TURBIDITY TMDL PROTOCOLS
AND SUBMITTAL REQUIREMENTS

Prepared by the Turbidity TMDL Protocol Team:
Greg Johnson, Nick Gervino, Larry Gunderson, Louise Hotka, Molly MacGregor, Mike Vavricka, Bill Thompson, Lee Ganske, Maggie Leach, Tom Schaub, Chris Zadak, and Jim Klang

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I. Introduction

A. Purpose

The purpose of this Turbidity Total Maximum Daily Load (TMDL) protocol is to provide a common understanding between TMDL project team members and reviewers of the expectations, requirements and science principles used in completing a turbidity Total Maximum Daily Load study and following report. This document outlines both the science and the steps needed for approval by the Minnesota Pollution Control Agency (MPCA) and the United States Environmental Protection Agency (EPA). The protocol is a discussion of the key questions to be asked, and an overview of the principals and other technical references to be used as a basis to discover the answers, not a cookbook formula. The organization of this document is to provide you a science baseline on how and what are the typical key pollutant and physical parameters that commonly affect turbidity levels. Included in the discussion is an organizational layout for your investigation to be used to validate or eliminate the potential stressors. This layout can be used as a general outline to develop your investigation in the stages of monitoring, contract work plans, and communication of the results. This protocol is intended to build confidence and uniformity between the expectations of the TMDL project team and reviewers for determining stressors, evaluating needed expenditures, understanding project reporting requirements, and the TMDL project approval process itself.

A significant source of the organizational layout is based upon the concepts provided in the EPA guidance manual on “Stressor Identification” for Biotic Impairments. This manual can be found online at [http://www.epa.gov/ost/biocriteria/stressors/stressorid.pdf](http://www.epa.gov/ost/biocriteria/stressors/stressorid.pdf). It provides useful techniques that can be applied in all TMDL projects, and should be strongly considered for any investigation that is sorting through multiple potential stressing pollutant parameters and/or multiple sources of pollutants. This process also blends well with the public involvement process the MPCA promotes for a TMDL project’s team. When the advisory teams for a project use the stressor identification and weight of evidence concepts routinely in their meetings, it can build common assumption bases quicker and has a better chance of developing conclusions that have a broader consensus in the group.
B. Protocol Structure

The protocol is written as an educational document to foster the development of technical skills required for watershed management regarding turbidity, ultimately to provide for a healthy ecosystem. As such, a reader familiar with the issues may want to jump out of order or look up key sections for review. For this, Figure 1 provides a flowchart of the general TMDL process laid out in the MPCA TMDL protocols. The figure is followed by Table 1 that contains an Outline Key for the flowchart describing the suggested organizational steps for a project investigation. The table also has the key discussion pages of the protocol listed in the right-hand column. By combining both the diagram and outline, a project team may use these resources as either a quick locator or as a guide to the order for key project steps and questions.

The narrative below briefly describes the chapter and section content and provides the page numbers for each:

Basic Principles and Concepts

A Balanced Stream Ecosystem
A general discussion that provides background on what comprises a healthy stream ecosystem, defines the concept of “loading capacity” and stresses the importance of turbidity-related variables in aquatic systems. Page 9

Stream Turbidity Interactions
This section describes some of the physical, chemical, and biological factors that interact and need to be considered in setting up the project area boundaries. Page 10

Stressors on Stream Turbidity
This section provides a partial list of pollutants and stressors on turbidity levels in a stream. This section organizes these sources using the required EPA, TMDL wasteload (National Pollutant Discharge Elimination System [NPDES] permitted sources) and load allocation (nonpoint source) designations. Page 18

Problem Definition

Applicable Water Quality Rules
This section cites the Minnesota Rule 7050 provisions on beneficial uses and numeric criteria. Page 27

Initial Problem Assessment
This section reviews limited sources of existing data that can be used in the early scoping stages of a project to form teams and inform the project teams of what types of additional sources of information may be critical to the understanding of the impairment. Page 28
Comprehensive Data Compilation from Existing Sources
This section deepens the data collection efforts using the “Strength of Evidence” process to pursue physical and chemical information sets to further define the projects critical design conditions, and prominent data gaps. Page 30

Analysis

Select Analysis Framework
This section discusses the basic objectives and criteria of a turbidity TMDL study, appropriate analytical tools and general approach alternatives to define and develop a specific approach for the project. Page 45

Additional Data Acquisition to Support Framework
This section further defines steps to gain data sets to fill in the gaps in data previously identified. Page 49

Model Setup and Evaluation
This section, for projects choosing to model the impairment and/or its watershed, will provide guidance to common terms and needs of setting up a model to assess the impairment. Page 49

Model Application and Example TMDL Components
This section, for projects running a model, provides commonly used model applications to evaluate and determine source partitioning (i.e., defining each source’s pollutant loads) and reduction potential. This section ends with a discussion of Uncertainty Analysis procedures to help define cumulative potential errors in the modeling system. Page 52
Figure 1. Flowchart for the Turbidity TMDL Study and Attainment Strategy

1. **General Problem Definition**
   - WQ Standards
   - NPDES data
   - Stakeholder input

2. **Comprehensive Data Collection (existing)**

3. **Data Review and Evaluation**

4. **Are key turbidity stressors solely due to natural background or in attainment?**

5. **Acquire New Data to Evaluate Background**

6. **Delisting Strategies:**
   - Natural background
   - Site-specific standards
   - Use Attainability Analysis to remove/modify beneficial uses
   - New Data in Attainment

7. **Select Analysis Framework**

8. **Identify Data Gaps**

9. **Acquire New Data to Support Analysis**

10. **Develop Analysis Tool(s)**

11. **Develop WLA and LA Scenarios**

12. **Is turbidity standard attainable?**

13. **Develop and Implement the TMDL**

14. **Delisting Strategies:**
   - Site-specific standards
   - Use Attainability Study to remove/modify beneficial uses
   - Variance

Policy and Stakeholder Inputs
<table>
<thead>
<tr>
<th>Box Key</th>
<th>Description</th>
<th>Protocol References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1: Technical Flow Path</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Develop a general description of what is known about the water quality impairment, using readily available information on applicable water quality standards, discharger data, monitoring data, assessment data and local knowledge.</td>
<td>II. Problem Definition ¶ A and B</td>
</tr>
<tr>
<td>2</td>
<td>Identify sources of physical, chemical and biological data; obtain and compile data and develop a data management system.</td>
<td>II. Problem Definition ¶ C</td>
</tr>
<tr>
<td>3</td>
<td>Provide preliminary review and evaluation. What are key stressors on stream turbidity? What are critical conditions for turbidity impairments? What are the prominent data gaps?</td>
<td>II. Problem Definition ¶ D</td>
</tr>
<tr>
<td>4</td>
<td>From existing data review and evaluation, is the impairment due solely to natural and/or irreversible conditions? If yes, then consider strategy for delisting the impaired water (6). If no, then proceed into detailed analysis (7). If additional data is needed to make a determination on natural conditions, identify data needs and acquire new information (5).</td>
<td>II. Problem Definition ¶ D</td>
</tr>
<tr>
<td>5</td>
<td>Identify data gaps and collect additional background information</td>
<td>II. Problem Definition ¶ D</td>
</tr>
<tr>
<td>6</td>
<td>Delisting considerations may include: natural background conditions preclude WQ standard attainment; unique conditions warrant a site-specific standard development; designated beneficial uses are neither present nor attainable; and the existing condition may not be natural but is basically irreversible.</td>
<td>Detailed delisting guidance is beyond the scope of this protocol.</td>
</tr>
<tr>
<td>7</td>
<td>With consultation and input from stakeholders, assess project objectives, available resources and analytical tools to develop an overall project framework that identifies roles of key participants and stakeholders. What is the proper balance of local/state/contracted resources? Define scope of services, if any, to be provided by contracted consultants. Develop RFP(s) as needed.</td>
<td>III. Analysis ¶ A</td>
</tr>
<tr>
<td>8</td>
<td>Based on the preliminary data review and evaluation (3), identify information gaps critical to the selected analysis alternative.</td>
<td>III. Analysis ¶ B</td>
</tr>
<tr>
<td>9</td>
<td>Design and conduct field studies to obtain physical, chemical, biological stream information; flow; turbidity and surrogate parameter(s) data; point and nonpoint loadings; bio-assessments; etc., to satisfy data needs of analysis tool (model).</td>
<td>III. Analysis ¶ B</td>
</tr>
<tr>
<td>10</td>
<td>Set up the selected general modeling framework with site-specific information. Calibrate and validate model with observed data. Use model to perform component analysis of turbidity sources and sinks and relate to the prominent stressors. Perform sensitivity analysis on key parameters to understand model response to loadings. Perform accuracy check by comparison of model output with observed data. Report results; receive feedback from stakeholders.</td>
<td>III. Analysis ¶ C</td>
</tr>
<tr>
<td>11</td>
<td>With consultation and input from stakeholders, design and perform analysis for various example scenarios that evaluate and define WLA, LA, MOS, and reserve capacity.</td>
<td>III. Analysis ¶ D</td>
</tr>
<tr>
<td>12</td>
<td>Does the analysis predict management scenarios having reasonable potential to meet project objectives for attaining water quality standards? If yes, proceed to TMDL development and implementation (13). If no, then consider strategies for delisting the impaired water (14).</td>
<td>III. Analysis ¶ D</td>
</tr>
<tr>
<td>13</td>
<td>Prepare final technical report with recommendations for developing and implementing the TMDL.</td>
<td>IV. Final DO Investigation Report</td>
</tr>
<tr>
<td>14</td>
<td>Delisting strategies may include: natural background conditions preclude WQ standard attainment; unique conditions warrant a site-specific standard development (Joe – how do these two differ?); designated beneficial uses are neither present nor attainable; the existing condition may not be natural, but is basically irreversible and water quality variance.</td>
<td>Detailed strategy guidance is beyond the scope of this protocol.</td>
</tr>
<tr>
<td>Box Key</td>
<td>Description</td>
<td>Stakeholder Key</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td><strong>Part 2: Strength of Evidence (Stakeholder Flow Path)</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Assemble stakeholder group(s) that will: 1) provide local information, 2) communicate well with other watershed interests, 3) assess policy questions, 4) assess technical questions, and 5) fulfill the title of “Reasonable Decision Maker”.</td>
<td>(a)</td>
</tr>
<tr>
<td>2</td>
<td>Identify sources of physical, chemical, and biological data; obtain and compile data; and develop a data management system.</td>
<td>(a)</td>
</tr>
<tr>
<td>3</td>
<td>Provide preliminary review and evaluation. What are key stressors on stream turbidity? What are critical conditions for turbidity impairments? What are the prominent data gaps? Do local perceptions line up with data evaluation?</td>
<td>(b)</td>
</tr>
<tr>
<td>4</td>
<td>From existing data review and evaluation, is the impairment due solely to natural and/or irreversible conditions? If yes, then consider strategy for delisting the impaired water (6). If no, then proceed into detailed analysis (7). If additional data is needed to make a determination on natural conditions, identify data needs and acquire new information (5).</td>
<td>(b)</td>
</tr>
<tr>
<td>5</td>
<td>Identify data gaps and collect additional background information (a); Box Key 2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Delisting considerations may include: natural background conditions preclude WQ standard attainment; unique conditions warrant a site-specific standard development; designated beneficial uses are neither present nor attainable; the existing condition may not be natural but is basically irreversible.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>With consultation and input from stakeholders, assess project objectives, available resources, and analytical tools to develop an overall project framework that identifies roles of key participants and stakeholders. What is the proper balance of local/state/contracted resources? Define scope of services, if any, to be provided by contracted consultants. Develop RFP(s) as needed. Set up RFP(s) to answer questions, validate or modify preconceived notions and provide detailed reports.</td>
<td>(c)</td>
</tr>
<tr>
<td>8</td>
<td>Based on the preliminary data review and evaluation (3), identify information gaps critical to the selected analysis alternative.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Design and conduct field studies to obtain physical, chemical, biological stream information; flow; turbidity and surrogate parameter(s) data; point and nonpoint loadings; bio-assessments; etc., to satisfy data needs of analysis tool (model).</td>
<td></td>
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<td>10</td>
<td>Set up the selected general modeling framework with site-specific information. Calibrate and validate model with observed data. Use model to perform component analysis of turbidity sources and sinks and relate to the prominent stressors. Perform sensitivity analysis on key parameters to understand model response to loadings. Perform accuracy check by comparison of model output with observed data. Report results; receive feedback from stakeholders.</td>
<td>(d)</td>
</tr>
<tr>
<td>11</td>
<td>With consultation and input from stakeholders, design and perform analysis for various example scenarios that evaluate and define WLA, LA, MOS, and reserve capacity.</td>
<td>(e)</td>
</tr>
<tr>
<td>12</td>
<td>Does the analysis predict management scenarios having reasonable potential to meet project objectives for attaining water quality standards? If yes, proceed to TMDL development and implementation (13). If no, then consider strategies for delisting the impaired water (14).</td>
<td>(f)</td>
</tr>
<tr>
<td>13</td>
<td>Prepare final technical report with recommendations for developing and implement the TMDL.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Delisting strategies may include: natural background conditions preclude WQ standard attainment; unique conditions warrant a site-specific standard development; designated beneficial uses are neither present nor attainable; the existing condition may not be natural but is basically irreversible; and water quality variance.</td>
<td>(g)</td>
</tr>
</tbody>
</table>
C. Overview of the TMDL Process

The TMDL process offers an excellent opportunity to identify and restore water quality in stream, rivers, and lakes, as well as enhance involvement of watershed residents and stakeholders in water quality issues. Other potential benefits of the TMDL process to lakes include:

- Encourages the development of a consistent framework for conducting water quality studies;
- Defines existing impairments and pollution sources, quantifies source reductions, and sets comprehensive restoration strategies to meet water quality standards;
- Provides a framework for assessing future impacts to water quality;
- Accelerates the schedule at which impaired waters are addressed through more effective coordination of existing and future resources among local entities, state, and federal environmental agencies;
- Provides a basis for revising local regulations (e.g., zoning and sub-division) and developing performance-based standards for future development; and
- Facilitates the incorporation of TMDL schedules and implementation activities into local government water plans.

What is a TMDL?

A TMDL or Total Maximum Daily Load (TMDL) is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Section 303(d) of the Clean Water Act (CWA) and its implementing regulations (40 C.F.R. § 130.7) require states to identify waters that do not or will not meet applicable water quality standards and to establish TMDLs for pollutants that are causing non-attainment of water quality standards.

Water quality standards are set by States, Territories, and Tribes. They identify the uses for each water body, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing), and the scientific criteria to support that use.

As described in detail in Part II of this guidance, a TMDL needs to account for seasonal variation and must include a margin of safety (MOS). The MOS is a safety factor that accounts for uncertainty that may occur in different areas of TMDL analysis. Also, a TMDL must specify pollutant load allocations among sources. The total of all allocations, including wasteload allocations (WLA) for point sources, load allocations (LA) for nonpoint sources (including natural background), and the MOS (if explicitly defined) cannot exceed the maximum allowable pollutant load:

\[
TMDL = \text{sum}WLAs + \text{sumLAs} + MOS + RC*
\]

* The MPCA also requires that “Reserve Capacity” (RC) which is an allocation for future growth be addressed in the TMDL. See page 69 for more information.

Finally, a TMDL study includes the identification of pollutant sources as specifically as possible, and determines or estimates how much each source must reduce its contribution in order to meet
the maximum allowable pollutant load. The sum of all contributions must be less than the maximum daily load.

It should be noted that not all TMDLs involve simple single-pollutant load analysis. Dissolved oxygen, for example, is affected by a number of pollutants and conditions that may vary substantially from water body to water body. Biological impairments may be the result of habitat degradation or unstable hydrology, conditions that aren’t generally thought of as “pollution.”

**What is the process for completing TMDLs?**

As noted above, the Clean Water Act Section 303, establishes water quality standards and TMDL programs. Section 303(d) of the CWA requires states to publish, every two years, an updated list of streams and lakes that are not meeting their designated uses because of excess pollutants. These water bodies are considered impaired for their uses.

The list, known as the 303(d) list, is based on violations of water quality standards and is organized by river basin. States must establish priority rankings for waters on the lists and develop TMDLs for listed waters. Minnesota’s 303(d) list can be found on the MPCA Web site at: [http://www.pca.state.mn.us/water/tmdl/index.html](http://www.pca.state.mn.us/water/tmdl/index.html). The 2006 Guidance Manual for Assessing the Quality of Minnesota’s Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List explains MPCA's process for assessing water bodies for the 305(b) report and the 303(d) impaired waters list. The guidance manual is also on the MPCA web site at: [http://www.pca.state.mn.us/publications/manuals/tmdl-guidancemanual04.pdf](http://www.pca.state.mn.us/publications/manuals/tmdl-guidancemanual04.pdf).
The Clean Water Act requires a completed TMDL for each water identified on a state’s Impaired Waters list. Lakes or river reaches with multiple impairments require multiple TMDLs. States have the primary responsibility for developing TMDLs and submitting them to EPA for review and approval. If EPA disapproves a TMDL, EPA is required to establish the TMDL.

The process for completing a TMDL study is complex and varies significantly from project to project. Some of the many variables that determine scope of a project include:

- Number of pollutant sources
- Type of pollutant and size of the watershed
- Amount of existing data
- Relationship of one impairment to others that may exist in the same or nearby water bodies
- Extent of stakeholder involvement
- Availability of necessary resources.

Public participation is critical throughout the TMDL process and Minnesota expects advisory groups to be involved from the earliest stages of the project. At a minimum, the EPA requires that the public must be given an opportunity to review and comment on TMDLs before they are formally submitted to EPA for approval. Every TMDL is formally public noticed in Minnesota with a minimum 30-day comment period.

After a TMDL is approved by the EPA, a detailed implementation plan is finalized to meet the TMDL’s pollutant load allocation and achieve the needed reductions to restore water quality. Depending on the severity and scale of the impairment, restoration may require 10-20 years or longer and millions of dollars. Further information on MPCA’s TMDL implementation policy can be found at: http://intranet.pca.state.mn.us/policies/programpolicies/i-wq2-031.pdf

A more detailed analysis of the timeline and steps required to complete a typical TMDL, as well as the MPCA staff resources required, see Appendix A. The reader is also encouraged to refer to EPA’s 1991 guidance document: “Guidance for Water Quality-based Decisions: The TMDL Process” at http://www.epa.gov/OWOW/tmdl/decisions/ for a more complete description of the federal program.

**Who is responsible for doing TMDLs?**

The MPCA is ultimately responsible for completing and submitting TMDLs to the EPA. However, stakeholders play a critical role in the development and implementation of TMDLs. Locally-driven projects are most likely to succeed in achieving water quality goals because local communities often best understand the sources of water quality problems and effective solutions.
to those problems. Their work to develop and implement TMDLs is a key tool to restore and maintain our rivers, streams and lakes.

For nearly two decades, the MPCA has contracted with counties, watershed districts, soil and water conservation districts, and other local organizations to diagnose and help restore lakes and streams polluted from nonpoint sources. This watershed work was completed through the agency’s Clean Water Partnership and Clean Water Act Section 319 programs. Many local government agencies have gained considerable expertise in watershed work and public involvement in part due to this experience. Building off of this success, the MPCA will provide grant contracts to qualified local governments and watershed organizations to lead an estimated two-thirds of TMDL projects. The MPCA will direct the remaining projects. The contracts cover staffing, equipment, lab costs, and other project expenses.

In addition, scientific and technical experts provide valuable information and insight. In many cases, private consultants assist with data collection, modeling, and development of draft reports.

The MPCA estimates that nearly 95 percent of all the state’s TMDL funding for study completion will be passed through to local-governments and contractors. The MPCA provides oversight, technical assistance, and training to ensure regulatory and scientific requirements are met. The MPCA submits final TMDLs for EPA approval.

For additional information on TMDL grant requirements, see MPCA’s TMDL workplan guidance at: http://www.pca.state.mn.us/publications/wq-iw1-01.pdf.
II. Methodology for Developing Turbidity TMDLs

A. Basic Principles and Concepts

1. A balanced stream ecosystem

Turbidity in water is caused by suspended soil particles, algae, etc., that scatter light in the water column making the water appear cloudy. Excess turbidity can significantly degrade the aesthetic qualities of water bodies. People are less likely to recreate in waters degraded by excess turbidity. Also, turbidity can make the water more expensive to treat for drinking or food processing uses. Turbidity values that exceed the standard can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected, and spawning beds may be covered.

Minnesota’s water quality standards include a numeric criterion for turbidity as a measure of whether a water body meets its designated uses. Specifically, Minn R. ch. 7050.0220, Specific Standards of Quality by Associated Use Classes, states:

... “The numerical and narrative water quality standards in parts 7050.0221 to 7050.0227 prescribe the qualities or properties of the waters of the state that are necessary for the designated public uses and benefits. If the standards in this part are exceeded, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, or injurious with respect to designated uses or established classes of the waters of the state.” The numeric criteria for turbidity by use class are shown below.

<table>
<thead>
<tr>
<th>Classes (and descriptions) related to 303(d) list use support:</th>
<th>Turbidity (NTUs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B (drinking water)</td>
<td>10</td>
</tr>
<tr>
<td>2A (cold water fishery, all recreation)</td>
<td>10</td>
</tr>
<tr>
<td>2B (cool &amp; warm water fishery, all recreation)</td>
<td>25</td>
</tr>
<tr>
<td>2C (indigenous fish, most recreation)</td>
<td>25</td>
</tr>
</tbody>
</table>

The turbidity standard is written to address the designated use of “supporting aquatic life” and hence, is being applied in that manner in the assessment of streams for 303(d) impairment.

Unfortunately, the quality of water and uses supported are often not determined by a single pollutant criterion. Rather, multiple pollutants and/or other factors often interact in affecting water quality when considering ecosystem health and functioning. Use of turbidity as a measure of use attainment is complicated by unclear documentation of how the numeric criteria was determined, by differences in measurement technology, and variable responses of material in water to light passage. Appendix B provides more information on the background of the development of the turbidity standard in Minnesota.

Aside from these complexities/complications, water bodies (streams and rivers) are assessed for impairment of designated uses based on turbidity following the requirements of the Clean Water
Act and ensuing Minnesota water quality rules. To be sure, turbidity is associated with definite pollution impacts whether due to direct turbidity or other factors associated with elevated turbidities.

The overall goals of the Clean Water Act (CWA) and related programs are to provide good water quality so that designated uses are met. While the best approach to accomplishing these goals is through a holistic ecosystem or watershed approach, the CWA specifies that state water quality standards be established and ensuing program work be done to meet these standards. The TMDL provisions of the CWA are now near the forefront of work intended to provide for improved water quality in individual water bodies. In this, individual TMDLs are to be developed for individual pollutants identified as impairing individual stream reaches and lakes.

The challenge then becomes that of using TMDLs as a tool for assessing and improving water quality and yet incorporating an ecosystem or watershed approach that recognizes the interplay of numerous factors in affecting water quality. Turbidity or related variables can affect aquatic life function and habitat (breathing, sight, feeding, siltation, sedimentation, plant growth, etc.), aesthetic and recreation uses (swimming, boating, etc.), drinking water use, sedimentation and filling of lakes and reservoirs, and industrial and agricultural uses.

While the turbidity TMDLs have to specifically address the turbidity standard, the broader ecosystem functioning of a stream and its watershed has to be incorporated into the studies and the solutions. Efforts are needed in distinguishing the presence and impacts of pollutants versus pollution, symptoms versus causes, and the presence and effect of parallel and/or multiple stressors on the designated uses (i.e., is there an additive chronic toxicity), in this case aquatic life support.

2. Turbidity Interactions

As described above, turbidity is an expression of the optical property of a sample of water which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. It is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, bacteria, plankton and other microscopic organisms. In the past, some publications used the terms “turbidity” and “suspended solids” almost synonymously. However, the degree of turbidity is not equal to the concentration of suspended solids, but is only an expression of one effect of suspended solids upon the character of the water. Measurement of turbidity is based upon a comparison of the amount of light passing through the given water sample with that passing through a standard sample. Turbidity is measured in standard units, defined in terms of the depth of water to which a candle flame can be clearly distinguished (McKee and Wolf, 1971).

