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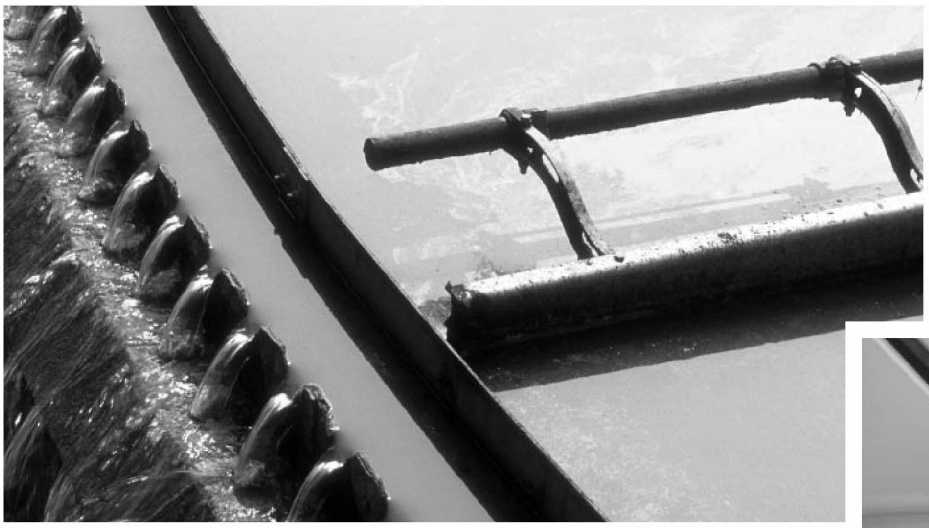

Navigating the TMDL Process: Evaluation and Improvements

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NAVIGATING THE TMDL PROCESS: EVALUATION AND IMPROVEMENTS

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ABSTRACT

TMDLs, or Total Maximum Daily Loads, are required under the Clean Water Act, Section 303(d), for waterbodies that do not attain specified water quality standards. The objective of this research was to review the existing TMDL process and to develop an improved design for TMDL development where improvements are needed. This objective was accomplished through: 1) Identifying and verifying problems with the existing TMDL program; 2) Formulating a range of recommended improvement options on specific topics that address identified weaknesses; and 3) Providing case studies and examples that highlight these recommended changes to improve the TMDL process.

The research team identified ten specific areas for improvement, based on a review of approved TMDLs, a survey of state programs, and an in-depth review of specific case study examples. These topics relate to specific steps and/or methods employed in the TMDL development process. They include:

- Estimating background pollutant loads;
- Quantifying nonpoint source loads using simple methods;
- Incorporating urban wet weather sources;
- Selecting critical conditions;
- Guiding principles for modeling;
- Estimating the TMDL Margin of Safety;
- Approaches to the allocation of loads;
- Linking best management practices to load reductions;
- Implementation planning, tracking, and adaptation; and
- Adaptive watershed management.

Each topic is addressed in a separate chapter of the report, with a discussion, recommendation of improved approaches where appropriate, and specific examples to help guide water quality professionals when developing or reviewing TMDLs.

AR0023307

BENEFITS

- Identifies issues and challenges associated with current TMDL development, helping water quality professionals better focus development and review efforts at issues of importance;
- Provides recommendations for improving on specific topics in TMDLs that address identified weaknesses and improve the scientific reliability and effectiveness of TMDLs;
- Explores alternative approaches to various components of TMDLs, offering TMDL practitioners options to improve the TMDL analysis in response to technical problems; and
- Provides case study examples and an inventory of technical resources that illustrate the improvements to the TMDL process, and efficiently directs practitioners to useful information.

Keywords: TMDL, Watershed, Nonpoint Sources, Background, Wet Weather Sources, Margin of Safety, Allocation, Adaptive Management, Implementation, BMP, Modeling

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LIST OF ACRONYMS

ACWF	America's Clean Water Foundation
AMSA	Association of Municipal Sewerage Agencies
ARS	Agricultural Research Service (USDA)
ASCE	American Society of Civil Engineers
ASIWPCA	Association of State and Interstate Water Pollution Control Administrators
BCC	Bioaccumulating Chemicals of Concern
BMPs	Best Management Practices
BOD	Biological Oxygen Demand
CALM	Consolidated Assessment and Listing Methodology
CFR	Code of Federal Regulations
COD	Chemical Oxygen Demand
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DO	Dissolved Oxygen
EMC	Event Mean Concentrations
FACA	Federal Advisory Committee Act
FOEA	First-Order Error Analysis
FR	Federal Register
GAO	General Accounting Office (U.S.)
GIS	Geographic Information System
GWLF	Generalized Watershed Loading Function
MCL	Maximum Contaminant Level
MOS	Margin of Safety
MUSLE	Modified Universal Soil Loss Equation
NAS	National Academy of Sciences
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRDC	Natural Resources Defense Council
NTU	Nephelometric Turbidity Unit
RCWP	Rural Clean Water Program
RUSLE	Revised Universal Soil Loss Equation
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
USDA	U.S. Department of Agriculture
U.S. EPA	U.S. Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WCS	Watershed Characterization System
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WMM	Watershed Management Model
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

The purpose of this report is to provide a useful reference document for water quality professionals involved in the process of developing TMDLs, or Total Maximum Daily Loads. The focus is on technical tools used in the development of TMDLs. This is not intended to be a "how to" manual, or a technical guidance document. Rather, it is designed to provide a discussion of current issues and problems with the TMDL process and to suggest improvements, supported, where appropriate, by case study examples. In cases where recommendations for improvements are inappropriate, the authors explore alternative approaches, or provide an inventory of available resources.

ES.1 Background

TMDLs are required under the Clean Water Act, Section 303(d), for waterbodies that do not attain specified water quality standards. While this provision has existed in the Clean Water Act for many years, it was brought to light through a series of citizen lawsuits in the 1980s and 1990s which required states and the U.S. Environmental Protection Agency (U.S. EPA) to list waterbodies not attaining water quality standards (so-called 303(d)-listed waterbodies) and develop maximum loadings as necessary to meet water quality objectives. In many cases, aggressive schedules for development of TMDLs for those waterbodies were also required.

The TMDL program has come under considerable criticism. Some have argued that the program is long overdue, and demand aggressive schedules for TMDL development to conform with the law. Others have argued that the schedules are too aggressive, leading to poorly developed TMDLs based on insufficient data, poor science, and overly restrictive assumptions. Further, many have argued that the program fails to adequately address nonpoint source issues and unrealistically focuses too heavily on point source controls, and as a result will be ultimately ineffective in restoring designated uses. Overall, although the criticisms are many and diverse, most agree that significant improvements are needed to help the TMDL program to achieve the nation's water quality goals.

This research project was developed to investigate and evaluate the current TMDL program, and to provide recommendations on improved approaches for developing TMDLs. The focus was on technical tools used in the development of TMDLs. Separate Water Environment Research Foundation (WERF)-supported research projects (not reported on herein) focused on issues related to the TMDL listing and delisting process (WERF, 2003a) and issues related to narrative TMDLs (WERF, 2003b).

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ES.2 Objectives

U.S. EPA's efforts to support the TMDL program have been substantial. However, the scope, diversity, schedule, and resource demands of the program are enormous. Progress to date has been applauded by many, but criticized by many others. The objective of this research was to review the existing TMDL process and develop an improved design for TMDL development where improvements are needed. This was accomplished through:

- Identifying and verifying challenges posed by existing TMDLs;
- Formulating a range of recommended improvement options on specific topics that address identified weaknesses; and
- Providing case studies and examples that highlight these recommended changes to improve the TMDL process.

ES.3 Identification of Challenges Posed by Existing TMDLs

The first step in the identification of issues was to develop an initial list of hypotheses to investigate. The intent in developing the original list of hypotheses was to write clear statements describing what were believed to be the challenges with the TMDL program, and then examine the evidence to support or refute each of these hypotheses.

The list of hypotheses was developed based in part on the experience of the investigators and a WERF expert review panel (Project Subcommittee). In addition, issues were refined and supplemented by investigating other information sources, including a Federal Advisory Committee Act (FACA) report, U.S. General Accounting Office (GAO) reports, and comments submitted to the U.S. EPA on the 1999 proposed TMDL rule.

The list of issues was refined and supplemented by investigating other information sources, including relevant reports related to the TMDL program and stakeholder comments on the 1999 proposed TMDL rule. Three lines of evidence were then examined to confirm and refine this list of issues:

- Survey of State TMDL programs;
- Review of approved TMDLs; and
- In-depth review of specific case study examples.

The research team selected eight states from which to gather detailed information and to interview about their TMDL programs. In addition, the team reviewed 176 TMDLs that have been approved by the U.S. EPA. An effort was made to acquire TMDLs that generally represent a variety of parameters from a wide geographical distribution. While a statistical analysis was not conducted, the team made an attempt to review TMDLs across all geographic regions, with approximately the same distribution of parameters and source types as the complete 303(d) list. Finally, researchers carefully examined numerous case study TMDLs as part of their investigations.

A long list of TMDL issues was developed from this review, and these can be categorized into the following five major challenges of the TMDL program:

1. ***Inadequate Standards:*** The TMDL program is fundamentally driven by comparison to quantitative water quality objectives. Yet, ironically, many of the impaired waters are for pollutants or pollution without established numeric standards, and for many sites established numeric standards are of questionable applicability.
2. ***Insufficient Data:*** The program is intrinsically quantitative, requiring data for calculating loads and assessing water quality. Unfortunately, the data support needed is often insufficient. Hence, are developed with approximations, estimates, and guesses.
3. ***Uncertainty Analysis:*** The program essentially requires a single and precise calculation of the allowable loading and the effectiveness of proposed management and controls. Unfortunately, inexact science, insufficient data and natural variability preclude a precise, reliable answer. The resulting uncertainty is currently not being adequately assessed.
4. ***Unsure Implementation and Outcome:*** The fundamental purpose of the program is to restore impaired uses. Because of inadequate information and uncertain implementation, however, this goal is not assured in many of the TMDLs conducted to date.
5. ***Need for More Documented Consistent Methodologies.*** The TMDLs that were reviewed often had widely differing procedures for activities, ranging from data collection to allocation to public involvement. This resulted in sometimes satisfactory but often unsatisfactory TMDLs. It is recognized that different approaches are often warranted, but more standardized guidance is needed.

The first challenge is being addressed through two separate WERF-funded research efforts that focus on narrative TMDLs (WERF, 2003b) and the listing/delisting process (WERF, 2003a). To address the other four major challenges, the research team identified ten specific areas for improvement in the TMDL program. These relate to specific steps and/or methods employed in the TMDL development process. These topics include:

- Estimating background pollutant loads;
- Quantifying nonpoint source loads using simple methods;
- Incorporating urban wet weather sources in a TMDL;
- Selecting critical conditions;
- Guiding principles for modeling in the TMDL process;
- Estimating the TMDL Margin of Safety;
- Approaches to the allocation of loads in TMDLs;
- Linking best management practices to Load Reductions;
- Implementation planning, tracking, and adaptation; and
- Adaptive watershed management in the TMDL process.

For each issue, the nature of problems was summarized based on insights gained from the state surveys and review of individual TMDLs. Ideas for improvements were then provided. Following is a brief review of findings on some of these topics. More detailed findings are provided in individual chapters on these various topics.

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ES.4 Formulating Key Improvements on Specific Issues

The project team has developed a range of recommended improvement options related to the 10 issues. Each issue is addressed in a separate chapter of this report, with a discussion, recommendations for improved approaches where appropriate, and/or specific examples to help guide water quality professionals when developing or reviewing TMDLs. A brief description of the selected investigations follows.

ES.4.1 Estimating Background Pollutant Loads

A TMDL is legally defined as "the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and *natural background*" (40 CFR 130.2). Yet the review of approved TMDLs and the survey of states indicated that background pollutants, or non-regulated sources, are inadequately considered in many TMDLs. Approximately 30% of the reviewed TMDLs did not include separate consideration of background sources. Few of them clearly articulated the difference between controllable nonpoint sources and background. This research was conducted in response to this deficiency.

Many researchers and states suggest that there is no working definition of background sources. U.S. EPA's guidance documents on TMDLs routinely define background levels as "levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution." This definition implies no development and no anthropogenic (man-made) loadings of any type, which is difficult or impossible to quantify. As a result, it is difficult to separate nonpoint sources from background conditions.

This research was directed at assisting water quality professionals in defining and estimating background contributions and loads for TMDL studies. Existing federal and state guidance was summarized along with a range of analytical approaches for estimating background. The focus was on methods for accurately estimating background loads for different types of pollutants, not physical modifications. Methods ranged from using historical data, reference site data, models, and literature as examples.

Evaluation of background conditions in TMDLs requires different considerations than point and nonpoint sources, and these issues were explored and recommendations provided. For example, natural background levels may have to represent the "best attainable state" that includes some anthropogenic impacts considered to be irreversible or uncontrollable. The use of reference sites can help in this assessment. Further, allowing for natural background conditions may differ for natural substances compared to synthetic pollutants. In addition, the persistent problems of legacy pollutants may necessitate a phased or adaptive management approach to TMDLs, and may also require reconsideration of the attainability of existing water quality standards. For all TMDL projects, however, an explicit characterization of background is needed.

ES.4.2 Quantifying Nonpoint Source Loads Using Simple Methods

Of the impaired waters on the current 303(d) list, 90% are indicated to have been caused in whole or in part by nonpoint sources. The review indicated that more than 20% of the TMDLs that addressed nonpoint sources never estimated current nonpoint source loads, so there was no

way of knowing the feasibility of reducing those loads. In addition, almost half of the TMDLs reviewed used in-stream monitoring to estimate total nonpoint source loads to a segment, so it was not possible to estimate the feasibility of reducing specific sources. Only one TMDL considered uncertainty in loadings using a quantitative method.

Data support for estimating nonpoint loads was also observed to be lacking. The state surveys indicated that TMDL developers usually did not have sufficient data to characterize nonpoint source loads (15 of 22 states surveyed), whereas U.S. General Accounting Office investigations indicated 44 of 50 states had insufficient data. Recognizing this scarcity, the investigations focused on how to analyze nonpoint source loads and controls for TMDL analysis when data are limited. This typically requires the use of simple methods, the focus of this chapter.

In data-limited environments, empirical approaches can provide more precise estimates of runoff and contaminant loading than some dynamic, process-oriented models. Spatial heterogeneity in rainfall intensity and amount contribute to greater uncertainty in some spatially explicit, process-oriented models than in empirical models that consider only total rainfall over an area. With improved computing power and capacity, dynamic models have become easier and more efficient to use, but the data available to drive these models have not kept pace with computational technology. Simpler approaches are therefore often more applicable.

To aid in the application of simple models with limited data, this project has summarized and categorized empirical approaches used to estimate nonpoint source pollutant loads to receiving water systems. The emphasis in this work unit was on sediment loads (delivery) and pollutants sorbed or associated with this sediment delivery. While these approaches might not be applicable for soluble nutrient loading, four of the top five causes of impairment in U.S. waters are related to sediment or sediment-sorbed constituents.

Evaluation criteria were developed to assist the user in determining the category of models that might be appropriate and to further refine the selection of models that are applicable to the geographic region and for the specific pollutant of concern. These criteria can be expanded if other factors are considered critical to model evaluation. A flow chart and decision criteria are presented to help the reader move quickly and easily through the possible models that might be available to estimate nonpoint source loads. In most instances, the user is referred to several models that should be considered, rather than a single model for estimating nonpoint source loads. In addition, several approaches for estimating uncertainty using the simple methods are provided.

This chapter includes a description of the various methods and models, for both land use and watershed use, aids for selecting the right tool, an analysis of uncertainty issues when using simple tools, and numerous examples documenting how these tools have been successfully used.

ES.4.3 Incorporating Urban Wet Weather Sources in a TMDL

From the review, it appears that the difficult issues of evaluating and controlling urban stormwater sources either have been avoided or are poorly addressed. Stormwater and other urban wet weather sources are often difficult to incorporate into TMDLs because these sources load intermittently to waterbodies, and the resulting water quality problems are often also

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intermittent. To confound the problem, data on wet weather pollutant sources are difficult and/or expensive to obtain. Also, water quality studies for several urban waterbodies indicate that water quality standards often cannot be attained during wet weather events.

This research highlights some of the difficulties related to incorporating urban wet weather sources into TMDLs, describes the characteristics that make urban wet weather issues different from dry weather issues, and highlights several innovative methods for addressing wet weather sources within TMDLs and in non-TMDL watershed studies. It discusses the different sources and nature of stormwater loads, the transient nature of the water quality impacts, the different receiving water conditions and uses, and the need for different criteria and analytical tools. Collectively, these factors support special considerations for urban stormwater TMDLs. Three major changes are recommended:

1. ***Separate analysis of event-related wet weather TMDLs from dry weather TMDL analysis:*** Wet weather TMDL considerations involve different source, spatial and temporal scales, different controls, and different analytical tools.
2. ***Reevaluate wet weather issues and criteria:*** TMDLs should not be developed for unrealistic or unattainable standards. Traditional water quality standards were developed for prolonged exposure under drought, and are not necessarily applicable to wet weather conditions.
3. ***Implement watershed management plans:*** Restoring water quality and uses during wet weather requires a comprehensive watershed assessment and management plan involving regulatory and voluntary actions. A prescriptive and definitive TMDL is unrealistic, and an adaptive approach is needed.

Associated with these recommendations, a series of technical and regulatory options that could be used for wet weather TMDLs are discussed. These include:

- Selecting a percentage rather than the absolute compliance to standards;
- High-flow wet weather controls for evaluating standards;
- Flow-variable TMDL calculations;
- Use of adaptive management;
- Development of a wet weather subcategory for use description; and
- Seasonal variations on TMDLs and standards.

A discussion is provided for each option, along with examples.

ES.4.4 Selecting Critical Conditions

Federal regulations for TMDLs require that they take into account critical conditions for stream flow, loadings and water quality parameters. However, the review of state programs and individual TMDLs indicated a lack of specific guidance on how to select critical conditions for a specific TMDL. This research was conducted to summarize available information, guidance and experience on selecting critical conditions, and to discuss its applicability to TMDL analysis and its shortcomings.

In analyzing the existing experience and guidance on selecting critical conditions, several recommendations were developed. First, regulations often exist for critical low flows and must be

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considered first and foremost. However, in most cases the critical conditions must be tailored to the specific pollutant source and water quality standards. The critical conditions should represent a low but realistic recurrence interval, not a worst case and unrealistic conditions. Antecedent history is also an important consideration that should not be ignored. Last, nonpoint source-dominated systems require special consideration and may often be suited to an adaptive management approach as opposed to use of a design condition.

ES.4.5 Guiding Principles for Modeling in the TMDL Process

Central to the TMDL program is the calculation of the allowable load, which implicitly requires a quantitative linkage between loadings and water quality response. Models are intrinsically conceived with this objective, but poorly supported or incorrect applications can lead to incorrect TMDLs or high levels of uncertainty.

In the evaluation of 176 TMDLs, the project team identified numerous issues related to the proper selection and application of models for determining assimilative capacity and identifying load-response relationships for allocation purposes. The review indicated that almost one-fifth of the TMDLs did not even calculate the assimilative capacity. Of those that did use a model to do this, only about 16% employed a complex model, defined for this purpose as one requiring some site-specific calibration, and none of the reviewed TMDLs had data collected explicitly for model support. Additionally, only one-half of the TMDLs using models included adequate documentation to critically evaluate the reliability of the models. This research, along with the recommendations from several other groups, underscores the need for better guidance on TMDL modeling.

The objective of this investigation was to provide guiding principles for the use of models in TMDL projects, not to provide a technical guidance model on modeling. Using these principles will promote a more thorough and formal thought process in developing a practical yet scientifically credible modeling approach, including model selection, calibration, application, and documentation of the entire process. This research described principles related to:

- ***Model selection:***
  - Models are not absolutely necessary if observed data can answer the questions;
  - There is no best model for all TMDLs; model selection should be driven by an explicit consideration of 1) management objectives; 2) site-specific characteristics; and 3) resource constraints;
  - Questions drive desired model complexity, but data constrain it; and
  - Select the simplest model that adequately addresses the management objectives.
- ***Model development:***
  - Start simple and build complexity only as justified;
  - Model credibility requires validation to data;
  - Model calibration is a scientific process, not a mathematical exercise; and
  - Model confirmation with data should be judged qualitatively and quantitatively.
- ***Model application:***
  - Model scenarios for TMDL must incorporate realistic conditions, not idealized assumptions;
  - Model sensitivity and diagnostics are essential to confident model use;

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— Using model predictions without a defined uncertainty is irresponsible;
— When resource constraints are an issue, consider an adaptive approach; and
— Full disclosure of modeling details leads to better credibility and utility.

ES.4.6 Estimating the TMDL Margin of Safety

Section 303(d) of the Clean Water Act specifically requires that a TMDL include a Margin of Safety (MOS), which is designed to account for uncertainty in TMDL calculations. However, it is recognized (e.g. NRC, 2001) that the MOS component is not currently being rigorously addressed. In this research, the team found that for 10% of the TMDLs reviewed, it was not clear from the documentation if or how the MOS was estimated. In some cases, it may have been estimated implicitly, but the documentation did not provide any supporting information. Although 58% of the TMDLs specified an explicit MOS, less than 1% of these actually performed a rigorous analysis of uncertainty and incorporated that into the selection of the MOS.

The problems that presently inhibit the application of the Margin of Safety were investigated and divided into three categories:

1. Limited experience in defining the uncertainty in the TMDL calculations;
2. Absence of guidance on the degree of protection required by the MOS; and
3. Practical limitations of data poor situations.

As a result, most TMDLs employ very simplistic approaches to MOS, and/or often have arbitrary specification and/or justification.

To improve on how MOS is addressed, this research explored key attributes of approaches applied in various case studies that avoided these problems and met the statutory requirements. These attributes included explicit recognition and accounting for uncertainty, thoughtful assessment of the degree of protection necessary, consideration of data shortcomings and uncertain success in implementation, and use of relatively simple methods to facilitate wide understanding and application.

An improved method for incorporating the MOS into the TMDL process was developed, consisting of four steps:

1. Define desired level of protection;
2. Choose appropriate method for calculating MOS;
3. Calculate MOS; and
4. Consider implementation feasibility.

The third step of calculating the MOS can be done either implicitly or explicitly, depending upon the capabilities of the TMDL developer and the nature of the methods used to calculate the TMDL. The implicit method involved calculating the TMDL using alternative assumptions. A simple explicit approach involved setting aside a percentage of the TMDL for MOS based on the type of analysis performed. A rigorous approach involved explicit calculation of the probability of compliance. More detailed description is provided for the three alternative methods along with actual TMDL examples illustrating the methods.

ES.4.7 Public Involvement in the TMDL Process

An in-depth review of public participation in the TMDL program was beyond the scope of this project. However, any report related to the TMDL program would be lacking if it failed to highlight the essential role that the public plays in the TMDL process. A brief discussion of what existing TMDL regulations and guidance say about public participation is provided, and the importance of public involvement in many specific elements of TMDLs is highlighted throughout this report.

ES.4.8 Approaches to the Allocation of Loads in TMDLs

The allocation of loads is a policy decision, not a technical decision like many other TMDL issues. However, existing federal guidance provides no specific criteria for making the decision, and state guidance is generally lacking as well. The review of approved TMDLs revealed that less than 15% used an established, documented procedure for allocating loads. A large majority of documents described only the allocation result, not the method or criteria used for determining the allocation. There was no reduction or allocation made at all in more than 20% of the TMDLs reviewed. This research was conducted to improve understanding on this issue.

This report provides an inventory of guidance and approaches to the allocation of loads, along with commentary on different considerations. Since allocation is a policy issue, specific recommendations are not appropriate. Rather, the various options that states and/or TMDL developers need to consider when developing an allocation plan are discussed. Specific questions and considerations are listed that should be considered before deciding on an allocation strategy. These include factors such as fairness and equity, ability to implement, degree of consensus, credit for previous reductions, ability to pay, cost-effectiveness, trading options, and feasibility.

ES.4.9 Linking Best Management Practices (BMPs) to Load Reductions

In the review of approved TMDLs that addressed nonpoint sources, only 59% explicitly considered the effectiveness of BMPs for reducing nonpoint source loads. Of the TMDLs that did, only 28% cited references (a document, data, or plan) to indicate that BMPs would be effective to reduce loads, and only 14% provided a quantitative estimate of the expected load reduction. This is a significant shortcoming that may limit the reliability and effectiveness of TMDLs for nonpoint impacted waters.

One factor limiting the development of TMDLs for nonpoint sources is that sufficient information and data on BMP effectiveness and percent reduction are not readily available for all land use/land cover types. While some of this information exists, it is in disparate forms and not easily accessible. This research compiles and summarizes existing information to assist water quality professionals in linking BMP effectiveness to load reductions, including ranges of effectiveness, uncertainties, time frames for implementation, capital/operation and maintenance costs, and expected life. Guidance is also provided on how to use such information.

ES.4.10 Implementation Planning, Tracking and Adaptation

Putting aside issues of regulatory requirements, most everyone recognizes that TMDLs will be useful only if allocations are implemented. However, in the review of 176 approved TMDLs, the team found that only about one-half included implementation plans, and of these, less than half had detailed plans including specific actions and schedules. Furthermore, only a

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quarter had plans for monitoring and revision if water quality standards were not met. This research was conducted to provide TMDL practitioners with better information and guidance on implementation planning.

In reviewing state and individual experiences with implementation plans, the following observations were compiled:

- States with more detailed implementation plans have the greatest confidence that TMDLs will be executed and succeed;
- For TMDLs to be effective, implementation planning must start from the beginning of TMDL development and be linked to other programs;
- TMDL implementation requires widespread stakeholder and agency cooperation;
- Nonpoint source implementation plans are typically more general than specific, but still can provide reasonable assurance;
- States that have regulatory tools to address nonpoint sources are better positioned to address water quality problems; and
- Funding and monitoring need to be considered in implementation plans.

ES.4.11 Adaptive Watershed Management in the TMDL Process

The development and implementation of many TMDLs is significantly hindered by limited data, high uncertainty, and unproductive debate over the efficacy of proposed controls to achieve water quality standards. The result is often a total lack of any water quality progress as the TMDL undergoes critical debate. Adaptive watershed management can provide an improvement on the conventional TMDL in many of these situations. Through this research, the team developed a non-prescriptive approach for certain situations requiring a total maximum daily load. This approach, adaptive watershed management, combines concepts from adaptive management and watershed management to address the various uncertain elements in a TMDL. It provides a process to be progressively implemented over a specific timeframe until water quality standards are attained. The research discusses how adaptive watershed management allows initial progress to be made and additional information to be collected to definitively define a TMDL number and to specify final control actions.

Adaptive watershed management differs from conventional TMDL analysis by utilizing feedback loops to allow progressive refinement of standards, TMDL targets, data, analytical tools and proposed controls—all aspects of the TMDL process. This approach is not universally applicable and best employed in nonpoint source dominated systems, where TMDLs have a large uncertainty and/or multiple stressors. Other usage guidance is provided in the report.

Many water quality professionals have been advocating the wide use of adaptive management in TMDLs. However, the wide use of adaptive watershed management has some obstacles to overcome, especially concurrence that it meets statutory requirements. Nonetheless, this type of approach is gaining consideration and use, both inside the TMDL program and elsewhere. Case examples are provided in Chapter 14.0 along with elements that can improve its effectiveness and acceptance.

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CHAPTER 1.0

INTRODUCTION

This research project addressed a wide range of topics related to the TMDL process, from methods to quantify existing and future nonpoint source loads, to employing an adaptive management approach in TMDLs. The focus was on technical tools used in the development of TMDLs, whereas separate WERF-supported research projects (not reported on herein) focused on TMDL issues related to the listing and delisting process (WERF, 2003a) and narrative criteria (WERF, 2003b).

This report is not intended to be a technical guidance document. Rather, it was created to be a useful reference document for water quality professionals involved in the TMDL process. The reader will find a discussion of current issues and problems with the process, and a range of suggested improvements, supported where appropriate by case study examples. In cases where recommendations for improvements are not appropriate, the authors explore alternative approaches or suggest available resources to address the issue.

1.1 Project Objectives

The U.S. Environmental Protection Agency's efforts to support the TMDL program have been substantial. However, the scope, diversity, schedule, and resource demands of the TMDL program are enormous. Progress to date has been applauded by many, but criticized by many others. The objective of this research was to review the existing TMDL process and to develop an improved design for TMDL development where improvements are needed. This objective was accomplished through:

- Identifying and verifying problems with existing TMDLs;
- Formulating a range of improvement options related to the TMDL process on specific issues that address identified weaknesses; and
- Providing case studies and examples that highlight these recommended changes to improve the TMDL process.

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1.2 Background

TMDLs are required under the Clean Water Act, Section 303(d), for waterbodies that do not attain water quality standards after technology-based pollution control requirements are applied. While this provision has existed in the Clean Water Act for many years, it was brought to the forefront through a series of citizen suits in the 1980s and 1990s which required states and the U.S. EPA to list waterbodies not attaining water quality standards (so-called 303(d)-listed waterbodies), and develop maximum loadings as necessary to meet water quality objectives. In many cases, aggressive schedules for development of TMDLs for those waterbodies were also required. It was expected that the implementation of TMDLs would occur through both regulatory mechanisms such as National Pollutant Discharge Elimination System (NPDES) permits, as well as non-regulatory mechanisms such as voluntary agreements, management practices, and environmental assistance programs. Non-regulatory mechanisms are considered to be particularly appropriate for nonpoint source issues, which are generally not covered by NPDES permit or other regulatory programs.

The TMDL program has come under considerable criticism. Some have argued that the program is long overdue, and demand aggressive schedules for TMDL development to conform with the law. Others have argued that the schedules are too aggressive, leading to poorly developed TMDLs based on insufficient data, poor science, and overly restrictive assumptions. Further, many have argued that the program fails to adequately address nonpoint source issues, and unrealistically focuses too heavily on point source controls, and as a result will be ultimately ineffective in restoring designated uses. Overall, although the criticisms are many and diverse, most agree that significant improvements are needed to effectively use the TMDL program to help achieve the nation's water quality goals.

1.2.1 Existing Situation

Recent court rulings have moved TMDLs to the forefront of water pollution control activities in most states. Several rulings have required aggressive schedules for TMDL development. TMDL activities are now being conducted or planned in virtually all U.S. states and territories. According to 1998 statistics, 21,845 waterbodies have been listed as impaired on 303(d) lists, and 41,318 TMDLs are scheduled to be conducted over the next 10 to 15 years (U.S. EPA, 2000a).

U.S. EPA has issued guidance and protocols for the TMDL process, including the following documents:

- Guidance for Water Quality-Based Decisions: The TMDL Process (U.S. EPA, 1991a)
- Draft Guidance for Water Quality-Based Decisions: The TMDL Process (Second Edition) (U.S. EPA, 1999b)
- Protocol for Developing Nutrient TMDLs (U.S. EPA, 1999d)
- Protocol for Developing Sediment TMDLs (U.S. EPA, 1999e)
- Protocol for Developing Pathogen TMDLs (U.S. EPA, 2001c)
- 2002 Integrated Water Quality Monitoring and Assessment Report Guidance (U.S. EPA, 2002a)

U.S. EPA has also initiated activities to increase state capacity to develop TMDLs, including:

- Nationwide TMDL training seminars;
- Development of TMDL-oriented software (e.g. BASINS);
- Preparation of TMDL case studies; and
- Provision for U.S. EPA contractor support to state agencies.

1.2.2 Activities Supporting Positive Progress

Beyond U.S. EPA's official regulatory functions, the agency has initiated numerous activities that support positive progress on TMDLs. These efforts have been ongoing in spite of the budgetary, legal, and time restraints inherent to the TMDL program. Many of these activities have produced or are in the process of producing published documents, and the highlights relevant to this research project are summarized below. This is not intended to be a comprehensive summary; rather, the text provides a brief annotated reference guide, and the reader is referred to the cited sources for more detail. Specific findings and recommendations of these efforts are also discussed in individual chapters on research investigations in this report, as appropriate.

In 1996, U.S. EPA convened a committee under the Federal Advisory Committee Act (FACA) to evaluate U.S. EPA's and the states' implementation of the TMDL program and recommend improvements. The "FACA Report" (U.S. EPA, 1998a) served as the basis for many of the provisions in the agency's new TMDL rules that were proposed in August 1999 and finalized in July 2000. Subsequent legislation prohibited U.S. EPA from spending funds in fiscal year 2000 or 2001 to implement the new rule. This legislation also directed the agency to contract with the National Academy of Sciences to undertake a review of the adequacy of methods and approaches of the TMDL program (NAS, 2001). The 2000 TMDL rule was formally withdrawn by U.S. EPA in March of 2003 because it believed that significant changes would need to be made to make it a workable framework.

Many activities related to improving the TMDL program were ongoing and evolving throughout this research project. For example, U.S. EPA recently issued a report on research needs to improve the TMDL Process: "The Twenty Needs Report: How Research Can Improve the TMDL Program" (U.S. EPA, 2002e). Where possible, the products of these efforts were used in this research project as issues were identified and recommendations for improvements to the TMDL program were developed. Highlights of these activities are briefly described below.

1.2.2.1 TMDL FACA Recommendations

In 1996, U.S. EPA formed a TMDL advisory committee of stakeholders to develop recommendations for possible changes to the TMDL program. The FACA recommendations were published in July, 1998 (U.S. EPA, 1998a) and were used as the agency deliberated about its proposed TMDL rules that were issued in 1999. The report provides detailed recommendations related to identifying and listing impaired waters, the pace and scheduling of TMDL development, the TMDL development process, implementation, and allocations. Also discussed are special challenges, stakeholder involvement, tribal participation, program/agency cooperation, and federal/state/tribal capacity. Several specific FACA recommendations are addressed in the summary of stakeholder comments, as part of identifying issues and challenges (see Section 2.2).

1.2.2.2 National Research Council Review

U.S. Congress called upon NRC to examine the TMDL process. NRC was specifically requested to review how scientific data and information should be used in the TMDL program.

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The authors provide recommendations related to TMDL program goals and the TMDL process, and suggest changes in the data used and analytical methods employed in TMDLs. The results of this study were published in July, 2001 (NRC/NAS, 2001). Many of the report's recommendations were addressed in this research project. Among the issues discussed are the need for better water quality standards and use attainability analyses, improved data, better modeling, better analysis of uncertainty and Margin of Safety (MOS), better implementation, and the use of adaptive management. Specific conclusions and recommendations of the NRC study are highlighted throughout this report, as appropriate.

1.2.2.3 CALM Process

The Consolidated Assessment and Listing Methodology (CALM) was developed to help improve state water quality monitoring and assessment programs. More specifically, the methodology, which was developed with state and other stakeholder input, was intended to:

- Reflect the best thinking of state and U.S. EPA water quality program experts on appropriate approaches to assessment and listing under the Clean Water Act;
- Provide information to states to assist in preparation of state methodologies for assessment and listing;
- Summarize key technical issues and provide information on available technical information and guidance, as well as to acknowledge important gaps or limitations in current scientific knowledge/methods;
- Encourage a greater degree of appropriate consistency among states, while still allowing for flexibility to meet state-specific needs; and
- Foster collection and use of high quality data and the best available scientific methods in assessment and listing programs.

The CALM report was issued in July 2002 (U.S. EPA, 2002b). It outlines an iterative process for monitoring and assessment programs.

1.2.2.4 EPA Office of Water Integration Project

Under the leadership of four Office of Water Division directors, U.S. EPA recently undertook an effort to identify opportunities to better integrate national water program activities. As a first step, the analysis identified major barriers to program integration as well as opportunities to strengthen programmatic linkages. Several of the critical program linkages already identified in the project's first phase are directly related to the TMDL program. Key linkages identified thus far include "aligning water programs to reinforce an integrated watershed approach," "developing monitoring programs that support management decisions," and "aligning water programs to implement source controls more effectively." Next, the project assessed what institutional changes (regulatory, policy, programmatic) would be needed to support the recommended integration approaches, and determined how performance goals and measures could be modified to track the efficiency and effectiveness of newly integrated processes and activities. U.S. EPA will be exploring opportunities to make structural changes to the national program to strengthen these critical linkages.

1.2.2.5 EPA Twenty Needs Report

The "Twenty Needs Report" (U.S. EPA, 2002e) was issued *after* the issues identification phase of this research project was completed, but many of the identified needs are consistent with

the issues discussed in Chapter 2.0 of this report. The Twenty Needs report focuses on science needs identified by the National Research Council (see Section 1.2.2.2), states and tribes, U.S. EPA National and Regional TMDL programs, and others. Seven of the identified needs were recognized previously in this research project, and are being addressed in part through this project:

- Develop "state of the science" syntheses in several high priority subject areas to aid busy TMDL practitioners and decision-makers;
- Increase quantity and quality of completed TMDLs;
- Improve watershed and water quality modeling;
- Improve uncertainty analysis and statistical techniques for TMDLs;
- Improve guidance for allocation development and methods to translate allocations into implementable control actions;
- Improve information on BMP, restoration or other management practice effectiveness, and the related processes of system recovery;
- Develop adaptive implementation approaches for doing TMDLs.

Four identified needs were addressed in part through a companion WERF project addressing narrative TMDLs (WERF, 2003b):

- Improve the science base concerning all stressors (pollutants and pollution) and their impacts;
- Assist states in translating narrative standards into numeric criteria;
- Clarify and quantify selected parameters used in criteria definitions; and
- Develop and improve biocriteria, address other criteria gaps, and evaluate the potential for ecological water quality standards.

One identified need was addressed in part through a companion WERF research project on the Listing/Delisting process (WERF, 2003a):

- Evaluate defensible scientific standards for listing and delisting.

All 20 needs listed in the report are considered by U.S. EPA as high priority needs. To gain a sense of the highest priorities, regional coordinators and staff were asked for their top five of the 20 needs. Three of the needs listed above, related to improvements in modeling, information on BMPs, and standards for listing and delisting made it on the "top five" list.

1.2.2.6 Useful Websites

Several websites have been developed to provide additional information on TMDLs, including:

- America's Clean Water Foundation (ACWF) and the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA) have developed http://www.tmdls.net to provide examples of various TMDLs.
- U.S. EPA's TMDL website (http://www.epa.gov/owow/tmdl) provides information on the number of TMDLs and links to the agency's TMDL regulations and guidance, as well as information on waterbodies listed or assessed for 303(d) and 305(b) lists.

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- U.S. EPA's nonpoint source partnership website (http://www.epa.gov/owow/nps/partnership.html) provides links to a variety of nonpoint source resources for state and local governments as well as a link to the products of the Watershed Planning and Implementation Work Group.

The reader is encouraged to consult these websites and other resources previously referenced in this chapter for more background on the TMDL program.

1.3 Project Design and Project Team Roles

This section provides an overview of the approach used to conduct this research, and describes the structure of the project team and Project Subcommittee (PSC) of WERF-appointed experts.

1.3.1 Research Approach

There were two main components of this research effort. During the first year, the project team focused on identifying issues and challenges with the current TMDL program. The approach for this process is described in Section 2.1. This issues identification effort provided the basis for the selection of ten research topics to be pursued during the second year of the project. The approach used to identify these topics and conduct the research investigations is described in Section 3.2. The investigations were assigned to team members based on the knowledge, experience, and interest of the individuals described below.

This project involved a collaborative effort both among the researchers and with the Project Subcommittee members. This involved regular conference calls and discussions among the team, quarterly conference calls and meetings between the team and the subcommittee, and regular exchanges of documents and findings. These forums allowed the project team to constructively incorporate new ideas and critical feedback.

1.3.2 Project Team and Role of Project Subcommittee

Many individuals were involved in this research project, either as project team members, Project Subcommittee members, or WERF staff. The project team consisted of four firms:

- Limno-Tech, Inc., Ann Arbor, Michigan;
- Ross & Associates Environmental Consulting, Ltd., Seattle, Washington;
- FTN Associates, Little Rock, Arkansas; and
- Technology Planning and Management Corp., Scituate, Massachusetts.

Limmo-Tech served as the lead on the project, with Paul Freedman serving as principal investigator. The names and roles of the key individuals on the project team are listed in Table 1-1. Other staff at the above firms provided project support related to various aspects of the research.

The members of the Project Subcommittee (see Acknowledgments) played a crucial role in guiding the team throughout the project. The committee consisted of TMDL experts representing municipalities, states, industry, academia, and U.S. EPA. Subcommittee members served as

advisors during the initial project design, provided guidance and resources related to the issues identification phase and for individual investigations, and provided the project team critical feedback throughout the duration of the project.

Table 1-1. Project Team Members and Roles.

Affiliation	Name	Primary Role
Limno-Tech, Inc.	Paul L. Freedman, P.E., DEE	Principal Investigator Senior Advisor & Reviewer Investigator: Principles for Modeling (Chapter 8.0); Wet Weather (Chapter 6.0); Adaptive Watershed Management (Chapter 14.0).
	Wendy M. Larson	Project Manager and Reviewer Report Preparation
	David W. Dilks, Ph.D.	Senior Advisor & Reviewer Investigator: Principles for Modeling (Chapter 8.0); Margin of Safety (Chapter 9.0)
	Adrienne Nemura, P.E.	Investigator: Adaptive Management (Chapter 14.0)
	Dan Schechter, P.E.	Investigator: Wet Weather (Chapter 6.0)
	Joseph DePinto, Ph.D.	Investigator: Principles for Modeling (Chapter 8.0)
	Troy Naperala, P.E.	Project Support: Issues Investigations
Ross & Associates, Ltd.	Gerald W. Boese	Investigator: Allocation of Loads (Chapter 10.0)
	Lane Nothman	Investigator: Implementation Planning (Chapter 12.0)
	Anne Dettelbach	Investigator: Allocation & Implementation (Chapters 10.0 and 12.0)
	Martha G. Prothro	Investigator: Allocation and Implementation (Chapters 10.0 and 12.0)
FTN Associates, Ltd.	Kent Thornton, Ph.D.	Investigator: NPS Loadings (Chapter 5.0)
	Dennis Ford, P.E., Ph.D.	Investigator: Background Loadings (Chapter 4.0) Critical Conditions (Chapter 7.0)
	Philip Massirer, P.E.	Project Support
	Thomas Soerens, P.E., Ph.D.	Project Support
Technology Planning and Management Corp.	Kristyn B. Stevens	Investigator: Linking BMPs (Chapter 11.0)
	Jose A.H. Sobrino	Investigator: Linking BMPs (Chapter 11.0) Project Support: Issues Investigations

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CHAPTER 2.0

IDENTIFICATION OF ISSUES AND CHALLENGES

The first year of this research project was focused on evaluating the current TMDL program, and identifying issues and challenges. This outcome of this process was then used to identify topics for the research investigations that were pursued in the second year, as discussed in Chapter 3.0.

2.1 Approach

The first step in the identification of issues was to develop an initial list of hypotheses to investigate. The intent in developing the original list of hypotheses was to write clear statements describing what at the time was believed to be the problems with the TMDL program, and then to examine the evidence to support or refute each of these hypotheses.

The list was developed based primarily on the experience of the investigators and Project Subcommittee members. Subcommittee comments were solicited during the project kickoff meeting in November 2000, as well as through quarterly progress reports to WERF. In addition, issues were identified by investigating other relevant sources, including:

- U.S. EPA FACA Report on the TMDL Program (U.S. EPA, 1998a) (Section 1.2.2.1);
- Report by the U.S. General Accounting Office (GAO, 2000a) entitled "Water Quality: Identification and Remediation of Polluted waters Impeded by Data Gaps";
- Report by the GAO (2000b) entitled "Water Quality: Key EPA and State Decisions Limited by Inconsistent and Incomplete Data";
- U.S. EPA comment database compiling the approximately 34,000 comments provided to the agency on the 1999 proposed TMDL rule;

In-depth review of specific comments to U.S. EPA on the 1999 proposed TMDL rule by the following groups:

- TMDL Coalition;
- Association of State and Interstate Water Pollution Control Administrators (ASIWPCA)/Environmental Commissioners of States/Coastal States Organization;
- Association of Municipal Sewerage Agencies (AMSA);
- American Farm Bureau;

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- Natural Resources Defense Council;
- U.S. Department of Agriculture; and
- Water Environment Federation (WEF).

The list of issues was further developed and refined through discussion among the project researchers and communication with the PSC. During this process, the list of hypotheses was converted into a list of issue questions to be investigated.

For example, with respect to scheduling and resources, the original hypothesis statement was:

> "Data are often inadequate to accurately quantify existing and future nonpoint source loads."

This was rewritten as a question:

> "Are data adequate to quantify existing and future nonpoint source loads?"

The list of issues was refined and supplemented by investigating other information sources, including relevant reports related to the TMDL program and stakeholder comments on the 1999 proposed TMDL rule. Three lines of evidence were then examined to confirm this list of issues:

- Survey of state TMDL programs;
- Review of approved TMDLs; and
- In-depth review of specific case study examples.

This effort is described in Sections 2.2 to 2.7, and the list of issue questions is presented in Section 2.8.

2.2 Review of Stakeholder Comments

Stakeholder comments on proposed TMDL regulations and other developments were reviewed to gain an understanding of the public's perception of the issues. This section provides a general overview of these comments. In addition, the FACA Report and the two GAO reports cited in Section 2.1 were reviewed. Project team members also participated in several of the five TMDL listening sessions hosted by U.S. EPA in autumn 2001. The purpose of these meetings was to "get stakeholder perspectives on key issues associated with the TMDL program and related issues in the NPDES program, and to identify/discuss ideas about how to address issues in the TMDL and NPDES programs." Summaries of the listening sessions can be found at: http://www.epa.gov/owow/tmdl/meetings.

Sections 2.2.1 through 2.2.9 provide a brief summary of many of these stakeholder comments, categorized by topics relevant to this research project. They are presented in abstracted form, without analysis or commentary. The purpose is to provide readers with some background on the context in which this research was undertaken.

2.2.1 Scheduling and Prioritization

Stakeholder comments reflect a variety of opinions on the scheduling of TMDLs. With respect to the 15-year timeframe, the TMDL Coalition and the alliance of state water pollution control and environmental officials state that 15 years may not be enough time to complete all TMDLs and that state flexibility should be allowed. The FACA Report recommends an 8–15 year timeframe, and says that high-priority waters should be done in the first five years. The Natural Resources Defense Council states that 15 years is too long, and WEF comments that "difficult to solve" problems (e.g., wet weather TMDLs) should be given longer timeframes.

With respect to prioritization, several reviewers stated that state flexibility should be allowed. The groups representing states' interests note that this flexibility should be based on the severity of pollution and designated uses. A GAO report (2000a) notes that some states reported that, because of a lack of data, they are focusing on TMDLs that are relatively easy to do rather than those that are high priority. The FACA Report notes that U.S. EPA guidance is needed for identifying high priority waters. FACA also notes that priority ranking should influence scheduling, and should be documented and made available for public review. The TMDL Coalition states that violations of maximum contaminant levels or the presence of threatened and endangered species should not be criteria for a high priority ranking. WEF recommends state flexibility where adequate stakeholder input is afforded.

2.2.2 Consistent Protocols

Some reviewers (e.g., WEF, TMDL Coalition, and AMSA) support consistent documented protocols for listing, but support flexibility in TMDL development. NRDC notes that the Clean Water Act and U.S. EPA regulations set forth specific procedural requirements to be followed (and are not always) for developing legally valid TMDLs.

2.2.3 Numeric Targets

A review of comments on numeric targets reflects the challenges in the TMDL process related to problems involving narrative standards. The TMDL Coalition and the alliance of state water pollution control and environmental officials state that waters should not be listed unless there is objective, quantifiable evidence of impairment. The FACA Report states that all waters not attaining water quality standards, including narrative, must be listed, and that guidance and regulation is needed to explain how to apply narrative criteria in 303(d)(1)(a). NRDC states that states should be required to establish a numerical TMDL figure for each listed waterbody.

2.2.4 Source Assessment

Many of the comments on source assessment relate to the adequacy of data to characterize sources. The TMDL Coalition states that only data that are collected under an approved quality assurance plan should be used. The Farm Bureau agrees, supporting listing decisions and TMDL calculations that are based on reliable data. This group notes that if data are inadequate, U.S. EPA should reject that list or TMDL. USDA comments that there is insufficient technical and scientific precision and reliability to allocate loads to nonpoint sources.

In contrast, the FACA Report notes that lack of certainty should not delay TMDL development. It states that the highest level of quantitative rigor should always be used, and when scientific information is insufficient to determine the course of action, best professional judgment should be used. The GAO report on identification and remediation of polluted waters (GAO,

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2000a) notes that few states (six of the 50) have sufficient data to assess all their waters, and particularly to identify nonpoint sources and to develop TMDLs for waters impaired by them. WEF supports nationally consistent data standards.

2.2.5 Loading Capacity or Linkage Analysis

The TMDL Coalition supports not requiring TMDLs where an estimation of assimilative capacity is infeasible (e.g., ephemeral streams). The Natural Resources Defense Council supports inclusion of high and low flow analyses for all pollutants to ensure that the TMDL reflects the critical conditions for a waterbody. The GAO report on identification and remediation of polluted waters (GAO, 2000a) points out that the majority of states they surveyed stated that they needed additional technical tools and assistance, particularly relating to watershed models to address nonpoint source problems.

2.2.6 Allocation of Loads

Concerns related to methodologies for allocating loads between point and nonpoint sources were expressed in many stakeholder comments. The FACA Report notes that equitable allocation is important, and that the allocation scheme should be left to the states (the TMDL Coalition agrees with this). However, the report notes that the scheme must be designed to achieve water quality standards. If a combination of controls established in a TMDL does not accomplish water quality standard attainment, FACA recommendations support modifying the TMDL to assure that goals will be met.

WEF supports guidance that encourages states and tribes to explicitly document the basis for allocations. USDA emphasizes that regulations should recognize the limits in scientific understanding regarding allocation of loads among nonpoint and point sources.

AFB notes that Section 303(d)(1)(C) limits TMDL establishment only to point sources, since there are no "proper technical conditions" under which "daily loads" can be established for nonpoint sources. The alliance of state associations supports addressing allocation problems under NPDES permit delegation agreements and current regulations.

With respect to the issue of reserve for future increased loadings, The Natural Resources Defense Council comments that TMDLs must account for all uncertainties between pollutant loads and estimated levels necessary to achieve water quality standards year-round. The Farm Bureau states that U.S. EPA has no authority to require states to allocate for future growth. The TMDL Coalition comments that this needs to be clarified to achieve a technically sound application, and that appropriate flexibility should be allowed. The Coalition also states that reserve for future increased loading cannot be a substitute for collecting needed data.

2.2.7 Margin of Safety

Comments on the Margin of Safety (MOS) component of the TMDL process reflect concerns related to its intent and derivation. The FACA Report states that the MOS should be included in the allocation to address modeling uncertainty associated with relating loads to water quality conditions, not as substitute for lack of data and rigor. WEF notes that as a key element of a TMDL, the MOS should be accompanied by "scientifically valid supporting analyses." The TMDL Coalition states that there is no authority to require an MOS, and that uncertainty created

by lack of data should not be used to justify a larger MOS. The National Research Council report (NRC, 2001) states that U.S. EPA should end the practice of arbitrary selection of the MOS and instead require uncertainty analysis as the basis for MOS determination.

2.2.8 Public Participation

Comments related to public participation focus on how the public should be involved in the TMDL process. WEF supports requiring only those public involvement elements that are appropriate under applicable state law and not imposing additional requirements. WEF also supports ensuring that public participation procedures cannot be the basis for lawsuits. USDA raises a concern that U.S. EPA is proposing a prescriptive approach with short, unrealistic deadlines that will preclude extended public involvement. The FACA Report supports actively soliciting input on listing methodology and TMDL development, and recommends setting up informal meetings with stakeholders to explain the TMDL process and to encourage a stakeholder role in TMDL development. The state water pollution control and environmental officials' group comments that petitioners should be required to demonstrate that they have exhausted their administrative remedies in seeking the requested action in the state TMDL development process before taking their petitions directly to U.S. EPA.

Some comments relate to public accessibility to data. The TMDL Coalition supports posting listing data in a formal docket and on a website or bulletin board. WEF supports a requirement for states to explain to the public the types of data that are available and how they will be used.

2.2.9 Implementation Plans

The TMDL Coalition, the alliance of state officials, and the Farm Bureau note that there is no authority to require plans under 303(d). The FACA Report supports requiring submittal of plans with TMDLs, and that these plans should require nine basic elements. The Natural Resources Defense Council supports inclusion of implementation plans and also requiring resource deadlines to implement controls and to attain water quality standards. USDA states that it is important to specify how implementation plans relate to ongoing nonpoint source activities. WEF believes that plans should be required, but should not be one of the requirements of a TMDL itself.

2.3 Review of State Programs

To gain an understanding of issues and challenges currently being addressed by the states, the project team conducted a review of state programs. This was done through a written survey of eight states (Section 2.3.1), phone interviews with U.S. EPA regional coordinators (Section 2.3.2), and a review of state guidance material (Section 2.3.3). The team also drew on the experience of project team and WERF Project Subcommittee members. Later in the project, team members conducted phone interviews with staff at many dozens of states and also with U.S. EPA staff related to particular research topics. These efforts are described below.

2.3.1 Survey of Eight State Programs

Four pairs of contiguous states were selected for review. The review occurred in the form of a written survey and an interview. The reasons for selecting contiguous pairs of states were:

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- Contiguous states have similar physiographic or ecoregional patterns, and therefore would be expected to have similar water quality standards. Similar water quality standards among states, however, are the exception more than the norm.
- Contiguous states in the same U.S. EPA region can indicate if the review of the TMDL process is similar across the region.
- Contiguous states can have interstate waterbodies that are listed or delisted differently.
- Contiguous states can be evaluated at minimal additional costs because the Project Team has experience in working in each of these state pairs.

Four geographic regions were selected so that the review would consider:

- All waterbody types, including stream segments, lakes/reservoirs and estuaries;
- A range of listing/delisting processes among states;
- A range of maturity in state programs; and
- A range of water quality conditions throughout the nation.

The list of states surveyed changed slightly from the originally proposed pairs of states because of difficulty obtaining detailed information. The paired states that were interviewed were Oregon and California; Arkansas and Louisiana; Indiana and Michigan; and Rhode Island and Massachusetts. These states use various approaches for establishing water quality standards, represent a range of stringent and flexible regulatory programs, have various levels of experience with the TMDL program, have different levels of guidance, and include various types of waterbodies.

In summary, these pairs of states have a range of:

- Criteria for listing and delisting;
- Data available for use in developing TMDLs;
- Aquatic systems;
- Program maturity; and
- Rationale for listing/delisting and developing TMDLs.

Each of the eight states was provided with a comprehensive survey that covered all aspects of its TMDL program. Project team members worked with each state to complete the survey. The results of these surveys are discussed throughout this report as they apply to specific investigations.

2.3.2 Interviews with U.S. EPA Regional Coordinators and Other States

The project team conducted phone interviews with all U.S. EPA regional coordinators to refine the list of issues and identify innovative approaches being used by the states related to particular topics. Questions were also asked in an effort to locate state guidance documents and specific TMDLs that employed innovative approaches. Follow-up calls to dozens of states were then made, related to particular research topics. The findings are reported and discussed in the chapters reporting on individual research investigations.

2.3.3 Review of State Guidance Documents

State guidance documents were reviewed as part of the issues identification phase, and also to understand current approaches that are being used to develop TMDLs. The project team contacted U.S. EPA Regional coordinators to identify which states in each region have guidance documents or methodologies for conducting TMDLs. In addition, each state agency website was reviewed for downloadable TMDL guidance documents. The findings from each approach were consistent, with few exceptions.

Electronic guidance documents were available for the following states: (Table 2-1): California, Florida, Idaho, Indiana, Kansas, Kentucky, Louisiana, Minnesota, Montana, New Mexico, New York, Ohio, Texas, and Washington. Where available, URLs for these documents are included. Guidance documents for all 15 states were downloaded and reviewed.

The content of these guidance documents varies greatly. While several states had general guidance documents outlining the TMDL process, other guidance was quite specific (e.g., how to do a MOS). Following are brief descriptions of selected documents, to illustrate the types of state guidance that are available for this review.

Florida provided guidance on the TMDL development process, best management practices, and allocation strategy topics.

Idaho provided general overview related to the TMDL process, including background, schedule, public involvement and comment, and requirements of TMDL submittals. A separate document provides supplemental guidance on the definition and use of "surrogate measures" for TMDLs developed in Idaho.

Indiana provided general guidance and information regarding the TMDL process. Timing of each task, responsible parties for each task, and general descriptions of each task are provided.

Kansas provided general guidance related to the TMDL process, as well as some specific guidance highlighting TMDL curve methodology (see section 5.3.4.5). An explanation of the bacteria TMDL curve is presented, as well flow duration curves. Methodology used in Kansas lake TMDLs is also discussed, addressing eutrophication TMDLs, dissolved oxygen, pH, and aquatic plant TMDLs.

Louisiana provided a list of procedures that should be followed in determining TMDLs, wasteload allocations, and load allocations for nonpoint sources. It specifies the technical management and planning procedures to be followed in the TMDL development process. Water quality modeling and analysis is addressed in detail, highlighting several modeling approaches. An outline is provided for TMDL report preparation as well.

Minnesota's guidance incorporated different protocols into one document, and provided a 12-step TMDL process, which includes stakeholder involvement, data collection, analysis and interpretation of data, and other steps toward delisting the impaired reach.

Montana's guidance included a TMDL project coordination flow chart and TMDL checklist with eight basic components for TMDL approval. It specifies that a plan should be

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developed to meet state water quality standards that has quantified goals, targets or endpoints, as well as quantified pollutant reduction targets. The guidance also states that responsibilities for implementation should be assigned, and an appropriate level of public involvement should be documented.

New York has prepared some guidance documents that address very specific methodologies (e.g., calculation of Phase II TMDLs of phosphorus for New York City drinking water reservoirs). While specific results are presented for waterbodies, the documents outline methodologies to be followed for the development of Phase II TMDLs to assist with the completion of the TMDL process for phosphorus. Documentation of MOS calculations, Reckhow land use models, phosphorus export coefficients, TMDL and wasteload allocations are provided.

Ohio had two documents that provide assistance with TMDL development. One provided an overview of the basic needs for performing TMDLs to ensure a successful program. General information regarding TMDL development, the basics of listing, the proposed TMDL process, and the steps and challenges during the process are outlined. The second document provided an overview of technical and legal basis for nutrient target values used in TMDL projects.

Oregon had guidance for developing Water Quality Management Plans (WQMPs) that serve as TMDLs for nonpoint sources. WQMP guidance thus provide basic guidance on TMDL development. Basic elements of a WQMP are discussed in detail including goals and objectives, proposed management measures, public participation, funding strategies, implementation timeline, monitoring and evaluation, and maintenance of effort over time.

Texas provided guidance that focuses on the TMDL process as a component of the statewide watershed management program. Initiating the TMDL process, TMDL development, the implementation plan, public participation in the process, water quality monitoring in the process, modeling in the process, and TMDL tracking progress are discussed.

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Table 2-1. State TMDL Guidance Documents.

STATE	REPORT TITLE	URL
California	Guidance for Developing TMDLs in California – EPA Region 9	http://www.epa.gov/region09/water/tmdl/caguidefinal.pdf
Florida	A Report to the Governor and the Legislature on the Allocation of Total Maximum Daily Loads Florida	http://www.stormwater-resources.com/Library/DEPTMDLAllocation%20Report.pdf
Idaho	Guidance for Development of Total Maximum Daily Loads	http://www2.state.id.us/deq/water/tmdlguid.pdf
Idaho	Using Surrogate Measures in TMDLs	http://www2.state.id.us/deq/water/tmdls/surrogates1.htm
Indiana	TMDL Maximum Daily Load Program Strategy	http://www.in.gov/idem/water/assessbr/tox&chem/webtmdlg.pdf
Kansas	The TMDL Process	www.kdhe.state.ks.us/tmdl/process.htm
Kansas	Methodology Used in Kansas Lake TMDLs	http://www.kdhe.state.ks.us/tmdl/eutro.htm
Kansas	TMDL Curve Methodology	http://www.kdhe.state.ks.us/tmdl/Data.htm
Kansas	Explanation of Bacteria TMDL Curves	http://www.kdhe.state.ks.us/tmdl/curve_notes.pdf
Kansas	Conceptual Framework for the Development of TMDLs for Water Quality Limited Streams.	NA
Kansas	Kansas Water Quality Assessment Protocols; Kansas Implementation Procedures for Surface Water	NA
Kentucky	Implementation Plan for Achieving Load Allocations for Nonpoint Source TMDLs	NA
Louisiana	Louisiana Total Maximum Daily Load Technical Procedures	http://www.deq.state.la.us/technology/tmdl/ltp2001.pdf
Minnesota	2002 Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment	http://www.pca.state.mn.us/publications/tmdl-guidancemanual.pdf
Minnesota	Minnesota's TMDL Process (The 12 Steps)	http://www.pca.state.mn.us/water/pubs/tmdl-12step.pdf
Montana	TMDL Project Coordination Flow Chart	http://www.deq.state.mt.us/ppa/mdm/Images/flowchart.gif
Montana	TMDL Checklist – Basic Components for Approval	http://www.deq.state.mt.us/ppa/mdm/TMDL/tmdl_checklist.asp
New Mexico	New Mexico Implementation Guidelines (1994)	http://www.nmenv.state.nm.us/swqb/TMDL_Library.html
New York	Methodology for Calculating Phase II TMDLs of Phosphorus for New York City Drinking Water Reservoirs	http://www.ci.nyc.ny.us/html/dep/pdf/tmdl/methodology.pdf
New York	Development of a Water Quality Guidance for Phase II Total Maximum Daily Loads (TMDLs) in the New York City Reservoirs	http://www.ci.nyc.ny.us/html/dep/pdf/tmdl/guidance.pdf
Ohio	Complete Report of the TMDL Team, October 1,1999	http://www.epa.state.oh.us/dsw/tmdl/FinalTMDLReport.pdf
Ohio	Legal and Technical Basis for Nutrient Target Values Used in TMDL Projects	http://www.epa.state.oh.us/dsw/guidance/wqs4.pdf
Oregon	Guidance for Developing Water Quality Management Plans that will function as TMDLs for Nonpoint Sources	http://www.deq.state.or.us/wq/nonpoint/NPCover.htm
Texas	Developing Total Maximum Daily Load Projects in Texas: A Guide for Lead Organizations (full document)	http://www.tnrcc.state.tx.us/admin/topdoc/gi/250/fulldoc.pdf
Washington	Guidance Document for Developing TMDLs	http://www.ecy.wa.gov/biblio/9923.html
Washington D.C.	District of Columbia's TMDL Allocation Process Document	NA

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2.4 Review of Approved TMDLs

The list of issues was further refined through a review of TMDLs. The project team reviewed 176 TMDLs that have been approved by U.S. EPA. The first step was to obtain almost 300 TMDLs that had been approved by the agency. In some cases, multiple TMDLs were described in one document. The primary basis for selection was whether the TMDLs were approved and readily available from U.S. EPA and on the internet at the time of this review. Team members visited the agency's Office of Wetlands Oceans and Watersheds and reviewed its files and library on the TMDL program. The team also reviewed dozens of state TMDL websites.

Fifty-two TMDL documents in hard copy format were obtained from U.S. EPA. An additional 211 electronic documents were gathered from various Internet sources. Although all documents were listed as final TMDLs, U.S. EPA staff did inform the team that TMDLs could have been further modified after U.S. EPA approval was granted. A single TMDL document often contained several actual TMDLs because, in many cases, more then one waterbody or pollutant was considered. An estimated 600 TMDLs were included in the electronic and hard copy documents received.

In this first screening, an effort was made to acquire TMDLs that generally represent a variety of parameters from a wide geographical distribution. The next step was to select a subset of these TMDLs to review that was approximately representative of the complete set of TMDLs that have been approved by U.S. EPA. While a statistical analysis was not conducted, the Project Team made an attempt to review TMDLs across all geographic regions, with approximately the same distribution of parameters and source types as the complete list (Figure 2-1).

