheds were selected as examples for application of the watershed approach to TMDL development (Figure 1). Shingle Creek is a small urban stream located in the northwest inner ring suburbs of Minneapolis. The Ann River is relatively large agricultural watershed located about 70 miles north of the Twin Cities metropolitan area.

Shingle Creek. The Shingle Creek watershed covers 44.7 square miles in east-central Hennepin County. The main stem of Shingle Creek begins in Brooklyn Park and flows generally southeast to its confluence with the Mississippi River in Minneapolis. Shingle Creek is about 11 miles long and drops approximately 66 feet from source to mouth.

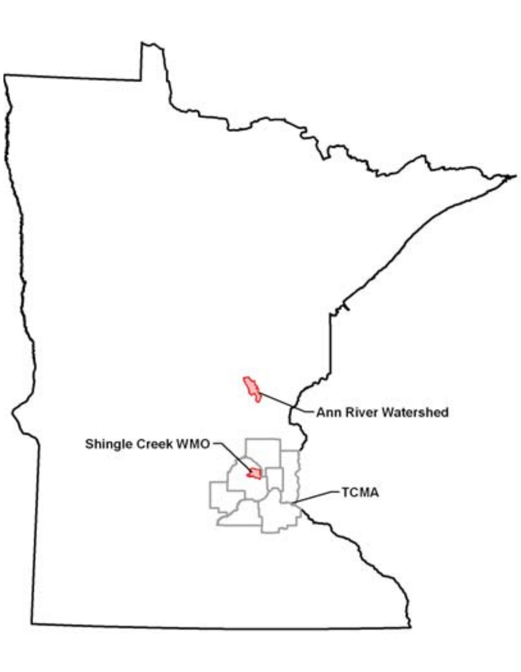

Figure 2. Location of the Shingle Creek and Ann River watersheds in relation to the Twin Cities Metropolitan Area (TCMA).

The Shingle Creek watershed is almost entirely developed. Single family residential is the largest land use classification at 44 percent of the total watershed area. The entire watershed is on average 30-35 percent impervious. There are several sizable flow-through wetlands on the streams, including the 400+ acre Palmer Lake basin.

Ann River. The Ann River in Kanabec County is a third-order stream located approximately 2 miles west of Mora, Minnesota. The Ann River watershed is predominantly agriculture with row crops and animal agriculture as the dominant practices.

RESULTS AND DISCUSSION

Stressor Identification. Candidate causes of impairment for the Shingle Creek and Ann River Watersheds were evaluated using EPA's Causal Analysis/Diagnosis Decision Information System (CADDIS), MPCA's biological TMDL protocols, and weight of evidence analysis (MPCA 2009, Wenck 2010).

Five stressors for Shingle Creek were identified as potential candidate causes including low dissolved oxygen; altered habitat; loss of connectedness; altered hydrology; and ionic strength, specifically chloride (Figure 3). These five stressors were evaluated according to CADDIS' structured, weight-of-evidence approach to determine which stressor or stressors were the likely candidate cause or causes of the impairments to Shingle Creek (Wenck 2010). The evidence for altered hydrology is strongest followed closely by dissolved oxygen and lack of habitat. While the loss of connectedness and ionic strength are plausible stressors and are likely contributing to the impairment, there is less direct evidence of their role. Altered hydrology, dissolved oxygen, and habitat are interrelated and interacting.

Figure 3. Drop structure in Webber Park that disconnects Shingle Creek from the Mississippi River.

The results of the Stressor Identification analysis for the Ann River watershed pointed to four probable causes for the biological impairment (MPCA 2009). These include:

- Loss of habitat due to substrate embeddedness
- Low dissolved oxygen (DO) concentrations
- Altered riparian corridor / channel morphology
- Loss of Connectivity / Habitat fragmentation (Dams)
- Altered flow regime (Dams)

The Ann River has undergone significant alteration over the years, causing several of the stressors. Several impoundment structures located in the Ann River watershed may be altering streamflow and impeding fish passage. Furthermore, these structures may be exacerbating low flow conditions resulting in hydrologic stress as well as low dissolved oxygen concentrations. Loss of habitat due to sedimentation appears to be most problematic in the lower reaches of the river, which are lower in gradient and serve as natural depositional areas for sediment from upstream sources (Figure 4). Observations collected during stream reconnaissance efforts indicate that agricultural land-uses (primarily cattle grazing) are a significant source of sediment delivery in the watershed. In addition, historical logging, and the use of the Ann River as a log driving waterway may also play a role in present day sediment dynamics.

Figure 4. Reach of the Ann River showing piles of coarse grained sediment within the stream channel. Under high flows, stream power is sufficient to transport these materials along the stream bottom. As flows recede, sand and gravel drop out and reduce benthic habitat quality (Picture provided by the Minnesota Pollution Control Agency).