Nephelometry has been adopted by Standard Methods as the preferred means for measuring turbidity because of the method’s sensitivity, precision and applicability over a wide range of particle size and concentration. The preferred units for expressing turbidity are NTU (Nephelometric Turbidity Units). EPA has approved three methods for turbidity measurements in drinking water. These include EPA method 180.1, Standard Method 2130B, and Great Lakes Instrument Method 2 (EPA, 1999a).
Turbidity is affected by several factors in water, including the presence of dissolved and suspended solids, size and shape of particles and composition of the particles. EPA (1999) provides the following general information:

- The largest component of the particles creating turbidity in rivers is caused by the erosion of materials from the contributing watershed. These materials may be clay, silt, mineral particles from soils or organic matter.
- To understand the formation of turbidity, it is important to understand the hydrologic cycle.
- Watershed characteristics (size, slopes, soils, land use and cover, etc.) affect runoff patterns and stream flows which in turn affect the amount of suspended particles in the water which then creates turbidity.
- Precipitation events often provide for increased turbidity levels due to increased runoff and stream flows which can cause surface erosion and channel erosion.
- Turbidity in streams and rivers is a constantly changing phenomenon. During dry periods, when no precipitation occurs, turbidity levels usually drop to a somewhat stable value for the stream. A precipitation event in the watershed can then bring additional suspended material into the stream and greatly increase the turbidity. Generally, the more intense the precipitation event, the higher the turbidity values experienced in the stream.

Water quality measurements that can help in the characterization of turbidity include total suspended solids, volatile suspended solids, total dissolved solids, suspended sediment concentration, chlorophyll a, and particle size analysis. Other factors such as flow, sediment source and composition, algal species and sediment transport characteristics can also provide important information in characterizing the turbidity present in water.

Turbidity is a parameter that has a significant amount of variability associated with its measurement. Unlike most parameters which are a measurement of mass of one or several constituent(s), turbidity measures how light interacts with biological, physical and chemical components of water. Factors contributing to this variability include spatial and temporal changes in the adsorption, reflectance and transmittance of light in a water sample; different sensor technologies; different sampling techniques; and spatial and temporal differences in the water body.

**Turbidity sensor technology and data set variations**

Technological advances in the measurement of turbidity have resulted in the development of several types of instruments to meet various measurement objectives. While these advances have addressed specific needs, the various instrument designs often do not yield equivalent results. This is in part due to the different optical designs, but also occurs due to different responses in the mixing of different source waters and dilutions of environmental samples given the factors affecting turbidity. Therefore, selection of an appropriate instrument requires consideration of project objectives, data requirements and the physical and chemical properties of the water body (Anderson 2005).

The United States Geological Survey (USGS) conducted a national level interagency workshop on turbidity method variability in an effort to adequately deal with the variability issues.
surrounding the measurement of turbidity. As a result, the USGS has implemented a category system for differentiating turbidity technology in its National Water Information System (NWIS) database. The system uses NWIS parameter codes along with reporting unit distinctions for each category (USGS 2004). Table 2 lists the ten reporting categories (method codes) with a brief description of the sensor technology for each category. The MPCA is beginning to use these reporting units in STORET. The instrument make and model should also be included in the metadata for each project.

The USGS also recently revised Chapter 6.7 - Turbidity, of the National Field Manual, to incorporate the results of this work. The chapter provides protocols and guidelines for selecting appropriate field and laboratory instruments and procedures for instrument calibration and maintenance, turbidity measurement, data storage and quality assurance that meet stated objectives for U.S. Geological Survey (USGS) data-collection efforts. The use of consistent procedures and instruments within and among projects or programs for which turbidity data will be compared over space and time is crucial for the success of the data-collection program (Anderson 2005).

Given the variability in measurements, raw data from different instrument types should not be considered directly interchangeable. While there is no documented method for converting data from one category to another, keeping a record of these distinctions allows for better interpretation of the data from various sources as the technology improves. One outcome that has been observed is that turbidity measured using instruments with different optical designs can differ by factors of two or more for the same environmental sample, even with identically calibrated instruments. Thus, raw data from differently designed instruments should not be considered directly interchangeable - the resultant data are inherently incomparable without additional work to establish relations between instruments over the range of the environmental conditions present.
## Table 2. TURBIDITY PARAMETER AND METHOD CODES

<table>
<thead>
<tr>
<th>Instrument Type:</th>
<th>Description:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTU (Nephelometric Turbidity Units)</td>
<td>White or Broadband (400-680 nanometers) Light Source, 90-degree detection angle, one detector.</td>
</tr>
<tr>
<td>NTRU (Nephelometric Turbidity Ratio Units)</td>
<td>White or Broadband (400-680 nanometers) Light Source, 90-degree detection angle, multiple detectors with ratio compensation.</td>
</tr>
<tr>
<td>BU (Backscatter Units)</td>
<td>White or Broadband (400-680 nanometers) Light Source, 30- (plus or minus 15) degree detection angle (backscatter).</td>
</tr>
<tr>
<td>AU (Attenuation Units)</td>
<td>White or Broadband (400-680 nanometers) Light Source, 180-degree detection angle (attenuation).</td>
</tr>
<tr>
<td>NTMU (Nephelometric Turbidity Multibeam Units)</td>
<td>White or Broadband (400-680 nanometers) Light Source, Multiple light sources. Detectors at 90 degrees and possibly other angles to each beam.</td>
</tr>
<tr>
<td>FNU (Formazin Nephelometric Units)</td>
<td>Near Infra-Red (780-900 nanometers) or Monochrome light source. 90-degree detection angle, one detector.</td>
</tr>
<tr>
<td>FNRU (Formazin Nephelometric Ratio Units)</td>
<td>Near Infra-Red (780-900 nanometers) or Monochrome light source. 90-degree detection angle, multiple detectors, ratio compensation.</td>
</tr>
<tr>
<td>FBU (Formazin Backscatter Units)</td>
<td>Near Infra-Red (780-900 nanometers) or Monochrome light source. 30- (plus of minus 15) degree detection angle (backscatter).</td>
</tr>
<tr>
<td>FAU (Formazin Attenuation Units)</td>
<td>Near Infra-Red or monochrome Light Source, 180-degree detection angle (attenuation).</td>
</tr>
<tr>
<td>FNMU (Formazin Nephelometric Multibeam Units)</td>
<td>Near Infra-Red (780-900 nanometers) or Monochrome light source, Multiple light sources. Detectors at 90 degrees and possibly other angles to each beam.</td>
</tr>
</tbody>
</table>
**Turbidity Measurements for TMDLs in Minnesota**

Given the differences in methods, instruments, and resulting data, it is important to clarify the basis upon which measurements of turbidity will be used in completing turbidity TMDLs in Minnesota. The USEPA does not specifically require the use of a specific method for measuring turbidity in regulations associated with the Clean Water Act (USEPA, 2002). Minnesota Rules Chapter 7050 also does not identify a required method for measuring turbidity. However, given the history in the development of the turbidity measure and the history in the development of Minnesota’s water quality standards, it seems that a “standard” method should be used when measuring turbidity for use in assessing the impairment of a water body under Section 303(d) of the CWA. Indeed, the standard laboratory procedures used by the MPCA call for the use of EPA Method 180.1 when measuring turbidity (MPCA, 2006).

A comparison of laboratory turbidity meters commonly used in MPCA-funded watershed and TMDL projects was made to determine what mix of turbidity reporting units the Agency is currently dealing with and to see if there was one preferred reporting unit to use. The most commonly used laboratory meters were the Hach 2100A and Hach 2100AN meters. Using the USGS reporting codes, the Hach 2100A meter provides turbidity measurements in NTUs, while the Hach 2100AN meter can provide turbidity measurements in four of the ten reporting codes. Two of the seven, NTU and NTRU, meet the requirements of the EPA 180.1 method. The difference in the use of the two reporting codes is based on whether the ratio compensation feature of the Hach 2100AN is used or not. Note that the Hach 2100A does not have a ratio compensation feature.

A survey of the four primary laboratories used by watershed projects in the Minnesota River Basin showed that three of the four labs used Hach 2100AN meters set to read turbidity as NTRUs. The fourth lab (MCES) used a Hach 2100A meter providing turbidity measurements as NTUs. A comparison of paired data from these labs indicates a significant difference in the values, primarily between the MCES Hach 2100A and the other meters. MCES turbidity data was generally nearly one-half of the values recorded by labs using Hach 2100AN meters. However, the differences between values are much less when turbidity measurements are less than 25. The MCES is switching from their Hach 2100A meter to a new turbidimeter (Hach 2100N). Attachment 1 lists the turbidity meters used by other laboratories commonly used in Minnesota.

A set of technical memoranda from the USGS National Water Quality Laboratory (NWQL) provides documentation of their change from the Hach 2100A, to the Hach 2100AN turbidimeter in 2000 and a comparison of results from the two meters (USGS 2000). The NWQL noted that the 2100A tended to underreport turbidity compared to the 2100AN and that the 2100AN provided improved turbidity measurements in water containing color. The Hach 2100A is no longer manufactured given the advanced technology of the Hach 2100AN.

The following text identifies the methods and instruments to be used in completing turbidity TMDL studies in Minnesota. A description of the basis for each method is also given. Please note that these may be revised following MPCA and external review and comment on the December 2006 protocol.
1) **EPA Method 180.1** will serve as the selected standard method for use in measuring turbidity as a water quality impairment.

Given the variability present in turbidity measurements due to various factors, it is important to provide guidelines for measuring turbidity to limit the variability in measurements. The MPCA has been working to select an “official” turbidimeter in measuring turbidity for assessment against the water quality criteria for turbidity (turbidity standard) in Minnesota’s water quality standards (MN R. 7050). Standard operating procedures for the MPCA identify that EPA Method 180.1 be used in all sample analyses. Therefore, in “connecting” this documentation to the USGS reporting code methods, **EPA Method 180.1** will serve as the selected standard method for use in measuring turbidity as a water quality impairment.

2) **“Official” Turbidity Reporting Categories and Measurement Instrument**

The selection of the “official” turbidimeter is still complicated by the use of two main laboratory instruments in laboratories providing turbidity analyses for water quality monitoring in Minnesota. As described above, the two meters are the Hach 2100A and Hach 2100AN. The Hach 2100A provides the “most similar” measurement of turbidity as originally developed in the use of nephelometry. While the Hach 2100A provides the “closest” design to the original measurement of turbidity, its production has been discontinued. The Hach 2100AN (and newer 2100N) utilize some of the newer measurement technologies developed for specific industrial processes, but can still be operated in a single beam, 90 degree detector mode without ratio compensation that is the same as the Hach 2100A.

Another factor affecting the use of a particular instrument configuration is that the data for many of the turbidity impaired waters on Minnesota’s 303(d) list were measured using a Hach 2100AN in the ratio compensation “ON” mode and reported as NTUs (Keith Peacock, Minnesota Department of Health, personal communication). With the introduction of the USGS reporting codes, data from these meters is now being reported as NTRUs. In contrast, the MCES has a significant amount of data from 303(d) listed sites that was measured with a Hach 2100A and, using the USGS reporting codes, is reported as NTUs. The discrepancy in the measured values was briefly described above.

Given these issues, the **MPCA recommends the following hierarchy in the use of turbidity reporting categories and/or instrument types** for evaluating turbidity as a water quality impairment:

a) if there is a significant amount of turbidity data using a Hach 2100A meter (with correct USGS reporting units of NTU) present for an impaired stream reach, the NTU (Hach 2100A) data can be used as the authorized data for use in evaluating turbidity as a water quality impairment;

b) if the primary turbidity data present for an impaired reach is from a Hach 2100AN or 2100N in the ratio compensation “ON” mode or equivalent laboratory meter, the NTRU (Hach 2100AN and 2100N) data will be used as the authorized data for use in evaluating turbidity as a water quality impairment; and

c) if the primary data present for an impaired reach is from any other instrument type, a correction factor must be used to evaluate the data against the turbidity standard.
A correction factor can be developed using paired sampling and analysis and correlation of the paired data. Note that the use of the Hach turbidimeters in this discussion does not indicate the endorsement of a single vendor. Rather, it represents the most common make of instrument used by laboratories providing data for turbidity TMDL projects in Minnesota.

The use of field turbidimeters and sensors while common and useful should not be used in evaluating turbidity against the turbidity water quality standard unless an adequate correlation is made with a laboratory turbimeter through paired sampling. Turbidity gathered with this equipment must be properly reported using the USGS reporting codes. For example, YSI 6800 Series multiparameter sondes are used by MPCA staff and projects both as an instantaneous field measurement and an in-situ continuous turbidity recorder. The turbidity sensor in these sondes measures turbidity in USGS reporting category units of FNU. Attachment 1 lists other turbidity sensors currently in use by MPCA staff.

3) **Sampling Method**

Another factor affecting turbidity measurements involves the method in which the water sample is collected. Traditionally, most turbidity data has been obtained from grab samples submitted to a laboratory for measurement with a laboratory turbidimeter. The location of the grab sample in the cross-section of the stream can greatly influence the turbidity measurement. This also complicates the use of turbidity as a surrogate for TSS and SSC given sample location differences for these methods (grab sample versus depth and width integrated composite sample). Given that the most common sampling approach for turbidity and total suspended solids is through the use of grab sampling, the “standard” sampling method for measuring turbidity will be grab sampling in a well-mixed location in the stream. There are many situations where a different sampling method may provide important information regarding sediment source and impairment. When there are specific reasons for other sampling approaches, the reasons should be documented.

To summarize, sampling, measurement, and analysis of turbidity with other methods would need to be correlated and adjusted, if needed, to the defined standard method.

**Correlation of turbidity with other parameters to enable load calculations**

As noted previously, turbidity as a water quality variable is not a quantitative measure of mass, length, or volume. Rather, it is a qualitative measure of the amount of light passing through a sample compared to a standard sample. Physical and chemical properties of the water and particles in the water can greatly affect the movement of light through a sample thus often allowing for a fair amount of variation in turbidity compared to other properties of water. A related issue is that turbidity as a standard analytic method is limited to a measurement range of 0 to 40 NTU. Water samples are to be diluted and reanalyzed if turbidities are greater than 40 in a water sample. With these variations and measurement constraints, various water quality variables should be considered for analysis along with turbidity. The use of variables such as total suspended solids, suspended sediment concentration, volatile suspended solids (VSS), and
chlorophyll a are needed to help in characterizing the materials causing the turbidity as well as to identify a surrogate measure in which to calculate loads for the TMDL. A correlation between turbidity and a surrogate variable is then used in determining the target surrogate concentration that is “equivalent” to the turbidity criteria. Once a surrogate target is established, the TMDL study would focus measurements, analyses, and other work on the surrogate parameter to lessen the variability experienced in turbidity measurements.

Given typical sampling and analysis approaches, the surrogate parameter for turbidity will often be TSS. If a project includes USGS sampling for SSC, SSC may be used as the surrogate variable. Care must be made within and between projects to account for the differences between TSS and SSC when using them as surrogates for turbidity. It is always important to determine a project’s information needs prior to selecting water quality variables to use in a project. If there is any suspicion that organic material may be a significant contributor to turbidity, measurement of the organic component through VSS and/or chlorophyll is recommended. The use of turbidity and related water quality variables in evaluating the aquatic life impairment linked to the turbidity water quality standard (criteria) in MN Rule 7050 is complex. Much additional work is needed to better define the factors causing aquatic life impairment due to turbidity-associated factors. However, the current protocol will not delve into these issues. Rather, its primary purpose is to provide direction in developing a surrogate variable for load calculations for the TMDLs.

Examples of the relationship of turbidity to TSS are shown in Attachment 2. While regional or watershed comparisons of turbidity to TSS may be made, there are typically sufficient differences between monitoring sites, streams, and watersheds to warrant the development of individual correlations for each impaired reach. Given these differences, individual correlations should be made for each monitoring site unless it can be documented that a combined correlation would be equivalent.

Development of the surrogate variable to be used in a turbidity TMDL will, at a minimum, follow these steps:

1. Select one or more variables for consideration as the surrogate variable.
2. Plot the turbidity data against the other variable data and visually evaluate the data and any relationship between each variable.
   a. First, plot all paired data.
   b. Second, plot only the paired data that has a turbidity value less than or equal to 40 NTU.
   c. Third, if enough data pairs are present, plot only the paired data that has a turbidity value less than or equal to 40 NTU and a surrogate variable value greater than 10 mg/l (presuming that TSS or SSC is the surrogate variable being evaluated).
3. Use summary statistics to check the data to see if it is normally distributed. If it is not, evaluate whether a log-transformation of the data will approximate a normal distribution in the data. A decision must be made as to the adequacy of the data in meeting the statistical assumptions needed to use regression in developing the correlation between variables. Note that there are different perspectives on how formally statistical analysis principles need to be followed versus their impact on the pragmatic environmental results needed and achieved. If necessary, log-transform the data.
4. Use regression analyses to evaluate the degree of correlation between the paired data. Depending on the amount of paired data available and the results of the visual analysis of the data plots, the regressions should be done for one or more of the data subsets plotted. The goal of these regression analyses is to “most appropriately” select the data set to use to determine the surrogate value for the turbidity standard.
   a. If there is enough data, the preferred subset of data used is that with turbidities less than 40 NTU and potential surrogate variable concentrations greater than 10 mg/l.
   b. The next preferred subset of data used is that with turbidities less than 40 NTU.
   c. The third preference for data use is the whole data set.

The three options provide a sequence of choices in an attempt to maximize the reliance on turbidity data collected within the original scope of turbidity measurement standard methods, and to minimize the possible influence of heavy sand particles in samples with low TSS or SSC concentrations.

5. Select the target surrogate concentration to be “equivalent” to the numeric turbidity criteria (10 or 25 NTUs) by solving for the regression equation selected in step 4.

When possible, the data used in developing a surrogate value for the turbidity standard should be limited to “standardized” turbidity values less than 40 NTU matched with the corresponding surrogate parameter data.

**Evaluating spatial and temporal differences in turbidity**

As noted above, many factors can affect turbidity in water. The factors can vary within and between projects, rivers, and monitoring sites. Given the variability present in turbidity measurements, direct comparisons of turbidity data between projects, rivers, and monitoring sites can be complicated. Turbidity and other data should be evaluated for patterns in magnitude, duration, and return frequency versus sampling time to aid in making comparisons between sites, projects, and locations. Alternative variables such as a stream bank/bed stability factor or an upland sediment delivery factor based on some set of elements in a watershed should be considered in addition to the “regular” suite of water quality variables.

**3. Turbidity Stressors**

Stressors affecting turbidity are varied and variable. A given stream watershed has multiple sources of the pollutants or physical features that affect the stream loading capacity. These can be subdivided into natural, or background, and human induced (anthropogenic) sources. Further social or political subdivisions exist for human induced categories such as those regulated by the National Pollutant Discharge Elimination System (NPDES) which are issued permits with requirements for pollution control, and those sources with a more diffuse nature like forestry logging or agriculture row cropping which are sometimes supported by programs to assist in funding soil conservation or better site planning.

Turbidity is affected by: rainfall and catchment runoff; catchment soil erosion; bed and bank erosion; bed disturbance, e.g. by introduced fish species such as carp; waste discharge; stormwater; excessive algal growth; riparian vegetation; floodplain and wetland retention and deposition; flow; waterway type; and soil types. Differentiating between sources and stressors is
often difficult and subject to professional judgement combined with scientific monitoring and analyses.

a. Natural Sources

Natural sources of turbidity include “natural” erosion from upland, riparian, stream bank, and stream channel areas. The amount of “natural” erosion is often difficult to quantify given the extensive anthropogenic forces present in Minnesota watersheds and water bodies. Tannic acids often associated with peat and bog areas cause water to be colored, resulting in turbidity. Algae that grow with nourishment entering the stream through leaf decomposition or other naturally occurring decomposition processes can also be a source of turbidity. Channel lateral migration will also entrain channel sediment.

b. Anthropogenic Sources

Figure 2 provides a representation of turbidity sources and stresses by the type of material that may cause turbidity, along with some of the pathways for the material to get from the source to the water. A simplified conceptual model of anthropogenic sources and causes of turbidity is presented in Figure 3.

One of the most thought of sources of turbidity is sediment entering water bodies from soil erosion resulting from runoff from various land uses, including urban, agriculture, and forest. Soil erosion in cropland has been a focus of soil and water conservation programs for many years. Urban stormwater runoff is now also recognized as an important contributor of sediment to water bodies, whether from construction site erosion, runoff from impervious surfaces, or other source. Sediment from any source that enters a water body will affect the turbidity of the water. The effect is varied depending on the composition, size, shape, and chemical properties of the sediment as identified previously. Other sources of sediment include: riparian area erosion from livestock overgrazing or increased rill and gully erosion from inadequate buffer areas; increased streambank erosion due to increased intensity and frequency of stream flows resulting from upstream ditching or climatic changes; wind erosion; and hydrologic modification.

The presence of algae and other forms of organic matter can also cause turbidity in water. As such, phosphorus from various sources can result in increased turbidities as it allows increased algal growth. These sources may include wastewater treatment facilities, nutrient runoff from cropland and other sources, and bottom sediment. Organic matter from sewage discharges, especially during treatment plant bypasses, can contribute to turbidity. Stains or colors in water can also affect turbidity. Stains may be associated with a point source discharge, but most color issues are likely to be a natural source.

Anthropogenic sources of pollution are divided into two categories – point and nonpoint sources.

i. Point Sources

In reference to TMDLs, point sources of pollution are defined as those sources of pollution regulated by the NPDES program. These sources include municipal and industrial wastewater treatment facilities, and construction areas, industrial facilities, and municipalities required to have stormwater NPDES permits. Turbidity from wastewater treatment plants is typically controlled by TSS limits in their permits. They may discharge organic solids during sewage by-
pass periods that contribute to turbidity. Dissolved nutrients released in treated wastewater may contribute to phytoplankton production which can affect turbidity.

ii. Nonpoint Sources

Nonpoint sources of pollution are those sources of pollution not regulated by NPDES permits. The sources include soil erosion from various land uses including agriculture, forestry and urban areas not subject to NPDES permits. Soil erosion can occur directly in the land use (sheet, rill and gully erosion) or downstream (gully, bluff, stream bank and channel erosion).
Figure 2. Turbidity Sources and Stresses by Type of Material in Water
* Phosphorus (P) contributes to turbidity through production of algal blooms during low flows or in low-gradient/low-velocity portions of stream.

** Ditches / channelization also can cause sediment delivery via:
- channel eroding banks by attempting to restore its original meander
- steeper gradient can cause headward erosion and downcutting (knickpoints may form; channel erodes knickpoint resulting in upstream scour)
- ditch cleaning / dredging
4. TMDL Goal Setting

Given the strong link between turbidity and flow typically present in Minnesota streams, and often elevated turbidity levels at the higher flows, it is likely that individual turbidity measurements will often be greater than the water quality standard. Setting a goal of attaining the standard instantaneously at all times may be very difficult given the linkage between flow and turbidity. With this in mind, it may be necessary to evaluate the adequacy and/or appropriateness of a range of goals. A range of possible goals is listed below:

1. The simplest goal would be to apply the standard to individual turbidity measurements, such that any individual exceedance of the standard would indicate an impaired water.
2. Given known variability and uncertainties in the data available for assessing impairments for the 303(d) list, the MPCA developed listing assessment guidance that accounts for some of this variability by setting a ten percent exceedance criterion for listing a reach as impaired for turbidity (MPCA, 2005). Some discussion have been held regarding using this guidance as the measure for determining the goal.
3. However, the general technical preference for goal setting is to include some sort of magnitude and duration component to the turbidity standard exceedances. While Minnesota’s water quality standards (Minn R. 7050) do not explicitly describe how the standard is to be applied, they do, through the location of the turbidity criteria in the rules, infer that a chronic persistence evaluation is appropriate.