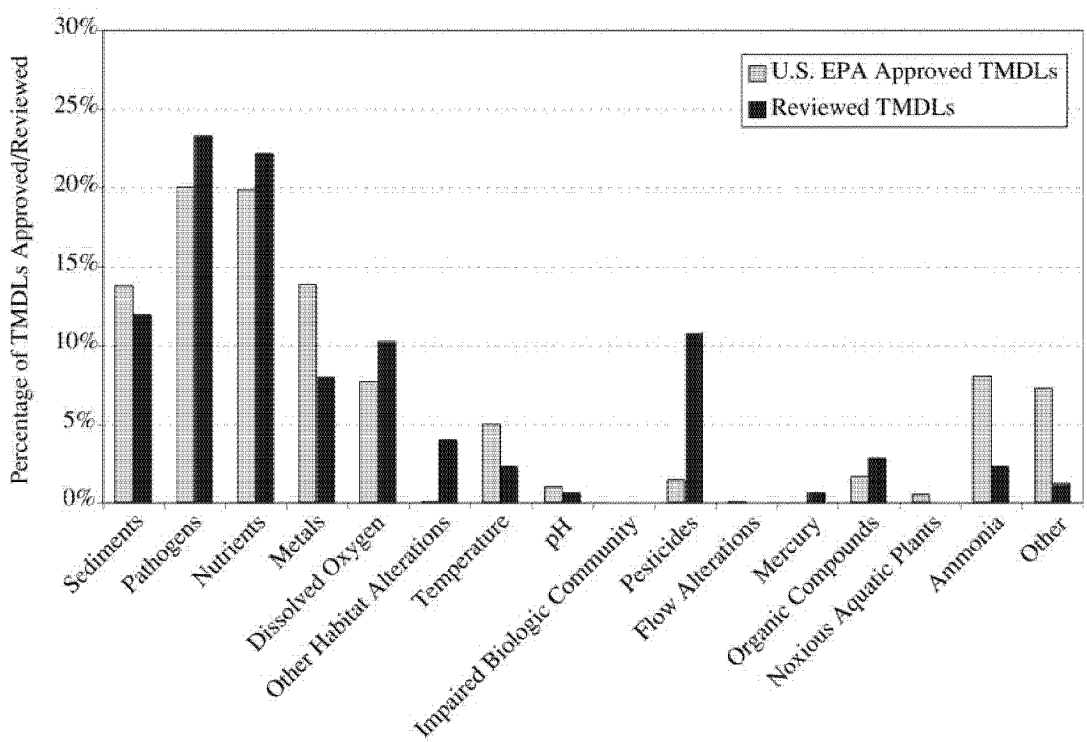

Figure 2-1. Percentage of TMDLs Approved by the U.S. EPA and Those Reviewed; Shown by Parameter.

Before reviewing these TMDLs, a review worksheet was developed that was based on the list of identified issues (Section 2.1), and consistent with the categories covered in the review of stakeholder comments (Section 2.2) as well as the state surveys (Section 2.3). Each reviewer completed a worksheet, and this information was then incorporated into a spreadsheet. The information compiled in the database was then synthesized and quantified through summary statistics. Because they apply to specific research investigations, the results of the TMDL reviews are discussed throughout this report. A list of the TMDLs that were reviewed is provided in Appendix A.

2.5 Specific Examples

The TMDL review provided a means of conducting a broad statistical review of a large number of approved TMDLs. The third line of evidence, a closer examination of specific approved TMDLs, provided a means of highlighting specific examples to illustrate findings. These specific examples are presented and discussed in Chapters 3.0 through 14.0, as appropriate.

2.6 List of Issues and Major Program Challenges

A list of issues and challenges was developed from the efforts described above, as follows:

1. ***Schedules:*** Many states have developed a broad schedule for completing TMDLs. However, the selection of which TMDLs to do first appears to be largely driven by factors other than the severity of the water quality problem.
2. ***Consistent protocols:*** TMDLs are not always conducted following consistent protocols.
3. ***Narrative TMDL targets:*** For narrative standards and for pollution (non-pollutant impairment), numeric targets for the TMDL are not generally selected based on documented procedures.
4. ***Nonpoint source loads:*** While data are usually adequate to quantify dry weather point source loads, data are often inadequate to accurately quantify existing and future nonpoint source loads.
5. ***Critical conditions:*** A rationale for selecting critical conditions for TMDLs is not well-established, and considerations for selection are generally not well-documented.
6. ***Urban stormwater:*** Impairments caused by wet weather point sources such as combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) do not appear to be currently addressed in the TMDL program.
7. ***Background sources:*** Background pollutants, or non-regulated sources (e.g., upstream, atmospheric deposition, sediment contamination) are often not fully considered in TMDL development.
8. ***Assimilative capacity:*** An estimate of assimilative capacity is not always considered in TMDLs. In some cases, loading reductions are specified regardless of how assimilative capacity was estimated.
9. ***Modeling:*** Complex water quality models are not often used in TMDLs. For the TMDLs that do involve models, it is not always easy to evaluate the appropriateness of model selection and application.

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10. ***Allocations:*** Allocation of loads among contributing sources often does not follow established documented protocols.
11. ***Nonpoint source controls:*** Nonpoint source control measures are mentioned in TMDLs as a way to meet load allocations. However, their effectiveness and feasibility is often not linked to specific reductions.
12. ***Future growth and attainment:*** Future growth and long-term attainment of the TMDL is not always considered.
13. ***Margin of Safety:*** The MOS is not always defined following a documented protocol.
14. ***Uncertainty:*** Uncertainty in the estimation of loads, calculation of assimilative capacity and modeling is often not explicitly defined.
15. ***Public involvement:*** The public is not always involved throughout the development and implementation of the TMDL; and information on the TMDL process, water quality conditions and best management practices is not always readily available to the public.
16. ***Implementation:*** Commitments to implement activities are not always clearly defined, tracked and evaluated throughout the life of the TMDL.

These issues can be categorized into the following five major program challenges of the TMDL program:

1. ***Inadequate standards:*** The TMDL program is fundamentally driven by comparison to quantitative water quality objectives. Yet, ironically, many of the impaired waters are for pollutants or pollution without established numeric standards, and for many sites established numeric standards are of questionable applicability.
2. ***Insufficient data:*** The TMDL program is intrinsically quantitative, requiring data for calculating loads and assessing water quality. Unfortunately, the data support needed is often insufficient. Hence, TMDLs are developed with approximations, estimates and guesses.
3. ***Uncertain analysis:*** The TMDL program essentially requires a single and precise calculation of the allowable loading and the effectiveness of proposed management and controls. Unfortunately, inexact science, insufficient data and natural variability preclude a precise, reliable answer. The resulting uncertainty is not currently being adequately assessed.
4. ***Unsure implementation and outcome:*** The fundamental purpose of the TMDL program is to restore impaired uses. However, because of inadequate information and uncertain implementation, this goal is not assured in many of the TMDLs conducted to date.
5. ***Need for more documented consistent methodologies:*** The TMDLs that were reviewed often had widely differing procedures for activities, ranging from data collection to allocation to public involvement. This resulted in sometimes satisfactory but often unsatisfactory TMDLs. While different approaches are often warranted, there is a need for more standardized guidance.

The first challenge is being addressed through two separate WERF-funded research efforts that focus on narrative TMDLs (WERF, 2003b) and the listing/delisting process (WERF, 2003a). To address the other four major challenges, the research team identified 10 specific areas for improvement in the TMDL program (Chapter 3.0). Most of the issues and challenges listed above were addressed in part through these research investigations. Exceptions were:

scheduling (#1); narrative TMDLs (#3); and public involvement (#15). Scheduling issues were considered to be more in the policy realm than science; therefore this topic was not pursued. Narrative TMDL issues were addressed under a separate project (WERF, 2003b). Public involvement was addressed as appropriate in individual chapters as it relates to particular topics, and a brief discussion in included in Chapter 13.0.

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CHAPTER 3.0

RESEARCH INVESTIGATIONS TO ADDRESS ISSUES AND CHALLENGES

To address the major challenges described in Chapter 2.0, the research team identified 10 specific areas for improvement in the TMDL program. These relate primarily to specific steps and/or methods employed in the TMDL development process. Each topic maps to one or more of the issues identified and discussed in Chapter 2.0, as shown in Section 3.1.

3.1 Research Topics

The 10 research topics are presented in Table 3-1. The table also includes the chapter on public participation. A separate research investigation was not conducted on this topic, but it was highlighted throughout the report and also a chapter was dedicated to a brief discussion. Each topic is linked to one or more of the issues identified in Chapter 2.0, as shown below:

Table 3-1. Research Investigations Linked to Identified Issues.

Research Investigation (Chapter)	Identified Issues (see Chapter 2.0)
Estimating Background Pollutant Loads (4.0)	Background pollutants, or non-regulated sources (e.g., upstream, atmospheric deposition, sediment contamination) are often not fully considered in TMDL development. TMDLs are not always conducted following consistent protocols.
Quantifying Existing and Future Nonpoint Source Loads (5.0)	While data are usually adequate to quantify dry weather point source loads, data are often inadequate to accurately quantify existing and future nonpoint source loads.
Incorporating Urban Wet Weather Point Sources (6.0)	Impairments caused by wet weather point sources such as combined sewer overflows and sanitary sewer overflows do not appear to be currently addressed in the TMDL program.
Selecting Critical Conditions (7.0)	A rationale for selecting critical conditions for TMDLs is not well-established, and considerations for selection are generally not well-documented.

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Table 3-1. Research Investigations Linked to Identified Issues. (cont.)

Research Investigation (Chapter)	Identified Issues (see Chapter 2.0)
Guiding Principles for Modeling Approach (8.0)	Assimilative capacity is not always considered. In some cases, loading reductions are specified regardless of how assimilative capacity was estimated. Complex water quality models are not often used in TMDLs. For the TMDLs that do involve models, it is not always easy to evaluate the appropriateness of model selection and application.
Estimating the Margin of Safety (9.0)	The Margin of Safety (MOS) is not always defined following a documented protocol. Uncertainty in the estimation of loads, calculation of assimilative capacity and modeling is often not being explicitly defined. TMDLs are not always conducted following consistent protocols.
Allocating Loads (10.0)	Allocation of loads among contributing sources often does not follow established documented protocols. TMDLs are not always conducted following consistent protocols. Future growth and long-term attainment of the TMDL is not always considered.
Linking Best Management Practices to Load Reductions (11.0)	Nonpoint source control measures are mentioned in TMDLs as a way to meet load allocations. However, their effectiveness and feasibility is often not linked to specific reductions.
Implementation Planning, Tracking, and Adaptation (12.0)	Commitments to implement activities are not always clearly defined, tracked and evaluated throughout the life of the TMDL.
Public Involvement (13.0)	The public is not always involved throughout the development and implementation of the TMDL, and information on the TMDL process, water quality conditions and best management practices is not always readily available to the public.
Adaptive Watershed Management in the TMDL Process (14.0)	This topic was undertaken because of a number of issues leading to uncertain calculations of TMDLs and uncertain attainability of water quality standards. This includes issues related to nonpoint sources, MOS, selection of critical conditions, model development, calculation of assimilative capacity, and others.

These topics are addressed in Chapters 4.0 through 14.0. The chapters vary considerably in their nature, because of the wide range of topics addressed. However, a general research approach was followed, described below.

3.2 Research Approach

The research approach differed somewhat between investigations, because of the varied nature of the research topics. In general, however, researchers followed a similar approach. First, the nature of problems was evaluated based on insights gained from the state surveys and

review of individual TMDLs and other sources. Second, ideas for improvements were developed, based on the review of state programs, the review of individual TMDLs, other data and information collected during the study, and the experience of the investigators and WERF Project Subcommittee members. Finally, these suggested improvements were illustrated, where possible, through case study examples. For some investigations, recommended improvements were inappropriate, and instead the researchers explored available alternatives or compiled and synthesized data and information.

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CHAPTER 4.0

ESTIMATING BACKGROUND POLLUTANT LOADS

The objective of this research element was to develop a working definition of background loads and to recommend appropriate methods to estimate the loads for different types of pollutants. Pollutant loads to receiving systems are contributed from three sources: point sources, nonpoint sources, and background sources. Background sources, in most instances, are not anthropogenic in origin. Background sources cannot be controlled and represent sustained pollutant loadings to the system. Unrealistic nonpoint source loading reductions and load allocations can result if background sources are not estimated accurately. Alternatively, failure to adequately account for background concentrations can impact the probability that the TMDL will result in attainment of standards.

This research was based on surveys of state programs, reviews of U.S. EPA and state guidance documents on TMDLs, and reviews of approved TMDLs that were recommended by U. S. EPA and state personnel as being unique, innovative, or technically superior. The focus was on pollutants, not physical modifications to natural systems such as reservoirs.

4.1 Background

The 1991 U.S. EPA Guidance Document on TMDLs (U.S. EPA, 1991a) describes a TMDL as "a tool for implementing State water quality standards and is based on the relationship between pollution sources and in-stream quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls." Based on 40 CFR 130.2, a TMDL is legally defined as "the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background." Quantifying the natural background load is therefore part of the TMDL process that needs to be considered. In many cases, however, background loads are simply included with nonpoint loads, if for no other reason than for lack of knowledge or simplicity.

A Margin of Safety (MOS) is also required as part of TMDLs to account for the uncertainty about the relationship between loadings and the associated water quality standard. The MOS can either be included implicitly with conservative assumptions or explicitly stated. Lack of knowledge concerning natural background loads could, therefore, be included as part of the MOS.

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In several U.S. EPA TMDL guidance documents (U.S. EPA, 1999e and 1999d), background levels are defined as "Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution." The phrase "result from natural geomorphological processes" clearly implies that natural background loadings should not include anthropogenic (man-made) loadings of any type. The actual process on how one determines natural background is not clear.

Natural background sources can enter a waterbody and be modified at any point in the hydrologic cycle through atmospheric deposition, surface runoff, groundwater flows, and internal sources (e.g., bottom sediments). Since anthropogenic sources also can enter the hydrologic cycle at these same points, it is difficult to separate the two sources. For example, pollutant concentrations in precipitation can be contributed by natural processes (e.g., wind erosion, volcanoes, fires) or by anthropogenic sources such as air pollution from vehicles and permitted stacks. When atmospheric pollutants are deposited on the land surface, these loads can be modified by either natural geomorphological processes such as dissolution or erosion or by anthropogenic sources such as commercial fertilizer application. Once the atmospheric loads percolate into the soils, they can become part of the groundwater system and be further modified by either natural processes or anthropogenic sources, making it even more difficult to distinguish what is natural and what is anthropogenic. From a practical standpoint, it is difficult to accurately separate the two sources, and also virtually impossible to find a location on earth that has not been impacted by man. Atmospheric sources are highly diffusive and transported and deposited globally.

The natural concentrations of some pollutants also vary from our predetermined water quality standards. For example, the typical pH standard is 6–9 SU, but the natural pH of precipitation based on a carbonate balance is 5.6 SU. Natural organic acids and air pollution can lower this value significantly. It is only after precipitation comes into contact with soils and vegetation that pH increases to within state water quality standards. Another example of natural variations of pH outside the 6–9 range is photosynthetic activity in sandbed streams under low flow, warm temperature conditions, where diurnal fluctuations can cause pH values to exceed 9.0 during late afternoon.

4.2 Issue Identification

A survey of TMDL programs in selected states was conducted as part of this research project to examine how background pollutants are being considered in TMDLs. This survey, which covered eight states across different areas of the United States, showed that background loadings are being considered much differently from one state to the next. Each state was asked whether adequate data were available to estimate background pollutant loads and what data sources and methods they were using to estimate background loads. Methods used to estimate background loads included using literature values, using ecoregion reference stream data, applying simple models with land use set to 100% forest, applying steady-state models, applying dynamic models, and combinations of monitoring and modeling. Also, several states indicated that there was no workable definition of background or natural conditions in either the state or U.S. EPA rules. This response may be partly because U.S. EPA's definition of background does not provide for any consideration of uncontrollable anthropogenic sources.

These findings were confirmed through telephone contacts with the U.S. EPA Regional TMDL Coordinators, who indicated that background loads were not being well addressed (Region 5), no innovative approaches were being used (Regions 1, 3), and most states used default values or literature values (Region 4). It is clear that background pollutants, or non-regulated sources, are not adequately considered in many TMDLs.

In addition to the survey of state TMDL programs, a large number of approved TMDLs were reviewed to examine how background pollutants are being considered. The project team obtained and reviewed 176 TMDLs that have been approved by U.S. EPA. This set of TMDLs represents a wide geographical distribution and also has similar distributions of parameters and source types as the complete set approved by U.S. EPA at that time. The review showed that almost 30% of the approved TMDLs did not include background sources in loading estimates, even though many of them addressed pathogen, nutrient, or sediment pollutants with non-anthropogenic sources. For TMDLs that did include background loadings, the background loadings were lumped together with anthropogenic nonpoint sources in approximately 23% of the TMDLs and were expressed separately in approximately 77% of the TMDLs. This review also showed little consistency in methods used to estimate background loadings, even for a single pollutant. For example, some of the background loads for clean sediment were estimated using monitoring data, some were estimated using empirical approaches, and some were estimated using mechanistic modeling.

These findings are supported by conclusions from the 2001 TMDL Science Conference Closing Session (WEF, 2001), which indicated that: 1) knowledge of natural and background conditions is inadequate; and 2) there is a need for information on how to define and use baseline/reference conditions.

4.3 Current Status

This section describes U.S. EPA and state guidance related to background load estimations, and discusses current approaches.

4.3.1 EPA Guidance

U.S. EPA has provided some guidance in its protocols for developing TMDLs. For example, in the Protocol for Developing Nutrient TMDLs (U.S. EPA, 1999d), it is recommended that data from regional reference streams be used to represent natural background conditions because they represent least impaired conditions. If these data are unavailable, it is recommended that literature values be used. The document indicates that the reference streams should be within the region of, and as similar to natural condition of the TMDL; that reference sites should represent pristine conditions or close to pristine conditions; and that only purely natural processes should be considered as background. It should be noted that U.S. EPA's guidance for nutrient criteria (separate documents from the TMDL guidance) suggests that reference stream conditions can be used as nutrient criteria (i.e., water quality standards). However, setting the criteria equal to reference stream conditions would allow for only minimal human impacts and would not be attainable for most waterbodies.

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In the Protocol for Developing Pathogen TMDLs (U.S. EPA, 2001c), the guidance and examples use upstream values of fecal coliform as the background load. The document recommends, "where it is possible to separate natural background from NPS, separate load allocations (LA) should be made and described." This approach could be interpreted to imply that natural background sources may need to be reduced to meet existing water quality standards, or that it is not possible to separate natural background from anthropogenic sources. However, the protocol does acknowledge that large natural populations of waterfowl and wildlife can result in extremely high fecal coliform levels that exceed existing water quality standards. An example of this is the L'Anguille River, Arkansas, which was on the 303(d) list for fecal coliforms even though there are few livestock in the watershed, few septic systems, and only small discharges of municipal wastewater (which is disinfected). The presumed source of fecal coliforms was wildlife in the wooded corridor along the most of the length of the river. The question still remains on what is natural, and if these levels need to be reduced, and whether standards can be attained in this situation.

In the Protocol for Developing Sediment TMDLs (U.S. EPA, 1999e), it is noted that sediments are a natural part of all waterbody environments, and separating natural or background conditions may be difficult. It is recommended that either reference sites be used or that mathematical modeling be employed to estimate background loads.

4.3.2 State Guidance

Many states refer to naturally occurring conditions in their water quality standards, but there are few, if any, states that provide guidance on how to determine naturally occurring conditions.

Some states define background as upstream and explicitly distinguished it from "natural." For example, in the water quality standards for the State of Washington, background is defined as "the biological, chemical, and physical conditions of a waterbody, outside the area of influence of the discharge under consideration," and natural conditions are defined as "surface water quality that was present before any human-caused pollution."

Natural background concentrations also vary with flow conditions. Turbidity or sediment loadings during storms usually differ drastically from base flow conditions. Some states address this by setting a standard at natural background plus a certain percentage or increment. Several examples of these standards for turbidity are:

- ***Alabama:*** background plus 50 NTU (background = natural condition without human influence);
- ***Delaware:*** natural levels plus 10 NTU (natural = WQ characteristics without human influence);
- ***Mississippi:*** background plus 50 NTU (background is not defined);
- ***New Hampshire:*** naturally occurring conditions plus 10 NTU (natural = absence of human influence); and
- ***Oregon:*** natural stream turbidities plus 10% (natural = measured at upstream control point).

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Detailed guidance is not provided in these state standards on how to determine natural background, but it could be rationalized that natural background variation could be included in the standard by expressing it as a function of flow and season.

Wildlife and waterfowl can contribute significantly to nutrients and fecal coliform levels in waterbodies. These sources are obviously naturally occurring, and controls to reduce their loads to existing water quality standards would be difficult to implement.

4.3.3 Current Approaches to Estimating Background Loads

Based upon this review, background levels have been defined or estimated in TMDLs in the following ways (with selected examples listed):

- ***Upstream concentrations***, which may include nonpoint and point sources that are controllable. Example: For a nutrient TMDL for the Lower Colorado River in Arizona, background concentrations were estimated using multiple years of monitoring data from an upstream USGS gage. There were both nonpoint sources (e.g., irrigation return water) and point sources of nutrients in the upstream watershed.
- ***Reference or minimally impacted waterbodies.*** Example: For a bacteria TMDL for Mill Creek in South Carolina, background levels were assumed to be represented by the geometric mean of fecal coliform counts in waterbodies flowing through forested areas in South Carolina during all flow conditions.
- ***Mathematical model studies that eliminate anthropogenic sources.*** Example: For a clean sediment TMDL in Upper Lapwai Creek in Idaho, background concentrations were estimated using the Revised Universal Soil Loss Equation (RUSLE).
- ***Reference watersheds*** with reasonably implemented BMPs.
- ***Literature values.*** Example: For a bacteria TMDL for Muddy Creek in Virginia, background levels were estimated based on literature values for fecal coliform production for deer in forested land.
- ***Regulatory-assigned values.*** Example: For an ammonia TMDL for Big Sioux River in South Dakota, background concentrations were arbitrarily assumed to be equal to the 80th percentile of available water quality data.
- ***Assigned a load of zero.*** Example: For a BOD/ammonia TMDL for Sanders Branch/ Coosawhatchie River in South Carolina, background loads were set to zero because the $7Q_{10}$ flow was zero, and it was assumed that the point sources were the only significant loads to the stream under $7Q_{10}$ conditions.

Little or no guidance is currently available concerning which of these methods is most appropriate for which pollutants, nor is guidance available for the limitations of these approaches. Assuming that background loads and concentrations were zero was prevalent in a number of approved TMDLs, even though natural background levels must exist (i.e., the TMDLs were for pollutants that are known to have background loads in nearly all situations). A few of the TMDLs for which background loads are being set to zero appear to be for situations where the background loads are actually zero or insignificant (e.g., a synthetic pesticide that does not occur naturally or a stream dominated by a point source discharge with no other sources of flow or pollutant loading to the stream).

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4.4 Problems with Current Status

A number of problems exist with the current situation. The failure to consider background or non-controllable sources in TMDLs will result in inaccurate pollutant reductions for point and nonpoint sources and can overestimate potential percent reductions achievable from controllable nonpoint sources. Alternatively, failure to adequately account for background concentrations can impact the probability that the TMDL will result in attainment of standards. For example, a dissolved oxygen (DO) TMDL was developed for Freshwater Bayou Canal, located in an area of primarily marshland in southern Louisiana. This TMDL calls for a 25% reduction of the total nonpoint source load. However, because a significant portion of the total load is natural (and therefore uncontrollable), the percentage of the controllable nonpoint source load that needs to be reduced is much higher than 25%.

Some TMDLs are being developed that require large nonpoint source reductions on the order of 90% or more. For example, the DO TMDL for Corney Bayou in northern Louisiana calls for a 91% reduction in the total nonpoint source loading to the bayou to meet the current DO standard of 5 mg/L. Because Corney Bayou is mostly forested and does not have a large amount of human activity, a significant portion of the total nonpoint source loading is probably natural. TMDLs like this may be impossible to implement with any combination of BMPs.

TMDLs for temperature can also present challenging situations for addressing natural background conditions. For some Pacific Northwest streams that have been classified for cool or cold water biota, it is difficult to meet the applicable temperature standards, particularly at low elevations during the summer as a result of natural background sources of heat. Oregon and Idaho have addressed this situation by incorporating language into their standards stating that, when natural background conditions exceed the standard, the standard is automatically revised upward to be 0.25°F (Oregon) or 0.3°C (Idaho) above background. An example of a TMDL that used this approach was the Snake River Hells Canyon TMDL (Idaho DEQ and Oregon DEQ, 2001).

Using reference waterbodies is often an effective method for estimating background conditions for TMDLs, except in regions where nearly all of the waterbodies have been impacted. For example, in parts of southern Louisiana, nearly all streams and canals have been dredged and/or channelized, and movement of water is highly controlled through various structures designed for flood control, irrigation diversions, control of salinity intrusion, and other purposes. In these situations, other methods must be developed to estimate background conditions.

U.S. EPA's definition of background conditions implies that no anthropogenic or man-made sources should be considered natural background, and that only natural geomorphic processes like weathering and dissolution should be considered. It is unreasonable to assume that natural background represents pristine conditions with no anthropogenic impacts, because this condition cannot reasonably be attained. Man in one way or another has impacted all ecosystems in every part of the world, including areas in the United States. Atmospheric sources are dispersed globally. Anthropogenic sources that should not be considered natural background include any compounds or elements that do not naturally occur (pesticides, some radionuclides).

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A more reasonable approach would be to define natural background to represent "best attainable" considering controllable sources within a finite time and reasonable economics.

If a source is uncontrollable, it is unreasonable to try to allocate reductions to that source. This definition is consistent with the use of least disturbed reference systems. It also has the advantage of partitioning the load into controllable and uncontrollable categories. This will result in more realistic load reductions and increase the likelihood that the TMDL will accomplish its purpose of ensuring that the standards are attained.

The concept of "best attainable" can also be tied directly to the assigned designated uses. If a designated use is being attained and if conditions represent the best attainable, then those conditions should be considered representative of natural background, and the TMDL should be considered achieved.

Conversely, natural background conditions can also result in some instances where a water quality standard is not achievable either because of natural background levels already exceeding the standard or because of insufficient controls which will attain the water quality standard. This creates a problem because U.S. EPA cannot currently approve a TMDL that does not achieve water quality standards. Because of this, TMDLs are being approved with unachievable reductions to meet deadlines. There are situations throughout the United States where the water quality standards are incorrect. Use attainability analyses provide a vehicle to address these situations, but cannot always be completed within the time constraints of a TMDL. The State of Kansas has used phased TMDLs to address these situations. The first phase considers the existing standard with the recommendation that the standard be revisited. A use attainability analysis is then completed to change the standard, and a new TMDL is completed.

Background levels can vary seasonally and spatially within a watershed. Background levels can include natural sources that may exceed state water quality standards in some instances. Large populations of birds and wildlife (e.g., geese) can result in unnaturally high concentrations of bacteria and nutrients that, in turn, can impact designated uses. Some states like Kansas, Oregon, and North Dakota have a clause in their water quality standards that allow them to use the natural or upstream concentration as the standard if the published standard cannot be met.

4.5 Recommendations

Recommendations from this study are as follows:

The definition of natural background should be changed from representing pristine conditions to representing "best attainable" or that part of the allocation that is not controllable.

It is not feasible to restore waterbodies to the pristine conditions that existed before any human impacts. Because natural background conditions tend to be used as a target for water quality improvement, the definition needs to represent conditions that are reasonably attainable. A proposed definition is: "Natural background levels represent minimally impacted systems that may include anthropogenic impacts considered to be irreversible or uncontrollable."

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The natural background portion of the load allocation should be considered as that part which is not controllable and which therefore cannot be reduced in the allocation of loads. This will allow for more realistic estimates of reductions needed from anthropogenic sources.

For synthetic substances that do not occur naturally within the environment (i.e., pesticides, herbicides), and are not considered legacy pollutants, a zero background concentration should be used. In most other cases, a natural background concentration should be defined.

Background sources need to be quantified as accurately as possible in all TMDLs to develop realistic loads and reductions for point and nonpoint sources for water quality standards attainment.

If background loads are not quantified separately from anthropogenic loads, the TMDL will underestimate the percent reduction for the anthropogenic loads that is needed to meet water quality standards. Proper consideration of background conditions may result in some instances where a water quality standard is not achievable.

Methods to quantify background loads include:

a. Regional reference waterbodies relatively undisturbed by human activities. This method is recommended for nutrient TMDLs whenever an acceptable reference waterbody can be identified.
b. Upstream concentrations representing historical regional values. This method is recommended for TMDLs for pollutants such as metals or dissolved minerals where upstream concentrations are not significantly impacted by human activity and represent best attainable conditions. However, many upstream watersheds do include impacts of past or present human activities.
c. Modeling studies to separate out background levels. This method is recommended for most sediment TMDLs, especially in cases where streambank erosion is a major source of sediment and the best attainable conditions may be specific to that stream.
d. Ecoregion literature values. This method may be used when acceptable regional reference waterbodies cannot be found.
e. Watershed with reasonably implemented BMPs. This method is included as an option for identifying the best conditions that are attainable through implementation of BMPs.

Phased TMDLs, or adaptive management, may be appropriate for some situations.

Legacy pollutants should not be defined as background, but it must be understood that they may not be reduced within a finite period. A separate allocation should be developed for these pollutants with the understanding that while they may not be currently controllable, technology may change in the future. Scheduled monitoring and implementation should be required.

There will also be instances where it may be impossible to realistically achieve existing state water quality standards. In these situations, it may be necessary to change the water quality standard through a use attainability analysis or variance, and/or to modify TMDL approval criteria for situations where the standard is not achievable without violating the Clean Water Act.

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4.6 Future Research Needs

There is an important need for future research to develop more extensive information to characterize "best attainable" conditions. This would likely include collecting more field data on reference water bodies in areas where this has not already been done extensively. In other situations, this may involve performing modeling studies (e.g., where reference sites are not available, or for certain pollutants). The objective of the field data collection and/or modeling would be to develop information that can be extrapolated to other sites with certain similarities. The results and conclusions from future research in this area should be compiled, summarized, and published for use by TMDL practitioners.

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CHAPTER 5.0

QUANTIFYING NONPOINT SOURCE LOADS USING SIMPLE METHODS

This chapter:

- Describes simple order-of-magnitude and empirical modeling approaches for estimating nonpoint source pollutant loads for data limited TMDLs;
- Discusses approaches for providing uncertainty estimates with these nonpoint source pollutant loading estimates; and
- Presents examples of TMDLs that have been completed and approved using these or similar empirical approaches.

It is not intended to be an extensive compilation of all order-of-magnitude or empirical models that have been developed or used, but rather to describe the types of simple quantitative tools that can be used in estimating nonpoint source pollutant loads for TMDLs.

First, background related to current shortcomings in the estimation of nonpoint source loads for TMDLs, the need for simple models, and the implication to the uncertainty in calculations is provided (5.1). Presented next is the importance of order-of-magnitude estimates and their suggested inclusion in any TMDL (5.2). Next, various nonpoint source pollutant loading approaches are discussed, including both empirical equation approaches (5.3) and software programs (5.4). Temperature, sediment, phosphorus, and other chemical pollutants are discussed in this section. Uncertainty is a part of all estimations and several approaches for estimating the uncertainty associated with nonpoint source pollutant loads are presented in the Section 5.5. Methods used to partition the potentially controllable nonpoint source load from the background load are discussed in Section 5.6. The last section (5.7) discusses several approved TMDLs that have used simple approaches for estimating nonpoint source pollutant loads.

5.1 Background

The following sections describe nonpoint source loading issues related to TMDLs (5.1.1), provide a rationale for simple models (5.1.2), and discuss precision and accuracy in this context (5.1.3).

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5.1.1 TMDL Nonpoint Source Loading Issues

Pollutant loads to receiving streams are typically attributed to a combination of point source and nonpoint source pollutants. Point source loads are discharges from a pipe, ditch, or other well-defined source. Nonpoint source loads can be attributed to anthropogenic or non-anthropogenic origins. A variety of pollutants can arise from nonpoint sources, including metals (e.g., mercury), sediment, pesticides, and nutrients. Realistic estimates of nonpoint source loads are necessary to effectively allocate load reductions required to meet water quality standards in impaired waterbodies. In addition to TMDL development, information on nonpoint source pollutant loadings may be helpful in establishing water quality criteria, particularly for pollutants such as nutrients.

A review of TMDL studies and state surveys were used to characterize the approaches that states used to quantify nonpoint source loads:

- 21% of reviewed TMDLs did not estimate current nonpoint source loads, so there was no way of knowing the feasibility of reducing those loads.
- 44% of the TMDLs reviewed used instream monitoring to estimate total nonpoint source loads to a segment, so the feasibility of reducing specific sources was difficult to determine.
- Often there was only a vague distinction between nonpoint sources and ambient surface water quality. Also, many TMDLs did not account for background load, assuming only anthropogenic nonpoint sources contributed to tributary water quality.

These observations illustrate the current deficiencies in the TMDL program related to nonpoint considerations and why additional guidance is needed.

5.1.2 Rationale for Simple Models

Although nonpoint source pollutant contributions are a crucial component of many TMDL computations, this study found during its preliminary investigations that TMDL developers usually have insufficient data to characterize nonpoint sources:

- State surveys and a TMDL review indicated that TMDL developers usually did not have sufficient data to characterize nonpoint sources (15 of 22 states in the survey indicated that there were insufficient data to characterize them).
- GAO (2000) found that 44 of 50 states indicated that they did not have the majority of data needed to identify nonpoint sources and develop TMDLs.
- Insufficient data exist to isolate and estimate nonpoint source loads from specific sources.
- All state surveys indicated that intensive sampling programs would need to be designed and implemented on a site specific basis to gather sufficient data to characterize nonpoint sources.

One of the conclusions of the National Research Council report on the scientific basis of the TMDL process (NRC/NAS, 2001) was:

> "EPA should not advocate detailed mechanistic models for TMDL development in data-poor situations. Either simpler, possibly judgmental, models should be used or, preferably, data needs should be anticipated so that these situations are avoided. The strategy of accounting for data-limited TMDLs with increasingly detailed models needs rigorous verification before it should be endorsed and implemented. Starting with simple analyses and iteratively expanding data collection and modeling as the need arises is the best approach."

Simple models are generally empirical in nature. These methods are compilations of expert judgment and empirical relationships incorporating watershed physiography and pollutant export, or they are statistical estimates based on existing data. Simple models generally rely on large-scale aggregation and neglect features of small patches of land. They rely on generalized sources of information and therefore have low to medium requirements for site-specific data. Default values provided for these methods are derived from empirical relationships that should be evaluated based on regional, cross-sectional, or site-specific data.

The estimates from simple models usually are expressed as mean values on a seasonal or annual basis. Simple models provide aggregated (e.g., annual average) estimates of sediment and pollutant loadings. Because they often neglect seasonal variability, they might not be adequate to model short-term water quality problems for which specific loadings of shorter duration are important. However, in some instances, simple models can be used to estimate short-term or event pollutant loads.

In simple models, pollutant loads typically are determined based on export coefficients, such as the Watershed model (see Section 5.3.3.3), or as a function of the sediment yield, as in the U.S. EPA screening procedures (Section 5.3.4.1), and the Simplified Pollutant Yield Approach (Section 5.3.3.2). The Simple Method (Section 5.3.4.3), the U.S. Geological Survey regression method (Section 5.3.4.2), and the Federal Highway Administration model (Section 5.3.4.4) are statistically based approaches developed from past monitoring information. In general, the empiricism contained in the models limits their transferability to other regions. The application of empirical models should be limited to the watershed types for which they were developed, with similar land uses or activities. Applications to new areas require recalibration with relevant data.

New Mexico recommends simple models in the first phase of a phased TMDL, with more complex models used later, if necessary. As part of its process, New Mexico Environmental Department suggests (NMED, 2002b):

> "In situations where both point and nonpoint source reductions are part of the TMDL, a 'phased approach to TMDL development' will be used to:

- develop a preliminary TMDL/BMP;
- replace models with simple (yet reasonable) screening methods;
- implement control strategies;
- monitor to determine if water quality objectives were achieved; and
- perform more modeling, if necessary.

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> ...The use of such preliminary screening applications can provide water quality managers with an initial assessment of water quality, pollutant loading and source determination for river/stream reaches."

Often, the greatest modeling needs are in rural, ungaged watersheds. Consequently, lumped parameter models requiring calibration are of limited value because there is little if any historical data available for calibration. Other models do not require calibration; however, they require extensive amounts of information on watershed characteristics which may not be readily available for these types of watersheds.

5.1.3 Precision and Accuracy

A general, but fallacious, assumption typically made about the use of empirical approaches is that they are inaccurate and imprecise. Initiating any study without gaining some insight into the magnitude of the problem is unwarranted. Unfortunately, in the current technology-rich environment, it is assumed that if it is generated by a computer, it must be accurate and precise.

In comparing the rational formula, an empirical method, and a dynamic hydrologic model for estimating peak runoff and total runoff from a watershed, Loague and Freeze (1985) found that the rational formula estimates of peak discharge and the empirical method estimates of peak discharge and total discharge were closer to the gaged flow measurements than the dynamic hydrologic model estimates. Spatial heterogeneity in rainfall volume and intensity over the watershed contributed to the imprecision and inaccuracy in the dynamic models, but was averaged or smoothed out with the empirical and rational methods.

In comparing the Simple Method to the more complex models, Chandler (1994) found that, in four case studies, the Simple Method yielded annual load estimates within an order-of-magnitude, and in most cases within a factor of two, of the more complex models. The author concluded "there is little quantitative reason for using complex models when estimating annual non-point-source pollutant loads."

EPA's Protocol for Developing Sediment TMDLs (U.S. EPA, 1999e) points out:

> "Most modeled estimates may be accurate to only within 50–100 percent (e.g., monthly or daily estimates). Other methods that focus on specific sources of concern [e.g., road assessment method (Weaver and Hagens, 1996)] are capable of yielding relatively accurate estimates of potential future erosion volumes. Simpler, screening-level methods (e.g., models that apply simple default erosion rates or regression relationships) are believed to be capable of yielding order-of-magnitude estimates of total sediment production along with estimates of relative inputs from different sources."

Simplified methods and approaches, then, permit reasonable and adequate estimates of non-point source pollutant loads. These approaches are especially pertinent for data-limited waterbodies. Presented next is a discussion of how the most simple order magnitude methods can be used in TMDL analysis, followed by more precise empirical methods, with later discussions of software, uncertainty and examples.

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5.2 Order-of-Magnitude Estimates

Order-of-magnitude estimates can be used in TMDL analysis as a rough check on more complex methods or as an independent first estimate. The process of obtaining quick approximate solutions is called "order-of-magnitude analysis or estimation" (Fischer et al., 1979). Engineering programs historically required students to be familiar with order-of-magnitude estimation, including dimensional analysis, to bound the range of possible solutions and quickly assess possible errors in analyses. Fischer et al. (1979) indicated that any environmental problem should be able to be worked out by a skillful analyst within a fraction of an hour. Results of order-of-magnitude analysis typically include the most important parameters and yield quantitative estimates within factors of three to five of the true value (Fischer et al., 1979). Harte (1988, 2001) provides a series of examples and approaches for using order-of-magnitude analyses that incorporate procedural methods ranging from probability, optimization, scaling, differential equations, stability, and feedback for solving environmental problems. Order-of-magnitude approaches have been called "back of the envelope" procedures because these analyses are easy to perform. Harte's examples (Harte, 1988, 2001) increase our ability and awareness of using order-of-magnitude estimates for quickly establishing the credibility of model output or other quantitative statements of "fact."

There are a number of dynamic models and software programs that provide nonpoint source pollutant loading estimates, and order-of-magnitude estimates can be used to check model results. These dynamic models and programs typically require meteorological, hydrologic, physical, chemical, and perhaps biological data, as well as multiple calibration parameters to provide nonpoint source pollutant loading estimates. In many instances, only one model is applied so the estimates are based solely on that model and its underlying assumptions. These always need a "reality check." As an example, one simple approach to bound dynamic model loading estimates would be to multiply the mean annual flow (m^3/sec) by the mean concentration of the pollutant (mg/m^3) by 86,400 sec/day and 365 days/yr to estimate an annual pollutant load. This estimate will typically be within an order-of-magnitude (or better) of the load estimated by the dynamic model. If there are gross differences between the two estimates, the model simulations should receive greater scrutiny to ensure the loading estimates are reasonable.

Order-of-magnitude estimates of annual pollutant load can also be calculated for ungaged watersheds where flow measurements are unavailable. In these cases the watershed area (e.g., 106 m^2), can be multiplied by a pollutant export coefficient (e.g., kg/m^2 yr) assuming a completely forested watershed (lower bound) and a pollutant export coefficient assuming a completely urban or agricultural watershed (upper bound) to bound the expected pollutant loadings for the watershed. Pollutant loadings that are outside these bounds or that are inconsistent with what would be expected given the land use in the watershed indicate the analyses should be further evaluated.

Average pollutant concentrations also can be estimated and compared with measured or modeled values. Runoff coefficients, available from the USGS for most areas across the U.S., can be multiplied times the average precipitation for the area to estimate the volume of water entering the receiving system. For example, watershed area (106 m^2) times the annual average precipitation (e.g., 1 m/yr) times a dimensionless runoff coefficient (e.g., 0.3) estimates the annual volume per year (32 m^3/yr). Dividing the pollutant load (kg/yr) by the volume (32 m^3/yr) estimates pollutant concentration (g/m^3).

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Order-of-magnitude estimates should always be used as an additional tool in evaluating all loading estimates provided in TMDLs, whether for point or nonpoint sources.

5.3 Empirical Models

The intent of this section is to provide the user with examples of the types of nonpoint source pollutant loading models that are available for use. This section summarizes some commonly used simple, empirical nonpoint source loading models (Table 5-1). Many other models can be found in the literature for specific watersheds, water body types, pollutant types, and geographic regions of the U.S. Empirical models have been used, and are adequate, for estimating nonpoint source pollutant loads for many TMDLs, particularly for TMDLs in data-limited environments.

Table 5-1. Examples of Empirical Models.

MODEL TYPE	PARAMETER	MODEL NAME
Algorithms/Approaches	Temperature	Equilibrium temperatures USGS SNTEMP
	Sediment Transport	USLE RUSLE MUSLE WCS and Sediment Tool
	Phosphorus	Unit area load/Export coefficient SLOSS-PHOSPH Watershed Model
	Other Pollutants	U.S. EPA Screening Procedures USGS Regression Simple Model FIIWA (statistical) KS Curve Method for *F. coliform* bacteria
Software Programs	Phosphorus	EUTROMOD BATHTUB
	Other Pollutants	PLOAD Watershed Management Model (WMM) USGS SPARROW

The empirical models presented in this section are for estimating total pollutant transport to the receiving water body and subsequent concentration/load/response in the receiving system. Most of the models are based on first estimating sediment transport and delivery from the watershed and then estimating the pollutant transport associated with these sediment loads. A flow chart has been developed to help the user quickly identify the types and categories of simplified approaches applicable for their TMDL (Figure 5-1).

Summaries of the selected simple models in Table 5-1 are based on information from the cited references as well as from Donigian and Huber (1991) and U.S. EPA (1997b). The models are listed in Table 5-2 and general model capabilities are shown in Table 5-3.

Sections 5.3.1 through 5.3.4 below describe temperature equations, sediment transport methods, phosphorus loading models, and methods for estimating other types of pollutant loads.

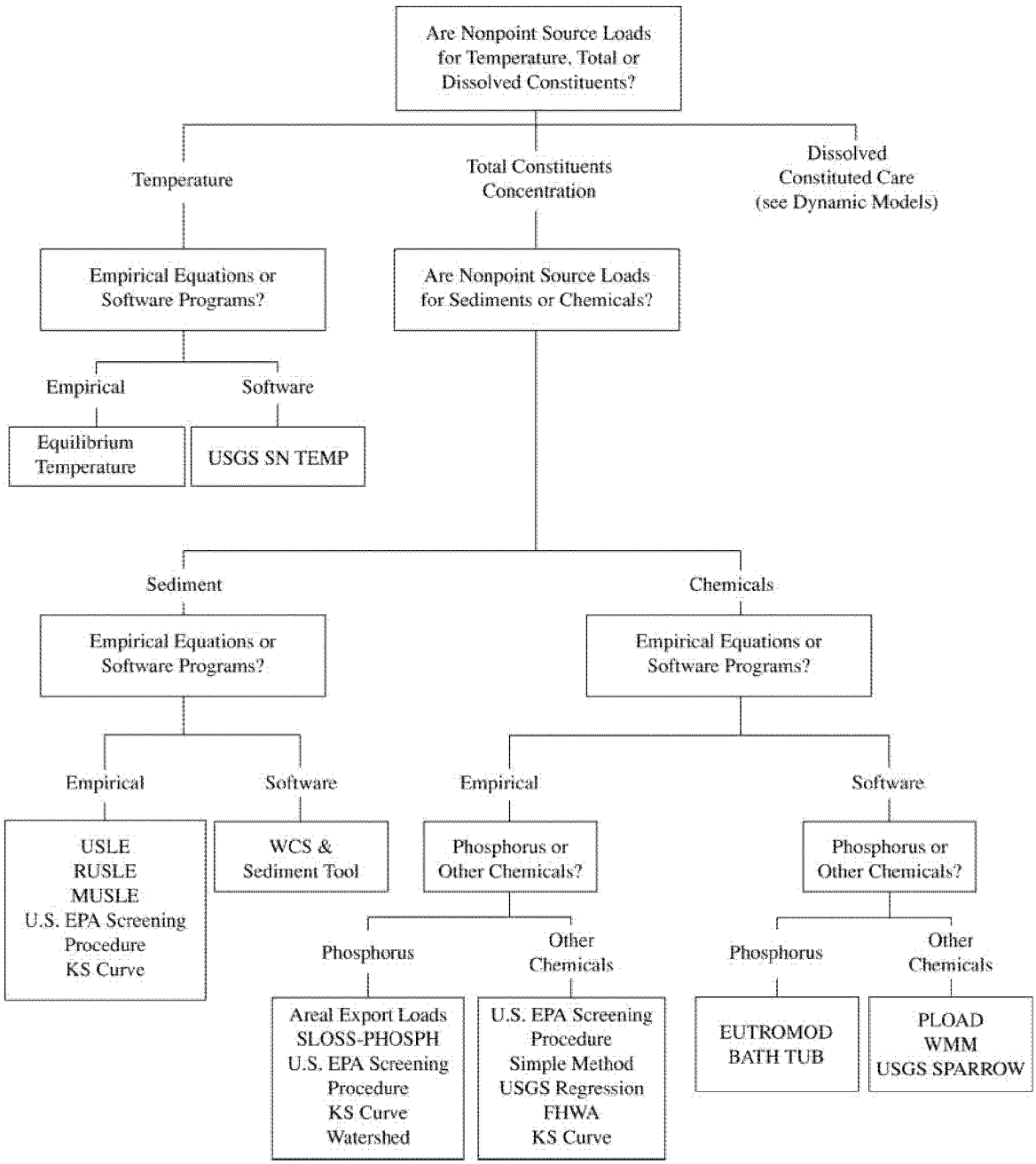

Figure 5-1. Nonpoint Source Pollutant Loading Estimates Simplified Approaches Flow Chart.

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Table 5-2. Model Description Summary.

Model	Author	Description	Type	Load calculated by	Pollutants	Pollutant sources	Advantages	Disadvantages	Applications	Data Required
USLE	USDA	Predicts soil erosion based on character-istics of land and weather	Empirical	soil loss	sediment	nonpoint sources	Simple, spreadsheet	limited land use	Sediment loads from erosion; used in many other models	Soil, slope, and land-use factors
RUSLE	USDA	Revision of USLE	Empirical / process-based hybrid	soil loss	sediment	nonpoint sources	Improvement on USLE		Sediment loads from erosion; used in many other models	Soil, slope, and land-use factors
U.S. EPA Screening	U.S. EPA	Loading functions and simple empirical expressions.	not a model. series of equations and techniques	loading functions, potency factors	N, P, sediment, metal, organ-ics, salinity, BOD/DO, coliform	Point sources, nonpoint sources, irrigation, atmosphere	Simple, easy	not coded, not recommended for large watersheds		USLE factors, enrichment ratio
Simple	Schueler, Wash DC	empirical expression	Empirical	mean concentration	P, N, COD, BOD, metals	nonpoint sources	Simple, easy	developed for small urban developments	Qualitative: compare relative load-ings from watersheds within a basin	USLE factors in GRASS format
Regression	Tasker, USGS	correlates load to variables	Statistical	regression equation	COD, TSS, TDS, N, NH3, TP, DP, Cu, Pb, Zn	nonpoint sources	use for unmonitored sites	underestimates extreme events, limited transferability	Estimate average annual storm event loads with limited data	Area, imper-vious %, mean annual rainfall, min Jan Temp, land use
SLOSS-PHOSPH		screening application	loading functions	loading functions	sediment, P	nonpoint sources	good fit for GIS	P and sediment only, annual load only	Ag phosphorus	USLE, channel parameters, P in soil, P enrich-ment ratio
WCS & Sediment Tool	U.S. EPA & Tetra Tech	Arcview system to display water-shed info; Sediment tool uses USLE	GIS tool	erosion (USLE)	sediment	nonpoint sources (displays point sources)	more detailed spatially	WCS other than sediment tool too complex	Display GIS data for watershed	USLE
Watershed	Walker, USGS	Spreadsheet model for P loads	Spreadsheet	unit area loadings	sediment and associated pollutants	point sources and nonpoint sources	evaluates cost-effectiveness	limited use		USLE
FHWA	FHWA	Statistical	Statistical spreadsheet	median concentration	Cu, Pb, Zn, N, P	nonpoint sources	addresses variability	no soluble pollutants, no atm, no P settling	Highways screening	Rainfall mean and coefficient of variation, traffic volume, runoff conc, areas

Table 5-2. Model Description Summary. (cont.)

Model	Author	Description	Type	Load calculated by	Pollutants	Pollutant sources	Advantages	Disadvantages	Applications	Data Required
Unit Areal Load/ Export Coefficient	Reckhow-Simpson	Mass balance model for P loading and lake concentration based on land use.	loading functions	loading functions	N and TP	point sources, agriculture, atmospheric nitrogen	uncertainty estimate, simple, widely accepted	limited no. of land uses & export coefficients	lakes, reservoirs	areas by land use, export coefficient, septic, PS, uncertainity
USGS SPARROW	USGS	Statistical model based on USGS gaging station data	Statistical	Regression equation	TN and TP	point sources, nonpoint sources, atmosphere	spatially referenced	more complex than other simple models	regional assessment, large rivers, coastal	source, delivery, and decay parameters
WMM	CDM	Spreadsheet-based, loads from storm water runoff	Spreadsheet screening	Event mean concentration	TP,N, Pb, Zn	point sources, nonpoint sources	event loads, spreadsheet format	does not estimate sediment	watershed management – storm water	land use, soil types, meteorology and hydrology, concentrations, BMP efficiencies
EUTROMOD	Reckhow 1990	P Loading & Lake response	Loading function	Loading functions		point sources, nonpoint sources, atmosphere	software package		lakes, reservoirs	areas by land use, export coefficient, septic, PS, uncertainity
BATHTUB	Walker 1987	Nutrient Loading-Lake	Loading function	Loading function		point sources, nonpoint sources, atmosphere	software package	inflexible	lake, reservoirs	areas by land use, export coefficient, septic, PS, uncertainity
PLOAD	CH2mHiII	Nutrients, metal loads	Loading function	EMC loading, loading function		nonpoint sources	multiple loading approaches	GIS based software	watershed management	watershed area, land use
KS Curve Method	KDEH	*F. coli* loading	Nomogram	statistical	*F. coli*	nonpoint sources, point sources	easy to use	no uncertainty estimates	assessment	coliform, flow

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Table 5-2. Model Description Summary. (cont.)

Model	Output	Examples	Uncertainty	Intended Land Use	Temporal Resolution	Spatial Resolution	Model Source	Public or Proprietary	Documents
USLE	Average annual erosion caused by sheet and rill erosion			Rural + others with soil data	Long-term average annual	Field, small watershed	http://www.epa.gov/ceampubl/swater/usle/index.htm	public	
RUSLE	Sediment yield and deposition			"Land use independent"	Long-term average annual	Field, small watershed	http://www.ga.nrcs.usda.gov/gatechnical/download_page.htm	public	http://www.sedlab.olemiss.edu/rusle/index.html
U.S. EPA Screening	Mean annual sediment and pollutant loads	Incorporated into GWLF and others		Mixed watershed	Annual	Watershed	U.S. EPA docs	public	Mills WB, Borcella BB, Ungs MJ, et al. 1985. Water quality assessment. A screening procedure for toxic and conventional pollutants in surface and ground water. Parts 1&2. U.S. EPA, Environmental Research Laboratory, Athens, GA. EPA/600/6-85/002a &...b.
Simple	Runoff volume and pollutant concentration/load, storm or annual	Santa Clara Valley		Urban	Annual, monthly, event	Watershed		public	Chandler, R.D.. Estimating Annual Urban Nonpoint Pollutant Loads. Journal of Management in Engineering, 10(6) 1994, pp. 50-59.
Regression	Mean annual storm event load and confidence interval		confidence interval around mean	Urban	Annual and mean event	Watershed	USGS, literature	public	Tasker and Driver. 1988. Nationwide Regression Models… Water Resources Bulletin, 24(5), pp.1091-1101.
SLOSS-PHOSPH	Mean annual load for P and sediment	Nomini Creek (VA)		Rural	Annual	Field, small watershed			
WCS & Sediment Tool	Sediment yield for each grid cell	Chattooga River Watershed (GA) TMDL		Mixed watershed	Annual	Grid cell	U.S. EPA Region 4	proprietary (Tetra Tech)	Chattooga River Watershed (GA) TMDL
Watershed	Mean annual pollutant loads, BMP cost-effectiveness			Mixed watershed	Annual	Watershed	USGS?		Walker et al., 1989. Spreadsheet Watershed Modeling… Water Resources Bulletin, 25(1), pp.139-147.
FHWA	Statistics on storm runoff and concentrations; impacts on receiving water		probability distribution of concentrations	Highways	Storm event	Field, buffer areas	Federal Highway Administration		

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Table 5-2. Model Description Summary. (cont.).

Model	Output	Examples	Uncertainty	Intended Land Use	Temporal Resolution	Spatial Resolution	Model Source	Public or Proprietary	Documents
Unit Areal Load/ Export Coefficient	Most likely lake P concentration, trophic state uncertainty in concentration	NYC reservoirs	confidence intervals, estimated loading errors	Mixed watershed	Annual	Watershed	EUTROMOD, which incorporates techniques, available at http://www.nalms.org/bkstore/software.htm	public, EUTROMOD proprietary	Reckhow KH, Simpson JT. 1980. A procedure using modeling and error analysis for the prediction of the lake phosphorus concentration from land use information. Can J Fish Aquat Sci 37:1439-1448.
USGS SPARROW	Annual stream loadings	Chesapeake Bay	confidence intervals	Mixed watershed	Long-term average annual	Spatially detailed within large-scale watershed	http://water.usgs.gov/nawqa/sparrow/	public	Smith, R.A., Schwarz, G.E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data, Water Resources Research, 33, 12, 2781-2798
WMM	Annual loads, BMPs; lake concentrations	Rouge River, (FL)	display in spreadsheet	Mixed watershed	Annual, seasonal if seasonal EMCs available	Watershed	http://www.wcdoe.org/rougeriver/proddata/wmm.html	public	
EUTROMOD	TP, TN, clel, SD, THMP, HOD		uncertainty analysis	Mixed watershed	Annual, seasonal	Lake, reservoir	http://www.nalms.org/bkstore/software.htm	proprietary	Reckhow, K.H. 1990. EUTROMOD spreadsheet program-a regional modeling scheme for nutrient runoff and lake trophic state modeling. School of Forestry and Environmental Studies. Duke University. Durham, NC.
BATHTUB	TP-Pm TN, chil, SD, HOD		uncertainty analysis	Mixed watersheds	Annual, seasonal	Lake, reservoir		public	Walker, W W, Jr. 1996. Simplified procedures for eutrophication assessment and predictions user manual. Instruction report W-96-2. U.S. Army Engineer Waterways Experiment Stations, Vicksburg, MS.
PLOAD	Pollutant loads			Mixed watershed	event	Watershed	BASINS	public	http://www.epa.gov/waterscience/BASINS/b3docs/PLOAD_v3.pdf
KS Curve Method	Exceedance freq., sources			Mixed watershed		Reach	http://www.kdhe.state.ks.us/tmdl/data.htm	public	http://www.epa.gov/waterscience/BASINS/b3docs/PLOAD_v3.pdf

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Table 5-3. Empirical Model Capabilities.

Criteria		EPA Screening	Simple	Regression	SLOSS-PHOSPH	WCS Sediment Tool	Watershed	FHWA	Unit Areal Load/ Export Coefficient
Land Uses	Urban	O	◐	◐	-	●	◐	O	●
	Rural	◐	-	O	◐	●	◐	O	●
	Point Source	-	-	-	-	●	O	-	●
Time Scale	Annual	●	●	●	●	●	●	●	●
	Event	O	O	O	-	-	-	O	-
	Continuous	-	-	-	-	-	-	-	-
Hydrology	Runoff	-	◐	-	-	◐	-	O	-
	Baseflow	-	-	-	-	-	-	-	-
Pollutant Loading	Sediment	◐	◐	◐	◐	●	◐	-	-
	Nutrients	◐	◐	◐	◐	-	◐	◐	●
	Other	O	◐	◐	-	-*	◐	◐	-
Input Data	Requirements	O	O	O	O	◐	O	O	◐
	Calibration	-	-	-	O	-	◐	-	O
	Default Data	●	●	◐	◐	◐	O	◐	◐
	User Interface	-	-	-	-	●	◐	O	-*
BMPs	Evaluation	O	O	-	O	O	◐	◐	O
	Design Criteria	-	-	-	-	-	-	-	-
Documentation		●	●	●	◐	O	O	●	●

*WCS has other modules

*in some packages

●	High
◐	Medium
O	Low
-	not incorporated

(Similar to table in U.S. EPA 1997. Compendium of Tools for Watershed Assessment and TMDL Development. U.S. EPA, Office of Water, Washington, D.C. EPA841-B-97-006. Models added and some entries changed)

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Table 5-3. Empirical Model Capabilities. (cont.)

Criteria		USGS SPARROW	WMM	EUTROMOD	BATHTUB	PLOAD	KS Curve
Land Uses	Urban	●	●	●	●	●	-
	Rural	●	●	●	●	●	-
	Point Source	-	O	●	●	●	-
Time Scale	Annual	●	●	●	●	●	◐
	Event	-	-			◐	◐
	Continuous	-	-			-	
Hydrology	Runoff	-	O	-	●	-	◐
	Baseflow	-	O	-	●	-	
Pollutant Loading	Sediment	●	-	-	-	-	-
	Nutrients	●	◐	●	●	●	-
	Other	O	◐			●	●
Input Data	Requirements	O	O	◐	◐	◐	-
	Calibration	-	◐	O	O	O	-
	Default Data	◐	◐	◐	◐		-
	User Interface	-	◐	●	●	●	-
BMPs	Evaluation	-	◐	◐	◐	◐	◐
	Design Criteria	-	-	-	-	◐	-
Documentation		●	◐	●	●	●	-

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5.3.1 Temperature Equations

This section describes equilibrium temperature equations (5.3.1.1) and a water temperature model for streams, SNTEMP (5.3.1.2).

5.3.1.1 Equilibrium Temperatures

Water temperature affects not only chemical, but also aquatic biota reaction rates. An approach for estimating the addition of thermal energy above ambient conditions is through the use of equilibrium temperature equations. The equilibrium temperature of a waterbody is the hypothetical water surface temperature at which the net rate of surface heat exchange would be zero. The equilibrium temperature can be calculated using the equation:

$$E = Td + Hs / K \qquad (5.3.1.1\text{-}1)$$

where:

- E = the equilibrium temperature (°C),
- Td = the dewpoint temperature (°C),
- Hs = the gross rate of shortwave solar radiation (W/m^2), and
- K = an exchange coefficient (W/m^2C) determined by water temperature and wind speed (Edinger et al., 1974).

In evaluating the effects of thermal addition on stream temperature, the effect is considered to be effectively dissipated when the stream temperature reaches equilibrium. In field measurements of water temperatures downstream from a thermal addition, the stream temperature is considered to be in equilibrium when measured values become fairly constant. This indicates that stream temperature is in equilibrium with its environment (e.g., air temperature, solar radiation, evaporation, shading, wind, stream bed geometry and material). This equation can be used to evaluate the difference between measured temperatures and equilibrium temperatures and determine how far downstream thermal impacts might be occurring.

5.3.1.2 SNTEMP

SNTEMP is a water temperature model for streams developed by the U.S. Fish and Wildlife Service Instream Flow and Aquatic Systems Group (IFASG) with the U.S. Soil Conservation Service. Documentation for this model is available from the U.S. Geological Survey. The software is available from the U.S. Fish and Wildlife group.

SNTEMP is designed to predict the average daily water temperature and diurnal fluctuations in water temperature throughout a stream network. The model assumes steady state conditions and uses meteorologic and hydrologic data that are usually readily available. The model accounts for heat transport and exchange in streams to predict changes in temperature as a function of stream distance, changes in solar radiation and shading, and heat transfer between water and environment (e.g., bottom sediment and atmospheric exchange). The model predicts the stream temperature and calculates the equilibrium water temperature. The extent (i.e., river miles) of the temperature effect of a human activity (e.g., reservoir releases, cooling water discharge) on a stream can be determined by comparing the predicted temperature to the calculated equilibrium temperature.

5.3.2 Sediment Transport

This section provides a description of four sediment transport methods: Universal Soil Loss Equation (USLE) (5.3.2.1); Revised USLE (RUSLE) (5.3.2.2); Modified USLE (MUSLE) (5.3.2.3); and Watershed Characterization System and Sediment Tool (5.3.2.4).

5.3.2.1 Universal Soil Loss Equation (USLE)

The USLE was developed by the U.S. Department of Agriculture-ARS and Purdue University to predict water erosion. It is considered outdated by some, but is still the most widely used method for predicting soil loss. The model is empirical and was developed from regression analysis of a large database of runoff and soil loss data. USLE is a component of a number of other models and modeling packages. It is being gradually replaced by the Revised USLE (RUSLE). When models say they are using USLE, it's not always clear whether they are using the original USLE, its new version RUSLE, or another modification. The Modified USLE (MUSLE) is another modification of USLE used by several parties. Other modified versions of USLE exist as well (e.g., Kinnell, 2001).

USLE was designed to predict long-term average annual soil erosion for combinations of crop systems and management practices with specified soil types, rainfall patterns, and topography. USLE is not recommended for prediction of specific soil loss events. The model equation is:

$$A = C_1 \cdot R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (5.3.2.1\text{-}1)$$

where:

- A = average annual soil loss (Mg/ha),
- R = rainfall and runoff erosivity index factor (Mg-m/ha-cm),
- K = soil-erodibility factor (Mg/ha) (per unit of the erosion index),
- L = slope length factor (dimensionless),
- S = slope factor (dimensionless),
- C = cropping-management factor (dimensionless),
- P = conservation practice factor (dimensionless), and
- C_1 = units conversion term = 1.0, 1.292, 1.735, or 2.242, depending on units of K and R.

USLE, being an empirical model, does not explicitly represent physical processes and is a poor representation of erosion, infiltration, slope, slope length, and especially contouring. If USLE is to be used for situations different from the croplands, slopes, and other characteristics of the original data the empirical relationships are based on, new data should be incorporated into the model (Dillaha, 2002a, b).

USLE is available in spreadsheet form at http://www.ga.nrcs.usda.gov/gatechnical/download_page.htm. A spreadsheet version called "TMDL USLE" is available from U.S. EPA at http://www.epa.gov/ceampubl/swater/usle/index.htm.