TMDL Development. Traditional TMDL pollutants are easily addressed through the use of well established models or load duration curves. In Shingle Creek, dissolved oxygen impairments were addressed using the QUAL2K model. The TMDL for chloride was completed using load duration curves (Cleland 2002; Figure 5).

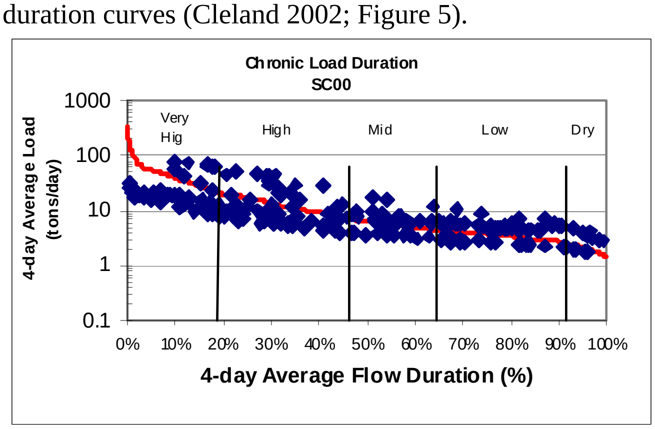

Figure 5. Chloride load duration curve for Shingle Creek.

Based on the results of the SI, several of the identified stressors in both systems are not considered pollutants in the TMDL program and are therefore not easily addressed in the TMDL document. These stressors include altered hydrology, loss of habitat, altered riparian corridor, and loss of connectivity. However, these stressors are quite common and critical components in the restoration of the identified beneficial uses including aquatic life.

To address the loss of habitat and altered riparian corridor, stream restoration "design standards" aimed at restoring a more natural channel were developed to provide lost habitat features (Figure 6). Specific features can be teased out of the IBI analysis, however that analysis is beyond the scope of this paper. In the case of Shingle Creek, QUAL2K modeling also demonstrated that reintroduction of a low-flow channel was one of the primary steps necessary to bring dissolved oxygen back into compliance with state standards.

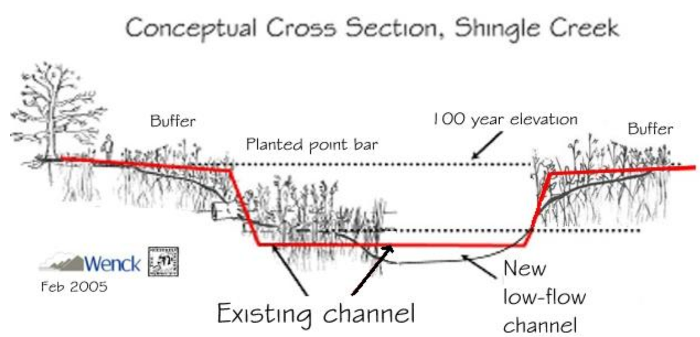

Figure 6. Desirable stream cross section with enhanced habitat and a low-flow channel.

Although the TMDL is still currently under development for the Ann River, geomorphologic targets are being developed to reduce the amount of sedimentation that occurs in the stream system. The channel design standards, in conjunction with more common BMPs such as animal exclusion, will result in less sedimentation in the channel and increase the available benthic habitat.

CONCLUSIONS

Restoring the aquatic life beneficial use in our nation's waters requires more than just reductions in traditional pollutants such as nutrients, sediment and toxics. Successful restoration action plans require a linkage between the biological communities we are trying to protect and the factors causing degradation of the community. Many of the stressors do not lend themselves to being addressed in a traditional TMDL and therefore require some creativity by the TMDL developer.

Minnesota's "Watershed Approach" is a good first step toward building a link between the biological community and the factors limiting the health of that community. The "Watershed Approach" provides a systematic plan for identifying impaired waters, and then resampling to develop a robust data set for linking watershed conditions and the biological community.

The "Watershed Approach" is not without its limitations. Long term hydrologic records are often not available at many of the sites making load duration curves impossible to develop. The State of Minnesota intends to develop HSPF models for all of the basins in the state; however, this process has lagged behind the development of the TMDLs and stressor identification analyses.

The "Watershed Approach" also requires a significant investment by the State to develop rigorous IBIs. The development of the IBIs requires a high volume of detailed biological monitoring, organism identification and data analysis. Development of an IBI takes a significant amount of time and money.

Finally, many of the stressors commonly identified in the stressor identification process are not easily addressed with the current TMDL format. These other stressors must be either linked to more traditional TMDL parameters such as sediment or endpoints need to be developed specifically for those parameters.

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