It is likely that individual projects will choose different goal setting approaches given the wide range of and variability in factors affecting turbidity. The approach selected for any given project must parallel and be consistent with the approaches outlined in this protocol. However, it should also encompass the expected range of conditions and responses specific to the stream, watershed and aquatic life presence. Documentation of how the approach adequately will provide for the support of aquatic life in the impaired reach must be present in the TMDL that is developed.

Determining Rigor: Key Concepts to Consider when Preparing TMDL Work Plans

“Rigor”, as used in the TMDL assessment process, means the strictness or rigidity of the science and professional judgment being applied. The use of extreme rigor comes with a high time, staff and financial resource cost, while lax rigor may not be sufficient to develop an adequate plan or allow successful defense of the TMDL when challenged. To prepare an adequate TMDL work plan, project managers need to carefully consider the degree of rigor needed in order to better anticipate resource needs. This is often best done as an iterative process as the project development and scoping work is begun.

All watersheds are unique regarding scale, hydrology, types of land use, number and sources of pollutants and their political culture. The TMDL study for your specific watershed must balance the complexity of the watershed, the potential for controversy, and a limited staff and financial resource pool in the decisions to achieve the appropriate level of rigor to be useful, for ultimately returning the water quality back to attainment conditions.

There is not a test or quantified metric to use for setting rigor. Instead, after the team has completed pulling together the initial available information for land use and water quality data, they should discuss the following open ended questions to guide the project towards an appropriate level of resources needed for developing and implementing a monitoring plan and watershed land use assessment. The process is then extended again when consideration of the
data is used in selection of the analysis tool(s) required for a balance of complexity, controversy and cost:

**Water Quality Monitoring**

- How robust is the data set?
  - What is the watershed scale?
  - Do the data sets adequately define the extent of the impairment for the study?
  - Are the sample sets adequate for concentration determinations?
  - Are the flow stations adequate for determining loading?
  - Are the data sets available for the critical conditions for the impairment? (Considering seasons, changes in flow, temporal factors and source(s) prominence?)
  - Are there critical breaks in information? (either spatially or temporally)

**Land Use Information**

- What is the watershed scale?
- What are the suspected pollutant sources in the watershed?
  - Is there information on what pollutant sources potentially discharge?
  - Are the sources easily related to the water chemistry quality findings?
  - Are the pathways of the pollutant sources known?
  - Are their obvious significant loaders or is it a cumulative issue?
  - What are the NPDES DMR monitoring results for the parameters of concern?
  - How specific should the Load Allocation source partitioning be? Would finer resolution improve negotiations significantly?
  - Are the water quality monitoring stations located adequately to help define the sources?

How many potential pollution parameters contribute to the impairment?

- Can any of the potential pollutant parameters possibly be eliminated based on monitoring?
  - Do some parameters warrant further investigation?
  - Are some pollutant parameters more significant than others?

What are the probable outcomes of the study?

- Will meeting the water quality standard be difficult?
  - Are there NPDES implications?
  - Is there a commonly held or developing majority consensus on fairness?

These questions, and others you may think of, help a project consider if the data sets currently are adequate for the negotiations ahead. Also, the rigor of the assessment process can be selected appropriately when the problem and complexities are better understood. This list is used to find out the current perceptions and explore a process to manage the project, with expectations being appropriate as early as possible.

**Examples of Different Levels of Rigor in TMDLs**

A simple approach to setting the turbidity goal may work when the level of impairment is not that great, sources are clear, and/or restoration activities can be expected to result in significant reductions in the materials causing turbidity. This could entail a relatively simple spreadsheet or duration curve approach. A key to developing the TMDL in such an approach is to adequately document the assumption that the TMDL will be met, and that if it is not met following restoration work, that the TMDL will be revisited. This encompasses the use of adaptive management as defined by EPA. The draft Lower Otter Tail River Turbidity TMDL and Lower
Cannon River Turbidity TMDL are examples of the use of duration curves in setting the turbidity goal and completing the TMDLs.

A more complex approach may be needed when the level of impairment is great, there are several possible sources with an uncertainty as to which ones are significant, and adequate restoration activities will be difficult to complete. A higher level of rigor in such an approach is especially important in situations where the defensibility of the TMDL must be strong. The Minnesota River Basin Turbidity TMDL Project is an example of a project requiring a more complex approach to adequately complete the TMDL. Use of the HSPF model for turbidity requires the development of a correlation of turbidity to each of the model outputs – chlorophyll-a, clays, silts, and sands – that are suspended in the water column. To do this, additional monitoring and analyses are required to evaluate the effects of algal species, chlorophyll-a concentrations and sediment particle size and fraction to turbidity. Completion of this work and the modeling will provide a more specific prediction of turbidity reduction needs and the capabilities of restoration activities in achieving the reductions. The model can then better define the expected outcome and should set the target goal at a more accurate level than a spreadsheet approach would be able to do.

The use of the increased rigor in the Minnesota River Basin Turbidity TMDL: will provide better information to stakeholders on the level of effort required for land use controls to achieve the goal; will be more defensible if point source stakeholders are faced with nutrient effluents due to significant turbidity levels related to elevated nutrient and chlorophyll-a levels; and will quantitatively integrate the whole basin into a single mainstem result, including basin hydrology, algal growth and decay cycles, temporal changes in weather, watershed characteristics, growing season and groundwater interactions. Some or all of these may be critical in providing a reasonable assurance that beneficial uses will be protected and the turbidity standard will be achieved.

The goal being developed for turbidity in the Lake Pepin TMDL is being linked to water clarity conditions needed to provide for the growth of submergent aquatic vegetation (SAV) in the backwaters and shallow pool areas of the Mississippi River. An abundance of submersed aquatic vegetation is critical for various species of fish and waterfowl. In this case, the approach for setting the goal involved the link of the turbidity standard to research identifying the seasonal water clarity needed for rooted SAV to grow in the Mississippi River. Thus, this TMDL will link the turbidity criteria to the designated use of supporting aquatic life via the presence of adequate SAV in the water body. The Upper Mississippi River (reach from Minnesota River confluence to Iowa Border) is a unique riverine system. The application of the turbidity standard for this TMDL is not expected to be applicable throughout the state.

Additional examples will be added to this section over time as they are developed.

The turbidity protocol, at this time, will not specify a single application of the turbidity standard in TMDLs. In addition to the examples provided above, other possible applications may be made based on select time intervals or flow regimes. The use of time intervals must be based on professionally accepted assumptions and/or documentation of duration intervals of the turbidity standard being met to provide the support of aquatic life. Examples of time intervals that may be considered include a daily average, a four-day average, a monthly geometric mean, or a percent exceedance threshold for a selected time interval such as a month, season, or year. Application of the standard based on a flow regime might take the form of different “standards” being applied...
for different flow levels. A hypothetical example would be to set a goal for achieving the standard for flow duration curve categories (Cleland, 2003) of low flows, dry conditions, mid-range conditions with an allowance for higher turbidities in the moist conditions and high flow categories. Note that any application of the standard must be consistent with the need for TMDLs to be presented as “daily” values.

The USEPA Protocol for Developing Sediment TMDLs (USEPA, 1999) describes the general goal of sediment-related TMDL analyses as “to protect designated uses by characterizing existing and desired watershed condition, evaluating the degree of impairment to the existing (and future) conditions, and identifying land management and restoration actions needed to attain desired conditions.”

B. Beginning the Project – Problem Definition

Section II.B. of the turbidity protocol is written to parallel the steps contained in Session 5 of the MPCA TMDL Training Program. The training program provides a complete start to finish description of the steps to be used in completing TMDLs; whereas, this section is intended to provide the more technical and/or specific information and questions pertaining to turbidity impairments. Projects should use the protocol to add to and complete the Training Program process and worksheets. Training Program sections that correspond to the headings below are shown in parentheses.
1. Advisory Committees

Prior to, or as a TMDL study is begun, it is important to develop the stakeholder advisory committee and technical advisory team. The committee and team are needed to help shape the scope of the project and to provide some level of consensus on what the project will entail. These can be developed as described below:

Stakeholders Advisory Committee – Identify and initiate contact with individuals and groups in the governmental and private sectors that should be advised of the TMDL development schedule and plan. Potential stakeholders may include representatives of federal, tribal, state, and local (county and municipal) governments; NPDES permitted dischargers; watershed organizations; landowners; agricultural producers; industry trade organizations; and environmental advocacy groups. Consider the potential role each stakeholder could play in the TMDL development and implementation.

Technical Advisory Team – A technical advisory team of representative stakeholders with technical knowledge of turbidity and related issues should be (will be) developed to provide a forum of interdisciplinary expertise to discuss project needs and direction. The technical advice solicited during development of a TMDL will include both water quality management issues land use specific issues. The presence of a diverse group of local representatives, who work with the different land uses and in different areas of expertise on critical aspects of change potential in resource management, assists in the task of identifying the potential local sources of parameters affecting turbidity in water. The team will provide continued assistance and direction, especially in the process of defining reasonable levels of expected change from technical as well as economic and social points of view. The individual members also can be sources of communication to others in their sphere of influence.

2. Applicable Water Quality Rules

As introduced in Section II.A.1, Minnesota’s water quality standards include a numeric criterion for turbidity as a measure of whether a water body meets its designated uses. Specifically, MN Rules Chapter 7050.0220, Specific Standards of Quality... by Associated Use Classes, states:

... “The numerical and narrative water quality standards in parts 7050.0221 to 7050.0227 prescribe the qualities or properties of the waters of the state that are necessary for the designated public uses and benefits. If the standards in this part are exceeded, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, or injurious with respect to designated uses or established classes of the waters of the state.” The numeric criteria for turbidity by use class are shown below.

<table>
<thead>
<tr>
<th>Classes (and descriptions) related to 303(d) list use support:</th>
<th>Turbidity (NTUs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B (drinking water)</td>
<td>10</td>
</tr>
<tr>
<td>2A (cold water fishery, all recreation)</td>
<td>10</td>
</tr>
<tr>
<td>2B (cool &amp; warm water fishery, all recreation)</td>
<td>25</td>
</tr>
<tr>
<td>2C (indigenous fish, most recreation)</td>
<td>25</td>
</tr>
</tbody>
</table>
3. Initial Problem Assessment

(TMDL Training Session #5 – ‘Understand the “Big Picture” First’ and ‘Describe What is Already Known About the Water and the Watershed’)

Stream reaches included on the 303(d) list as impaired for turbidity were identified using available data and data analyses described in the MPCA Impaired Waters assessment guidance. For additional information on the assessment process, see: Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment, 305(b) Report and 303(d) List, MPCA, October 2005 (http://www.pca.state.mn.us/publications/wq-iwl-06.pdf) or most current available version after this date.

Initial project assessment work should include a review of the 303(d) listing data and documentation materials for each reach. The data used in assessing each reach for impairment is contained in a database maintained by the MPCA Environmental Analysis and Outcomes Division. Much, if not all of the data, can be accessed from the MPCA Environmental Data Access (EDA) website; however, the EDA will provide all data for a given reach by individual monitoring site. The actual impairment assessment may include multiple sites in a reach and is limited to a ten-year assessment period. The assessment period is the ten years prior to the second year before the 303(d) list is published (i.e., 1994 – 2004 for the 2006 303(d) list). MPCA staff can access the Lookup Assessment Database, an internal agency database, at x:\Databases\Water_Quality\Assessment Data Lookup to more easily export data to spreadsheet files for the project. This database contains 303(d) list transparency information from professional judgment group (PJG) assessments, meetings, and data summaries for AUIDs listed between 1992 and 1998, and direct access to assessment data for AUIDs listed starting in 2002 and thereafter.

Once the listing data and documentation materials are reviewed, the following preliminary problem assessment activities should be undertaken:

1) Summarize the Findings of the Review of the 303(d) Listing Data and Documentation Materials for each Reach.

   Documentation of the listing decisions is provided on the MPCA TMDL website at http://www.pca.state.mn.us/water/tmdl/index.html#support. This documentation is typically quite brief in describing the number of standard exceedances. Additional information can be looked at by plotting the data against time and/or flow in comparison to the standard.

2) Prepare a Preliminary Delineation of the Study Area.

   Create project maps of the stream reaches of concern, their contributing watersheds, current land use, and permitted discharger locations. Use appropriate paper maps and MPCA GIS software (ArcGIS) with readily available data layers.

   Ensure that all newly constructed or imported data layers are fully compatible with MPCA spatial data storage standards:

<table>
<thead>
<tr>
<th>Coordinate system:</th>
<th>UTM zone 15 (extended)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datum:</td>
<td>North American Datum of 1983 (NAD83)</td>
</tr>
<tr>
<td>Spheroid:</td>
<td>GRS1980</td>
</tr>
</tbody>
</table>
In addition to full GIS maps, simple stick diagrams are often useful to illustrate the connectivity of the river system and the relative locations of tributary inputs, permitted dischargers, and nonpoint source regions.

3) Define the Spatial and Temporal Scale of the Impairment.

Determine if the following questions can be answered with the data used for listing the reach impairment(s):

- Does the data fully document and explain the impairments for turbidity?
- Is the impairment problem localized and distinct or is it more extensive?
- Does the monitoring data indicate any seasonal pattern in the impairment?
- Does the monitoring data provide any insight into the duration (days, weeks, months) of turbidity excess?
- What is the frequency of high turbidity occurrences? Are the occurrences predictable or do they occur randomly?

In most cases, the assessment data will be insufficient to answer these questions well. The questions and answers and/or inability to answer the questions should be documented in an information protocol. More information on using the information protocol process in developing projects can be found in MPCA TMDL project training materials currently being developed.

4) Investigate Flow Dependency of the Impairment

Using available stream flow information in the project area, determine the flow conditions at the time of water quality sampling. Determine if the following questions can be answered with the data used for listing the reach impairment(s):

- Are there any apparent relationships between flow conditions and the instances of elevated turbidities? For example, are turbidity problems most prevalent during periods of high stream flow?
- Is there a seasonal influence (spring runoff, storm flow events) on turbidity values associated with flow?
- Also, identify any reservoirs, dams, or hydropower facilities that may regulate flows in the project area.

Answers to these questions can only be given if it is determined that there is adequate flow information for the project area.

5) Compile a List of Permitted NPDES Dischargers in the Study Area

Using MPCA discharger inventory databases (WQ DELTA), generate a list of all permitted dischargers, including major animal feedlots in the study area. Describe each facility including its design flow, facility and receiving waters location, permitted load limits, discharge frequency, and general compliance status.
6) Document the results of each task above in writing

Documentation is a key in the development of a good project. It assists in organizing the project and presenting the preliminary findings for all to see. The project manager should compile the answers to the questions above along with the other information asked for to aid in the next steps of the protocol, especially the more comprehensive task of gathering and compiling existing data from various sources that will be used later in the problem analysis tasks.

The project manager should develop a summary statement to the extent possible that describes the impairment problem, its spatial and temporal boundaries, and which identifies known factors potentially impacting the turbidity of the impaired stream. This summary will provide a focus for the more comprehensive follow-on task of gathering and compiling existing data from various sources that will be used later in the problem analysis tasks.

4. Comprehensive Data Compilation from Existing Sources
(TMDL Training Session 5 – ‘Plan and Conduct a Data Inventory’ and ‘Where to Find Data for Your TMDL’)

A next step in the TMDL project activities is to compile all available water quality and other environmental data and/or information that may be pertinent to the turbidity impairment(s) being studied. The initial review described above is intended to be an initial compilation and review of the water quality data used in assessing the reach(es) for impairment, and the identification of watershed boundaries and available flow data. A more comprehensive effort is needed to begin determining the degree of complexity present in the identified impairment. Turbidity can be affected by many factors, such that site-specific information is almost always needed in order to define the important cause-effect relationships present in different projects. A comprehensive inventory of data/information will help reveal areas of data or information deficiencies in content, quality, and spatial and temporal coverage. The types, quantity and quality of the data available will in large part set the scope of the project.

Types of environmental data and information to look for in this step include:

- Ambient Water Chemistry

A number of federal, tribal, state, and local government entities, watershed districts, and local water management organizations collect water quality data. Much or all of this data may have been compiled in the Initial Problem Assessment step of the project, but there will be many cases where additional data is available.

Any data that is stored in STORET can be accessed from the EDA website http://www.pca.state.mn.us/data/eda/index.cfm. However, data can only be downloaded one site at a time. If data from several monitoring sites is needed, it may be easier to request a data query from MPCA Environmental Data Management Unit staff. The staff can also assist in other data searches and retrievals using STORET.

Receiving water quality data from NPDES permitted facilities may be available from the MPCA WQ Delta permitting database, if an NPDES permittee is required by permit to sample the
receiving water upstream and/or downstream of the discharge. Standard reports are available in the database that includes all individual sample results. This data has not gone through the QA/QC process that applies to data in STORET, so should be used with some caution. Various MPCA staff can assist in data searches via WQ Delta.

Although the MPCA encourages the submission of water quality data for inclusion in STORET, not all data is in STORET. It is important to check with other units of government and organizations for data that is not in STORET.

Water chemistry parameters that may be of use in identifying the type of turbidity present includes:
- TSS
- Turbidity
- Suspended Sediment Concentration
- Chlorophyll-a
- Total Organic Carbon
- Total Volatile Suspended Solids
- Total Phosphorus
- Total Nitrogen
- Others (acute and chronic toxics…)

In addition to the parameters, it is important to evaluate the frequency and type of sampling completed.
- Frequency – monthly, weekly, storm events and/or base flow, etc.
- Type – grab samples, automatic sampler, depth and width integrated, etc.
- Period of record – few years to many years

- Biological Data

The MPCA conducts biological monitoring to assess the health of riverine and wetland environments utilizing fish, macroinvertebrate, or plant communities. Biological communities are subjected to the cumulative effects of all activities within a watershed and are continually integrating environmental conditions over time. They represent the condition of their aquatic environment. Biological monitoring is often able to detect water quality impairments that other methods may miss or underestimate. It provides an effective tool for assessing water resource quality regardless of whether the impact is chemical, physical, or biological in nature. Information and data from biological monitoring sites are available online at the MPCA EDA site: [http://www.pca.state.mn.us/data/eda/index.cfm](http://www.pca.state.mn.us/data/eda/index.cfm) or from the MPCA Biological Monitoring Unit staff.

The DNR also conducts biological monitoring as part of their fisheries and ecological services programs. The DNR Area Fisheries staff is probably a good first point of contact regarding data they may have for a stream. Biological monitoring data may also be available from some citizen monitoring programs and university research projects.

- Stream Flow

Stream flow data is essential for the analysis of most water quality impairments. The U.S. Geological Survey (USGS) is the principal source of stream flow data in Minnesota. Current
and historical mean daily flow data and other statistics (i.e., frequency and duration) are available via the USGS on-line database, NWIS Web, located at: http://waterdata.usgs.gov/mn/nwis/nwis The USGS Minnesota District homepage (http://mn.water.usgs.gov/) provides links to other sources of water resource and stream flow data, such as the Minnesota DNR and the U.S. Army Corps of Engineers.

Flow data may also be available from various watershed project monitoring efforts. MPCA-funded flow monitoring will eventually be available through the joint MPCA-DNR database called Hydstra. Protocols for the Hydstra database are currently being developed and tested, so that not all sites with data have been added to the database. Hydstra will also be used to store and manage other continuous data. Flow data from other projects may be available directly from the organization.

• Meteorological Data

Weather conditions play an important role affecting turbidity in streams. Historical meteorological data for Minnesota is available online from the Climatology Working Group at http://climate.umn.edu/ and National Climatic Data Center at http://lwf.ncdc.noaa.gov/oa/ncdc.html.

• NPDES Point Sources

The MPCA maintains a computerized database of permitted NPDES dischargers in its WQ Delta system. Monthly summary reports (Discharge Monitoring Reports or DMRs) of effluent quantity and quality monitoring submitted by each permittee are available electronically from the database. Web-based access to data from the same reports is available at the MPCA EDA site: http://www.pca.state.mn.us/data/eda/index.cfm.

The MPCA also has OnBase Web Client software that provides access to more detailed supplemental reports that are submitted along with the DMRs. Staff in the Regulatory Data Management and Analysis Unit in the Land and Water Quality Permits Section of the Industrial Division can provide assistance in data search and retrieval.

• Soils and Land Use Data

GIS-based information on land use, soils, and other mapping layers are available at the Minnesota Land Management Information Center (http://www.lmic.state.mn.us/). More detailed and/or recent information may be available from other sources, especially if a local resource agency has developed GIS-based inventories and analyses. Various universities in Minnesota may also be a source of geographic information. An example is the Minnesota River Basin Data Center (http://mrbdc.mnsu.edu/) located at the Minnesota State University, Mankato.

MPCA GIS staff can provide assistance through the MPCA GIS system.

• Historical Water Quality and Hydrological Studies

Federal, state and local entities may have conducted special stream studies in your project area that can have valuable historical information applicable to current impairments. Check with the
regional USGS office and the MDNR area hydrologist for information on past studies. The MPCA Environmental Analysis and Outcomes Division maintains paper files of historical stream and water quality surveys. Typically these are intensive synoptic surveys conducted over 1 to 3 days duration to collect physical and chemical stream data to be used for waste load allocation purposes.

- Local Watershed Studies

Local watershed and lake management organizations may have completed watershed studies on their own or with grant assistance from one or more agencies. These studies can provide a range of information from valuable historical information on the resource to current day studies delineating the water quality problems present in the project.

The following list is a compilation of information to look for in the data and studies described above:

- Size of watershed
- River Miles (total river, stream, ditch)
- GIS layers
  - Land use
  - Soils maps
- Drainage information
  - Tile intake density
  - Open ditch
  - Subsurface tile density
  - Buffers
- Point Source Inventories
  - Feedlots
  - Industries
  - Municipal WWTPs
- Channel Classifications
  - Rosgen's – Level 1, Level 2
  - Channel Evolution Models
  - Check with USGS and MnDOT (for channel information at road crossings)
- Channel Stability/Habitat
  - Pfankuch Rating
  - Rosgen Troendle technique
  - MADRAS
  - QHEI
- Previous upland modeling projects and assessments
  - PCA
    - AGNPS, AnnAGNPS
    - HSPF
    - Others
  - NRCS
    - GLEAMS
    - TR-20
    - Others
  - University
Development of an efficient and reliable data management system is important for each TMDL project to provide for the proper documentation of subsequent analysis and implementation planning. Decisions on how paper files and electronic data are to be inventoried and stored should be made early in the TMDL planning phase. The data management system should be designed so that project staff and cooperators have efficient access to the data and files. The data management system must be consistent with all MPCA policies and procedures (ref: Policy and Procedures Manual for Management of Public Access to Government Data, MPCA, March 2003). Consideration should be given to developing an on-line web presence for the TMDL project that will allow public access to project information.

Continued documentation of this information is important in the development of a good project. The results of the more extensive compilation of existing data should be documented in a report that builds on the initial summary of the problem in Section II.B.3.

5. Data Review and Evaluation
(TMDL Training Session #5 – ‘Evaluate the Data Collected in the Data Inventory)
Once existing data have been collected and compiled, the TMDL team needs to provide a critical evaluation and interpretation of the data with a goal of addressing the key questions:

(1) What are the prominent data gaps?
(2) Can the key stressors affecting turbidity be identified?
(3) Are there critical conditions for the impairment analysis? If so, what are they?

The questions listed below are intended to stimulate and continue the question and answer process of the information protocol for your project. Some of the questions will apply to every turbidity project, while others may or may not apply. The information protocol should be referenced for additional questions regarding the adequacy of the existing data. Completing this step of the protocol entails the continued iteration and expansion of the information protocol for the project.