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5.3.2.2 Revised USLE (RUSLE)

RUSLE is a computerized update of the USLE incorporating new data and making some improvements. The basic USLE equation is retained, but the technology for evaluating the factor values has been altered and new data introduced to evaluate the terms for specific conditions (Foster et al., 1996; Renard et al., 1991, 1994, 1997). RUSLE retains the six factors of the USLE and calculates average annual soil loss from a hillslope. Major differences between RUSLE and the USLE include:

- ***Rainfall and runoff erosivity factor (R):*** database has been expanded in the western US and a correction developed for rain falling on ponded water conditions.
- ***Soil erodibility factor (K):*** changed to reflect variability within the year due to freeze-thaw conditions and consolidation due to moisture extraction by growing crops; an alternative regression was developed for tropical volcanic soils; and a correction was developed for rock fragments in the soil profile.
- ***Slope length (L) and steepness factors (S):*** revised to reflect the ratio of interrill/rill erosion.
- ***Cropping-management factor (C):*** now calculated as the product of terms reflecting prior land use, surface cover, crop canopy, surface roughness, and in the Pacific Northwest small grain farming areas, soil moisture. C factor is now a continuous function of the product of four subfactors: 1) prior land use (PLU), 2) surface cover (SC), 3) crop canopy (CC), and 4) surface roughness (SR). These subfactors include the effects of root mass in the upper 10 cm of the soil mass, changes in crop cover and root mass with time, tillage, and residue decomposition.
- ***Conservation practice factor (P):*** changed to consider conditions for contouring, strip cropping, terracing, and subsurface drainage as well as for addressing conditions for rangeland and pastures.

Climatic data used by RUSLE includes monthly precipitation and temperature, the frost free period, and 15-day distributions for the EI (product of kinetic energy and maximum 30-min precipitation intensity) (Dillaha, 2002a, b).

RUSLE is available in spreadsheet form at http://www.ga.nrcs.usda.gov/gatechnical/download_page.htm.

5.3.2.3 Modified Universal Soil Loss Equation (MUSLE)

MUSLE is a modification of USLE, with the rainfall energy factor of the USLE replaced with a runoff energy factor. The equation is (Smith et al., 1984):

$$A = 11.8 \cdot (Q.q)^{0.56} \cdot K \cdot L \cdot S \cdot C \cdot P \qquad (5.3.2.3\text{-}1)$$

where:

Q = surface discharge (m^3), and
q = peak rate of runoff (m^3/s).

The runoff factor, $11.8(Qq_p)^{0.56}$, has replaced the rainfall energy factor in the USLE. The remainder of the equation is identical to USLE.

5.3.2.4 Watershed Characterization System (WCS) and Sediment Tool

U.S. EPA and Tetra Tech developed the Arcview-based Watershed Characterization System (WCS) to provide tools for characterizing various watersheds in EPA Region 4. WCS is used to display and analyze Geographic Information System data including land use, soil type, ground slope, road networks, point source discharges, and watershed characteristics.

An extension of WCS is the Sediment Tool, which incorporates the USLE. The Sediment Tool can be used to perform the following tasks:

- Estimate the extent and distribution of potential soil erosion within a watershed.
- Estimate the potential sediment delivery to the receiving waterbody.
- Evaluate the effects of land use, BMPs, and road networks on erosion and sediment delivery.

For each grid cell within the watershed, the WCS Sediment Tool calculates the potential erosion using the USLE based on the specific cell characteristics. The model then calculates the potential sediment delivery to the stream grid network. Sediment delivery can be calculated using one of the four available sediment delivery equations: a distance-based equation, a distance slope-based equation, an area-based equation, or a water erosion prediction project regression equation. The WCS Sediment Tool estimates the total soil erosion and sediment delivered to the stream from each grid cell based on land use cover. Separate estimates of soil erosion and sediment delivery are made from the grids representing roads.

5.3.3 Phosphorus

Three methods for estimating phosphorus loadings are described below: Unit Areal Load/Export Coefficient (5.3.3.1); Simplified Pollutant Yield Approach (SLOSS-PHOSPH) (5.3.3.2); and Watershed Model (5.3.3.3).

5.3.3.1 Unit Areal Load/Export Coefficient

Unit areal loading or export coefficients have been used extensively in estimating phosphorus contributions from different land uses (Beaulac, 1980; Reckhow et al., 1980; Reckhow and Simpson, 1980; Uttormark et al., 1974). The concept is straightforward; different land uses contribute different phosphorus loads to receiving waters. By summing the amount of phosphorus exported per unit area of the different land uses in the watershed, the total phosphorus load to the receiving system can be calculated:

$$M_T = \sum_{i=1}^{n} (Ec_i \cdot Area_i) \qquad (5.3.3.1\text{-}1)$$

where:

M_T = total mass for the watershed (kg/yr),
Ec_i = phosphorus export coefficient for land use i ($kg/m^2 - yr$), and
$Area_i$ = area for land use i (m^2).

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The export coefficients are usually based on average annual loads. These land use based loading estimates can be converted into average annual phosphorus concentrations in the receiving stream by summing the estimated runoff from the area of each land use type within the watershed. This model has often been incorporated into spreadsheets.

If the receiving system is a lake, the precipitation load can also be included by adding a term to include direct precipitation on the lake surface. These areal water loads are also estimated on an annual basis:

$$Q = (R_i \bullet Area_i) + (Area_l \bullet Precip) \qquad (5.3.3.1\text{-}2)$$

where:

Q = total annual inflow volume (m^3/yr),
R_i = runoff coefficient for land use i (m/yr),
$Area_i$ = area of land use i, (m^2),
$Area_l$ = lake area (m^2), and
$Precip$ = total annual precipitation (m/yr).

This model relies on phosphorus export coefficients and land use as the basis for estimating phosphorus loading to receiving waterbodies. The model can be used to estimate current or existing loading as well as reductions in phosphorus export for each land use required to achieve a target TMDL phosphorus load. This model can be combined with methods on BMP effectiveness (Chapter 11.0) to assess the land uses and percent reductions in loading that might be reasonably expected in the watershed as a result of implementing BMPs.

An approach for bounding the likely phosphorus loading from a watershed is to select high, likely, and low estimates for export coefficients for each of the watershed land uses. These can be based on analyses of water quality data or estimates of different land use in the watershed (Reckhow and Simpson, 1980). The range of estimates can be used to bound the loadings expected from the watershed and for more formal uncertainty analyses (See Section 5.5).

The accuracy of the loading estimates from this model is dependent on the quality of the land use data, the appropriateness of the phosphorus export coefficients for the region, and the quality of the in-lake data used to initially test the model. Appropriate aggregate phosphorus export coefficients can be difficult to estimate. This is especially true for lakes with large watersheds and/or lakes which have extensive lake or wetland areas in their watersheds. In these instances, routinely published export coefficients will often overestimate actual phosphorus loading. Although a spreadsheet model of this type may have many limitations, it often is the only readily available model that can be used to estimate the effects of land use changes in the watershed when data are very limited (as is often the case for local governments needing to assess the impact of small scale land use changes on the water quality of a lake).

5.3.3.2 Simplified Pollutant Yield Approach (SLOSS-PHOSPH)

SLOSS-PHOSPH uses two simplified loading algorithms to estimate loads from distributed watershed areas: SLOSS, which estimates sediment yield, and PHOSPH, which estimates sediment-bound phosphorus.

SLOSS is a simplified pollutant yield model designed to estimate soil loss and sediment delivery to a stream. It uses the USLE to predict erosion and a delivery ratio to predict watershed sediment yield:

$$A_s = \sum_{i=1}^{n} K_i \cdot LS_i \cdot C_i \cdot P_i \qquad (5.3.3.2\text{-}1)$$

$$DR_i = \exp[-(b_i \bullet Sf_i \bullet Lf_i)] \qquad (5.3.3.2\text{-}2)$$

where:

A_s = soil loss per unit area of watershed,
K_i = soil erodibility factor,
LS_i = topographic factor,
C_i = land use/land cover management factor,
P_i = support practice factor,
n = the maximum number of cells,
DR_i = delivery ratio,
b_i = land cover factor,
Sf_i = slope function, and
Lf_i = length of flow path from cell to outlet.

Total sediment yield (L_s) is then calculated in the expression:

$$L_s = \sum_{i=1}^{n} (A_s)_i \cdot DR_i \qquad (5.3.3.2\text{-}3)$$

where the parameters are as previously defined.

PHOSPH is a simplified phosphorus loading model developed to circumvent the intense data requirements of more complex phosphorus models. PHOSPH calculates phosphorus loading as the product of average phosphorus content of the surface soil and a phosphorus enrichment ratio. The basic equation in PHOSPH is:

$$TP_s = \sum_{i=1}^{n} Pc_i \cdot (L_s)_i \cdot (ER_p)_i \qquad (5.3.3.2\text{-}4)$$

where:

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TP_s = total sediment-associated phosphorus delivered to the stream outlet,
Pc_i = average phosphorus content of the surface soil layer in cell i,
L_s = sediment yield, and
ER_p = phosphorus enrichment ratio.

The phosphorus enrichment ratio is defined as the mass of phosphorus in the eroded sediment per unit mass of phosphorus in the surface soil layer. It is calculated in the equation:

$$ER_p = 4.79 \cdot \left(\frac{C_{max} + C_{min}}{2} \right)^{-0.29} \qquad (5.3.3.2\text{-}5)$$

where:

C_{max} = maximum percent clay content of the soil in each cell, and
C_{min} = minimum percent clay content of the soil in each cell.

This model is useful for identifying critical areas of pollutant production in watersheds and predicting annual soil loss and phosphorus yields. The model is amenable to Geographic Information System (GIS) applications and has been incorporated into GIS-based models.

5.3.3.3 Watershed Model

Watershed is a spreadsheet model developed at the University of Wisconsin to calculate phosphorus loading from point sources, combined sewer overflows, septic tanks, rural croplands, and other urban and rural sources (Walker et al., 1989). It can be used to evaluate the trade-offs between control of point and nonpoint sources. It uses an annual time step to calculate total pollution loads and to evaluate the cost-effectiveness of pollution control practices in terms of cost per unit load reduction. The model uses a series of worksheets to summarize watershed characteristics and to estimate pollutant loadings for uncontrolled and controlled conditions. Because of the simple formulation describing the various pollutant loading processes, the model can be applied using available default values with minimum calibration effort. Watershed was applied to study the trade-offs between controlling point and nonpoint sources of phosphorus in the Delevan Lake watershed in Wisconsin.

Separate methods are used to calculate urban, rural non-cropland, and rural cropland phosphorus loads. Urban loads are calculated from point source estimates of flow and concentration. Rural non-cropland loads are estimated on a unit area basis. Rural cropland loads are based on the USLE. The model ranks the control alternatives in terms of cost effectiveness.

5.3.4 Other Pollutants

Selected methods for estimating loads of other pollutants are described below. These include: U.S. EPA Screening Procedures (5.3.4.1); USGS Regression Approach (5.3.4.2); Simple Method (5.3.4.3); The Federal Highway Administration Model (Statistical) (5.3.4.4); and Kansas TMDL Curve Methodology (5.3.4.5).

5.3.4.1 U.S. EPA Screening Procedures

The U.S. EPA screening procedures (Mills et al., 1985) are a collection of methodologies for calculating pollutant loads from point and nonpoint sources, including atmospheric deposition.

The procedures consist of loading functions and simple empirical expressions relating nonpoint pollutant loads to other readily available parameters. Agricultural nonpoint loads are based on the USLE, Soil Conservation Service runoff curve number procedure, and loading functions using enrichment ratios. Urban nonpoint loads are estimated using the buildup-wash-off concept. Data required generally include land use/land cover, management practices, soils, and topography. Methods are provided for calculating loads for both conventional pollutants as well as metals and toxic organics. These two volumes (Mills et al., 1985) are the most complete reference for estimating nonpoint source pollutant loads and assessing waterbody response when using simplified procedures.

Application of these procedures requires little training or calibration, and default values are provided for use when there is no site-specific data. In addition, methods are provided for estimating point and nonpoint source pollutant loads and loading responses in streams, rivers, lakes, reservoirs and estuaries. These procedures are particularly recommended for estimating pollutant loads in data-limited watersheds and for making bounding loading estimates for dynamic models. Although the procedures are not coded into a computer program, many of the techniques have been incorporated into other models, including the Generalized Watershed Loading Function model described in Section 5.7.1.

5.3.4.2 USGS Regression Approach

The USGS Regression Approach was developed to predict mean annual event pollutant loads at unmonitored sites using historic records of storm runoff responses on a watershed level (Tasker and Driver, 1988). Simple regression equations were developed for 10 pollutants using available monitoring data for pollutant discharges at 76 gaging stations in 20 states.

The method provides mean storm pollutant loads and corresponding confidence intervals. The user should choose the regression coefficients most appropriate for the watershed. The regression coefficients can be updated with additional and/or more recent data.

The general form of the regression model is:

$$W = 10^{[a + b(DA^{0.5}) + c\,IA + d\,MAR + e\,MJT + f\,X2]}BCF \qquad (5.3.4.2\text{-}1)$$

where:

W = the mean load (lbs) for a runoff event,
DA = drainage area (mi^2),
IA = impervious area (%),
MAR = mean annual rainfall (in),
MJT = mean minimum January temperature (°F),
X2 = land-use indicator, and
BCF = bias correction factor.

The mean annual pollutant load can be calculated by multiplying W by the mean annual number of storm events. This method is useful for estimating mean events and for comparing different sites.

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5.3.4.3 Simple Method

The simple method is an empirical method developed as a planning tool for estimating pollutant export from urban development sites in the Washington, D.C. area (Schueler, 1987). Although intended primarily for small (less than one square mile) urban development sites, the Simple Method is nonetheless recommended by several agencies for use in estimating nonpoint pollutant load concentrations for municipalities applying for NDPES permits (Chandler, 1994).

Pollutant concentrations of phosphorus, nitrogen, COD, BOD, and metals are calculated from flow-weighted concentration values for new suburban areas, older urban areas, central business districts, hardwood forests, and urban highways. The method utilizes the National Urban Runoff Program data for default values. A graphical relationship is used to determine the event mean sediment concentration based on readily available information. The Simple Method uses the following equation:

$$L_1 = P \cdot P_j \cdot R_v \cdot C \cdot A \cdot 2.72/12 \qquad (5.3.4.3\text{-}1)$$

where:

L_1 = pollutant loading (lb/yr),
P = average annual rainfall (inches),
P_j = unitless correction factor for storms with no runoff,
R_v = runoff coefficient (dimensionless),
C = flow-weighted mean pollutant concentration (mg/L), and
A = area of development (acres).

Pollutant concentrations in runoff for a certain land use/land activity are taken from the database (e.g., National Urban Runoff Program). Sediment event mean concentrations are calculated as a function of the surface area of the drainage basin.

5.3.4.4 The Federal Highway Administration Model (Statistical)

This is a simple statistical spreadsheet procedure for estimating pollutant loading and impacts on water bodies from highway stormwater runoff. The methods in this model are similar to, and perhaps incorporate, techniques that were known as the U.S. EPA Statistical Methods. The model calculates runoff volumes, pollutant loads, and the magnitude and frequency of occurrence of instream pollutant concentrations. Default values are provided for event mean pollutant concentrations as a function of traffic volume and the setting of the highway (i.e., urban or rural).

Pollutant loadings and the variability of loadings are estimated from runoff volume distributions and event mean pollutant concentrations for the median runoff event at a site. Rainfall is converted to runoff using a runoff coefficient calculated from the percent imperviousness of the site. Runoff velocity is estimated from runoff intensity. Mean runoff concentrations are calculated from site median pollutant concentrations, the coefficient of variation for event mean concentrations (EMCs), and the mean EMC as:

$$MCR = TCR \cdot \sqrt{(1 + CVCR^2)} \qquad (5.3.4.4\text{-}1)$$

where:

MCR	=	mean EMC for site (mg/L),
TCR	=	site median pollutant concentration (mg/L), and
CVCR	=	coefficient of variation of EMCs.

Mean event mass loading is computed as:

$$M(Mass) = MCR \bullet MVR \bullet (62.45 \times 10^{-6}) \qquad (5.3.4.4\text{-}2)$$

where:

M(Mass)	=	mean pollutant loading (lbs per event),
MCR	=	mean runoff concentration (mg/L), and
MVR	=	mean storm event runoff volume (ft^3).

Annual loads are calculated by multiplying by the number of storms per year. Pollutant buildup is based on traffic volumes and characteristics of the surrounding area.

5.3.4.5 Kansas TMDL Curve Methodology

The Kansas TMDL Curve method has been used with conventional pollutants, toxics, and fecal coliform bacteria. The general procedure is the same for any constituent and follows the stepwise process outlined below.

Step 1. A flow duration curve for the gage site of interest is developed. This is done by generating a flow frequency table and plotting the points (Figure 5-2).

% Exceed	Flow
99	694.2
95	803.3
90	920.2
85	1213.3
80	1629.7
75	2081.3
70	2692.9
65	3130.3
60	3583.3
55	4177.9
50	5092.2
45	6074.7
40	7068.8
35	8398.1
30	9801.8
25	11617.5
20	13838.5
15	17136.8
10	22281.1

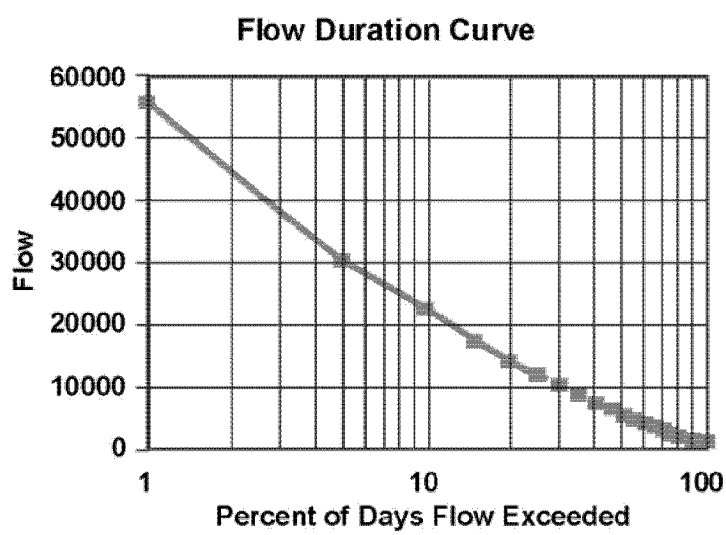

Figure 5-2. Step 1 Flow Frequency Table and Plot.

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Step 2. The flow curve is translated into a Load Duration (TMDL) Curve. To accomplish this, the flow value is multiplied by the water quality standard and by a conversion factor. The resulting points are graphed (Figure 5-3).

% Exceed	Flow	Atrazine (lbs/day)
99	694.2	11.50
95	803.3	13.31
90	920.2	15.25
85	1213.3	20.10
80	1629.7	27.00
75	2081.3	34.49
70	2692.9	44.62
65	3130.3	51.87
60	3583.3	59.38
55	4177.9	69.23
50	5092.2	84.38
45	6074.7	100.66
40	7068.8	117.13
35	8398.1	139.16
30	9801.8	162.42
25	11617.5	192.50
20	13838.5	229.30
15	17136.8	283.96
10	22281.1	369.20
5	30245.9	501.17
1	55562.3	920.67

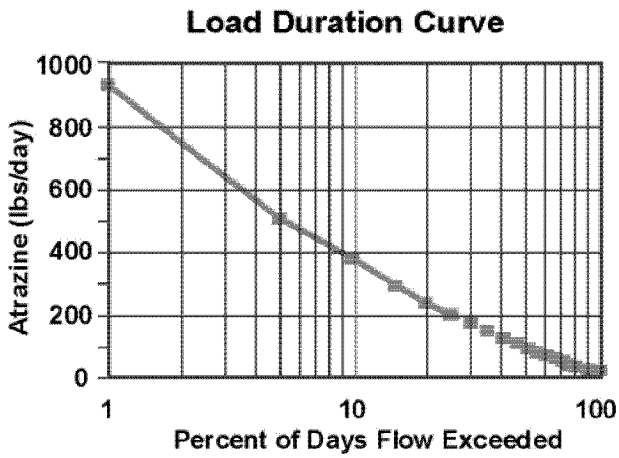

Figure 5-3. Step 2 Load Duration (TMDL) Curve Table and Plot.

Step 3. A water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was taken. Then, the load is plotted on the TMDL graph (Figure 5-4)

% Exceed	Flow	Atrazine (lbs/day)	Atrazine Load
99	694.2	11.50	4.33
95	803.3	13.31	
90	920.2	15.25	
85	1213.3	20.10	12.92
80	1629.7	27.00	
75	2081.3	34.49	
70	2692.9	44.62	122.91
65	3130.3	51.87	
60	3583.3	59.38	95.87
55	4177.9	69.23	
50	5092.2	84.38	
45	6074.7	100.66	
40	7068.8	117.13	
35	8398.1	139.16	
30	9801.8	162.42	
25	11617.5	192.50	
20	13838.5	229.30	
15	17136.8	283.96	154.43
10	22281.1	369.20	804.32
5	30245.9	501.17	
1	55562.3	920.67	

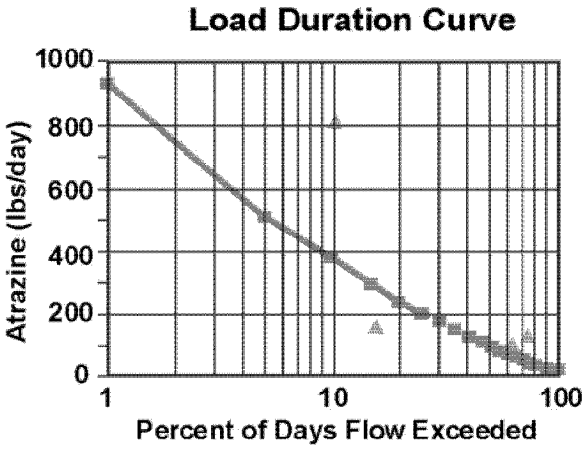

Figure 5-4. Step 3 Table and Plot Showing Loads Calculated from Samples (Triangles).

Step 4. The sample based loads (triangles) plotting above the curve (the solid line) represent deviations from the water quality standard and the permissible loading function (see

Figure 5-4). Those plotting below the curve represent compliance with standards and represent adequate water quality support for the appropriate designated use. Similar analysis can be done for certain lakes, using cumulative frequency distributions of their volume or elevation.

The load duration curve and sample plots provide information to:

- Help identify the issues surrounding the problem and differentiate between point and nonpoint source problems;
- Show seasonal water quality effects;
- Address frequency of deviations (how many samples lie above the curve vs. those that plot below), magnitude (how far the deviations plot away from the curve), and duration (potentially how long the deviation is present) questions;
- Compare water quality conditions between multiple watersheds; and
- Aid in establishing the level of implementation needed.

The location of loads that plot above the load duration curve is meaningful. Loads which plot above the curve in the area of the plot defined as being exceeded 85–99% of the time are considered indicative of point source influences on the water quality (Figure 5-5). Those loads plotting above the curve over the range of 10–70% exceedence likely reflect nonpoint source load contributions. Nonpoint source loads are pollution associated with runoff or snowmelt from numerous, dispersed sources over an extended area. Some combination of the two source categories lies in the transition zone of 70–85% exceedence. Those loads plotting above the curve at exceedences less than 10% or more than 99% reflect extreme hydrologic conditions of flood or drought.[1]

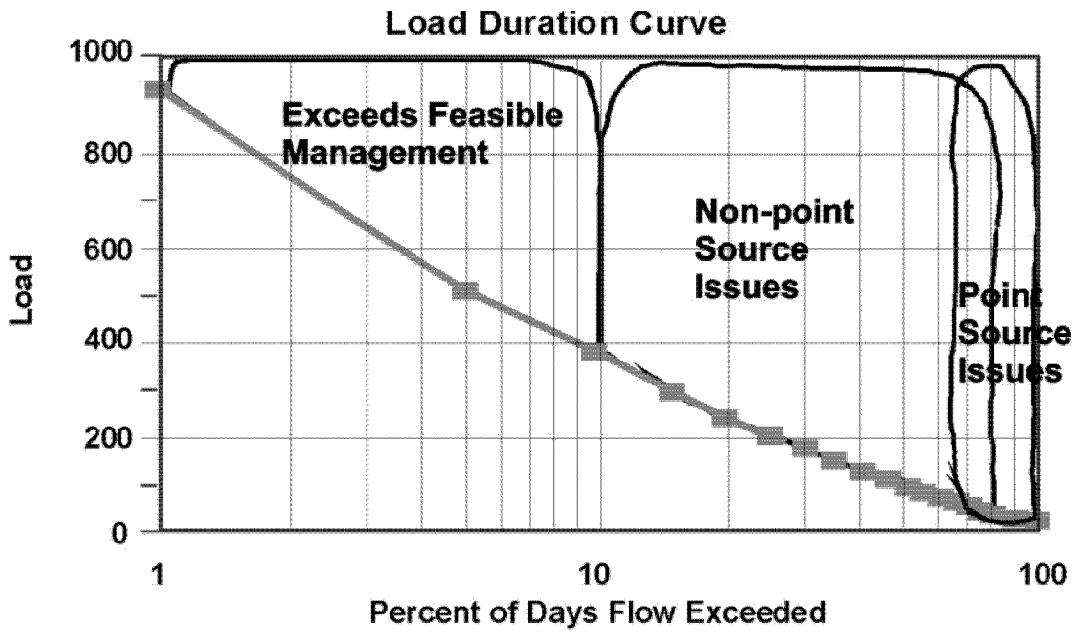

Figure 5-5. The Meanings of the Location of Loads That Plot above the Load Duration Curve.

[1] This method can be downloaded from www.kdhe.state.ks.us/tmdl/Data.htm.

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5.4 Software Programs

The previously described empirical methods can be conducted using nomographs and hand calculators, incorporated into computer spreadsheets or implemented through application software. This section describes various other software programs which make use of empirical methods more convenient and useful for more complex watersheds. They are presented first for phosphorus calculations (5.4.1) and then other pollutants (5.4.2). Each of these software programs is included in Tables 5-2 and 5-3.

5.4.1 Phosphorus

EUTROMOD is the only phosphorus loading program included in our discussion. EUTROMOD is a spreadsheet-based modeling procedure for estimating phosphorus loading and associated lake trophic state variables, distributed by the North American Lake Management Society (Reckhow, 1990). The procedure first estimates phosphorus loads from watershed land uses or inflow data using approaches developed by Reckhow et al. (1980) and Reckhow and Simpson (1980). The model accounts for both point and nonpoint source phosphorus loads. Then, statistical algorithms are used to predict in-lake phosphorus, nitrogen, hypolimnetic dissolved oxygen, chlorophyll, trihalomethane precursor concentrations, and transparency (Secchi depth). The model also estimates the likelihood of blue-green bacteria dominance in the lake. The statistical algorithms are based on regression analyses performed on cross-sectional lake data. Lake morphometry and hydrologic characteristics are incorporated in these algorithms. EUTROMOD also has algorithms for estimating uncertainty associated with the trophic state variables and hydrologic variability and for estimating the confidence interval about the most likely values for the various trophic state indicators.

5.4.2 Other Pollutants

Nonpoint source loads of other pollutants can be estimated using several software programs that are discussed in the following sections.

5.4.2.1 BATHTUB

BATHTUB is a software program for estimating nutrient loading to lakes and reservoirs, summarizing information on in-lake water quality data, and predicting the lake/reservoir response to nutrient loading (Walker, 1996). It was developed, and is distributed, by the U.S. Army Corps of Engineers. BATHTUB consists of three modules: FLUX, PROFILE, and BATHTUB (Walker, 1996). The FLUX module estimates nutrient loads (or fluxes) to the lake/reservoir. It provides five different algorithms for estimating nutrient loads based on the correlation of concentration and flow. In addition, the potential errors in loading estimates are quantified. PROFILE is an analysis module that permits the user to display lake water quality data. PROFILE algorithms can be used to estimate hypolimnetic oxygen depletion rates, area-weighted or mixed layer average constituent concentrations, and similar trophic state indicators. BATHTUB is the module that predicts lake/reservoir responses to nutrient loads. Because reservoir ecosystems typically have different characteristics than many natural lakes, BATHTUB was developed to specifically account for some of these differences, including the effects of non-algal turbidity on transparency and algal responses to phosphorus.

BATHTUB contains a number of regression equations that have been calibrated using both cross-sectional lake and reservoir data sets (Walker, 1996). It can treat the lake or reservoir as a continuously stirred, mixed reactor, or it can predict longitudinal gradients in trophic state variables in a reservoir or narrow lake. These trophic state variables include in-lake total and orthophosphorus, organic nitrogen, hypolimnetic dissolved oxygen, metalimnetic dissolved oxygen, chlorophyll concentrations, and Secchi depth (transparency). Uncertainty estimates are provided for the predicted trophic state variables. There are several options for estimating uncertainty based on the distribution of the input and in-lake data. Both tabular and graphical displays are available from the program.

5.4.2.2 PLOAD

PLOAD, developed by CH2M-Hill, estimates annual average nonpoint source pollutant loads using simplified procedures within a GIS-based model. Watershed physiography and land use are obtained from GIS layers. The pollutant loads can be estimated using export coefficients or the Simple Method.

When using export coefficients, the nonpoint source load is calculated using the following equation:

$$L_p = \sum_{u=1} (L_{pu} \bullet A_u) \qquad (5.4.2.2\text{-}1)$$

where:

Lp = pollutant load (lbs),
L_{pu} = pollutant loading rate for land use type u (lbs/acre/year), and
A_u = area of land use type u (acres).

The loading rates are derived from the export coefficient tables, while the land use areas are interpreted from the watershed land use GIS data.

When the Simple Method is used, runoff coefficients for each land use type are calculated using the equation:

$$R_{vu} = 0.05 + (0.009 * I_u) \qquad (5.4.2.2\text{-}2)$$

where:

R_{vu} = runoff coefficient for land use type u ($inches_{runoff}/inches_{rain}$), and
I_u = percent imperviousness.

Percent imperviousness is extracted from the impervious terrain factor table. The pollutant loads are then calculated with the following equation:

$$L_p = P \,.\, P_j \,.\, R_{vu} \,.\, C_u \,.\, A_u \,.\, 2.72/12 \qquad (5.4.2.2\text{-}3)$$

where:

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L_p = pollutant load (lbs),
P = precipitation (inches/year),
P_j = ratio of storms producing runoff (default = 0.9),
R_{vu} = runoff coefficient for land use type u ($inches_{runoff}/inches_{rain}$), and
C_u = event mean concentrations for land use type u (milligrams/liter), and
A_u = area of land use type u (acres).

In BASINS, areas calculated from GIS data are in square meters. PLOAD converts areas from square meters to acres prior to using the information in the above equation.

Pollutant loading tables of event mean concentrations and export coefficients are associated with the model. The event mean concentrations table contains pollutant rates for urban land use types. The export coefficients table contains pollutant rates for rural land use types. Any pollutant can be predicted if event mean concentrations and pollutant export coefficients are available. Commonly evaluated pollutants are listed in Table 5-4.

Table 5-4. Pollutants Commonly Evaluated Using PLOAD.

Total suspended solids	Nitrogen	Lead
Total dissolved solids	Nitrate + Nitrite	Zinc
BOD5	Total Kjeldahl nitrogen	
COD	Ammonia	
Phosphorus	Fecal coliform	

In addition to estimating pollutant loads to receiving systems, PLOAD permits an evaluation of nonpoint source reductions through the implementation of BMPs. A BMP efficiency table contains percent removal efficiency multipliers for each BMP type included in the model. The PLOAD software has been included in the BASINS program available from U.S. EPA.

5.4.2.3 Watershed Management Model (WMM)

The Watershed Management Model was developed by Camp Dresser & McKee for the Florida Department of Environmental Regulation for use in watershed management planning and estimation of watershed pollutant loads. It is a planning level model that provides a basis for evaluation of long term nonpoint pollution loads and the relative costs of nonpoint pollution management strategies. A version called WMM for Windows was developed under the Rouge River National Wet Weather Demonstration Project.[2]

This user-friendly spreadsheet-based model simulates the generation and fate of pollutant loads resulting from stormwater runoff. Runoff coefficients are used for rural areas. Urban runoff calculations are based on percent impervious area. The model uses 12 land use categories with associated event mean concentrations (EMCs) for a number of pollutant types, and average annual precipitation to simulate annual or seasonal pollutant loads carried in stormwater runoff. Pollutants simulated include nitrogen, phosphorus, lead, and zinc from point and nonpoint sources. The model also calculates in-lake or in-stream water quality from pollutant loads. Several options are available to model the resulting water body quality. It allows evaluation of load reductions based on BMPs and comparisons between point and nonpoint sources.

[2] This version is available at http://rougerivercom.readyhosting.com/proddata/wmm.html.

EMCs are either measured locally or taken from the National Urban Runoff Program data. Baseflow load is estimated from flow records and concentrations. Data requirements for the model include:

- Land use and soil types;
- Average annual precipitation, evaporation, and evapotranspiration;
- Nutrient concentrations in precipitation;
- Annual baseflow and baseflow pollutant concentrations;
- Event mean concentration in runoff;
- Reservoir, lake, or stream hydraulic characteristics; and
- Removal efficiencies of proposed BMPs.

The model is implemented in a spreadsheet environment and will calculate standard statistics and produce plots and bar charts of results. Although it was developed to predict annual loadings, this model can be adapted to predict seasonal loads provided that seasonal event mean concentration data are available. In the absence of site-specific information, the event mean concentrations derived from the National Urban Runoff Program surveys may be used as default values. The model includes computational components for stream and lake water quality analysis using simple transport and transformation formulations based on travel time.

WMM has been applied to several watersheds and was used for the development of a watershed master plan for Jacksonville, Florida, and its stormwater Part II estimation of watershed loadings for the NPDES permitting process. It has also been applied in Norfolk County, Virginia; to a Watershed Management Plan for North Carolina; and to a wasteload allocation study for Lake Tohopekaliga, near Orlando, Florida. A TMDL workshop concluded: "Of all the screening models reviewed, only WMM could evaluate urban, rural, and point sources, use runoff and baseflow (if known) and evaluate BMP options." (TMDL workshop, March 4, 1999).

The Rouge River WMM version has been significantly modified from earlier versions and now incorporates options for using the RUNOFF and TRANSPORT blocks from the Stormwater Management Model (SWMM) and the Water Quality Analysis Simulation Program (WASP).

5.4.2.4 SPARROW

The SPARROW model (Smith et al., 1997), USGS's Spatially Referenced Regressions on Watershed Attributes Model, uses spatially referenced regressions of contaminant transport on watershed attributes to support regional water-quality assessment goals. Model output includes descriptions of spatial and temporal patterns in water quality and identification of the factors and processes that influence those patterns. The model is designed to reduce the problems of data interpretation caused by sparse sampling, network bias, and basin heterogeneity. The model is rather data intensive for a "simple" model, but can incorporate data from different scales. Model precision depends on spatial variation rather than temporal variation and large watersheds are typically needed for calibration.

The sophisticated regression procedure used in the model relates measured transport rates in streams to spatially referenced descriptors of pollution sources and land-surface and stream-channel characteristics. Spatial referencing of land-based and water-based variables is accomplished via superposition of a set of contiguous land-surface polygons on a digitized network of

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stream reaches that define surface water flow paths for the region of interest. Predictor formulae describe the transport of contaminant mass from specific sources to the downstream end of a specific reach. Loss of contaminant mass occurs during both overland and in-stream transport.

Water quality measurements are obtained from monitoring stations located in a subset of the stream reaches. Water quality predictors in the model are developed as a function of both stream reach and land-surface attributes, and include quantities describing contaminant sources (point and nonpoint) as well as factors associated with rates of material transport through the watershed (such as soil permeability and stream velocity). For example, variables for nitrogen prediction include fertilizer application, livestock waste production, atmospheric deposition, temperature, soil permeability, and stream density.

In calibrating the model, measured rates of contaminant transport are regressed on predicted transport rates at the locations of the monitoring stations, giving rise to a set of estimated linear and nonlinear coefficients from the predictor formulae. Once calibrated, the model is used to estimate contaminant transport and concentration in all stream reaches. A variety of regional characterizations of water quality conditions are then possible based on statistical summarization of reach-level estimates. The application of bootstrap techniques allows estimation of the uncertainty of model coefficients and predictions.

5.5 Estimating Uncertainty

Uncertainty is the term applied to the condition of having incomplete knowledge about an effect or condition. All assessments and decisions, therefore, are made under varying degrees of uncertainty (Thornton et al., 1990). Uncertainty is defined as follows:

Uncertainty = Randomness + Error

Randomness refers to intrinsic or natural variability, which is a characteristic of most physical, biological, and behavioral systems. Although this component cannot be removed from analyses, it can be estimated and quantified. Error is the difference between an observed or calculated value and the true value. Error becomes an important source of uncertainty when models are used because of both input error and modeling error. Imprecision and bias are examples of two types of error. Imprecision is error that fluctuates around the true value with similar frequency on both the high and low sides. Bias is a systematic deviation of an estimate from the true value (i.e., consistent over- or underestimation). In many instances, not all the components of error can be estimated quantitatively. Beck (1987) has an excellent review on the analysis of uncertainty with particular emphasis on water quality modeling.

Quantifying projection or prediction uncertainty generally has focused on input error, parameter error, and errors in initial conditions. Initial condition error usually is transient and is accommodated in the calibration process. The effects of input and parameter error on model output have been reported for multiple environmental modeling studies (Beck, 1987; Fedra et al., 1981; Gardner et al., 1980; Hornberger et al., 1985; McLaughlin, 1983).

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Uncertainty should be considered part of the TMDL process and, at a minimum, included in the margin of safety. However, having uncertainty estimates for each of the pollutant source loads can provide additional insight regarding source reduction strategies and selection of BMPs. Many TMDLs do not provide estimates of the uncertainty related to model estimates, instead incorporating the uncertainty implicitly in the margin of safety. Most dynamic model applications use deterministic models and do not explicitly consider uncertainty, except through single parameter sensitivity analyses.

Three approaches that can be used to provide uncertainty estimates for simple nonpoint source loading models are discussed below. Some of the software programs used to estimate nonpoint source loads, such as EUTROMOD or BATHTUB, have several options for estimating uncertainty.

The sections that follow describe four methods for estimating uncertainty: First Order Error Analysis (5.5.1); Modified Latin Hypercube Approach (5.5.2); Modified Chebyshev Inequality (5.5.3); and Computationally Intensive Error Analyses (5.5.4).

5.5.1 First Order Error Analysis

First-order error analysis is a technique for partitioning or dividing the total error in the model predictions into the error contribution for each variable and parameter included in the model formulation (Berthouex, 1975; Cornell, 1972). It is based on a Taylor series expansion of the function, f(x), as shown below:

$$f(\underline{x}) = f(\underline{x}_0) + \delta f_1(\underline{x})/\ \delta\underline{x}\ (\underline{x} - \underline{x}_0) + \tfrac{1}{2}\ \delta^2 f_2(\underline{x})/\delta\underline{x}^2\ (\underline{x} - \underline{x}_0)^2 + \qquad (5.5.1\text{-}1)$$

If it is assumed the error ($\underline{x}$ - $\underline{x}_0$) is relatively small and the higher order terms (e.g., $\delta^2 f_2(\underline{x})/\ \delta\underline{x}^2$) are not large (implying the function does not vary drastically in the region of interest), then only the first-order term is retained as shown below:

$$f(\underline{x}) - f(\underline{x}_0) \approx \delta f(\underline{x})/\ \delta\underline{x}\ (\underline{x} - \underline{x}_0) \qquad (5.5.1\text{-}2)$$

When the first two moments are calculated (i.e., the mean and variance), it is possible to compute the contribution to the total variance from each of the individual variables or parameters (Reckhow, 1979a). The single variable function then becomes:

$$s^2[f(\underline{x})] \sim s^2(\underline{x})\ [\delta f(\underline{x})/\ \delta\underline{x}]^2|\underline{x} \qquad (5.5.1\text{-}3)$$

where s^2 is variance.

In the case of a simulation model, the function is the model itself. In this case, the partial derivatives generally cannot be calculated explicitly. An approximation of the partial derivatives can be obtained by perturbing the xi's in turn through sensitivity analysis. If a suitably small perturbation is chosen, then the ratio of the change in output to the perturbation is an estimate of the partial derivative. These estimates can then be used in the first-order propagation equation stated above.

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An example is taken from Reckhow and Chapra (1983b) to illustrate first order error analysis. The approach will estimate the independent variable error contributing to the total prediction for a steady-state phosphorus lake model. The model is:

$$P = \frac{L}{V_s + q_s} \tag{5.5.1-4}$$

where:

L = loading,
v_s = apparent settling velocity, and
q_s = areal water load.

Application of regression analysis to a cross-sectional data set resulted in the empirical model:

$$P = \frac{L}{11.6 + 1.2q_s} \tag{5.5.1-5}$$

with variables L and q_s as defined above. To use this equation for first-order error analysis, calculate the partial derivatives:

$$\frac{\partial P}{\partial L} = \frac{1}{11.6 + 1.2q_s} \quad \text{and} \quad \frac{\partial P}{\partial q_s} = \frac{-1.2L}{(11.6 + 1.2q_s)^2} \tag{5.5.1-6}$$

These are the sensitivity factors. Now, with estimates for the variable standard errors (s_L and s_{q_s}) and the correlation term (ρ_{Lq_s}), the required error term is:

$$s_p^2 = \frac{1.44L^2}{(11.6 + 1.2q_s)^4} s_{q_s}^{\ 2} + \frac{1}{(11.6 + 1.2q_s)^2} s_L^{\ 2} - \frac{2.4L}{(11.6 + 1.2q_s)^3} s_{q_s} s_L \rho_{Lq_s} \tag{5.5.1-7}$$

First order error analysis is incorporated in the nutrient loading algorithms in BATHTUB.

The extension of conventional sensitivity analysis to the first-order analysis of prediction error propagation was proposed for water quality and ecological models by Burges and Lettenamier (1975) and Argentesi and Olivi (1976) (Beck, 1987). It has since been applied by Lettenmaier and Richey (1979), Reckhow (1979a, b), Di Toro and van Straten (1979), van Straten (1983), Chadderton et al. (1982), and Walker (1982). Nearly all these studies have focused on the problem of lake eutrophication, with the models analyzed ranging from the single-response variable, steady-state model of Vollenweider (Reckhow, 1979a, b; Reckhow and Chapra, 1983b; Walker, 1982) to a multi-state variable, dynamic model for Lake Ontario (Di Toro and van Straten, 1979; van Straten, 1983).

5.5.2 Modified Latin Hypercube Approach

Even simple regression models can have multiple parameters and input variables to consider as part of uncertainty analysis. Sensitivity analysis typically varies a single parameter by some percentage (e.g., 20–30%) around the nominal or calibrated value to determine how sensitive the output is to the perturbation in the parameter or input value. Sensitivity analysis can help guide model calibration by focusing on those parameters to which the model is sensitive, but it does not provide information on the interactions among parameter and/or input values. An approach that provides insight into the uncertainty associated with model parameters and input variables as well as uncertainty in the model output is a Latin Hypercube model.

Latin Square experimental designs are used to reduce or eliminate the error associated with the arrangement of field plots or treatments in rows or columns where two factors (treatments) are being varied (Cochran and Cox, 1957). If each parameter and input value for a model represented a factor, there would need to be more than two dimensions to represent these factors, which is the concept behind a Latin Hypercube design (Figure 5-6). A Latin Hypercube selects a finite subset of parameter and input combinations (e.g., ~20 combinations) from the infinite number of combinations that could be selected from the continuous distribution of each parameter or input value (Figure 5-6). A finite set of combinations are selected to cover the range of possible parameter-input combinations so only this limited number of simulations need to be made to characterize the uncertainty in the output. The model output distribution can be used to indicate the likelihood that various load reductions or target loads might be achieved.

For example, the distribution of the existing load of sediment or phosphorus can be estimated using simple models with associated distributions in annual precipitation, areal land use, and export coefficients (Figure 5-6). With the implementation of BMPs, this output distribution might be reduced by an average of 40%. The output distribution can provide an estimate of the probability that the target load might be exceeded. This permits decisions on whether additional controls are needed. The Latin Hypercube is less computationally rigorous than Monte Carlo analyses, but still reasonably characterizes the model output distribution.

This approach is similar to that recommended by Lall et al. (2002) in guiding uncertainty analyses for the modeling studies being conducted in support of the South Florida Everglades Restoration Program. Lall et al. (2002) recommended the following steps:

1. Select a set of significant independent parameter and input variables that contribute most significantly to the final model predictions.
2. Construct probability density functions for each parameter over the range of selected variable values.
3. Propagate the uncertainties through the model to generate a probability density function for the predicted output variables.
4. If desired, derive confidence limits for the output variables.
5. Use these confidence intervals to make quantitative statements about the probabilities of achieving the desired reduction or target load.

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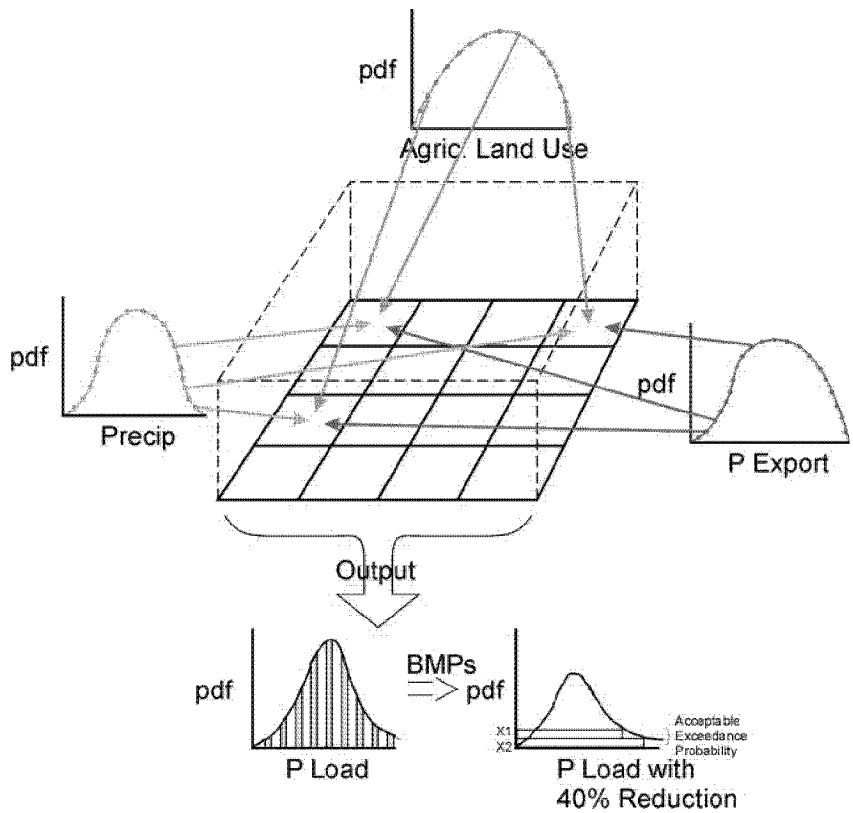

Figure 5-6. Latin Hypercube Approach for Using ~20 Simulations to Estimate Uncertainty in Output and Evaluate Likelihood of Achieving Target Load.

5.5.3 Modified Chebyshev Inequality

This approach represents a modification of the first-order error analysis (Section 5.5.1, Benjamin and Cornell, 1970) as applied by Reckhow and Simpson (1980). This approach is useful because it relaxes the requirements for normality so the confidence intervals can be constructed based on a nonparametric approach.

The approach uses three estimates for the pollutant export coefficient: high, most likely, and low. In general, it is useful if the range of high minus low export values are about two times the standard deviation in the data. This is based loosely on the characteristics of the Chebyshev inequality where about 90% of the distribution is contained within 2 standard deviations of the mean (Reckhow and Simpson, 1980). Reckhow and Simpson (1980) present step by step calculations of the "high" and "low" estimates of model error for a phosphorus loading model. With these estimates, it is possible to then provide confidence intervals around the most likely estimate of the pollutant concentration (e.g., phosphorus) in the lake.

The confidence intervals can be written as:

$$\text{Prob}[(P_{ml} - hs_{T}-) \leq P \leq (P_{ml} + hs_{T}+)] \geq 1 - 1/(2.25h^2) \qquad (5.5.3\text{-}1)$$

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The probability that the true pollutant concentration (P) lies within certain bounds, defined by a multiple, h, of the prediction error is greater than or equal to $1 - (1)/2.25\ h^2$. Substituting values for h into the equation above reveals that a value of 1 corresponds to a probability of about 56% and a value of 2 corresponds to a value of about 90%. Therefore, a value of 1 corresponds to a confidence interval about the most likely pollutant concentration of about 56% and a value of 2 corresponds to a confidence interval of about 90% (Reckhow and Simpson, 1980).

This nonparametric approach relaxes some of the concerns about normally distributed data and is recommended for many of the empirical models that are being used to estimate nonpoint source pollutant loads.

5.5.4 Computationally Intensive Error Analyses

Although this chapter is about simplified procedures, there are some approaches that have been used with dynamic models that can be used with the simple models to provide uncertainty estimates. Some of these approaches have been incorporated in software programs, such as BATHTUB, that use simplified methods for loading estimates. In addition, commercial software programs such as Crystal Ball® permit these simpler models to be loaded and uncertainty analyses performed.

5.5.4.1 Monte Carlo Simulations

Monte Carlo simulations have most frequently been used with water quality models to estimate the effects of input and parameter error propagation (Ford et al., 1981; Hornberger, 1980; O'Neill et al., 1980; Rose et al., 1990; Walker, 1996). In Monte Carlo simulations, parameters and inputs are repeatedly selected at random from specified distributions. These distributions can be based on statistical analyses of measured data (e.g., Gaussian, log-normal, uniform) or user-specified (e.g, triangular).

Random number generators are used to select values from these prescribed density functions. The number of iterations is usually determined by convergence of the output on some specified statistic such as the mean or variance (Thornton et al., 1990). The accumulated runs and simulated constituent values can be analyzed to define the statistical attributes of the output.

Two disadvantages of Monte Carlo simulations are the computational time and expense associated with the analyses, and the assumed independence among parameter distributions. With greater computational efficiency and speed in computers, the first disadvantage diminishes, but does not disappear. In general, 40% of the modeling study is spent in model calibration, and 50% in output evaluation. Only 10% of the study effort is spent in making the simulations. However, introducing covariance structures in Monte Carlo simulations is difficult, so the second disadvantage persists. It is likely that parameter combinations will be selected that can never exist in the watershed or receiving system.

5.5.4.2 Regional Sensitivity Analysis

An approach that has been used to reduce some of the disadvantages of Monte Carlo approaches is regional sensitivity analysis. Regionalized sensitivity analysis is a procedure used to determine ranges and combinations of parameters and input sequences that produce "acceptable" predictions of system response (Spear and Hornberger, 1980; Hornberger and Spear, 1981; Hornberger and Cosby, 1985). Monte Carlo procedures are used to randomly select a set

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of parameter values from within the designated range of the selected distribution and drive the model using this particular set of values. The result of each simulation run is then classified as either producing acceptable results (i.e., predicted chemical constituent concentrations within the range of measured observations of those properties) or as not producing acceptable results (Hornberger and Cosby, 1985). This procedure is repeated many times to accumulate a set of values for the input parameters for acceptable results and another set for unacceptable results. These sets of values, then, are analyzed to identify the subset of physically or chemically meaningful input parameters that appear to account for the acceptability of the results. This is done by comparing the distributions of parameter values associated with acceptable and unacceptable results. If the two distributions are not statistically different, the input parameter is unimportant for simulating that particular set of results. If the two distributions differ significantly, the input parameter is important for producing results within the specified ranges. The two distributions may reveal smaller ranges of values for the input parameters that are favorable for adequate simulation.

5.6 Nonpoint Source Pollutant Loads and Background Estimates

The nonpoint source pollutant loading estimation approaches that have been discussed in this chapter do not necessarily distinguish between anthropogenic and background pollutant loads. For example, export coefficients or similar estimates for land use are based on aggregate or average estimates of pollutant loads from that land use type or source. Chapter 4.0 discusses various approaches for defining and estimating background conditions. Methods based on those approaches for establishing background conditions and that might be used to partition the potentially controllable nonpoint source load from the background load are discussed below.

5.6.1 Upstream Concentrations

Example: For a nutrient TMDL for the Lower Colorado River in Arizona, background concentrations were estimated using multiple years of monitoring data from an upstream USGS gage. There were both nonpoint sources (e.g., irrigation return water) and point sources of nutrients in the upstream watershed.

Upstream concentrations are assumed to represent background conditions. These may include nonpoint sources and point sources that are controllable. An approach for partitioning potentially controllable nonpoint source loads from background loads would be to compute the flow-weighted loads based on pollutant concentrations upstream and subtract these from flow-weighted loads based on pollutant concentrations downstream. The difference represents the potentially controllable nonpoint source pollutant load.

For ungaged watersheds, an annual areal water load can be estimated for the upstream watershed and multiplied by the annual average mean or median pollutant concentration to obtain an annual background load. This background load is then subtracted from a similarly estimated downstream load using a similarly derived areal water load multiplied by the annual average or median downstream pollutant concentration. The difference represents the potentially controllable nonpoint source pollutant load.

5.6.2 Reference or Minimally Impacted Waterbodies

Example: For a bacteria TMDL for Mill Creek in South Carolina, background levels were assumed to be represented by the geometric mean of fecal coliform counts in waterbodies flowing through forested areas in South Carolina during all flow conditions.

An approach similar to upstream concentrations can be used to estimate the loads from reference watersheds or waterbodies where water quality data are available. If water quality data are unavailable, export coefficients or similar methods discussed in this chapter can be used to estimate the pollutant load based on land use in the reference watershed. This pollutant load can then be subtracted from the total nonpoint source pollutant load estimated for the TMDL watershed to obtain an estimate of the potentially controllable nonpoint source load. The reference watershed pollutant load can be adjusted to accommodate differences in watershed areas between the reference watershed and the TMDL watershed. For example, area proportioning can be used to adjust the background pollutant load to reflect differences in watershed areas. If the reference watershed is 60% of the area of the TMDL watershed, then the background pollutant load might be multiplied by 1.67 to represent the greater load expected from the larger watershed.

Reference watersheds with reasonably implemented BMPs can also be used with this method for determining background conditions.

5.6.3 Mathematical Model Studies That Eliminate Anthropogenic Sources

Example: For a clean sediment TMDL in Upper Lapwai Creek in Idaho, background concentrations were estimated using the Revised Universal Soil Loss Equation (RUSLE).

The nonpoint source empirical models discussed in this chapter can be used to estimate both the background pollutant load and the total nonpoint source load for a watershed or water body. The background load can then be subtracted from the total nonpoint source load to estimate the potentially controllable nonpoint source load.

This approach can also be used to establish loads for "best attainable" conditions in the watershed, which can then be used as a reference for estimating the controllable nonpoint source loads. Some agricultural watersheds, for example, are going to remain agricultural, so using a reference condition of a forested watershed is inappropriate. However, pollutant loads can be estimated for an agricultural watershed where BMPs have been implemented to estimate "best attainable" loads. These loads then can be used to estimate the nonpoint source load reduction that might be expected following the implementation of BMPs.

5.6.4 Literature Values

Example: For a bacteria TMDL for Muddy Creek in Virginia, background levels were estimated based on literature values for fecal coliform production for deer in forested land.

Literature values for pollutant loads can be subtracted from empirically modeled total nonpoint source pollutant loads to estimate the potentially controllable nonpoint source loads. Literature values should be checked to determine if they are consistent and comparable with those estimated using the models. This can be done by generating pollutant loads based on land use

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associated literature values using the empirical approaches. If the literature values are not comparable to the empirical estimates, estimates of controllable nonpoint source loads might not be reasonable.

5.6.5 Percentile-assigned Values

Example: For an ammonia TMDL for Big Sioux River in South Dakota, regulations required that background concentrations be assumed to be equal to the 80th percentile of available water quality data.

For this situation, flow-weighted pollutant loads can be estimated and subtracted from the total nonpoint source pollutant load to estimate the potentially controllable nonpoint source load. Empirical approaches can be used to assess the reasonableness of the percentile-assigned values.

5.6.6 Assign a Load of Zero

Example: For a BOD/ammonia TMDL for Sanders Branch/Coosawhatchie River in South Carolina, background loads were set to zero because the $7Q_{10}$ flow (the lowest expected consecutive seven-day flow over a 10-year period for a given waterbody) was zero and it was assumed that the point sources were the only significant loads to the stream under $7Q_{10}$ conditions.

The estimates from the empirical models, in this situation, represent the potentially controllable nonpoint source load because the background pollutant load is assumed to be zero. Empirical approaches can be used to assess the reasonableness of this assumption.

5.7 TMDL Examples Using Simple NPS Loading Models

Some examples of TMDLs and related projects that used simple and innovative approaches are discussed below.

5.7.1 New York City Reservoirs, Phosphorus

Models Used: Reckhow Model and GWLF: New York City used the Reckhow Land Use Model (Reckhow et al., 1980) for Phase I TMDLs. For Phase II TMDLs, the Reckhow model was used for east-of-Hudson reservoirs, while the more sophisticated Generalized Watershed Loading Function (Haith and Shoemaker, 1987) was used for west-of-Hudson Reservoirs (Kane, 1999a, b). The latter model was preferred for the west-of-Hudson Reservoirs because it predicts both temporal and spatial variability in the loads and is based on observed precipitation and temperature data rather than annual representations. The Vollenweider lake model is used in both models. A computer interface was developed for the TMDLs to interface the models with the data in a GIS format.

In Phase I of the TMDL project, the Reckhow model was able to predict the observed concentrations in 1993 to within 20% in 18 out of the 19 reservoirs. Export coefficients were adjusted for Phase II.

Results from the two models are compared. Below is a quote from the Cannonsville Reservoir (West of Hudson) TMDL:

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"The Reckhow model and the GWLF model use the same point source database and the same land use database (although the Reckhow model has the land uses aggregated into more generalized categories). The predicted phosphorus loads from each model, however, are quite different. The GWLF phosphorus loads are greater than the predicted loads from the Reckhow model. The percent of the total load from each general land use category is similar between models for nonpoint source loads. However, the relative contributions of point sources versus nonpoint source changes since GWLF predicts greater nonpoint source phosphorus loads."

"The differences between the model estimates is due to the model development history and the type of input data. The Reckhow model was presumably developed using baseflow monitoring data only, and it seems to predict the fraction of the load delivered during nonstorm periods. This has been partially verified using annual phosphorus loads derived from baseflow sampling data East-of-Hudson. The GWLF model more closely predicts the total load delivered during both baseflow and storm periods."

5.7.2 Uinta River, Utah, TDS

Models Used: Statistical: A statistical model based on flow was used to establish associated total dissolved solids (TDS) loads (TetraTech, 2001). The flow record of five years was judged to be of sufficient length and representative of long-term conditions.

To evaluate the allowable TDS loading for the watershed, each flow was multiplied by the 1,200 mg/L criterion to calculate a corresponding maximum loading limit for each flow. The individual values were plotted to present a loading capacity line by flow percentile (Figure 5-7).

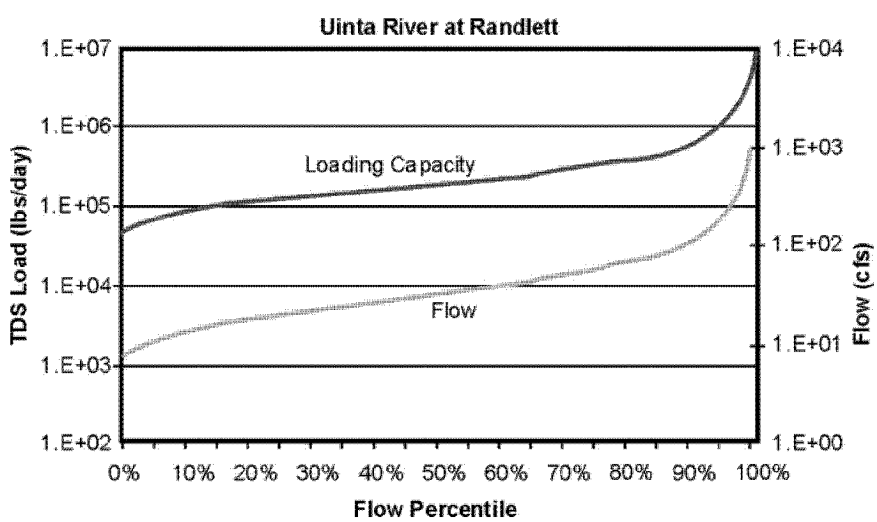

Figure 5-7. TDS Loading Capacity for Uinta River, Utah (from Tetra Tech, 2001).

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To calculate the existing loading, the 46 measured daily loads of TDS (flow and TDS concentration data pairs) were plotted versus flow percentile (Figure 5-8). Using the product of the 75th percentile concentration with discrete 20% flow classes (e.g., 0% to 20%, 20% to 40%) produced an existing load line that was representative of observed instream concentrations, without overestimating or underestimating the loadings (Figure 5-8). Therefore, the 75th percentile TDS concentration for each 20% flow range (i.e., 0% to 20%, 20% to 40%) was identified and that concentration was then multiplied by the flows in its associated flow range to establish an existing TDS loading line for Uinta River (Figure 5-8).

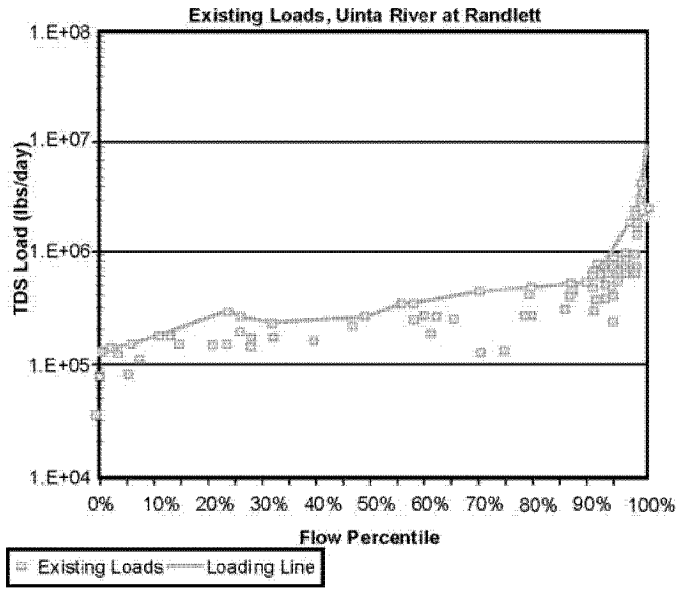

Figure 5-8. Existing TDS Loads and Existing TDS Load Line (from Tetra Tech, 2001).

Figure 5-9 is the plot of existing load and loading capacity together. Comparing the existing load to the loading capacity yields the necessary percent reduction within each flow range.

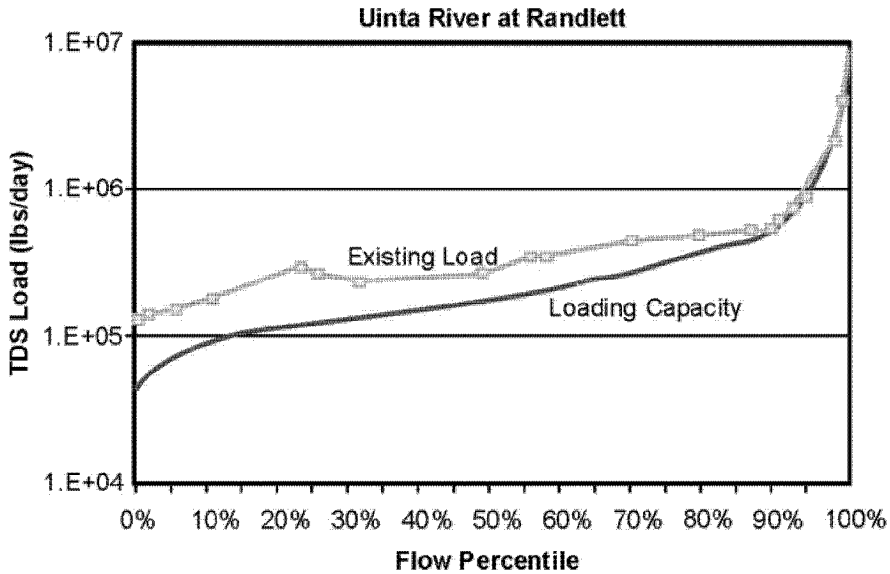

Figure 5-9. TDS Loading Capacity with existing TDS Load Line (from Tetra Tech, 2001).

