Technical Guidance for Designing a TMDL Effectiveness Monitoring Plan

1. Introduction

Water quality impairments in lakes, rivers, and other water bodies are often addressed through the Total Maximum Daily Load (TMDL) process. Included in the TMDL process is the determination of the maximum pollutant amount a water body can receive without exceeding water quality standards, and the allocation of this amount between point and nonpoint sources of pollution. Additionally, the TMDL process can include the development of guidelines for TMDL implementation, or water quality management initiatives that are needed to achieve the TMDL target.

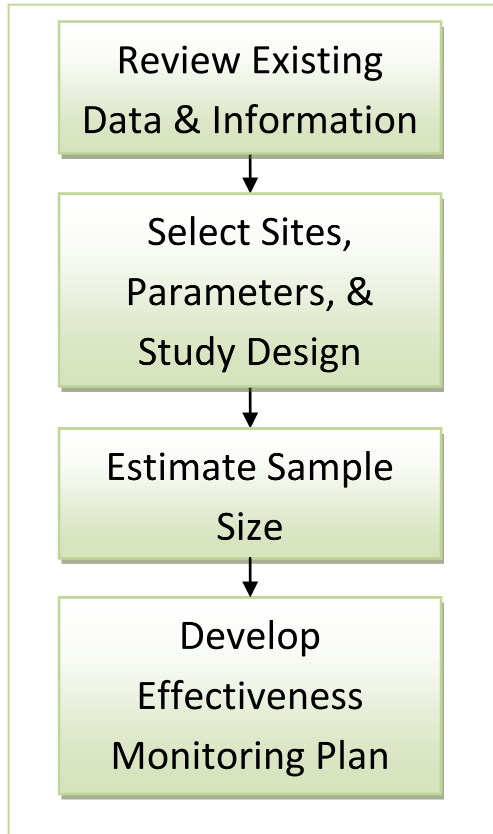

Figure 1. Recommended steps for TMDL effectiveness monitoring planning.

A fundamental yet often overlooked component of TMDL implementation is ***TMDL Effectiveness Monitoring***. The primary goal of TMDL effectiveness monitoring is to identify water quality improvements (or lack thereof) that result from TMDL implementation. This information serves as an important source of feedback for refining and optimizing management approaches. Like any project involving data collection, the value of TMDL effectiveness monitoring can be greatly enhanced if monitoring activities are preceded by thorough and detailed project planning. Without proper planning, effectiveness monitoring may not produce the type and quantity of data needed to detect water quality changes. Oftentimes, the need for planning is not apparent until a monitoring project is underway or complete. In a review of stream restoration monitoring activities in the Pacific Northwest, 64% of project managers indicated that, in retrospect, they would have used a more methodical monitoring design that allowed for an improved scientific evaluation of project effectiveness (Rumps, et al., 2007). This document is intended to serve as a guide for water quality practitioners planning a TMDL effectiveness monitoring project. Several steps are outlined that inform the design of a detailed TMDL effectiveness monitoring plan (Figure 1).

Specific topics covered in this guide include:

- The benefits of watershed scale TMDL effectiveness monitoring;
- Sources for data review and data review outcomes;
- Selecting sampling parameters and monitoring sites;
- Estimating sample size requirements using power analysis; and
- Integration of these and other considerations into a final TMDL effectiveness monitoring plan.

A key recommendation in this guide is for planners to make data-driven planning decisions using a pilot dataset that captures the general characteristics of the data to be collected through TMDL effectiveness monitoring. A discussion of pilot data exploration methods can be found in a companion document titled *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*. Additionally, an Excel-based TMDL effectiveness monitoring planning Tool has been provided as a complement to this document to facilitate data-driven planning.

2. Watershed Scale TMDL Effectiveness Monitoring

The watershed approach to water resource management is becoming the standard model for maintaining and improving the quality of surface waters in the U.S. The watershed approach considers linkages among landscape conditions, ecological resources, and multiple interconnected water bodies throughout a land area to guide adaptive water resource management strategies.