**Water Data**

Given that turbidity is not a unit of mass, the turbidity data needs to be related to a variable that can be expressed in some unit of concentration and load. As noted above, TSS or SSC are the most likely variables in which data will be present as well most likely having the strongest correlation to turbidity. Other variables may have significant relationships to turbidity at times. Comparisons made between variables should look for the effects of season, flow, location, and other variables on turbidity. Questions that should be addressed include:

- Are there lab and field results for the water quality variables of interest? Are the results paired – i.e., turbidity and TSS data for the same sample or date and time?
- How many data points are available?
- Are the data points distributed throughout the flow range and throughout the monitoring season at the site?
- Are data present for both base flow and event flow conditions?
- Are event-based data present for rising limb, peak, and falling limb portions of the hydrograph?
- What type of turbidity are we dealing with?
- Is the “content” of the turbidity known? Is it sediment, algae, organic matter, and/or color?

Note that a “no” answer to any of the questions above begins to indicate that water quality data may be lacking for the completion of a TMDL and that additional data may need to be collected.

One of the first tools to use in evaluating the water data is duration curves. Duration curves provide a good visual comparison of flow, turbidity, TSS and/or SSC, and other water quality variables. MPCA staff has spreadsheet templates that can be used to develop duration curves. However, the directions for using the templates are not complete at this time and require staff assistance to figure them out.
Biological Data

If biological data is available, is there any apparent relationship to the biological quality of the stream with the water chemical data? Can the data be used to describe the quality of the aquatic life in the impaired reach and/or entire stream?

Watershed Data

A similar process should be used in reviewing and evaluating the other types of data in the project. Watershed data often is given less attention than water quality data in the early stages of a project; however, its adequacy is a key to delineating and defining the potential sources and stressors of pollutants affecting turbidity.

Ideally, up-to-date GIS data layers of a watershed’s geology, topography, soils, hydrography, land cover, and land use will already be available for use in the project. If up-to-date data is not available, the compiled data should be reviewed for its use in the project. Questions to ask in this review include:

- Is a GIS system needed and/or available for the project?
- Is the data available in a compatible format to the GIS system to be used in the project?
- Are the data layers available in a scale appropriate for the project?
- Any watershed study present for the study area should be reviewed for its findings in relation to issues that affect turbidity.
- Do the study results provide a qualitative and/or quantitative assessment of pollutant sources or other factors that may affect turbidity?
- Are there any suspected changes in the watershed system that may affect the resource?
- Has the physical condition of the stream been assessed (stability, channel characteristics, etc.)?
- Is there a sediment and nutrient budget for the watershed?
- Are there any land uses that have the potential of contributing significant amounts of pollutant loads affecting turbidity in the stream?
- Are there areas where significant implementation of pollution control measures has occurred to reduce the likely contribution of pollutants causing turbidity?

Additional questions to contemplate and eventually answer as the project moves through its development and completion include:

- What is/are the source(s) of the turbidity?
  - Are the sources considered to be pollutants or pollution?
  - How much of the turbidity is from natural sources? “Natural” is defined as a source or a portion of a source that has no anthropogenic influences either currently or historically.
  - USEPA considers some processes to be pollutants (i.e., point sources, feedlots, storm runoff…) and others to be pollution (i.e., habitat loss, altered hydrology, channel destabilization…). EPA requires that TMDLs are written for pollutant loaders and effects of pollution do not have to be addressed. However, TMDL projects in Minnesota will use science-derived approaches to quantify, describe and classify pollution.
  - Is the light being deflected or absorbed by suspended sediment, eutrophication related plant life, or stains from natural sources or point sources?
• Are there obvious significant sources? Do they include:
  o Urban stormwater
  o Construction erosion
  o Industrial stormwater
  o Roads and highways
  o Agricultural land – crop land, pasture
  o Bluffs, gullies and other upland sensitive areas
  o Channel bank – channel bank is defined as the stream bank below the two-year flow return interval
  o Forests and forest management activities
  o Eutrophication
  o Stains/color in water
  o Wetlands
  o Point Sources

• What level of assessment and management is present for the sources that contribute to the turbidity impairment? Does it include:
  • Urban Stormwater
    o MS4
    o Modeling
    o Existing BMPs
  • Road and Highways
    o Is runoff management present?
    o Grassed ditches and swales versus buried tile
    o Width of right of ways
  • Agricultural Land
    o Crop rotations
    o BMP adoption rates
  • Bluff and other upland sensitive areas
    o Geologic material
    o Vegetative cover
    o Is altered hydrology going through these sites?
    o Is there groundwater seepage present?
    o Are BMPs present (armored channels, terracing, drop structures…)?
  • Channel Bank
    o Are channels stable (neither degrading or aggrading)?
    o Is altered hydrology dominant?
    o Is there evidence of mobile channel sediment?
  • Forest Silviculture
    o Percent of watershed
    o BMP adoption rate
    o Landscape considerations practiced
  • Eutrophication
    o Does total organic carbon, total volatile suspended solids, total phosphorus, and chlorophyll-a indicate significant contribution to turbidity?
    o Are there hydraulic residence times, lakes, and wetlands available to produce algae?
  • Stains
    o Wetlands
To begin to answer the question of what type of turbidity your project is faced with, an evaluation of monitoring gaps/needs and assessment tool selection needs to be done. It is strongly recommended that you consult with technical staff about the upland and channel assessment tool to be selected early in the process, as each tool may have monitoring needs that must be met by your monitoring plan.

**a. Prominent Data Gaps**

If the data review identifies large and obvious data gaps that are critical to the preliminary identification of stressors on turbidity, the TMDL team needs to consider the need for additional data collection. This can be done within the information protocol or as a separate scoping document to identify the information needs and develop a monitoring plan to meet these needs through additional monitoring. The plan should be designed with flexibility to screen out less likely sources in order to focus efforts on the more likely stressors.

Turbidity impairments are often based on data collected from a single monitoring site, or at best, from a very few monitoring sites. The amount of data present for any given site is often quite small. Often, the coarse spatial and temporal resolution of the existing monitoring data does not provide an adequate definition of the turbidity impairment. For these cases, additional monitoring sites need to be identified and data collected. The same issues pertain to the temporal resolution of existing data. If the existing data was only collected under similar seasonal or flow conditions, the potential for impairment at other times is unknown. Additional monitoring is warranted for screening purposes to identify other possible periods of impairment.

It is just as important to identify gaps in watershed information. Water quality projects have often focused attention on water monitoring to the detriment of source delineation via watershed evaluations and assessments. To identify these data gaps, it is important to have a good idea of what analytical tool and/or model is to be used in the project and what each requires for proper use. Section II.C and II.E provide more details on the selection and use of watershed analysis tools.

**b. Stressor Identification**

The data review can also be used to begin the stressor identification process. As noted previously, there are several potential sources (or stressors) of elevated turbidity levels in streams. A stressor identification process developed for biological integrity assessments (EPA 2000) can also be applied to other impairments, including turbidity.

The stressor identification process entails evaluating the existing data to identify the pollutants of concern by looking for evidence of strong linkages between stressor sources and the turbidity impairment via one or more source generation and transport processes. If a strong linkage to a single source can be made with the existing information, the project may be able to proceed to the next step in the TMDL development process. A project may also be able to move to the next...
step if all but one or a few sources can be eliminated from consideration as a potential contributing source. This is usually not the case, though.

When the data does not offer cause and effect relationships or adequate information to eliminate a potential source from further consideration, then the EPA stressor identification guidance recommends using a weight of evidence approach. Weight of evidence (sometimes called “strength of evidence”) is best explained as sufficient circumstantial evidence to convince the reasonable decision maker that the source is or is not a primary candidate in the stress. Similar to how a doctor diagnoses a patient or a detective investigates a crime, certain key requirements must be met before a source can be considered for further evaluation. These include:

- Does the source contain or emit the critical parameters?
- Is there a causal pathway to the reach in question?
- Is the key parameter(s) persistent enough to impact the reach in question?
- Does the source discharge the key parameters in the same time period that the impairment occurs over?

Only when the answers to these questions are positive should further investigation be done to quantify or estimate the relative potential and actual loadings that do occur.

In many cases, cause-effect linkages will be obscured by a combination of stressor sources impacting turbidity through multiple processes. The stressor identification process should then be used in conjunction with the data gaps evaluation to lay out a monitoring plan (water and watershed) that will provide the additional data and information needed to either eliminate or select the sources causing the turbidity problems in the stream.

If the stressor identification process indicates that turbidity is solely a natural phenomenon (and not from a direct result of human influence within a watershed), the reach may be able to be reassessed for possible impairment de-listing, and not need to have a TMDL developed for it.

If data evaluation suggests that the turbidity impairment is caused by an obvious and dominating stressor and that it can be readily mitigated through voluntary actions or the use of existing regulatory authorities (e.g., a NPDES discharge permit), there may be reason to consider implementing the mitigation directly and monitoring for improvements in water quality before making a decision to continue through the TMDL development process. If the mitigation corrects the turbidity impairment, this situation would also become a candidate for delisting.

c. Critical Conditions

TMDLs must take into account critical conditions for stream flow, and water quality parameter concentrations and loading, as part of the analysis of loading capacity (40 C.F.R. §130.7(c)(1) ). Factors, such as leaf canopy protection or the rate of human soil disturbance activities, affecting the critical conditions and the resulting TMDL often vary seasonally. Likewise, different sources may dominate the stressor parameter loading under different flow regimes. Dominance of nonpoint runoff related sources may significantly drop off during dry weather periods when point sources become a more significant portion of the loading. TMDLs should define applicable critical conditions that consider these source and delivery factors and the timing of when the beneficial use is impaired. A lake eutrophication or late summer low flow DO impairment can be impacted by loadings delivered earlier in the year and by loads occurring during the observed impairment, depending on watershed dynamics. TMDLs should describe their approach to
estimating both point and nonpoint source loadings under such critical conditions. In particular, the TMDL should discuss the approach used to compute and allocate nonpoint source loadings, e.g., meteorological conditions and land use distribution.

The data review can also be used to evaluate when, how long, how much, and where turbidity exceeds the water quality standard. A thorough evaluation of existing data should characterize the turbidity impairment problem by identifying the conditions under which the turbidity standard is most often exceeded in the stream. This characterization will provide the framework for establishing the conditions to be used in designing the impairment analysis. Critical conditions to consider include:

- Flow regime – Are turbidity exceedances present at various flow levels (i.e., low, moderate, high)?
- Discharge events – Are elevated turbidity levels associated with any type of point source discharge event?
- Storm/runoff events – Are elevated turbidity levels associated with storm and/or snowmelt runoff events?
- Seasonality – Do turbidity levels vary with season (i.e., spring, summer, fall, pre-canopy crop cover, post-canopy crop cover, etc.)?
- Biological activity – Can turbidity be associated with biological activity (fish disturbance of bottom sediments, algae in water, etc.)?
- Boundary issues – Are there physical differences in the stream or watershed that can be related to turbidity levels (soils, geology, slope, channel form and composition, etc.)?

An evaluation of the magnitude, frequency, and duration of pollutant loads to the stream is an important consideration for designing the impairment analysis. A continuously discharging point source with low effluent variability has a much different impact on stream water quality than does a seasonal or intermittent point source discharge, or a nonpoint source loading driven by storm events. Impacts from a continuous discharge may best be evaluated under design conditions using steady-state analytical methods and assumptions. The event-based and intermittent loading situations will require non-steady state analysis with variable design conditions.

### 6. Data Gaps Identification and Plan to Fill the Gaps (Monitoring and Assessment Plan)
(TMDL Training Session #6)

As the compiled existing data is reviewed as described in Section II.B.vi above, data and information gaps will usually be identified. The most prominent gaps are likely to be observed early in the review (i.e., Section II.B.iii). If this occurs, a pre-TMDL or scoping monitoring plan and effort may be warranted. Such an initial effort would help fill the basic data needs to more fully complete the previous sections of this protocol. Monitoring may consist of longitudinal sampling along the stream and its tributaries, storm event sampling, and synoptic paired turbidity and related parameter sampling. This monitoring will usually be done by the local project sponsor or partner. Note, again, that this protocol process entails an integrative and iterative approach where the project will continue to develop as more information and analysis is done. The information protocol should be updated and a pre-TMDL monitoring plan should be finalized for presentation to the technical team and stakeholders for their consideration in
pursuing the additional work. Such a monitoring effort is likely to aid in reducing the final cost of completing a TMDL, and may aid in prioritizing the selection and completion of projects for final TMDL development.

The process of identifying the data gaps and monitoring needs can then be revised and/or expanded as the preliminary data is collected. The review continues with the stressor identification process and analysis of critical conditions. This may appear a bit out of sync in terms of the order of this protocol, given the need to determine the source assessment and analysis needs described in Section II.C prior to completing a second phase or “full-TMDL” monitoring plan. However, it does demonstrate how the process requires an iterative approach to accomplish the goals of the Impaired Water program. The information protocol should continue to document: the information gaps; data collection needs to address the gaps; and the analysis techniques/methods that will fill the gaps. If the source assessment and needs analysis identifies the need for the use of a model in the project, the information protocol and monitoring plan should also identify how the additional data collection will provide the input, calibration, and/or validation needs of the computer model.

C. Source Assessment and Analysis Needs

Inherent in each of the steps described above is a need to identify, evaluate, and select the type/method of analysis to be used in quantifying the source loads and allocations for the TMDL. As each step is worked on and completed, the technical team should consider the level of rigor that will be needed to adequately answer people’s concerns about the TMDL. A relatively simple approach may entail a basic spreadsheet approach. As the decision needs increase, more complex approaches including computer modeling may be necessary. This can be documented as the strength of evidence process weighs what level of confidence is needed for the technical advisory team to concur that there is enough basis to make a decision.

Initial analysis work for turbidity TMDLs will usually involve the use of duration curves. Cleland (2003) provides a discussion of typical source contributions that may occur through the flow duration intervals. In some instances, this analysis may be sufficient to delineate sources through the strength of evidence process. However, the assignment of sources of the impairment at the different flow intervals is based on general principles of source generation and transport. If there is evidence or concern that the sources and loads do not align with general conditions, an additional level of assessment may be needed.
It is at this point that a model may be needed to move the project to completion in terms of estimating and/or predicting loads and load reductions needed for the TMDL. While the technical needs for a project play a role in selecting the analysis approach for a TMDL, the level of rigor needed in a project will also depend on its likelihood of being challenged legally. The following circumstances should be considered when determining the level of rigor to be used in a project:

1. The number and quantity of contributing parameters that exist in the water sampling results.
2. The number and complexity of sources that exist in the watershed.
3. The presence or likelihood of a NPDES permit that could be significantly restricted by the findings.
4. The likelihood of a balanced healthy ecosystem coexisting with anthropogenic sources. If site specific standards are necessary due to natural background limitations or if the sources can not balance the TMDL, future growth may be curtailed and the most restrictive measures placed on the existing sources.

Several different approaches for assessing loading capacity, sources and their contribution to the load, and allocating loads are available. The following list of approaches and/or tools provides an example of what is available:

- Simple spreadsheet assumptions and calculations
- Load Duration Curves
- “Simple or basic” models – RUSLE, WEPP
- More complex models – HSPF, SWAT
- Watershed models – AnnAGNPS, SWAT
- Stream dynamics and transport models – QUAL2E, CONCEPTS

Reference Reach Approach

Another approach that may be useful in setting target goals for the stream, especially in situations where the achievability of the standard may be in question, involves the use of a reference reach or watershed. A reference reach in this context is somewhat different than it is in biological monitoring usage. Here, a reference reach refers to either a minimally or least impacted watershed in terms of its affect on the stream reach. While a reference reach may be useful in an individual TMDL project, it will be especially helpful in the further development and refinement of the turbidity standard. Data needs typically will entail parallel water and watershed monitoring efforts to the impaired reach.

A physical and geomorphic evaluation of the stream is almost certainly needed to provide a characterization of the physical “health” or stability of the stream. Any success in attaining the turbidity standard will depend on the presence of a stable stream. Stream stability is a function of its geology and hydrology. Streams will always carry some degree of sediment load due to the sediment transport and deposition processes in moving water. Stability is then a measure of a balanced deposition and suspension of sediment through a stream system. An unstable stream will tend to excessively aggrade or degrade its bed and banks, often resulting in elevated turbidity levels.
A TMDL may be developed “traditionally” for a stable stream, essentially assuming that the stream bank and channel contributions to turbidity are not the driving factors on elevated turbidity. In unstable streams, TMDL projects will need to identify and evaluate the factors contributing to their instability before calculating the TMDL and allocations. Questions to consider when determining the information needs to accomplish this include:

- What is the overall stage of channel evolution?
- What steps may be available to advance the channel evolution process (i.e., stabilize the watershed hydrology, provide stream access to the flood plain, provide an adequate amount of time for the “natural” stream energy to mold the channel into a stable stream)?

This work begins to identify the need for a stable hydrologic system to meet water quality goals more than whether turbidity is a symptom rather than a cause.

**Future Refinement of the Reference Reach Approach**

A further refinement in the use of a reference site approach and a stream stability assessment approach in doing TMDLs would involve the development of a physical metric index for hydraulic, geotechnical, and geomorphologic conditions. Such an index would be similar in concept to an index of biotic integrity (IBI) for fish and macroinvertebrates. The physical index (i.e., a “stream key”) combined with chemical and biological information would be used to help define the level of rigor needed in a TMDL and, from a program perspective, possibly adjust the timetable in which to complete a TMDL for individual reaches. Physically stable streams could enter a TMDL process requiring less rigor to complete. Unstable streams, presumably impacted by more than just water column turbidity (i.e., habitat loss or flashy flows), would be identified as needing a higher level of rigor with an associated increase in time required to complete the TMDL. Given the likelihood that other factors are also impairing the stream, consideration should be given to identifying the reach as an aquatic life impairment and reschedule it to deal with the physical and chemical stresses in one project.

This refinement would involve the following:

1. Conducting a broad stream classification to determine if physical factors are impairing designated uses. Various channel evolution models, such as the Rosgen Stream Classification/Stability Assessment method, have been developed to do this.
   a. If the stream is deemed “stable”, a “traditional” TMDL approach may be used.
   b. If the stream is deemed “unstable”, continue with the following steps.
2. Complete a more detailed gathering of information (USDA Sediment Lab procedures or Rosgen Level II with Magner modifications) that would be used to characterize the condition and aquatic life designated use. (Aquatic life being defined as the appropriate aquatic biologic community for the waterbody classification: warm, cool or cold water fisheries.)
3. Using the biological monitoring metrics and water chemistry from reference sites as well as the TMDL reach, evaluate the degree to which the current turbidity standard provides protection of the aquatic life.
   a. If the standard appears to be adequate, continue with the “traditional” TMDL approach.
b. If the standard does not appear to adequately protect the aquatic life, a site-specific standard could be considered as part of the TMDL

4. The next step in the Impaired Waters process is the implementation of the restoration measures, and eventual monitoring and assessment of the chemical, physical and biological characteristics to determine if the aquatic life is being supported.

5. The Impaired Waters process then continues depending on whether the necessary aquatic life is achieved or not.
   a. If the designated use is achieved, then a rule change for either a site-specific standard or a regional standard for turbidity may be considered along with the completion of the TMDL work.
   b. If the aquatic life does not return to a healthy status, then the problem investigation process of the TMDL program would need to be re-entered to address the undetected cause of the impairment.

This approach would allow MPCA staff to keep working on the current 303(d) list schedule by placing the focus on the designated use. Along with the physical and biological data collection described above, MPCA staff would concurrently work on developing new turbidity and/or physically-based standard(s), where regionally necessary and/or appropriate. A revised standard could be developed in four to six years given adequate staff and financial resources. The use of this approach would require extra monitoring and assessment on reference reaches in addition to TMDL listing reaches to determine the appropriate goals to use.

The appropriate use of any tool or model requires the availability and use of specific data or other model inputs. It is therefore important to determine both the tools to be used and the information needed to use the tools prior to completing the assessment of data gaps and developing a TMDL monitoring plan. Section II.E provides additional information regarding the selection and identification of data needs for the tools and/or models to be used in a TMDL.

D. Additional Data – Monitoring Needs

Incorporating all of the information gathered from the previous sections via updates to the information protocol, the overall work plan and full monitoring plan can be “finalized” as presented in Section II.B.vi. The additional monitoring can then be completed as defined in the monitoring plan and incorporated into a contract or contracts. It is often at these points in time that a master contractor or lab and monitoring contractor may need to become involved in the project.

E. Analysis and Modeling

1. Select Analysis Framework

   a. Basic Objectives

   The basic objective for an impairment analysis is to understand the cause-and-effect relationships governing water quality such that management alternatives can be explored that will bring the water quality back into compliance. Water quality monitoring is necessary to define existing
When selecting an appropriate analytical tool, some basic guidelines to consider include:

- Choose the simplest analysis that will provide reliable answers and which will meet project objectives.
- Focus on the key parameters of interest identified in the problem definition phase, avoiding unnecessary complexities that can waste time and project resources.
- Ensure that the analytical framework will provide understandable and workable linkages for connecting the diagnostic analysis to decisions about resource management alternatives.
- For complex impairments, ensure that the analytical tool provides a capability to define and partition loadings from the various pollutant sources.
- Ensure that funding and human resources are available to perform the analysis.
- Document the strengths and weaknesses of the tools being considered for use against these guidelines. No tool will perfectly meet these guidelines.

b. Selecting an Appropriate Analytical Tool

When monitoring and basic water quality investigations do not meet the goals and objectives of a TMDL for addressing turbidity impairments, it will be necessary to select an appropriate water quality model that provides analytical and predictive capabilities. Water quality models are mathematical abstractions or simplifications of enormously complex natural aquatic systems and/or equally complex watershed systems. They can range in complexity from screening-level analysis employing simple mass balances and empirical relationships to multi-dimensional, fully-dynamic models designed for large and complex river systems. The models may focus on in-stream transport and cycling processes, watershed source and runoff processes, or some combination of in-stream and watershed processes. Given the typical magnitude of nonpoint sources in turbidity TMDLs, in-stream and watershed models may need to be linked.

Selection of an appropriate model or analysis framework suitable to a specific TMDL application is no small task. In addition to the basic guidelines presented in the previous section, a basic understanding of the river system and its impairment problem can be applied to select the appropriate time and space dimensions needed for modeling.

c. Tools/Models Available

Generally, water quality models employed by the MPCA for TMDL development should be readily available in the public domain, be well-tested, widely used, and be supported by or acceptable to the U.S. EPA. Again, the preferred and most cost-effective approach is to use the simplest model that includes all the important processes affecting water quality in your study area. However, caution should be exercised in selecting too simple a model which may result in inaccurate predictions that will affect resource management decisions. When the complexities of
an impairment are not understood at the outset, it is advisable to initially employ a flexible and comprehensive model, but simulate only those processes that appear significant and are supported by monitoring data. As project needs dictate and as more supporting data is obtained, additional model processes can be incorporated to provide better definition to the impairment and management alternatives. Some of the tools and models that may be useful in turbidity TMDL projects are listed below.

Duration Curves:

Duration curves are tools that provide an evaluation and comparison of historical flow, current project flow, and sampling data using a percentile exceedance curve developed originally for hydrologic characterizations of rivers. Cleland (2002, 2003) describes how duration curves can be applied in TMDL analyses. Flow duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). This indicator can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all important considerations when identifying those controls that might be most appropriate and under what conditions. In addition, duration curves also provide a context for evaluating both monitoring data and modeling information. This offers another way to look at identifying data needs where adaptive management is being considered or utilized (Cleland 2002).

Screening Analysis and Models:

A simple mass balance can be used to evaluate the significant loading sources in an impairment study. Nonpoint pollutant loads can be estimated using simple loading functions and empirical expressions relating nonpoint loads to other available parameters.