5.7.3 Madawaska Lake, Maine, Phosphorus

Model: Export Coefficients: Estimates of total phosphorus export from different land uses in the Madawaska Lake watershed represented the extent of external phosphorus loading to the lake, expressed as a range to reflect a degree of uncertainty associated with such estimates. The watershed total phosphorus loadings were determined using literature-derived export coefficients (e.g., Reckhow et al., 1980) for the following land use categories: forest (managed, state-owned, and non-managed); agriculture (rotation crops and USDA Conservation Reserve Program); suburban (residential lots/camps, shoreline erosion, and septic systems), commercial-public property, and road-types (logging, highway, private). The phosphorus loading from atmospheric deposition was estimated by using a literature derived export coefficient for watersheds dominated by forested land. Of the total land area within the Madawaska Lake watershed, 90.8% (7,690 ha) was forested, most of which (88.7% or 6,819 ha) was owned and actively managed as a commercial forest by the Van Buren-Madawaska Corporation (ME-DEP, 1994).

5.7.4 Wake County Watershed Management Plan, North Carolina

Model: PLOAD (in BASINS): The Wake County Watershed Management Plan uses the model PLOAD, which is a component of the EPA modeling framework BASINS. PLOAD is a simple watershed model that estimates point and nonpoint pollution loadings on an annual basis for any user-specified pollutant. Nonpoint source loads are calculated based on land use information, pollutant loading coefficients and annual rainfall. The model has a built-in feature to evaluate the pollutant removal effectiveness of urban, suburban, and some rural BMPs. PLOAD has a relatively low volume of data required to use the model.

5.7.5 Fourth Creek, North Carolina, Fecal Coliform

Model: CRAP: The Coliform Routing and Allocation Program (CRAP), a Geographic Information System (GIS) based tool (ArcView) developed by the North Carolina Department of Natural Resources (NC DNR), was selected for the Rocky River fecal coliform bacteria TMDL evaluation in order to satisfy a variety of modeling objectives. CRAP is designed to be an easy to use GIS based model for fecal coliform TMDL development. In 1998 the Modeling Unit staff reviewed the available tools potentially suitable for use in fecal coliform TMDLs and determined that most of the models examined tended to be either overly complex for the modeling objectives or too simple and inflexible. With the notable exception of a few major urban areas, most fecal coliform impaired streams are located in watersheds where relatively little information is available on sources and stream/watershed morphology. Monthly instream fecal concentration data, collected at Department of Water Quality ambient stations, tends to comprise the bulk of the available data on fecal coliform bacteria in these watersheds.

Hence, in 1999 Modeling Unit staff began development of a simple, flexible, steady state modeling tool which could be applied in a variety of watersheds for which there is limited available data. CRAP is a customized ArcView project, written in Avenue, ArcView's scripting language. Output from the model is intended to represent "typical" instream fecal coliform concentrations within a given time step, for predefined design (critical) conditions. The disadvantage to developing your own model is that it has not been validated by more general review and use.

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5.7.6 Deep Creek, Montana, Suspended Sediments

Model: Regression: The approach for this suspended sediments TMDL was to obtain a measurable reduction in suspended sediment load either by decreasing the slope and intercept of the regression line between discharge and total suspended solids (TSS) by half in four out of five years or by demonstrating no significant difference in daily TSS load between Deep Creek and an unimpaired reference stream during spring runoff in four out of five years. U.S. EPA allows a TMDL to be based on a target other than a numeric water quality criterion, if a description of the process used to derive the target is included in the submittal. Also, U.S. EPA regulations define load allocations for nonpoint sources as "best estimates of the loading which may range from reasonably accurate estimates to gross allotments ..." This TMDL was developed under a phased approach. This approach requires adaptive management where initial load allocations or mitigation strategies are established based on best estimates and subsequently refined as responses to these actions are observed (see Chapter 14.0).

5.7.7 Jewel Lake, Alaska, Fecal Coliform

Model: Simple Loading Model for the Only Source: Geese in a park were identified as the primary source of fecal coliform in Jewel Lake. To calculate the loading from the geese, the TMDL used a simple loading coefficient equation. The equation factored in loading rate from geese, time geese spend in the park, percent that runs off the park and beach, average weight of geese droppings, and defecation rate. These numbers were divided by the volume of the lake to yield a loading coefficient of 2.51 CFU/100 mL per goose. The loading can be estimated by multiplying the number of geese times the loading coefficient. This example shows that if sources are identified before modeling is begun, some sources that require detailed modeling may be ruled out, and it's possible that a simple estimate of the load from the most likely source will yield sufficiently accurate estimates.

5.7.8 Chattooga River Watershed, Georgia, Sediment

Model: WCS and Sediment Tool: The limited amount of data available for the Chattooga River Watershed prevented U.S. EPA from using a detailed dynamic watershed runoff model, which would need a great deal of data for calibration. Instead, the agency determined the sediment contributions to the Chattooga River Watershed from the surrounding watershed based on an annual mass balance of sediment in water and sediment loading from the watershed.

Watershed-scale loading of sediment was simulated using the Watershed Characterization System (WCS) described in section 5.3.2.4. The complexity of this loading function model falls between that of a detailed simulation model, which attempts a mechanistic, time-dependent representation of pollutant load generation and transport, and simple export coefficient models, which do not represent temporal variability. The WCS provides a mechanistic, simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable without calibration. Solid loads from runoff can then be used to estimate pollutant delivery to the receiving waterbody from the watershed. The Sediment Tool, which incorporates the USLE equation, is an extension of the WCS.

5.7.9 Pawnee Reservoir, Nebraska, Sediment TMDL

Model: Load Estimated from Reservoir Volume Loss: Sediment sources to Pawnee Reservoir stem entirely from nonpoint sources. There are no point source contributions of sediment to

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the reservoir. The primary source of sediment entering Pawnee Reservoir is overland sheet and rill erosion. Approximately 2,520 acres (12% of the watershed) have been identified as having a gross erosion rate of more than 5 tons/acre-year.

Gully erosion also contributes sediment to the reservoir. Due to the widespread nature of overland gullies and the lack of access to private lands, the quantification of gully erosion in the watershed is not possible. Streambank erosion is a widespread problem in this drainage basin and shoreline erosion has also been identified as a problem in some areas of the reservoir.

Sedimentation information dating back to 1966 was assessed to determine long-term average annual volume losses within the reservoir. Based on this assessment, Pawnee Reservoir was estimated as having an average annual volume loss to the conservation pool of 0.75%, which is equal to the Section 303(d) listing criteria.

Volume loss estimates (acre-foot) were converted to sediment load (tons) using a sediment density factor of 1,400 tons/acre-foot, which is based on the soils in this region. Loading calculations were conducted to determine the amount of sediment deposited in the flood storage zone and conservation zone of the reservoir as well as the amount transported downstream through the outlet works. The average annual sediment load to Pawnee Reservoir is estimated to be 90,513 tons, of which 82,320 tons (91%) are deposited in the conservation zone.

5.7.10 Steilacoom Lake, Washington, Phosphorus TMDL

Model: Lower Quartile of Export Coefficient: To determine the pre-disturbance (non-anthropogenic) phosphorus loading, data on the pre-disturbance vegetation were taken from the General Land Office Surveys conducted in the 1870s; i.e., prior to extensive development. The purpose of these surveys was to establish section lines. During the surveys, the size and species of trees along with other vegetation were recorded. For the area of Clover Creek watershed the following description was recorded: "Timber, chiefly fir, cedar and hemlock grown to immense size and is of the finest quality" (GLO, 1870). As a margin of safety, the lower quartile of phosphorus export coefficients found in the literature (Reckhow et al., 1980) for forests (0.019 kg/ha/yr) was applied to the 66.9 mi^2 Clover Creek watershed area for estimating pre-disturbance phosphorus loading. Using this approach, the phosphorus loading in 1870 was estimated to have been 373 kg/yr (2.2 lbs/day).

5.7.11 Nomini Creek, Virginia, Sediment and Phosphorus

Models: SLOSS, PHOSPH: The Virginia Department of Conservation and Recreation selected the Nomini Creek watershed as an area in which to evaluate and monitor the effectiveness of best management practices (BMPs) for the Chesapeake Bay Program. To identify the critical phosphorus and sediment loading areas within the watershed so that BMPs could be sited effectively, the Division tested the feasibility of integrating VirGIS, a state-run geographic information system, with two simple pollutant yield models, SLOSS and PHOSPH, described in section 5.3.3.2. VirGIS was initiated in 1985 by the Division as a tool for developing modeling and mapping procedures that could readily identify land areas with nonpoint source pollution potential. Because Virginia's database was sufficiently large, VirGIS was able to provide the data required to run the models. The output from these models successfully identified critical areas of nonpoint source loading. BMPs were sited on these areas and an intensive water quality

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monitoring program was put in place to evaluate BMP effectiveness and to verify the estimated pollutant loads.

Virginia Polytechnic Institute and State University and the State used the two models to characterize the Nomini Creek watershed. SLOSS was used to estimate potential soil erosion for each hydrologically homogeneous cell in a watershed. For Nomini Creek, a cell size of 1/9 hectare was used. A sediment delivery ratio was also calculated for each cell. This ratio relates the amount of sediment lost from a cell to the amount that will actually be delivered to the stream channel. PHOSPH was selected as the phosphorus loading model for this project in order to circumvent the intense data requirements of more complex phosphorus models. PHOSPH uses a phosphorus enrichment ratio, which is defined as the mass of phosphorus in the eroded sediment per unit mass of phosphorus in the surface soil layer.

5.7.12 Sycamore Creek, Michigan, Sediment TMDL

Model: Estimation Techniques from Literature: In the Sycamore Creek sediment TMDL, the pollutant load associated with each monitored runoff period in the urban and agricultural subwatersheds was calculated from the interval method (Richards and Holloway, 1987). The calculated loads did not include bedload.

For each agricultural subwatershed, pollutant loads during baseflow were estimated by multiplying the average baseflow pollutant concentration (from monitoring data) by the total annual flow for baseflow days. Total annual flow for baseflow days at a location was determined by correlating a United States Geological Survey (USGS) gage at Holt Road for days when flows at both the sampling locations and the gage were at baseflow conditions. For runoff periods, a linear regression model was derived from the runoff data to predict individual storm loads from the peak daily average flow at the USGS gage. Annual average channel erosion for actively eroding banks was determined by multiplying the bank height at the location of erosion, the length of the eroding portion, the lateral recession rate, and the density of the soil in the eroding banks.

An urban load estimation model (Driver and Tasker, 1988) was used to predict pollutant loads from the Mason urban area. The model was calibrated by adjusting the bias correction coefficient until model predictions matched measured values. A +290% adjustment was made for Rayner Creek, and a –20% adjustment was needed for Columbia Drain.

5.8 Summary and Future Research Needs

In most TMDL studies there are inadequate data to characterize nonpoint source loads. In situations where data are limited, simple models can provide estimates of these loads that are similar to estimates calculated using complex models. In TMDL studies, nonpoint source loads must be divided into a controllable component and background component, and simple nonpoint source models can be used to estimate both components. Fortunately, a large number of simple models are available to estimate such loads, and many are described in this chapter along with aids to selecting the right tool. It must be recognized, however, that some uncertainty is inherent in nonpoint source load estimates no matter what model is used. Some model

programs calculate uncertainty of their estimates. Uncertainty approaches are available for bounding the estimates from simple nonpoint source loading models and should be employed.

There are many research needs related to nonpoint source load estimation, including:

Research on specific nonpoint source constituents: There currently are no good techniques for partitioning loads for pathogens (specifically *E. Coli*) and Total Suspended Solids into their respective sources. There is also a need for risk assessment procedures for assessing potential effects of these pollutants on biological endpoints. In addition, there is a need for fate and transport models linking transformation of the various nitrogen species (nitrate; ammonia; and organic nitrogen). Currently, nitrate loadings might arise from various sources, including transformation from other nitrogen species. Without knowledge of potential transformations, the wrong sources, and species, could be targeted. Also needed is development of BMPs for controlling nitrate from various sources.

Inventory of nonpoint source contributions: Nonpoint sources can include background sources, non-human activity sources (e.g., deer, ducks, geese, etc.), and human related activity. Having an inventory of these sources by region of the country would be very useful in using some of the simplified nonpoint source procedures because it could provide a reference for likely contributing sources and relative magnitude.

Minimizing impacts of urban development: There is a need for design criteria for minimizing nonpoint source contributions due to urban development, and post-development assessment to determine these contributions. Also needed are software programs for design criteria and post-development assessment.

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CHAPTER 6.0

INCORPORATING URBAN WET WEATHER SOURCES

This chapter investigates some of the difficulties of incorporating urban wet weather sources into TMDLs, describes the characteristics that make urban wet weather issues different from dry weather issues, and highlights several innovative methods for addressing wet weather sources within TMDLs and in non-TMDL watershed studies.

6.1 Introduction

Implementation of the TMDL program is intended to control both point and nonpoint sources of pollution, resulting in the attainment of ambient WQS. However, developing TMDLs that incorporate loads from urban wet weather pollution sources, such as stormwater and combined sewer overflows, can be challenging.

The calculation of allowable loads which address wet weather conditions is fundamentally different from calculating loads during dry weather. This is due to factors related to environmental conditions such as receiving water flows, loading variations, methods and models used for quantifying loads, and impacts on water quality. The intermittent nature of wet weather loads and their resultant transient impacts make them challenging to incorporate into TMDLs, which by definition assume a constant daily loading. Further, water quality standards were typically developed based on achieving compliance during low-flow conditions. Applying these standards during wet weather events may often be unrealistic.

The types of TMDLs (i.e., pollutants) most likely to be included as urban wet weather sources are bacterial (fecal coliform, *E. coli*). However, other pollutants, including sediment, oxygen-depleting substances, toxics, metals, oils and grease, trash, temperature, and nutrients also load during wet weather events.

6.2 Findings and Observations

The first year research of this project identified urban wet weather issues as a significant challenge for TMDL development. Interviews with regulators and stakeholders, and reviews of comments submitted on proposed TMDL regulations, identified urban wet weather as a specific area that needed more attention from researchers and those developing TMDLs.

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Urban issues were also identified as being different from rural wet weather issues. While overlap exists between urban and rural wet weather issues, urban wet weather tends to produce more pronounced transient impacts than do the nonpoint source loadings that typically characterize rural wet weather events. In many cases in the urban environment, the existence of storm sewers and large amounts of impervious surfaces will accentuate the loading peaks related to wet weather pollution. While the discussion here will identify some key points to assist in rural wet weather TMDLs, the intent is to focus on urban sources.

Interviews and reviews of literature and approved TMDLs resulted in the following three observations related to TMDLs, urban wet weather sources, and the difficulties in developing a TMDL:

- Wet weather loads and resulting water quality problems can be significant. These loads are challenging to quantify.
- Wet weather water quality impacts are transient, with widespread impairments from bacteria and uncertain impacts on aquatic life uses.
- Urban wet weather sources such as stormwater, combined sewer overflows (CSOs), and sanitary sewer overfolws (SSOs) are not typically addressed in TMDLs.

These issues are further described below.

1. Wet weather loads can be significant, and resulting water quality problems can be significant. These loads are challenging to quantify.

Wet weather runoff from urban areas is responsible for an increasing portion of water pollution problems in rivers, lakes, and streams. Since secondary treatment became commonplace for wastewater treatment plants, urban runoff has come to represent a larger portion of the total pollutant load. Researchers reported shortly after secondary treatment was adopted that storm-generated runoff accounted for 40-80% of the total biochemical oxygen demand (BOD) load for urban areas (Novotny and Chesters, 1981). In cases where untreated or partially treated wastewater is reaching waterbodies, such as when CSOs or SSOs occur, these predominantly wet-weather related events can be the cause of, or contribute to, water quality impairments (U.S. EPA, 2001b).

While there is wide perception that wet weather loads are significant factors for water pollution, national statistics neither support nor refute this statement. Only a few studies have attempted to document nationwide impairments in waterbodies due to wet weather events, most prominently the Nationwide Urban Runoff Program (NURP), which gathered storm-event data in the late 1970s and early 1980s. The National Water Quality Inventory Report, produced biennially by U.S. EPA, attempts to document impairment due to wet weather sources, based on information supplied by state water quality agencies. In the 1998 report "National Water Quality Inventory," urban runoff/storm sewers were listed as the primary pollutant source for 11% of the impaired river and streams and 12% of impaired lakes, reservoirs and ponds (U.S. EPA, 2000d). Municipal point sources, which could include CSOs, as well as conventional wastewater treatment plants, represented an additional 10% of river and stream impairments and 11% of impaired lakes, reservoirs and ponds. In the U.S. EPA TMDL

database (1998) 8% of the listed segments were impaired due to CSOs (203 of 22,688 sites) or urban/storm-sewer runoff (1,525 of 22,688 sites).

Water quality regulations over the past decade have focused on controlling wet weather sources of pollution, including CSOs, SSOs, and stormwater. To this end, the process starts with quantifying the loads. However, wet weather loads are challenging to quantify, and will often require models and estimates to substitute for actual data. Results from the NURP program are often utilized to develop event-mean concentrations for pollutant loading during wet weather events, and these results are being refined through additional data collection channels such as the National Stormwater Best Management Practices Database (www.bmpdatabase.org). Urban areas that have performed large-scale wet weather flow and water quality monitoring have found that data collection costs are substantial and often allow for a few weeks or months of data collection.

2. **Wet weather water quality impacts are transient, with widespread impairments due to bacteria and uncertain impacts on aquatic life uses.**

Importantly, many wet weather water quality impairments are often transient in nature. Recreational uses are often impaired by bacterial exceedences from hours to days following a wet weather event. As contaminated runoff subsides following a wet weather event, the waterbody will usually return to background levels.

Bacterial impacts can be significant. Numerous beach closings in urban areas are precipitated by urban wet weather events. In 1991, in a report detailing the sources of 11,270 beach closures and advisories nationwide, polluted runoff and stormwater was identified as the source of 4,102 closings or advisories, and 2,208 closures were tied to CSOs and SSOs (NRDC, 2001). Several communities will now preemptively close beaches and other recreational uses of waterbodies during and following a significant rainfall, knowing that such conditions will result in elevated bacteria concentrations to unacceptable levels, even before obtaining sample results. In the NRDC report, 569 closures/advisories were tied to "rain" or preemptive closures.

Impacts on aquatic life uses are less certain and tend to be site-specific. Transient impacts on dissolved oxygen have been observed at many sites; however, these impacts are not routine and universal, but rather storm and site specific. While several studies have identified loss of habitat and biodiversity as a result of increased impervious area and correspondingly higher flows during wet weather events, the overall impact on aquatic life is often uncertain and needs to be determined in a site-specific manner (Roesner et al., 2003). Imperviousness and the resulting changes in stream channels have been identified as threats to habitat and aquatic life, and have been summarized in review studies (Schueler, 1994).

3. **Urban wet weather sources (stormwater, CSOs, SSOs) are not commonly addressed in TMDLs.**

Of the eight states interviewed in-depth by the research team, most could not point to a single TMDL that specifically addressed urban wet weather sources. In subsequent

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investigations of approved TMDLs from across the country, it was found that those that did address urban wet weather sources were most likely to include stormwater in the TMDL.

Of 176 approved TMDLs reviewed, only one specifically included a permitted wet weather point source (CSO outfall). Stormwater loads were often lumped together with all the NPS loads in the Load Allocation portion of the TMDL, and not evaluated as a separate distinct source.

The TMDL review indicated that urban stormwater is generally incorporated as a nonpoint source but not addressed very rigorously; it is often included as an urban land use category. Several TMDLs listed stormwater as a source, but did not mention a permit, and often did not include stormwater as a separate allocation. These TMDLs were located around urban areas: Tampa, San Diego, Portland (Oregon), and Washington, D.C.

6.3 Why Are Wet Weather TMDLs in Urban Areas So Challenging?

By definition, a TMDL is merging a Waste Load Allocation (WLA), a point-source allocation, with the Load Allocation (LA), the nonpoint source component. Many urban area wet weather sources are permitted point sources (e.g., CSOs, stormwater) but act like nonpoint source (load during wet weather, load variably depending on rainfall intensity).

Add in the fact that many of these urban wet weather sources are regulated in other programs (e.g., CSO permits, stormwater) with different schedules, implementation requirements, and sometimes different water quality endpoints, and there is a resulting conflict.

A typical plot of bacteria (or other pollutant) levels in a river during wet weather events will show high peaks that will often greatly exceed the WQS developed for low-flow or chronic conditions. Figure 6-1 provides an example of a typical plot for bacteria on a river influenced by urban wet weather pollutant discharges.

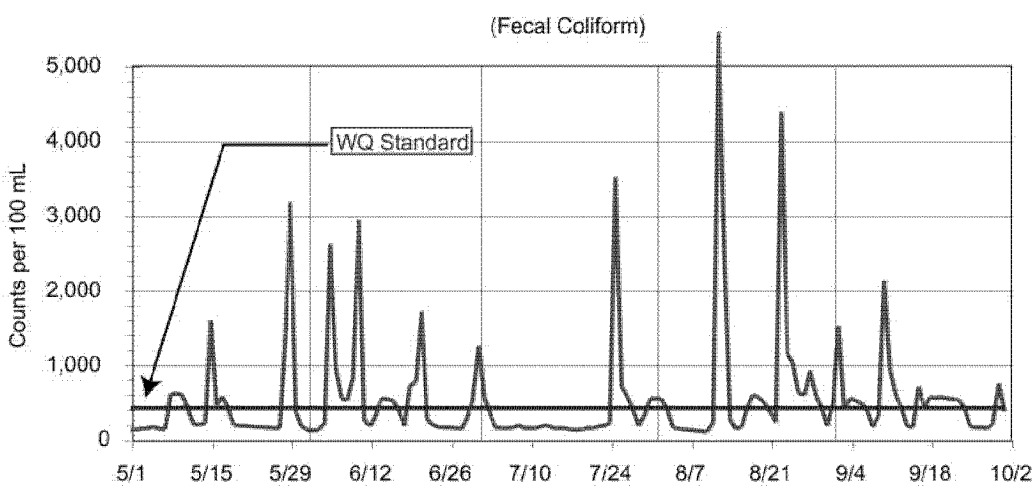

Figure 6-1. Bacteria Levels on a River Influenced by Urban Wet Weather Pollutant Discharges.

The definition of wet weather varies across studies and for different climactic zones. For this reason, this report does not provide a single definition of wet weather that fits all circumstances. For small drainage areas, wet weather may be the period when rain is falling only. For other areas, wet weather will also need to incorporate the time when the river level is rising, or when flow is above a stated level. Some areas may have a wet season, when it rains nearly every day. Examples of definitions of wet weather include:

- Rain event;
- Rain event and a fixed duration after;
- When the river flow is above a certain level;
- When a thaw (snowmelt) is occurring; or
- A combination of the above factors.

Wet weather urban TMDLs raise important issues that are fundamentally different from dry weather TMDLs. The process of analyzing loads and conditions in wet weather is often different than in dry weather, especially for pollutants with transient impacts like bacteria and dissolved oxygen. Key differences include:

- Wet weather loading sources are fundamentally different than dry weather loading sources.
- Wet weather loads vary dramatically from event to event and during events.
- Wet weather loadings typically cannot be examined as annual average or even as daily loads.
- Many water quality impacts during wet weather are transient in nature.
- Receiving water conditions are different for wet weather than for dry weather.
- Actual uses during wet weather can be different than during dry weather (e.g., swimming).
- Water quality criteria for wet weather need to consider transient exposures, not constant exposure as for dry weather.
- Analysis tools, estimation methods, and models are more complex for wet weather.

Each of these is described in detail below:

Wet weather loading sources are different than dry weather loading sources: In the urban setting, wet weather loads often occur from buildup and washoff of pollutants associated with stormwater from streets and other impervious areas, soil erosion in streams and gullies, and bacterial loads from accumulated animal wastes, as well as overflows of sewer systems. The nature of these sources is highly variable, dependent on antecedent conditions, and highly challenging to quantify and control. These load sources differ from the principal controllable sources of pollutants during dry weather, including point sources from industrial and municipal operations, which are relatively much more definable, less variable, more easily quantified, and offer more options for control (U.S. EPA, 1995a).

In addition, data on wet weather pollutant sources are difficult and/or expensive to obtain. Most states (44 of 50) reported to the U.S. Government Accounting Office (GAO, 2000a) that they did not have adequate data on wet weather sources to adequately estimate wet weather loadings.

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Wet weather loads vary dramatically from event to event and during events: Wet weather loads can vary tremendously from event to event. Rainfall intensity, duration, time between events, and antecedent moisture conditions all have a large impact on wet weather loads, both in terms of the amount of water delivered and in the amount of pollutants that are delivered to a stream (Nix, 1994).

Wet weather loads also vary dramatically during events. When wet weather loads in an urban environment are dominated by stormwater, the first portion of runoff or so-called "first flush" can often contain the highest concentration of pollutants. Pollutants of concern for urban wet weather issues, which include bacteria and solids, can often be associated with the "first flush" of runoff. For some systems (e.g. CSOs), bacteria may continue to be a major load throughout the wet weather event, and even for days following the event.

Runoff and sewer system models can be used to calculate runoff and pollutant loads due to wet weather. They often have factors for rainfall intensity and duration, as well as a method for accounting for pre-existing conditions that help describe system dynamics and transects. They typically can adequately simulate the flow variations when properly "tuned" with detailed inputs. However, the concentration dynamics provide more difficult challenges that are not adequately addressed. Most often, modeling studies crudely utilize a mean concentration, unable to simulate dynamics.

Wet weather loadings typically should not be examined as annual average or even as daily loads: Pollutant loads during wet weather occur during and after rain events. To treat them as an annual average, or even daily loads, as for dry weather sources, would greatly distort the estimated impacts of wet weather loadings (Moffa, 1996; Moffa, 1997). A bacterial load that occurs during several large rainfall events can cause high bacteria concentrations in a waterbody from hours to a few days. These concentrations will often be orders of magnitude higher than dry weather values. To express such loads as an annual average would drastically diminish the peak loading rates, and potentially could mathematically dilute a serious acute loading problem into a low-grade chronic problem.

For some waterbodies, even considering daily loads may not provide the resolution necessary to identify water quality problems, as flashy streams with short duration rainfall can produce high levels of turbidity and bacteria which rapidly rise and fall as the wet weather event occurs and then dissipates.

Another averaging factor is the associated receiving water flow. Wet weather events typically are associated with higher or at least changing flow conditions in rivers and streams. To associate these conditions with an average or drought flow as in dry weather analysis would be inappropriate and inaccurate.

Many water quality impacts during wet weather are transient in nature: Water quality impacts during wet weather are often transient, and occur on a timescale of hours to days, rather than the long-term water quality impacts that occur during dry weather conditions (Marr and Freedman, 1997; Freedman and Dilks, 1996). Wet weather events will often lead to a short-lived, sharp peak in pollutant load as rain occurs, and a longer slower peak as river flow increases and other flows in the watershed combine and are routed to the waterbody. Upstream

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loadings can also rise significantly during and after wet weather events, and this may not coincide with the peak loading in the local area.

Long-term simulations of flows and variability are often necessary to obtain results that will direct resources properly for future conditions. The choice of conditions for long-term simulations can be complex. Options include 10-15 year simulations, wet/dry/average years, and synthetic streamflows that will try to reproduce a "typical" year.

Receiving water conditions are different for wet weather when compared to dry weather: Receiving waters are often flowing higher during a wet weather event. This will sometimes provide greater dilution for pollutant loadings, and it will also sometimes provide a larger background pollution component than during dry weather (U.S. EPA, 1999a). Traditional TMDLs do not often account for flow-variable loading, nor does the background contribution typically change over time. Therefore, if incorporated, these different receiving water conditions would change the nature of the TMDL.

Actual uses during wet weather can be different than during dry weather (e.g., swimming): Some actual waterbody uses during wet weather events are different than during dry weather events, and therefore designated use and applicable water quality criteria need to be examined (U.S. EPA, 2001b). In many areas, wet weather events may preclude swimming in a waterbody during some rainfall events. This may be due to practicality (e.g., beaches are less frequented during rainstorms) or safety-related (e.g., swimming or wading in a river during high flows is not safe). There still are some sports that may occur during wet weather or high flow events, such as kayaking, that may make this provision not applicable in certain parts of the country. Care must be taken in assessing the actual use during wet weather for the specific region and waterbody being addressed.

Water quality criteria for wet weather need to consider transient exposures not constant exposure as for dry weather: Water quality criteria are typically developed through testing or calculations that assume constant exposure over a prolonged period. Transient exposures such as those resulting from wet weather are often not incorporated in water quality criteria. For this reason, some have argued for wet weather water quality standards that will address these transient exposures, and take into account the frequency, magnitude, and duration of exposure. This includes the National Research Council, which in its review of the TMDL program, recommended that "all chemical criteria and some biological criteria should be defined in terms of magnitude, frequency, and duration." (NRC/NAS, 2001).

Many chronic water quality criteria are developed assuming a four-day average exposure, which may be of longer duration than those experienced during wet weather events. However, local climactic and waterbody conditions must be considered when determining the appropriate duration of exposure. Some regions will experience a quick rain event with a correspondingly short-duration increase in pollutant concentration, while other areas may have protracted times of exposure of days, weeks, or months, when precipitation and correspondingly high flows occur.

Analysis tools, estimation methods, and models are more complex for wet weather: Tools, estimation methods, and models differ for wet weather and often require more complex

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and more robust models than for dry weather or steady state analyses (U.S. EPA, 1999b). Most simple models utilized for TMDL analysis are not capable of performing single event or wet weather loading analysis. To determine the period over which a waterbody is impaired, tools, estimation methods, and models must be able to work with transient phenomena.

6.4 Recommendations

There have been relatively few TMDLs to date conducted for urban wet weather sources; therefore this project looked outside of the current program for innovative solutions to addressing urban wet weather problems.

Research looked into other methods used to address urban wet weather issues, including the CSO program, attempts in some states to develop wet weather water quality standards, and approaches used in other countries.

Three general recommendations that emerged from these investigations are:

- Separate and distinct event-related wet weather TMDLs should be developed independent of dry weather TMDLs.
- Uses and criteria for wet weather TMDLs should be re-examined, and refined uses and criteria should be developed as appropriate.
- Watershed management plans need to be considered as a suitable and effective substitute for the traditional TMDL.

6.4.1 Separate and Distinct Event-Related Wet Weather TMDLs Should Be Developed Independent of Dry Weather TMDLs

Separate wet weather TMDLs should be calculated for pollutants that have major wet weather loadings and transient impacts (e.g., bacteria, oxygen-depleting substances, solids, and others). The reasons highlighted above demonstrate why TMDLs for pollutants that have major wet weather loads should be developed separately from dry weather TMDLs. Specific reasons include that the sources are often different, the loads will vary based on weather, and the analysis tools are different.

A simple example would be a stream that shows bacterial impairment. If the stream were bacterial impaired only during wet weather, the likely causes could include stormwater runoff, sewer overflows, resuspension of bacteria, or upstream loads. If the same stream were impaired for bacteria during dry weather, likely sources would include point source discharges, illicit connections, faulty septic systems, or upstream loads. Were a single TMDL to be developed for both cases, it would either miss some of the potential sources, or impose controls on dischargers not responsible for impairment. Furthermore, the difference in dry versus wet weather stream flows results in a different assimilative capacity.

Unlike a TMDL that addresses all sources all of the time, a wet weather TMDL would allow focus on the cause of impairment during the time that the waterbody is impaired. A separate dry weather TMDL could be required, but in many cases, streams (and particularly urban

streams) may be impaired primarily during wet weather and thus only a wet weather TMDL would be required.

6.4.2 Uses and Criteria for Wet Weather TMDLs Should Be Re-examined, and Refined Uses and Criteria Should Be Developed as Appropriate

Appropriate designated uses are important for developing urban wet weather TMDLs. It may be reasonable to modify uses for waterbodies that can attain designated uses during most of the year, but not attain water quality standards during wet weather conditions. The issue of wet weather water quality standards has been discussed in detail, and was one of the issues addressed as part of a multi-year U.S. EPA advisory committee (U.S. EPA, 1998a). The National Research Council also supported more refined designated uses as a means of addressing the different conditions that lead to non-attainment of water quality standards (NRC/NAS, 2001). Refining uses and criteria for wet weather is also strongly supported in U.S. EPA's Guidance for Coordinating CSO Long-Term Planning with Water Quality Standards Reviews (U.S. EPA, 2001b).

Use attainability analyses are often required in order to redefine a designated use. The procedure for conducting them is described in U.S. EPA guidance documents as well as WERF guides (WERF, 1999).

6.4.3 Watershed Management Plans Need to be Considered as a Suitable and Effective Substitute for Traditional TMDLs

The understanding, let alone the effective control, of wet weather sources is highly challenging. It is difficult to establish a single value TMDL, given the variable conditions of wet weather. Alternatively, innovative TMDLs with variable load limits are both technically difficult to properly calculate and administratively difficult, if not impractical, to regulate. Further, many argue that adequate controls of all stormwater sources are currently impractical.

Given these challenges, many would argue that establishing a traditional TMDL for wet weather urban sources is futile. As an alternative, properly constructed watershed management plans may be equally effective in initiating constructive programs for water quality restoration. These plans would consider all sources and prioritize beneficial controls with a well-constructed implementation plan. They might not, however, include a quantitative allocation of loads. Rather, they would have a more qualitative course of action coupled with monitoring and explicit plans for additional follow-up, including additional controls and reevaluation of water quality standards as may be justified.

This approach is controversial, and many believe inconsistent with current TMDL regulations. These ideas are recommended however, because traditional TMDL approaches are often difficult and impractical. Chapter 14.0 of this report on Adaptive Watershed Management addresses this approach and concept in more detail.

6.5 Options for Developing Wet Weather TMDLs

Building on the first recommendation for a separate wet weather TMDL, several improvements are needed from dry weather approaches to better address wet weather conditions.

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Following are several options for developing wet weather TMDLs. Case studies utilizing these approaches are also provided in this section:

- Percentage compliance with standards
- High flow exemption/cutoff
- Flow-variable TMDL
- Adaptive management
- Wet weather subcategory
- Seasonal variation

6.5.1 Percentage Compliance with Standards

Water quality standards attainment should be evaluated on a statistical basis for wet weather. For example, the water quality objective should be able to attain standards, say, 80% or 95% of the time, not unlike the analysis done for a dry weather WLA at $7Q_{10}$ low flows. $7Q_{10}$ flows are the lowest expected consecutive seven-day flow over a 10-year period for a given waterbody. A percentage is a better goal than a design flow condition because of the high variability and complexity of wet weather conditions.

It has been recognized that a statistical approach must be used in the listing and delisting of waterbodies. This concept was well described in the NRC report on TMDLs, which stated that "EPA should endorse statistical approaches to proper monitoring design, data analysis, and impairment assessment" (NRC/NAS, 2001). A companion research project conducted for WERF on listing and delisting approaches for TMDLs (WERF, 2003a) also endorsed statistical approaches towards determining impaired waterbodies.

Standards attainment during wet weather should also consider a statistical approach that would allow a percentage compliance goal with the applicable criteria. This approach would recognize that controls will not meet water quality criteria under all conditions, but would allow for a particular compliance rate, e.g. 95%. This is implicitly acknowledged in some existing water quality criteria, such as those that incorporate a geometric mean for bacteria. Use of a geometric mean allows some samples to be above the criteria level, so long as the geometric mean is below the criteria. In fact, the geometric mean reduces the impact of high values on the calculated mean.

Other examples of statistical approaches include the use of a $7Q_{10}$ low flow to calculate permit limits for NPDES permits. The use of $7Q_{10}$ flows acknowledges implicitly that streamflows below $7Q_{10}$ could result in pollutant levels in excess of the water quality criteria. This allows for a percentage of time under which water quality standards will not be met. Both the use of geometric mean and the use of $7Q_{10}$ flow have within their calculations an implicit statistical attainment for water quality standards. It should be noted that it is inappropriate to use $7Q_{10}$ flows for the evaluation of wet weather impacts, since the coincidence of low flows and rain events is highly unlikely.

It is suggested that wet weather TMDLs adopt a more explicit approach to statistical attainment, based on knowledge of the waterbody and the degree of control that the local community can provide. It is unlikely that urban wet weather pollution sources will be able to be controlled with 100% certainty. A frequently used swimming or recreational use (kayaking,

surfing) area where the pollutant sources are well-defined and controlled may opt for a higher degree of attainment, such as 95% or more. A waterbody rarely used for recreation, with difficult or unknown sources of pollution may opt for a lower degree of attainment, such as 85%. This research report does not recommend a specific value for statistical attainment, but recommends that for wet weather TMDLs a statistical approach is highly desirable. States would have the responsibility to select the appropriate value.

Other researchers have suggested more rigorous statistical approaches to water quality standards attainment (e.g., McBride and Ellis, 2001). These approaches are more statistically precise, but they also identify the difficulty of using a small number of samples to assess water quality conditions. This presents a dilemma similar to that encountered in the Margin of Safety discussion (Chapter 9.0), where fewer data points create greater uncertainty and lead to a need for greater controls to ensure standards attainment. In cases where limited data are available, an adaptive management approach (Chapter 14.0) may be more appropriate to allow one to collect more data to provide greater certainty prior to establishing final TMDLs.

Case Study—Ohio EPA Water Quality Standards: Several states have adopted a percentage compliance approach to standards attainment. Although these approaches were not developed to address wet weather issues, additional investigation could point to ways to adapt such approaches to wet weather.

Ohio's bacterial standards specify that samples must not exceed criteria more than 10% of the sampled time. This means that up to 10% of the samples may exceed bacterial criteria without violating water quality standards. This recognizes that many waterbodies will not be able to meet standards for every sample during every time period. Note that Ohio's standards still require compliance with the geometric mean criteria, which will require using all measured samples in order to calculate the geometric mean. An excerpt from Ohio EPA's bacterial water quality standards is shown below:

> *Primary Contact*
> *Fecal coliform—geometric mean fecal coliform content (either Most Probable Number or Membrane Filtration) based on not less than five samples within a thirty-day period, shall not exceed 1,000 per 100 ml and fecal coliform content (either Most Probable Number or Membrane Filtration) shall not exceed 2,000 per 100 ml in more than ten percent of the samples taken during any thirty-day period (State of Ohio Water Quality Standards, Chapter 3745-1 of the Administrative Code)*

This type of percentage approach also appears in other state water quality standards, including those of Washington, Connecticut, Massachusetts, Rhode Island, and New Jersey.

6.5.2 High Flow Exemption/Cutoff

A high flow exemption/cutoff cutoff on water quality standards has been considered by several states, particularly for recreational uses. The concept is two-fold: the realization that high flows represent dangerous conditions under which swimming should not occur; and that some pollutant loads entering a waterbody during high flow are not economical to control under extreme scenarios. U.S. EPA suggested several considerations in the 2001 Guidance for Coordinating CSO

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Long-Term Planning with Water Quality Standards Reviews (U.S. EPA, 2001b) that should take place when considering a "high-flow cutoff" in state water quality standards, including:

- Will the cutoff protect the other uses?
- What is the resulting velocity?
- Would the velocity preclude all recreational uses (including kayaking) that would typically occur during high-velocity flows?
- Do the high flows have a minimal effect on the velocity of the flow, posing little or no danger to persons using the waters for recreation?
- For how many days would the cutoff apply?
- Will the state adopt the cutoff statewide, create a discharger-specific variance, or develop recreational subcategories that correlate to the cutoff?
- Has a use attainability analysis shown that an affordable, well-designed, and well-operated control program could not achieve a higher level of CSO control than that afforded by the cutoff?
- What effect would the high-flow cutoff have on implementing controls for other sources of bacterial contamination into the waterbody (e.g., storm water, leaking septic systems, feed lots, row crops, etc.)?

The state of Kansas, as well as Delaware, the District of Columbia, and others have proposed a high flow provision within their water quality standards. These have been removed during standards review at the request of U.S. EPA, but the issues and interpretation may have changed. In light of wet weather concerns in urban areas, these high flow provisions may again be worthy of consideration.

Case Study—Lower Arkansas River TMDL: This urban fecal coliform TMDL just below Wichita, Kansas, allows for partial nonattainment of standards during high flow events (upper 10% of flow). The state also allows for a TMDL based on a load curve that varies based on flow, rather than a single number load, thus further accounting for increased loads during wet weather.[3]

Fecal coliform loading is identified as resulting from urban stormwater, livestock operations, farmsteads, and rural homesteads. BMPs for urban stormwater and agricultural practices, as well as maintenance of on-site waste systems for rural homesteads, are identified as implementation activities. The long-term goal of the TMDL (2005–2009) is to support primary and secondary contact recreation. Kansas water quality standards used to allow for excursions above criteria when the stream flow exceeded flow that is surpassed 10% of the time, but this has since been rejected by EPA and is being re-evaluated by the state. Kansas water quality standards used to read:

> *High flow. Classified streams may be excluded by the department from the application of the numerical criteria for fecal coliform bacteria in K.A.R. 28-16-28e(c) when actual stream flow exceeds the flow that is, over the long term, surpassed only 10% of the time.*

[3] http://www.kdhe.state.ks.us/tmdl/la/belowWichitaFCB.pdf

In light of these changes to the high-flow cutoff, Kansas is currently considering alternate approaches to setting a wasteload allocation for stormwater, including:

- A zero wasteload allocation for flow conditions below the critical flow threshold which signifies the onset of wet weather conditions;
- Establishing a goal such as reduced average event loads or concentrations;
- Aggressive monitoring of frequency, magnitude and duration and concentration patterns before, during and after runoff events; and
- Ongoing monitoring of the effectiveness of controls/BMPs and a feedback loop into an adaptive management strategy.

6.5.3 Flow-variable TMDL

A flow-variable TMDL allows the load to increase as the flow in a stream increases. This approach allows greater load in a stream during wet weather, so long as the pollutant concentration remains the same. This method is easily accommodated into a TMDL; however, several states have expressed reluctance at making this a part of their NPDES permit program, because it makes it more challenging to assess and monitor compliance with permit requirements.

Case Study—Columbia River Slough TMDL: The Columbia River Slough is a 19-mile long series of channels located on the southern floodplain of the Columbia River between Fairview Lake and the Willamette River, with substantial portions in the Portland, Oregon, metropolitan area.

Rather than determine a single river flow and an associated loading capacity and allocation for the TMDL, the Columbia River Slough TMDL allows for variable flows. This flow-variable TMDL acknowledges that during wet weather, loadings will be higher, and that standards could perhaps still be met. Wet weather standards were not utilized, but the swimmable bacteria concentration standard was utilized at all flows, and thus a higher loading capacity was allowed when higher flows occur. An example is shown below for *E. coli* loading capacities under several flow scenarios.

Table 6-1. Flow-variable *E. coli* Loading Capacity.

	Flow (m^3/s)	Criteria (MPN/100 mL)[1]	Loading Capacity (MPN/day)
Base Flow	1.98	126	2.16×10^{11}
Storm Flow	2.83	126	3.08×10^{11}
	5.66	126	6.16×10^{11}
	8.50	126	9.25×10^{11}

(Excerpt from Table 9 of Columbia River Slough TMDL)

A similar approach is also used in the load-frequency approach described in Cleland et al., 2002 (Cleland uses the term load-duration curve). This approach plots pollutant loads versus flow frequency, along with a water quality standard that adjusts for flow (Figure 6-2). This approach allows the user to identify whether exceedences of standards are occurring infrequently,

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from flood flows; somewhat more frequently, from nonpoint source or other wet weather loads that act like nonpoint source loads; or almost constantly, which would imply that point sources that are continually loading would be the main source. It permits diagnostics as to the causes of impairment, as well as proposing a relationship focus.

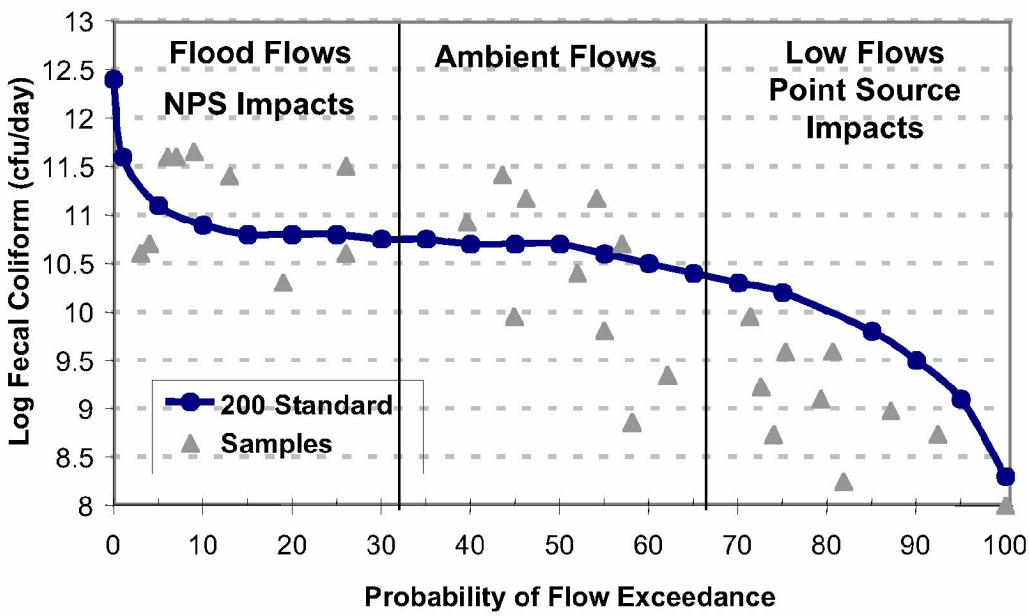

Figure 6-2. Illustrative Load-Frequency Analysis ("Load Duration" Curve).

6.5.4 Adaptive Watershed Management

Adaptive watershed management represents a process to be progressively implemented over a specific timeframe until water quality standards are attained. The process, further described in Chapter 14.0, can be especially useful for urban wet weather challenges, which often suffer from a lack of information and high costs to implement controls. The initial steps are the same as in the traditional TMDL; however, managers are allowed to begin implementation without delay, not held up by debate over uncertainty in the numeric value of the TMDL or the efficacy of recommended controls. Monitoring is intended to provide additional information not initially available that facilitates improvement in the TMDL or perhaps the water quality standards. More detailed discussion of this approach is provided in Chapter 14.0.

Case Study—Combined Sewer Overflow Long Term Control Plan: The Long Term Control Plans required for CSO communities in a sense incorporate an adaptive management process to achieve control CSO communities. Key elements of the CSO Control Policy were to: 1) provide levels of control required for combined sewer systems; 2) provide flexibility for site-specific solutions; 3) allow a phased approach to control; and 4) review and revise water quality standards as appropriate (U.S. EPA, 1995b).

Long-term control plans have a strong monitoring and modeling component to collect data on water quality and system characteristics, but also have an expectation that communities will

begin to implement controls that achieve positive impacts. While a long-term control plan may take decades to fully implement, a process is developed to put controls in place, evaluate, and adjust as necessary. This process is adaptive management, and the CSO long-term control plan approach can serve as an example for similar approaches to address wet weather issues (and other challenging issues) in the TMDL program.

6.5.5 Wet Weather Subcategory

Reclassification of designated uses for wet weather is a feasible option to address the issue of practical attainability of water quality standards. A wet weather subcategory would allow some waterbodies to have either modified water quality standards during wet weather, or a period of time following a rain event during which standards may be suspended. This type of wet weather subcategory is now being utilized in Massachusetts, Indiana, and Maine, although on a site-specific basis. In all three cases, CSO control and the cost-prohibitive nature of designing structures that prevent sewer overflows under periods of significant rainfall prompted the development of a wet weather subcategory to the existing water quality standards.

Case Study—Commonwealth of Massachusetts: The Massachusetts Department of Environmental Protection (DEP) recognized it is not always feasible for communities served by combined sewer systems to completely eliminate the adverse impacts of CSOs. This inability may be due to technological limitations or control costs that would cause substantial and widespread economic and social impact in the community.

As a result, the Massachusetts DEP established that CSO controls that achieve standards at least 95% of the time will be presumed to meet the water-quality based requirements of the Clean Water Act (http://www.state.ma.us/dep/brp/stormwtr/files/csoguide.doc). To codify this, the DEP established subcategories in their water quality standards in 1995 to identify segments that will be subject to minor CSO discharges. These include:

- ***Class B or SB:*** CSOs are eliminated.
- ***Class B (CSO):*** CSOs remain but must be compatible with water quality goals.
- ***Variance:*** CSOs remain when allowed under a short-term modification of water quality standards through an NPDES permit administered by Massachusetts.
- ***Partial Use Designation:*** CSOs remain with moderate impacts resulting in intermittent impairment of water quality goals.
- ***Class C:*** CSOs remain, causing permanent and sustained impairment so that Class B water quality goals cannot be met.

Where elimination of CSOs is not economically feasible and the impacts from remaining CSO discharges will be minor, the segment will be identified as B (CSO). Although a high level of control will be achieved, B (CSO) recognizes that Class B standards may not be met during infrequent, large wet weather events.

An identification of B (CSO) will be made only after the DEP has approved a CSO control plan showing that minor CSO discharges are the most environmentally protective and cost-effective option available. The DEP will then prepare a use attainability analysis (in accordance with 40 CFR 131.10(j)), based on the CSO control plan, to document that achieving a higher level of CSO control is not feasible or appropriate.

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6.5.6 Seasonal Variation

Seasonal variations can take two forms. Some states, Oregon, for example, have two flow regimes, a high-flow season and a low-flow season. This allows for different loadings and TMDL calculations in each season, while retaining the same uses for the waterbody. Other states have revisions in the numeric water quality criteria during the warm and cold months, based primarily on temperature. Michigan, Indiana, and Vermont, for example, have different water quality criteria from November – March, when recreational uses are not expected. Other areas in a milder climate may not be able to use such an approach.

Case Study—Michigan Recreational Criteria: Michigan is one of several states that allows for the primary recreation criteria to apply only during months in which swimming is likely to occur. The state allows suspension of bacterial standards during the period Nov 1 – April 30 of each year. An excerpt from the Michigan Water Quality Standards states:

> *R 323.1100 Designated uses.*
> *Rule 100. (2) All surface waters of the state are designated for, and shall be protected for, total body contact recreation from May 1 to October 31 in accordance with the provisions of R 323.1062. (Rule 100 of Michigan Water Quality Standards)*

6.6 Future Research Needs

Many research needs exist related to incorporating wet weather sources in TMDLs. These include research into:

- Developing improved methods for quantifying wet weather loads;
- Developing refined uses and criteria for wet weather TMDLs; and
- Developing and specifying a statistical basis for water quality standards attainment during wet weather.

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Table 6-2. A Sampling of State Wet Weather Provisions within Water Quality Standards.

State	Document	Date	Finding
Maine	Water Classification Program, Maine Revised Statues Annotated, Title 38, Article 4-A (commonly known as the "Blue Book") http://www.state.me.us/dep/blwq/class.htm	July 2001	The Board may temporarily remove designated uses when these uses do not exist and create a temporary CSO subcategory in waters classified as B (fresh water classification 3rd of 4), C (fresh water classification 4th of 4), SB (estuarine/marine water classification 2nd of 3), SC (estuarine/marine water classification 3rd of 3) only. The primary purpose of this category is to provide financial relief to towns that have limited budget for repairing old sewer systems. Approval is contingent upon acceptance of a remediation plan/schedule/budget for fixing the problems. The Board may also temporarily modify water quality criteria in the area covered by the temporary CSO subcategory.
Massachusetts	http://www.state.ma.us/dep/bwp/iww/files/314cmr4.htm	5/12/2000	Water quality standards developed based on $7Q_{10}$ flow rate for rivers/streams, based on extreme conditions defined by the Department for lakes/estuaries/marine environments. The Department may remove a use classification if the use does not exist, or for a variety of other reasons. Excursions from criteria due to natural background conditions will not constitute a violation of criteria. Receiving waters may be designated as impacted by CSO, which offers some provision for partial use classification after meeting several requirements, none of which pertain to flow rate.
New Hampshire	http://www.des.state.nh.us/wmb/Env-Ws1700.pdf	12/10/1999	A use attainability analysis is required to show that waters receiving CSO discharges cannot meet Class B water quality standards. If accepted, the Department has the authority to change the classification of that receiving water. No mention of stream flow rate exceptions.
Indiana	http://www.in.gov/legislative/iac/title327.html	Reviewed 7/1/2002, but document is updated regularly	Water quality standards include a rule suspending all standards for flows less than the $7Q_{10}$ flow, with the exception of still being free of floating materials/oil/grease/scum that might result from human activities.
Kansas	Article 16. SURFACE WATER QUALITY STANDARDS	8/6/2001	This special flow condition for *f coli*, "High flow. Classified streams may be excluded by the department from the application of the numerical criteria for fecal coliform bacteria in K.A.R. 28-16-28e(c) when actual stream flow exceeds the flow that is, over the long term, surpassed only 10% of the time", has been removed from the standards.

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Table 6-2. A Sampling of State Wet Weather Provisions within Water Quality Standards. (cont.)

State	Document	Date	Finding
Washington	http://www.ecy.wa.gov/pubs/wac173201a.pdf	11/18/97	Dissolved gas criteria does not apply to flow rates higher than $7Q_{10}$. No other apparent exceptions, other than a 1/yr CSO mixing zone size exceedance exception.
Ohio	http://www.epa.state.oh.us/dsw/rules/3745-1.html	Effective dates are included at the bottom of each PDF file	http://www.dep.state.fl.us/water/surfacewater/index.htm
Oregon	http://www.deq.state.or.us/wq/wqrules/wqrules.htm	Effective dates are included at the end of each rule, but seems to be 8/13/1991	**OR defines low flow season as May-Oct, and high flow season as Nov-Apr.** 340-04I-0026 Policies and Guidelines Generally Applicable to All Basins (3) The Commission or Department may grant exceptions to sections (2) and (6) of this rule and approvals to section (5) of this rule for major dischargers and other dischargers, respectively. Major dischargers include those industrial and domestic sources that are classified as major sources for permit fee purposes in OAR 340-045-0075(2) (a) In allowing new or increased discharged loads, the Commission or Department shall make the following findings:(A) Environmental Effects Criteria:(ii) Instream Effects. Total stream loading may be reduced through elimination or reduction of other source discharges or through a reduction in seasonal discharge. A source that replaces other sources, accepts additional waste from less efficient treatment units or systems, or reduces discharge loadings during periods of low stream flow may be permitted an increased discharge load year-round or during seasons of high flow, as appropriate; Additionally, OR suspends the WWTP effluent load limitations when the incoming flow to the WWTP exceeds 2X dry weather flow, or exceeds the lesser hydraulic capacity of the secondary treatment stage. Under these conditions the WWTP is to be operated to obtain the maximum possible removal of BOD, TSS, bacteria as possible. There is much language relating to WWTP discharges, permitted loads related to NPDES permits, so this section is worth reading for all the details.

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Table 6-2. A Sampling of State Wet Weather Provisions within Water Quality Standards. (cont.)

State	Document	Date	Finding
Illinois	http://www.ipcb.state.il.us/Title_35/main.htm	The WQ Standards are actually maintained by the Water Pollution Control Board. There is a history of promulgation at the end of the TOC. The final effective date is 2/22/2002	Unless otherwise noted, standards apply to flows greater than the $7Q_{10}$ flow. However, there is some language regarding loading to the Lake Michigan basin for bioaccumulating chemicals of concern (BCCs). Water quality for BCCs must not be lowered due to new or increased discharges unless it can be proven to be necessary to accommodate social and economic development (see Section 302.521 Supplemental Antidegradation Provisions for BCCs). There are several provisions listed...one of which is Changes in loadings of any BCC within the existing capacity and processes of an existing NPDES authorized discharge, certified activity pursuant to Section 401 of the Clean Water Act, or joint permits from the Agency and the Illinois Department of Natural Resources under Section 39(n) of the Act are not subject to the antidegradation review of subsection (a) of this Section. These changes include but are not limited to: A) normal operational variability, including, but not limited to, intermittent increased discharges due to wet weather
Louisiana	http://www.deq.state.la.us/planning/regs/title33/index.htm	Updated through 5/20/2002	Excerpt from ...§1113. Criteria. A. 13 C...Although naturally occurring variations in water quality may exceed criteria, water quality conditions attributed to human activities must not exceed criteria when flows are greater than or at critical conditions (as defined in LAC 33:IX.1115.C). §1115. Application Of Standards B. Flow Conditions. Except where indicated elsewhere in this Chapter, the water quality standards specified herein shall apply during all flow conditions greater than the critical flows defined in LAC 33:IX.1115.C. (See LAC 33:IX.1107 and intermittent streams exception category, LAC 33:IX.1109.C.1.) Also, for DO criteria in Ouachita River - Arkansas State Line to Columbia Lock and Dam, the Department recognizes that seasonal DO criteria may be unattainable during flood. Foot note [15] to table 3 gives specific details.
Florida	http://www.dep.state.fl.us/water/surfacewater/index.htm	12/26/1996 is the effective date in the primary document 62-302.pdf	No special provisions for high flow/wet weather conditions. In fact, though the standards are reported to be based on mean annual flow, they apply to all flow conditions.
North Carolina	http://h2o.enr.state.nc.us/admin/rules/rb010102.pdf	1/1/02	$7Q_{10}$ flow used to establish discharge loading rates, however, Commission may consider permitting variable loading based upon variable assimilative capacity of the receiving water. Exemptions to the existing standards, on a case by case basis, may be granted by the Commission, following review. Existing exemptions are available to the public.

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Table 6-2. A Sampling of State Wet Weather Provisions within Water Quality Standards. (cont.)

State	Document	Date	Finding
Arizona	http://www.sosaz.com/aar/2002/13/final2.pdf	3/29/02	The following water quality standard for suspended sediment concentration, expressed as a geometric mean (four-sample minimum) shall not be exceeded. The standard applies to a surface water that is at or near base flow and does not apply to a surface water during or soon after a precipitation event: A&Wc (aquatic & wildlife cold water), A&Ww (aquatic & wildlife warm water), 80 mg / L. Also, a designated use can be altered for a variety of reasons, such as designated use is not existing use, natural conditions preclude use as designated, remedy of anthropogenic conditions would be worse environmentally than maintaining status quo, etc.

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CHAPTER 7.0

SELECTING CRITICAL CONDITIONS

The objective of this research element was to assist water quality professionals in determining critical conditions for TMDLs, a consideration required by federal regulations (40 CFR 130.7). Although determination of critical conditions is straightforward for some TMDLs, it is often difficult or confusing for others.

7.1 Introduction

TMDLs for which critical conditions are most easily determined are usually the traditional scenario of a continuous point source discharging effluent with oxygen demand into a stream. For this scenario, critical conditions are usually defined by the critical low flow from the state water quality standard.

For other TMDLs, however, critical conditions are more difficult to determine. As part of this research project, a survey was conducted to solicit input from state agency personnel involved with developing TMDLs in eight states across different areas of the United States (see Section 2.5). Survey respondents indicated that critical conditions were not well established for low flow TMDLs for parameters other than dissolved oxygen (e.g., for metals TMDLs, what values of pH and hardness should be used to define critical conditions?). Even for dissolved oxygen TMDLs, some respondents indicated that additional guidance is needed for selecting a critical combination of low flow and high temperature. Also, most states surveyed expressed a need for specific definitions for critical conditions associated with high flow events when non-point source loading is greatest. Flow frequency analyses for high flows, similar to the low flow $7Q_{10}$, have been conducted by some states, but states indicated that critical conditions for high flows have not been incorporated into water quality standards or state guidance documents. The survey indicated inadequate guidance on defining "worst case" conditions for high flow, non-point source TMDLs (e.g., a TMDL for turbidity caused by storm runoff).

The need for additional guidance for critical conditions, particularly as it relates to water quality criteria, is also noted in U.S. EPA's "Twenty Needs Report" (U.S. EPA, 2002e). This report indicates that water quality criteria need to be reviewed and refined, including determining "whether concepts such as five-day average, four-day minimum, monthly average, $7Q_{10}$, and other semi-quantitative measures make ecological sense and are filling their intended purpose."

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This report also concludes that research needs to be conducted to "assist state decisions on when standards are supposed to be met, at what flows, and determine how to technically translate the standards into TMDLs and permits..."

A review of existing TMDLs (see Section 2.9) across the United States showed a lack of specific guidance for determining critical conditions for certain scenarios. One scenario involves intermittent point sources (such as storm runoff from an industrial facility) where the loading to the receiving stream increases with larger storms, but so does the quantity of upstream dilution water (see Chapter 6.0). Critical conditions for this scenario can differ significantly from site to site. Another scenario for which more guidance is needed for determining critical conditions is the occurrence of both point and nonpoint sources contributing loads at different times (e.g., a pathogen TMDL with nonpoint loads having the greatest impact during storms, and point source discharges having the greatest impact during low flows). TMDLs for dissolved oxygen (DO) and eutrophication also have situations where the nutrient loading to the waterbody may be greatest during storm conditions, but the response by the DO and algae/macrophytes may occur later during low flow conditions.

Based on these findings, this research element focused on critical conditions for TMDLs involving either multiple parameters or both point and nonpoint sources characterized by different timing. Also, because the majority of TMDLs are being performed for streams, this research element was limited to streams (i.e., lakes/reservoirs, estuaries, and offshore coastal waters were not considered).

7.2 Regulations and Definitions

The requirement for considering critical conditions for TMDLs is found in 40CFR 130.7(c)(1), which states that "Determinations of TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters." Neither a definition of critical conditions nor guidance for determining critical conditions is given in these regulations, but definitions and guidance can be found in several U.S. EPA guidance documents. In the glossary section of recent TMDL protocol documents for sediment (U.S. EPA, 1999e), nutrients (U.S. EPA, 1999d), and pathogens (U.S. EPA, 2001c), critical conditions are defined as follows:

- "... the 'worst case' scenario of environmental conditions in the water body in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence." (U.S. EPA, 1999e and U.S. EPA, 1999d)
- "The combination of environmental factors that results in just meeting the water quality criterion and has an acceptably low frequency of occurrence." (U.S. EPA, 2001c)

These definitions are consistent with the discussion of design conditions (i.e., critical conditions) in the agency's general guidance document for TMDLs (U.S. EPA, 1991a), which states that critical conditions are "reasonable 'worst case' conditions" that vary for different situations.

The purpose of accounting for critical conditions is not explicitly stated in the regulations, but can be seen from several U.S. EPA guidance documents and technical support documents (U.S. EPA, 1991a and 1991b; U.S. EPA, 1999e and 1999d; U.S. EPA, 2001c). These documents indicate that TMDLs are to be developed so that water quality standards will be maintained at all times except during extreme, worst case conditions that occur so infrequently that designated uses of the waterbody can still be maintained. The most extreme set of conditions for which water quality standards must still be maintained is referred to as critical conditions.

7.3 National Guidance

Numerous U.S. EPA documents were identified and reviewed to compile available guidance on a national level that pertains to the selection of critical conditions for TMDLs. This guidance is summarized in the following sections.

7.3.1 Stream Flow

Most of the available guidance for determining critical conditions pertains to hydrologic conditions, particularly stream flow. U.S. EPA's general guidance document for TMDLs (U.S. EPA, 1991a) concludes that critical conditions are generally low flow, dry weather conditions for continuous point source discharges; high flow, wet weather conditions for nonpoint and intermittent point source discharges (e.g., storm sewers); and harmonic mean flows for some situations, such as carcinogenic pollutants.

U.S. EPA's technical support document for toxics control (U.S. EPA, 1991b) states that critical conditions should be determined by evaluating "worst" case conditions for both point and nonpoint source loadings (i.e., low flow drought and high flow conditions). Then critical conditions would be defined as whichever situation results in the lower allowable loading. This document also notes that, for nonpoint source TMDLs, there is usually a lack of information needed to describe the runoff quantity and quality associated with storm events when much of the loading occurs. For TMDLs involving carcinogens, this document recommends using the harmonic mean flow for critical conditions.

For steady-state water quality modeling or dilution calculations, the critical stream flow can be hydrologically based or biologically based (U.S. EPA, 1991b; 1986). A hydrologically based critical flow is based on selecting and identifying an extreme value (e.g., the lowest 7-day average flow that is likely to occur in one year out of every 10 years, or $7Q_{10}$ flow). Hydrologically based critical flows are calculated from frequency analyses that use only the single most extreme flow for each year. Frequency analyses only look at the probability of any one year having a flow excursion (i.e., a flow more extreme than the critical flow); they do not consider how many excursions might happen during any one year. Alternatively, a biologically based critical flow is based on a duration analysis that uses an entire record, not just annual extreme events. From the duration analysis, the critical flow is calculated as the least extreme flow that limits the frequency and duration of excursions to desired values. U.S. EPA developed a computer program called DFLOW to calculate biologically based critical flows (U.S. EPA, 1990), but this program was unavailable on the agency's website. Based on reviews of recent TMDLs and guidance documents, most critical flows appear to be hydrologically based.