The U.S. Environmental Protection Agency (EPA) has promoted the watershed approach for TMDL development rather than single-segment TMDLs as a means to streamline and improve the TMDL process. A watershed TMDL incorporates watershed-wide information on pollutant types and sources to simultaneously complete TMDLs for all impaired waters within the watershed. Specific benefits of using the watershed approach for TMDLs include (U.S. Environmental Protection Agency, 2008):

- The ability to conduct a broad assessment of pollutant sources;
- The ability to capture the interaction between upstream and downstream sources and impacts;
- The restoration of unimpaired but threatened waters and/or protection of high-quality waters;
- Reduced per-TMDL costs;
- The involvement of multiple stakeholders; and
- The opportunity to integrate TMDLs with other watershed programs.

Each of these benefits is relevant to watershed scale TMDL effectiveness monitoring. Relative to a single-segment effectiveness monitoring project, watershed monitoring has the potential to be more efficient and informative due to the integration of a broad assessment of pollutant sources, and knowledge of interactions between upstream and downstream pollutant sources, impacts, and controls into project planning. Further, watershed scale effectiveness monitoring can demonstrate water quality improvements in waters that are at risk for impairment, and can take advantage of partnerships with interested stakeholders and existing data collection programs.

It is highly recommended that practitioners design a TMDL effectiveness monitoring project using the watershed framework. Note that the term "watershed" itself does not explicitly denote the actual scale of the project (i.e., the size of the study area), as a watershed can range from a small headwater drainage to a major river basin. The project scale should be decided upon by project planners using information on the number and extent of impaired or threatened waters in the region of interest, project resources, and project partners. One important point to consider is that water quality improvements that are demonstrated for projects that include one or more watersheds at the 12-digit hydrologic unit code (HUC-12) scale can be reported under EPA's National Water Program Guidance Measure SP-12[1]. Measure SP-12 is intended to measure and track incremental improvements in water quality at the HUC-12 watershed scale that are attributable to implementation measures using a watershed approach. Measure SP-12 is a useful framework on which to build an effectiveness monitoring program because it requires use of a watershed approach and demonstration of statistically significant changes or multiple lines of evidence indicating improvement.

3. Review Existing Data & Information

The design of a TMDL effectiveness monitoring project begins with a thorough review of all available information that may direct the process, including:

- TMDL report(s) and implementation plan(s);
- Water quality reports;
- Locations of best management practices (BMPs) and other TMDL implementation actions;
- Timing of TMDL implementation;
- Existing watershed management plans and stakeholder groups;
- Existing water quality monitoring sites and data;
- TMDL effectiveness monitoring project goals and resources (staff, funding, etc.); and
- Other sources describing watershed features and conditions.

[1] http://water.epa.gov/resource_performance/planning/def_wq11.cfm#SP-12

The above information should provide an understanding of: current and historic water quality conditions, including short- (daily/seasonal) and long- (annual) term variability; and the type(s), location, and timing of TMDL implementation actions within the watershed. Planners should have a firm grasp of the ecological resources in the watershed and how these resources have been impacted by degraded water quality. Finally, planners should understand how upstream management activities can potentially influence downstream water quality conditions throughout the watershed.

Ultimately, the review of existing data and information will provide direction on selecting TMDL effectiveness monitoring sites. In general, a monitoring site should be located where TMDL implementation is expected to have discernible water quality effects. This includes sites on impaired or degraded water bodies that are located downstream of:

- Point sources with new or revised wasteload allocations;
- Discontinued illicit discharges;
- Nonpoint sources that are managed through BMPs;
- Stream channel restoration projects;
- Improved onsite wastewater management or expansion of sanitary sewer service; and
- Other TMDL-specific pollution control measures.

Knowledge of pollutant types/sources, TMDL implementation, ecological conditions, and watershed characteristics gained from the information review will also inform decisions regarding the selection of monitoring parameters and methods for demonstrating water quality improvements. These steps, and further guidance for site selection, are presented in the following section.

4. Select Monitoring Sites, Parameters, and Study Design

As discussed in Section 3, the selection of TMDL effectiveness monitoring sites will be based on a review of existing information to identify locations where water quality improvements are expected to occur. Potential monitoring locations can be further refined based on project goals and resources. A central goal of watershed scale TMDL effectiveness monitoring should be the demonstration of watershed-wide water quality improvements. Two general methods are available to meet this goal. A basic approach is to perform water quality monitoring at the watershed outlet (the ***pour point*** method) (Figure 2). Under this option, the cumulative effect of all TMDL implementation actions in the watershed is evaluated using data collected at the watershed outlet. The pour point method is well-suited for projects in which water quality is known to be degraded at the watershed outlet and where limited monitoring resources are available.