- FLUX – a load calculation computer program given water quality data and daily flow data
- Runoff Coefficients – literature and/or research based flow and loading coefficients developed by some set of physical factors (i.e., soils, slope, land use, etc.)
- RUSLE – Revised Universal Soil Loss Equation – predicts potential soil erosion due to sheet and rill erosion in individual fields
- WEPP – Water Erosion Prediction Project model – a process-based, distributed parameter, continuous simulation, erosion prediction model applicable to hill slope erosion processes (sheet and rill erosion), as well as simulation of the hydrologic and erosion processes on small watersheds
- PLOAD is a simple, screening model that can be used to estimate nonpoint sources of pollution on an annual average basis, using either an export coefficient or another simple method approach.

River Process Models:

- WASP – Water Quality Analysis Simulation Program – It is a multi-dimensional, dynamic stream model and is currently supported by the U.S. EPA. The model is available at: http://www.epa.gov/waterscience/wqm/
WASP is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The model can be used to simulate 1, 2, and 3-dimensional systems for a variety of pollutant types. Time-varying processes of flow advection and dispersion; point and diffuse mass loading; and boundary exchanges are represented in the model. WASP can be linked with hydrodynamic flow and sediment transport models that can provide flows, depths, velocities, temperature, salinity, and sediment fluxes. The modeling framework in development for the Mississippi River (Lake Pepin) eutrophication model shares basic simulation processes used in WASP.

- CE-QUAL-RIV1 and CE-QUAL-W2 – The US Army Corps of Engineers (USACE) supports these models. CE-QUAL-RIV1 simulates flow and water quality in rivers and run-of-the-river reservoirs where variation in depth is neglected. Where vertical water quality gradients are important, another Corps model designated CE-QUAL-W2 provides a two-dimensional hydrodynamic and water quality analysis that includes the major processes of eutrophication kinetics and sediment interactions. An adaptation of the CE-QUAL-W2 model is being proposed for the Lower Minnesota River Modeling update study. Additional information on the USACE models is available at: http://el.erdc.usace.army.mil/products.cfm?Topic=none

Watershed Process Models:

- HSPF – HSPF is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment interactions. HSPF was designed as a basin-scale model that includes fate, transport, and transformation of pollutants in one-dimensional stream channels. HSPF is a complex model normally run on an hourly time scale, requiring large amounts of data. The MPCA uses a stand-alone version of HSPF for simulating a majority of the Minnesota River Basin.

- SWAT – SWAT, developed by the USDA Agricultural Research Service (ARS), is a physically based watershed-scale model run on a daily time steps. Its design facilitates the prediction of impacts from land management practices over long periods of time on water, sediment, and agricultural chemical yields in large complex watersheds having varying soils, land uses, and management conditions. Additional information on the SWAT model can be found at: http://www.brc.tamus.edu/swat/index.html

- AnnAGNPS – Annualized Agricultural Non-Point Source model – AnnAGNPS is a continuous-simulation, multi-event model used to predict non-point source pollutant loadings from agricultural watersheds. Additional information on the AnnAGNPS model can be found at: http://www.ars.usda.gov/Research/docs.htm?docid=5222

- AGNPS – AGNPS is a tool for use in evaluating the effect of management decisions impacting a watershed system. The AGNPS system is a direct update of previous versions of the model. The usage of the term "AGNPS" now refers to the
system of modeling components instead of the original single event AGNPS, which was discontinued in the mid-1990's. Additional information on the AGNPS model can be found at: http://www.ars.usda.gov/Research/docs.htm?docid=5199.

Combined Process Models:

- **BASINS** – The U.S. EPA supports and promotes the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software system for watershed and water quality-based analyses. The system is designed to be flexible, allowing analysis at a variety of scales using tools that range from simple to sophisticated. A geographical information system (GIS) provides the integrating framework for BASINS and organizes spatial information so it can be displayed as maps, tables, or graphics. The software system includes data retrieval and management tools, a series of simulation models, and customizable databases. Core data to run the models can be downloaded via an EPA website.

  Simulation models included in the BASINS system include the Hydrological Simulation Program – Fortran (HSPF), the Soil and Water Assessment Tool (SWAT), and a simplified pollutant loading program known as PLOAD.

  For additional information on BASINS, see: [http://www.epa.gov/OST/BASINS/](http://www.epa.gov/OST/BASINS/)

Riparian and Channel Models:

- **CONCEPTS** – The National Sedimentation Laboratory developed the CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) computer model to simulate the evolution of incised streams and to evaluate the long-term impact of rehabilitation measures to stabilize stream systems and reduce sediment yield. CONCEPTS simulates unsteady, one-dimensional flow, graded sediment transport, and bank-erosion processes in stream corridors. For additional information on BASINS, see: [http://www.ars.usda.gov/Research/docs.htm?docid=5453](http://www.ars.usda.gov/Research/docs.htm?docid=5453)

**d. Use of the Tools/Models Available**

As the analytical tool is selected for the TMDL study, the next step is to determine a general approach for conducting the technical analyses. This should be done with input from project stakeholders and consideration of schedule, budget, and staffing. This will direct the most efficient utilization of resources to complete the TMDL study. The unique needs of each project will effect the mix of resources available for use in a project. Options to consider include:

- Use a cooperative mix of local resources and state staffing;
- Use a cooperative mix of local and state resources with contracted support for specific technical expertise; or
- Use contracted consultant as project lead with cooperative support from state and local resources.
Once a general approach is selected, the next step is to identify the specific roles and responsibilities of each project participant and develop the scope of service for which each participant will be responsible. Stakeholder input is essential to this plan design. For technical services to be provided by contracted consultants, detailed requests for proposals (RFP) must be developed to clearly define the scope of needed services and work product deliverables.

This information again should be documented in an updated information protocol and overall work plan. The details for each are then incorporated into separate work plans for local contracts and detailed requests for proposals (RFP) for private contractors. Details are needed to clearly define the scope of services and work product deliverables for the contracts and work orders.

2. Additional Data Acquisition to Support Analysis Framework

As noted in Section II.C, the analysis tool or model selected for use in completing the pollutant impairment analysis for turbidity TMDLs may require specific data inputs for the most appropriate use of the tool/model. Watershed and water quality models are general in nature and need to be calibrated with site-specific information to validate their use as reliable tools for analyzing pollutant responses and predicting changes associated with management alternatives. Model documentation should be consulted for specific data requirements. Customizing a model setup for specific applications requires information about the physical characteristics of the river system, information on boundary conditions of the study area, and adequate spatial and temporal coverage of water quality conditions. Water quality models also employ many kinetic rate parameters to simulate the physical, chemical, and biological processes affecting stream water quality. Rate parameters that can be field-measured should be obtained. Parameters that can not be measured directly will be set during the model calibration process and adjusted within acceptable ranges supported by the literature.

Much of the needed information is generally not available from previous data collection programs. The specific data gaps need to be identified and incorporated into the information protocol and the development of the TMDL study monitoring plan so that the information critical to the analysis is obtained. This evaluation needs to be done as part of Section II.C.

3. Model Setup and Evaluation

Introduction

Generally, models are simplified mathematical representations of the extremely complex real world systems. Models cannot accurately depict the multitude of processes occurring at the various chemical and physical levels. Still, models can make use of known interrelationships among variables in order to predict how a given quantity (or extensive variable such as sediment load) or state variable (or intensive variable such as water temperature or pollutant concentrations) would change in response to a change in an interdependent quantity or state variable. These interrelationships are expressed as sets of equations. In this way, models may be useful frameworks for investigations of how a given system would likely respond to a perturbation from its current state. For this reason, the predictive capabilities of models are often helpful in the study of large natural systems. Watershed models are particularly useful, since it is often difficult to actually change such existing conditions as land use or weather patterns in the real world to examine changes to the system.
Each set of equations contain different variables. Some of these variables are input parameters which must be assigned for the model to formulate a simulation. Other variables are output variables. The model uses the set of equations to estimate output variables as a result of the simulation process.

Model Parameter Assignment

The modeler must assign values to each of the required input parameters. Some of these input parameters can be direct measurements of real world quantities or state variables. For instance, watershed models generally require meteorological records for input. These contain quantities such as hourly rainfall amounts and state variables such as air temperature, dew point, and solar radiation. These values are generally placed directly into the model input files without manipulation or estimation of uncertainties associated with these parameter values. This type of input is often called a “forcing function” since it is regarded as a fundamental condition affecting model output.

Other input parameters are not as easily measured as air temperature. They require the modeler to use professional judgment in the estimation of that parameter. In some cases, the parameter can be estimated on the basis of laboratory or field experimentation. In other cases, there is no “real world” surrogate for that parameter. The modeler must use available information to determine an appropriate parameter value. In other cases, the parameter has surrogates in the physical world, but the parameter is averaged over such a large and heterogeneous scale that it is impossible to extract a single value based on experimentation. The estimated parameter value must be the result of the aggregation or lumping of values over various smaller scales.

Selecting values for estimated parameters is a critical step in the initial set-up of the model. It is these parameters that normally require some adjustment in the calibration process. Since most of the uncertainty of the model results is related to parameter estimation, it is usually prudent to include a sensitivity analysis of the output of interest to changes in value of the estimated parameters as part of the model evaluation.

Comparison of Simulated Output with Observed Data

Comparison of simulated output with observed data should be made during all phases of the model set-up process. When the modeler is assigning values to estimated input parameters she/he should do so in such a way that the simulated output generated by the model resembles the observed data. For hydrological models, in general, the meteorological conditions (temperature, rainfall amounts) are considered forcing functions and are direct parameter inputs. The modeler then assigns values to estimated input parameters (i.e. infiltration, field roughness) so that the model output (simulated flow in a river reach) matches the observed data, which in this case would be measured flow in that river reach. The modeler should systematically compare observed data with simulated output during the calibration process, and adjust the estimated parameters accordingly. Statistical comparisons of the simulated output with the observed data should be made during the model validation and the sensitivity analysis, to demonstrate the utility and relative “accuracy” of the model.

Calibration
Calibration of most models involves adjusting the estimated model parameters in such a way that model output resembles values available in observed data. In the case where observed data is lacking, the model should output values that are in a reasonable and expected range.

Watershed models contain a hierarchy of simulations. This hierarchy dictates the order of model routine calibration. The calculation of water flow within a given riverine reach is the most fundamental routine in a model. Any error in water flow will be propagated and often multiplied in other model routines. For this reason, the flow calculations in a given model should be calibrated first. Once the modeler is satisfied with the calibration of flow, the calibration of routines simulating sediment and dissolved constituents, such as dissolved oxygen, can occur. Finally, once the sediment simulation has been adequately calibrated, the modeler can calibrate routines involving the simulation of sediment-sorbed constituents, such as phosphorus.

For watershed models which simulate output in a time series format (i.e. hourly values for a period of several years), it is recommended that the simulated time series output be compared to the time series of observed data. Visual comparisons should be made to assure that the simulated output is in general agreement with the available data.

These comparisons should be made on different time scales, beginning with a long-term coarse timeframe. For instance, when calibrating flow, one should first compare simulated annual flows to observed annual flows. On this broad timescale, it is particularly important to be sure that the model is neither consistently over predicting nor under-predicting observed data. Next the plots on the monthly timeframe should be examined. It is not uncommon for some models to accurately predict annual flows, however, these models can have a seasonal bias (i.e. under-predict flows in the spring and over-predict flows in the summer). An analysis of monthly plots allows the modeler to recognize these seasonal inaccuracies. The modeler can then proceed with the comparisons at a daily, or in some cases, even hourly timeframe. At these timeframes, not only is the magnitude of an event very critical, but the timing of the event is also important. When calibrating flow, it is important not only to compare peak height, but also the peak width, the area under a storm peak, the overall shape of a storm peak and the position in time of a storm peak. It is also important to compare the values of base flow between storm peaks.

These visual comparisons are usually the most helpful and informative tool in model calibration. It is critical to make these comparisons for flow as well as concentrations and loads of constituents of interest. Unfortunately, a lack of observed data often compromises the utility of concentration, and especially load comparisons. In this case, it is often beneficial to rely on statistical comparisons between the data sets of observed values and simulated output. These comparisons are often useful. It is important however, to only compare data on time periods when observed data is available. Often, a lack of data from a station consistently occurs under certain conditions. For example many gauging stations are unable to report flow when water elevation drops below a certain level. In this case, the low flow portion of the observed record is absent. Care should be taken not to compare this observed data set with the entire corresponding simulated output which would contain flow values under all conditions.

It is also important to construct plots of observed versus simulated loads and concentrations. These plots and their associated linear regressions are often useful in identifying systematic biases within the set of model parameters.

**Validation**
Model validation involves the input of a separate record of time series data into the simulation. This data record must not have been used in the model calibration process. The modeler follows the steps of the calibration process and makes the same visual and statistical comparisons. However, the model output must satisfactorily match the observed record for that time period without the manipulation of any model parameter values, estimated or otherwise, which were determined during the calibration process. In this manner, the validation process must be completely independent of the calibration. If the model output does not adequately match the observed data for the validation record; the calibration and subsequent validation process must be repeated.

**Principal Component Analysis**

Principal component analysis is a statistical technique usually applied to a large set of variables to identify which sets of variables within the larger set form coherent subsets that are independent of other subsets. Variables that correlate with one another and are also mostly independent of other subsets of variables are combined into “factors”. Principle component analysis can be very useful in determining which groups of variables are interrelated and also in reducing the number of variables in the system by combining correlated variables into factors.

**Sensitivity Analysis**

Sensitivity Analysis is the study of how the uncertainty in the output of a model can be assigned to different sources of uncertainty in the model input. Sensitivity analysis is an essential step in the evaluation of any model and a required part of any discussion of model defensibility. In any model, there are one or more input parameters which are interrelated with the output parameter of interest. The modeler must identify the input parameters which have a mathematical influence on the value of the output parameter. Once the related input parameters are identified, the modeler must systematically and individually increase and decrease the value of each relevant input parameter. If small changes in the value of an input parameter result in a large change in value of the output parameter, the output parameter is said to be very sensitive to that input parameter. If large changes in the value of an input parameter result in a small change in value of the output parameter, the output parameter is said to be relatively insensitive to that input parameter. The modeler must identify to which input parameters the output parameter displays the greatest sensitivity. The modeler should statistically quantify the uncertainties apportioned to the values of each of the sensitive input parameters, especially the estimated input parameters. The modeler should also use statistical tests to express the impacts of varying more than one of the sensitive input parameters simultaneously.

**4. Model Application and Example TMDL components**

**Development of Example Evaluation Scenarios**

Commonly occurring within stakeholder advisory discussions is the desire to have a discussion on three main themes;

- What range of reductions could be expected from each source type or category?
- What are the costs in terms of dollars and risk of failure?
• What are equitable balances between source categories that will balance the TMDL allocation?

To answer these questions in a public setting, some preparation work must be done in advance. It is a good practice to have some pre-selected scenarios ready to foster discussion. Typical examples could be:

(a) Natural background/presettlement – Some models balanced on hydrology cannot reverse the simulation of drainage enhancements already in place in the system because the hydrographs and resulting loadings reflect the altered pathways, yet it is valuable to consider a regional presettlement vegetation coverage. This can be used to evaluate the extreme end point of current day loading with a given hydrology.

(b) Seasonal/critical conditions – The system may move in and out of compliance with the numeric criteria at different flows and for different reaches in the watershed. A detailed output for current day conditions can help the discussions along regarding the effect of flow and season.

(c) Geographic assessments – In larger watersheds with tributaries, a system of model runs to vary a subwatershed’s input can help in defining area hot spots and the potential for reductions from significantly contributing subwatersheds.

(d) Future loading considerations (no action) – An estimate of the effect of potential new point and nonpoint loadings for the watershed without other changes.

(e) Ranges of point source reductions in the watershed – Using different levels of treatment for the key stressor parameters, what are the expected load reductions for each parameter and how would they be expected to affect turbidity?

(f) Results from varying levels of effort for nonpoint source Best Management Practice Systems (BMPs) – Using different levels of adoption for various sets of BMPs, provide the output results for changes in loading of the key stressor parameters and the improvement in turbidity.

(g) Best available technologies – Application of the highest level of effort that current treatment technology supports for each source and sector.

(h) Balanced allocation – Present an example combination of treatment measures from the various sources that will work to balance the TMDL.

None of these model outputs will generate the whole background for the discussions to be held. Other aspects should include the local perspectives on the controversial issues, sector specific cost estimates for the ranges of technology changes modeled, resource management risk elements (such as crop yield loss, compliance determinations, etc.). When developing these scenarios and the scenario discussions, the team should keep in mind the needed Margin of Safety (MOS). Can these scenarios be used to assist in understanding the benefits from incorporating implicit or explicit safety assumptions?

Uncertainty Analysis

Uncertainty analysis can be used in exploring the requirements for the level of MOS that is needed in the specific watershed and this model application. The uncertainty analysis will tie in nicely with the sensitivity analysis mentioned in section II.E.i.3. However, if a balanced
allocation scenario is developed, it may be important to rerun the allocation and select incremental key stressor parameter changes. Evaluating factors affecting turbidity in this way will assist in understanding the needed MOS for the TMDL. A suggested starting increment trial would be 5 percent steps, ranging from -10 to +10 percent of the given loading for the pollutant parameters at the future conditions.

III. Turbidity TMDL Submittal Requirements

A. Minnesota’s Checklist

This checklist outlines the basic needs for all TMDLs. It is used by MPCA management prior to submittal to EPA and should be utilized by TMDL preparers as a resource to ensure the completeness of the final report. It summarizes the detailed description of EPA’s review guidelines (Section III.B.).

<table>
<thead>
<tr>
<th>Item</th>
<th>Page</th>
<th>Adequate (yes/no)</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Executive Summary – should briefly summarize the key findings in each of the sections below, particularly the final allocation of pollutant loads.</td>
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Background Information, including:

- Spatial extent of watershed (HUC codes are helpful)
- Waterbody identified as on list (with numeric identifier)
- Land use distribution
- Population, including present & future growth trends
- Wildlife resources
- Recreational uses, if relevant
- Pollutant of concern and, if applicable, justification for using surrogate measures
- Description of pollutant sources (PS and NPS; also, describe natural background, if distinguishable from NPS)

Description of Applicable Water Quality Standards and Numeric Water Quality Target

- Water quality standard (numeric or narrative)
- Designated use
- Description of impairment (extent, magnitude, etc.)

Pollutant sources (PS and NPS; also, describe natural background, if distinguishable from NPS)
## Turbidity TMDL Protocol Guidance and Submittal Requirements

<table>
<thead>
<tr>
<th><strong>Loading capacity</strong> of each listed waterbody</th>
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<tbody>
<tr>
<td>- Description of methodology used</td>
<td></td>
</tr>
<tr>
<td>- If both acute and chronic standards exist, as with fecal coliform, and are exceeded then must explain how both are addressed in TMDL</td>
<td></td>
</tr>
<tr>
<td>- Critical conditions (e.g., low flow) accounted for, if applicable</td>
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</table>

| **Load allocation** attributed to existing and future NPS, including description of methodology used |  |

| **Wasteload allocations** for each NPDES permitted source and straight pipe septics (loading of 0 for these septics) |  |

| **Margin of Safety** and justification |  |

| **Reserve Capacity** description (if not included in TMDL needs discussion of why not) |  |

| **Reasonable Assurance** that TMDL will be achieved (describe regulatory and nonregulatory efforts at state and local levels; funding possibilities) |  |

| **Seasonal Variation** |  |

| **Monitoring plan** to track TMDL effectiveness |  |

| **Implementation Strategy** providing general approach, but not a formal implementation plan. This should include broad cost ranges for implementation, per the 2006 Clean Water Legacy Act. |  |

| **Public Participation** summary, including public notice process to be used |  |

| Is technical discussion throughout transparent and defensible in court (BPJ is justified at all points) balanced with "is this a reasonable approach"? |  |
B. Detailed Submittal Requirements for Turbidity TMDLs

To supplement Minnesota’s checklist above, here are the federal requirements (shown in boxes) for each section of the TMDL. Each requirement is followed by a description of Minnesota protocols for turbidity TMDLs, if applicable.

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Section 303(d) of the Clean Water Act (CWA) and EPA’s implementing regulations at 40 C.F.R. Part 130 describe the statutory and regulatory requirements for approvable TMDLs. Additional information is generally necessary for EPA to determine if a submitted TMDL fulfills the legal requirements for approval under Section 303(d) and EPA regulations, and should be included in the submittal package. Use of the verb "**must**" below denotes information that is required to be submitted because it relates to elements of the TMDL required by the CWA and by regulation. Use of the term "**should**" below denotes information that is generally necessary for EPA to determine if a submitted TMDL is approvable. These TMDL review guidelines are not themselves regulations. They are an attempt to summarize and provide guidance regarding currently effective statutory and regulatory requirements relating to TMDLs. Any differences between these guidelines and EPA's TMDL regulations should be resolved in favor of the regulations themselves.
1. Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking

**Federal Requirements:** The TMDL submittal should identify the waterbody as it appears on the State's/Tribe's 303(d) list. The waterbody should be identified/georeferenced using the National Hydrography Dataset (NHD), and the TMDL should clearly identify the pollutant for which the TMDL is being established. In addition, the TMDL should identify the priority ranking of the waterbody and specify the link between the pollutant of concern and the water quality standard (see section 2 below).

The TMDL submittal should include an identification of the point and nonpoint sources of the pollutant of concern, including location of the source(s) and the quantity of the loading, e.g., lbs/per day. The TMDL should provide the identification numbers of the NPDES permits within the waterbody. Where it is possible to separate natural background from nonpoint sources, the TMDL should include a description of the natural background. This information is necessary for EPA's review of the load and wasteload allocations, which are required by regulation.

The TMDL submittal should also contain a description of any important assumptions made in developing the TMDL, such as:

1. the spatial extent of the watershed in which the impaired waterbody is located;
2. the assumed distribution of land use in the watershed (e.g., urban, forested, agriculture);
3. population characteristics, wildlife resources, and other relevant information affecting the characterization of the pollutant of concern and its allocation to sources;
4. present and future growth trends, if taken into consideration in preparing the TMDL (e.g., the TMDL could include the design capacity of a wastewater treatment facility); and
5. an explanation and analytical basis for expressing the TMDL through surrogate measures, if applicable. Surrogate measures are parameters such as percent fines and turbidity for sediment impairments; chlorophyll a and phosphorus loadings for excess algae; length of riparian buffer; or number of acres of best management practices.

**Protocol for Minnesota Turbidity TMDLs:**

One thing unique to turbidity TMDLs is the need to select a surrogate variable for turbidity to allow the expression of the TMDL as a load. In doing so, there is an opportunity to evaluate the composition of the material causing the turbidity in the stream or river. Whether the work and results are reported here or elsewhere, monitoring and data analysis must occur to link turbidity to a concentration variable. This variable will usually be total suspended solids (TSS) or suspended sediment concentration (SSC), given a typically good relationship between the parameters and the use of the parameters as the basic sediment measurement in water. Although the 303(d) listing process has used a regional relationship between turbidity and TSS in some stream reach assessments, specific reach, stream, and/or watershed relationships should be made in each TMDL project.

The development of a relationship for selecting a surrogate variable and value for the turbidity standard can range from simple to relatively complex. The simplest approach would solely compare paired values of turbidity and TSS. A more complex approach would involve sampling and analysis for comparisons of turbidity with other parameters that may have a relationship to turbidity. Water quality variables that may have a linkage to turbidity include TSS, SSC, chlorophyll a, inorganic suspended solids, volatile suspended solids, and sediment particle size.
The relationship(s) developed in selecting a surrogate value for the turbidity standard will likely fit one of four scenarios in terms of the strength of the relationship(s). These include the relationship providing: 1) a “perfect fit” with an absolute and direct linkage between parameters; 2) a “significant fit” with the linkage being “easily” accepted given good statistical results, good logic and professional judgment; 3) a “moderate fit” indicating a possible to likely linkage, but may need more work or can be accepted with a bigger level of uncertainty; and 4) a “poor fit” where there is no or limited linkage apparent with a resulting need for more information. In many to most cases, the level of fit present in turbidity impairments will be “significant” or “moderate” and once in awhile “perfect” or “poor”. As noted above, it is quite possible to have a multiple parameter relationship.