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Biologically based critical flows for steady-state analyses should be developed based on the duration and frequency of water quality criteria excursions that can be tolerated without impairing the designated uses of the waterbody (U.S. EPA, 1991b). U.S. EPA reviewed biological research that examined the effects of exposure of aquatic life to different durations and frequencies of pollutants. Based on this research, U.S. EPA considers four days to be an acceptable duration for excursions of chronic criteria, one hour to be an acceptable duration for excursions of acute criteria, and once in three years to be an acceptable frequency for excursions of either criterion (U.S. EPA, 1991b). Therefore, for protecting aquatic life, the recommended critical flows are the 4B3 flow for chronic conditions and the 1B3 flow for acute conditions (U.S. EPA, 1991b). The 4B3 flow is the four-day, three-year biologically based design flow and the 1B3 is the one-day, three-year biologically based design flow. The 4B3 is the lowest four-day average flow that will occur no more than once every three years on average (but it is not the same as the 4Q3, which is the lowest four-day average flow that will occur in one year out of three on average). Similarly, the 1B3 is the lowest one-day average flow that will occur no more than once every three years on average. U.S. EPA compared the 4B3 and 1B3 biologically based critical flows with the $7Q_{10}$ and $1Q_{10}$ hydrologically based critical flows for 60 streams across the U.S. This comparison showed that, on average, the 4B3 and $7Q_{10}$ were similar in magnitude, and the 1B3 and $1Q_{10}$ were similar in magnitude (U.S. EPA, 1986). This shows that when the $7Q_{10}$, for example, is used as the critical flow, the analysis is typically protecting aquatic life for an excursion frequency of once in three years rather than once in 10 years.

7.3.2 Factors Other Than Stream Flow

For factors other than stream flow, there is little guidance on selecting critical values. Water temperature is an important factor in many TMDLs other than just thermal TMDLs (e.g., any TMDL that includes dissolved oxygen analyses, simulation of algal growth cycles, ammonia toxicity calculations, or estimation of pathogen die-off rates). However, several U.S. EPA guidance documents were reviewed (U.S. EPA, 1991a and 1991b; U.S. EPA, 1997d; U.S. EPA, 1999e and 1999d; U.S. EPA, 2001c), and no specific guidance was found for selecting a critical temperature. For some TMDLs, other water quality parameters may require specifications for critical conditions, such as pH (for metals TMDLs or ammonia toxicity TMDLs) or hardness (for metals TMDLs). No guidance for either of these parameters was found in these documents.

U.S. EPA's general guidance document for TMDLs (U.S. EPA, 1991a) mentions that critical conditions may be dependent on other factors besides flow, such as rainfall intensity and duration, time since previous rainfall, pollutant accumulation rates, stream flow previous to rainfall, and various land management practices (cropping patterns, logging rates, or grazing practices). However, the document does not provide any specific guidance on how to evaluate these factors. Similarly, U.S. EPA's technical guidance manual for BOD/DO and nutrient/eutrophication TMDLs (U.S. EPA, 1997d) mentions several factors that would cause critical conditions for DO TMDLs to be something other than high temperature low flow during summer: 1) ice cover that restricts reaeration during winter, 2) upstream organic carbon sources from phytoplankton and/or aquatic plants during fall, 3) floods that pick up large amounts of organic debris from adjacent floodplains in spring, and 4) low flows that occur in some Great Plains streams just prior to snowmelt. The only guidance provided for determining critical conditions based on these factors is to evaluate observed DO data collected during several seasons to determine the critical season.

7.3.3 Simultaneous Occurrence for Multiple Factors

As discussed above, critical conditions are often dependent on several factors, such as stream flow and temperature for DO TMDLs. Sometimes critical values for different factors will occur at different times. An example DO TMDL is presented in U.S. EPA's technical guidance manual for BOD/DO and nutrient/eutrophication TMDLs (U.S. EPA, 1997d), where the critical flow ($7Q_{10}$) and the critical temperature (maximum average monthly value) were assumed to occur simultaneously even though historical data showed that September was the driest month and August was the hottest month. A recommendation was made to evaluate the critical flow and critical temperature for each month, and then use the month that had the most critical combination of flow and temperature for that waterbody.

Another example of critical values occurring at different times for different factors is a point source that discharges more during wet weather than during dry weather. For this situation, the most critical discharge flow rate (i.e., the largest discharge flow rate) does not occur at the same time as the most critical stream flow rate (i.e., the smallest stream flow rate). The U.S. EPA guidance manuals that were reviewed did not address how to determine critical conditions for this type of situation.

U.S. EPA developed a computer program called DESCON to evaluate design conditions (i.e., critical conditions) for TMDLs affected by combinations of stream flow, water temperature, pH, and alkalinity (U.S. EPA, 1991b). This program was developed to read long-term records (at least 10 years) of daily stream flow data as well as available water quality data for the stream (temperature, pH, and alkalinity). Based on seasonal patterns of the observed water quality data, the program will synthesize a daily record of water quality data. Then the program will evaluate each daily combination of parameter values and identify the most critical combinations based on user-specified frequencies for excursions of critical conditions. Neither this program nor its user manual were available on the U.S. EPA website.

7.3.4 Sediment, Nutrient, and Pathogen TMDLs

U.S. EPA's protocol for sediment TMDLs (U.S. EPA, 1999e) states that "Sediment TMDLs should consider seasonal and inter-annual variations in pollutant discharges, receiving water flows, and designated or existing use impacts." Critical conditions for sediment TMDLs should take into consideration whether the designated uses are: 1) much more sensitive during certain times than at other times (e.g., anadromous fish habitat); 2) more continuous and consequently sensitive to excess sediment impacts throughout the year (e.g., drinking water or industrial process water intakes); or 3) more affected by cumulative effects of sediment loading over long periods of time (e.g., reservoir storage capacity, which affects water supply). This document also states that high flows are often considered to be the critical flow, but the traditional approach of selecting a single critical flow "might be less useful for sediment TMDLs because sediment impacts can occur long after the time of discharge and sediment delivery and transport can occur under many flow conditions." The guidance provided is limited to identifying which general category of conditions is most critical for a sediment TMDL (e.g., just high flow conditions, long term cumulative effects, etc.).

For nutrient TMDLs, U.S. EPA's protocol document (U.S. EPA, 1999d) states that taking into account temporal variations is "especially important for stream nutrient TMDLs because

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both point and nonpoint nutrient sources can discharge at different rates during different time periods and plant growth can vary considerably by season. A frequent critical period for a nutrient stream TMDL is the summer low-flow, high-temperature period, because these conditions are favorable for nuisance plant growth. Critical conditions also can occur during other times of the year, however." The document also mentions that critical conditions may need to be based on longer-term loadings in receiving waters with longer residence times, or episodic loadings in waterbodies with shorter residence times. A recommendation is presented that, "in general, a steady-state analysis should be widely useful for developing a nutrient TMDL.... A dynamic analysis might be justified when standards require that minimum dissolved oxygen levels be maintained at all times and nutrient loads are known to cause varied levels of dissolved oxygen in the stream." Like the sediment TMDL protocol document, the guidance that is provided is limited to identifying which general category of conditions is most critical for a nutrient TMDL.

For pathogen TMDLs, U.S. EPA's protocol document (U.S. EPA, 2001c) states that "The critical conditions of impairment are determined by the source behavior. Often, sources of bacteria are diverse and occur in combination. For example, a stream may receive bacteria loads from such direct sources as watering livestock and illicit sewer connections and from runoff from agricultural areas. Varying sources can result in multiple critical conditions. In some cases, it may be necessary to evaluate a TMDL under a variety of conditions to account for the different times of greatest impact from sources (e.g., low flow and high flow). Analysts may want to identify the different critical conditions and evaluate them separately. Another option is to develop the TMDL for a time period that encompasses all of the possible critical conditions. For example, develop a TMDL based on various flow rates or develop separate TMDL allocations for different seasons." Examples of factors that affect seasonality include different bacteria standards for summer vs. winter, and seasonal application of livestock manure on farmland. The document also states that "Appropriate critical design conditions for an analysis should not exceed the frequency of occurrence limit stated in the water quality standard. For instance, to approximate the geometric mean coliform count, as measured over a 30-day period, an appropriate critical design condition for flow might be the minimum geometric mean 30-day flow." The document concludes that "Ideally, the design condition will identify the combination of environmental factors that result in meeting the water quality criterion and will have an acceptably low frequency of occurrence." No guidance is provided for how low the frequency of occurrence should be.

7.4 State Level Guidance

While national guidance documents tend to provide general information, state water quality standards or state guidance documents provide more specific information for determining critical conditions. Water quality standards for all 50 states were reviewed through U.S. EPA's website (U.S. EPA, 2001h) to identify critical values for stream flow or other parameters. In water quality standards documents, critical flows are often expressed as the lowest flow at which water quality standards are applicable. This review indicated that the most commonly used critical flows for aquatic life are $1Q_{10}$ for acute criteria and $7Q_{10}$ for chronic criteria. For protection of human health, the most commonly used critical flows are harmonic mean flow for carcinogens and $30Q_5$ or $7Q_{10}$ for non-carcinogens. Also, most of the regulations in these documents appear to have

been developed based on steady-state analysis of continuous point source discharges during low flow conditions. Certain states (Delaware, Kansas) and the District of Columbia have experimented with high flow provisions in their water quality standards. Also, a reference to applicability of standards under high flow conditions was found for intermittent streams in Utah. A summary of the critical flow values for each state is included as Table 7-1.

The Kansas Department of Health and Environment has TMDL guidance on its website describing the methodology for expressing a TMDL using a load duration curve (KDHE, 2002). The curve represents the allowable load at all different flows rather just at one flow rate that is selected as the critical flow.

Additional information can be found in state guidance documents such as those for Arkansas, Oklahoma, and Louisiana. Critical values of TSS, hardness, and pH for metals TMDLs are given in Arkansas's Continuing Planning Process (CPP) document (AR DEQ, 2000), and in Oklahoma's Implementation of Water Quality Standards (OWRB, 1996). Louisiana's TMDL Technical Procedure Manual (LDEQ, 2001) specifies the critical temperature for DO TMDLs as the 90th percentile of observed data during that season, or 30°C for summer and 20°C for winter if data are unavailable. This manual also specifies that the critical flow for summer should be the annual $7Q_{10}$ flow or 0.1 cfs, whichever is greater, and that the critical flow for winter should be the seasonal $7Q_{10}$ or 1.0 cfs, whichever is greater. DO TMDLs developed by the Louisiana Department of Environmental Quality were developed using the simultaneous occurrence of critical temperature and critical flow, and that this was considered to add an implicit margin of safety to the TMDLs.

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Table 7-1. Critical Flows for Each State.

State	For Protection of Aquatic Life	For Protection of Human Health	Other
Alabama	1Q10 for acute criteria 7Q10 for chronic criteria	Non-carcinogens – 7Q10 Carcinogens – mean annual flow	
Alaska	1Q10 for acute criteria 7Q10 for chronic criteria	Carcinogens – harmonic mean flow	3Q2 for conventional or nontoxic substances
Arizona	Critical flow information not found online	Critical flow information not found online	
Arkansas	Seasonal Fishery – 1 cfs minus the point source design flow (but not less than zero) Other aquatic life uses – 7Q10	Harmonic mean flow or long term average flow	Minerals – harmonic mean flow or 4 cfs
California	1Q10 or 1B3 for acute criteria 7Q10 or 4B3 for chronic criteria	Harmonic mean flow	
Colorado	1B3 for acute criteria 30B3 for chronic criteria		
Connecticut	7Q10	7Q10	
Delaware	1Q10 for acute criteria 7Q10 for chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean flow	
D.C.	1Q10 for acute criteria 7Q10 for chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean flow	
Florida	Critical flow information not found online	Harmonic mean flow	
Georgia	Toxic pollutants with acute criteria – 1Q10 Toxic pollutants with chronic criteria and any other toxic pollutants– 7Q10		
Hawaii	Critical flow information not found online	Critical flow information not found online	
Idaho	Critical flow information not found online	Critical flow information not found online	
Illinois	7Q10	Harmonic mean flow	
Indiana	7Q10	7Q10	
Iowa	7Q10	7Q10	
Kansas	7Q10	7Q10	
Kentucky	7Q10	Non-carcinogens – 7Q10 Carcinogens – harmonic mean flow	7Q10 for water-based recreation and protection of aesthetics and changes in radionuclides
Louisiana	7Q10	Non-carcinogens – 30Q5 Carcinogens – harmonic mean flow	
Maine	7Q10	7Q10	30Q10 for color pollution
Maryland	Critical flow information not found online	Critical flow information not found online	
Massachusetts	7Q10	7Q10	For artificially regulated waters – flow equaled or exceeded 99% of

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Table 7-1. Critical Flows for Each State. (cont.)

State	For Protection of Aquatic Life	For Protection of Human Health	Other
			the time on a yearly basis
Michigan	90Q10	Harmonic mean flow	Unless otherwise stated, critical flow is equal to the lowest of the 12 monthly 95% exceedance flows
Minnesota	7Q10	7Q10	30Q10 for ammonia
Mississippi	7Q10 for acute and chronic toxicity	Mean annual flow	7Q2 for stormwater
Missouri	7Q10	7Q10	
Montana			Use 7Q10 for design of disposal systems and mixing zone calcs
Nebraska	1Q10 for acute criteria 7Q10 for all non-acute criteria	7Q10	
Nevada	1Q10 or 1B3 for acute criteria 7Q10 or 4B3 for chronic criteria	Non-carcinogens 30Q5 Carcinogens – harmonic mean flow	TDS standards do not apply when flows are greater than 110% of average flow
New Hampshire	7Q10	Non-carcinogens – 7Q10 Carcinogens – harmonic mean flow	
New Jersey	1Q10 for acute criteria 7Q10 for chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean flow	All other criteria 7Q10
New Mexico	4Q3	4Q3	
New York	1Q10 or 50% of 7Q10 for acute criteria 7Q10 or 30Q10 for chronic criteria	Short term effects 7Q10 Long term effects 30Q10	
North Carolina	Non toxic and non-aesthetic 7Q10 Toxic 7Q10	Non toxic and non-aesthetic – 7Q10 Toxic but non-carcinogenic – 7Q10 Toxic and carcinogenic – mean annual flow	Aesthetic 30Q2
North Dakota	1Q3 for acute criteria 4Q3 for chronic criteria	Carcinogens – harmonic mean flow Non-carcinogens 4Q3 or 1Q3	
Ohio	7Q10 for chronic (except for ammonia-nitrogen) 1Q10 for acute (except for ammonia-nitrogen) NOTE: ammonia-nitrogen levels not given	Harmonic mean flow	Harmonic mean flow for agric. water supply and aesthetic criteria 90Q10 for wildlife criteria
Oklahoma	Greater of 7Q2 or 1.0 cfs	Greater of 7Q2 or 1.0 cfs	
Oregon	Critical flow information not found online	Critical flow information not found online	
Pennsylvania	7Q10	7Q10	
Rhode Island	7Q10 for acute and chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean flow	
South Carolina	7Q10	7Q10	
South Dakota	High quality fishery waters 7Q25 Low quality fishery waters – greater of 7Q5 or 1.0 cfs	Critical flow information not found online	

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Table 7-1. Critical Flows for Each State. (cont.)

State	For Protection of Aquatic Life	For Protection of Human Health	Other
Tennessee	Fish and aquatic life criteria: Unregulated streams – 7Q10 Regulated streams – once in 10 years	All other criteria – 30Q2	Livestock watering and wildlife: Unregulated streams – 7Q10 Regulated streams – once in 10 yrs
Texas	7Q2	7Q2	
Utah	Chronic 7Q10 Acute 50% 7Q10		For intermittent streams: 1Q10 or "unusually high flows"
Vermont	Acute and chronic 7Q10	Carcinogens – median annual flow Other substances – 7Q10	
Virginia	1Q10 for acute criteria 7Q10 for chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean (except dioxin)	
Washington	1Q10 or 1B3 for acute criteria 7Q10 or 4B3 for chronic criteria	Non-carcinogens – 30Q5 Carcinogens – harmonic mean	Total dissolved gasses does not apply at flows above 7Q10
West Virginia	7Q10 in general specification	7Q10 in general specification	Default mixing vales if dilution attained at design flow and stream 7Q10
Wisconsin	Mixing zone, chronic: 25% 7Q10 No mention of acute	Harmonic mean flow Mixing zone: 25% of harmonic mean flow	Wildlife: 90Q10 Wildlife mixing zone: 25% 90Q10
Wyoming	7Q10 or 1B3 for acute criteria 4B3 for chronic criteria		

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7.5 Review of Existing TMDLs

The project team developed a database of 176 TMDLs that have been approved by U.S. EPA. This set of TMDLs represents a wide geographical distribution across the U.S. and also has similar distributions of parameters and source types as does the complete set of TMDLs approved at the time of this review. The interrelationship between multiple loads and critical conditions was considered in 58 of the 176 TMDLs (33%) in the database. Among the TMDLs that did consider the interrelationship, there was a wide variation in approaches for determining critical conditions for a given pollutant. Some of this variation is unavoidable due to differences in watershed-specific sources of the pollutant, but much of the variation can likely be attributed to a lack of published guidance for determining critical conditions.

The review of these 176 TMDLs (and other recently approved TMDLs) showed that many TMDLs are currently being developed using summer low flow for critical conditions. Some TMDLs being developed for summer low flow conditions are for waterbodies where point sources are the primary loading, but some are for waterbodies dominated by nonpoint sources. For example, numerous DO TMDLs have recently been developed for Louisiana waterbodies that are impacted primarily by nonpoint sources (LDEQ, 2002; U.S. EPA, 2002d). These TMDLs were developed using steady-state modeling under summer low flow conditions. The rationale presented for these TMDLs is that analyses of historical data have shown that low DO values are most likely to occur during high temperatures (from lower DO saturation and higher decay rates) and low flows (less reaeration). However, nonpoint sources were modeled indirectly (through sediment oxygen demand and mass loads of BOD and organic nitrogen), so that the analysis does not address critical periods when most of the nonpoint source loads enter the waterbody. In DO TMDLs in other states, critical conditions have sometimes been addressed through the use of long-term continuous simulations.

For pathogen TMDLs, a wide range of methods is being used for addressing critical conditions. In Mississippi, some fecal coliform TMDLs have been developed using continuous simulations over 11–15 years, while others have been developed using a mass balance based on average flow conditions (MDEQ, 2002). The TMDLs based on the continuous simulations assume that there should be no 30-day period at any time during the simulation where the 30-day geometric mean coliform count exceeds the standard. The TMDLs based on a mass balance for average flow conditions use the same standard, but they do not account for variability from periods that are wetter than average and drier than average. Fecal coliform TMDLs in Louisiana have also been developed based on average flow conditions (U.S. EPA, 2002d).

For turbidity TMDLs, a wide range of critical conditions has been used. In New Mexico, two turbidity TMDLs have used the greatest mean monthly flows at USGS gages (Jemez River and Rio Guadalupe); another used the greatest flow measured during routine monitoring (Sapillo Creek); and another used an estimate of bankfull discharge (Canyon Creek) (NMED, 2002a). All of these turbidity TMDLs in New Mexico were for streams impaired by NPS. The only reason for using different critical conditions for these turbidity TMDLs in New Mexico was apparently the availability of flow data. In Alaska, critical conditions used for different turbidity TMDLs include average annual flow conditions (Upper Birch Creek) and average flows during critical seasons (Duck Creek) (ADEC, 2002). Average flows during critical seasons have also been used for critical conditions for turbidity TMDLs in Arizona (Nutrioso Creek and

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Little Colorado River), although another turbidity TMDL in Arizona was based on a "critical storm flow" (Verde River) (AZ DEQ, 2002). No documentation for using "critical storm flow" conditions was provided for the Verde River TMDL. Turbidity TMDLs in Louisiana have been developed using average flows during critical seasons (U.S. EPA, 2002d).

The TMDLs for DO, pathogens, and turbidity discussed above illustrate the wide variations of critical conditions used for each pollutant. In general, TMDLs for other pollutants and in other states also use a wide range of critical conditions for a given pollutant.

7.6 Problems with Current Status

The review of existing TMDLs shows a lack of consistency for establishing critical conditions for similar situations (i.e., for a certain pollutant and a certain set of pollutant sources, there is a wide variation in critical conditions that are being used). The lack of consistency for critical conditions is likely to cause some TMDLs to be overly protective (calling for greater pollutant reductions than what is really necessary), while other TMDLs may not be stringent enough to protect the designated use.

As shown in the review of existing TMDL guidance (Section 7.5), there is little guidance for determining critical conditions for situations other than the "traditional" wasteload allocation involving a continuous point source discharge. The recommendations below are presented to provide guidelines and helpful information for determining critical conditions for different TMDLs.

7.7 Recommendations

Based on this research, recommendations for determining critical conditions are as follows:

First, Look to Existing Regulatory Requirements: First, comply with existing regulations outlined previously. For "traditional" TMDLs involving only continuous point sources with oxygen-demanding effluent, critical conditions should be determined following existing guidance from state water quality standards and guidance documents.

Tailor Selection to the Specific Pollutant: U.S. EPA's definitions of critical conditions (Section 7.2) are appropriate, but the actual specification of critical conditions should vary by pollutant, because different pollutants are affected by different parameters. For example, ammonia toxicity is affected primarily by temperature and pH, while some metals are affected primarily by hardness and TSS.

Tailor Selection to the Pollutant Sources: The source of the pollutant should be a factor in determining critical conditions because low flow conditions are usually the most critical for continuous point source discharges, but critical conditions for TMDLs addressing nonpoint sources could be at high flows or low flows.

Tailor Selection to the Water Quality Standard: The water quality standards and designated uses affect critical conditions because the frequency, duration, and magnitude of water quality standards violations that is acceptable vary among different designated uses. For example, protection of aquatic life requires that excursions of water quality criteria be few and infrequent when compared to protection of human health due to bioaccumulation, which is affected more by cumulative loading rather than frequency and duration of individual excursions.

The "acceptably low frequency of occurrence" for excursions of water quality criteria, as well as the duration of those excursions, should be based on the designated uses being protected. For protection of aquatic life, U.S. EPA recommends once in three years as an acceptable frequency for excursions of water quality criteria, with maximum durations of four days for chronic toxicity and one hour for acute toxicity. For protection of primary and secondary contact recreation, the acceptably low frequency of occurrence should be consistent with the applicable water quality standards for pathogens (typically specified as a 30-day geometric mean based on a minimum number of samples). The acceptably low frequency of occurrence for some designated uses may vary from one waterbody to another, depending on site-specific conditions and the desires of local stakeholders.

For TMDLs that involve cumulative effects over long periods of time (e.g., buildup of sediment deposits in a reservoir, bioaccumulation of substances in fish, etc.), the TMDL needs to be based on long-term loadings or concentrations rather than a single set of critical conditions. Examples of this would be several mercury TMDLs that have been done in the Ouachita River basin in Arkansas and Louisiana. These were based on average annual loadings because the issue that the TMDLs were addressing was human health from fish consumption, a long-term phenomenon.

Select a Low But Realistic Recurrence Interval: For TMDLs where critical conditions are dependent on multiple parameters, critical conditions should be defined as the combination of the relevant parameters that has an acceptably low frequency or occurrence, not unrealistic extreme conditions. This is especially important for situations where the parameters do not typically reach their most critical values during the same time period.

An example of this would be a DO TMDL performed for the Arkansas River near Pine Bluff, Arkansas (AR DEQ, 1995), in which critical conditions for DO were characterized by low stream flow and high temperature (the primary focus was on several continuous point source discharges). For this stream, the lowest flows typically occur in October and the highest temperatures occur in July – August. Therefore, a separate model run was made for each month during July through October using the 90th percentile water temperature for that month and the appropriate monthly $7Q_{10}$ low flow. If the critical high temperature for July and the critical low flow for October had been used simultaneously in the model, the required wasteload reductions for the point source dischargers would have been much greater and would have been unnecessarily costly.

Where Appropriate, Consider Antecedent History: For TMDLs where antecedent conditions or sequences of events are important, a long period of continuous data should be analyzed (e.g., a continuous simulation). Critical conditions should be determined by selecting the output from the analysis that provides an acceptably low frequency or occurrence.

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Examples of this would be several DO TMDLs performed for small streams downstream of wet log storage facilities in Arkansas. Discharges from these facilities occur only when storm runoff from the log storage area exceeds the available pond storage. The pond storage that is available at the beginning of any storm is dependent on the season (there is much more evaporative loss from the ponds in the summer than in the winter) and conditions prior to the storm (i.e., rainfall amounts for the preceding days). The amount of rainfall necessary to cause a discharge is highly variable. Although a large storm creates a large discharge volume, it also generates a large amount of upstream dilution water in the receiving stream. Therefore, the critical conditions for each TMDL could not be based on a single design storm. Instead, a daily water balance was constructed for the log storage area and pond system to keep track of pond storage, to predict timing and volumes of discharges to the receiving stream, and to estimate the volumes of dilution water in the receiving stream based on rainfall. The daily water balance was simulated for 40 years to incorporate a wide range of observed sequences of rainfall. Critical conditions were then selected as the day with the fourth lowest dilution ratio in the receiving stream (to approximate a recurrence interval of 10 years).

Special Consideration for Nonpoint Source Dominated Waters: For nonpoint source TMDLs, where NPDES actions are not required, and adaptive management may be the preferred approach (Chapter 14.0). Here, the definition of critical conditions is not as important as in point source TMDLs, where it is typically defined by regulations. Critical conditions should still be determined as discussed above, but more emphasis should be placed on implementation of management practices and monitoring for compliance with water quality standards. The end point of the TMDL, however, would still be compliance with water quality standards such that designated uses are maintained.

7.8 Future Research Needs

Future research that would provide useful information for determining critical conditions includes developing better information on what is acceptable for the magnitude, frequency, and duration of water quality excursions to protect different designated uses (must include high flow excursions as well as low flow excursions and should look at a wide array of pollutants). This research would address questions such as "What effect do elevated levels of turbidity for short durations (i.e., during storms) have on different types of aquatic life?" The results of this research would help TMDL practitioners select critical conditions with an appropriate recurrence interval for a particular designated use.

Such results would also be beneficial for states as they review their water quality standards periodically to ensure that the standards are written appropriately for protecting designated uses. For example, many states require that most water quality standards be met whenever the stream flow is at $7Q_{10}$ or higher. This research would address questions such as:

- Is this requirement (e.g., $7Q_{10}$) stringent enough or too stringent?
- Should there be a high flow exclusion for some pollutants?
- For specifying when a standard must be met, should different measures other than stream flow be used (especially since many water quality impairments are due to

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nonpoint sources and the idea of requiring standards to be met at all flows above the $7Q_{10}$ is based on dilution of a point source discharge)?

- Should standards be specified in terms of magnitude, frequency, and duration of excursions (like some standards for fecal coliforms are already written)?

If water quality standards are revised to address magnitude, frequency, and duration of excursions, then those standards will form the basis for critical conditions in TMDLs. This should reduce the amount of inconsistency among TMDLs and yield TMDLs that are less likely to be too stringent or not stringent enough to protect designated uses.

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CHAPTER 8.0

GUIDING PRINCIPLES FOR MODELING

Mathematical models of watersheds and receiving waterbodies are often an integral part of the TMDL process. At their essence, TMDLs define the pollutant load necessary to meet water quality objectives. Some type of predictive relationship is required to define the linkage between loads and water quality, and models provide this linkage.

Models can serve multiple purposes in the TMDL process. They can be used to calculate watershed loads for existing conditions; relate loads to water quality response; and evaluate the effectiveness of proposed control alternatives in reducing loads and improving water quality to meet standards. The potential exists, however, for abuse of models in the TMDL process. This can occur through limited data, budget and schedule inherent to the current TMDL process, coupled with poor training and inadequate experience on the part of model users. Recognizing these problems, several reviews and evaluations of the TMDL process over the past several years have identified the need for improvement in the modeling applications (NRC/NAS, 2001; U.S. EPA, 2002e; WEF, 2001; Dilks, 2001).

This section presents a set of guiding principles for using models to support TMDLs. These guiding principles have been developed to answer the most basic questions a TMDL developer may ask regarding the use of models, including:

"How do I pick a model for my TMDL, and how complex does it need to be?"
"How much and what kind of data do I need to support the model?"
"How do I apply the model and calculate a TMDL?"

This chapter is not meant to be a comprehensive reference for the use of models in general, or even in the TMDL process. The topic is far too broad to cover in a single section, and other highly respected books and reports already provide this type of information. They are referenced throughout this chapter. The intent of this chapter is to provide general guidance that a practitioner can employ when specifically conducting TMDLs. This guidance is more philosophical or conceptual. It consists of principles rather than specific technical guidance.

The chapter begins with a background discussion of the use of models in the TMDL process and inherent issues (Section 8.1), followed by sections providing guiding principles in model selection (8.2), model development (8.3), model application (8.4), and model documentation (8.4.5).

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8.1 A Summary of Background and Issues

Models can be used in many aspects of the TMDL process, although there are many indications that these models are commonly not applied properly. This section provides background on the use of models in the process, and problems with model application that have been observed in this research and elsewhere. It is divided into discussions of the use of models in the process, whether improvements are needed, and the need for guiding principles.

8.1.1 Use of Models in the TMDL Process

Models are an integral part of the TMDL process, in that they provide a quantitative link between pollutant sources and receiving water quality. This section discusses how models are used in the process, and provides an overview of modeling and the modeling process for the reader who is not an experienced modeler.

A model is a mathematical abstraction of real-world processes. Its function is to relate inputs to outputs: stressors and loads to water quality response. The simulation of natural processes in a model can be empirical, mechanistic, or a mixture of both. The simulation of natural processes in an empirical model is based on a statistical fit of data relating causes and effects. A mechanistic model applies equations to represent the scientific understanding of cause-effect mechanisms. Models simulate cause-effect relationships between inputs, such as human activities (e.g. land use and point source loadings) and environmental conditions, and outputs or environmental response.

The National Research Council (NRC/NAS, 2001) has stated the importance of models in the TMDL development process:

> "Because they represent our scientific understanding of how stressors relate to appropriate designated uses, models play a central role in the TMDL program. Models are the means of making predictions—not only about the TMDL required to achieve water quality standards, but also about the effectiveness of different actions to limit pollutant sources and modify other stressors to reach attainment of a designated use."

Models simulate the relevant and important natural relationships linking pollutant sources to water quality. As such, the model is a quantitative tool that can be used to determine the TMDL.

The use of modeling to link loading and water quality in the process is simply characterized in Figure 8-1. Here the model results define the relationship between load and water quality response. Where the relationship exactly meets the water quality objective (standard) is defined as the assimilative capacity. The model defines the maximum load that results in attainment of the desired water quality objective; i.e., the TMDL. The load that is allocated to point and nonpoint sources is generally less than the TMDL, reflecting a margin of safety.

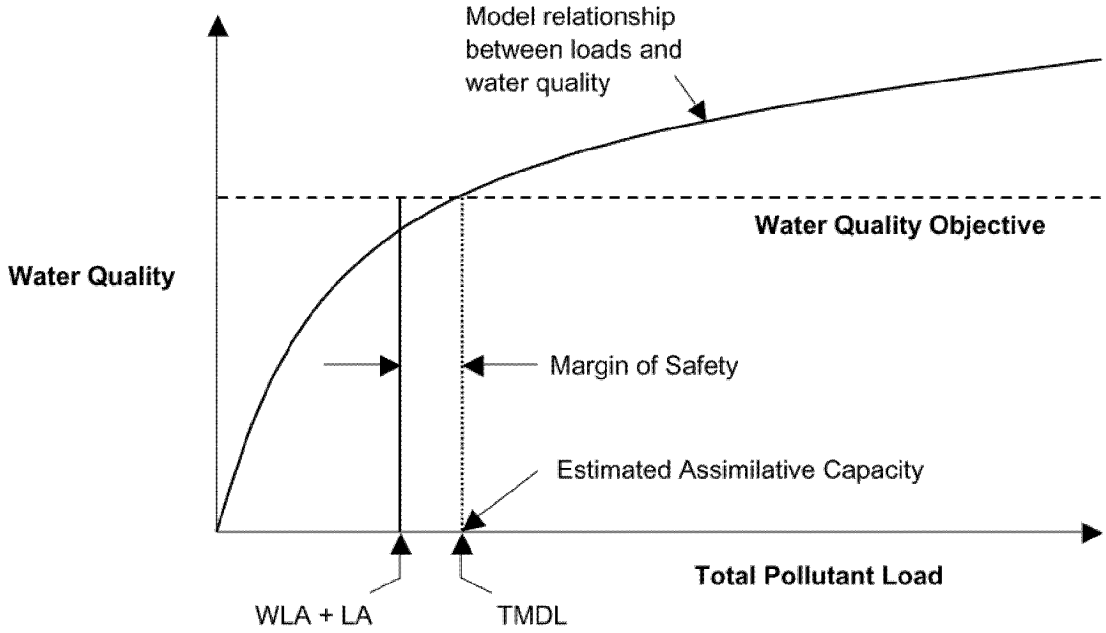

Figure 8-1. Application of a Model to Calculate a TMDL.

The functionality in Figure 8-1 is only illustrative: the shape of the curve will vary depending on the pollutant and the nature of the system response. Additionally, in a rigorous analysis one would want an error band around the model relationship, and this would be used to establish model uncertainty and a margin of safety (Chapter 9.0).

The above example provides a simplistic description of how models are used in the TMDL. Figure 8-2 provides additional detail, illustrating that separate models can be used to simulate both watershed source loads, and simulate the load response relationship in the receiving water; and listing examples of the specific types of information required by, and generated by, each type of model.

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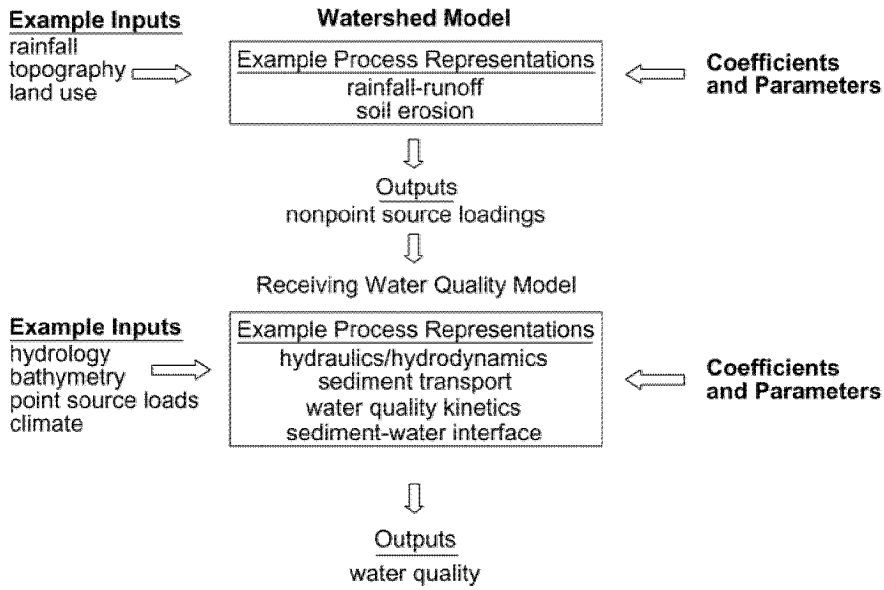

Figure 8-2. Conceptual Modeling Framework for the TMDL Process.

While in practice the types of models, inputs, and representations can differ widely, the conceptual linkages shown in Figure 8-2 are typical.

8.1.2 Are Improvements Needed?

Although mathematical models have been long and widely used in the field of water quality management, many in the water quality field believe that TMDL modeling is not being properly implemented, and that improvements are needed. This sentiment was expressed during the 2001 TMDL Science Issue Conference, in the National Research Council's scientific review of the TMDL process. It was also an observation in the review of individual TMDLs conducted as part of this project.

In March 2001, the Water Environment Federation (WEF) and the Association of State and Interstate Water Pollution Control Administrators (ASIWPCA), in cooperation with U.S. EPA and USGS, conducted a national technical conference on TMDL science issues. In the closing session, the participants were divided into work groups to identify science gaps and needs in various elements of the TMDL program. Related to model selection and modeling practices, the following observations were made:

- Developers of TMDLs need guidance on how modeling and data collection go hand in hand.
- There is not enough training on how to properly use models and how to choose the appropriate model.
- Guidance on selection, use of models, and good modeling practices is lacking. It is difficult to find the optimum degree of complexity for the job.
- Modelers are not communicating enough about data needs for effective modeling in the TMDL process.

This group, composed largely of TMDL practitioners, saw modeling as a priority area needing better guidance for improved TMDLs. Recognizing these shortcomings, many believe that the need for TMDL modeling far exceeds the current availability of trained and experienced modelers (Dilks and James, 2001).

Later in 2001, the National Research Council of the National Academy of Sciences (NRC/NAS, 2001) published an assessment of the TMDL approach to water quality management, conducted and reviewed by a panel of technical experts. The NRC panel made a number of specific recommendations relative to modeling in the TMDL process:

- U.S. EPA needs to provide guidance on model application so that thorough uncertainty analyses will become a standard component of TMDL studies.
- U.S. EPA should end the practice of arbitrary selection of the margin of safety (MOS), and instead require uncertainty analysis as the basis for MOS determination.
- Given the computational difficulties with error propagation for large models, U.S. EPA should selectively target some post-implementation TMDL compliance monitoring for verification data collection to assess model prediction error.
- U.S. EPA should not advocate detailed mechanistic models for TMDL development in data-poor situations.
- U.S. EPA needs to provide guidance for determining the level of detail required in TMDL modeling that is appropriate to the needs of the wide range of TMDLs to be performed.

The panel's report placed a heavy emphasis on the need for improved modeling.

Finally, in this WERF research project, 176 approved TMDLs were reviewed and examined for their use of models (Appendix A). Several evaluation questions related to modeling led to the following observations in that survey:

- Approximately 18% of the reviewed TMDLs did not calculate assimilative capacity, let alone use a model to conduct the calculation. Most of these were clean sediment TMDLs, contaminated sediment TMDLs, or for other narrative standard TMDLs.
- Only about 16% of the reviewed TMDLs employed a "complex" model (defined for this purpose as one that included some site-specific calibration).
- 15% of the reviewed TMDLs used simple dilution analysis and did not consider any issues of in-stream/lake processes attenuating the pollutant loadings.
- Of the TMDLs reviewed that used models, none used data specifically collected for the purpose of supporting the model use in TMDL development.
- Of the TMDLs using models, only 50% provided sufficient documentation to assess the reliability of the modeling.

These previously noted observations highlighted the need for more guidance on TMDL modeling. This was reinforced recently by an independent U.S. EPA study entitled "The Twenty Needs Report: How Research Can Improve the TMDL Program." In this report, the agency states:

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> "Better water quality modeling is among the most significant of all TMDL-related science needs reviewed in this study."

U.S. EPA further indicated that its Office of Research and Development has not met key program needs. They stressed that far more model development and training are needed.

Overall, the assessment suggested that the use of models for TMDL development was more limited and much less rigorous than expected. This may be a consequence of timing, where states have been deferring development of TMDLs at the more complex sites that would require this level of modeling because of time and resource limitations. Even if this is the case, however, there is a concern that when TMDLs are done for these more complex sites in the future, inappropriate models may be selected or improperly used.

Thomann (1998) describes the value of models and the need for quality modeling in resolving conflicts over alternative management and control options:

> "...poor models that are not considered credible or believable can add to the conflict with misinformation and exacerbate the problems...But when a modeling framework that is recognized as valid is present, conflict is lessened through increased *understanding*, permitting enhanced and informed *dialogue* and ultimately contributing to *consensus* decision-making."

The challenge in using models for TMDL development is to make sure that models are applied properly, and that they contribute to better decision-making with stakeholder consensus, not poor decisions and more conflict. That is the motivation of this segment of research.

8.1.3 Need for Guiding Principles

Numerous texts and technical guidance manuals have been written about model selection, use and the various technical elements in modeling. Some examples include:

- Chapra, S.C. 1997. Surface Water-Quality Modeling. New York, The McGraw Hill Companies, Inc.
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- Fitzpatrick, J., J. Imhoff, E. Burgess, and R. Brashear. 2001. Water Quality Models: A Survey and Assessment. WERF Pub. No. D13209. Water Environment Research Foundation Project, Alexandria, VA.
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- Schnoor, J.L., C. Sata, D. McKenchnie, and D. Sahoo. 1987. Processes, Coefficients, and Models for Simulating Toxic Organics and Heavy Metals in Surface Waters. U.S. EPA EPA/600/3-87-015.
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Although these texts and reports and many others provide extensive technical support for modeling, they focus more on technical detail and less on the philosophical approach. This kind of guidance is lacking.

Recognizing this shortcoming and the needs outlined previously, this research was undertaken to develop a set of modeling principles that could be used by practitioners to guide them in the application of models for TMDL development. References to the literature and case study examples are included to support the guiding principles, and to provide the reader with resources for additional information and guidance. These principles are not designed to technically train novices to become modelers, but rather to guide modelers in the use of technical knowledge for the proper application of models in TMDL projects.

8.2 Basic Principles for Model Selection in the TMDL Process

This section addresses the question, "How do I pick the right model to support the development of a TMDL?" To help answer this question, the TMDL developer should refer to several good model selection compendiums available (U.S. EPA, 1997b; Limno-Tech, Inc. 1999; Fitzpatrick, et al. 2001). To better guide the TMDL developer through the model selection process, this section presents some basic principles for model selection. Those principles are:

- Models are not absolutely necessary if observed data can answer the questions (8.2.1).
- There is no one best model for all TMDLs; model selection should be driven by an explicit consideration of: 1) management objectives; 2) site-specific characteristics; and 3) resource constraints (8.2.2).
- Questions drive desired model complexity, but data constrain it (8.2.3).
- Select the simplest model that adequately addresses the management objectives (8.2.4).

8.2.1 Models Are Not Absolutely Necessary If Data Are Sufficient to Address the Problem

Before selecting a model, a TMDL developer might ask the question, "Do I even need a model to complete this TMDL?" While the value of models in the TMDL process was previously described, in some situations the answer is no—a model is not always needed for the

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development of a TMDL. The TMDL is defined as the maximum load that will meet water quality objectives; this load is typically defined using a predictive relationship (i.e., a model) between loads and water quality. A formal predictive relationship is not necessarily required, however, if actual data are available to define the permissible level of loading.

For example, historical data on loads during a time when water quality objectives were being attained can be used in the development of a TMDL. In situations where these data are available, the TMDL can be established at a level of loading that historically resulted in attainment of the water quality objectives. This approach has the desirable quality that relevant site-specific observations are generally more accurate than model predictions. This approach is not without uncertainty, as some natural processes are not immediately reversible, and a return to historical loads may not result in an instant return to historical water quality.

In other situations, the use of a reference site to establish allowable loadings may preclude the need for a model in the TMDL process. This approach establishes target pollutant loads or watershed characteristics based on observations from a similar nearby waterbody that is meeting its designated use. Using comparable reference sites can be effective; every watershed is unique, however, and site-to-site differences can create significant uncertainty.

In effect, these "non-modeling" approaches are the most simplified version of an empirical model; they use data observations to define the relationship between loading and water quality. If a distinction were to be made, these non-models define only a single point along the load-response relationship, while empirical models relate the response along a range of conditions.

In these cases, where TMDLs can be established without a model, the practitioner must acknowledge the uncertainty. Historical observations, although demonstrative, are not definitive in forecasting. Future environmental and watershed conditions will always differ to some degree from the past. Further data observations are not always accurate or comprehensive. Supplementing this kind of analysis with a modeling analysis adds significantly to the reliability of the TMDL, and is the preferred option. The model can be used to evaluate a range of alternatives for which data are not available, and can evaluate the degree of uncertainty to better define the margin of safety (Chapter 9.0). Without a model, practitioners must give careful thought to how to address the margin of safety. They should also allow for post-TMDL monitoring and consider adaptive approaches (Chapter 14.0).

8.2.2 There Is No One Best Model for All TMDLs

Model selection should be driven by an explicit consideration of: 1) Management objectives; 2) Site-specific characteristics; and 3) Resource constraints.

A wide range of models exists to support TMDL development. For example, U.S. EPA's Compendium (U.S. EPA, 1997b) lists dozens of models applicable to the TMDL process. No single model is applicable for all situations. Just as a Phillips screwdriver cannot drive a slotted screw, certain models might not be appropriate for the specific TMDL under investigation. The success (or failure) of TMDL development can depend upon selection of the appropriate model.

To facilitate proper selection, three separate but interrelated factors must be given explicit consideration (Figure 8-3):

- ***Management Objectives***—What questions does the model have to answer, and with what degree of precision?
- ***Site-Specific Characteristics***—What system characteristics are relevant to the management objectives?
- ***Available Resources***—What resources are available to support the modeling?

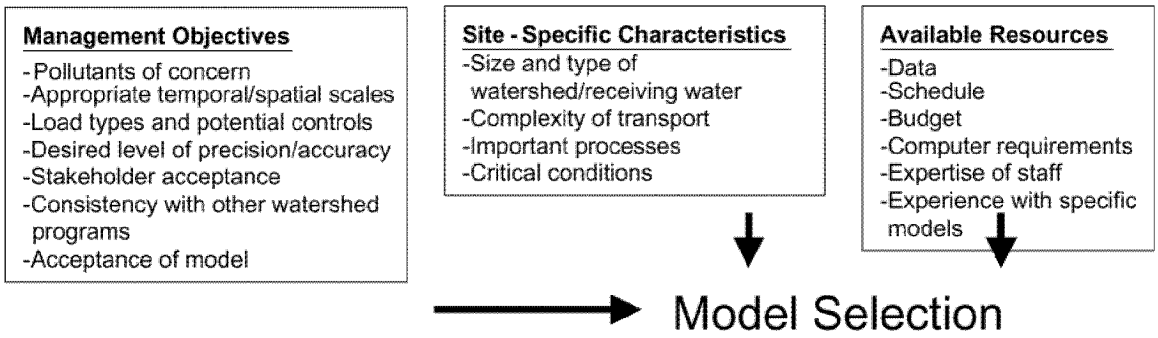

Figure 8-3. Selected Factors for Consideration in Model Selection.

Building a table can provide an analogy to selecting a TMDL model. In deciding on your tools and design, you need to consider your skill level, schedule, and the intended use. Obviously the approach would differ dramatically if you had a morning project to build a lemonade stand for your child versus a six-month project to build an end table for your living room. Building the lemonade stand is probably feasible for us all, whereas the end table would require special woods, tools, and most of all expertise. Similarly, in selecting a TMDL model one needs to consider objectives, characteristics, and resource constraints.

Consideration of Management Objectives: Clear delineation of the management objectives to be addressed by the model is an essential first step of the modeling process. The model must be selected to fully answer the management questions posed by the TMDL. At first glance, the management objectives associated with modeling in the TMDL process may seem obvious. The objectives need to be specified, however, at a level of detail beyond simply stating the pollutants of concern and the required level to achieve through the TMDL process if they are to influence the model selection process. Different models address different problems, consider different processes and include different levels of spatial and temporal resolution.

For example, the need to specify the spatial and temporal scales of the problem is essential (i.e., how, when, and where will water quality standard compliance be assessed). Different models provide steady-state, temporal average, or hourly output with coarse or refined spatial definition in 1, 2, or 3 dimensions. For example, localized hourly assessments reflecting diurnal variations are often needed to address dissolved oxygen issues, whereas coarse-scale seasonal or peak conditions are often adequate for algal/nutrient considerations. The model needs to be compatible with the problem and site-specific spatial and temporal scales of interest.

Another important aspect of defining management objectives is to specify whether nonpoint source loads are important to the problem, and if so, what types and how they will be

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estimated. Will nonpoint source loads be measured, specified from historical data or literature, or modeled? All models cannot address all types of nonpoint source loads and all types of proposed controls. Furthermore, the importance of nonpoint sources and how they will be specified will determine the need for a watershed loading model linked to a receiving water body model for the analysis.

It is also important to attempt to couch the objectives of the modeling in terms of the maximum level of uncertainty that can be tolerated in defining the load-response relationships. This specification of desired accuracy will drive the data needs and associated model complexity. Proper use of models for decision-making requires not only a consideration of the value of the output, but also a firm understanding of the confidence level (uncertainty) associated with the prediction. Both considerations must be incorporated when selecting the right model. The inability to provide TMDL results that meet desired accuracy may require consideration of adaptive or iterative model approaches (Chapter 14.0).

Other management objectives relevant to model selection may include the level of review and acceptance the model will receive. This may also include regulatory, public, and peer review. The model selected may also need to be consistent or compatible with other efforts in the watershed. Finally, the cost of the modeling software and the public availability of the model and its source code may be issues.

Consideration of Site-Specific Characteristics: Every watershed and receiving water is unique; the physical characteristics and the important natural processes will differ for each TMDL assessment. The unique features of the watershed and receiving water should, therefore, influence model selection. Models are neither universally applicable to all watersheds and water bodies nor capable of describing all processes.

The impairments and potential sources affecting water are linked in the real world through a series of cause-and-effect mechanisms. The intent of the watershed/receiving water model is to describe the important relationships in mathematical terms. This aspect of model selection consideration requires documenting the constituents and processes of concern. The recommended approach for documenting these linkages can be conducted in a three-step process: develop detailed conceptual model; estimate magnitude of component processes; and remove/combine minor processes.

The first step is to define all of the potential processes composing the linkages between causes and effects. This documentation can be in the form of a simple list, or in a linkage diagram. This step consists of defining all *potentially* important processes linking watershed causes and receiving water body effects.

The next two steps are designed to eliminate those processes that do not play a significant role. This is done by first estimating the order of magnitude of each of the component processes, using available data and simple "back-of-the-envelope" calculations. The final step, once the magnitude of the component processes has been identified, is to delete those processes from consideration that play an insignificant role in the cause-effect linkage. Spatial and temporal scales determined by the problem and system characteristics also come into play when

deciding on necessary processes for inclusion. This refined conceptual model needs to be compared with the computational model selected.

Developing this conceptual model before model selection is important because models do not have universal applicability. For example, individual watershed models are often better suited to urban or rural applications, with varying levels of flexibility and capabilities that need to be matched to the problem. Similarly, individual receiving water models have characteristics that may map well for a river but not for a lake or estuary. Individual process details can differ widely even in simple DO models which address algal and periphyton. It is essential that the conceptual model be developed first and then used as a tool to select the best-suited computational model.

For the receiving waterbody, the conceptual model must address temporal and spatial resolution, plus important variables and processes. The watershed model must consider pollutant sources, land uses, and most importantly management/control options. The available model inventories referenced previously provide the reader a more detailed list of these features and capabilities.

Consideration of Resource Constraints: TMDL model applications require a variety of resources, which can be grouped into data, time, and human resources. Site-specific data are essential to any model application, as models are only as good as the data upon which they are based. Time (schedule) is another important consideration, as sufficient time must be made available to collect the necessary data, develop the model, and conduct predictive scenarios. Human resources are a third important component, both in terms of quality and quantity. Sufficient staff time must be made available for model development and application. Proper application of TMDL models also requires significant training and judgment, making the quality of staff an important consideration. One additional resource is budget, as this can dictate the amount of data to be collected as well as the quality and quantity of staff resources.

An often-used axiom is that you can have a project done "fast, cheap, or high quality" but that you can "only pick two." Unfortunately, TMDL projects often demand all three. The role of the practitioner is to guide the model selection to get the right balance of timeliness, cost and complexity to reliably answer the TMDL questions.

Employing the analogy of building a table again, resource constraints must be considered upfront in the design. It is better to build a simple work bench out of 2x4 studs and plywood and complete a solid table when needed, than to attempt to build an overly ornate or complex workstation that is not completed or hurried and structurally tenuous. One must select the model based on a realistic understanding of constraints and expectations.

The large number of TMDLs that must be developed over a relatively short period of time will result in many TMDLs being conducted with fewer resources than desired. Constraints in any of the available resources will lead to limitations in the predictive accuracy of the TMDL model. There will often be an incompatibility between the desired accuracy defined by the management objectives and the accuracy that can be delivered because of resource constraints. Methods to deal with incompatibility are addressed in the following guiding principle, as well as in the guiding principles related to model application.

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8.2.3 Questions Drive Model Complexity, But Data Constrain It

When conceptually evaluating model frameworks for TMDLs, it is easy to list dozens of complicating factors to consider in the model. Questions about factors such as spatial or temporal resolution, linkages between different water quality parameters and processes, and consequences of changes in watershed or environmental conditions, however, can push models towards increased complexity. Modelers must resist this temptation, and focus on the core management issues, not merely scientific curiosity. Tempering the whole issue of complexity is a practical constraint—the extent of data available to support the model. Mathematical models and associated site-specific data have a symbiotic relationship that must be achieved in any TMDL modeling application. Correct interpretation of site-specific data benefits from a modeling framework to assist that interpretation, and a site-specific model can only achieve acceptance for use in management applications through comparison with system data.

While no universal criterion for the minimum quantity of data is needed for a successful TMDL, it is safe to say that the amount of data needed to achieve a desired level of reliability is largely determined by the complexity of the model being applied. Model complexity is a function of three factors that compose the development and application of a model: kinetic complexity, spatial resolution, and temporal resolution. A model that combines multiple individual fate processes into a single, lumped loss rate is simpler than a model that describes each individual process. A model that predicts lake-wide average concentrations is simpler than a model that predicts how concentrations vary over space. Finally, a steady-state model is less complex than a time-variable model. In general, the more complex the model, the more data necessary for its successful application. In turn, the model complexity is driven by the problem definition.

One essential concept in assessing whether the data are sufficient for the model application is that **a model is only as good as the data available to support it**. This is often characterized by the adage "garbage in, garbage out." Data support refers to data for theoretical understanding, process description and parameterization, and field observations for calibration, confirmation, and application. Increased data are needed to support models as they become more complex (Figure 8-4). It is desirable to stay on the "reliable" side, so that one has at least as much data as needed, if not more. Often the resources (time, money, or both) available for data collection to support modeling are limited for TMDLs. In this case, the available data govern the complexity of a model that can be successfully applied. Under conditions of limited data budget, one must ask, "Can that level of model complexity answer the management questions being posed?" Of course, if there were unlimited resources, enough data could be collected to support even the most sophisticated model. That does not necessarily mean, however, that the answer would be better (as discussed in the next section).

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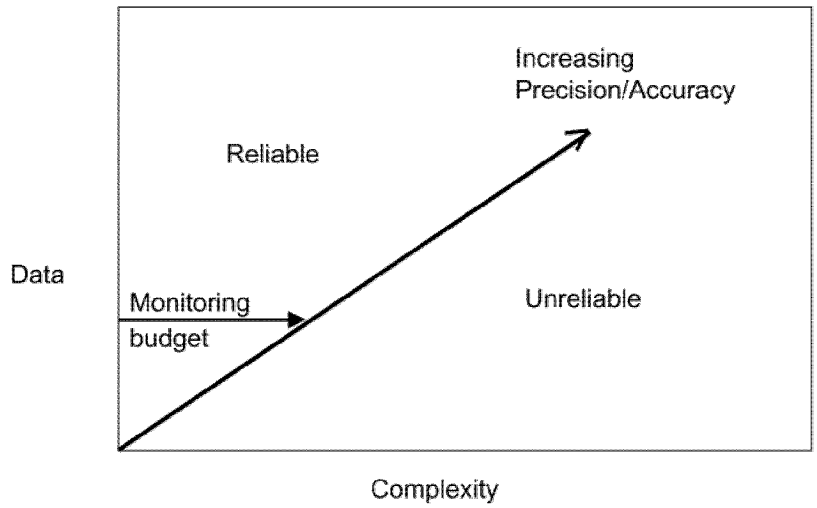

Figure 8-4. Relationship between Available Data and Model Complexity.

Figure 8-4 appears to indicate that as long as there are enough data, one can continue to increase model complexity and thereby continue to increase model reliability (as defined by increased accuracy). Experience has shown, however, that even with virtually unlimited resources, one can produce a model in which utility and reliability do not continue to increase—and may even decrease with increased complexity. This occurs when limits to the ability to mathematically represent the complexity of nature are encountered. Also, there is rarely sufficient budget to support highly complex models to be used for management purposes.

Figure 8-5 presents a graph that depicts the qualitative relationship between model complexity and model utility (or reliability). Model reliability can be thought of as the inverse of model uncertainty.

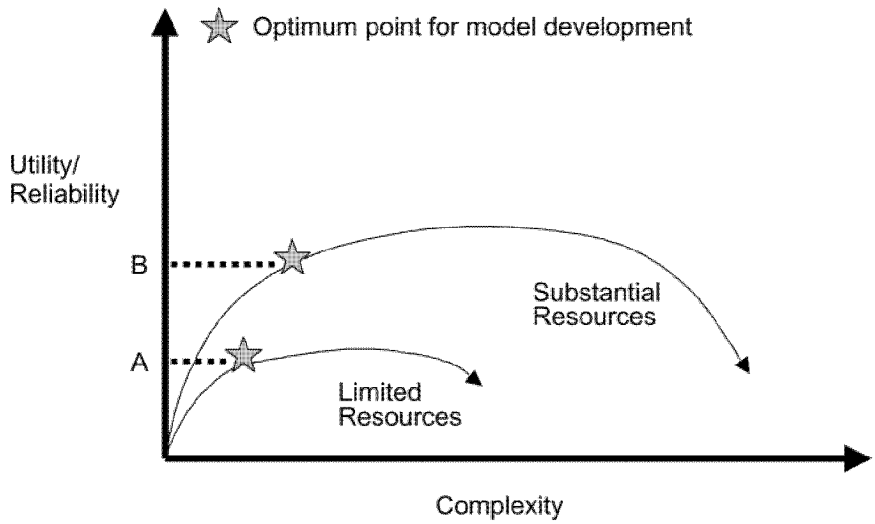

Figure 8-5. Relationship between Model Reliability, Model Complexity, and Available Data and Resources.

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8.2.4 Select the Simplest Model that Adequately Addresses Management Objectives

The challenge in balancing model reliability against model complexity is selecting the simplest model that can answer the management questions being posed: in other words, reaching the optimum model reliability on a curve that represents the available resources. The "optimum" point is driven by both the management questions being asked and the resources available to develop and apply the model. As indicated, if one has more resources, one can generally answer more complex questions with greater reliability. This may be necessary if the relevant management questions require the degree of reliability indicated by point B on Figure 8-5. If the management questions require the degree of reliability indicated by point A, however, it does not make sense to use more resources and increase model complexity to get to point B. In either case, there is an optimum point on the curve (the "knee") where increasing model complexity adds little in terms of reliability or utility.

Data richness and quality govern the level of model complexity that can be applied to a given system. The model should never be more complex than the data allow. Although the appropriate level of model complexity is difficult to quantify and generally requires experienced professional judgment, it is always desirable to begin with a simple model and increase complexity only as the data, and other project constraints, allow and the problem definition (water quality endpoints and tolerable uncertainty) demand (Section 8.3.1). Simple models can provide insightful diagnostic understanding of the system. Also, in applying a model, one should always quantify the uncertainty in predictions. In general, quantifying uncertainty is easier with simple models, which is another reason to begin with a simple framework.

TMDL models are being developed to answer management questions and to establish a TMDL. The selection and adequacy must therefore be judged by how it meets these needs, not by the level of sophistication with which it describes the system. When given alternative models that can address these objectives, the modeler should apply "Ockham's razor," a 14th century maxim that said (paraphrasing): "Given two theories that both explain an observation, the simpler theory is better"; in other words "keep it simple" whenever possible.

First and foremost, one should select a model with a complexity (spatial, temporal, and kinetic resolution) that is compatible with the available resources, and no more complex than is needed to address management objectives and site-specific characteristics. The best practice is to start with a simple modeling representation of the system and increase complexity only as the problem (defined by management question, desired level of accuracy, and system characteristics) demands and the available resources allow.

If one starts with the basic tenet to "start simple and increase complexity of the analysis only as required by management objectives (including desired level of certainty) and permitted by available data and resources," then one should end up with the most compatible model with the correct level of complexity. In other words, the relationship between problem definition, model complexity, and available data must be continually examined through the modeling process.

Keeping the analysis and modeling simple has several advantages over more complex approaches:

- ***Resources:*** Simple models consume fewer resources, whereas unnecessarily complex models waste valuable time and resources if they do not provide any better information for making the required decision.
- ***Understanding:*** Simple models provide an easier framework to understand the system response to assumptions. Complex models often prevent insightful and intuitive understanding of the system because of the complex interactions.
- ***Communication:*** The TMDL and its basis must be communicated to stakeholders. Simpler approaches are often easier to explain and more amenable to demonstration and interaction with stakeholders.
- ***Parameterization:*** Simple models generally require fewer inputs and specification of parameters. Complex models often require large lists of inputs and parameters for which little information or data are available. This can lead to more uncertainty, not more accuracy.
- ***Uncertainty:*** Simple models generally incorporate more approximations than complex models. Ideally, the sophistication of complex models (when properly supported) provides more accuracy. It is generally easier to define and fully understand the uncertainty of simple models, however, whereas complex models often have many assumptions with undefined consequences. As discussed later, understanding the uncertainty is centrally important to good decision-making.

8.3 Basic Principles for Model Development

Once a specific model framework has been selected, the next step is to develop the model application to best describe site-specific conditions. This section provides four guiding principles related to model development:

- Start simple and build complexity only as justified (8.3.1);
- Model credibility requires validation to data (8.3.2);
- Model calibration is a scientific process, not a mathematical exercise (8.3.3); and
- Model confirmation with data should be judged qualitatively and quantitatively (8.3.4).

8.3.1 Start Simple and Increase Complexity Only as Needed and Supported

It is almost always valuable to begin a TMDL analysis with a "simple" model to gain a general understanding of the system behavior. The modeling process should include a conceptual model and "back-of-the-envelope" calculations at the earliest stage of the TMDL process, and then proceed to preliminary application of the model selected to support the development of the TMDL. These early stages of "simple" modeling may not be sufficient to conduct a TMDL. For many situations, however, the initial analysis will identify uncertainties, data gaps, or inadequate simulation of system behavior. The latter situation may require additional data collection or, only if necessary data are available and the problem requires it, increased model complexity.

The benefits of starting simpler and building complexity were illustrated previously in Figure 8-5. It is better to begin model development on the left side of the curve, moving to the right with increased complexity and improved reliability/utility. Starting at the right side of the curve, and reducing complexity to reach the optimum can often be frustrating; this is because

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the extreme complexity makes it difficult to interpret model output and to prioritize processes to lump or ways to reduced spatial or temporal resolution. A general rule is that it is better to have a robust application of a simpler model than a weak application of a complex model. In the former one fully understands the utility and reliability; in the latter case, reliability is often unknown or large, and therefore utility is low.

8.3.2 Model Credibility Requires Validation to Data

The review of existing TMDL studies found that many, if not most, of the models were applied in the absence of any formal model calibration. Model inputs were defined with no demonstration that the model was capable of accurately predicting water quality.

To develop a scientifically credible TMDL model application, one must have sufficient data quality and quantity to demonstrate an ability to simulate actual observed conditions. Because a complete theory of terrestrial and aquatic system behavior in response to external perturbations does not yet exist, a model that mechanistically captures all processes relevant to a given problem cannot be developed. It is important, however, to use a model that is consistent with current scientific theory. Whether this model is simple or complex, it will still have a certain degree of empiricism that must be calibrated on a site-specific basis. Model calibration consists of comparing model predictions to observed data, and adjusting model coefficients as necessary to best describe observed conditions. The understanding of the relevant processes is such that the use of literature values for model coefficients can result in predictions that range over a wide magnitude, depending upon which literature coefficients are used. Without a demonstration that model inputs are appropriate for a given site, the uncertainty in model predictions will be large.

The degree of demonstration necessary depends on the number of model inputs that have to be estimated. A river dilution equation or an empirical lake model may have no coefficients that need to be calibrated, and will require a much lower level of demonstration than a more complex model. But these simple models often will have much less predictive power (i.e., management utility) than more complex models.

This principle covers the most remedial aspect of model calibration by requiring some type of reality-check to demonstrate that the model is capable of describing the system observations. The following principles focus more on the calibration process itself.