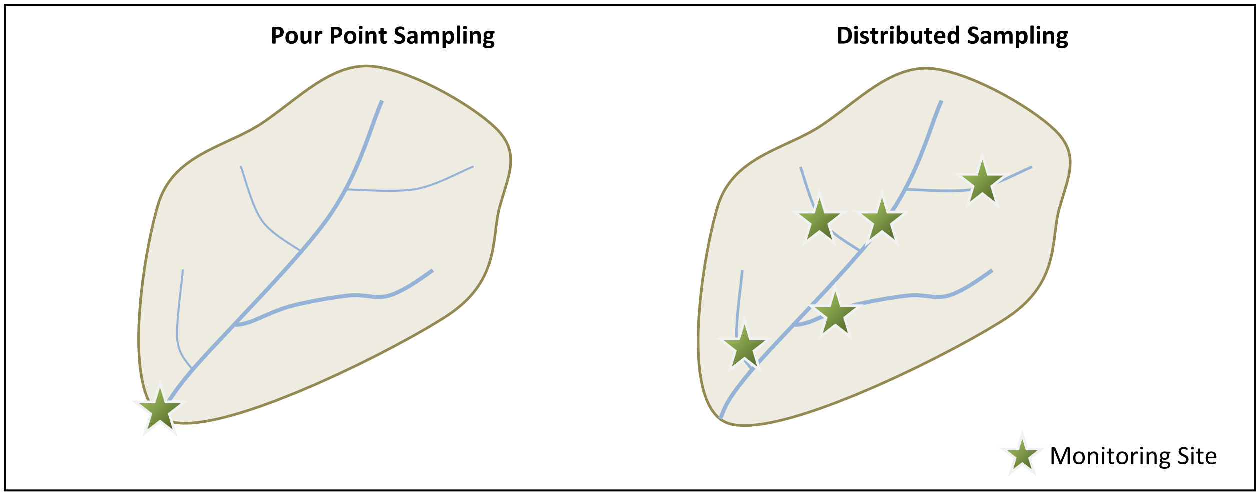

Figure 2. Illustration of the pour point and distributed sampling methods.

A more intensive approach for demonstrating watershed-wide water quality improvements is through the collection of water quality data at multiple sites within the watershed (the ***distributed sampling*** method) (Figure 2). Under this approach, conclusions drawn for individual sites can be pieced together to infer watershed-wide water quality improvements. Distributed sampling can be applied when project resources or partnerships allow for a rigorous sampling effort. Benefits of distributed sampling include the ability to assess the effects of individual TMDL implementation actions. Such information is key to adaptive, cost-effective management. A distributed sampling approach may also be preferred when project goals include monitoring to justify changes to the impairment status of multiple water body segments in the watershed (e.g., from an impaired water body with an approved TMDL to a water body that meets water quality standards).

In many cases, the location of potential monitoring sites will coincide with an existing water quality monitoring network. In such cases, existing monitoring sites should be reviewed to determine the past and present status of monitoring activities, parameters monitored, data quality, and monitoring organization(s). If existing monitoring activities agree with the needs/goals of the TMDL effectiveness monitoring project, these sites and existing data can be integrated into the project.

If newly-established monitoring sites are needed for TMDL effectiveness monitoring, planners are faced with the additional task of identifying their precise location. The following are a number of site-specific characteristics to consider when identifying sampling sites.

<u>Site Accessibility and Safety</u>

- Consider road access, parking availability, and ownership of adjacent land.
- Ensure that access to the site is not obstructed by natural or manmade features.
- Avoid steep banks and/or other hazardous features (wire or other debris).
- Be aware of the presence of poisonous plants or poisonous animal habitat.

- Note hazardous flow and channel conditions (rapidly flowing water, sudden changes in water depth).
- Consider how each of the above may change seasonally.

<u>Physical Conditions</u>

- Be sure that discharges from tributaries, point sources, or groundwater are well-mixed with upstream flows.
- Avoid areas with a high potential for damage/loss of sampling equipment.