In addition to looking for a “simple” correlation between variables, the data should be evaluated for temporal and spatial relationships. If there is insufficient data, the project must determine if a next step will be to gather more data to accomplish this.

The key to setting the basis for an adequate turbidity TMDL is to ask the questions, develop/pursue an answer, and then determine if the answer is adequate to meet the needs and/or demands of the stakeholders and technical advisory team.

2. Description of the Applicable Water Quality Standards and Numeric Water Quality Target

**Federal Requirements:** The TMDL submittal must include a description of the applicable State/Tribal water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the antidegradation policy. (40 C.F.R. §130.7(c)(1)). EPA needs this information to review the loading capacity determination, and load and wasteload allocations, which are required by regulation.

The TMDL submittal must identify a numeric water quality target(s) - a quantitative value used to measure whether or not the applicable water quality standard is attained. Generally, the pollutant of concern and the numeric water quality target are, respectively, the chemical causing the impairment and the numeric criteria for that chemical (e.g., chromium) contained in the water quality standard. The TMDL expresses the relationship between any necessary reduction of the pollutant of concern and the attainment of the numeric water quality target. Occasionally, the pollutant of concern is different from the pollutant that is the subject of the numeric water quality target (e.g., when the pollutant of concern is phosphorus and the numeric water quality target is expressed as Dissolved Oxygen (DO) criteria). In such cases, the TMDL submittal should explain the linkage between the pollutant of concern and the chosen numeric water quality target.

**Protocol for Minnesota Turbidity TMDLs:**

The surrogate measures developed as described above (Section II.A.2.) should be included in this section along with the description of the turbidity standard and target. The target may need to include a duration and/or magnitude component to clarify the application of the turbidity standard as a chronic standard. Please refer to the MPCA turbidity technical team and progress in other turbidity TMDL projects as this need is evaluated and an application is developed.

Minnesota Rules Chapter 7050.0227 does not explicitly state how the numeric water quality standard for turbidity is to be applied (see Section II.A.i); however, the standard is listed in the
context of being a chronic standard (Dave Maschwitz, personal communication, 2006). As such, a single exceedance of the standard would not cause a violation of the standard; rather, some chronic condition involving the standard would result in a violation of the standard. A violation of a standard due to a single exposure to a pollutant would indicate an acute condition. Chronic conditions in terms of pollutant toxicity are often based on a four-day average concentration of a substance. Use of a four-day average “chronic” turbidity as the determinant of impairment is one option for the application of the standard.

Other applications of the standard may be warranted as turbidity TMDL studies are completed. These applications might include some measure of duration and/or magnitude that begins to impair aquatic life. As noted previously, the direct impairment of aquatic life by turbidity is not completely described. Impairments related to turbidity may be more the result of stresses caused by other parameters or stream conditions, including sedimentation, and habitat degradation.

3. Loading Capacity - Linking Water Quality and Pollutant Sources

**Federal Requirements:** A TMDL must identify the loading capacity of a waterbody for the applicable pollutant. EPA regulations define loading capacity as the greatest amount of a pollutant that a water can receive without violating water quality standards (40 C.F.R. §130.2(f)).

The pollutant loadings may be expressed as either mass-per-time, toxicity or other appropriate measure (40 C.F.R. §130.2(i)). If the TMDL is expressed in terms in addition to a daily load, e.g., an annual load, the submittal should explain why it is appropriate to express the TMDL in the unit of measurement chosen. The TMDL submittal should describe the method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many instances, this method will be a water quality model.

The TMDL submittal should contain documentation supporting the TMDL analysis, including the basis for any assumptions; a discussion of strengths and weaknesses in the analytical process; and results from any water quality modeling. EPA needs this information to review the loading capacity determination, and load and wasteload allocations, which are required by regulation.

TMDLs must take into account critical conditions for stream flow, loading, and water quality parameters as part of the analysis of loading capacity. (40 C.F.R. §130.7(c)(1)). TMDLs should define applicable critical conditions and describe their approach to estimating both point and nonpoint source loadings under such critical conditions. In particular, the TMDL should discuss the approach used to compute and allocate nonpoint source loadings, e.g., meteorological conditions and land use distribution.

**Protocol for Minnesota Turbidity TMDLs:**

Flow information is needed to calculate loads in streams and rivers. Each TMDL project must evaluate whether or not there is adequate flow data available for determining the loading capacity of the impaired reaches. The amount and availability of flow data will vary greatly between projects. The longest records of stream flow will usually be found at USGS monitoring sites.

The current approach to calculating load capacity for turbidity involves multiplying the surrogate variable target concentration times stream flow at the impaired reach. Given that flow varies each day due to climate, season, and other factors, a single flow value and hence a single load...
value does not represent the variability present in a stream. To accommodate the need to provide a daily load representation of the loading capacity for turbidity, turbidity projects will normally use duration curves in presenting flow and loads. Duration curves provide a description of flow by the percent of time a given flow is exceeded over a long term.

If a USGS flow gage is located on or near the impaired reach, the long-term data can be used directly to develop a flow duration curve for the reach. In many cases though, a long-term flow gauging site will not be located near the impaired reach. When this is the case, the project then needs to determine how flow data will be obtained. Options include extrapolating flow from another site to the impaired reach or collecting new data via a stream flow monitoring site. Many watershed projects have begun collecting flow data in the past five to ten years as part of other project efforts. New TMDL studies need to determine through their information protocol and monitoring plan development if additional flow monitoring is needed. Given the variability in flow, a duration curve based on one or a few years of data may not be representative of the long-term functioning of the stream. Given this, the “short” duration curves should be evaluated against the duration curve of a long-term gage site. As with most aspects of the TMDL protocols, the advantages and disadvantages of the approaches need to be weighed when determining what and how data will be used to represent flows in the impaired reach.

Cleland (2003) provides a framework for the use of duration curves in estimating the loading capacity of a stream. The draft Lower Cannon River Turbidity TMDL provides a specific example of how loading capacity is presented with a duration curve.

References:

“Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs” (November 22, 2002); http://www.epa.gov/npdes/pubs/final-wwtmdl.pdf.


4. Load Allocations (LAs)

**Federal Requirements:** EPA regulations require that a TMDL include LAs, which identify the portion of the loading capacity attributed to existing and future nonpoint sources and to natural background. Load allocations may range from reasonably accurate estimates to gross allotments (40 C.F.R. §130.2(g) ). Where possible, load allocations should be described separately for natural background and nonpoint sources.

**Protocol for Minnesota Turbidity TMDLs:**

As noted in the federal requirements above, load allocations for turbidity impairment TMDLs are to include the loads attributable to nonpoint source pollutants and natural background conditions. The load allocation, at a minimum, will consist of a single load associated with each TMDL, with a general discussion of the likely sources and magnitude of each to the whole. However, the LA should be as source specific as the data allows. Source specific allocations could be by watershed sub-basin, land-use activity (agriculture), land-use sub-activity (row crop agriculture) or by individual sources (a particular row crop field). The more source specific the LA is, the more tailored the implementation recommendations can be.

One of the main issues in the presentation of the LA in many turbidity TMDLs will be the separation of natural background from anthropogenic nonpoint sources. Natural background may be a portion of the load from in-stream processes, streambank erosion, and bluff erosion. The separation of these from anthropogenic sources will sometimes require careful “strength of evidence” analysis by the project, technical advisory team, and stakeholder team. For these reasons, each source should be defined as precisely as possible. Tools that may be needed in projects include various monitoring and modeling efforts that can be identified through the information protocol, work plan, and RFP development efforts of the project. As an example, the Minnesota River Turbidity TMDL project is developing plans to combine physical and geomorphic channel assessments, sediment particle composition and age dating analysis, and GIS modeling to characterize the amount of sediment loading from natural background versus human caused and/or affected sources.

5. Waste Load Allocations (WLAs)

**Federal Requirements:** EPA regulations require that a TMDL include WLAs, which identify the portion of the loading capacity allocated to individual existing and future point source(s) (40 C.F.R. §130.2(h), 40 C.F.R. §130.2(i) ). In some cases, WLAs may cover more than one discharger, e.g., if the source is contained within a general permit.

The individual WLAs may take the form of uniform percentage reductions or individual mass based limitations for dischargers where it can be shown that this solution meets WQSs and does not result in localized impairments. These individual WLAs may be adjusted during the NPDES permitting process. If the WLAs are adjusted, the individual effluent limits for each permit issued to a discharger on the impaired water must be consistent with the assumptions and requirements of the adjusted WLAs in the TMDL. If the WLAs are not adjusted, effluent limits contained in the permit must be consistent with the individual WLAs specified in the TMDL. If a draft permit provides for a higher load for a discharger than the corresponding individual WLA in the TMDL, the State/Tribe must demonstrate that the total WLA in the TMDL will be achieved through reductions in the remaining individual WLAs and that localized impairments will not result. All permitees should be notified of any deviations from the initial individual WLAs contained in the TMDL. EPA does not require the establishment of a new TMDL to reflect these deviations.
revised allocations as long as the total WLA, as expressed in the TMDL, remains the same or decreases, and there is no reallocation between the total WLA and the total LA.

Protocol for Minnesota Turbidity TMDLs:

- **Sources in the WLA**
  All sources that are covered by a National Pollutant Discharge Elimination Permit System (NPDES) permit plus certain septic systems are to be considered in the WLA. These sources, for the purpose of the TMDL are referred to as point sources.

  Point Sources that are part of the WLA include:
  - Publicly Owned Treatment Works (POTWs) and other wastewater treatment facility (WWTF) permittees with discrete discharges and explicit numeric discharge limits.
  - NPDES stormwater permits, including from those communities designated as Phase I and Phase II Municipal Separate Storm Sewer System (MS4s), and for permitted construction and industrial stormwater activities.
  - Straight-pipe septic systems: However, straight-pipe septic systems are illegal and un-permitted, and as such are assigned a zero WLA.
  - Livestock facilities that have been issued NPDES permits are assigned a zero wasteload allocation. This is consistent with the conditions of the permits, which allow no pollutant discharge from the livestock housing facilities and associated site. Discharge of pollutants from fields where manure has been land applied may occur at times. Such discharges are covered under the load allocation portion of the TMDLs, provided the manure is applied in accordance with manure management provisions of the permit.
  - It is important to note that all relevant NPDES wastewater permits in an impaired watershed need to be listed individually in the TMDL document. For stormwater, all MS4 Phase I and Phase II permits should be listed, and any other regulated stormwater activity included in the WLA.
  - To the extent possible and practical, individual WLAs should be established for NPDES dischargers, including regulated MS4s (see below – “Estimating WLAs”). Construction and industrial stormwater permits should get an individual WLA when deemed necessary, although categorical allocations may be the norm in most TMDLs.
  - The location of sources in the watershed may need to be evaluated for their water quality impact at the point of load contribution calculation. For example, while phosphorus entering surface waters is generally transported downstream there may be specific instances where phosphorus load retention upstream of an impairment should be taken into account. In order to justify any allocation allowances based on source location, clear support and documentation is necessary. This consideration may apply to both the WLA and LA.
  - Pollutant trading, including either trading between point sources or trading between point sources and nonpoint sources, can be included in the TMDL and developed in detail in
the subsequent implementation plan, as a means to meet a WLA. However, the MPCA’s trading policy has not been finalized. Trading may further the need for geographic consideration of loads.

- **Estimating WLAs**

  **Wastewater point sources:**
  For POTWs and industrial wastewater facilities, either the MPCA should be contacted for the electronically-available discharge monitoring reports (DMRs) for that facility, or the facility should be contacted directly. These data should be used to define the current WWTF phosphorus loading to the water body, which will serve as a basis for the allocations.

  **MS4 Stormwater:**
  For estimating current loads from regulated MS4s and establishing allocations, each MS4 should be contacted for pertinent information. Current loading should be estimated as precisely as data allows. Guidance issued in 2002 from EPA (“Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs” (November 22, 2002); [http://www.epa.gov/npdes/pubs/final-wwtmdl.pdf](http://www.epa.gov/npdes/pubs/final-wwtmdl.pdf)) will be useful in determining your approach.

  EPA notes that it may be reasonable to express NPDES-regulated storm water discharges from multiple point sources as a single categorical waste load allocation, when data and information are insufficient to assign each source or outfall individual WLAs. More specifically, the waste load allocation in the TMDL can be expressed as either a 1) single number for all NPDES-regulated stormwater discharges, or 2) when information allows, as different WLAs for different categories, such as all MS4s separated out from construction and industrial stormwater and treated either in aggregate or as individual MS4s (City A vs. City B).

  In keeping with this guidance, the MPCA believes that many waste load allocations for regulated MS4s will be made in the aggregate by categorical sector (e.g. a 33 percent reduction for the MS4 sector) because of the insufficient quantity and quality of existing data on each individual MS4. However, if enough data exists, it is strongly encouraged that an individual WLA be set for each MS4 discharger.

  Here are examples of these two options, as described for Lake Nutrient TMDLs (turbidity TMDLs would follow the same process but using sediment-related units):

  1. **Sector-wide allocation:** A TMDL could find that all regulated MS4 sources together contribute a total of 300 lbs. of phosphorus and a load reduction of 100 lbs. is necessary to meet the WLA goal, or roughly a 33 percent load reduction. All MS4s would be evaluated together to achieve the load reduction of 100 lbs.

  2. **Individual allocation**
     a.) If a city-by-city WLA approach for MS4s is preferred, the MPCA proposes that the WLA be divided equally among MS4s, in proportion to the size of their contributing watershed. For example, the TMDL finds that a 33% reduction
(equivalent to 100 lbs. of phosphorus) is needed. The total contribution from three cities in a TMDL watershed is 300 lbs. and the total WLA requires a reduction of 100 lbs of phosphorous. If cities A, B, and C together have 100% of the impaired watershed, and City A’s permit boundaries cover 80%, City B’s 10% and City C’s 10%, then the load allocation for City A’s reduction goal would be 80 lbs, and City B and C would be 10 lbs each. However, all three cities reduce the same proportional amount of phosphorus.

b.) If sufficient water quality data exists on specific MS4 contributions and applied BMPs, a more tailored WLA can be set for each city. For example, if a city has eliminated its illicit discharges while another city has not, equal load reductions may not be equitable.

- **Water Quality-Based Effluent Limits**
  As noted in the federal requirements in the box above, NPDES permits must be consistent with the assumptions and requirements of a TMDL’s wasteload allocation. Therefore, for Wastewater Facilities, water quality-based effluent limits contained in the permit must be consistent with the individual WLAs specified in the TMDL. In most cases, the WLA in the TMDL and effluent limit in the permit will be expressed in terms of mass. For regulated MS4s, water quality-based effluent limits may be in the form of Best Management Practice (BMPs) or in the form of numeric effluent limits. If data allows, the TMDL should define the percentage of the load allocation for each NPDES permitted facility and for each MS4.

- **NPDES Permit Compliance Schedules and Water Quality Trading**
  Federal regulations set requirements for NPDES permit compliance schedules to meet effluent limits. In general, there are two expectations:
  1. Each NPDES permit must meet effluent requirements; and
  2. The compliance schedule for meeting the requirements should be within one permit cycle.

  Despite these expectations, there is flexibility in setting permit compliance schedules to meet TMDL WLAs in certain situations. It is important that TMDL project teams discuss these situations with MPCA permitting staff as WLAs are being developed to ensure that compliance schedules are set appropriately.

**Compliance Options for Wastewater Facility Permits:**
As noted above, there is an expectation for all wastewater NPDES permits to meet the TMDL WLA in the first five-year permit cycle. However, there can be exceptions to this process when justified:

1) **Multiple TMDLs in the same watershed:** When NPDES permitted facilities may have to comply with more than one TMDL for the same pollutant parameter but are on different completion timelines, a longer compliance schedule may be necessary. This is to ensure that facility upgrades are made to meet the most restrictive TMDL WLA (i.e., the TMDL that may require more restrictive limits or longer seasonal application of the limits).

For example, in the case of the Minnesota River low dissolved oxygen TMDL, the critical period was during summer months. However for the Lake Pepin excess nutrient TMDL, the critical period will most likely be year-round. Therefore, the
upgrade of the facilities for the seasonal effluent limitation versus the upgrade needed for year-round treatment can be significantly different. Setting milestone markers until the other TMDL studies are completed will minimize the occurrence of new or expanding systems being built that are immediately required to upgrade again to meet a more restrictive TMDL.

It is important to discuss this type of justification (including expected timelines for milestones and steps necessary to meet them) in the TMDL report to clarify how NPDES permit compliance schedules will meet the TMDL’s WLA.

2) **Pollutant Trading and Watershed Permits:** For NPDES-permitted wastewater facilities that may not be able to meet a TMDL WLA, two options are emerging: pollutant trading and watershed permitting. A policy for pollutant trading, is currently being developed by the MPCA. Trading enables entities located upstream of a given impairment to work together to cumulatively achieve the WLA. Pollutant trading can benefit dischargers by using either the benefits of economy of scale, or by limiting the upgrades or installations of BMPs (in the case of point to nonpoint trading) to those that are the least expensive, and “trading” the activities of the most expensive for an equivalent reduction or a net pollutant load decrease.

The second option, a watershed permit, allows all NPDES activities to be sequenced and considered on a cumulative basis in a watershed. In this process, a cumulative problem can be solved by sequencing all the NPDES permits to implement a specified set of reductions across a given timeframe. This has the potential to accelerate implementation schedules and also provides a better opportunity to set expectations for reductions at an equitable level.

It is important that if either of these alternatives are factored into final TMDL implementation strategies to meet a WLA, they are discussed in the TMDL report. This will provide guidance on permit compliance schedules and/or the use of more flexible compliance alternatives.

**Compliance Options for Stormwater Permits:**

TMDL WLAs for regulated MS4s should reflect the timing required to retrofit existing developed areas with BMPs and to set adequate milestones for developing areas. In general, it should be assumed that multiple permit schedules will be needed to meet TMDL reduction targets, and the regulated MS4 needs to make progress in each permit cycle to meet a WLA. Progress indicators include establishing a stormwater program, doing good housekeeping, addressing retrofits and new development, prevention and education, and structural BMPs.

If the TMDL study has enough data to set reduction milestone timelines and goals, then the SWPPP for each permit cycle can reference the TMDL and the milestones to justify its compliance with the TMDL. Other options are also possible:

1) **Phased TMDLs:** For instances where the TMDL study has significant uncertainty about stormwater loadings and management practices to effectively address that loading, an EPA memorandum dated August 2, 2006 entitled *Clarification Regarding “Phased” Total Maximum Daily Loads* ([http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.pdf](http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.pdf)) outlines acceptable methods to discuss “phased” approaches in the TMDL study.
Phased TMDLs should be limited to TMDLs that for scheduling reasons need to be established, despite significant data uncertainty, and where the State expects the loading capacity and allocation scheme will be revised in the near future as additional information is collected. As with any TMDL, each phase must be established to attain and maintain the applicable water quality standard and would require re-approval by EPA if the loading capacity, wasteload or load allocations are revised.

For stormwater TMDLs using a phased approach, collection of missing data needed to assess loading or management practices would be required through SWPPPs. This should be clearly discussed in the TMDL report.

2) Pollutant Trading: EPA is currently developing an approach for stormwater pollutant trading. There are a few pilot programs ongoing at the national level testing the situations that would provide clarity on how and when stormwater pollutant trading would be allowed. The MPCA will be developing options in this area as well.

References:

“Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs” (November 22, 2002); http://www.epa.gov/npdes/pubs/final-wwtmdl.pdf.

6. Margin of Safety (MOS)

**Federal Requirements:** The statute and regulations require that a TMDL include a margin of safety (MOS) to account for any lack of knowledge concerning the relationship between load and wasteload allocations and water quality (CWA §303(d)(1)(C), 40 C.F.R. §130.7(c)(1) ). EPA’s 1991 TMDL Guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS **must** be described. If the MOS is explicit, the loading set aside for the MOS **must** be identified.

Protocol for Minnesota Turbidity TMDLs:

If a load duration curve approach is used to define the TMDL, the margin of safety for each flow category is presented as the difference between the median and minimum target loads for each category (Cleland 2003). The draft Lower Cannon River Turbidity TMDL provides a specific example of how the margin of safety is presented with a duration curve.

7. Reserve Capacity (allocation for future growth)

**Federal Requirements:** Only implied under LA and WLA requirements (see above) as the “portion of the loading capacity attributed to existing and future sources”
Protocol for Minnesota Turbidity TMDLs:

Reserve Capacity is that portion of the TMDL that accommodates future loads. The MPCA’s policy on reserve capacity is that it be considered by all TMDL projects, and the final report should clearly describe the rationale for a decision regarding this issue.

Inclusion of an allocation for reserve capacity in the TMDL is strongly encouraged. Reserve capacity can be ascribed singly to the WLA, the LA or both; e.g. new and expanding WWTF’s, MS4s that will be covered by a permit in the future or that are permitted now and may expand, and/or land use changes. If an allocation for reserve capacity is not included, either no new future loads are anticipated or allowed, or increased loads must be accommodated by pollutant trading. In the case of MS4s, growth may also be accommodated in the WLA based on larger municipal boundaries or expansion area designations, if appropriate. If reserve capacity is accommodated by trading only, a discussion of a viable trading program and the implications to new loads should be included. A typical 20-year planning timeline for consideration of reserve capacity is recommended.

The TMDL report should provide the basis for the amount of reserve capacity, guidelines for making reserve capacity available to new loads and the means to replenishing reserve capacity when it has been depleted. Replenishing reserve capacity can be accomplished through the following options:

**WWTF sources**
- Concentration adjustments – reallocation based on concentration effluent limits at the given design flow;
- Flow adjustments – reallocation of allowed design flow at the given concentration; or
- Mass adjustments – mass-based effluent limit.

**Nonpoint sources and MS4s**
- Additional BMP implementation;
- Reducing watershed loads.

**General**
- Reducing margin of safety through greater understanding of load response conditions.

It is anticipated that reserve capacity issues will largely be a policy discussion that requires input from all affected parties and consideration of future loads in the watershed. Policy considerations for allocating reserve capacity to new loads should be based on an equitable and consistent set of criteria.

In the case of WWTFs, it may not be completely possible to anticipate all new future loads. An example of this would be those loads from new unplanned industrial sources. If this appears a likely scenario, an increased reserve capacity over that anticipated to be necessary may be warranted.

The allocation of reserve capacity should be fully documented so that any future reallocation can consider past allocation changes. Additionally, reserve capacity balances must be documented at
all times. This should include detailed documentation of all new loads that have been transferred to the WLA and LA.

Where appropriate for particular parameters like phosphorus, consideration may be given to requiring new loads to provide a higher level of treatment/BMP implementation to access reserve capacity. For example, if WWTFs are generally meeting 1 mg/L phosphorus effluent limitations of 0.5 mg/L phosphorus may be a criterion to access reserve capacity. New loads from new sources or expanded sources may be treated the same or differently.

8. Seasonal Variation

Federal Requirements: The statute and regulations require that a TMDL be established with consideration of seasonal variations. The TMDL must describe the method chosen for including seasonal variations. (CWA §303(d)(1)(C), 40 C.F.R. §130.7(c)(1)).

Protocol for Minnesota Turbidity TMDLs:

The current approach being used to evaluate seasonal variation, again, involves the use of duration curves.

9. Reasonable Assurances

Federal Requirements: When a TMDL is developed for waters impaired by point sources only, the issuance of a National Pollutant Discharge Elimination System (NPDES) permit(s) provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. This is because 40 C.F.R. 122.44(d)(1)(vii)(B) requires that effluent limits in permits be consistent with "the assumptions and requirements of any available wasteload allocation" in an approved TMDL.

When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur, EPA's 1991 TMDL Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for EPA to determine that the TMDL, including the load and wasteload allocations, has been established at a level necessary to implement water quality standards.