8.3.3 Model Calibration Is a Scientific Process, Not a Mathematical Exercise

Model calibration involves adjusting process formulations and coefficients until a model is able to reproduce site-specific observations. Chapra (1997) provides a schematic of the model calibration process (Figure 8-6). As indicated in this diagram, once a model has been selected, a coordinated data collection program is undertaken to obtain a calibration data set. This field data collection program should be designed to simultaneously obtain site-specific physical data, forcing function data, necessary process-related data, and spatial and temporal profiles of all model state variables (dependent variables). The calibration data set should be as similar as possible to design conditions for the problem being studied. For example, for a DO TMDL, the design condition might be for summer low flow in a river. Consequently, the calibration data set should be collected during warm, low-flow conditions. Also, a statistical criterion should be established for the acceptable difference between the model computation and the measurement.

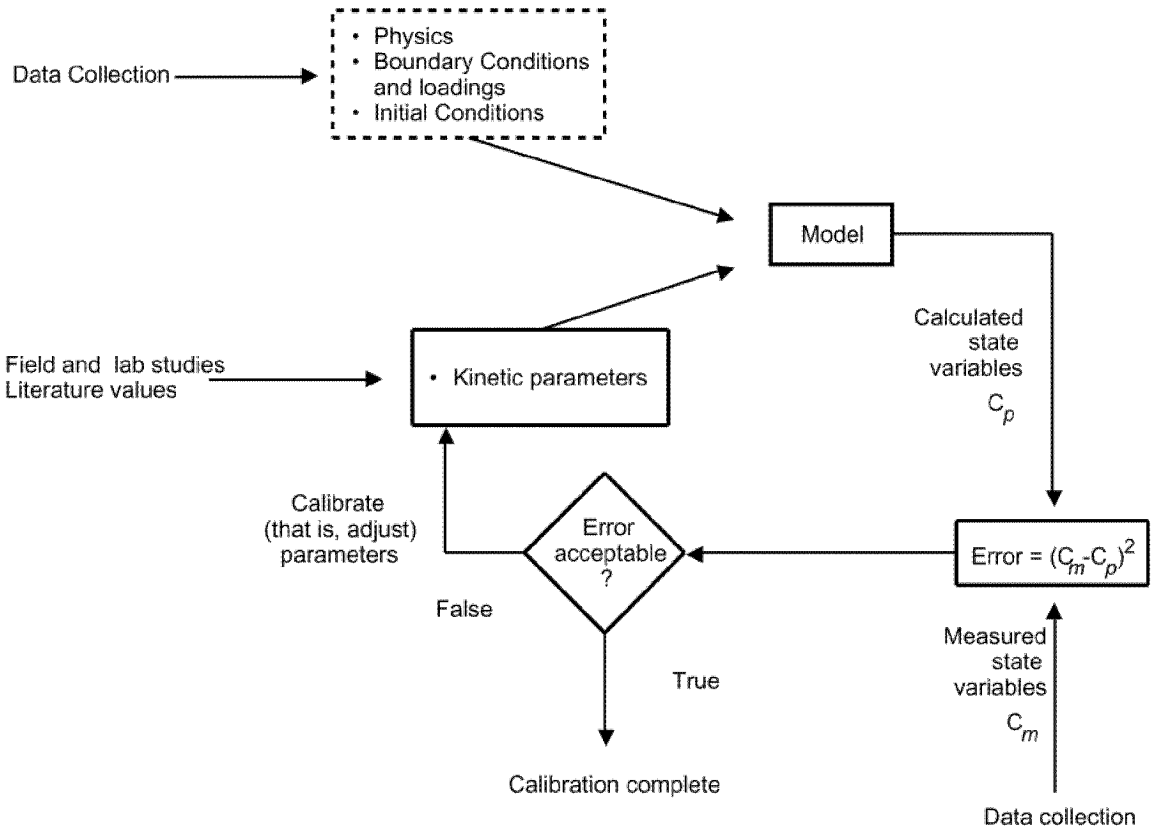

Figure 8-6. Schematic of the Model Calibration Process (From Chapra, Surface Water-Quality Modeling, 1997. Reproduced with permission of The McGraw-Hill Companies).

While design of a calibration data set depends on the water quality problem and parameters of concern, some general categories of data should be included in all calibration data sets. These are, by category:

- Physical data to set up the model configurations;
- External loading/environmental data to drive the model processes;
- Process-related data to govern the fate and transport of water and pollutants; and
- Ambient System Response Data on loadings and concentrations to compare against model output.

With a coherent, complete calibration data set that is consistent with the resolution of the model, the focus of the calibration then becomes the adjustment of the coefficients (within an acceptable range dictated by field and lab literature values) until the difference between model computations and measured state variables is within acceptable tolerance.

Modelers are strongly discouraged from arbitrary adjustment of coefficients to improve a point-by-point fit and relative statistical performance. Without scientific justification, this becomes merely a process in curve fitting. The result is a model with an appearance of high precision but actually unknown predictive reliability. It is better to use a logical and consistent

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set of coefficients and accept model-to-data discrepancies. These discrepancies should be quantified and used as a basis to quantify the degree of model uncertainty/precision.

The process of "tuning" the model coefficients to calibrate it to data is an art coupled to scientific foundations. A few considerations that should be kept in mind are as follows:

- Define as many coefficients independently as possible, and try to leave these fixed while other coefficients are adjusted.
- Always *a priori* establish an expected range for each coefficient that is to be adjusted in calibration. The range should be based on scientific experience from laboratory and other field studies. Avoid deviating from the range.
- To the extent possible, justify coefficient adjustments based on logical scientific observations or theory, qualitative if not quantitative.
- Do not arbitrarily adjust coefficients spatially and/or temporally merely to improve the model performance without logical justification. This is curve fitting, not calibration.

The following principle provides guidance on evaluating the quality of a site-specific calibration.

8.3.4 Model Confirmation with Data Should Be Judged Qualitatively and Quantitatively

Model reliability is best judged by comparison to data. This is often termed model confirmation or validation. The terms model calibration or verification are also used in this context, referring to a process of adjusting model parameters and then a comparison of model results to data. Whatever terminology is used, it is essential that model credibility be supported by some comparison to actual data. Most complex models are under-determined. They contain more coefficients than state variables. Multiple sets of calibration parameters can therefore provide results that are roughly consistent with the observed data. It is often possible to follow a scientific calibration approach (Section 8.3.3), and still be faced with difficult decisions on how to judge the quality of the calibration and how to select which specific set of parameters to use for the final calibration.

The traditional approach to assess the validity of a calibration was to present a graphical comparison of model predictions, and rely on the judgment of the modeler to select the set of coefficients that "best" described the observed data. This approach has the limitation of being primarily qualitative, and not providing a quantitative assessment of model performance. Furthermore, simple graphical comparisons are often not feasible when dealing with multi-dimensional, time-variable models. Thomann (1982) and Reckhow and Chapra (1983a) called for the use of more quantitative measures to assess model performance, and described several statistical techniques that could be used to assess model performance. These include measures such as regression analyses or calculation of relative error. Parameter optimization routines have been developed that can define parameter values that provide a "best" comparison to a given quantitative performance measure.

While the calibration process should be done in a quantitative and systematic fashion (Section 8.3.3), there is often considerable professional judgment involved in obtaining a satisfactory model calibration. There is as much "art" as "science" in model calibration. Automated

error-minimization techniques can provide some guidance, but they almost never derive the "best" calibration data set because it is often more important to describe some aspects of the observed data than others. It is difficult to define *a priori*, or in quantitative terms, the specific importance of capturing varying aspects of the observed data.

As a result, model practitioners must avoid "curve fitting" and focus on observing if the model performs consistent with the data and scientific understanding. Considerations important to examine include:

- Does the model respond consistent with the theory and data?
- Are the spatial trends in model and data consistent?
- Are the temporal variations in the model and data consistent?
- Are the timing and magnitude of peaks and valleys in the model and data similar?

Anomalous data, and high environmental variability, can often confuse the model calibration process if governed by statistical assessments alone or a point-by-point focus. Thus, consistency in magnitude and trends is equally important as the statistical residuals. In the end, the adequacy of the calibration must be judged by a weight of evidence approach considering quantitative measures as well as qualitative characterizations and explanations (Reckhow et al., 1990).

As a closing note on model calibration, it must be recognized that models are only approximations of nature; they rarely reflect the natural process with complete accuracy and almost never fully reflect the significant variability that exists in nature. So do not be discouraged by isolated discrepancies or uncaptured small-scale variability. Paraphrasing Aristotle:

> "The mark of an educated mind is to be satisfied with an approximate answer when that is all the nature of the problem permits."

Ideally, before a calibrated model is applied to address TMDL management questions, it undergoes a confirmation (some call it validation) process. Model confirmation is conducted by applying the calibrated model to a new data set for the system of interest (or ideally more than one data set collected under a range of conditions) that was ideally collected under a set of forcing conditions (i.e., loads, flows) as different as possible from those used for the calibration. For example, one will have more confidence in applying a model for making management decisions if it simulates field observations well under both low and high flow conditions without adjusting model coefficients. To accomplish this, the model simulation for the confirmation period is compared against the *in-situ* observations made during this period, *without* changing any model coefficients from those determined in the calibration process. If the error associated with the model simulation of the confirmation data set is no larger than that for the calibration period, then the model has been "confirmed" as an effective prediction tool for the range of conditions observed. In fact, this uncertainty analysis on calibration and confirmation data sets is a recommended means of determining a Margin of Safety (MOS) for the TMDL process. If the confirmation process yields significantly larger error than for the calibration data set, it may be necessary to repeat the model building/selection or the model calibration process.

Models are almost never confirmed in the TMDL process because of cost and time constraints. That being the case, the TMDL practitioner should acknowledge that the uncertainty

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determined using the calibration data set may underestimate the uncertainty associated with application of the model to a different set of loads that might be used in determining assimilative capacity or in evaluating alternative load reduction scenarios.

8.4 Principles for Model Management Application

Once the model has been developed, the next step is to apply it to define the TMDL. Four guiding principles are provided in this regard:

- Model scenarios for TMDLs must incorporate realistic conditions, not idealized assumptions (8.4.1);
- Model sensitivity and diagnostics are essential to confident model use (8.4.2);
- Using model predictions without a defined uncertainty is irresponsible (8.4.3);
- When resource constraints are an issue, consider an adaptive approach (8.4.4); and
- Full disclosure of modeling details leads to better credibility and utility (8.4.5).

8.4.1 Model Scenarios for TMDLs Must Incorporate Realistic Conditions, Not Idealized Assumptions

The TMDL program is designed to establish loading reductions and management conditions that will lead to compliance with water quality standards. It is therefore essential that the model inputs be selected to represent realistic conditions, assumptions for background loadings and realistic expectations for future point and nonpoint source loads.

Different chapters in this research report address the issues for selecting suitable critical conditions (Chapter 7.0) and background conditions (Chapter 4.0). The reader is referred to these chapters for detail. These assumptions must not be established casually: selection of overly critical conditions and/or background loadings can result in an unfair and/or unattainable TMDL, while the opposite can lead to a TMDL that will not attain water quality standard.

It is not uncommon for inexperienced practioners to make quick and overly conservative choices for critical conditions, compounding the effects of various individual critical assumptions. The result is a combined condition that is at best extremely unlikely if not unrealistic. The responsible practioner selects a critical condition for the TMDL model simulation that matches well with the duration and frequency attributes of the standard, as well as providing a realistic representation of the watershed. The same needs to be held true for background conditions. Irresponsible or poor choices for background and critical conditions can easily undermine and discredit model development efforts.

Modeling projects often wrongly focus more on development than on applications. The forecasts can often be conducted using quick and arbitrary assumptions, when faced with a pressing schedule delayed by prolonged efforts to develop a more reliable model. It is important, however, to reserve significant schedule and budget for these final TMDL forecasts. As much thought needs to go into these simulations as went into the model development. Unreliable assumptions in these forecasts can undermine the credibility of even an exceptional model.

8.4.2 Model Sensitivity and Diagnostics Are Essential to Confident Model Use

While the primary use of the model is to define the total load required to attain water quality standards, it must also be used to provide insight on important environmental processes and the optimal means to reduce loads. Thorough model sensitivity analyses and additional model diagnostic simulations are essential steps that a modeler must undertake to ensure they have confidence in their results and recommendations. Through sensitivity analyses and component analyses, the modeler can gain insight to the relative importance of different model assumptions and environmental factors. This provides insights into one's confidence in the model results and which topic areas may need additional inquiry or investigation.

The model can also be used to generate a load response curve representing different levels of point and nonpoint source controls. Through analysis of these simulations, the modeler can establish the relative effectiveness of various proposed controls. There often is observed a point of diminishing returns from additional load reductions (the "knee of the curve"). This point of diminishing returns can be caused by uncontrollable sources, background loads, irreversible alterations, or even natural stresses. The model can provide these kinds of insights, and such information should be used to establish a practical TMDL with realistic expectations.

The results of the sensitivity and diagnostic analyses need to be summarized and reported with the model findings to allow the decision-maker full understanding of the responsiveness of the model and the sensitivity of the results to different assumptions or choices.

8.4.3 Using Model Predictions Without Defining Their Uncertainty Is Irresponsible

Models are inherently approximations of nature. In this regard, it is irresponsible to use model results as absolute to make regulatory or watershed management decisions. Since the models are approximations, they have an inherent range of uncertainty that must be defined and considered when calculating the TMDL and making recommendations for controls. The National Research Council's Expert TMDL Panel (NRC/NAS, 2001) was explicit in citing the need for uncertainty analyses, stating that uncertainty analyses need to become standard components in TMDL modeling studies.

The issue of model uncertainty (Chapter 9.0) cannot be over-emphasized. At a minimum, model uncertainty can be estimated from statistical tests employed in establishing model calibration and through sensitivity analysis. More rigorous methods are available and practiced, as discussed elsewhere. The bottom line is that any application of a model must not only provide a forecasted result, but must also include a characterization of the degree of uncertainty.

8.4.4 When Resource Constraints Are an Issue, Consider an Adaptive Approach

As described previously, model reliability and accuracy often go hand-in-hand with the need for more resources, more data, and possibly more model complexity. Unfortunately, many TMDL projects do not have the adequate resources to achieve this end. The result is a model that has significant uncertainty.

The most common problem is a lack of adequate data. TMDL model development requires significantly more data than the initial 303(d) listing process. Defining impairment requires only data on water conditions, whereas model development requires data on a wide range of factors

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including loading, environmental conditions, and numerous other important impacts. One telling example of these problems is that in a study by the General Assembly Office (GAO, 2000), only three states felt they had sufficient nonpoint source data to support TMDL development. Without data, models can be impotent and dangerous in their potential inaccuracy.

Faced with limited resources, the TMDL analyst has a choice of a simple model well done or a complex model poorly supported. The recommendation, as stated previously, is that it is better to start simple and later build complexity as data and resources become more available. A robust application of simple model is much better than weak application of a complex model.

Simple models may have limited accuracy because of spatial or temporal averaging and simplifications of system processes, but they still offer advantages. First, it is often easy to define the range of uncertainty in these models, which can be used to guide decision-making. Further, the models typically provide sufficient insight to select priority controls, estimate a TMDL, and guide needs for additional data and model complexity. Full TMDL model development then proceeds on an adaptive or iterative process.

This is consistent with the concept of *iterative modeling* recently recommended by the National Research Council (2001). In this approach, one begins with a simple screening model that is less complex than the optimum. Then, with additional data collection, one can impose the more obvious controls and continue to increase model complexity and reliability to the point where the TMDL can be completed.

The iterative modeling process does not necessarily require a complete progression to the most complex model. In many cases, the initial controls implemented by this process may be sufficient to attain water quality standards and to achieve the TMDL without using a more complex model. This adaptive approach also reduces some of the concerns related to model uncertainty and the Margin of Safety (Chapter 9.0). By incrementally increasing the level of management controls, the observed water quality response will provide a direct indication of when sufficient load reductions have been implemented (i.e., reduce loads incrementally until water quality standards are achieved).

Iterative or adaptive modeling is necessary if a given model application does not fully address the load allocation questions for the system or produces an application that demands a Margin of Safety too high relative to the objectives set forth in the problem definition. There are several points to which one can iterate in this process. First, one can return to model selection and increase model complexity to reduce uncertainty and address higher resolution questions. This would, of course, require recalibration and most likely additional higher-resolution data to conduct that recalibration. It is also possible to strategically collect additional data to reduce the MOS with the existing simpler model framework. If project constraints preclude collection of additional data and/or increasing model complexity, then it may be necessary to apply the existing framework with the existing level of uncertainty (MOS) to initiate the most obvious level of controls. This should, however, be followed by monitoring the system's response to these initial controls with the goal of post-auditing the model to reduce uncertainty and, thereby, the necessary MOS.

The concept of adaptive improvements in modeling and how it can be incorporated into the TMDL development process is described in more length (including important constraints and limitations) in Chapter 14.0. What should be emphasized here, is that TMDL modeling can often be viewed not as a single, one-shot effort, but as an evolutionary/adaptive process.

8.4.5 Full Disclosure in TMDL Modeling Leads to Better Credibility and Utility

Modeling combines both art and science, and typically involves many assumptions. It is therefore essential that the development and use be fully transparent through comprehensive documentation of all inputs, assumptions, representations, and results. "Black box" modeling, wherein only selected inputs and results are provided, is inappropriate for TMDL application. Model credibitility is best enhanced by communicating fully the nature and limitations of the modeling. This is best facilitated by comprehensive documentation.

It is important that all aspects of the TMDL modeling process be clearly explained and documented. This includes description of the following:

- Problem definition and conceptual model development
- Data syntheses
- Model selection and justification
- Model theoretical formulations
- Model site-specific configuration and key assumptions
- Model calibration and confirmation
- Model applications
- Model sensitivity and uncertainty analysis
- Limitations and recommended improvements

This will allow stakeholders and decision-makers to fully understand the utility and limitations of the model. TMDLs often involve costly or imposing recommendations. These decisions are best made when one fully understands the reliability and uncertainty of modeling tools used to support the decision. The rejection of model results is often more a result of poor communication and limited disclosure than poor analysis.

Model documentation should be simple enough to convey key assumptions and important limitations to the non-modelers, but supplemented with enough detail so that model reviewers can critically evaluate the effort, if not duplicate it.

8.5 Future Research Needs

The focus in this chapter was not research-oriented; rather, it focused on guiding principles to allow routine application of models by TMDL practitioners. Although not discussed specifically in the chapter, many research needs still exist related to modeling in the TMDL process. These include research into:

- Continued development of models that best describing our evolving understanding of the behavior of natural systems. This includes models that convert narrative standards into quantitative targets;

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- Continued development of models that can incorporate spatially detailed remote sensing data;
- Continued development of models that link physical transport processes with water quality processes;
- Continued development of linked watershed-receiving water body models;
- Continued development of decision support systems that incorporate process model results in the decision process;
- Improvements in computational efficiency for complex models; and
- Research to improve our ability to quantify the relationship between model complexity, data availability, and model uncertainty.

CHAPTER 9.0

ESTIMATING THE MARGIN OF SAFETY

Total Maximum Daily Loads (TMDLs) are required to include a Margin of Safety (MOS) to account for uncertainty in TMDL calculations. The Margins of Safety in the TMDLs reviewed for this project were found to be selected largely on an arbitrary basis. This problem is caused by the absence of guidance in how to define an MOS, as well as practical difficulties in defining TMDL uncertainty.

This chapter provides a range of options for better defining the MOS. Three different methods are described that vary based upon the degree of rigor desired and the capabilities of the TMDL developer.

The following sections provide an overview of the Scientific and Policy Issues (Section 9.1), followed by the Attributes for Improved Use of MOS (Section 9.2), then Improved Methods (Section 9.3), and Examples of Improved Methods (Section 9.4).

9.1 Overview of Scientific and Policy Issues

An MOS, designed to account for uncertainty in TMDL calculations, is a required element of a TMDL (40 CFR 130.33(b)(7)). The standard equation defining a TMDL includes a Margin of Safety component, i.e.:

$$TMDL = \Sigma WLA + \Sigma LA + MOS \qquad (9.1\text{-}1)$$

where:

ΣMDL = maximum pollutant load a receiving water can assimilate and still attain water quality standards
ΣWLA = total allowable loading allocated to point sources (wasteload allocation)
ΣLA = total allowable loading allocated to nonpoint sources (load allocation)
MOS = Margin of Safety

The MOS can be expressed explicitly as unallocated assimilative capacity, or can be incorporated implicitly in the TMDL through the use of conservative assumptions when calculating the allowable load (U.S. EPA, 1991a).

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This section highlights the need for improvements in how the MOS is currently being defined in TMDLs, followed by a more detailed summary of the basic problems.

9.1.1 Why Improvements Are Needed

It is widely recognized by water quality professionals that the MOS component of TMDLs is not being addressed adequately. The primary concerns are that the uncertainty in TMDL calculations is not being assessed in a rigorous manner, and that the approaches currently used vary widely (arbitrarily) on a site-specific basis. Evidence for these concerns comes from the following sources: 1) NRC TMDL Review; 2) Review of State Program Survey; and 3) Review of Approved TMDLs

The National Research Council Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction has recognized the arbitrary way in which the Margin of Safety has been applied. Specifically, its Executive Summary contains the following recommendation (NRC/NAS, 2001):

> "The TMDL program currently accounts for the uncertainty embedded in the modeling exercise by applying a Margin of Safety (MOS); EPA should end the practice of arbitrary selection of the MOS and instead require uncertainty analysis as the basis for MOS determination."

This panel of experts basically characterized the current MOS practices as varied, arbitrary and unscientific. This observation was confirmed through the project team's research investigating current practices in various state programs and individual TMDLs.

A survey of state TMDL programs conducted during the Problem Identification phase of this study found that six of the eight states surveyed in depth had no standardized procedure for defining the MOS. The approach for incorporating an MOS into a TMDL is typically conducted on a site-specific basis for these states, leading to wide variability in how the MOS was calculated across TMDLs.

These observations were further confirmed in the project team's review of 176 individual TMDLs (Appendix A). The review first looked at whether an implicit or explicit MOS was used. For the explicit TMDLs, the review looked at how the explicit MOS was determined. For the implicit cases, the review investigated how the level of protectiveness associated with the MOS was estimated. Of the 176 TMDLs reviewed, 103 (58%) specified an explicit MOS and 56 (32%) used an implicit MOS. For the remaining 17 (10%), it was not clear from the documentation if or how the MOS was estimated. The MOS may have been estimated implicitly, but the documentation did not provide any supporting information. Of the 103 TMDLs that used an explicit Margin of Safety, 102 arbitrarily selected a safety factor. Only one TMDL explicitly calculated the uncertainty in the analysis and reflected this uncertainty in a Margin of Safety. None of the 56 implicit TMDLs provided any indication of the degree of protection provided.

A second review, conducted independently of this study, investigated how the MOS was considered in TMDLs (Dors and Tsatsoros, 2001). They found 17 cases (31%) of an explicit MOS being used, and 37 cases (69%) of an implicit MOS. Sixteen of the 17 explicit Margins of

Safety were arbitrarily selected. For the explicit MOS cases, the Margin of Safety ranged from 5 to 90% of the TMDL value.

Overall, the opinions of the experts and the evidence of how MOS is currently used in practice demonstrate major inadequacies in the current implementation of this TMDL requirement.

9.1.2 Summary of Problems

The problems that presently inhibit the proper application of MOS may be characterized as:

1. Limited practical experience in defining the uncertainty in the TMDL calculations.
2. Absence of information regarding the degree of protection provided by the MOS.
3. Data poor/high uncertainty situations can result in MOS values so large as to make implementation impractical.
4. Incomplete consideration of existing safety factors prevents a complete understanding of the true level of protection provided.

Each of these issues is discussed below.

9.1.2.1. Limited Practical Experience in Defining Uncertainty

The first problem in defining an MOS that accounts for uncertainty in the TMDL pertains to calculation of the uncertainty itself. The National Research Council (2001) highlighted the absence of practical experience and guidance in calculating model uncertainty, stating:

> "EPA needs to provide guidance on model application so that thorough uncertainty analyses will become a standard component of TMDL studies."
> "To date, we know of no thorough error propagation studies with the mechanistic models favored by EPA...Further, the track record associated with even limited uncertainty analysis is not encouraging for water quality models in general."
> "The need for understanding the prediction uncertainty of chosen models is not new. Indeed, recent TMDL modeling and assessment guidance from EPA often mentions the importance of formal uncertainty analysis in determining the MOS (U.S. EPA, 1999b). However, EPA has consistently failed to recommend predictive models that are amenable to thorough uncertainty analysis or provide adequate technical guidance for the reliable estimation of prediction error."

Model uncertainty can come from many sources. These include insufficient data (on external forcing functions and state variables) to allow for rigorous model calibration; incomplete model frameworks whose equations may not accurately represent the system; and uncertainty in the future environmental conditions for which the TMDL will be developed.

Techniques do exist for estimating model uncertainty (e.g., Beck, 1987), but their application has been primarily restricted to the research arena. Activity in the area of defining uncertainty for purposes of calculating a MOS has been increasing (e.g., Dilks and James, 2001; Zhang and Yu,

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2001), but is still rare. Many of the uncertainty analysis techniques are described briefly in Section 9.5.

9.1.2.2 Absence of Information Regarding Degree of Protection

The second limitation in the current TMDL approach pertains to the absence of information regarding the degree of protection to be provided by the MOS. As described below, most TMDLs neither specify the desired degree of protection to be provided, nor the level of protection expected to be provided by the selected MOS.

Current regulations require that TMDLs contain an MOS that accounts for uncertainty, with no detail on the desired degree of "safety" to be provided. Even if TMDL uncertainty could be calculated, it is not clear from existing TMDL rules or guidance how this uncertainty should be factored into calculation of the MOS. Presumably, the MOS is designed to provide a given degree of certainty that the water quality standards will be met. Practically speaking, the specific degree of protection to be provided has a large bearing on the size of the MOS. If, as an extreme example, the MOS is designed to provide 99.99% assurance that water quality standards will be attained, its magnitude will approach the magnitude of the TMDL, and little to no external loading will be allowed. Conversely, if only a 50% assurance of water quality standards compliance is required, the required MOS could approach zero, relying on the best estimated values in the TMDL analysis.

Along with failing to specify the desired level of protection to be provided by the MOS, the overwhelming majority of the TMDLs reviewed for this study also lack any information regarding the level of protection expected to be provided by the MOS. Explicitly specified Margins of Safety currently allocate an arbitrary portion of the loading capacity to the MOS, with little correlation to model uncertainty and no thought to whether the MOS will provide protection at the 51% or 99% confidence level. Implicitly calculated Margins of Safety rarely document the degree of protection provided, nor do they even provide any indication of the magnitude of the MOS that is incorporated into the TMDL.

9.1.2.3 Barriers to Implementation

There are other practical considerations that affect determination of the MOS. Many TMDL sites have limited data, meaning that the uncertainty in TMDL calculations will often be large. This means that if an MOS is designed to provide high assurance that standards will be met, it would be extremely large, leaving little load available for allocation to sources. Dilks (2000) concludes that that rigorous consideration of the MOS could lead to the requirement for extensive load reductions at sites with data limitations and high uncertainty. Extremely high MOS values will lead to reluctance on the part of affected stakeholders to implement required controls.

The Margin of Safety is designed to account for uncertainties in defining the relationship between pollutant loads and resulting water quality. Sites with inadequate data will have a high degree of uncertainty, which would lead to a large MOS. The TMDL equation can be rearranged to define the total allocated load (i.e., the sum of all WLAs and LAs), as follows:

$$\text{Total Allocated Load} = \text{TMDL} - \text{MOS} \qquad (9.1.2.3\text{-}1)$$

This equation demonstrates that the total allowable load will decrease as the MOS increases. This decrease in allowable load directly translates into an increase in the magnitude (and cost) of required pollution controls. As a result, the following progression can be expected for development of detailed implementation plans for many TMDLs with limited data:

1. Inadequate data leads to high uncertainty
2. High uncertainty leads to high MOS
3. High MOS leads to small allowable load
4. Small allowable data load translates into extensive requirements for control

Parties affected by TMDLs will therefore be required to implement the largest amount of control on those sites where the data are weakest. This will be an unacceptable situation for most stakeholders, who will demand that extensive pollution control efforts be based upon scientific understanding gained from a sufficient amount of site-specific data.

Zhang and Yu (2001) also recognize this limitation, stating: "In practice, there should be an upper limit for the Margin of Safety. This maximum MOS...can be established based on the requirement of the regulatory agencies or based on administrative considerations...A MOS exceeding 10% of the TMDL may be too conservative for load allocations."

The conclusion is that rigorous interpretation of Margin of Safety rules for data-poor sites will lead to reluctance on the part of affected parties to implement what they believe to be largely unnecessary reductions based upon limited data. Adaptive management approaches, which initially allow less than a full Margin of Safety to be implemented at the onset of a TMDL, have been successfully used to address this problem at some sites, and are discussed in greater detail later in this section.

9.1.2.4 Incomplete Consideration of Existing Safety Factors

Multiple safety factors exist in the current system of water quality protection, beyond those provided for by the TMDL Margin of Safety. These include safety factors used in the derivation of water quality standards, as well as safety factors used in the development of NPDES permit limits. None of the TMDL studies reviewed during this research considered the cumulative degree of protection provided by all of these safety factors.

Additional research is needed to define the cumulative effects of the multiple safety factors that exist throughout the water quality protection process. Once these effects are defined, guidance is required defining extent to which these cumulative safety factors should be considered when defining the TMDL Margin of Safety.

9.2 Attributes of Improved Use of MOS

The previous section outlined four major problems evident in the existing application of MOS in the TMDL program. In developing recommendations and methods to improve on the use of MOS, these problems must be properly addressed in a manner that can be widely applied throughout the TMDL program. Additionally, proper inclusion of a Margin of Safety must meet the statutory requirements of the TMDL rules. The four attributes that satisfy the required needs

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are: 1) Account for uncertainty in TMDL calculations; 2) Consider degree of protection; 3) Address data limitation/implementation concerns; and 4) Be feasible to conduct on a widespread basis.

Each attribute is discussed below.

To account for uncertainty in TMDL calculations is a requirement of the TMDL rule. Furthermore, it is desirable for the MOS to *directly* account for this uncertainty, rather than address it through the use of arbitrarily selected safety factors. The NRC/NAS (2001) report recognizes this need, concluding, "Uncertainty must be explicitly acknowledged both in the models selected to develop TMDLs and the results generated by those models," as well as, "EPA should end the practice of arbitrary selection of the MOS and instead require uncertainty analysis as the basis for MOS determination."

A second desired attribute of an appropriate Margin of Safety is explicit consideration of the **degree of protection** provided. The desired degree of protection is most directly stated as a probability that the water quality standard will be attained if the TMDL is implemented. The specific magnitude of this degree of protection is ultimately a policy decision; however, specification of a scientifically credible Margin of Safety must begin with this policy input. Several factors need to be considered in defining the desired degree of protection. The relative importance of the affected community is a consideration; for example, as human health considerations would likely require a greater degree of protection than aquatic life. The ramifications of failing to comply with the standard should also be considered, as minor impacts would require less assurance of protection than catastrophic ones. Once the desired degree of protection is specified, the MOS used in the TMDL should be selected to be consistent with this degree of protection.

A third attribute is that the proper incorporation of the Margin of Safety into a TMDL must also account for the practical reality that extremely large Margins of Safety, expected for many data-poor situations, will typically lead to **delays in implementation**. The specific means to deal with this issue is also a policy decision, but should be factored into the overall approach.

Last, **widespread applicability** is important. The NRC/NAS (2001) report recognizes that the limited experience base available related to conducting uncertainty analysis provides a practical limitation to properly calculating a Margin of Safety. This attribute recognizes this limitation by requiring an approach that can be immediately applied on a widespread basis. Widespread applicability is not reflective of a good individual TMDL, but the attribute of a good overall approach for determining a Margin of Safety.

9.3 Improved Methods

An improved approach for incorporating the MOS into the TMDL process is diagrammed in Figure 9-1. It is divided into four main steps, allowing the use of different methods for defining the MOS:

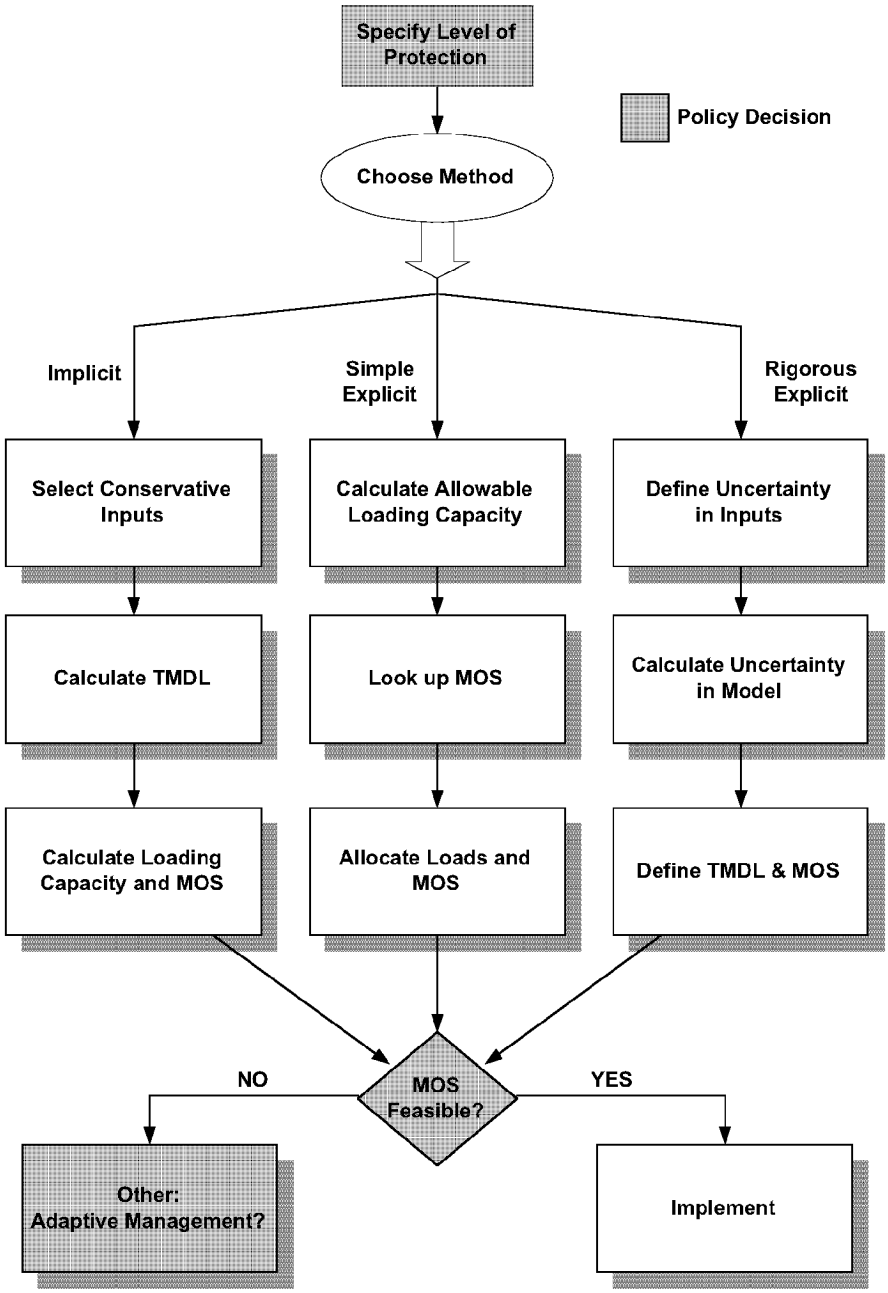

Figure 9-1. Diagrammatic Flowchart of Improved Approach to MOS.
The steps are explained in Section 9.3.

1. Specify Desired Level of Protection
2. Choose Method
3. Calculate MOS
4. Consider Implementation Feasibility

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The third step of calculating the MOS can be done either implicitly or explicitly, depending upon the capabilities of the TMDL developer. Each step is described below.

9.3.1 Step 1: Specify Level of Protection

An essential first step in incorporating a Margin of Safety is specification of the degree of safety (i.e., level of protection) to be provided. This is essentially a policy decision, and is a required part of the process. In the simplest case, the level of protection can be specified as a probability of complying with the water quality standard.

The desired level of protection may vary on a site-specific basis to meet policy needs. For example, human health considerations may require a higher degree of protection than aquatic life issues. The specific format of the level of protection may also vary, i.e. it need not be specified as a probability. The means by which the level of protection is specified is not important; however, it is essential that some explicit description of the desired level of protection be provided to allow the MOS calculation to proceed.

9.3.2 Step 2: Choose Method

The next step in the process is to choose the method to be used to calculate the MOS. The improved method will allow for three alternative approaches: implicit, simple explicit, and rigorous explicit.

A range of alternatives is provided only because the desired attributes of incorporating the MOS into TMDLs are somewhat contradictory. Accurately calculating the uncertainty in model predictions is to a large part not feasible for widespread application. The NRC/NAS (2001) explicitly identified this dilemma, calling for the use of rigorous uncertainty analysis but recognizing the absence of tools or guidance to allow the analysis to be conducted on a widespread basis. This is an appropriate long-term solution because it is the only option that rigorously defines uncertainty; however, it will not facilitate proper selection of the MOS in the interim.

The improved approach will allow the TMDL developer three options with various levels of difficulty, consisting of:

1. An implicit approach that considers the degree of protection by using conservative assumptions but can be applied without extensive training in uncertainty analysis;
2. A simple explicit approach that defines a Margin of Safety as a percentage of the total TMDL, with the percentage selected based on guidelines; or
3. A rigorous explicit approach that directly calculates the degree of protection, but requires specialized capabilities to perform.

Each of these approaches is reviewed in Section 9.3.3.

The use of the implicit method is recommended only as an interim measure for the TMDL program until more rigorous uncertainty analysis methods can be employed on a widespread basis. Even with the improvements provided here, the implicit method has severe limitations. Foremost among these limitations is an inability to define the degree of protection provided when there is more than one uncertain input. Continued long-term use of the implicit method to

define the TMDL Margin of Safety is discouraged, and explicit methods should be employed as soon as is feasible.

9.3.3 Step 3: Calculate MOS

The approach taken for this third step differs depending upon whether the implicit, simple explicit, or rigorous explicit approach is taken. All three approaches yield an MOS; however, they differ in the degree of rigor and the resources required to conduct the analysis. Each method is described below.

9.3.3.1 Implicit Method

The implicit method introduces a Margin of Safety through the use of conservative assumptions used in calculating the allowable load compared to the loading capacity calculated using nonconservative assumptions. This method is relatively easy to apply, in that it requires no complex calculations or uncertainty analysis. The TMDL developer chooses appropriately conservative values for uncertain model inputs, and the resulting TMDL directly includes the MOS.

The problems with the implicit method are: 1) there is no guidance regarding how to choose "appropriately" conservative input values, nor understand the degree of protection they provide; and 2) the magnitude of the resulting MOS is unknown. The improved approach provides initial guidance towards addressing the first problem, and directly addresses the second problem. As seen in Figure 9-1, it includes three component steps: 1) Select conservative inputs, 2) Calculate the TMDL, and 3) Estimate MOS.

In the first step, conservative values are selected for the TMDL model inputs that are deemed uncertain. Some general guidance can be provided in terms of selecting input values and determining their degree of protectiveness. The analysis is relatively straightforward for the (admittedly rare) case where there is only a single uncertain input parameter. In this situation, a Margin of Safety that is protective at the 90% confidence level can be obtained by selecting a conservative value for the input parameter that is not exceeded 90% of the time. The approach of selecting a conservative input values consistent with the degree of protection desired for the TMDL can be extrapolated for the case where there are only few input values, while recognizing that the degree of protectiveness of the TMDL will be somewhat larger than desired (because of compounding safety factors). The approach breaks down when there are numerous uncertain inputs. In these cases, the degree of protectiveness must be inferred from the magnitude of the calculated Margin of Safety as described below.

In the second step, the TMDL is calculated identically to the way in which the implicit MOS method is currently applied, i.e. using the conservative inputs defined in Step 1. The watershed/water quality model is applied using the conservative input values, and the maximum allowable pollutant loads that maintain compliance with water quality standards are defined. This step defines the TMDL that contains the implicit MOS.

The final step provides an explicit estimate of the Margin of Safety. It is conducted by replacing the conservative input values that were used to determine the TMDL with best-estimate values for each parameter. The TMDL analysis/modeling is then re-applied using the

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best-estimate input values, and the best estimate of the loading capacity is defined. The Margin of Safety can then be defined as the difference in allowable load between that calculated using the conservative inputs (i.e., the TMDL) and the load capacity using best estimates. The resulting equation is:

$$\text{MOS} = \text{Best estimate of loading capacity} - \text{TMDL with Implicit MOS} \qquad (9.3.3.1\text{-}1)$$

This step in no way affects the TMDL. It is strictly designed to provide a quantitative estimate of the magnitude of the MOS. It should also be noted that the final TMDL value does not include an explicit MOS, but rather that the total TMDL loading has been implicitly reduced by the conservative assumptions, and that the above process merely quantifies the equivalent effect of this MOS.

9.3.3.2 Simple Explicit Method

The simple explicit approach, in contrast to the implicit approach, explicitly includes a value for the Margin of Safety in the TMDL allocation process. This approach first calculates the allowable loading using the best possible values and no consideration of safety factors. In the second step, the TMDL developer would look up a pre-determined Margin of Safety that was most relevant to the site application. This involves setting aside a specified percentage of the loading capacity for a margin of safety. This MOS would be based on guidelines provided by the U.S. EPA or states. These guidelines would consider the water quality parameter of concern, and could also consider the rigor of data and/or modeling analysis, as well as the desired level of protection.

Application of this approach would ideally require additional research, where the uncertainty in a range of TMDL case examples was explicitly calculated, and the results tabulated to develop guidelines. The results of these rigorous uncertainty analyses could be compiled and provided in tabular format such as that shown in Table 9-1. This table shows hypothetical appropriate Margins of Safety to be used for DO TMDLs, stratified by model complexity and available data. Separate tables could be generated for different types of TMDLs, and the analysis could be further stratified to consider desired level of protection. This table is purely illustrative and should not be construed as explicit recommendations of MOS values.

Table 9-1. Illustrative MOS Table for Simple Explicit Approach for Dissolved Oxygen TMDLs.

	Illustrative Magnitude of MOS		
	No calibration data	Calibration data available	Calibration and validation data available
Streeter-Phelps DO equation	20%	15%	10%
Qual-2E type analysis	25%	15%	7.5%
Time-variable DO model	30%	10%	5%

The MOS specified and calculated from the second step would then be subtracted from the allowable loading capacity determined in the first step to define the TMDL and permit the allocation of remaining loads to sources.

9.3.3.3 Rigorous Explicit Method

The rigorous explicit method would provide the most direct consideration of model uncertainty in determining the MOS. The TMDL developer would calculate the uncertainty in model predictions, and then explicitly define the MOS based upon this uncertainty and the desired level of protection. It comprises three component steps (Figure 9-1):

1. Define uncertainty in inputs
2. Calculate uncertainty in model
3. Define TMDL and MOS

The specific means by which these steps are conducted would depend upon the uncertainty analysis method selected, as Monte Carlo uncertainty analysis would require different activities from first-order error analysis. In general, however, the uncertainty in the model input must be characterized, and these uncertainties translated into uncertainty in model results.

From a practical standpoint, Step 3 must be conducted in an iterative fashion, to define the loads necessary to achieve compliance with water quality standards with the desired level of protection. For example, consider the case with a desired 90% level of certainty of compliance. For a given loading scenario, the probability of compliance with water quality standards is determined based upon the uncertainty calculated in Step 2. Assuming that the predicted probability of compliance is less than 90%, the allowable load is reduced and the analysis repeated. Different loading scenarios are tested until the load that provides the desired level of compliance is determined. This load corresponds to the $\Sigma WLA + \Sigma LA$ terms in the TMDL equation.

The above approach defines the allowable load that provides the desired certainty of compliance with water quality standards. At this point, though, an explicit value for the MOS has not yet been defined. The magnitude of the Margin of Safety is calculated by performing another set of iterative analyses, to define the total load that results in a 50% compliance with water quality standards. The difference between the load that results in a desired probability of compliance, and the load that results in a 50% probability of compliance, is the Margin of Safety.

Calculation of the MOS using the explicit approach is demonstrated in Figure 9-2. Model results for each loading scenario are plotted as a family of curves representing the cumulative probability distribution for in-stream concentration. The probability of compliance with water quality standards is examined for each scenario. As shown in Figure 9-2, the daily loading scenario of 70 pounds results in a 90% probability of compliance with the water quality standard. This means that the maximum allowable daily load is 70 pounds. The second curve on Figure 9-2 shows the results for the 100 pounds scenario, which has a 50% probability of complying with standards. The MOS for this TMDL is therefore 30 pounds (i.e., 100 minus 70).

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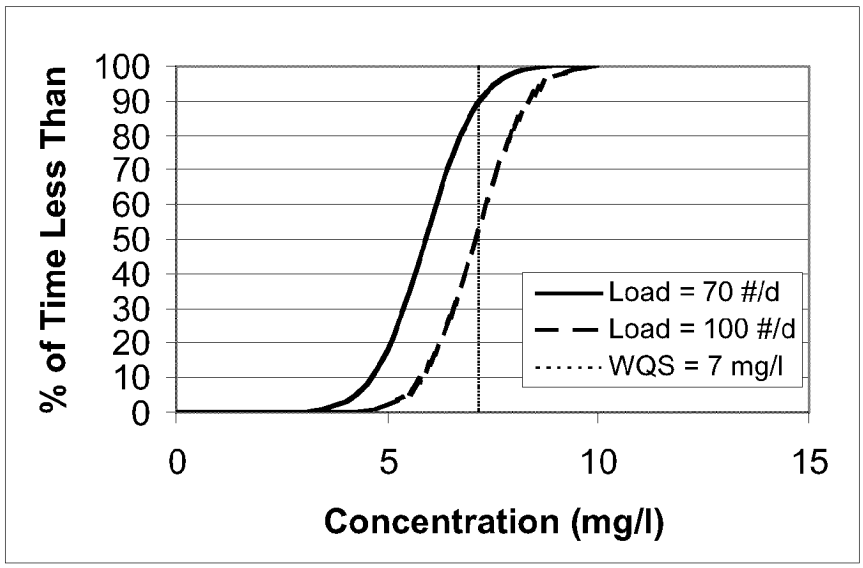

Figure 9-2. Graphical Representation of Calculation of MOS Using the Rigorous Explicit Method.

9.3.4 Consider Implementation Feasibility

The final step of the revised Margin of Safety approach requires a decision regarding whether the MOS can be feasibly implemented. While it is recognized that this is primarily a policy decision, it is appropriate to describe some of the factors that determine implementation feasibility. These factors include:

- ***Magnitude of the MOS:*** The magnitude of the MOS itself will play a primary role in its acceptance. An MOS that accounts for 80% of the total allowable load will be more likely to be challenged than one that accounts for 20% of the total allowable load.
- ***Additional Cost:*** Another important factor in determining the feasibility of the MOS is the additional cost of implementation relative to a less conservative MOS. Marginal costs of treatment generally increase as the level of treatment increases; a significant increase in marginal cost for an uncertain benefit may argue for reconsideration of the MOS.
- ***Site-Specific Considerations:*** This factor is designed to consider the importance of protecting an individual site. The policy decision may be made to ensure that certain waters are ensured of near-term compliance regardless of cost; while other waters may appropriately allow a lower degree of certainty when the degree of potential harm is less or the economic considerations of a large MOS are considered.

If the MOS is judged too large to be feasibly implemented, an alternate implementation scheme may be selected. A policy decision is again required regarding the alternate approach, but the framework to be considered would consist of reducing the required degree of certainty that standards would be immediately attained, followed by additional monitoring and adaptive management. As an extreme example, one could include no explicit Margin of Safety and allocate all the available loading capacity calculated using the best estimates for inputs. Without a Margin of Safety, this would imply a 50% probability of compliance, since actual values would be equally likely greater or less than the best estimates. Post-implementation monitoring would

be conducted to determine if water quality standards attainment was achieved from the initial implementation; if not, the TMDL would be revised to include additional controls.

9.4 Examples of the Improved Method

This section provides case study examples where different aspects of the improved MOS approach were applied to real-world TMDLs. One example is provided for each: the implicit approach (Section 9.4.1) and the rigorous explicit approach (Section 9.4.2). No examples are provided on the simple explicit approach, because it differs little from the existing practices of setting aside a percentage of the load for MOS. It only differs in how this value is selected, a procedure not yet fully developed.

9.4.1 Implicit Approach

The Geddes Pond, Michigan, pathogen TMDL (LTI, 2000) used an implicit approach to defining the MOS that was consistent with many aspects of the improved approach defined here.

Lower Geddes Pond was placed on Michigan's 303(d) list because of impairment of recreational uses by elevated levels of pathogens, and required the development of a TMDL for the indicator bacteria *Escherichia coli*. Bacteria standards are exceeded during both wet and dry weather, but more commonly during wet weather. The available data were sufficient to indicate that tributaries draining urban watersheds in the Ann Arbor area were the major source of bacteria loads to the study area. The primary contributing sources were believed to be illicit sanitary sewer connections to the Ann Arbor stormwater system; pet feces in public places and private yards; wildlife feces in the watershed and in Gallup Park; and malfunctioning on-site wastewater treatment systems.

A simple, steady-state, spreadsheet-based first-order loss model was used to calculate the relationship between external loads and resulting in-stream concentrations. The model is based on the assumption that external load, dilution, in-stream transport, and decay are the primary processes affecting bacteria concentrations. The model can be expressed mathematically by Equations 9.4.1-1 and 9.4.1-2. Equation 9.4.1-1 describes how concentrations change downstream of a specific location, while Equation 9.4.1-2 describes the dilution of an external load as it enters the river.

$$C_x = C_0 e^{-kx/u} \qquad (9.4.1\text{-}1)$$

$$C_0 = (C_{up}Q_{up} + C_wQ_w)/(Q_{up} + Q_w) \qquad (9.4.1\text{-}2)$$

where:

C_x = Bacteria concentration in Huron River at distance x downstream of initial point (counts/volume of water)
k = First-order bacteria decay rate (1/time)
u = River velocity (length/time)

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C_0 = Bacteria concentration in Huron River after initial mixing with a waste load (counts/ volume of water)

C_{up} = Bacteria concentration in Huron River immediately upstream of mixing point (counts/volume of water)

Q_{up} = Huron River stream flow immediately upstream of mixing point (volume of water/time)

C_w = Bacteria concentration in waste load (counts/volume of water)

Q_w = Waste flow rate (volume of water/time)

The spreadsheet model considers six unique loading sources to the Huron River: Allen Creek, Traver Creek, Millers Creek, Malletts Creek, Swift Run, and direct stormwater drainage. Equations 9.4.1-1 and 9.4.1-2 were applied in a sequential manner in a computer spreadsheet, starting at the upstream boundary of the segment and proceeding downstream to include each potential waste load.

A rigorous application of this model would have required sufficient data to define all existing source loads and stream velocity to calibrate an in-stream bacterial decay rate. These data were not available for the Huron River in the area of interest. Instead, the model was applied for TMDL purposes, using a literature value for the bacterial decay rate to define the maximum allowable bacterial loading rate that will maintain compliance with water quality standards. A decay rate of 0.5/day, representing the lower end of the expected decay rate, was selected.

The allocation strategy for this TMDL allowed equal bacteria loads per unit land area for all lands within each watershed. Maximum allowable loads per tributary were determined for each month of the recreational season (May through October) by gradually increasing the watershed loads in the model until the water quality standard was reached. These loads defined the load allocation and wasteload allocation for each source, with an implicit MOS.

The water quality model used to develop this TMDL was relatively simple, as it is based only on the principles of dilution and decay. The dilution calculation is based upon the principle of conservation of mass, and contains no uncertainty. The amount of in-stream decay is the only potential source of model uncertainty. Chapra (1997), Thomann and Mueller (1987), and Mancini (1978) all recommend a bacterial decay rate (k) for freshwater modeling purposes following the formula:

$$k\ (1/\text{day}) = 0.8 \times 1.07^{(T-20)} \qquad (9.4.1\text{-}3)$$

where:

T = water temperature

For a typical summertime water temperature of 25°C, this corresponds to a decay rate of 1.1/day. Zison et al. (1985) list a range of coliform-specific disappearance rates used in several modeling studies. The average value of these decay rates is 1.7/day at 20°C. The decay rate of 0.5/day used in this TMDL is less than half of the typically recommended value, and served as a conservative value.

The magnitude of this implicit Margin of Safety was calculated by conducting an independent TMDL calculation, using a more "typical" bacterial loss rate of 2.0/day. The wasteload and load allocations resulting from this calculation were 7% higher than those determined using the lower bound decay rate for typical summer flows, meaning that the Margin of Safety included in this TMDL was approximately 7%. This MOS changes as a function of river flow, as the lower velocities that occur during low flows make in-stream decay a more important process. As such, the margin of safety was greater than 7% for lower than average flows, and less than 7% at greater than average flows. This relatively low Margin of Safety compared to other TMDLs results because the only source of uncertainty in the model, the estimate of in-stream decay, has relatively little effect on bacterial concentrations during the relatively short residence time in Geddes Pond.

9.4.2 Explicit Approach

The Muddy Creek, Virginia, nitrate TMDL (Zhang and Yu, 2001) provides an example of explicitly specifying the degree of protection provided by a Margin of Safety.

The Muddy Creek watershed is located in Rockingham County, approximately 15 miles to the west-northwest of Harrisonburg, Virginia. Virginia's water quality standards for nitrate in the reaches designated for drinking water is 10 mg/L nitrate as nitrogen. Historically, elevated nitrate concentrations have been recorded in Muddy Creek.

Excess nitrogen loading is attributed to both point sources and nonpoint sources in the watershed. The only active and significant permitted point source within the watershed is a poultry processing industry. In general, nonpoint source nitrogen originates from residential, agricultural, and natural sources. Specific nonpoint sources include land application of cattle manure and poultry litter, runoff from concentrated animal operations, grazing livestock, nitrogen-based fertilizer applications to agricultural and residential lands, septic tanks, atmospheric deposition, wildlife waste, and decaying organic matter. The watershed/water quality model HSPF was calibrated to describe both the hydrology and water quality of the Muddy Creek system (Zhang et al., 2001).

Model uncertainty was calculated and factored into the MOS determination in a five-step process:

1. Determine the key parameters in the model
2. Calculate the sensitivity of model results to changes in the key parameters
3. Estimate the uncertainty of each key parameter
4. Propagate input uncertainty into model results
5. Calculate MOS

Each step is described below.

Step 1: Determine Key Model Parameters Causing Uncertainty. Model sensitivity analyses were conducted, in conjunction with literature reviews, to determine which input parameters were primarily responsible for the uncertainty in model predictions. Two categories of key parameters were identified:

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1. Rainfall (hourly precipitation data);
2. Water quality parameters associated with the nitrogen cycle simulation.

The nitrogen cycle parameters include the nitrification coefficient, denitrification coefficient, ammonia volatilization coefficient, and adsorption coefficient of ammonia on sand, silt and clay, as well temperature correction coefficients.

Step 2: Calculate the Sensitivity of Model Results to Key Parameters. First-order error analysis requires a description of the change in the output variable in response to a unit change in the input parameter of interest (Section 9.5). This derivative can be calculated analytically for simple models; but for as complex a model used for Muddy Creek as HSPF, a finite difference approach was used to determine this derivative. With the finite difference approach, numerous model sensitivity analyses are conducted, with each key input parameter being individually varied by a small amount. The results of the Muddy Creek sensitivity analysis runs were tabulated, and the derivative Δoutput/Δinput was calculated for each input. The model state variable of concern for this TMDL was the in-stream nitrate-nitrogen concentration.

Step 3: Estimate the Uncertainty in Each Key Input Parameter. The next step in first-order error analysis was to define the magnitude of the uncertainty in each of the key parameters, in terms of a variance or coefficient of variation. This uncertainty is difficult to define on a site-specific basis, especially for those parameters which are not measures of actual physical characteristics of the watershed, but are obtained through model calibrations (e.g. kinetic reaction coefficients). For the Muddy Creek TMDL, the uncertainty of each parameter was estimated from the scientific literature.

Step 4: Propagate Overall Input Uncertainty to Model Output. First-order error analysis automatically provides two key types of uncertainty output: 1) the overall uncertainty in model results; and 2) the fraction of the total uncertainty contributed by each uncertain parameter. The overall uncertainty is of concern for Margin of Safety purposes, and is expressed as a variance around the model calibration.

Step 5: Conversion of Overall Model Output Variance to the Margin of Safety. The result of the first-order error analysis is expressed as a variance around the model output. This variance can be translated into a Margin of Safety (Figure 9-2).

The Muddy Creek TMDL set the desired probability of compliance at 84%, corresponding to one standard deviation above the average concentration as predicted by the first-order error analysis. No specific rationale was provided for choosing this level of protection other than the statement, "It appears that selecting one standard deviation of the output concentration of the MOS is reasonable and practical in this application."

The Muddy Creek TMDL demonstrates that it is possible to explicitly determine a Margin of Safety that provides a pre-specified level of assurance that water quality standards will be achieved. For this example, the level of assurance was set by the TMDL developers. For other situations, the level of assurance may be a state policy decision.

9.5 Model Uncertainty Analysis Techniques

The most commonly used methodologies to define the uncertainty in model predictions are:

- Sensitivity analysis
- First-order error analysis
- Monte Carlo analysis

Each of the above methodologies is described in this summary. The discussion consists first of a brief description of the method and its availability for application to water quality models, followed by a discussion of the advantages/disadvantages of each method, and concluding with commentary on the applicability of each method to define model uncertainty in the TMDL and NPDES process.

9.5.1 Sensitivity Analysis

Sensitivity analysis is a simple method designed to define the uncertainty in model outputs caused by the uncertainty in any single model input. It is merely an initial step as part of an uncertainty analysis and should not be considered an uncertainty analysis technique in and of itself. Sensitivity analysis is typically conducted by varying one or more model coefficients, with the amount of variation in the model input representing the uncertainty in the parameter being analyzed. The uncertainty in model projections is determined by the change in model results observed in response to the change in inputs.

Sensitivity analysis can be easily applied to any model, as it can be conducted without the need for any specialized software. All that is needed is the ability to perform multiple model simulations, and the ability to track changes in results that occur in response to changes in inputs.

The primary advantage of sensitivity analysis is that it is the simplest of the uncertainty analysis methodologies to apply. It provides a direct indication of model uncertainty as caused by a single input parameter of well-defined uncertainty. Although easy to perform, it poses several limitations as an uncertainty analysis methodology. Its primary limitation is that it is designed to assess only one parameter at a time. Sensitivity analyses have been conducted that look at the joint perturbation of several parameters, in an attempt to define their overall effect on model uncertainty. Gardner et al. (1981) have shown that this approach may be valid when the uncertainty in inputs is small, but is violated when uncertainty values more typical of the real world are used. The inability to accurately consider the overall uncertainty caused by multiple uncertain parameters provides a severe limitation on the ability of sensitivity analysis to serve as a stand-alone uncertainty analysis method.

Another limitation of sensitivity analysis is that the uncertainty in each model parameter must be specified in advance as a single value, with little guidance available on selection of an appropriate value. This limitation is not restricted to sensitivity analysis, as all of the model uncertainty techniques considered here require some prior specification of the uncertainty in the model input(s) under consideration.

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9.5.2 First-Order Error Analysis

First-order error analysis (FOEA) expands upon the concept of sensitivity analysis to define the uncertainty in model output caused by the uncertainty in multiple model inputs. From a mathematical perspective, first-order error analysis consists of expanding the differential equations in the model into their respective Taylor series, and truncating all terms after the first (linear) one. The terms of each equation are combined, and can then be used to determine the variance associated with model results as a function of the uncertainty in model inputs.

A full understanding of the mathematics is not required to understand the role that first-order error analysis can play in defining model uncertainty. Simply put, the uncertainty in each model input is specified in terms of its variance (or standard deviation), and the uncertainty in model results is produced by the FOEA as a variance around the calibration value.

FOEA requires specialized software to be applied to water quality models. The QUAL2E model uncertainty analysis routines (QUAL2E-UNCAS) contain the software necessary to apply FOEA to QUAL2E results. FOEA software is generally unavailable for other water quality models, and would need to be developed on a site-specific basis. It is also possible to use QUAL2E-UNCAS to perform first-order error analysis for other models (e.g., simple stream toxics models) whose processes can be represented in the QUAL2E framework.

First-order error analysis provides an improvement over sensitivity analysis by directly accounting for the overall uncertainty in predictions caused by simultaneous uncertainty in multiple parameters. It also provides a deeper understanding of model uncertainty than for sensitivity analysis by characterizing uncertainty as a variance instead of as a single value. It also has an advantage over Monte Carlo analysis for models with long computational run-times, as numerous iterations of model simulations are not required.

The disadvantages of first-order error analysis are:

- Model predictions must be approximately linearly related to the model coefficients over the entire range of input uncertainty;
- Analyses must be conducted using QUAL2E-UNCAS, or site-specific FOEA software must be developed; and
- Results of the analysis depend solely on prior assumptions regarding the uncertainty in model coefficients.

A full understanding of the first disadvantage requires a grasp of the mathematical theory behind first-order error analysis. In simplest terms, models with non-linear equations (typically models of algal growth) are not well suited for first-order error analysis unless the uncertainty in model inputs is small. The third disadvantage, that the modeler have prior knowledge of the uncertainty in model inputs, is shared by most of the uncertainty analyses commonly in use.

9.5.3 Monte Carlo Analysis

Monte Carlo analysis provides a theoretically straightforward technique to determine the uncertainty in water quality model predictions without the assumption of linear relationships inherent to first-order error analysis. It is an iterative technique where many simulations are conducted with model inputs chosen randomly during each iteration from pre-specified

statistical distributions. These input distributions are selected to represent the uncertainty in each model parameter. The results of each model iteration are tracked, and the variability in model results between iterations represents the uncertainty in the model caused by the uncertainty in model inputs. The uncertainty in model output can be defined as precisely as desired, by performing a sufficient number of model simulations, assuming that the uncertainty in model inputs is well known.

Monte Carlo analysis requires specialized software to be applied to water quality models. The QUAL-2E model uncertainty analysis routines (QUAL2E-UNCAS) contain the software necessary to apply Monte Carlo analysis to QUAL2E results. Monte Carlo software is generally unavailable for other water quality models, and would need to be developed on a site-specific basis.

Software packages (e.g., Crystal Ball®) are available that allow Monte Carlo analysis to be easily conducted as part of a computer spreadsheet, such that any modeling effort that was conducted via spreadsheet is amenable to Monte Carlo analysis. It is also possible to use QUAL2E-UNCAS to perform first-order error analysis for other models (e.g. simple stream toxics models) whose processes can be represented in the QUAL2E framework.

The advantages of Monte Carlo analysis are the simplicity of the theory and the ability to produce rigorous uncertainty estimates for non-linear models. The disadvantages to traditional Monte Carlo analyses are:

- Application to complex models may create extreme computational requirements;
- Analyses must be conducted using QUAL2E-UNCAS or a spreadsheet model, or site-specific Monte Carlo software must be developed; and
- The uncertainty in model inputs must be well defined.

The first disadvantage relates to the fact that several thousand (or many more) model simulations must be conducted to accurately characterize uncertainty. This can be unworkable for a computationally intensive model that takes several hours or longer to perform a single simulation. The third disadvantage is common to all of the uncertainty analysis techniques presented here.

9.6 Summary of Future Research Needs

The future research needs related to improved consideration of the Margin of Safety can be divided into two general categories:

- Better definition of methods to define model uncertainty
- Better definition of converting uncertainty into a Margin of Safety

Better Definition of Methods to Define Model Uncertainty: The NRC (2001) report, as well as this research, was clear in reporting the need for additional research regarding methods to define watershed and water quality model uncertainty. Research needs exist at both a basic and applied level. From a basic level, existing uncertainty analysis techniques need to be

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reviewed, and refined as necessary, to account for issues such as errors introduced by incomplete model frameworks and correlation between input parameters. From an applied research standpoint, there is a need to apply existing uncertainty analysis to a wide range of TMDL systems. This widespread application will serve two purposes. First, it will identify any practical constraints (e.g., excessive computational times) that will need to be addressed before these techniques can be applied on a widespread basis. Second, it will begin to provide better understanding on the true relationship between model uncertainty, model complexity, and data availability. This understanding is necessary to proceed with the simple explicit approach to defining the Margin of Safety discussed previously.