<u>Logistical Considerations</u>

- Note travel time relative to other monitoring sites.
- Consider travel time and maximum holding time for lab analysis.

In addition to the selection of sampling locations, planners must also determine which water quality parameters will be monitored. In general, this will include the pollutant(s) addressed by the TMDL(s) developed for water bodies in the watershed. Project resources may allow for monitoring of additional parameters that relate to water body impairments. These can include stressor variables (e.g., nutrients, bacteria, sediment) and/or response variables (e.g., macroinvertebrates, fish counts, riparian habitat). Monitoring of response variables can be highly informative, as improved biological diversity, habitat, etc. may be observed prior to detectable improvements in water quality and can provide supporting evidence for watershed-wide water quality improvement under Measure SP-12.

Monitoring of additional water quality parameters can be useful if those parameters are statistically associated with the primary pollutant(s) of interest. Such ***covariates*** can improve the power of subsequent statistical analyses (see *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*). A common covariate for pollutants in streams and rivers is flow magnitude (streamflow). Streamflow monitoring should be conducted in conjunction with water quality monitoring whenever possible, as stream flow data allow for the calculation of pollutant loads, and can improve the analysis of water quality data. To reduce costs, planners may be able to situate monitoring sites near existing streamflow gaging stations.

The collection of water quality data under a TMDL effectiveness monitoring program should be completed in the context of a specific study design. The study design formally outlines how water quality improvements will be demonstrated. Haphazard study design decisions can derail an otherwise well-planned TMDL effectiveness monitoring program and result in the collection of data that is unfit for achieving program goals. Potential study designs for TMDL effectiveness monitoring are depicted in Figure 3 and include:

- Before/After Study;
- Upstream/Downstream Study;
- Paired Watersheds Study; and
- Trend Monitoring Study.

Study design selection is dependent on multiple factors. Planners need to consider the type(s) of TMDL implementation actions, implementation schedule, the availability and quality of previously collected data, project resources, and the existence of suitable reference sites. Monitoring duration and sample size requirements are also key pieces of information to consider. Sample size requirements for a particular study design can be estimated using Power Analysis (see Section 5).