EPA's August 1997 TMDL Guidance also directs Regions to work with States to achieve TMDL load allocations in waters impaired only by nonpoint sources. However, EPA cannot disapprove a TMDL for nonpoint source-only impaired waters, which do not have a demonstration of reasonable assurance that LAs will be achieved, because such a showing is not required by current regulations.

Protocol for Minnesota Turbidity TMDLs:

Generally, reasonable assurances include descriptions of the regulatory and non-regulatory efforts at the state and local levels that will likely result in reductions from the load allocation portion of the TMDL. Reasonable Assurances also include the identification of potential or likely funding sources that will enable reductions from the load allocation.
The following list of scenarios describes when to include Reasonable Assurances in the TMDL submittal:

- **Nonpoint source only TMDLs (Load Allocation only):** Although EPA does not require reasonable assurances in this type of TMDL, the MPCA requires a description of reasonable assurances for nonpoint only TMDLs. Reasonable assurances in these types of TMDLs allow the MPCA to evaluate the potential options available to enable reductions from nonpoint sources.

- **TMDLs with offsets in the Waste Load Allocation from the Load Allocation:** EPA requires reasonable assurances in this situation in order to approve the TMDL. This is clarified in the 1991 EPA guidance document, *Guidance for Water Quality-Based Decisions: The TMDL Process*. The guidance addresses waters impaired by both point and nonpoint sources where the waste load allocation to point sources is predicated on nonpoint source loading reductions, i.e., where point sources receive a more generous waste load allocation because the TMDL assumes that a larger share of load reductions will come from nonpoint sources. In such cases, some additional provision in the TMDL, such as a schedule and description of the implementation mechanisms for nonpoint source control measures, is needed to provide reasonable assurance that the nonpoint source measures will achieve the expected load reductions. Such additional provisions are also needed in this type of TMDL to assure compliance with the federal regulations at 40 CFR 130.2(i), which provide that in order for waste load allocations to be made less stringent, more stringent load allocations must be “practicable.”

- **TMDLs without offsets in the Waste Load Allocation from the Load Allocation:** Although EPA does not require reasonable assurances in this type of TMDL, the MPCA requires a description of reasonable assurances. Reasonable assurances in these types of TMDLs allow the MPCA to evaluate the potential options available to enable reductions from nonpoint sources.

- **TMDLs with wastewater permittees in the Waste Load Allocation:** Reasonable assurances are not required for wastewater permittees because federal regulations require that permits with numeric effluent limits comply with the Waste Load Allocation in the TMDL.

- **TMDLs with required and discretionary MS4 stormwater permittees in the Waste Load Allocation:** As noted in the box above, NPDES permit requirements must be consistent with the assumptions and requirements of available WLAs. See 122.44(d)(1)(vii)(B). Since permits for required and discretionary MS4 do not contain numeric limits, the MPCA requires an MS4 to provide reasonable assurances in the following manner:

  “If an EPA-approved TMDL(s) has been developed, you must review the adequacy of your Storm Water Pollution Prevention Program to meet the TMDL’s Waste Load Allocation set for storm water sources. If the Storm Water Pollution Prevention Program is not meeting the applicable requirements, schedules and objectives of the TMDL, you must modify your Storm Water Pollution Prevention Program, as appropriate, within 18 months after the TMDL is approved.”
This permit language should be cited in the reasonable assurance section of the TMDL. In addition, note that the implementation plan, likely to be finalized one year following EPA approval of the TMDL, will identify specific BMP opportunities sufficient to achieve their load reduction and their adoption schedule, and the individual SWPPPs would be modified accordingly following the recommendations of this plan.

- **TMDLs with construction stormwater permittees in the Waste Load Allocation:**
  As noted in the box above, NPDES permit requirements must be consistent with the assumptions and requirements of available WLAs. See 122.44(d)(1)(vii)(B). Since permits for construction stormwater do not contain numeric limits, the MPCA requires construction stormwater included in the TMDL’s wasteload allocation to provide reasonable assurances by citing the TMDL compliance requirements of provisions in the NPDES Construction Stormwater Permit (Part I.B.7, Part III.A.4.d, and Part III.A.7). According to Part I.B.7 of the General Permit:

  “Discharges to waters for which there is a total maximum daily load (TMDL) allocation for sediment and parameters associated with sediment transport are not eligible for coverage under this permit unless the Permittee(s) develop and certify a SWPPP that is consistent with the assumptions, allocations and requirements in the approved TMDL. To be eligible for coverage under this general permit, Permittee(s) must incorporate into their SWPPP any conditions applicable to their discharges necessary for consistency with the assumptions, allocations and requirements of the TMDL within any timeframes established in the TMDL. The SWPPP must include the provisions in Part III.A.7. If a specific numeric waste load allocation has been established that would apply to the project's discharges, the Permittee(s) must incorporate that allocation into its SWPPP and implement necessary steps to meet that allocation.”

As with MS4s, the permit language above should be cited in the reasonable assurance section of the TMDL. In addition, note that the implementation plan that is finalized within one year following EPA approval of the TMDL, will identify specific BMP opportunities for any allocations to construction stormwater sufficient to achieve the load reduction and adoption schedule, and the individual SWPPPs would be modified accordingly following the recommendations of this plan.

**References:**


MS4 permit requirements: [http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html#requirements](http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html#requirements)

Construction stormwater permit requirements: [http://www.pca.state.mn.us/water/stormwater/stormwater-c.html#forms](http://www.pca.state.mn.us/water/stormwater/stormwater-c.html#forms)
10. Monitoring Plan to Track TMDL Effectiveness

**Federal Requirements:** EPA’s 1991 document, Guidance for Water Quality-Based Decisions: The TMDL Process (EPA 440/4-91-001) [http://www.epa.gov/OWOW/tmdl/decisions/] recommends a monitoring plan to track the effectiveness of a TMDL, particularly when a TMDL involves both point and nonpoint sources, and the WLA is based on an assumption that nonpoint source load reductions will occur. Such a TMDL should provide assurances that nonpoint source controls will achieve expected load reductions and, such TMDL should include a monitoring plan that describes the additional data to be collected to determine if the load reductions provided for in the TMDL are occurring and leading to attainment of water quality standards.

**Protocol for Minnesota Turbidity TMDLs:**

A monitoring plan associated with TMDLs offers an opportunity to focus existing monitoring activities in the watershed, as well as identify additional needs, toward achieving the common goals of assessing and improving water quality. Many of Minnesota’s waters have active watershed associations that routinely collect water quality data and information. The monitoring plan for the TMDL could outline how collaborative monitoring efforts could be used to better define sources, target sources for control actions, evaluate the effectiveness of controls, and ultimately assess the adequacy of the TMDL.

Generalized monitoring designs for streams and watersheds are presented below. In addition, it is also recommended that the reader review EPA’s clarifying guidance [http://www.epa.gov/owow/tmdl/tmdl_clarification_letter.html] on three situations where follow-up monitoring strategies are needed to provide assurances that nonpoint source controls will be achieved: “phased TMDLs”, “adaptive implementation” and “staged implementation”.

**Figure 4: Iterative TMDL Process**

```
<table>
<thead>
<tr>
<th>Iterative TMDL Process</th>
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<tbody>
<tr>
<td>Define Management/Use Objectives</td>
</tr>
<tr>
<td>Identify Water Quality Standards</td>
</tr>
<tr>
<td>Monitor &amp; Model</td>
</tr>
<tr>
<td>Estimate TMDL's</td>
</tr>
<tr>
<td>Evaluate Controls</td>
</tr>
<tr>
<td>Develop Load Allocations</td>
</tr>
<tr>
<td>Implement Controls</td>
</tr>
<tr>
<td>Monitor Results</td>
</tr>
<tr>
<td>Objectives Achieved?</td>
</tr>
</tbody>
</table>
```

~ 5-10 years?

*Schematic of TMDL Adaptive Management (Walker, 2001)*

Monitoring – Rivers
Consideration of critical conditions and the analysis tool used to assess the progress towards and compliance with the numeric criteria is the first step to designing an effectiveness monitoring program for turbidity in rivers. It is necessary to facilitate a monitoring program that will track the resource conditions as implementation activities take place so that it can be used to estimate the progress in a flow regime where monitoring data is not available.

Delisting will only be possible after the critical conditions have existed and adequate monitoring can be provided that demonstrates the system to be in complete water quality attainment.

**Monitoring Change**

Tracking of water quality changes over time resulting from the implementation of watershed and lake rehabilitations can be reasonably accomplished with due consideration of time lags, geographic scale, monitoring approaches and quality assurance.

The efforts in Minnesota have been routine based (every month or every two weeks), and event based with consideration to continuous measurement of flows. Whether the monitoring data is collected by grab sampling, or by storm hydrograph sampling by automated equipment, depends on the project goals and station location to field crew. The selection will depend both on the analysis tool used for tracking progress (suggested to be the analysis tool utilized in the TMDL) and the critical parameters identified by the TMDL.

In addition, the implementation of significant percentages of BMPs or treatment measures needs to be in place prior to initiating the "after" condition water quality monitoring efforts. It is suggested that upon obtaining a good "prior" condition baseline, that a skewed roll out be used with the more significant resource monitoring being initiated after 60 percent or more of the reduction measures are implemented (this percentage best applied by load; however, if not available then a number count of the measures can be done). This requires adequate land use tracking efforts to be set up and in place during the implementation period, such as e-Link, the residue transect survey, wastewater DMR reports, county feedlot inventories and others as determined by the specific TMDL.

**Time Lags**

Before and after monitoring, quality assurance plans are required for TMDL projects by ensuring that appropriate field and laboratory procedures are employed. Use of certified labs is a part of this quality assurance process. Other typical quality assurance aspects include consideration of:

- **accuracy** as a function of methods (field and laboratory);
- **precision** as a function of methods, and sample frequency; and
- **probability** of detecting change as a function of precision, variability, and duration of sampling, much of which was described in previous sections of this document.

Over the course of a watershed management effort, there can be significant time periods that occur from the time of recognition of water quality problems, rehabilitation of key watershed areas and improvement of water quality. Projects usually begin with a one to three year diagnostic study coupled with building requisite local partnerships. Additional time is needed for public notices and contracts leading up to planning and design of watershed corrective actions. The final leg of the restoration journey involves BMP construction usually coupled with vegetative re-growth. All of these changes need to occur before the stream has a chance to reach attainment. After implementation and establishment of all the treatment measures, the flow
regimes in the stream may need to be from a wet weather period to be high enough to flush SOD out of the system prior to the complete compliance attainment.

**Geographic scale and Rehabilitation Sequencing**
The size of the contributing watershed to a given impaired reach will be a large determinant in the time and effort needed to effect improved water quality. The monitoring options defined in the above guidelines will help guide establishment of required stream flow gauging and sampling efforts, with smaller areas showing changes more quickly. Smaller watersheds can be typically expected to respond more quickly to watershed corrective measures. Large watershed projects are encouraged to develop smaller more optimal detection tracking project areas.

**References:**

### 11. Implementation

**Federal Requirements:** EPA policy encourages Regions to work in partnership with States/Tribes to achieve nonpoint source load allocations established for 303(d)-listed waters impaired by nonpoint sources. Regions may assist States/Tribes in developing implementation plans that include reasonable assurances that nonpoint source LAs established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved. In addition, EPA policy recognizes that other relevant watershed management processes may be used in the TMDL process. EPA is not required to and does not approve TMDL implementation plans.

**Protocol for Minnesota Turbidity TMDLs**

For Turbidity TMDLs, the detailed and site-specific implementation planning will take place during the implementation plan development.

Projects must include in the written TMDL submitted to MPCA the broad implementation strategies to be refined and finalized after the TMDL is approved. Projects are required to submit a separate, more detailed implementation plan document to MPCA within one year of the TMDL’s approval by EPA. For example, highly complex TMDLs or TMDLs requiring reductions for NPDES-permitted point sources (wastewater, stormwater, feedlots) may require this additional time following approval to prepare detailed implementation plans. The implementation plan document is not approved by the EPA.

In addition, the recently enacted Clean Water Legacy Act requires that a TMDL include a range of cost estimates for implementation of the TMDL; and for point sources, the individual waste load data and estimated cost of compliance with the TMDL. It should be emphasized that it is appropriate to provide a cost range in this estimate which may be refined after the TMDL is approved and a detailed implementation plan is developed.

For further information on implementation plan requirements, review MPCA’s TMDL work plan guidance at [http://www.pca.state.mn.us/publications/wq-iw1-01.pdf](http://www.pca.state.mn.us/publications/wq-iw1-01.pdf)
In the implementation plan section, the broad implementation strategies, activity areas and mechanisms for achieving loading reductions should be identified. The implementation plan section should identify:

- How the public will be involved;
- What mechanisms such as financial assistance, ordinances etc., exist or are proposed for development;
- How progress will be monitored such as WQ monitoring, BMP tracking, etc.;
- How pollution control activities will be sited;
- What planning tools or processes will be used to achieve nonpoint source reductions;
- What planning tools, processes, ordinances are in-place or will be proposed to control point sources; and
- What educational and cooperative efforts among stakeholders, landowners, and agencies exist or a proposed for development.

For MS4s, this section of the TMDL should provide a broad overview of activities that will be refined in the implementation plan. Providing this information will help enhance reasonable assurance and explain the adaptive management process planned during implementation, including:

- The current categories of BMPs that are planned (to be refined during implementation planning and SWPPP development);
- The current schedule (i.e., how many permit cycles) for putting BMPs in place; and
- Expected range of potential reductions, based on literature, which can be achieved for each category of BMP (e.g., citizen education program, stormwater ponds, alum treatment, etc.). Note: Additional guidance on this is currently being developed by the MPCA.

For additional information on implementation requirements, the reader is also encouraged to read the Chapter III of the Lakes Nutrient TMDL protocol on site-specific approaches. The chapter outlines data needs and requirements to justify the reopening of a TMDL where everything reasonable has been achieved during implementation to meet water quality standards, but a site-specific standard may be more appropriate for the water body than the original TMDL endpoint.

References:

MPCA’s TMDL work plan guidance at: [http://www.pca.state.mn.us/publications/wq-iw1-01.pdf](http://www.pca.state.mn.us/publications/wq-iw1-01.pdf)
12. Public Participation

**Federal Requirements:** EPA policy is that there should be full and meaningful public participation in the TMDL development process. The TMDL regulations require that each State/Tribe must subject calculations to establish TMDLs to public review consistent with its own continuing planning process (40 C.F.R. §130.7(c)(1)(ii) ). In guidance, EPA has explained that final TMDLs submitted to EPA for review and approval should describe the State's/Tribe's public participation process, including a summary of significant comments and the State's/Tribe's responses to those comments. When EPA establishes a TMDL, EPA regulations require EPA to publish a notice seeking public comment (40 C.F.R. §130.7(d)(2)). Provision of inadequate public participation may be a basis for disapproving a TMDL. If EPA determines that a State/Tribe has not provided adequate public participation, EPA may defer its approval action until adequate public participation has been provided for, either by the State/Tribe or by EPA.

**Protocol for Minnesota Turbidity TMDLs:**

An active stakeholder and public participation process is required throughout the development of every TMDL, from the development of the project work plan to the approval of final pollutant load allocations and public notice process. The ultimate success of the project is in large part dependent upon the effectiveness of this process and development of practical, pragmatic solutions with stakeholders. It is critical that the diverse stakeholders affected by any given TMDL project (and those who must implement it) share a common understanding of the problem and what is needed to solve it.

Public participation is also required through the 2006 Clean Water Legacy Act, which requires the MPCA to seek “broad and early public and stakeholder participation in scoping the activities necessary to develop a TMDL, including the scientific models, methods, and approaches to be used in TMDL development, and to implement restoration…”

Based on the recommendations of a broad-based group of stakeholders (“The G16”) advising the MPCA on TMDLs, the MPCA has piloted an intensive public participation process through its Lake Pepin TMDL. The results of this process will be critical to determining guidance for other TMDL projects. This will include development of a stakeholder advisory group which will provide recommendations on a project throughout the process. The stakeholder advisory group can also receive advice on technical issues from a technical/science advisory group, composed of experts from academia and other institutions. More information on this structure and process can be found by referring to a fact sheet on the Lake Pepin project: [http://www.pca.state.mn.us/publications/wq-iw9-01f.pdf](http://www.pca.state.mn.us/publications/wq-iw9-01f.pdf)

Probably the most critical phase of a stakeholder advisory group process is in developing and making recommendations for source reductions and pollutant load allocations (load allocations, waste load allocations, margin of safety, and reserve capacity). Federal regulations specify only that the total allocations (point source and nonpoint source, margin of safety) prescribed by a given TMDL must satisfy water quality standards for that water’s designated use. The specific method for allocating pollutant loads among sources is a policy issue that must be determined by states according to their own priorities and judgment.
The MPCA will carefully consider stakeholder recommendations, but the final decision will be made after considering a range of allocation options, ensuring that they meet water quality standards, are technically and practically feasible, and are consistent with other regulatory programs that might apply. In addition, competing measures of desirability (where regulatory flexibility allows), such as cost-effectiveness and equity, will be critical factors in determining load allocations.

More specifically, final policy decisions on allocations should reflect public and stakeholder perceptions about acceptable tradeoffs. For example, strategies that minimize costs may be perceived as unfair if particular sources carry most of the load reduction, while allocations based on equal load reductions may be more costly. Other factors that should be considered when making allocation decisions include relative source contributions, technical limitations of any given source to reduce, ability of small entities to pay, and prior load reductions.

Additional information on the allocation process and options can be found at these EPA websites: [http://www.epa.gov/waterscience/models/allocation/def.htm; and http://www.epa.gov/waterscience/models/allocation/19schemes.htm](http://www.epa.gov/waterscience/models/allocation/def.htm; and http://www.epa.gov/waterscience/models/allocation/19schemes.htm).

Local government contractors will have a primary role throughout the public participation process. In general, local government should be prepared to be engaged in these public participation activities:

- Help identify stakeholders that can represent diverse public and private interests in affected watersheds on the Stakeholder Advisory Group for the project.
- Conduct public outreach and education activities at key points throughout the project and prepare a report or section of the draft TMDL that describes those activities.
- Coordinate with the MPCA as needed to assist in the formal public notice process for the draft TMDL, including:
  - Help organize a public meeting(s) for the draft TMDL and compile comments from the public.
  - Help respond to comments, as needed, on the draft TMDL from technical staff, citizens and other interested parties, and EPA.
  - Submit public outreach materials along with the draft TMDL or final report, such as charts, graphs, modeling runs, fact sheets, presentation materials, maps, etc.

Following the allocation process and the final development of a draft, the public notice process can begin. These steps will be led by the MPCA, coordinating with the local government contractor. Most activities will be conducted by the project manager, basin coordinator, public information officer, or impaired waters coordinator, as appropriate.

In general, following are the basic steps to the public notice process:

1. MPCA public information staff and project manager prepare public notice package, to include draft TMDL, fact sheet, public notice and news release.
2. Public Notice
   - The draft TMDL must be on public notice for a minimum of 30 days.
   - The public notice must be published in the *State Register*.
   - The notice must be published on the MPCA Web site.
o The notice should also be mailed or e-mailed to a list of interested parties for the project, and must be mailed to a statewide list of interested parties maintained by the impaired waters program coordinator.

o Public meetings during the public notice phase will be determined based on the level of public participation and outreach during other phases of the project.

3. Public comments: All written public comments must be provided to EPA with the submission of the TMDL. Copies of each comment letter must also be submitted.

4. Final MPCA approvals (either by the Commissioner or the Citizens Board).

5. The TMDL is submitted to EPA for final approval. In accordance with the 2006 Clean Water Legacy Act (114D.25), the final TMDL is submitted to EPA no sooner than 30-days following the conclusion of the public notice period.

Ultimately, a successful public participation process will help ensure that the TMDL is sent to EPA on schedule and has the stakeholder support needed to launch effective implementation.

References

13. Submittal Letter

**Federal Requirements:** A submittal letter should be included with the TMDL submittal, and should specify whether the TMDL is being submitted for a technical review or final review and approval. Each final TMDL submitted to EPA should be accompanied by a submittal letter that explicitly states that the submittal is a final TMDL submitted under Section 303(d) of the Clean Water Act for EPA review and approval. This clearly establishes the State's/Tribe's intent to submit, and EPA's duty to review, the TMDL under the statute. The submittal letter, whether for technical review or final review and approval, should contain such identifying information as the name and location of the waterbody, and the pollutant(s) of concern.

**Protocol for Minnesota Turbidity TMDLs:**

The submittal letter is written by the MPCA and signed by the Commissioner. In addition, the final TMDL report, and any other documents that are a necessary part of the TMDL submittal are ultimately approved by the Commissioner.

14. Administrative Record

**Federal Requirements:** While not a necessary part of the submittal to EPA, the State/Tribe should also prepare an administrative record containing documents that support the establishment of and calculations/allocations in the TMDL. Components of the record should include all materials relied upon by the State/Tribe to develop and support the calculations/allocations in the TMDL, including any data, analyses, or scientific/technical references that were used, records of correspondence with stakeholders and EPA, responses to public comments, and other supporting materials. This record is needed to facilitate public and/or EPA review of the TMDL.

**Protocol for Minnesota Turbidity TMDLs:**

The MPCA project manager and administrative staff will gather and file all necessary documents for the administrative record. This will include all documents listed in the federal requirements above and should be processed according to current MPCA filing protocols.
IV. Site-specific Approaches

The Clean Water Act, federal regulations, Minnesota’s State Water Pollution Control Act and Minnesota’s water quality rules establish opportunities to use site-specific approaches to address water quality impairments. These may be appropriate for some water bodies where numeric criteria different from those presently contained in the water quality standards need to be established to protect beneficial uses. Site-specific options allow the MPCA to consider data on local water body characteristics to apply more precise numeric standards to protect the beneficial uses of the water body. A detailed discussion of site-specific approaches is contained in the companion TMDL protocol for lakes impaired by excessive nutrients. The MPCA does not anticipate that site-specific approaches will be applied frequently, especially in the area of bacteria TMDLs.

VI. References


APPENDIX A: MPCA TMDL Development Activities for Typical Projects

Year 1
1. Organize MPCA technical team
2. Stakeholder involvement and work plan development
   a. Recruit stakeholders, plan stakeholder/technical advisory meetings
   b. Conduct meetings and necessary follow-up
   c. Draft and finalize work plan with stakeholders
   d. Prepare fact sheets and public information as needed
3. Contract development and execution
4. Phase I of work plan
   a. Data compilation and assessment
   b. Identify monitoring needs
   c. Develop assessment approach (level and type(s) of modeling)
   d. Complete Phase I report
   e. Review results w/ stakeholder/technical advisory meeting

Year 2
1. Phase II of work plan
   a. Complete additional monitoring (flow chemical, biological, and physical)
   b. Complete watershed assessments (land use/cover, soils, geology, natural and artificial drainage, etc.)