Better Definition of Converting Uncertainty into a Margin of Safety: The second area of research is more policy-oriented, and equally important to rigorously incorporating the Margin of Safety into the TMDL process. Specific topic areas to be considered under this topic area include:

- Should existing safety factors in water quality standards be considered when defining the Margin of Safety?
- Should the MOS be defined to provide specific degree of assurance that the water quality standard will be attained, or that the designated use will be supported?
- How does uncertainty in BMP effectiveness factor into the MOS?
- How should implementation feasibility be considered in low data/high uncertainty situations?

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CHAPTER 10.0

APPROACHES TO THE ALLOCATION OF LOADS

The objective of this chapter is to provide TMDL developers with useful information about the range of approaches to the load/wasteload allocation portion of the TMDL. This is intended to improve TMDL developers' ability to choose and carry out an effective and defensible allocation method for the specific circumstances of a given TMDL. Because of the tremendous diversity of circumstances and environmental conditions when developing TMDLs, this study does not attempt to recommend any single approach to allocation.

10.1 Introduction

What is meant by allocation? Allocation is the apportionment, or distribution, of the available loading capacity in a given water body among point sources (referred to as wasteload allocation), nonpoint sources (referred to as load allocation), margin of safety (MOS), natural background, future growth, and any other categories of pollutant sources. By U.S. EPA regulation, TMDLs must include load and wasteload allocations when the relevant sources are present.

This chapter is different from most of the others in this document because its primary focus is a policy, rather than technical, issue. The National Academy of Sciences observed, "Allocation is first and foremost a policy decision on how to distribute costs among different stakeholders in order to achieve a water quality goal." (NRC/NAS, 2001, p.71). Yet it is clear that allocation is a policy decision that is heavily dependent on technical input, and is usually made in the context of technical discussions and model outputs. The NRC/NAS report went on to describe what the authors see as the key role for science in the allocation decision: determining when alternative actions (i.e., different allocation schemes) are "equivalent" in terms of ambient water quality outcome and level of uncertainty.

The importance of allocation can range from trivial to the most important issue of a TMDL. For many TMDLs, the allocation decision is a non-issue compared to issues such as setting the target, defining background loads, or dealing with a lack of definitive data. Examples of TMDLs for which allocation is a non-issue would include TMDLs with only one discharger, those with zero available load capacity, or those where nonpoint sources are the only sources and the decision is to assign the entire available load to nonpoint sources in the aggregate. Additional examples include TMDLs where an "obvious" allocation emerges during the

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analysis, or where stakeholders have already laid the groundwork for an allocation through local watershed planning.

On the other hand, allocation can be a crucial, high-stakes issue in some TMDLs, with the potential for extended conflict and/or lawsuits. For example, a dissolved oxygen TMDL for the Chehalis River in Washington State called for a zero allocation for six calendar months of the year. This would have imposed high costs on three point source dischargers, who challenged in court the TMDL-based permit provisions. To avoid the expense of litigation, the dischargers and the state agreed to mediate the dispute, and were able to design a flow-based, rather than calendar-based, allocation that greatly reduced the cost to the dischargers while achieving equal or better water quality results.

This chapter is organized as follows. Section 10.2 provides a brief summary of the research approach used. Section 10.3 identifies key issues and findings related to allocation outcomes and methods that emerged from detailed research into allocation approaches. Section 10.4 summarizes the federal guidance related to allocation. Section 10.5 provides more detail about the range of state approaches to allocation, summarizing four categories of approaches and providing representative state examples for each category. Finally, Section 10.6 provides concluding observations and two recommendations that emerged from this research. A brief summary of factors to be considered when a TMDL analyst or stakeholder group is deciding on which allocation criteria to use is included at the end of this chapter.

10.2 Research Approach

The research approach used for this investigation began with a statistical review of 176 U.S. EPA-approved TMDLs. The selection process for these TMDLs is described in Chapter 2.0, and the documents that were reviewed are listed in Appendix A. An initial review of each TMDL document was done, and the resulting data were loaded into a spreadsheet. For purposes of this allocation investigation, an additional, detailed review of each document was conducted in an attempt to provide increased resolution about the specific methods and approaches used to determine the allocation of loads and wasteloads.

The project team then conducted a web-based search for TMDL and allocation-related guidance documents from all 50 states. Each document identified in this search was obtained and reviewed to determine the allocation approach defined in the guidance. A relatively small number of documents were found in this search. U.S. EPA's regional TMDL coordinators were consulted for suggestions for state programs that should be considered. Also, a web search for TMDL documents and law review articles containing allocation-related key words was conducted, and a broad range of documents listed by the search engine was examined. Given this background, the project team developed a set of structured interview questions, and interviewed state staff to get further insight into allocation approaches that may not have been represented in the TMDL documents themselves. Concurrently with these interviews, the project team reviewed TMDL documents from 21 states (CA, CO, DC, FL, ID, IN, KS, MD, ME, MN, MO, MT, NE, OH, OR, RI, SC, TX, VA, VT, WA) to get an in-depth understanding of the allocation methods used. States that were not identified either by the web search, by EPA staff, or during interviews and document reviews in other states were not studied.

10.3 Identification of Issues and Findings

This section identifies a series of issues and findings that the project team found during detailed examination of the allocation portion of TMDLs. These issues and findings are divided into two categories: findings related to the outcome of the allocation decision (Section 10.3.1), and findings related to the method by which the allocation was determined (Section 10.3.2).

10.3.1 Findings Related to Allocation Outcomes

A review of 176 U.S. EPA-approved TMDLs (Appendix A) resulted in the following tabulation of how loads were allocated. Note that Table 10-1 represents the outcome of the TMDL allocation decision, not the method by which the allocation was determined.

Table 10-1. Examples of How Loads Were Allocated in 176 U.S. EPA-Approved TMDLs, Where Documented.

Description of how loads were allocated	Number	Percent
Only point sources considered; their loads reduced	14	8%
Only nonpoint sources present; their loads reduced	46	26%
All reductions to nonpoint sources, point sources present	28	16%
All reductions to point sources, nonpoint sources present	8	5%
Both point and nonpoint sources reduced	38	22%
Assimilative capacity is zero; load and wasteload allocations = 0	2	1%
No allocations made; no load reductions required; or indeterminate	38	22%
Allocation for Future growth set to zero	1	1%

1. **Of 176 approved TMDLs that were reviewed, 22% included either no allocations, or had an allocation but no load reduction was required, or the load reduction could not be determined. Generally, these TMDLs had one of the following characteristics:**

   No allocation:
   - Ongoing and anticipated control activities are expected to bring the waterbody into compliance.
   - The TMDL determined that natural attenuation would eventually reduce pollutant to acceptable levels.
   - The listed waterbody was found to meet water quality standards.

   No reduction, or reduction could not be determined:
   - Current loads were allocated as the TMDL.
   - Loads were allocated to meet water quality standards, but no current estimate of loads was provided, so load reduction could not be determined.
   - Allocations were not quantified. (For example, an allocation for oil and grease is described as "that which will not cause a sheen.")

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2. **Based on information available in this sample of TMDL documents, load reductions do not appear to be allocated more often to point sources as compared to nonpoint sources.**
Of 95 mixed TMDLs reviewed, both point and nonpoint sources were required to make reductions 42% of the time. Point-sources-only were required to make reductions 4% of the time, and nonpoint-sources-only were required to make reductions 25% of the time. In 27% of the cases, either no allocation was made, no reductions were required, or it was impossible to determine whether reductions were required. One TMDL (1%) met the target by removing any provision for future growth.

It is important to recognize the limitations of this finding. The data provide information only about whether a source type was required to make reductions, not about the relative quantity of reductions required or the burden represented by these requirements. For example, based on information available in TMDL documents, it was impossible to determine whether an allocation placed a disproportionate burden on any given source, whether point or nonpoint. Of course, this also does not take into account any reductions previously required (e.g., by NPDES permits). Also, this finding looks only at TMDLs explicitly addressing both point and nonpoint sources, and does not account for any TMDLs that did not identify the presence of nonpoint sources even when such sources were present, or vice versa.

10.3.2 Findings Related to Allocation Methods

1. **Most TMDL load allocations are done on a case-by-case basis, without documented reliance on specified allocation methods or protocols. Few states have specific criteria, rules, or protocols for TMDL allocations. A few states specify a process for considering allocations.**
TMDL documents and interviewees portray so much variation in the circumstances surrounding each individual TMDL that there is strong support for the idea that "every TMDL is different." It appears that because of the great variation in geographical, technical, institutional/legal, and stakeholder elements surrounding a TMDL, each TMDL must, almost unavoidably, be done on a case-by-case basis. Few overarching principles can be discerned to cover such a wide range of variability.

The following is partial list of the variables affecting any given TMDL:

1. pollutants of interest,
2. availability of data,
3. interest level of stakeholders,
4. whether there is a local stakeholder who will "champion" the TMDL issue,
5. severity of impairment and how it is perceived,
6. type and number of point sources,
7. type and number of nonpoint sources,
8. size and characteristics of the designated water segment under consideration,
9. specific state laws and rules (e.g., variations among state water quality standards),
10. history and politics in the local area,
11. condition of the area's economy,

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12. relationship to other issues in the watershed,
13. time and resources available to support the TMDL process,
14. potential financial stakes riding on the outcome of the TMDL, and
15. the degree to which relevant sources may have already controlled their discharges.

Most TMDL documents do not include any explicit recognition of the various allocation methods that are identified in U.S. EPA guidance documents (as described in Section 10.4, below).

A rare exception to the general finding that TMDLs do not explicitly address allocation criteria was found in the Idaho Portneuf TMDL Supplementary Document (Idaho DEQ, 2001), which lists the following "principles of fairness" that were developed by stakeholders:

"Loading allocations among point and nonpoint sources should be consistent with principles of fairness as enumerated below:

A. Information should be adequate to base decisions, with the monitoring intensity and associated level of uncertainty tailored to match the level of monetary significance of the water quality and aquatic habitat issues.
B. Allocations should treat like dischargers equally (nonpoint = nonpoint and point = point), with considerations made to promote equity with respect to the costs of pollutant removal.
C. There must be an equitable allocation between point and nonpoint sources.
D. Dischargers should not be penalized for past voluntary pollution reduction measures. This principle of giving credit for expenditures prior to TMDL-required pollutant reductions should be considered when making future allocations.
E. The allocations should not penalize dischargers in any part of the basin because of naturally occurring background concentration.
F. Principles of equity should extend beyond the Portneuf River Basin to include dischargers throughout the entire Snake River Basin."

2. **Many states rely on stakeholder processes to recommend or determine allocations.** Many TMDL documents explicitly state or imply that stakeholders either chose an allocation scheme or made recommendations that the agency used in making its allocation decision. Many states put considerable effort into the stakeholder involvement process to foster the development of an allocation scheme that stakeholders will find acceptable, and even "own."

   One state emphasized a problem that had occurred when, in previous TMDLs, staff implied at the outset that the stakeholders would definitely determine the allocations. Then, if a consensus did not emerge, it was problematic for the state to reassert its authority to make the final decision. Several states' guidance documents now make clear that a consensus of stakeholders is the first preference, but lacking that, the state will make the allocation decision after consideration of stakeholder views. Some states point out that the state is legally required to ensure that the selected allocations meet the target, and therefore must have final authority. A document from Ohio ("Total

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Maximum Daily Load: Improving Stakeholder Understanding and Involvement in the TMDL Process," Deal II Project Team, November 2000) recommends that a "process hammer" be established early in the stakeholder process. A process hammer is a milestone or deadline when the agency will withdraw from the collaborative public participation process if the needed decisions have not been made.

3. **Most states view public involvement as the key to the success of the TMDL, including the acceptability of the allocation.**
   Even as the needed level of public involvement may vary substantially across different TMDLs, states are virtually unanimous in their conviction that public involvement is a critically important factor in the success of a TMDL. What is necessary is that interested stakeholders, if any, are involved early enough and in sufficient depth to foster consensus, if possible, to help assure subsequent implementation of the results. As observed by one state, one of the operating principles for public involvement should be "no surprises" for the stakeholders.

   At the same time, state TMDL staff recognize that effective public involvement can be time-consuming and resource-intensive. Some states remarked on the difficulty of doing public involvement well while at the same time being under pressure to complete TMDLs rapidly to comply with court-driven schedules. Some states also observed that budget shortfalls make it difficult to conduct public involvement to the degree they would wish.

   The reader is referred to Chapter 12.0 on Implementation Planning for additional discussion of public/stakeholder involvement.

4. **Frequently, the rationale for the allocation is not documented in the TMDL report. Moreover, there is often no evidence in the TMDL document that the method of allocation, as opposed to the actual allocation decision or outcome, was explicitly considered.**
   Documentation of a rationale for the allocation decision is probably not critical for those TMDLs where the allocation is by consensus of a stakeholder group, assuming that the group is fully informed and adequately represents those with interests at stake. In such cases, the fact that the allocation was reached by consensus should be documented in the record. In cases where the agency must make the allocation decision (often this is when there is not consensus of stakeholders), there is more risk that the TMDL could be challenged, particularly if the rationale for the allocation is not included in the record. While the state may have great discretion in determining allocations, it cannot be arbitrary or capricious. The risks are made clear in the following passage from an informal guide for Association of Metropolitan Sewerage Agencies members (AMSA, 2000), speculating about ways to challenge a TMDL:

   "How does the TMDL process apportion the required loading reduction?

   ...there are no federal statutory or regulatory criteria on how loading reductions shall be apportioned between various point and nonpoint sources. The [Technical Support Document] includes a long listing of various apportionment

schemes but it is ultimately up to each state to decide how apportionment will take place. The areas that should be carefully examined are as follows:

A. Is the state allocating the assimilative capacity of the waterbody pursuant to a properly enacted regulation? If not, this could be deemed an illegal rulemaking. Policy and common sense would dictate that properly enacted regulations are critical in this area. The state is dispensing an extremely valuable and rare commodity—the assimilative capacity of a river. This is every bit as precious as distributing, for example, grant dollars. Yet, no state would consider even for one second distributing grant funds without carefully crafted regulations regarding eligibility, implementation, etc. Therefore, apportionment should always take place in accordance with properly enacted regulations in which the public had an opportunity to comment.
B. Do the state's Continuing Planning Process (CPP) documents discuss apportionment? Is the state following their guidelines set forth in the CPP? Is the state following any written guidelines regarding apportionment? How were these guidelines developed? Consider an arbitrary and capricious argument."

Recent U.S. EPA guidance puts increased emphasis on maintaining a complete administrative record of the TMDL (U.S. EPA, 1999b, p. 3-20; U.S. EPA, 2001c, p. 9-3; U.S. EPA, 2002c). In reviewing TMDLs for this research, no recent challenges to TMDL allocations were discovered; however, litigation has been common in the TMDL program in the past, and the risks are important to consider.

At least one state expressed concern that describing the allocation rationale could have the effect of limiting the state's flexibility to choose a different approach in future TMDLs. It may be possible to avoid this problem by having state guidance that specifically states that rationales for allocations may vary across different TMDLs. TMDL policy makers should carefully weigh the relative risks of a possible reduction in flexibility brought about by describing an allocation rationale, versus the risk of challenge to the TMDL based on claims that an allocation is arbitrary if a rationale is not documented.

5. Frequently, an allocation decision emerges from the technical analysis, such as trial-and-error model runs to determine a set of allocations that will reach the water quality standards.

Frequently the allocation decision, as described in TMDL documents, appears to come about as follows. Assuming that an overall loading target is established, and a water quality model is being used, the TMDL analysts develop a series of scenarios that cover a wide range of outcomes, from all loads reduced by one given point source, to all loads reduced by one category of nonpoint source. Middle-of-the-road scenarios are developed according to the analysts' perception of the level of reductions that seem "reasonable" for various sources, based on their knowledge of the watershed and of the capabilities of BMPs and other technologies to reduce loads. At this point, some stakeholders may think there is a significant technical reason for the choice of scenarios, without fully appreciating the large degree of judgment involved. Scenarios that the model shows will not reach the water quality standard are ruled out. Remaining

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scenarios are reviewed and one scenario is reported as the "chosen" scenario, generally without substantial documentation of any allocation principles or decision criteria.

It is possible that the allocation policy decision was more explicitly considered, but if so, this is rarely reported in the final TMDL document. The appearance is that the allocation results from the agreement on one scenario from among several scenarios generated by the TMDL analyst as being "reasonable."

This method of determining allocations is not necessarily good or bad, but it varies from the allocation decision method that is presented in U.S. EPA guidance and some state guidance, where orderly and explicit evaluation of various allocations, based on well-defined selection criteria, is contemplated.

There may be no problem in using the "implicit" allocation decision described above, as long as stakeholders accept the allocation, or the burden of complying is not seen as onerous. On the other hand, if the burden of complying with an allocation is seen as burdensome or unfair by one or more parties, the TMDL is much more likely to be challenged. In such cases, the rationale for the allocation, whatever the underlying approach, should be fully documented in the administrative record.

It is possible that stakeholder dynamics contribute to the frequent use of an "implicit" allocation approach. It may be difficult for a group of stakeholders to explicitly determine an allocation if there are "winners and losers" in terms of who must pay how much to reduce their loadings. It is also likely difficult to agree explicitly on criteria for allocation when there are obvious interests at stake that will win or lose based on any given criterion. Therefore, in some cases it may be unrealistic to expect the type of explicit evaluation that is contemplated in the guidance, and a rough sense of which alternative is least objectionable may serve the stakeholder group or agency decision-maker well. This dynamic may help to explain both findings 3 and 4.

6. **Most TMDLs do not include an explicit allocation for future growth.**
Only one in five of the TMDL documents reviewed for this study included text that reflected consideration of future growth. An even smaller number included an explicit allocation for future growth. A separate review of 55 TMDLs found only six that made explicit provision for future growth (Houck, 1999).

It is not necessarily surprising to find that explicit allocations for growth are unusual in view of the fact that:

- Existing rules (40 CFR 130.2) include existing or future point and nonpoint source loads within the definitions of wasteload allocation and load allocation, respectively; and
- U.S. EPA guidance (U.S. EPA, 1999a) states that TMDLs "may allow for future growth by including a separate allocation for this purpose or by allocating acceptable wasteloads and loads in a way that incorporates growth."

Many TMDLs simply declare that their wasteload allocations and load allocations include some provision for future growth, without being quantitative. In the case of point sources, this is most frequently reflected by calculating the load based on the discharge limits in the permit, even if the source is not yet discharging at that level. A possible benefit of this approach, particularly in view of limited resources for conducting TMDLs, is that it avoids the potentially contentious and uncertain process of predicting future growth and determining quantitative allocations based on such predictions. However, this approach may implicitly favor existing sources over any future new sources, a result that may or may not be intended, and which could have the effect of ensuring that new sources will go elsewhere.

Another possible effect of this approach is that it pushes these decisions into some future forum where they could be even more difficult to solve and may set up significant disputes. An extreme example of this comes from a case in Washington State involving the Puyallup River TMDL for BOD and ammonia. Following completion of the initial TMDL, it became clear that the allocation of the capacity reserved for future growth would be so contentious that the parties agreed to sponsor and participate in a complex, multi-party mediation involving 10 municipalities, four industries, two tribes, the state, and the U.S. EPA. Ultimately the parties in this case did arrive at an agreement for allocating the capacity for future growth.

Another possible disadvantage of the non-quantitative allocation for future growth is that it could create uncertainty that could hamper effluent trading. Any uncertainty about what allocation may accrue to a discharger in the future can greatly impact the perceived feasibility of a trade. (See also finding 8.)

One state, Florida, has guidance specifying a time horizon for determination of future growth. The state's Allocation Technical Advisory Committee recommended a five-year time horizon for including growth estimates in nonpoint load estimates. Increased loading from domestic wastewater facilities is expected to be addressed by the area's wastewater master plan, and generally accounted for by the design flow of the facilities.

7. **About one-third of reviewed TMDLs group all types of nonpoint sources together (i.e., they do not include any allocation for specific nonpoint subcategories or specific nonpoint sources).**
This finding is not surprising in light of the fact that aggregation of nonpoint allocations is allowed in the regulations. It is presented here for its possible relevance to implementation planning. Some may consider this lack of specificity a problem for implementation planning, while others may see implementation planning as the proper place to make more specific allocations. See Chapter 12.0 on Implementation Planning for additional discussion.

A possible effect of the lack of specificity of nonpoint allocations is that it could make effluent trading more difficult. (See also finding 8)

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8. **Although several states have policies favoring trading, trading has been looked at only sporadically in relation to TMDLs.**
Trading in its broadest sense can be employed during the TMDL itself, as stakeholders may informally negotiate and "trade" to arrive at an acceptable allocation. For purposes of this discussion, however, formal market-based trading can only occur after a TMDL is completed and allocations are clearly known.

Trading is theoretically highly desirable as a way to allow the market to work to minimize the costs of compliance, but few trades have been executed in practice. Many things must come together for the trading market to work. In addition, third parties may have concerns about a potential trade. Such concerns might relate to the sufficiency of monitoring and enforcement, the ability to accurately calculate nonpoint load reductions, a desire to avoid the creation of hot spots, and the need for an adequate trading ratio to create a net environmental benefit from a trade.

A TMDL writer who wishes to prepare a TMDL allocation that maximizes the chance for subsequent trading should consider the following factors:

- Point and nonpoint pollutants should be expressed in common units (i.e., dissolved phosphorus and total phosphorus would not serve the purposes of trading), or a translation ratio is necessary.
- The compliance period (e.g., annual, seasonal, weekly, daily) for all sources should be reasonably aligned.
- The quantities of baseline load, current load, and target load should be clearly specified. It may be useful to specify how baseline load will be calculated as early as possible, because of possible discharger reluctance to make early load reductions based on a concern that pre-TMDL reductions will not be fully credited during the baseline process.
- The schedule for implementation of the load reductions should be reasonably aligned.
- The TMDL should include provisions allowing the allocations to be adjusted when all specified criteria are met (e.g., for trades that comply with all requirements of the TMDL, NPDES permits, and any applicable federal or state trading policies).
- All aspects of the TMDL and implementation should be designed to minimize transaction costs. Experience such as that in U.S. EPA Region 10's Lower Boise River Demonstration Project suggests that the necessity for trade-by-trade changes to the TMDL or the NPDES permit should be avoided, and the need for agency approval of each trade should be minimized because of the transaction cost and uncertainty these transactions can create (Ross & Associates, 2000).

10.4 Federal Regulations and Guidance

This section summarizes federal regulations and guidance related to allocations. First, a summary of the limited guidance established by statute and U.S. EPA's currently effective rules is provided (Section 10.4.1). Next, U.S. EPA guidance documents that were produced prior to 1999 (i.e., prior to the debate and controversy about how to revise the TMDL program) are

reviewed (Section 10.4.2). Third, a summary is provided of the recommendations regarding allocation that the federal advisory committee on TMDLs provided in its final report to U.S. EPA in 1998 (Section 10.4.3). Fourth, U.S. EPA guidance that has been produced during the debate about revising the TMDL program (i.e., 1999 and later) is reviewed (Section 10.4.4). Fifth, a summary is provided of guidance put forward by two of U.S. EPA's regional offices and how it relates to the other guidance (Section 10.4.5). Sixth, U.S. EPA's policy statements from the preamble to the final TMDL rule that was published July 13, 2000 are capsulized (Section 10.4.6). This is the rule for which the effective date was postponed to April 30, 2003, and which may be revised or replaced with an entirely new rule. Finally, guidance currently presented as part of U.S. EPA's TMDL website is outlined, including guidance for a "Framework for Identifying Optimal Allocations" (Section 10.4.7).

10.4.1 What Do the Clean Water Act and EPA's Rules Say about Allocation?

Allocation is not specifically mentioned in the statutory language of the Clean Water Act, although many observers would agree that the concept and need for allocations can be inferred from the overall statutory structure of the Act. U.S. EPA's current rules for TMDLs (adopted in 1985 and 1992 and codified at 40 CFR 130.2 and 130.7) require load and wasteload allocations, but provide no specific guidance or constraints for determining allocations, other than the requirement that the sum of all allocations must allow the waterbody to attain the applicable water quality standards. The rules thus provide wide discretion to states for determining allocations.

The formula for a TMDL is generally represented as:

$$TMDL = \Sigma WLA + \Sigma LA + MOS \qquad (10.4.1\text{-}1)$$

where:

Wasteload allocation (WLA) and load allocation (LA) are defined to include existing and future point and nonpoint sources, respectively;

LA includes natural background; and

Margin of Safety (MOS) can be explicit or implicit. (Issues related to the MOS are discussed in Chapter 9.0.)

10.4.2 What Does U.S. EPA's pre-1999 Guidance Say about Allocation?

U.S. EPA has published several documents that provide guidance for TMDLs, including the allocation portion thereof. The Technical Support Document for Water Quality-based Toxics Control (U.S. EPA, 1991b, Chapter 4) lists 19 possible allocation schemes (see below) for developing wasteload allocations, but also indicates that this is not intended to be a complete list of approaches, and "any reasonable allocation scheme that meets the antidegradation provisions and other requirements of State water quality standards" can be used.

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Table 10-2. 19 Possible Allocation Schemes for Developing Wasteload Allocations.

1	Equal percent removal (equal percent treatment)
2	Equal effluent concentrations
3	Equal total mass discharge per day
4	Equal mass discharger per capita per day
5	Equal reduction of raw load (pounds per day)
6	Equal ambient mean annual quality (mg/l)
7	Equal cost per pound of pollutant removed
8	Equal treatment cost per unit of production
9	Equal mass discharged per unit of raw material used
10	Equal mass discharged per unit of production
11a	Percent removal proportional to raw load per day
11b	Larger facilities to achieve higher removal rates
12	Percent removal proportional to community effective income
13a	Effluent charges (pounds per week)
13b	Effluent charge above some load limit
14	Seasonal limits based on cost-effectiveness analysis
15	Minimum total treatment cost
16	Best Available Technology (BAT for industry) plus some level for municipal inputs
17	Assimilative capacity divided to require an "equal effort among dischargers"
18a	Municipal: Treatment level proportional to plant size
18b	Industrial: equal percent between best practicable technology (BPT) and BAT
19	Industrial discharges given different treatment levels for different stream flows and seasons

[Source: Chadderton, R., Miller, A. and A. McDonnell. 1981. Analysis of Wasteload Allocation Procedures. *Water Resources Bulletin* 17(5):760-66.]

In another 1991 document, "Guidance for Water Quality-based Decisions: The TMDL Process," U.S. EPA provided non-technical guidance about all aspects of the TMDL process. The document describes three common allocation schemes (U.S. EPA, 1991a, p. 50) that, at that time, had generally only been applied to point sources: 1) Equal percent removal (which could be measured either by overall removal efficiency or incremental removal efficiency); 2) equal effluent concentrations; and 3) a hybrid method where the criteria for waste reduction may not be the same from one source to the next.

10.4.3 What Did the Federal Advisory Committee Say about Allocation?

The Federal Advisory Committee on the TMDL Program looked at the allocation process as one of the many issues it examined. The committee's report emphasizes that the committee's greatest concern was that the TMDL allocations be sufficient to meet water quality standards. With respect to allocation approaches:

"The Committee generally concluded that a variety of approaches to allocations are legitimate and that it is important to provide flexibility for States to use the method that is most likely to work best in a given watershed." (NACEPT, 1998, p. 35)

The committee identified four general principles as appropriate considerations in making allocation decisions:

- technical and programmatic feasibility,
- cost-effectiveness,
- relative source contributions, and
- the degree of certainty of implementation (including the "reasonable assurances" in the implementation plan, past experience with similar approaches, and enforceability of point and nonpoint source controls).

The Committee developed an "Outline of the Hierarchy Approach to TMDL Approval" (NACEPT, 1998, Appendix G) that includes a description of the allocation step as related to the amount of information that is available. This hierarchy of steps is summarized as follows:

1. If available, use cost, feasibility, and other relevant information to make allocation decisions.
2. If this information is known with less certainty, additional monitoring and assessment will be needed.
3. If this information is not known, collect it, if feasible.
4. If this information cannot be collected, use best professional judgment regarding the cost and technical feasibility of alternative allocation strategies.
5. If this information cannot be estimated based on best professional judgment, another (default) method must be chosen on which to base allocation decisions, such as equal percent reduction by all sources, or equal incremental reduction by all sources.

The Committee observed that this hierarchy concept:

> "may not be entirely appropriate, because alternative approaches to pollution reduction allocations may reflect legitimate differences in regulatory philosophy. For example, one state might believe that it is most appropriate to favor older over newer sources in setting allocations; another might favor a purely pro rata approach based on equal pollution (or pollution reduction) percentages; while another might favor equalizing the total or incremental costs of pollution reduction among sources."

The Committee also recommended that states consider innovative approaches when making allocation decisions, provided that 1) the implementation plan provides reasonable assurances that allocation will be achieved and water quality standards will be met, 2) all legal requirements of the TMDL are met, and 3) the implementation plan includes specific provisions for follow-up evaluation of the innovative approach.

10.4.4 What Does U.S. EPA's Recent (1999 and later) Guidance Say About Allocation?

In 1999, U.S. EPA (1999b) published new guidance (Draft Guidance for Water Quality-based Decisions: The TMDL Process (Second Edition)) which elaborates upon the 1991 guidance and provides additional guidance for TMDLs based on the proposed 1999 rules. It includes a list of 13 U.S. EPA technical guidance manuals, published between 1984 and 1992, for calculating wasteload allocations for point sources for various categories of receiving waters (p. 3–18). This document also provides guidance for supporting decisions (including allocations) within the TMDL record.

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In addition, U.S. EPA has published three pollutant-specific protocols for TMDLs:

- *Protocol for Developing Sediment TMDLs, October 1999(e), U.S. EPA*
- *Protocol for Developing Nutrient TMDLs, November 1999(d), U.S. EPA*
- *Protocol for Developing Pathogen TMDLs, Jan. 2001(c), U.S. EPA*

Each of these documents includes a section providing guidance for allocations. The three documents, with minor variations, present four general recommendations for allocations:

- Identify the method of incorporating the margin of safety (i.e., implicitly or explicitly).
- Involve stakeholders in the development of the allocations.
- Include adequate documentation with allocations to provide reasonable assurance that the water quality standards will be attained.
- Reflect the relative size and magnitude of sources, where possible, and represent an appropriate and feasible balance between and among wasteload allocations and load allocations.

The *pathogen* document, in citing the challenging nature of the allocation task, includes a list of the issues that affect the allocation process:

- Economics
- Political considerations
- Feasibility
- Equity
- Types of sources and management options
- Public involvement
- Implementation
- Limits of technology
- Variability in loads, effectiveness of BMPs

The *sediment* document discusses factors that might influence how an allocation is best presented: for example, allocation should usually be organized along the same lines as the source analysis and the method by which potential load reductions are linked back to water quality targets, because this can ease the task of demonstrating reasonable assurance; allocations should be tailored to fit with the expected method of control (e.g., an allocation could be expressed in terms of tons of avoided sediment loading or percent reduction in sediment loading from tributary watershed, depending on whether the method of control is, respectively, replacing failing culverts or reducing the number of miles of active road per square mile).

The *nutrient* and *pathogen* documents also provide numeric examples of TMDL allocation calculations.

10.4.5 U.S. EPA Regional Guidance

U.S. EPA's Region 9 has prepared guidance for developing TMDLs in California (U.S. EPA, 2000b). The guidance provides a useful synthesis of the TMDL process with California's basin planning process. Regarding allocation, the guidance acknowledges that federal regulations

do not establish specific criteria for apportioning any available loading capacity, and suggests that the state might want to consider a mix of the following allocation criteria:

- technical and engineering feasibility,
- cost or relative cost,
- economic impacts/benefits,
- cost effectiveness,
- fairness/equity,
- ability to monitor implementation and effectiveness,
- assurance and timeliness of attainment of the TMDL and water quality standards,
- relative source contributions, and/or
- other appropriate criteria. (U.S. EPA, 2000b, p.6)

U.S. EPA Region 10's website includes several pages of guidance for TMDLs, including a description of a "TMDL shift model" that proposes that the agency be consulted in the early problem identification and scoping phase of TMDL development to minimize the risk that it would have to later disapprove a TMDL. The site includes guidance for maintaining a complete administrative record in case a TMDL is challenged. The site includes "TMDL Review Guidelines," dated January 2002, that provide a comprehensive checklist of the required and optional elements of a TMDL submittal to U.S. EPA. In the case of allocations, this checklist essentially summarizes existing regulations; other parts of the website refer the reader to other U.S. EPA documents (described above) for guidance about allocation.

10.4.6 U.S. EPA Commentary on Allocations

The preamble to U.S. EPA's TMDL rules (since delayed) published on July 13, 2000 (65 FR 43586), included a discussion of allocation issues that had been brought up by the comments on the draft rule. In concluding that it would not specify an allocation methodology, the agency said, "EPA's position has been, and continues to be, that States...may employ in TMDLs any kind of system or policy for allocating pollutant loadings among sources, as long as the resulting allocations will lead to attainment and maintenance of water quality standards."(65 FR 43620)

Commenters have urged U.S. EPA to require certain allocation methods, including:

- giving credit for reductions already achieved;
- reductions proportional to existing loadings;
- consideration of ability to pay, treatment capacity, and easiest-to-achieve reductions;
- requiring all sources to fairly share in load reductions regardless of size or relative contribution.

U.S. EPA declined to require any of these allocation methods, saying

> "EPA believes that the decision on how to identify the most cost-effective or equitable means of allocation loadings is best handled by the State...when the State establishes the TMDL."(65 FR 43620)

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The agency did suggest two underlying goals for the allocation, saying the allocation methodology should create a "technically feasible and reasonably fair division of the allowable load among sources." It also encouraged states to consider various allocation options, and, ideally, to bring stakeholders together "to work together to reach consensus on allocations that are believed by the stakeholders to be effective and equitable." (65 FR 43620)

As discussed elsewhere in this document, the effective date for these year 2000 rules was extended to April 30, 2003, and the rules appear likely to be superseded by a revised or different set of rules before they become effective. It is not clear how any new rules might affect the allocation process.

10.4.7 U.S. EPA's TMDL Website, 2002

U.S. EPA has recently added significant additional guidance on its TMDL website that goes beyond its previously published documents.[4]

The website describes a "Framework for Identifying Optimal Allocations," a spreadsheet-based modeling framework that allows the analyst to evaluate alternative decisions that meet allocation objectives, satisfy water quality goals, and satisfy stakeholder constraints. U.S. EPA recommends that final allocation decisions reflect acceptable tradeoffs between desirable outcomes such as cost-effectiveness and equity. Links are included to download the necessary software and to demonstrate how the framework was used in a case study in the Cottonwood Creek, a stream in rural Idaho impaired by fecal coliform bacteria. The website describes how the Framework was used to conduct an in-depth, quantitative analysis of three allocation scenarios:

- equal percent reduction,
- equal loads, and
- minimum total abatement cost.

The total compliance cost was significantly different across the three scenarios, as was the distribution of cost burden among types of dischargers.

10.4.8 Concluding Observations Regarding Federal Guidance

The thrust of federal guidance regarding allocation is to present options for states to consider as possible methods for doing allocations. This is consistent with U.S. EPA's expressed policy that "the decision on how to identify the most cost-effective or equitable means of allocation loadings is best handled by the State." An extensive list of options for allocation was published by U.S. EPA in 1991, based largely on a professional article originally published in 1981. Since 1999, the agency has published general and pollutant-specific guidance documents for TMDLs that, in terms of specific guidance for doing allocations, provide little additional information. Most recently, it has posted on its website additional guidance to assist with the quantitative evaluation of three different allocation methods. Overall, very little guidance or information is available about how a state might go about choosing a particular method from the numerous options listed.

[4] See http://www.epa.gov/waterscience/models/allocation/

10.5 State Regulations and Guidance: The Range of Allocation Approaches

The project team conducted a web-based search for TMDL and allocation-related guidance documents from all 50 states (Section 10.2). A relatively small number of documents were found in this search. U.S. EPA's regional TMDL coordinators were consulted for suggestions for state programs that should be considered, and a general web search was conducted for allocation-related keywords in TMDL documents. Finally, given this background, the project team interviewed state staff and/or reviewed TMDL guidance or TMDL documents from 21 states. States that were not identified either by the web search, by U.S. EPA staff, or during interviews and document reviews in other states were not studied.

The landscape that emerged from this review is consistent with the findings discussed above; that is, few states have specific criteria, rules, or protocols for TMDL allocations. Findings are presented in four categories:

- states with specific allocation methodologies (i.e., Florida);
- states prescribing a process for developing the allocation (e.g., Ohio);
- states that provide some suggested criteria for allocations; and
- states employing technical methods that help to inform the allocation decision.

10.5.1 States with Specific Allocation Methodologies

The most specific allocation methodology found was in **Florida**, which had a statutorily mandated advisory committee look specifically at the issue of TMDL load allocations. In 1999, Florida's legislature enacted the Florida Watershed Restoration Act (Chapter 99-223, Laws of Florida), which contained a variety of specific statutory requirements for TMDLs. TMDLs, including allocations, are now required to be adopted by rule by the Department of Environmental Protection. The statute requires that allocations be "reasonable and equitable," and while it does not mandate how individual allocations should be made, it enumerates eight factors that must be considered:

1. Existing treatment levels and management practices;
2. Differing impacts pollutant sources may have on water quality;
3. The availability of treatment technologies, management practices, or other pollutant reduction measures;
4. Environmental, economic, and technological feasibility of achieving the allocation;
5. The cost benefit associated with achieving the allocation;
6. Reasonable timeframes for implementation;
7. Potential applicability of any moderating provisions such as variances, exemptions, and mixing zones; and
8. The extent to which non-attainment of water quality standards is caused by pollution sources outside of Florida, discharges that have ceased, or alterations to water bodies prior to the date of this act. (Chapter 99-223, Laws of Florida)

The statute also called for a report to the governor and legislature on the process for allocating TMDLs, and mandated the creation of a technical advisory committee to help the Department develop its recommendations. This report was issued February 1, 2001, and laid out a three-step allocation methodology for initial allocations to individual point sources and major

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categories of nonpoint sources (i.e., agriculture, silviculture, urban stormwater, atmospheric deposition, and septic tanks), as summarized below:

Step 1: The first recommended step for the initial allocation is to calculate the amount of pollutant reductions that would be achieved if:

a. 45% of all agricultural and silviculture operations in the basin and in upstream watersheds implemented the appropriate BMPs for their specific type of operation;
b. 45% of all urban areas met stormwater treatment requirements for new construction; and
c. 45% of the homes with septic tanks within the 100-year floodplain or that were documented to be contributing to the impairment were hooked up to a regional sewer system.

Step 2: Identical to Step 1, except that the percentages are increased to 90% for all categories identified in Step 1.

Step 3: If the reductions for Step 2 were not sufficient to meet the TMDL, the third recommended step is to allocate reductions to all sources, except those where loading is at background levels or those that have provided treatment beyond "best available technology" levels, in increments of 10% until the TMDL is met. (summarized from State of Florida, 2001, p. 24–5)

The Allocation Technical Advisory Committee provided the following rationale to help explain how (in part) it decided to recommend the allocation methodology shown above:

> **"After much deliberation, the ATAC [Allocation Technical Advisory Committee] decided to recommend that the first step to achieve equity was to 'level the playing field' in treatment effort between point and nonpoint sources.** The ATAC recognized that traditional point sources are required to provide, at a minimum, Best Available Technology Economically Achievable (BAT), or technology-based treatment levels (defined as secondary treatment for domestic wastewater facilities and effluent guidelines for industrial wastewater facilities). As such, the ATAC felt that nonpoint sources, especially those not subject to Florida's stormwater or environmental resource permits, should be expected to provide comparable minimum levels of treatment before any additional reductions or increased treatment is required for traditional point sources. The ATAC subsequently decided that the comparable minimum treatment for nonpoint sources should be the BMPs developed and adopted for that activity. As noted in Section 4.2, the BMP development process should take into account the economic resources available and the feasibility of the management measures. If these BMPs are developed consistent with the recommendations made later in this report, they should include a performance standard and should be comparable to BAT for point sources."

(State of Florida, 2001, p.20, emphasis in original)

Florida's report on allocation appears to be unique in the nation in the degree of attention given to the principles and details of the allocation decision in TMDLs.

According to the report, a second level of allocation, providing more detailed allocations to nonpoint sources, is to be done as part of detailed implementation plans developed following the TMDL itself. The Florida Department of Environmental Protection has stated that it intends to facilitate the development of stakeholder consensus on these detailed allocations, but if consensus does not emerge, it reserves the right to make allocation recommendations "by applying the operating principles of cost minimization and equitable distribution."

10.5.2 States Prescribing a Process for Developing the Allocation

A second category of states prescribes some type of procedure for developing allocations without explicitly specifying criteria for the allocation decision itself. Ohio is one example of this approach.

In 1998, the Ohio Environmental Protection Agency chartered a team to study the TMDL issue in the state and to make recommendations for a process to develop TMDLs in Ohio. Its 1999 report (Ohio EPA, 1999) established a 12-step process for TMDLs beginning with the design of a watershed survey, and completing the cycle with the analysis of whether water quality standards have been achieved. The report provides detailed guidance for each step.

For purposes of allocation, the key steps are Step 5, "Develop restoration targets," and Step 6, "Select a restoration scenario." Step 5 calls for the analyst to generate example restoration scenarios that are presented, for educational purposes only, to the stakeholder group as a starting point for the group to use when determining an acceptable scenario. Step 6 spells out a detailed process for selecting the restoration scenario:

1. Discuss sample scenarios with stakeholders; generate other options
2. Develop watershed-specific decision criteria
3. Screen scenarios (using selected decision criteria) to select best option
4. Verify that scenario achieves reduction
5. Finalize allocations

While the guidance suggests that the decision criteria "should include" feasibility, acceptability, and sustainability, in general, the selection of these criteria is left to the stakeholder group. The process of screening and selecting a scenario is described as a joint undertaking of the stakeholders and the agency, with the goal of obtaining stakeholder consensus on a scenario, if possible. If no consensus can be reached, the guidance states that the Ohio EPA becomes responsible for selecting and implementing a restoration scenario.

Independent of the TMDL team's guidance, Ohio rules specify a formula for calculating wasteload allocations for toxic and carcinogenic pollutants as well as ammonia-nitrogen. In cases where multiple dischargers are present, the rule explicitly gives discretion to the agency director for determining load allocations "using a method considered appropriate by the director, based on site-specific considerations." (Ohio Administrative Code 3745-2-05(A)(8) and 3745-2-10)

Although Ohio provides more detailed process guidance than other states, several other states (e.g., Indiana, Maryland, Minnesota, Texas, Vermont, Virginia) embrace the general

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approach of analyzing several allocation scenarios and choosing a final allocation from among those shown to be able to meet water quality standards.

10.5.3 States That Provide Some Suggested Criteria for Allocations

A third category of states provides some suggested criteria for allocations but generally does not mandate their use or prescribe a specific process for arriving at an allocation. A majority of states fall into this category. **Idaho** is an example of this approach.

Idaho's TMDL guidance specifies that allocations must first be determined for the margin of safety, then background and a reserve for future growth. Following that, allocations for existing and future pollutant sources "may take into account equitable cost, cost effectiveness, and credit for prior efforts, but all within the ceiling of remaining available load." (State of Idaho, 1999, p. 41)

10.5.4 States Employing Technical Methods That Help to Inform the Allocation Decision

Finally, this section briefly describes a category of states that employ technical methods to help guide allocation. Three examples are Kansas, Pennsylvania, and Washington.

Kansas uses a duration curve methodology (described in Section 5.3.4.5) that provides technical guidance to help distinguish between point and nonpoint source loads. This methodology is described as being useful for informing allocation decisions, specifically the allocation between point and nonpoint sources.

Pennsylvania uses an allocation strategy called "equal marginal percent removal" (EMPR). EMPR is a two-step process in which a discharge is first considered independently of all other discharges in the relevant water body. In this step, the baseline condition for each discharge is set at the level of treatment the discharge must provide if it were the only discharge to the receiving stream. In the second step, called multiple discharge analysis, the cumulative impact of all discharges, if discharging at the baseline level, is evaluated against the stream quality objectives. If the analysis indicates that an objective is exceeded, then the baseline loads of all discharges significantly contributing to violations are reduced by an equal percentage until the stream quality objective is met (State of Pennsylvania, 1986 and 1999).

Washington has used a "statistical rollback technique" in several pathogen TMDLs, allowing a dual water quality standard for pathogens (e.g., a water quality standard requiring that fecal coliform organisms shall not exceed a geometric mean of "x" colonies per 100 mL, and not more than 10% of samples shall exceed "y" colonies per 100 mL) to be translated into a single number so that understandable and implementable allocations can be made.

10.6 Conclusions and Recommendations

In reviewing a large number of TMDLs and interviewing staff from several states, it became abundantly clear that the great variety of circumstances and environmental conditions (see finding 1 in section 10.3.2) surrounding each TMDL lend a great deal of validity to the statement that every TMDL is different. States generally develop allocations on a case-by-case

basis, with few explicit principles or criteria spelled out. Given the variability in TMDLs, such flexibility is probably necessary.

U.S. EPA guidance outlines a menu of options for determining allocations, but does not provide information for choosing between the various the options. On a broad scale, few general principles appear to apply.

Two strong recommendations did emerge from this research. First, as stressed by many state staff and even by many TMDL documents, an appropriate degree of stakeholder involvement is essential to arrive at an allocation that can be implemented. The "appropriate" level of stakeholder involvement can vary based on the local circumstances, and resources may constrain what is possible, but there is a great deal of emphasis on conducting the TMDL, including allocation decisions, with stakeholder involvement. One caution is to be clear at the outset the degree to which a group of stakeholders will have decision-making or advisory authority.

Second, contrary to current practice, the rationale for determining the allocation, whatever it may be, should be documented in writing. Lack of such documentation increases the risk that a TMDL would be challenged, particularly in cases where the allocations are perceived as burdensome.

During the course of this research, three categories of ideas for further research were suggested. First, the need was suggested to develop guidance for allocations for three specific types of loading situations: TMDLs where air deposition or legacy pollution (e.g., contaminated sediment) are important, and TMDLs involving dams. Second, because of the potential for watershed-based effluent trading to lower the ultimate costs of implementing a TMDL, the need became apparent to research ways to quickly assess individual TMDL projects for their potential suitability for such trading. Then, if appropriate, the TMDL can be set up to facilitate future trading. And third, it seems critical to undertake research to document and understand patterns in the actual water quality outcome of TMDLs across a range of allocation methods (including Florida's unique approach), across source types, and across other variables affecting the TMDL and its implementation.

Finally, based on this review of TMDL documents, guidance, and interviews with state staff, the project team has compiled a list of commonly considered allocation criteria together with factors to consider when deciding which criteria to use, as listed below.

Fair & Equitable. In general, an allocation that is seen as fair and equitable is a primary goal, but fairness and equity are often in the eye of the beholder, and more specific criteria may be needed. For example, to what degree should previous load reductions carried out by a discharger factor into a fair and equitable allocation?

Likelihood of Implementation and/or Enforceability. This criterion is often seen by point sources as inequitable because nonpoint sources are less likely to be heavily regulated or subject to enforcement; others see it as pragmatic, in determining allocations, to consider whether a load allocation is likely to be implemented inasmuch as the goal is to actually improve water quality.

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Consensus-based Allocation. Considered by most parties to be ideal, consensus may be most achievable in uncomplicated cases with little uncertainty in the TMDL analysis and where all sources are at the table. However, it is never possible to guarantee a true consensus. The rules for what happens in the absence of consensus by a certain date must be clear ahead of time. It is also advisable to ensure that the definition of "consensus" is clear to all participants. Significant resources and non-technical process skills may be necessary to set up a fully representative stakeholder group, provide adequate understandable information, and facilitate the group to consensus.

Proportional (i.e., Equal Percent) Reduction from Existing Load. This criterion is often seen as penalizing those who have already made load reductions if others have not. This method requires the ability to quantify existing loads. It is a frequently used method.

Credit for Previous Load Reductions. This approach requires a method to calculate the credit. This method may make "proportional reductions" more equitable if some adjustment is made to a discharger's share of future load reduction based on previous load reduction.

Ability-to-pay. This criterion requires a method to calculate costs and ability-to-pay, but may be seen as inequitable by those with a higher ability to pay.

Cost-effectiveness. This criterion requires a great deal of information and analysis on feasible reduction methods and costs. U.S. EPA has a spreadsheet model that can help in this analysis.

Allocations Based on Trading. In theory, trading allows market forces to bring about the optimal allocation. Trading is encouraged by U.S. EPA and many states. Concerns relate to tracking compliance, enforcement, liability, and complexity of completing the trading transaction. Trading still has a limited track record.

Feasibility (Technical and Programmatic). Of course, allocations must be feasible if they are to be implemented. But feasibility is often difficult to define and measure. In theory, load reductions could be capped at the level of feasibility.

CHAPTER 11.0

LINKING BEST MANAGEMENT PRACTICES TO LOAD REDUCTIONS

This chapter is a compilation of information about the effectiveness of a wide range of Best Management Practices (BMPs) to assist water quality professionals in the selection of BMPs when developing implementation plans for TMDL waterbodies. It brings together many of the BMP resources in one document, addresses the linkage between control actions and load reductions, documents sources of information regarding nonpoint source control, and provides examples of how this can be completed in practice.

11.1 Background

BMPs are structural or nonstructural practices that employ a device, practice or method for reducing, eliminating, or preventing runoff constituents from reaching receiving waters and adversely affecting water quality. BMPs are used in nonpoint source programs, including those related to TMDLs, for control of polluted runoff. Examples of non-structural controls include source control or pollution prevention; structural controls include retention or detention ponds for stormwater.

When selecting BMPs, it is important to choose the practice that is most effective for the pollution of concern. Combinations of BMPs that control the same pollutant are usually more efficient than individual ones. Typically the term "BMP system" is used to describe this situation when combinations of BMPs are used together to comprehensively control a pollutant from the same source. These combinations of BMPs can be specifically targeted for a particular environmental condition (e.g., agricultural issue) as well as for a particular pollutant (Osmond et al., 1995). The design, construction, maintenance, and monitoring of BMPs can be very time consuming and costly; therefore, an understanding of BMP effectiveness before selection and implementation is essential.

The difference between BMP performance, effectiveness, and efficiency is important to distinguish. Performance is a measure of how well a BMP meets its goal for pollution control. Effectiveness is a measure of how well a BMP or BMP system meets its goal in relation to other factors (e.g., all stormwater flows). Efficiency is a measure of how well a BMP or BMP system removes pollutants. Pollutant removal efficiency is typically expressed in terms of "percent reduction."

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Most TMDLs include a percent reduction to diffuse loads on a seasonal or annual basis, and the method of achieving this reduction is often not considered. Typically, no linkage is made in the TMDL between a specific nonpoint source control and percent reduction in load. While this step may have been left for the implementation stage in many TMDLs, this important step will have to be completed if nonpoint sources are to meet their load allocation. Thus, it is important that states re-evaluate the use of BMPs in reducing nonpoint sources in an effort to improve the efficiency of TMDL development and implementation.

11.1.1 Issues Related to BMPs in the TMDL Program

Several research findings indicate a need for this research product. These findings include:

- Information about BMP effectiveness and percent reduction is not readily available for all land use/land cover types, so it is difficult to use in TMDL development;
- In the review of 176 approved TMDLs (Appendix A), of the 155 TMDLs that considered nonpoint source contributions, 41% did not consider BMPs for reducing nonpoint source loads:
  - 72% of the TMDLs that considered BMPs did not cite a reference (a document, data, or plan) to provide support that they would be effective to reduce loads; and
  - Only 14% of the TMDLs that considered BMPs provided a quantitative estimate of the expected load reduction (for some or all BMPs).
- The uncertainty of the effectiveness of BMPs was considered in only about one-third of the TMDLs that included a discussion of nonpoint source controls.

These observations were supported by comments shared at the "TMDL: Science Issues Conference 2001" (WEF, 2001). In the closing session, several information gaps and needs related to Best Management Practices were noted, including:

- Inadequate installation, maintenance, and monitoring of BMPs;
- Insufficient understanding of the costs associated with BMPs, including a lack of knowledge regarding the distribution of those costs across the involved parties;
- A need to develop temporal, spatial, and economic value of BMPs;
- Lack of understanding of BMP effectiveness on a site-specific and watershed scale as well as the linkage to implementation and load reduction goals. Data gaps exist for a variety of pollutants particularly in agricultural areas;
- BMP effectiveness cannot be quantified to relate to TMDLs;
- Models do not predict BMP long-term effects to water quality; and
- Lack of knowledge regarding the evaluation of BMPs in variable weather conditions.

Several outcomes may arise if nonpoint source reductions are unrealistic and BMPs are not specifically linked to expected reductions:

- Greater load reduction might be allocated to point sources because nonpoint source load;
- Reductions from BMP implementation were not accurately assessed and greater nonpoint source load reductions have been documented;
- The receiving system will remain on the 303(d) list, with attendant limitations for discharge into the receiving system because nonpoint source load reductions are being achieved and water quality standards are not being attained; and

- Reasonable assurance cannot be provided for the attainment of water quality standards if the nonpoint source load reductions associated with specific BMPs cannot be stated.

U.S. EPA (1998a) documented that BMP effectiveness research "ranks among the second highest priorities for science and tool development" based on recommendations by the Federal Advisory Committee Act (FACA) committee in the 1998 TMDL FACA Report. In a recent publication, U.S. EPA (2002e) identified twenty TMDL science needs recognized by the National Research Council, states and tribes, the U.S. EPA, national and regional TMDL programs, the private sector, and others. One of the "top five" needs is identified in the report: "Improve information on BMP, restoration or other management practice effectiveness, and the related processes of system recovery." This is important, as TMDL approval is directly related to demonstrating reasonable assurance that management practices can be plausibly implemented, and that they will result in successful load reductions. The report notes that practically all types of BMPs, including agricultural, forestry, and urban runoff controls, would benefit from effectiveness research, as recovery of impaired systems is closely linked to effectiveness. This may include better measures of physical habitat characteristics and means for interpreting these measures, time scales needed to regain specific conditions, and methods for predicting recovery.

The U.S. EPA "Twenty Needs" report also identified the need to "make monitoring more program-relevant and results-relevant." It suggests focusing on more post-implementation monitoring to verify results of management practices. Post-evaluation monitoring is typically dropped in management practices, as most are implemented under tight budgets and the effectiveness record not completed. The report indicates that states need more results-related measures to directly link BMPs and other pollution controls to recovered waterbodies.

The U.S. Congress established a trial program "The Rural Clean Water Program—RCWP" in 1980 to address agricultural nonpoint source pollution across the nation's waterbodies. This work documented that information on BMP effectiveness and efficiency was not readily available for all land use/land cover types, so it was not considered in many TMDLs. Information on the RCWP program can be found in Gale et al.(1993).

Some state guidance documents discuss incorporation of BMP effectiveness into the TMDL process. For example, Texas guidance (TNRCC, 1999) includes a section on developing implementation plans that describes the development of a monitoring plan to evaluate the effectiveness of nonpoint source management measures. Other states are developing tools to assist in creating a more successful TMDL project. For example, Ohio State TMDL guidance recommends developing a handbook of BMPs with descriptions of each BMP and the effectiveness of each in Ohio and associated ecoregions (Ohio EPA, 1999).

11.1.2 Objectives of Investigation

This chapter is intended to assist water quality professionals in selecting BMPs and linking BMP effectiveness to load reductions. Information about urban stormwater, forestry, agricultural, and abandoned mine BMPs is provided. Existing information about BMP effectiveness was compiled and summarized in a series of tables, including selection factors, realistic estimates of the percent reductions that can be expected for various pollutants, uncertainties, time frames for implementation, and expected lifetimes. This investigation focuses principally on

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sediment (and sorbed pollutants) and sediment delivery. However, other areas have also been identified where BMP effectiveness work has been completed.

Several tables were developed to assist the user with BMP selection. Site constraints and applicability including physical feasibility (e.g., area typically served, slope, drainage area, land required for BMP), management considerations (capital costs, maintenance costs, effective life of the practice, training), as well as community and environmental factors (e.g., community acceptance, aesthetics, safety) are documented for several types of BMPs. Pollutant removal efficiencies for nutrients, sediments, heavy metals, and other conventional parameters are also documented. In addition, a number of case studies where BMPs were explicitly linked to load reductions are summarized.

11.2 Study Approach

There is a wealth of information about the effectiveness of BMPs. These resources are available through many different state agencies, cooperative extensions, environmental organizations, peer reviewed literature, synthesis documents, websites, and symposium proceedings. While various data exist in separate areas, this information was synthesized and reviewed into a central information resource. General guidance and some cautionary information have been included.

A series of resources were cited and tables were developed to assist the user in selecting appropriate BMPs and associated nonpoint source load reductions by pollutant type and land use for inclusion in TMDLs. Since site-specific and regional variability exist (in the selection of appropriate BMPs, design constraints, and pollution control effectiveness), guidance is presented with respect to specific regions with climate considerations where applicable. The following information sources were used to compile the information in this chapter:

- U.S. Environmental Protection Agency (Office of Water and Office of Science and Technology);
- Center for Watershed Protection (including the Stormwater Manager's Resource Center; and CWP reports);
- American Society of Civil Engineers database;
- Gray literature, including reports from:
  - U.S. Department of Transportation
  - United States Department of Agriculture (USDA) Agricultural Research Service (ARS)
  - USDA Natural Resources Conservation Service
  - USDA Forest Service
  - United States Army Corps of Engineers
  - USDA/U.S. EPA Rural Clean Water Program;
- Various land grant universities and the extension services (e.g., Idaho and Kansas);
- Peer reviewed literature;
- State guidance manuals; and
- Approved and established TMDLs.

Several resources were obtained throughout this process, many as electronic documents or interactive websites and databases. Several tools have been identified that help the user work through a series of assumptions when selecting BMPs. An annotated bibliography of useful references is provided in Appendix B. Information is presented for urban, forestry, agricultural, and abandoned coal mine/remining BMPs.

11.3 User's Guide to This Chapter

This chapter is divided into four sections: urban, forestry, agricultural, and mining BMPs. Each section contains information on the main pollutants of concern, key factors in the BMP selection process, types of BMPs, and their effectiveness. Useful resource material related to each BMP category is also provided. This may include comprehensive studies, other studies of interest, and/or interactive BMP selection tools. In addition, several synthesis tables (see Appendix B) were prepared to assist the user in interpreting the appropriateness of each BMP. The tables document load reduction ranges for various types of BMPs and associated pollutants. Costs, maintenance considerations, and community factors are also documented for various BMPs by geographic location.

11.3.1 Key Factors in BMP Selection

Important questions to address prior to any BMP implementation include:

- Which pollutants (e.g., sediment, nutrients) are causing the problem?
- Where are the pollutants ending up (e.g., surface water, groundwater)?
- How are the pollutants being transported (in the water or on sediment)?

Once these questions are answered and the objectives are clarified, the user can select a BMP or BMP system that is most suitable to the situation. Key considerations include:

- Geographic location (climate/regional factors);
- Land availability (land use/land cover);
- Watershed factors;
- Pollutant type;
- Groundwater levels;
- Soil types;
- BMP costs;
- Maintenance costs; and
- Desired pollutant removal efficiency.

It is important to consider what types of pollutants, if any, cannot be effectively controlled with BMPs. Capital costs, operation and maintenance, and the implementation time required for each BMP should be considered. The length of time it takes for the BMPs to achieve maximum effectiveness and its effective life are also important. The effective life of a BMP is especially important to consider, as it may improve, decay, or remain stable over time. In addition, it may contribute to an overall increase in relative costs when compared as cost per year of effectiveness. Other issues of concern include the level of pollution control the BMP provides under

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typical conditions, how its efficiency ranges from pollutant to pollutant, how its efficiency varies with wet weather conditions, and if the BMP has potential downstream negative impacts.

11.4 Urban Stormwater BMPs

Urbanization may cause changes in hydrology and water quality. U.S. EPA (1993a) discusses the main sources of urban nonpoint source pollution that adversely affect waterbodies, including runoff from developing areas, construction sites, and existing development on-site disposal systems, roads, highways, and bridges, as well as general sources (e.g., households, commercial, and landscaping practices). The primary pollutants targeted in urban stormwater BMP designs are total suspended solids, total phosphorus, total nitrogen, heavy metals, floating trash, BOD, bacteria, and turbidity.

BMPs can be temporary or permanent. Temporary ones are intended to address construction activities, and may include short-term erosion and sediment control activities. Permanent BMPs pertain to long-term stormwater management objectives. These are essential to the configuration of the project. Permanent BMPs should be designed by licensed professional civil engineers, be incorporated into the specifications for the project, and have provisions for long term maintenance.

U.S. EPA (2001d; 1997c) cites four main reasons that urban BMP programs may fail: 1) insufficient funding; 2) inappropriate BMPs or BMP systems for site-specific circumstances; 3) lack of inspection of the implementation process, proper monitoring, and overall program evaluation; and 4) inadequate public education and awareness.

11.4.1 Types of Urban Stormwater BMPs

Some general urban stormwater BMPs (also referred to as Management Measures) by U.S. EPA (1993a) include:

- Construction erosion/sediment control;
- New onsite disposal systems;
- Operating on-site disposal systems;
- Pollution prevention;
- Siting roads, highways, and bridges;
- Construction projects for highways, roads, and bridges;
- Construction site chemical control for roads, highways, and bridges;
- Operation and maintenance for roads, highways, and bridges; and
- Runoff systems for roads, highways and bridges.

The Urban Water Infrastructure Management Committee's Task Committee For Evaluating Best Management Practices (2001d) cites a number of BMPs that have been developed to control urban stormwater, both to reduce pollutant loadings and to reduce peak flows. These are:

- ***Various Types of Stormwater Ponds***. Stormwater ponds are the most-used treatment for polluted runoff.

- ***Alum Treatment Systems***. Aluminum treatment of stormwater introduces active treatment. Generally the first step is a passive treatment such as creation of a pond or wetland.
- ***Constructed Wetlands***. It is possible to retrofit natural wetlands for flood control.
- ***Media Filters***. Various types of filters (e.g., sand filters) can be used to remove sediments and pollutants from runoff.
- ***Baffle Boxes***. These are sediment removal traps used to remove suspended solids from stormwater pipe flows.
- ***Inlet Devices***. These devices are inserts that can be placed in inlets to trap pollutants.
- ***Vegetated Swales***. Grassed swales are shallow vegetated channels used to convey stormwater for infiltration through soil.
- ***Buffer Strips***. Vegetated strips of land, which are flat and low and designed to accept stormwater runoff.
- ***Infiltration/Exfiltration Trenches***. An infiltration trench is an excavated trench that has been lined and backfilled with stone. Runoff is diverted into the trench through a grassy area and exfiltrates into the soil or is rerouted.

11.4.2 Selection of Urban Stormwater BMPs

The U.S. Department of Transportation (1996) provided some suggestions to help to select the best urban BMP alternative, including analyzing existing or potential source controls, the purpose of the BMP, and/or site conditions. In addition, it is important to evaluate pollutant removal capabilities, aesthetic value/amenities, as well as costs and maintenance constraints.

U.S. EPA (2001d) described some important considerations that should be addressed before beginning the overall BMP selection process:

- Does the BMP require supplemental water?
- What is the required size of the BMP to protect water quality?
- Should nonstructural components be incorporated into the design?
- What are the benefits and costs of the BMP options?
- Do structural or nonstructural BMPs have limited removal effectiveness?
- Is there one or more BMPs that outperforms other BMPs?
- Is a combination of structural and nonstructural BMPs required?
- To determine whether multiple BMPs are necessary, the following questions need to be considered:
  - Does any one BMP meet all of the objectives?
  - Do structural BMPs meet the objectives, and if so, to what degree?
  - Does a nonstructural BMP satisfy the objectives, and if so, to what degree?
  - Is it possible to modify or enhance existing structural or nonstructural BMPs to increase the effectiveness?
  - Does a nonstructural BMP improve the structural BMP performance?
  - Do nonstructural BMPs reduce the structural BMP performance?