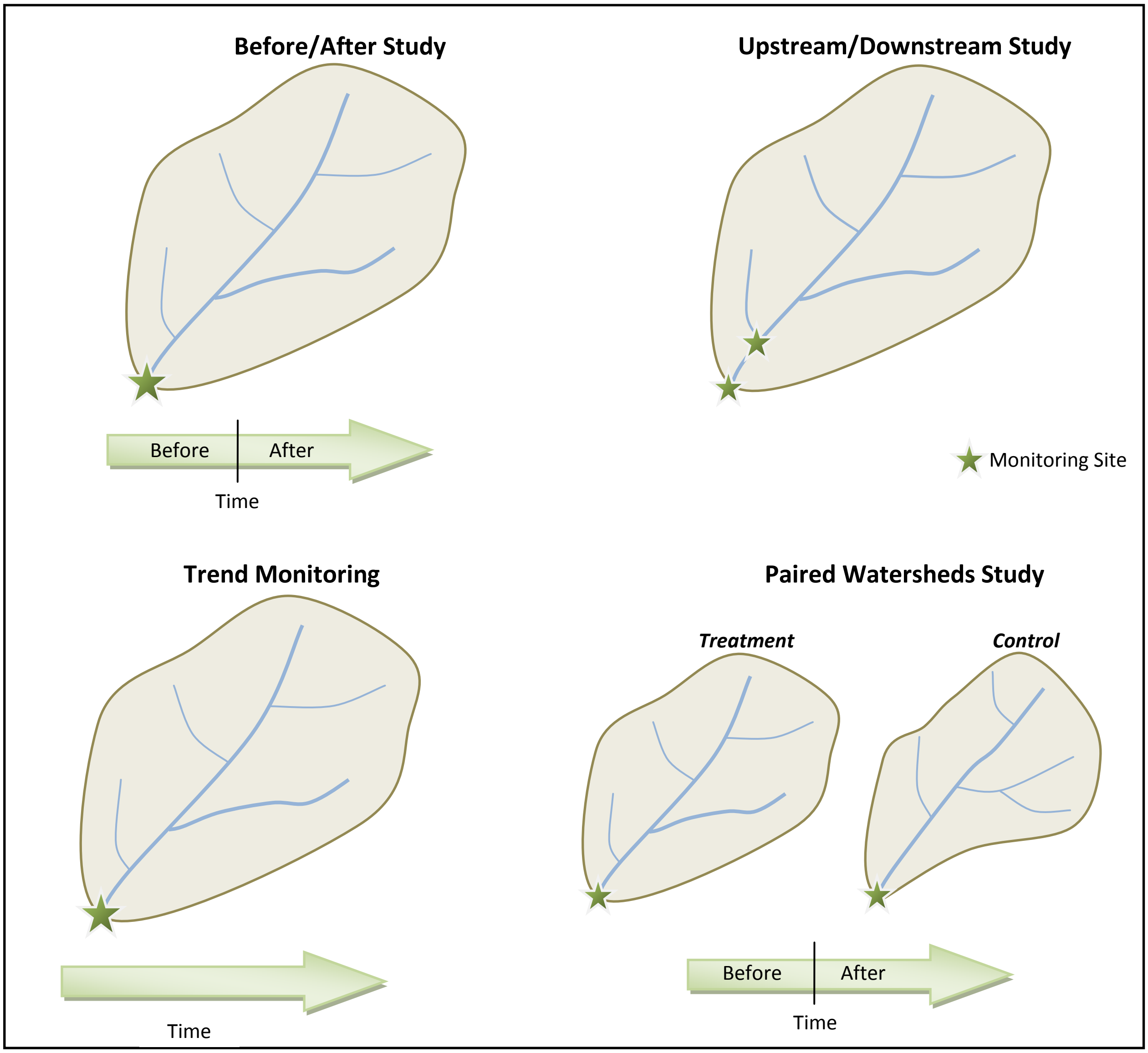

Figure 3. Study designs used for demonstrating TMDL effectiveness. Note that these diagrams reflect monitoring at the watershed outlet only (pour-point monitoring). If distributed sampling is undertaken, different study designs can be employed at each monitoring location.

Before/After Study

In a before/after design, a single monitoring site is established and water quality is sampled before and after TMDL implementation. Following data collection, data from each time period is compared. This design requires minimal data collection effort due to the use of a single site and can take advantage of existing water quality data. A before/after study cannot be employed if TMDL effectiveness monitoring begins after TMDL implementation has begun and if historical data are not available. Further, existing datasets should be reviewed to determine the number of observations, the date/time of sampling, and sampling frequency. These characteristics are especially important for water quality parameters that fluctuate over daily or seasonal scales. Annual variability in climate and hydrologic conditions between the two time periods can also interfere with the identification of water quality improvements if they are not accounted for. Local stream flow data can greatly enhance the power of this type of design. The two sample t-test or rank sum test are common statistical techniques for evaluating data from this type of monitoring design (see *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*).

Upstream/Downstream Study

The upstream/downstream study uses monitoring sites located upstream and downstream of TMDL implementation activities. Water quality monitoring is conducted during/after TMDL implementation and data from each location are compared. This study design is more resource intensive than the before/after study, but the variability of climate and hydrologic conditions over time is better accounted for.

The upstream/downstream study is one type of control/impact study, where control (upstream) and impact (downstream) sites are compared. In such studies, careful attention must be paid to the selection of the control site to ensure that water quality data from each location are comparable. For example, the upstream/downstream study is generally not appropriate where a tributary enters the reach of interest between potential upstream and downstream locations.. The two-sample t-test, paired t-test, or signed rank test are common statistical techniques for evaluating data from this type of monitoring design (see *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*).

Paired Watersheds Study

The paired watersheds study combines the before/after and control/impact study designs and is a specific type of before-after-control-impact (BACI) study. In the paired watersheds study, two monitoring sites are established, one located at the outlet of a treatment watershed and one located at the outlet of a control watershed where no management activities take place. The control site can be within an adjacent or nearby watershed, or upstream of the treatment area. Water quality is sampled at both sites before and after TMDL implementation. Data from the pre-implementation period is used to develop a statistical relationship between sites and this relationship is used to evaluate post-implementation water quality data.