Year 3
1. Phase II (continued)
   a. Continuation of Year 2
   b. Analyze new data
   c. Complete Phase II report
   d. Review results w/ stakeholder/technical advisory meeting
2. Begin Phase III of work plan
   a. Initial modeling

Year 4
1. Phase III (continued)
   a. Complete modeling--compute loads, assimilative capacity, identify sources
   b. Conduct stakeholder/technical advisory meetings to discuss allocation process, including MOS and growth options
   c. Compute/model allocation and reduction scenarios
   d. Develop implementation strategies with stakeholders
   e. Draft TMDL report
   f. Peer review draft TMDL report
   g. Submit draft to EPA/stakeholders/management for preliminary review
   h. Finalize report via contractor and technical team
2. Public notice process
   a. Publish public notice in State Register and MPCA website; mail to interested parties
   b. Prepare and send fact sheet, press release, web postings

Typical MPCA Staff Involved
- Project manager and technical team:
  - Hydrologist, Engineer, Stormwater, Wastewater, other scientific staff
  - Contracts, Payments, other Admin.
  - Basin coordinator
  - Facilitator
  - GIS staff
  - PIO staff

- Admin. staff (e.g. payments)
  - Field technicians
  - GIS staff

- Admin. staff (payments, tracking)
  - Field technicians
  - GIS staff

- Basin Coordinator
  - TMDL Coordinator
  - Administrative (payments, clerical)
  - GIS staff
  - PIO staff
  - Regional Supervisor/Manager, Commissioner
c. Plan and conduct public meeting(s)
d. Receive comments and develop responses
e. Finalize the TMDL report
f. Route document through MPCA approvals and submit final to EPA

**Year 5**

1. Implementation plan development -- coordinate/assist stakeholders or develop independently as appropriate.
2. Modify or issue NPDES permits to comply w/ allocations
3. Submit plan to MPCA management for approval
4. Assist stakeholders with grant proposal development

<table>
<thead>
<tr>
<th>Typical MPCA Staff Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project manager and Technical Team</td>
</tr>
<tr>
<td>NPDES staff</td>
</tr>
<tr>
<td>Basin coordinator</td>
</tr>
<tr>
<td>Regional and TMDL management</td>
</tr>
</tbody>
</table>

**Year 6 +**

1. Restoration project implementation
   a. Effectiveness monitoring -- assist as needed w/ water quality monitoring, BMP adoption tracking
   b. Manage compliance with allocations and process to access growth
   c. Oversee 319 grant contracts
   d. Report progress to management and EPA (annually)

<table>
<thead>
<tr>
<th>Typical MPCA Staff Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project manager</td>
</tr>
<tr>
<td>NPDES staff</td>
</tr>
<tr>
<td>Basin coordinator</td>
</tr>
<tr>
<td>Outcomes Div. staff</td>
</tr>
</tbody>
</table>
Appendix B

Background of the
Minnesota Turbidity Standard
November, 2006

Laws and Power
In 1927, the Minnesota State Legislature passed an act which charged the State Board of Health with the power and duty of administering and enforcing all laws relating to pollution of any waters of the state [Water Pollution Control Commission, 1963]. Monitoring of lakes and streams was performed, and a number of wastewater treatment plants were constructed. However, there is no evidence that a State standard for turbidity was enacted or enforced.

In 1945, the Minnesota State Legislature passed the Water Pollution Control Act (Minn. Stat. §115), which created the Minnesota Water Pollution Control Commission. The Commission, which included administrative officers of various State agencies and members appointed by the Governor, inherited the power and duty of administering and enforcing all laws relating to pollution of any waters of the state [MPCA, 1976]. Wastewater treatment plant construction, which ceased during World War II, was reinitiated, along with enforcement of dischargers whose effluent polluted the waters of the state. As in 1927, there is no evidence that a State standard for turbidity was enacted or enforced.

In 1956, Congress passed the Federal Water Pollution Control Act, which established the Federal Water Pollution Control Administration. The FWPCA would be the key federal agency in the initial development of water quality standards in the United States.

The Water Quality Act, passed by Congress in 1965 under the guidance of President Lyndon Johnson, required states to adopt criteria for the classification of interstate waters and develop water quality standards. The law ensured that all states would have comparable, but not necessarily identical, regulation. If a state failed to develop water quality standards for instate waters before June 30, 1967, standards would be adopted by the FWPCA. It is with the development of this law that evidence appears of the first ambient water quality turbidity standard for rivers and streams in Minnesota.

In 1967, the Minnesota State Legislature abolished the MWPCC and created the Minnesota Pollution Control Agency (Minn. Stat. §116). The MPCA Board inherited the powers and duties of the MWPCC, with the additional directives of establishing air quality standards and to develop recommendations on solid waste management and land use.

Turbidity Standard in Minnesota

The Water Quality Act of 1965 resulted in the development of Guidelines for Establishing Water Quality Standards for Interstate Waters [1966] by the Federal Water Pollution Control Administration. This document did not contain numerical criteria, but provided guidance to each state on the development of numeric standards.

The first evidence of a numeric ambient water quality standard for turbidity appears in the Proposed Procedures for Classification of Waters of the State and Adoption of Standards of
Quality and Purity prepared by the MWPCC in 1965. These classifications and standards were later adopted by the MWPCC as *Water Quality Standards for the Interstate Waters of Minnesota* in 1967.

A general effluent turbidity standard of 25 was promulgated for all interstate waters of Minnesota where adequate dilution or dispersion is not present, along with ambient turbidity standards for the following classes of interstate waters:

<table>
<thead>
<tr>
<th>Use</th>
<th>Class of Water</th>
<th>Turbidity</th>
<th>Monthly Average Flow Return Period (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Consumption</td>
<td>A</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Fisheries and Recreation</td>
<td>A</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Fisheries and Recreation</td>
<td>B</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Fisheries and Recreation</td>
<td>C</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. Turbidity Standards for Interstate Waters [MWPCC, 1967].

A Statement of Need and Reasonableness (SONAR) was not developed for these standards (the first SONAR for MPCA rules was written in 1980). No reference is given for the turbidity standard. Testimony from the rule hearings is available from MPCA staff. No questions, responses or testimony were made regarding the turbidity standard. Therefore, one can only speculate to the origin and/or logic used to develop the standard.

The units of turbidity were not indicated in the standard. At the time, several units for turbidity were used; including mg/l of a reference substance, such as SiO₂, depth of sample, such as cm; Jackson turbidity units; and depth at which the light that penetrates the sample is reduced to one-millionth of its intensity at the surface. This depth (usually in millimeters) is designated the “millionth intensity depth” of light penetration, abbreviated as m.i.d. It was common at the time to report turbidity results as “turbidity units,” as dictated in Standard Methods [American Public Health Association et al., 1965], or to simply omit units. In 1988, Minn. Rules pt. 7050.0220 was revised to include the units for turbidity as NTUs. The SONAR for the rule [MPCA, 1987] stated that the current units for turbidity were “ambiguous,” and were proposed to be changed to units that are commonly accepted by field analysts.

In an apparent effort to assist states in meeting the federal directive of the Water Quality Act to develop water quality standards, the FWPCA published the *Report of the Committee on Water Quality Criteria* in 1968. Commonly referred to as the “Green Book,” it was “the most comprehensive document on water quality requirements to date, and as such, will be used as a basic reference by groups and agencies engaged in water quality studies and standards setting activities [FWPCA, 1968].” While the publication of this document post-dates the promulgation of the interstate water quality standards by the MWPC in 1967, it is quite likely that MWPCC staff had access to earlier drafts of the Green Book. The Preface to the Green Book indicates that the final published version was partially based upon comments by agencies and individuals.

The Green Book is divided into sections based upon use classifications. The Fish and Aquatic Life section has a page of text which addresses turbidity. As with other parameters, the discussion on turbidity ends with a recommendation:
“Turbidity in the receiving water due to a discharge should not exceed 50 JTU in warm-water streams or 10 JTU in cold-water streams. There should be no discharge to warm-water lakes which will cause turbidities exceeding 25 Jackson Units. The turbidity of cold-water or oligotrophic lakes should not exceed 10 units.”

No reference or apparent logical development of this conclusion is given. However, the Green Book does cite a commonly referenced paper by Buck [1956] who investigated fish production in farm and hatchery ponds and in reservoirs. Thirty-nine farm ponds with widely ranging turbidities were ret honed and then restocked with largemouth bass and either bluegills or red ear sunfish. Turbidity was created artificially in 14 hatchery ponds. Natural, uncontrolled fish populations were studied in two reservoirs – one “muddy” (surface turbidities ranging from 51 ppm to 300 ppm, summer averages of 136 ppm and 126 ppm in 1954 and 1955, respectively), the other with clear water. Fish populations in the ponds were determined using seines, electro-fishing, and rotenone at the end of two growing seasons. The monitoring generated the following conclusions:

1. Relatively clear ponds yielded much greater weight of fish as well as greater numbers of large fish;
2. In clear water, fish grew more rapidly than in more turbid water, and bluegills and red ear sunfish reproduced more abundantly;
3. Muddy ponds did not yield as many bass of desirable length (10 inches or longer) as did intermediate or clear ponds;
4. At the end of the first summer, yearling bass were found in 7 of the 12 clear ponds, 4 of 12 intermediate ponds, and 0 of 9 muddy ponds. The most turbid pond from which young bass were recovered in 1954 had an average turbidity of 84 ppm;
5. During the first growing season, evidence indicated that turbidity and associated conditions had retarded development to the extent that fish were physically incapable of reproduction;
6. Newer ponds with hard bottoms produced young at higher average turbidities than older ponds with soft, silty bottoms;
7. Results from the two reservoirs confirmed the results found from the farm and hatchery ponds, with the addition that other species of fish (catfish, carp, and white crappies) were found to survive and reproduce in the muddy reservoir; and
8. Turbidity decreases light penetration which in turn decreases productivity.

Spectrophotometer analysis performed by Claffey [1955] revealed that increasing turbidity greatly decreases the penetration of red wavelength light in water, as shown in Table 2:

<table>
<thead>
<tr>
<th>Turbidity, ppm</th>
<th>Depth, inches</th>
<th>Red Wavelength Light Penetration, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>4</td>
<td>24.9</td>
</tr>
<tr>
<td>50</td>
<td>4</td>
<td>6.3</td>
</tr>
<tr>
<td>150</td>
<td>3</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 2. Red Wavelength Light Penetration versus Turbidity [Claffey, 1955].
The effects of turbidity upon fish production in the 12 farm ponds (four clear, four intermediate, and four muddy) where total population estimates were made at the end of the second growing season are presented in Table 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Clear Ponds</th>
<th>Intermediate Ponds</th>
<th>Muddy Ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Turbidity, ppm</td>
<td>&lt;25</td>
<td>25–100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Fish yield, lbs/acre</td>
<td>161.5</td>
<td>94</td>
<td>29.3</td>
</tr>
<tr>
<td>Ratio of volumes of net plankton</td>
<td>12.8</td>
<td>1.6</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Farm Pond Productivity [Buck, 1956].

Federal Criteria

The current Federal criteria for turbidity is given in the U.S. Environmental Protection Agency publication *Quality Criteria for Water 1986*. Commonly referred to as the “Gold Book,” the turbidity criteria for freshwater fish and aquatic life is given as:

“Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.”

Effluent Standard

As described above, the MWPC developed an effluent turbidity standard in 1967. A modified version of this standard was repealed in 1987. The reasons for deletion of the standard are given in the Statement of Need and Reasonableness [MPCA, 1987]: “...[turbidity] is a nonspecific parameter which primarily reflects the aesthetic appearance of the water as opposed to its chemical characteristics...” and “There is little information to be gained by monitoring for turbidity. The Agency staff has concluded the continued use of the total suspended solids test and other secondary treatment requirements will adequately monitor the aesthetic character of the wastewater discharges.” In addition, the $7.00 per analysis cost for turbidity was cited as an unnecessary financial burden for the wastewater treatment plant operator.

Test Methodology

In 1900 the first practical attempt to measure turbidity was developed by Whipple and Jackson, who developed a standard suspension using 1000 parts per million of diatomaceous earth in distilled water. A ppm–silica turbidity scale was developed from dilutions of this standard suspension. Jackson applied the ppm–silica scale to a diaphanometer – a type of turbidimeter that existed at the time. The resulting turbidimeter became known as the Jackson Candle Turbidimeter [Sadar, 1998].

The Jackson Candle Turbidimeter consists of a calibrated glass tube, a standard candle, and a support which aligns the candle and the glass tube. Turbidity is measured by determining the point at which the candle flame disappears when viewing from the top of the glass tube (Figure 1). The longer the sample length at which the flame disappears – the greater the turbidity (Table 4). The resulting depth of the sample was compared to the reference ppm–silica scale, with the resulting value given as Jackson turbidity units.
A problem with the JTU scale was that reference suspensions were made with materials found in nature – including Fuller’s earth, kaolin, and stream sediment – which made it difficult to obtain consistent and comparable results. This problem was addressed in 1926, when Kingsbury and Clark developed the formazin reference suspension, which consisted of dissolving 5 grams of hydrazine sulfate and 50 grams of hexamethylenetetramin in one liter of distilled water. After standing for 24 hours at 25°C, the solution develops a white turbidity. Under ideal conditions of temperature and light, this reference suspension can be developed with an accuracy of ±1%. Formazin is the only known standard suspension that can be made from traceable raw materials. For use as a turbidity reference solution, formazin has the desirable feature of polymer chains of varying lengths which fold into random configurations. This feature results in formazin particles of varying shapes and sizes ranging from 0.1 microns to >10 microns. Such a random reference suspension is likely to coincide with the varying particle sizes found in nature. In addition, the randomness of particle shapes and sizes within the formazin reference suspension yields statistically reproducible light scatter on all makes and models of turbidimeters.

In 1955, *Standard Methods for the Examination of Water and Wastewater* abandoned the ppm–silica scale, and turbidity was report simply as “turbidity units.” As will be described later, this lack of units for turbidity was used for many years, even though more descriptive units were subsequently developed. Turbidity came to be reported as “formazin turbidity units” after acceptance of the formazin solution as a reference standard. However, formazin was not adopted by the American Public Health Association and the American Water Works Association as the primary turbidity standard material until the publication of the 13th edition of *Standard Methods for the Examination of Water and Wastewater* in 1971.
Figure 1. Jackson Candle Turbidimeter.
The standard test apparatus for determination of turbidity at the time of propagation of the water quality standard for turbidity is the candle turbidimeter – commonly referred to as the Jackson Candle Turbidimeter [American Public Health Association et al., 1965]. The test was designed for “those industries where the product is destined for human consumption,” which includes beverage producers, food processors, and water treatment plants.

The MWPCC and the MPCA used the Hellige turbidimeter to determine turbidity from 1953 to 1969. In 1970, use of the Hach 2100 turbidimeter was initiated [MPCA, 1978]. The Hellige turbidimeter is similar to the Jackson candle turbidimeter in that it is a visual method based upon the amount of light that is transmitted from the source to the receptor, as opposed to the amount of light which is reflected, as with a nephelometer. The Hellige turbidimeter measures turbidity as the concentration of SiO$_2$, usually reported in mg/l. The Hellige turbidimeter was calibrated to a Jackson candle turbidimeter, and the results were reported to the MWPCC/MPCA as turbidity units [MPCA, 1968].

The Jackson candle turbidimeter is limited in that the lowest turbidity value which can be measured is 25 turbidity units. Turbidities less than 25 are estimated by visual comparison to samples of known dilution. Since treated water has a turbidity in the range of 0 to 5 units, “indirect secondary” methods have been used to determine the turbidity of treated water. Because of the difference in optical systems, no secondary instrument will duplicate the results obtained from a Jackson candle turbidimeter for all types of samples, even if the instrument has been calibrated to a Jackson candle turbidimeter. At low turbidities, nephelometers give a good estimation of light scattered in particular directions – especially at a reflected angle of 90º to the incident light. However, there is no direct relationship between turbidity determined by the

<table>
<thead>
<tr>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>1,000</td>
<td>7.3</td>
<td>300</td>
<td>19.6</td>
<td>110</td>
</tr>
<tr>
<td>2.6</td>
<td>900</td>
<td>7.5</td>
<td>290</td>
<td>21.5</td>
<td>100</td>
</tr>
<tr>
<td>2.9</td>
<td>800</td>
<td>7.8</td>
<td>280</td>
<td>22.6</td>
<td>95</td>
</tr>
<tr>
<td>3.2</td>
<td>700</td>
<td>8.1</td>
<td>270</td>
<td>23.8</td>
<td>90</td>
</tr>
<tr>
<td>3.5</td>
<td>650</td>
<td>8.4</td>
<td>260</td>
<td>25.1</td>
<td>85</td>
</tr>
<tr>
<td>3.8</td>
<td>600</td>
<td>8.7</td>
<td>250</td>
<td>26.5</td>
<td>80</td>
</tr>
<tr>
<td>4.1</td>
<td>550</td>
<td>9.1</td>
<td>240</td>
<td>28.1</td>
<td>75</td>
</tr>
<tr>
<td>4.5</td>
<td>500</td>
<td>9.5</td>
<td>230</td>
<td>29.8</td>
<td>70</td>
</tr>
<tr>
<td>4.9</td>
<td>450</td>
<td>9.9</td>
<td>220</td>
<td>31.8</td>
<td>65</td>
</tr>
<tr>
<td>5.5</td>
<td>400</td>
<td>10.3</td>
<td>210</td>
<td>34.1</td>
<td>60</td>
</tr>
<tr>
<td>5.6</td>
<td>390</td>
<td>10.8</td>
<td>200</td>
<td>36.7</td>
<td>55</td>
</tr>
<tr>
<td>5.8</td>
<td>380</td>
<td>11.4</td>
<td>190</td>
<td>39.8</td>
<td>50</td>
</tr>
<tr>
<td>5.9</td>
<td>370</td>
<td>12.0</td>
<td>180</td>
<td>43.5</td>
<td>45</td>
</tr>
<tr>
<td>6.1</td>
<td>360</td>
<td>12.7</td>
<td>170</td>
<td>48.1</td>
<td>40</td>
</tr>
<tr>
<td>6.3</td>
<td>350</td>
<td>13.5</td>
<td>160</td>
<td>54.0</td>
<td>35</td>
</tr>
<tr>
<td>6.4</td>
<td>340</td>
<td>14.4</td>
<td>150</td>
<td>61.8</td>
<td>30</td>
</tr>
<tr>
<td>6.6</td>
<td>330</td>
<td>15.4</td>
<td>140</td>
<td>72.9</td>
<td>25</td>
</tr>
<tr>
<td>6.8</td>
<td>320</td>
<td>16.6</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>310</td>
<td>18.0</td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Graduation of a Candle Turbidimeter [APHA et al., 1965].

<table>
<thead>
<tr>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
<th>Light Path, cm</th>
<th>Turbidity Units</th>
</tr>
</thead>
</table>
Jackson candle turbidimeter and the intensity of light reflected 90°. Therefore, there is no valid basis for calibration of a nephelometer to Jackson candle units [American Public Health Association et al., 1971].

The nephelometric method is the preferable method for determination of low turbidities when relatively high sensitivity and precision are desired. Visual methods such as the Jackson candle turbidimeter are useful for highly turbid waters.

**Suspended Solids**

In 1965, the European Inland Fisheries Advisory Commission published water quality criteria for freshwater fish. Technical Paper No. 1 was devoted to fine solids [EIFAC, 1965]. This is a report cited by many publications, including the EPA Gold Book.

The report lists five of the ways that fine solids can have a harmful impact upon freshwater fish:

1. by acting directly on the fish swimming in water in which solids are suspended, and either killing them or reducing their growth rate, resistance to disease, etc.;
2. by preventing the successful development of fish eggs and larvae;
3. by modifying natural movements and migrations of fish;
4. by reducing the abundance of food available to the fish; and
5. by affecting the efficiency of methods for catching fish.

The Commission divided the risk to fisheries into four categories, and estimated ranges of suspended solids concentrations which would correspond to the categories.

<table>
<thead>
<tr>
<th>Concentration Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25 mg/l</td>
<td>no evidence of harmful effects upon fisheries</td>
</tr>
<tr>
<td>25 – 80 mg/l</td>
<td>moderate or good fisheries, but lower yield than under 25 mg/l</td>
</tr>
<tr>
<td>80 – 400 mg/l</td>
<td>unlikely to support good fisheries</td>
</tr>
<tr>
<td>&gt; 400 mg/l</td>
<td>poor fisheries</td>
</tr>
</tbody>
</table>

Turbidity is a measure of the optical property of sample. It causes light to be scattered and absorbed, rather than transmitted in a straight line through the sample. According to the American Public Health Association, “attempts to correlate turbidity with the weight concentration of suspended matter are impractical, as the size, shape, and refractive index of the particulate materials are of most importance optically, but bear little direct relationship to the concentration and specific gravity of the suspended matter” [APHA et al., 1965]. In addition, total suspended solids only includes the sample material retained on a glass fibre filter (down to 1μm) and heated to 105°C to evaporate the water [APHA et al., 1989]. Total suspended solids does not include dissolved solids, which contribute to turbidity.
Alaskan Standards

Some useful information on the development of a turbidity standard can be obtained from the State of Alaska [Lloyd, 1987]. Standards for turbidity and suspended solids have been developed based upon research performed by staff of the Alaska Department of Fish and Game and by others. An increase in turbidity has been shown to dramatically reduce light penetration in lakes and streams. A decrease in light penetration produces an associated reduction in the production and abundance of plant material (primary production), the production and abundance of organisms used by fish for food (secondary production), and the production and abundance of fish. Relatively low turbidity (10–25 NTU) or suspended sediment concentrations (~ 35 ppm) may either stress fish, alter behavior patterns, or result in fatalities.

The standards focus on cold–water fisheries and salmonid habitat – a major resource of the State. For receiving waters which function as drinking water supplies, turbidity shall not exceed 5 NTU above natural background conditions for waters with a natural turbidity of 50 NTU or less. For waters with a natural turbidity of greater than 50 NTU, the turbidity increase shall be no greater than 10%, not to exceed a maximum increase of 25 NTU. These standards are based upon the prevention of loss of aquatic productivity and to avoid lethal or chronic sublethal effects upon fish and wildlife. A 5 NTU increase in turbidity in a clear–water lake may reduce the productive volume by approximately 80%. A 25 NTU increase in turbidity in a clear–water stream 0.5 meters deep may reduce plant production by approximately 50%, while a 5 NTU increase in turbidity may reduce plant production in the same stream by approximately 13%. Turbidity of greater than 8 NTU has been shown to reduce the quality of sport fishing.

Few waters in Alaska are not designated as drinking water supplies, which is the most restrictive turbidity standard. However, the turbidity standard of 25 NTU above natural background conditions for streams and 5 NTU above natural background conditions for lakes does exist for the propagation of fish and wildlife.

In addition to standards for turbidity, Alaska also has standards for sediment. High suspended sediment concentrations has been shown to be lethal to fish. Lower concentrations of suspended sediment have chronic effects upon fish, including reduction of visibility of prey, reduced growth, increased stress, and interference with environmental cues necessary for orientation in migrations.

For receiving waters which function as drinking water supplies, the sediment concentration, including settleable solids, shall not measurably exceed natural levels. The sediment standard for the propagation of fish and wildlife is quite involved, and is best repeated verbatim:

The percent accumulation of fine sediment in the range of 0.1 mm to 4.0 mm in the gravel bed of waters utilized by anadromous or resident fish for spawning may not be increased more than 5% by weight over natural condition (as shown from grain size accumulation graph). In no case may the 0.1 mm to 4.0 mm fine sediment range in the gravel bed of waters utilized by anadromous or resident fish for spawning exceed a maximum of 30% by weight (as shown from grain size accumulation graph). In all other surface waters no sediment loads (suspended or deposited) which can cause adverse effects on aquatic animal or plant life, their reproduction or habitat.

Lloyd et al. [1987], analyzed data compiled by the U. S. Geological Survey for Alaskan streams from 1976 to 1983. The data consisted of 235 samples obtained from 37 stations on 34 rivers.
throughout Alaska, although the data is dominated by samples from large, silt–laden rivers. Utilizing a log–log regression ($r^2 = 0.83$) the following transformed equation was developed:

$$T = 0.44(\text{SSC})^{0.858}$$

**Conclusion**

There appears to be no definitive conclusion as to the source of the water quality standard for turbidity in Minnesota. The MPCA turbidity standard of 25 was probably based upon FWPCA “Green Book” recommendations – specifically the recommendation of turbidity not exceeding 25 JTU in warm–water lakes. The Green Book recommendations seem to be based upon the farm pond fish productivity monitoring results presented in Buck [1956], but may have also been influenced by the EIFAC findings that suspended sediment concentrations less than 25 ppm have no effect upon fisheries. Units for turbidity were loosely used, and it appears that the use of ppm for turbidity may have been intertwined with the same units for suspended sediment. As an aside, the Standard Method for turbidity in 1965 had a lower detection limit of 25 turbidity units.

**References**


Minnesota Water Pollution Control Commission. *Water Quality Standards for the Interstate Waters of Minnesota.* June, 1967