The paired watersheds study is a highly rigorous study design that accounts for the variability of water quality in time and space. As such, it requires a major investment in resources. Additionally, watershed conditions in the control watershed must remain stable throughout the duration of the study, or the results will be compromised. Therefore, it may not be the most practical option. The paired t-test, signed rank test, or analysis of covariance (ANCOVA) are common statistical techniques for evaluating data from this type of monitoring design (see *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*).

Trend Monitoring

Trend monitoring typically uses water quality data from a single monitoring station to demonstrate TMDL effectiveness. Water quality data are collected over an extended time period (at least 5 – 10 years) and changes over time are assessed. The main advantage of trend monitoring versus a before/after study is the ability to evaluate TMDL implementation that occurs over an extended time period using regularly collected data. This is important for documenting incremental improvements, as full restoration of an impaired water body typically takes many years or decades. Further, trend monitoring in a watershed with multiple monitoring sites can be used to estimate the "regional" trend or overall trend for the watershed. Collection of streamflow and other covariate data (e.g., turbidity, temperature) is particularly valuable under this study design due to its ability to improve the statistical analyses performed on the resulting data. Linear regression and the Mann-Kendall test are common statistical techniques for evaluating data from this type of monitoring design (see *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*). More advanced methods are required for evaluating regional trends for multiple monitoring sites within a watershed.

5. Estimate Sample Size

Water quality data are often collected without considering the number of samples needed to demonstrate statistically significant changes. Statistically significant results are important for communicating improvements to decision makers and stakeholders with a specified level of confidence. They are also important for demonstrating improvement under Measure SP-12. Objective and informed sample size decisions can be made using a statistical method known as ***Power Analysis***. A power analysis uses information from pilot data to determine the optimal number of samples needed to identify statistically significant changes or trends. This ensures that sufficient data are available to identify future changes or trends where they actually exist, without sampling more than necessary, bringing improved efficiency to the monitoring program.

The power of a statistical test is defined as the likelihood of detecting a change that actually occurred and it depends on the magnitude of the change to be detected by the test (the effect size), the number of samples included in the test, the level of significance (the likelihood that the water quality change identified by the test actually occurred), and the variability of the parameter being tested. Power increases with sample size, effect size, and/or significance level, and decreases with sample variability.

Since the sample variability and effect size can be estimated from pilot data or set at minimum threshold levels, the sample size needed to achieve a pre-defined level of power and significance can be calculated. For TMDL effectiveness monitoring, planners can take advantage of this type of power analysis to estimate sample size requirements and plan for associated sampling costs.

Sample size calculations can be complex and vary depending on the type of statistical test that will be used to analyze the monitoring data. Therefore, a Microsoft Excel-based TMDL effectiveness monitoring planning tool that facilitates sample size estimation is available as a complement to this document. Note that sample size analysis that is carried out before a study is conducted (an *a priori* analysis) requires certain assumptions regarding the parameter variability, distribution, and the statistical test that will be applied. Such assumptions may not be valid for the final dataset or statistical approach. For example, the inclusion of covariates in trend analysis or presence of autocorrelation in sample data can require statistical methods that are more sophisticated than originally planned. For this reason, *a priori* sample size estimates may be biased high or low. Methods for exploring these assumptions are discussed in *Technical Guidance for Exploring TMDL Effectiveness Monitoring Data*, and several of these are featured in the Excel-based effectiveness monitoring planning tool.

6. Develop TMDL Effectiveness Monitoring Plan

The preceding sections have described recommended steps for planning a TMDL effectiveness monitoring project. These steps include:

- Review Existing Data and Information;
- Site Selection;
- Parameter Selection;
- Study Design Selection; and
- Sample Size Estimation.

The results of each step should be documented in a TMDL effectiveness monitoring plan. The planning document should include relevant background information and clearly spell out the goals of the project, where and when monitoring will occur, and what will be monitored. A preliminary discussion of intended data analysis methods should also be presented, including the selected level of significance. A TMDL effectiveness monitoring plan can be incorporated into a Quality Assurance Project Plan (QAPP). The QAPP should outline additional details related to field sampling and laboratory protocols, data management, and the proposed process for addressing data quality issues that arise during the course of the project. By spending adequate time on the development of a TMDL effectiveness monitoring plan, and following the plan's direction, those tasked with designing and managing a TMDL effectiveness monitoring program will maximize its ecological, economic, and social value.

7. References

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