Structural BMPs (e.g., retention or detention ponds) must consider site-specific conditions to ensure success. This process is critical to BMP success. Selecting an appropriate BMP depends on several factors. Table B-1 of Appendix B presents key selection factors to consider when implementing BMPs. Categories include land use, physical feasibility/site constraints,

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stormwater management capabilities, climate/regional considerations, pollutants, costs, maintenance requirements, and temporary/construction factors.

While many factors should be considered, as evidenced by Table B-1, the key factors that are applicable for most installations include (Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices, 2001):

- Soil types and conditions (e.g., percolation rate);
- Groundwater levels (e.g., height of ground above the groundwater level);
- Land availability;
- Types of pollutant to be removed;
- Desired pollutant removal efficiencies;
- Project cost (capital and maintenance); and
- Maintenance requirements.

Table B-1 indicates that these factors are the key consideration when selecting an urban BMP. However, other factors are also listed by several studies as key considerations in the BMP selection process. Other physical site constraints including size of drainage area, slope, and hydraulic head were found to be important. Community acceptance, affordability, safety, and habitat were also found to be critical in this process. Climatic considerations and land use (e.g., residential, rural, roads/highways, commercial development, hot spot land uses, and ultra-urban sites) were found to be important selection factors as well.

11.4.3 Climate/Regional Considerations

Regional climate issues can have an impact on quantity and quality of stormwater runoff. U.S. EPA (U.S. EPA, 1999c) documents the important climatic factors, which include antecedent dry periods between storms, average rainfall intensity, storm duration, and snowmelt. High amounts of suspended solids, metals, and nutrients may result in areas of significant atmospheric deposition. In addition, areas with infrequent rainfall in the southwest United States may have "hot spots" from parking lots, roads, and industrial areas. Typically, these may include high-intensity, short-duration rainfall resulting in increased loadings of suspended solids. Both cold climate and arid/semi-arid climate considerations are briefly discussed below.

Cold Climate Considerations: Cold climate design challenges include pipe freezing, ice formation on the permanent pool, reduced biological activity, reduced oxygen levels in bottom sediments, reduced settling velocities, frost heave, reduced soil infiltration, short growing season, high runoff volumes during spring melt, high pollutant loading during the spring melt, and snow management (Center of Watershed Protection, 1997; Barr Engineering, 2001). In addition to the typical pollutants of concern, pollutants in snowmelt such as sand (sediments), salt (chlorides), polycyclic aromatic hydrocarbons, cyanide, as well as trash and debris need to be considered.

Arid/Semi-Arid Climate Considerations: The Center for Watershed Protection (2000) presented stormwater strategies for arid and semi-arid watersheds including lower rainfall depths, higher evaporation rates, greater pollutant concentrations in stormwater, sparse vegetative cover in the watershed, greater sediment movement, rare dry-weather flow, and different aquatic resources and management objectives.

11.4.4 Effectiveness of Urban BMPs

U.S. EPA (U.S. EPA, 2001d) documented the necessary elements of successful urban BMP programs including:

- Definable program goals;
- Guidelines for site evaluation, design, implementation, operation, and maintenance;
- Routine monitoring of BMP systems;
- Certified or licensed providers;
- Successful enforcement mechanisms; and
- Suitable incentives for BMP implementation.

In addition, Schueler (1987) documents that pollutant removal is generally governed by three interrelated factors: 1) removal mechanism utilized, 2) fraction of annual runoff volume that is treated, and 3) nature of pollutant being removed.

Tables B-2 and B-4 present a "BMP Selection Guide" for the user, displaying key design factors and pollutant removal efficiencies for the BMPs. Table B-2 presents several factors including site constraints and applicability such as drainage area, area typically served, land area required, soils, slope, hydraulic head, depth to water table, proximity to wells, proximity to buildings, and climate considerations. Also important are capital costs, maintenance costs, effective life of the BMP, training, aesthetics, habitat, safety, and community acceptance. Table B-4 presents removal efficiencies by pollutant type: sediments; various forms of phosphorus (e.g., soluble phosphorus, total phosphorus); total petroleum hydrocarbons; various forms of nitrogen (NO_3, nitrate nitrogen, ammonia nitrogen); heavy metals and specific metals such as copper, lead, zinc; as well as other conventional parameters (e.g., organic carbon, chemical oxygen demand (COD)/BOD, oil and grease, bacteria, suspended solids, and floating trash).

Table B-3 reflects base capital costs for typical applications of each BMP category. Since many BMPs have economies of scale, it is not practical to extrapolate these values to larger or smaller drainage areas in many cases.

Table B-5 summarizes the pollutant removal efficiencies by BMP type: infiltration practices, retention basins, constructed wetland systems, stormwater filtration systems, and open-channel vegetated systems. Pollutant removal efficiencies are presented for various forms of phosphorus (e.g., soluble phosphorus, ortho phosphate, total phosphorus) various forms of nitrogen (e.g., ammonia-nitrogen, nitrate, organic nitrogen, and total nitrogen), suspended solids, bacteria, organic carbon, as well as various metals (e.g., cadmium, chromium, copper, lead, and zinc).

11.4.5 Useful Resource Material Related to Urban Stormwater BMPs

Studies of Interest: U.S. EPA (1999c) is a valuable resource, which provides several criteria for BMP selection, tables of base costs of typical applications of BMPs, details regarding cost equations, and pollutant removal efficiency of various BMPs. In addition, U.S. EPA (1999c) cites several documents, which may be of interest:

- Fundamentals of Urban Runoff Management (Horner et al., 1994);
- Controlling Urban Runoff; A Practical Manual for Planning and Designing Urban BMPs (Schueler, 1987);

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- A Watershed Approach to Urban Runoff: Handbook for Decision Makers (Terrene Institute, 1996);
- Urban Targeting and BMP Selection (Terrene Institute, 1990);
- Guidance Specifying Management Measures for Sources on Nonpoint Source Pollution (U.S. EPA, 1993a);
- Handbook Urban Runoff Pollution Prevention and Control Planning (US EPA, 1993b);
- Municipal Wastewater Management Fact Sheets; Stormwater Best Management Practices (U.S. EPA, 1996);
- Design and Construction of Urban Stormwater Management Systems (WEF and ASCE, 1992); and
- Urban Runoff Quality Management (WEF and ASCE, 1998).

Barr Engineering Company (2001) developed "Minnesota Urban Small Sites BMP Manual," which provides an excellent resource with an annotated bibliography of stormwater manuals, particularly for cold climates. See the Annotated Bibliography in Appendix B for more information.

Urban BMP Selection Tools: A number of useful interactive on-line and database tools can be used to provide guidance for the selection of urban BMPs. Several of the tools take the user through a series of decision trees, eventually directing the user to applicable BMPs. Brief descriptions of these tools are provided below.

- ***The Catalog of Stormwater Best Management Practices for Idaho Cities and Counties*** provides technical guidance for BMP selection. They provide a step-by-step procedure for site design that can be coupled with the stormwater BMP selection suitability decision tree. Temporary (construction) BMPs, permanent (post-construction) BMPs, and other structural controls are discussed. http://www2.state.id.us/deq/water/stormwater_catalog/index.asp
- ***City of Boise Catalog of Stormwater Best Management Practices.*** City of Boise defines minimum requirements, standards, and procedures. Removal rates are detailed for all types of BMPs including dry and wet detention ponds, dry and wet extended detention ponds, evaporation ponds, biofiltration swales, sand and organic filters, catch basin inserts, sediment traps, grass buffer strips, and water separators. http://www.ci.boise.id.us/public_works/services/water/storm_water/manual/des
- ***Texas Interactive BMP Selector.*** This tool prompts the user to select the level of annual precipitation, BMP category (e.g., pollution prevention, source control, and treatment control), pollutant removal effectiveness, type of application, soil type, and whether the materials are toxic. Capital costs, maintenance level, operation and maintenance costs, and training costs are also available; however, they are not part of the BMP selection criteria. http://www.txnpsbook.org/BMPs/URBMPS.htm
- ***DOT Ultra-Urban Best Management Practice Database.*** U.S. Department of Transportation ultra-urban database provides design criteria and monitoring results on BMPs from the U.S. and other countries. It provides information on successful and unsuccessful BMP implementation, level of effectiveness, reference information, study information, specific information for BMPs, BMP cost and maintenance data, and study results. (See Annotated Bibliography for more information)
- ***National Stormwater BMP Database.*** The American Society of Civil Engineers developed a BMP database in recognition of the wealth of information on BMP

effectiveness, and the lack of standardization in data collection procedures, reporting and performance protocols. The database tracks site location characteristics, watershed characteristics, BMP design parameters, monitoring location and instrumentation, cost, precipitation, flow, and water quality data. http://www.bmpdatabase.org/

- ***National Pollutant Removal Performance Database.*** This database developed by the Center for Watershed Protection builds upon Brown and Schueler's (1997a) National Database of BMP Pollutant Removal Performance. It consists of two components, a dynamic PC database and a succession of stormwater treatment practice pollutant removal efficiencies. (See Annotated Bibliography for more information).
- ***SMRC: Manual Builder.*** The Stormwater Manager's Resource Center stormwater design manual has several useful tools to assist the user with the development of a stormwater treatment practice manual including basic sizing criteria, list of acceptable stormwater treatment practices, performance criteria, and guidance on stormwater treatment practice selection. http://www.stormwatercenter.net/
- ***Center for Watershed Protection Website.*** This nonprofit corporation is responsible for providing local governments and watershed organizations with technical tools in an effort to protect the nation's streams, lakes and rivers. Its website is helpful in providing guidance on watershed planning, watershed restoration, stormwater management, watershed research, and better site design. http://www.cwp.org/

11.5 Forestry BMPs

Forestry BMPs are suggested practices that lessen the environmental impact of forest activities. The construction of roads, timber harvesting, mechanical equipment operation, burning, fertilizer and pesticide application are some silvicultural practices that may result in pollutants such as sediments, nutrients, and various pesticide chemicals reaching a waterbody (U.S. EPA, 2001d). Potential impacts are briefly described below (U.S. EPA, 2001d; 1993a).

- Sediment is considered to be one of the primary pollutants associated with forestry activities. The greatest impact occurs to stream systems when foresting is carried on too close to streams, and sediment is deposited into waterbodies. When soil is exposed by roads, skid trails, and/or log landings, the possibility exists for transport of sediment into streams. Sediment in waterbodies may harm benthic organisms, decrease fish species, affect water for human consumption, and increase turbidity, which can adversely affect aquatic vegetation (Neary et al., 1989).
- Nutrients (e.g., nitrogen and phosphorus) adsorbed to sediments resulting from forest fertilizers can also be harmful to receiving waters.
- Forest chemicals such as pesticides (herbicides, fungicides, and insecticides) used to control forest pests are also of interest, as they can be toxic to aquatic organisms. (Neary et al., 1989).
- Organic debris (e.g., slash, litter, soil organic material) from site preparation can be detrimental to waterbodies (Neary et al., 1989).
- Eliminating shade from river sides can raise water temperatures, which affects fish and other river dwellers. Disruption to these streamside forests also affects wildlife, which rely on these habitats.
- Physical barriers to upstream fish migration can also be an issue.

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- Streamflow alteration. Several site-specific conditions, such as total area harvested, topography, soil type, as well as harvesting practices, can alter streamflow. Increased streamflow can erode streambanks and cause an increase in sedimentation and peak flows.

11.5.1 Types of Forestry BMPs

BMPs for forestry may be structural (e.g., culverts, physical barriers) or managerial (e.g., preharvest planning, fire management, chemical management) (U.S. EPA, 1993a). Each type can be used to reduce nonpoint source runoff by minimizing the quantity of pollutants released into waterbodies, retarding the transport and delivery of pollutants, or decreasing or eliminating the harmfulness of the pollutants when delivered to a waterbody (U.S. EPA, 1993a). BMPs can be corrective or preventive, site-specific methods, pre-project, post-project, temporal or spatial. Forestry BMPs may include:

- Harvesting practices (timber harvesting, pre-harvest planning);
- Fire management (prescribed burning, wildfire practices);
- Ground cover management;
- Pesticide/herbicide management;
- Riparian zone management;
- Streamside management areas/streamside management zones;
- Road management (e.g., access road, skid trails, and landings);
- Road construction/reconstruction;
- Revegetation of disturbed areas;
- Wetlands forest management;
- Forest chemical (applications) management;
- Sinkholes;
- Logging debris;
- Fertilization;
- Site preparation for reforestation; and
- Livestock management.

Table B-6 presents nonpoint source pollutants resulting from forestry practices and the applicable BMPs for nonpoint source reduction. Pollutants therein include sediment, debris, water temperature, pesticides, fertilizer, and animal waste.

11.5.2 Selection of Forestry BMPs

The selection of the BMP is a critical factor in maximizing effectiveness. Several site-specific factors must be considered, including slope, soil type, proximity to streams, and layout of the harvests. This is important so the BMP will work well with other BMPs that are present in the system (U.S. EPA, 2001d). Timing of the activity within the season, and identification of sensitive areas (e.g., wetlands, threatened or endangered aquatic species habitat areas) should also be considered when selecting BMPs. In addition, a BMP system should be designed based on the source of pollutant, type of pollutant, environmental conditions (agricultural, climatic etc.), experience of system designer, and component acceptability by the producer of the BMP.

11.5.3 Effectiveness of Forestry BMPs

According to U.S. EPA (1993a; 2001d), BMP effectiveness has not been well documented on a watershed scale or for mixed land uses. Most of the studies have been conducted on field scales. U.S. EPA (2001d) cites the primary reasons for poor BMP effectiveness including: lack of time and/or willingness to plan timber harvests prior to the commencement of cutting; lack of skill and/or knowledge of effective BMP design; lack of equipment for proper BMP implementation; untimely implementation and lack of maintenance of BMPs; and assuming BMPs are not a fundamental part of the timber harvesting process and can be engineered and fitted to a logging site after the completion of timber harvesting.

To ensure BMP effectiveness, several factors must be taken into account. Stringer (2001) lists key factors to maximize BMP effectiveness including BMP selection, proper implementation, equipment type, operating systems, site characteristics, familiarity with the operating systems and equipment, time of year, timing of construction of water control structures, and revegetation mixes. In addition, U.S. EPA (1993a; 1997c) cites criteria used to monitor BMP effectiveness through the use of audits including geographic distribution, time since harvest, minimum size (site size), proximity to watercourse (e.g., stream), volume harvested, site preparation, compatibility with previous studies, representation of ownership, and random selection of sites.

The costs of specific forestry BMPs are presented for several regions including the Northeast, Southeast, Midwest, Rocky Mountains, Northwest, Southwest, and Alaska in Table B-7. Tables B-8 and B-9 present average costs of general forestry BMPs in the Southeast and Midwest. Table B-10 presents forestry BMP effectiveness for erosion control. Percent decrease in erosion is documented, as well as the portion of the road that was treated.

11.5.4 Useful Resource Material Related to Forestry BMPs

Effectiveness Monitoring Manual: Dissmeyer (1994) developed "Evaluating the Effectiveness of Forestry Best Management Practices in Meeting Water Quality Goals or Standards." This document provides information on which BMPs best protect water quality, and also addresses the effective life of BMPs. Effectiveness monitoring is provided for four levels, including chemical, physical, biological, and habitat integrity.

Water Quality Effects and Nonpoint Source Control for Forestry: U.S. EPA (1993d) developed an "Annotated Bibliography for Water Quality Effects and Nonpoint Source Control for Forestry." The purpose of this manual is to provide information related to NPS forestry-related pollution. Several management measures are discussed, and the bibliography is structured into sections to follow the management measures presented. Sections include program and policy studies and reviews, instream studies, road construction and use, timber harvesting, site preparation and regeneration, forestry chemicals, streamside management areas and riparian areas, wetlands, modeling, and water quality monitoring. Basic objectives, major results, and conclusions are presented for most references.

The Kentucky Master Logger Program: This program offers several sites of interest providing easy access to Logger Training and BMP Sites (http://www.masterlogger.org/links/). BMP information is provided as well as links to forestry agencies and organizations, and safety.

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Silvicultural BMP Library: The National Association of Foresters has a website that is Silvicultural Best Management Practices, which hosts a database of links to other BMP websites (http://www.stateforesters.org/reports/BMP/BMP_Library.html).

Water Quality and BMPs for Loggers website: Maintained at the University of Georgia's Warnell School of Forest Resources, this website provides an on-line service with BMP materials for the United States (www.usabmp.net). This site is intended to provide national, regional, and local on-line access to regulations, legislation, water quality, and BMP materials. It can be used to identify several useful forestry BMP sources, including South Carolina Forestry Commission, as well as Arkansas, Texas, Minnesota, Florida, Iowa, Wisconsin and Indiana sites. Guidance documents are just a small representation of the useful references found on this site that provide general guidance on BMPs and consideration related to the BMP selection process. Some of these sources are briefly discussed in the annotated bibliography.

11.6 Agricultural BMPs

Sources of agricultural nonpoint pollution include erosion from confined animal facilities, grazing management, application of nutrients and pesticides to cropland, and irrigation of and erosion from cropland (U.S. EPA, 1993a). U.S. EPA lists the primary pollutants resulting from agricultural practices as nutrients (e.g., nitrogen and phosphorus); sediment; chemicals that are transported with sediment in an adsorbed state (e.g., pesticides, phosphorus, and ammonium); animal wastes such as oxygen-demanding substances, soluble nutrients, absorbed nutrients, and organic solids; as well as salts and absorbed pesticides. Habitat impacts may also result from improper livestock grazing affecting shore/banks, water column, channel, and riparian vegetation.

11.6.1 Types of Agricultural BMPs

Table 11-1 lists agricultural BMPs, including general management practices, vegetative and tillage practices, and structural practices.

Table 11-1. Agricultural BMPs.

General Management Practices	
♦ Animal waste management	♦ Irrigation water management
♦ Animal feeding operations management	♦ Soil salinity management
♦ Nutrient management	♦ Fertilizer management
♦ Pesticide management	♦ Livestock exclusion
♦ Integrated pest management	♦ Range and pasture management
Vegetative and Tillage Practices	
♦ Conservation tillage	♦ Filter strip
♦ Contour farming	♦ Field border
♦ Field stripcropping	♦ Conservation cropping sequence
♦ Contour stripcropping	♦ Pasture and hayland management
♦ Crop rotation	
Structural Practices	
♦ Terraces	♦ Grassed waterway
♦ Water and sediment control basin	♦ Wetland development or restoration
♦ Diversion	

11.6.2 Selection of Agricultural BMPs

Important factors to consider in the selection of Agricultural BMPs include costs, climate and environmental conditions, local and regional agricultural economics, and soil needs (e.g., irrigation water management and soil salinity management).

U.S. EPA (1993b) developed management measures, which are synonymous with BMPs. Management measures for agricultural sources are addressed in chapter 2 of this U.S. EPA document. The purpose of each management measure, the appropriateness of the measure, the selection process, information on the effectiveness of the measure, and cost information for the measure are provided in the report. The effectiveness of each measure is dependent upon the pollutant of concern, types of BMPs being considered, and the site-specific conditions in which the BMPs will be implemented. In addition, national and some state costs are provided for a number of measures. Several case studies are also included.

Agricultural BMP capital costs and effective life of BMPs found in U.S. EPA (1993a) and other sources were synthesized and are detailed in Table A-11. Various erosion control, grazing management, and sediment control BMPs are documented. Table A-12 lists BMP removal efficiencies for various pesticide management, sediment control, and animal feeding operations management. Range of reductions for pesticides, total phosphorus, sediment, fecal coliform, BOD5, total suspended solids, ammonium nitrogen, and chemical oxygen demand are provided.

11.6.3 Effectiveness of Agricultural BMPs

U.S. EPA (1993a) states that animal feeding operations, fertilizer management, livestock exclusion and animal waste management are key components of every effective agricultural BMP program. While integrated pest management and pesticide applications should also be part of an effective agricultural BMP, they are not as critical (U.S. EPA, 1993a).

11.6.4 Useful Resource Material Related to Agricultural BMPs

Agricultural BMP selection tools include the following:

- ***Kentucky's Corn Growers Association:*** A state affiliate organization of the National Corn Growers Association has a website for BMPs for Kentucky Agricultural Water Quality (http://www.kycorn.org/producerpages/waterquality/bmp.html). This resource can help develop a plan for a given operation. The user is presented with a series of questions. The user is then directed to various BMP options with references and recommendations for the selected BMPs. This information is based on the Kentucky Agriculture Water Quality Producer Workbook.
- ***Best Management Practices Web Page:*** The Ohio State University Extension School has a BMP web page. It is designed to provide links to technical and economic information on several types of BMPs used in Ohio. This website has several links to BMP fact sheets and has economic decision templates that the user can download (http://www-agecon.ag.ohio-state.edu/people/sohngen.1/bmp/bmpinfo.htm).
- ***Natural Resource, Agricultural, and Engineering Service:*** An interdisciplinary, issue-oriented program sponsored by cooperative extension of 14 member land grant universities. They host a variety of topics on the website including horticultural production, dairy, livestock, and poultry production systems. They also provide tools for agricultural

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waste management, consumer education, natural resources management, and farm safety (http://www.nraes.org/).

- ***National Agricultural Pesticide Risk Analysis:*** A tool developed by the USDA, Natural Resources Conservation Service, which is capable of automated pesticide (e.g., atrazine) risk screening for Michigan. While this tool is confined to Michigan, it may be useful to see how the risks of applications are presented and calculated (http://www.iwr.msu.edu/~ouyangda/napra/).

11.7 Abandoned Coal Mine/Remining BMPs

Acid mine drainage is a chronic industrial pollution problem of the Appalachian Region within the Mid-Atlantic region of the eastern United States (U.S. EPA, 2001a). Acid mine drainage results from abandoned underground mines, surface coal mines, and coal refuse piles which cause excessive sediment runoff and leachate. Acid mine drainage typically has high metals concentrations, elevated sulfate levels, low pH, and excessive suspended solids (U.S. EPA, 1997a).

11.7.1 Types of Abandoned Coal Mine/Remining BMPs

Typically there are two types of systems, active and passive. Active treatment systems use strong chemicals (e.g., lime, caustic soda) to neutralize acid, which allows for metals to be precipitated and removed (U.S. EPA, 1997a). Passive treatment systems can treat drainage without the addition of chemicals. Passive treatment systems neutralize contaminants in coal mine drainage by exposing them to air, limestone vegetation in ponds, neutralizing ditches, buried channels, and wetlands (U.S. EPA, 1997a).

Some BMPs for treating coal mine drainage include:

- Aerobic wetlands
- Anaerobic wetlands
- Anoxic limestone drains
- Alkalinity producing systems and successive alkalinity producing systems
- Limestone ponds
- Reverse alkalinity producing systems
- Open limestone channels

The Abandoned Mine Land Program established by Title IV of the Federal Surface Mining Control and Reclamation Act assists with restoration of suitable land, mined or left abandoned (U.S. EPA, 2001a). Remining has been found to be a cost-effective option for this program, as it provides numerous environmental benefits to abandoned mine lands. Skousen et al. (1997c) define remining as "the surface mining of previously mined and abandoned surface and underground mines to obtain remaining coal reserve. Remining operations also reduce safety and environmental hazards by sealing existing portals and removing abandoned facilities, enhance land use quality, and decrease pre-existing discharges.

The Coal Remining BMP Guidance Manual was designed to guide the user to meet remining plan requirements as well as improve abandoned mine land conditions during remining

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operations. Various BMPs are discussed and implementation guidance is provided. Abandoned coal mine BMPs include (U.S. EPA, 2001a):

- Alkaline addition
- Anoxic limestone drains
- Ash fill placement
- Bactericides
- Check dams
- Constructed wetlands
- Daylighting
- Diversion ditch
- Diversion wells, alkalinity producing
- Drains, pit floor
- Regrading of abandoned mine spoil/highwalls
- Revegetation
- Sealing and rerouting of mine water from abandoned workings
- Silt fences
- Special handling of acid forming materials

The Guidance Manual documents the efficiency of various remining BMPs, and provides detailed BMP implementation unit cost information and cost equations when available (U.S. EPA, 2001a). While the effectiveness of each BMP is discussed, the document maintains that the user must acknowledge that the effectiveness of BMPs is the responsibility of those in charge of site operations. Proper installation and maintenance are also key factors for a successful BMP plan. While it is likely that more information on remining exists, this document is one of the most comprehensive documents available (U.S. EPA, 2001a).

11.7.2 Effectiveness of Remining BMPs

The following BMPs were evaluated alone or in combination. U.S. EPA reported on their effectiveness in reducing acidity, iron, sulfate, manganese, aluminum, and flow.

- ***Regrading.*** The restoration of positive drainage to conditions existing prior to enactment of the federal mining control and reclamation law. Regrading can approximate original contours, or terraced if existing spoil is inadequate.
- ***Revegetation.*** The establishment of a permanent vegetative cover on inadequately vegetated surface-mined area that is adequate to control surface water infiltration and erosion.
- ***Daylighting.*** The exposure by surface mining of a deep-mined coal seam to remove the remaining coal.
- ***Special Handling of Acid Producing Materials.*** The placement of acid-generating overburden rock at a location within the backfill that is advantageous for reducing the amount of acid that would otherwise be generated.
- ***Alkaline Addition.*** Used in a variety of circumstances, particularly where a mine lacks calcareous rock, but does contain a sufficient amount of pyritic material. Alkaline addition is measured as tons of $CaCO_3$, equivalent/acre.
- ***Special Water Handling Facilities.*** Refers to any BMP that is designed to prevent groundwater from entering the spoil. This can be accomplished by channeling groundwater through the spoil with the purpose of reducing water contact time with the spoil.

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- ***Biosolids Application.*** The application of nutrient-rich materials (such as solid or liquid residue generated during the treatment of sewage sludge) to the soil for enhancement of plant growth on surface mines.
- ***Mining of Highly Alkaline Strata.*** The mixing of naturally occurring calcareous rock during the mining process. The mining plan sometimes has to be altered to ensure that sufficient calcareous rock is encountered.
- ***Alkaline Redistribution.*** The process of taking excess calcareous material from a portion of a mine and placing it in areas of the mine that lack calcareous materials. Without the addition of the calcareous materials, these areas would not produce acceptable post-mining water quality.

The costs of these BMPs and the effectiveness of each BMP were evaluated by U.S. EPA, (2001a). Table B-13 presents BMP cost information by mine followed by effective life of the associated practice. Table B-14 presents water quality results of remining BMPs for several parameters, including iron, sulfate, manganese, acidity, aluminum, and flow. The number of discharges assessed and the observed effects of the BMPs on the discharges are also presented in Table B-14. Water quality and flow conditions should be considered for a period of time (e.g., two years) following site closure, because the effects of remining operations and associated BMPs are not immediate and may continue beyond mine closure.

Note that these data are specific and exclusive to remining operations in the Pennsylvania bituminous coal regions. Although hydrological and geologically similar, remining in other parts of the Appalachian coalfields may exhibit slight differences. No discharge data from mining on areas previously unmined, and no discharge data from areas unaffected by BMPs (control data) were included. At the time of the study, only contaminant loading and monitoring flow data were available.

11.8 Case Studies

Several case studies were reviewed in an effort to quantitatively link BMPs to nonpoint source load reductions. This review focused on TMDLs that have been in place for some time, as there is a better chance that the effectiveness of BMPs has been assessed. TMDLs were selected if they explicitly evaluated BMP effectiveness and if they specifically linked BMPs to load reductions.

11.8.1 TMDL Case Studies

Four TMDLs of interest are discussed below. These have been successful in reducing their contaminant levels by targeted approaches over a landscape level. Highlights of each are presented below.

11.8.1.1 Yakima River TMDL

- The Washington State Department of Ecology conducted a TMDL evaluation of the Yakima River basin in 1994-1995 to evaluate total suspended solids and DDT loads from irrigated agricultural areas.
- Turbidity will be limited to 5 NTU (turbidity units) increase in the 86.4-mile reach between the Yakima and Naches Rivers and Benton City. By the year 2002 all drains

and tributaries should be in compliance with the 90th percentile turbidity target of 25 NTU at their mouths. Total suspended solids concentrations must be reduced to 7 mg/L.

- Because a high percentage of the pollution in the lower Yakima comes from soil erosion on farms, significant changes in irrigation practices and irrigation water management are necessary. Sediment from farmland must be reduced 75–95%. Doing so will result in far-reaching water quality improvements in the Yakima basin.
- By 1997 there was already a 30% reduction in sediment load in the Moxee Drain, and a decrease in total suspended solids (86% in subbasin 10 and 56% in subbasin 5). In addition, the goal to reduce turbidity to below 25 NTU by the end of 2002 was already achieved two years before the deadline, by the year 2000, in most drains.

11.8.1.2 Nooksack River TMDL

- In 2000, the Washington Department of Ecology established a TMDL for the Nooksack River basin, located in Whatcom County, Washington. The goal of the TMDL is to restore water quality and re-open the Lummi shellfish beds, which were restricted in 1998 because of unsafe levels of fecal coliform bacterial pollutants.
- BMPs are improving such practices as dairy waste management, municipal sewage treatment, rural residential septic waste, county critical areas ordinance enforcement, and streamside revegetation.
- Compliance with the TMDLs is expected to reduce annual bacteria loads by 48%.
- Decreases of fecal coliform by 21% in several tributaries to the Nooksack have been observed where dairy farmers have implemented BMPs.

11.8.1.3 Nomini Creek

- Virginia's Department of Conservation and Recreation selected the Nomini Creek watershed in Westmoreland County, Virginia, as an area in which to evaluate and monitor the effectiveness of BMPs for the Chesapeake Bay Program in reducing nonpoint source pollution. If the BMPs result in a significant reduction in Nomini Creek, the study will help managers to achieve the Chesapeake Bay goal of 40% nutrient reduction.
- BMPs, including no-till farming, nutrient management plans, grassed waterways, drop structures, diversions, pasture management, and the removal of land from production, were implemented to reduce nonpoint source pollution from agricultural activities.
- BMPs were sited on critical areas of nonpoint source loading. A water quality monitoring program is currently evaluating BMP effectiveness.
- BMPs have been effective in reducing both the frequency of detection and peak concentrations of atrazine. The frequency of atrazine detection declined from 28.1% to 19.2% as a direct result of BMP implementation. The percentage of samples with atrazine concentrations in excess of the Maximum Contaminant Level also declined from 2% to less than 0.4%.
- The results indicated that the watershed-averaged curve number, sediment, and nutrient (nitrogen and phosphorus) concentrations were reduced by approximately 5, 20, and 40%, respectively, by BMP implementation.
- BMPs in the Nomini Creek watershed resulted in a 20% sediment reduction and a 40% reduction in nutrient concentration from agricultural activities.

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11.8.1.4 Nutrioso Creek

- Nutrioso Creek, located in the Little Colorado River Basin in Arizona, sought to reduce sedimentation through the implementation of BMPs after being listed as impaired water for violating turbidity standards.
- TMDL goals included public awareness and education, decreased stream velocities, decreased sheet flow and wind erosion, and reduced downcutting of the stream channel.
- There has been a high level of support by area landowners.
- Successful results are already beginning to show, with areas rated in 1996 as "non-functional" and "functional-at-risk with a downward trend" rated several years later as "functional-at-risk with an upward trend" and "in proper functioning condition."
- Monitoring showed that turbidity has stabilized at 9 NTU and flows have reached 50% above historical high levels.
- This case study demonstrates that with the support of landowners, BMPs can lead to improvements in water quality and meeting of TMDL goals.

11.8.2 U.S. EPA 319 Studies of Successful BMP Implementation

U.S. EPA (1994b) has identified several states that have seen improvements in water quality by the implementation of BMPs, including Louisiana and Texas. This information is available on-line at http://www.epa.gov/owowwtr1/NPS/Success319/. When implemented properly, BMPs led to reduced nonpoint source pollution and sedimentation in the following states, most of which suffered from pollution from agricultural activities.

- Louisiana evaluated four BMPs to reduce water quality problems resulting from rice production. It was found that alternating BMPs over two years decreased sediment loading from 20-63% and organic carbon by up to 92%. A summary of this study is available on-line at http://www.epa.gov/owow/nps/Success319/LA.html.
- Texas successfully implemented BMPs to control nonpoint source pollution from forestry activities. Some 20,000 people, including landowners, foresters, and the general public, have been reached by educational efforts. When properly implemented, BMPs minimized nonpoint source pollution, reducing stream sedimentation by 40%. Of the sites inspected, 88% received a compliance rate of fair or better. A sustained, cooperative educational effort is necessary to ensure that the voluntary BMP program succeeds. A summary of this study is available on-line (http://www.epa.gov/owow/nps/Success319/TX.html).

11.8.3 Other Studies of Interest

South Florida Water Management District (2002) documented that 16 BMP initiatives were implemented from 1979-1997 to improve water quality in the Everglades protection area, focusing on research, implementation, and education. BMPs have been shown to improve water quality at the farm level. BMP implementation has reduced the total phosphorus load from the Everglades Agricultural Area by 55%. Implemented BMPs include prevention of misplaced fertilizer, split application and slow-release fertilizer, minimizing water table fluctuations, use of aquatic cover crops, sediment control, and pasture management. Further reductions in phosphorus load and concentration are likely through additional BMPs currently being researched.

11.9 Discussion

The tables presented in this chapter provide information on a wide array of Best Management Practices that are effective at reducing nonpoint source pollution. However, each practice is associated with a wide range of costs, maintenance requirements, regional/climate considerations, and site-specific factors that must be considered. For instance, Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001) documented that typically ponds are the most commonly used BMP, as they are capable of treating the greatest number of pollutants and reducing downstream flooding. However, they have high construction costs and require the most land area of any BMP, potentially creating implementation difficulty in dense urban areas.

In summary, several factors are important in determining the percent reduction in nonpoint source loading due to particular BMPs:

- ***Physiography/geology/soils.*** BMP effectiveness is also controlled by the physiography, geology, and soils in the watershed. Some BMPs work much more effectively on certain soil types or terrain even though the land use or land cover might be similar.
- ***Cost of implementation.*** Cost is a critical component of any control approach, and can determine the feasibility of its implementation.
- ***Time scale of implementation*** (days, weeks, months, years, decades). The time scale associated with BMP implementation is critical in determining how long before the waterbody is able to attain water quality standards.
- ***Time scale of reductions*** (annual, storms, daily, seasonal). Some BMPs require significant O&M to remain effective, while the effectiveness of others increases through time.
- ***Uncertainty.*** Uncertainty estimates are an inherent part of the TMDL. Selection of BMPs also will be based on the uncertainty surrounding its effectiveness and previous applications.

This chapter presented comprehensive studies and tools for the various BMP categories. In addition, case studies were documented that specifically link BMPs to a reduction in nonpoint source reduction.

11.9.1 Considerations in the Selection of BMPs

This chapter provides detailed information on a wide variety of BMPs, and highlights several important considerations in selecting BMPs, including:

1. ***BMP effectiveness is pollutant specific***. The reductions that can be expected vary by pollutant type. Having an understanding of the expected range of reductions, as well as the reliability and consistency, by pollutant type and geographic area is an important preliminary step in assessing nonpoint source controls. Some BMPs work much more effectively on certain soil types or terrain even though the land use or land cover might be similar.
2. ***Evaluation methods can affect pollutant removal efficiencies***. Some commonly used calculations for BMP efficiency include: efficiency ratio, summation of loads, regression of loads, mean concentration, efficiency of individual storm loads, reference watersheds and before and after studies (U.S. EPA, 2001d). The Center for Water

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Protection indicates that the chosen evaluation method can affect the reported pollutant removal efficiencies. It cites an example of the potential mischaracterization of BMP types as less effective due to cleaner influent. In addition to the various methods, it is also important to consider the ease of the measurement, the costs and outcome of the measure (e.g., will it be easily understood by the public?).

3. ***Account for climate and regional considerations.*** The fact that maximum BMP effectiveness can be obtained in one geographic area does not mean it can be obtained in another. Since site-specific and regional variability exist (in the selection of appropriate BMPs, design constraints, and pollution control effectiveness), guidance is presented with respect to specific regions, with climate considerations where applicable. Regional climate issues can have an impact on quantity and quality of stormwater runoff.
4. ***BMP effectiveness should be estimated and implemented in aggregate (collectively), not for individual practices.*** BMPs should be considered as a system. The user must consider that while one BMP may be effective for one problem, it may be counterproductive to the goals of the second BMP. For instance, while some BMPs may solve a surface water quality problem, they can also create a groundwater quality problem. In addition, the potential exists for an aggravated situation to other pollutants. As previously stated, there are two types of BMPs—structural and nonstructural—and each has a different influence on a given pollutant. There have been situations where BMPs are directed to control one pollutant, and in turn, the BMP results in aggravating the loading of other pollutants. This is why it is critical to have BMPs for each project designed by a professional, and an expert trained in these systems should review the installation.
5. ***Consider Capital Costs and O&M Costs.*** It is important to consider Capital Costs and operations and maintenance costs carefully, as they tend to be the initial issue that hinders participation of voluntary BMPs. To manage this properly, consideration of the effective life of structural BMPs is a critical step in this process. Some BMPs may have greater construction costs and lower maintenance costs (e.g., traditional ponds and exfiltration trenches), whereas others may have greater maintenance costs and lower construction costs (e.g., baffle boxes, inlet devices).
6. ***Consider implementation time, effective life of the practice, and the efficiency of the practice.*** The effective life of a BMP is especially important to consider, as it may improve, decay or remain stable over time. In addition, it may contribute to an overall increase in relative costs when compared as cost per year of effectiveness. BMPs can require substantial time (in some cases, decades) to implement and achieve effective pollutant reductions. It may take a significant amount of time to attain water quality standards, perhaps even up to 20 years. Thus, water quality attainment will be incremental and should be accounted for when planning. It is also important to note that some BMPs need a significant amount of operation and maintenance to remain effective.
7. ***Consider the scale of the watershed and the density of BMP coverage.*** It is important to consider the scale of the watershed to evaluate the future effect of the BMPs. As an area grows, there will be more spatial variability, which will make it more difficult to describe a nonpoint source relationship. It is also important to consider the density of BMP coverage used to effectively communicate some of the reduction loads seen in an impaired situation. Many of the documents reviewed in this chapter stated the

importance of assessing the area typically served, drainage area, space required (percentage of total drainage area), proximity to wells, proximity to buildings, etc.

8. ***Recognize certain pollutants have been effectively controlled with BMPs***. In general, sediments, pathogens, nutrients, and particulates in nature are the easiest pollutants to control with BMPs. As evidenced by the case studies, sediments are the easiest to control with management measures (Yakima, Nomini, Louisiana, Texas), as well as nutrients (Nomini; Everglades), turbidity (Yakima, Nutrioso), and total suspended solids (Yakima). BMPs have also proved to be effective in reducing fecal coliform levels (Nooksack), organic carbon (Louisiana) and increasing flow (Nutrioso).
9. ***Community acceptance and public support are critical to BMP success***. Several of the documents reviewed indicated the need for community acceptance. This can be measured by three factors: 1) market and preference surveys, 2) reported nuisance problems, and 3) visual orientation (i.e., is it notably located, or is it in a discrete location?) (Stormwater Manager's Resource Center website http://www.stormwatercenter.net/). Affordability (e.g., design, land acquisition), safety (e.g., liability and safety are of especially important in to consider in residential settings), and habitat (adversely affect habitat or designed to create a better habitat) for wildlife should also be considered.
10. ***Post implementation monitoring is also recommended***. As part of an adaptive management approach, reassessments will be necessary approximately every five years to develop allocations based on the current effectiveness of BMPs. This will allow regulation of nonpoint sources based on lessons learned by BMP implementation.

11.9.2 Future Considerations

During this project, load reduction ranges were documented for various types of land uses/land covers and associated pollutants by geographic location. Future research needs may include:

- Linking the data sources, examples, and approach through a decision-support system approach;
- Developing a framework for selecting appropriate BMPs and associated nonpoint source load reductions by pollutant type and land use/land cover for inclusion in TMDLs; or
- Developing a website where the user could select a pollutant and type of land use, and then determine what type of BMP effectiveness information is available. A few databases exist for urban BMPs, but the user may benefit from a consolidated resource.

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CHAPTER 12.0

TMDL IMPLEMENTATION PLANNING, TRACKING, AND ADAPTATION

The purpose of this chapter is to help states develop or improve their approach to TMDL implementation planning, by providing information on a range of current state approaches and outlining "lessons learned" based on interviews of selected state officials.

12.1 Introduction

TMDL implementation is an essential aspect of the TMDL approach, since water quality standards cannot be attained without implementation. As the 1998 Report of the Federal Advisory Committee on the TMDL Program (U.S. EPA, 1998a) states, "implementing TMDLs is the key to program success. TMDLs should not be planning exercises but, rather, action plans for achieving water quality standards." In addition to this fundamental reason for implementing TMDLs—attainment of water quality standards—states expend significant resources on TMDL development, and those resources could be wasted if TMDLs are completed but not implemented. Further, the public generally expects results from these significant government expenditures.

Implementation plans can help ensure that implementation will occur by providing clarity about what actions will be implemented, by whom, and in what time-frame. Without these markers, it will be difficult to assess whether adequate progress is being made in implementing a TMDL. While there is debate on whether implementation plans should be required as part of an approved TMDL, implementation plans are, regardless, essential to the goals of the TMDL program, which are to set us on a course to restore water quality.

This chapter presents the results of research conducted to identify issues with, and potential improvements to, the development of TMDL implementation plans. The research involved a review of 176 individual approved TMDLs (Appendix A), a review of federal regulations, and a review of selected state programs. From these reviews, implementation planning challenges and key attributes have been identified that can help improve the implementation planning process. The remainder of this chapter first provides the regulatory context for implementation planning and then provides a set of observations and findings based on a review of selected state TMDL implementation plans and interviews with key state representatives involved in TMDL implementation planning.

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12.2 Review of Approved TMDLs

Despite general agreement on the need for implementation, the review of 176 TMDLs shows an inconsistent level of implementation planning across and within states. In some cases the states' approaches may not lead to full implementation of actions needed to attain water quality standards. For example:

- Nearly half (43%) of the surveyed TMDLs did not include implementation plans;
- Less than half (42%) of the implementation plans are "detailed" plans, containing specific actions, a schedule, and a monitoring plan; and
- Few of the implementation plans (28%) have contingencies in place in case the endpoint is not met.

It also appears that implementation plans may not always contain the specificity needed to ensure that proposed actions will be implemented in a timely manner. Finally, it appears that actions identified in TMDLs may not always be tracked over time to monitor effectiveness.

12.3 Review of Federal Regulations

Under its currently effective TMDL rule, U.S. EPA does not require states to develop formal implementation plans to ensure implementation of TMDLs. The regulatory landscape with respect to implementation planning has been changing over the last few years, and two sets of regulations are germane to any discussion of TMDL implementation: the 1992 TMDL rule and subsequent policy guidance currently in effect, and the revised TMDL rule promulgated in 2000, which was formally withdrawn by U.S. EPA in March of 2003 because the agency believes that significant changes would need to be made to make it a workable framework.

12.3.1 Currently Effective TMDL Rule and Guidance

Section 303(d) of the Clean Water Act does not establish any new implementation authorities beyond those existing elsewhere in state, local, tribal, or federal law. Point sources, therefore, implement the wasteload allocations within TMDLs through enforceable water quality-based discharge limits in NPDES permits authorized under Section 402 of the Act. U.S. EPA regulations (at 40 CFR 122.44(d)(1)(vii)) require that effluent limits in NPDES permits for point sources be consistent with assumptions and requirements of wasteload allocations for the discharge contained in a U.S. EPA-approved TMDL.

In 1997, U.S. EPA issued a memorandum, "New Policies for Establishing and Implementing TMDLs" to address how nonpoint source load allocations should be achieved for waters impaired solely or primarily by nonpoint sources. The memorandum directs U.S. EPA regions to work in partnership with states and tribes to develop implementation plans. It states that the implementation plan should include: 1) reasonable assurances that the nonpoint source load allocations will be achieved; 2) a public participation process; and 3) recognition of other watershed management processes (e.g., the continuing planning process). The implementation plan may address individual waters, several waters within a watershed, or all affected waters in the state. While states may develop implementation plans and submit them to U.S. EPA for

review, the agency does not require states to develop implementation plans, and does not approve or disapprove the plans.

12.3.2 TMDL Rule Promulgated in July 2000

While in March 2003 U.S. EPA formally withdrew the proposed TMDL rule promulgated in July 2000, the latter rule would have required states to develop an implementation plan for each TMDL. U.S. EPA would then be required to approve or disapprove each plan, and its decision would be subject to federal judicial review if challenged. This "rule" is being discussed herein, in the context of presenting the historical debate and recommendations. The 2000 TMDL rule establishes that the implementation plan should reflect point sources, nonpoint sources, and other sources of pollution, and include:

- A list of actions needed to reduce pollutant loadings and a time-line for implementation;
- Reasonable assurances that implementation will occur;
- A monitoring or modeling plan and milestones for measuring progress;
- Plans for revising the TMDL if progress toward cleaning up the waters is not made;
- The date by which water quality standards will be met, generally within 10 years;
- Runoff controls should be put in place five years after the implementation plan is developed, if practicable; and
- Reasonable assurances.

For point sources, reasonable assurance is to be provided through National Pollutant Discharge and Elimination System (NPDES) permits. For nonpoint and other sources, load allocations in each TMDL must meet a four-part test: 1) they apply to the pollutant; 2) they will be implemented expeditiously; 3) they will be accomplished through effective programs; and 4) they will be supported by adequate water quality funding.

Several parties filed suit over the July 2000 rule (American Farm Bureau Federation v. Whitman). In September 2001, U.S. EPA announced it was requesting court suspension of the lawsuit for 18 months because the agency was considering sweeping changes to the rule. A federal appeals court approved the suspension in October 2001. U.S. EPA delayed the effective date of the 2000 rule until April 2003 while it reconsidered the rule, including the implementation provisions. in March 2003, U.S. EPA formally withdrew the rule.

The regulatory landscape with respect to implementation planning continues to change. Recent key developments include the following:

- In early 2002, U.S. EPA officials announced that they were considering revision of existing continuing planning process requirements to replace the implementation requirements in the July 2000 rule. A continuing planning process is a management system for implementing the Clean Water Act in a state and is required under Section 303(e) of the Act. Unlike TMDLs, U.S. EPA is not required to approve/disapprove revisions to these plans (and therefore its action would likely not be subject to federal judicial review). If the agency does revise its continuing planning process rules, it could provide for states to develop general plans for implementing the Clean Water Act in Section 303(d) listed waters, rather than separate implementation plans for each TMDL.

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- Most recently, on July 2, 2002, the U.S. Court of Appeals for the 11th Circuit ruled that the Clean Water Act does not require formal implementation plans, but that states are still responsible for implementing TMDLs (Sierra Club, et al. v. Meiburg, et al.).

While the regulatory landscape will continue to evolve, most experts believe that TMDLs are intended to be implemented and that implementation plans for nonpoint sources in particular are helpful, if not necessary, for success. The evolving nature of TMDL regulations on implementation, particularly with respect to implementation planning, may help to explain the inconsistent nature (e.g., content, level of detail) of the implementation plans reviewed.

12.4 Review of State Programs

Recognizing the importance of implementation plans to achieving the goals of the TMDL program, state representatives were interviewed and implementation plans reviewed from six states: Oregon, Washington, Idaho, California, Kansas, and Massachusetts. These states were chosen because they have strong implementation planning programs and/or to provide geographic representation.

States generally are in the early stages of implementation. Most of the focus to date has been on TMDL development. Based on U.S. EPA's "Listening Summaries," states believe implementation planning makes good sense, but participants recommend a wide range of approaches. Indeed, states are now developing implementation plans in a variety of program contexts and are employing them in a variety of approaches.

States are planning for TMDL implementation in at least four different contexts, based on a review of selected state implementation plans:

- ***TMDL-specific plans:*** The implementation plan is tied directly to the TMDL and is sufficiently detailed to provide for source-specific (e.g., individual point sources and land owners) or, at least, sector-specific (e.g., the "agricultural community") actions.
- ***TMDL-preliminary plans:*** The implementation plan is developed as part of the TMDL, but is more general than source-specific, focusing, for example, on follow-up actions the state may take to identify needed source-specific actions.
- ***Watershed plans:*** Implementation of the TMDL is expected to be carried out as part of a broader watershed approach and plan.
- ***State-wide programs:*** The TMDL does not have an associated implementation plan or watershed initiative, but the state's broader water quality programs (e.g., nonpoint source management program) provides for a focus on Section 303(d) listed waters.

These are not mutually exclusive categories. For example, in some states (e.g., Oregon) an overarching TMDL-specific implementation plan is developed first, and source-specific implementation plans are developed later by the various implementing agencies.

The content of the implementation plans also varies considerably across and within states. For example:

- Some implementation plans are developed and submitted as part of the TMDL, while other states develop the implementation plan within a specific time-frame of TMDL approval (e.g., Idaho develops its plans within 18 months of TMDL approval);
- Some TMDLs include specific tasks (e.g., review/update NPDES permits by time-certain for specific facilities), while others propose general activities (e.g., consulting BMP guides); and
- For some TMDLs, environmental agencies with primary responsibility for water quality protection develop and execute the plan; for others, it is the responsibility of various "designated management agencies."

12.5 Observations and Findings

While states generally are in the early stages of TMDL implementation, state officials interviewed offered observations on keys to effective implementation planning based on their experience to date. The following six observations describe both insights and challenges to improved implementation planning gleaned from the interviews.

12.5.1 States with the most detailed implementation plans have the greatest confidence that the plans will be executed.

Most of the state representatives interviewed related that the more specific and detailed an implementation plan is, the greater confidence they have it will be implemented and water quality standards attained. As one state representative interviewed put it, "there's no substitute for clearly defining who, what, when, where, and how"; i.e., who will undertake the needed management practices, what actions will be taken, when will those actions be implemented, where will the actions apply, and how will they be funded, monitored, or otherwise assured of implementation and meeting the standards. To this end, some of the states interviewed have established specific components that should be contained in TMDL implementation plans.

The most comprehensive set of components reviewed are contained in Oregon's currently proposed TMDL rules, and include the following key elements.

- ***Condition assessment and problem description.*** Identifies the water quality concerns and their causes, including water quality standards and criteria of concern, water quality conditions, the types of pollution causing the problems, the sources of the pollution, and the loading capacity of the waters for the pollutants of concern.
- ***Goals and objectives.*** A statement of the water quality improvement and protection goals of the plan, accompanied by objectives which quantify the desired change in water quality, beneficial use support, pollution loading, and/or other measurable indicators of stream or watershed conditions.
- ***Proposed management strategies.*** Describes the proposed, specific activities for each source category, and how they are designed to meet the wasteload allocations and load allocations of the TMDL.
- ***Time-frame for implementation.*** Describes the timeline for implementing management strategies, including the schedule for implementing such strategies, for revising permits, for achieving appropriate incremental and measurable water quality targets, and

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for implementing control actions. Also establishes the target dates for attainment of water quality standards.

- ***Identification of responsible participants.*** Identifies the persons or organizations responsible for the implementation of the plan and lists the major responsibilities of each organization.
- ***Reasonable assurance.*** Provides evidence that participants in the plan are committed to full and timely implementation, or explains how and by whom the implementation of the action plan will be assured (e.g., signed agreements by which landowners and managers have committed to the plan, evidence that financial support for implementation has been formally secured or committed).
- ***Monitoring and adaptive management.*** Identifies parties responsible for monitoring and describes a plan for tracking implementation of the selected measures, collecting and analyzing information on the effectiveness of the specific measures at achieving the water quality goals, and providing a "feedback" or "adaptive management" process by which the results of implementation can be used to modify and improve the pollution control program as necessary.
- ***Public involvement.*** Describes the process to involve interested and affected stakeholders in both the development and the implementation of the plan.
- ***Costs and funding.*** Describes the financial resources needed to develop, execute, and maintain the proposed activities, to demonstrate that sufficient funding is available to begin implementation, and to identify potential future funding sources for implementation.
- ***Citation to legal authorities.*** Identifies the legal authorities under which the implementation plan will be conducted.
- ***Voluntary programs.*** Describes voluntary programs and incentives that will be used to implement management strategies.

A few other states require a similarly comprehensive set of components in TMDL implementation plans. These include, for example, other states in U.S. EPA Region 10 (Idaho, Washington), in part because the development of detailed implementation plans is required under a Memorandum of Agreement with U.S. EPA (established in response to a 1998 TMDL-related court settlement agreement). However, since 1998, each of these states has chosen to expand on its implementation plan approach by adding additional components to the plans, by defining further individual plan components, and/or by developing guidance to assist with successful execution of the plan.

Implementation plans reviewed from other selected states typically included some but not all of the components defined above, and the information provided was of a more general nature. Most often, for example, relevant, state-approved best management practices (BMPs) or other potential management actions are listed, but are not always tied to specific sources, timelines, funding availability, or monitoring plans.

The set of components and level of detail of individual implementation plans differ within as well as among states. In particular, the level of detail necessarily varies, based on the complexity of the TMDL and other factors. For example, if the sole management action needed to address water quality impairments is the creation of buffer strips along contributing tributaries, then the implementation plan may be relatively simple compared to dealing with a more

complex set of sources and problems. However, in all cases, addressing the components listed above to the degree necessary to clearly answer the "who, what, when, where, how" questions provides the greatest certainty that the implementation plan will be executed and water quality standards attained.

In addition to defining the components that should comprise the implementation plan, most of the states interviewed also believe that state guidance needs to be provided on how to interpret and execute each component. Four of the six states interviewed (OR, WA, CA, ID) have established or will soon establish guidance for developing TMDL implementation plans.

According to one state representative, implementation planning guidance is imperative because it provides "clarity, organization, and structure" to the implementation effort, which is needed in light of long implementation time-frames with staff turnover and the involvement of large numbers of individuals from varying backgrounds and organizations (generalists and scientists from various agencies, external stakeholders, etc.). Another state representative believed that such guidance helps stakeholders understand the process better and overcome their concerns. At the same time, some state representatives urged that it is important to provide flexibility in developing implementation plans. In one person's words, the guidance should provide "a set of ingredients, not a single recipe."

12.5.2 All states interviewed believe that TMDL implementation planning, to be most effective, should begin at the time of TMDL development, and should provide linkages to other water quality programs and activities.

All states interviewed strongly believe that implementation planning should be conducted in concert with TMDL development. The primary benefit, according to several state officials, is that "real world" implementation feasibility can be factored, at least informally, into TMDL allocation decisions. Sectors and/or sources may differ in their ability to achieve water quality improvements, and predicating allocation decisions, to some degree, on implementation feasibility provides greater likelihood that the TMDL will be implemented and TMDL allocations met. As one state official put it, "you want a TMDL that results in a real solution to a real problem."

Other state officials point out that beginning implementation planning at the time of TMDL development increases the overall pace of reaching water quality goals, because greater lead-time exists for educating sources, structuring stakeholder involvement, and getting to know the watershed. Another reason to conduct implementation planning at or near the time of TMDL development is to ensure that the data used to set control requirements still accurately reflects water quality conditions and is less likely to be challenged as outdated. U.S. EPA's recently completed Consolidated Assessment and Listing Methodology (CALM) document recommends that water quality assessments rely on data that are no more than five years old.

While state officials interviewed believe that TMDL development and implementation should be closely linked, they also believe flexibility in how this linkage is achieved is important. To be useful, the implementation plan does not necessarily need to be fully completed at the time the TMDL is developed or formally approved, according to those interviewed. For example, in Washington a "summary implementation plan" is developed (focused largely on source identification) and is submitted with the TMDL to U.S. EPA; subsequently, a much more comprehensive and specific "detailed implementation plan" is developed. Formal approval of an

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implementation plan at a particular time, in fact, may be problematic, according to those interviewed. Massachusetts, for example, considers its TMDL implementation plans "living" documents, and revises and adds more detail to them over time. Most states similarly provide for some type of periodic review of the efficacy of their implementation plans, in the expectation that revisions or fine-tuning may be required and an "adaptive management" approach (see Chapter 14.0) will best achieve water quality objectives.

State officials interviewed also emphasized that for TMDL implementation plans to be most effective, they should be linked to other water quality programs rather than being developed and/or implemented in isolation. States are striving to integrate the components of their myriad water quality programs so that they can better complement each other in achieving program goals and watershed protection. TMDL implementation plans are one potential avenue for this, and states have used them to create linkages between programs. For example, most states interviewed focus 319 grant monies on water quality-limited waters by giving them priority status in the 319 nonpoint source grant allocation process, and some of their implementation plans reflect this expectation of 319 funding assistance. Some states also develop their TMDL in the context of broader water quality programs (e.g., watershed planning approaches, nonpoint source programs) that can help to create formal linkages among water quality programs, activities, and resources. An important potential value of implementation planning is to direct and link many discrete program activities, such as traditional NPDES permitting, urban wet weather management, agricultural nonpoint source management, forest management, wetlands protection, source (compliance) monitoring, ambient monitoring, and enforcement, to accomplish water quality and/or watershed protection goals.

12.5.3 Engaging stakeholders, including other agencies and jurisdictions, is a challenging fact of life in TMDL implementation, and to be successful requires a different set of skills and interactions from those required from TMDL development.

All states interviewed consider stakeholder involvement a vital aspect of TMDL development and implementation. The importance of stakeholder involvement in the TMDL process is discussed in Chapter 13.0. Most states interviewed take a similar approach, the centerpiece of which is forming a local advisory group comprising a wide array of stakeholders to exchange information, discuss issues and options, and develop recommendations for meeting load and wasteload allocations. In some cases, states interviewed form new local advisory groups for each TMDL or watershed; in other cases already-existing groups are used as the advisory group. Idaho DEQ, for example, relies on its already-established "watershed advisory groups," established by law for most watersheds in Idaho to advise on water quality issues more generally. All states interviewed issue public notices, provide public comment periods, and hold public hearings as a part of their stakeholder involvement process.

In the states reviewed, stakeholder involvement for TMDL implementation planning is most often a continuation of the process used for TMDL development, sometimes with subtle differences. In Washington for example, the advisory group may be reorganized at the time of implementation plan development, to allow existing stakeholders to leave the group if they desire and to seek out additional stakeholders whose involvement may be particularly valuable (e.g., local landowners) during the implementation phase. In other states interviewed, the difference between the development and implementation phase is more marked. Oregon, for example,

requires a separate, typically sector-specific (e.g., agriculture, forestry, urban, etc.) public involvement plan and process for the implementation of management strategies.

Following are two examples of how states approach stakeholder involvement.

- ***Kansas Department of Health and Environment:*** By incorporating TMDLs into its Basin Plans, the Kansas TMDL process uses the public participation aspects of its State Water Planning Process. Briefings are made to the Kansas Water Authority at its quarterly meetings. Monthly meetings are held with the Basin Advisory Council in the basins where TMDL work is being conducted. Such councils are present in each of the 12 major river basins, appointed by the Kansas Water Authority. The 11 members of each council reside in the basin and represent some aspect of water use in the basins. Two public meetings are held to take public testimony on the TMDL subsection of the Basin Plan and on the TMDLs themselves. Additionally, basin-specific TMDL public forums are scheduled once a year at a couple of locations within the basin to facilitate a dialogue among the agencies, the general public, impacted dischargers, interest groups, and municipalities on the TMDLs and their implementation. The agency also schedules regular meetings with the interest groups representing municipalities, agriculture, and environmental concerns.
- ***Oregon Department of Environmental Quality:*** This agency either forms a local advisory group with diverse membership or uses existing watershed councils as the advisory group for TMDL and implementation plan development. The advisory group is kept informed throughout the entire TMDL development process, makes recommendations, and provides a forum for the discussion of issues. Public hearings are also held on the proposed TMDLs, which are then finalized. Under its proposed TMDL rules, a public involvement plan must also be developed and carried out specifically focused on implementation of management strategies. The agency also provides for stakeholder involvement after the management strategies have been implemented. As part of its adaptive management approach, and, with the assistance of local stakeholders, it establishes a science review team to review data and provide recommendations concerning adjustments to the TMDL and/or allocations. At least annually, a public meeting is held to provide updates on new data and progress toward implementing the TMDL.

States have an interest in providing for substantial stakeholder involvement in the development and execution of TMDL implementation plans, according to those interviewed. Most importantly, stakeholders will generally be more likely to implement a TMDL in which they have participated. In addition, states and the U.S. EPA have limited resources, which could go further if stakeholders are able to carry out and/or finance certain TMDL implementation activities. At the same time, stakeholder involvement can be difficult, time-consuming, and resource-intensive for state agencies.

State representatives interviewed offered the following observations on important elements of an effective stakeholder process.

- It is critical that staff working with stakeholders possess good communication and process skills. The largely voluntary nature of nonpoint source TMDL implementation means that work is largely "relationship-based," as agency staff work with stakeholders

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to inform, educate, develop solutions, and encourage them toward needed actions. As one state representative noted, "it requires a lot of TLC [tender, loving care]." Some of the states reviewed have appointed individuals (e.g., farmers) from within the community as watershed coordinators, and have found this "peer relationship" to give the process added credibility and, as a result, greater and more effective stakeholder involvement.

- When possible, build on existing organizational structures rather than forming new ones. Several of those interviewed stressed the importance of "connecting" with the local community to be effective, and that one of the first ways is to use existing watershed councils or other entities to serve as the advisory group. These groups are often already well informed, have established working relationships with each other, and have linkages to the broader community. In some cases, according to those interviewed, active watershed councils or similar bodies may be moving forward with restoration plans that could be modified to meet TMDL goals if the linkage between the two is made.
- Enabling stakeholder efforts to provide funding and assistance can accelerate the overall pace of TMDL implementation. States and the U.S. EPA have limited TMDL resources that can stretch further if stakeholders are able to carry out and/or finance certain TMDL activities. Indiana, for example, has developed guidance for third-party TMDL development. Massachusetts and California have well-established volunteer monitoring programs. In the San Francisco Bay area, the discharger community (e.g., publicly-owned wastewater treatment plants) is contributing significant resources to build, and in some cases lead the development of, a "better, quicker" TMDL. The dischargers, according to the state representative interviewed, are friendly toward the TMDL process because the process will likely find them to be small contributors to the problem (since they are already regulated), and if not, a more informed and better documented decision is also beneficial to them. As a point of process, the agency in Washington enters into a written agreement with stakeholders to clarify roles and other aspects of any stakeholder-based TMDL activities.
- Early and ongoing stakeholder involvement is important. Early involvement can contribute to greater support for implementing the TMDL and increased pace of reaching water quality goals. Involving stakeholders early, according to one representative interviewed, "provides needed lead time for identifying and educating stakeholders, getting their buy-in, and getting to know the watershed."

Other agencies and jurisdictions are often key stakeholders who warrant special consideration. In most cases of nonpoint source pollution, environmental pollution control agencies do not have direct regulatory authority; this responsibility rests, instead, with other agencies and jurisdictions such as local governments that have land use authority. For example, in Oregon and Idaho "designated management agencies" (e.g., state Departments of Agriculture, state forestry departments) are responsible for developing and executing TMDL implementation plans for most nonpoint source TMDLs. Even without formalized implementation plan responsibility, other agencies often possess valuable data and authorities, and are essential partners in successfully implementing TMDLs, according to those interviewed.

This "indirect" nature of TMDL implementation means that states will benefit from having processes in place for ensuring that other agencies are executing the implementation plan or

otherwise carrying out their responsibilities. For example, Idaho meets quarterly or semi-annually with the implementing agencies to get updates on how implementation is progressing. Oregon, under its proposed TMDL rules, would require designated management agencies to develop and submit for approval sector- or site-specific implementation plans, and provide evidence of sources' compliance with land use requirements (e.g., Land Use Compatibility Statements for permitted sources).

12.5.4 State implementation plans tend to rely on a general, rather than specific, set of "reasonable assurances" to demonstrate that nonpoint source activities will result in required load allocations.

Description. Reasonable assurances provide evidence that nonpoint source participants in the implementation plan are committed to full and timely implementation. This commitment may be assured by a number of different means, including but not limited to the following examples.

- Signed agreements by which landowners and/or land managers have committed to the plan;
- Signed commitments from agencies, local governments, schools, volunteer stewardship groups, or other watershed stakeholders;
- Signed contracts, licenses, or permits which include stipulations related to plan implementation;
- Evidence that financial support for implementation has been secured or committed;
- Financial incentives (e.g., cost-share funds, grants, crop support payments) are in place and have been committed to implementation;
- Identification of how and by whom the implementation of management measures will be enforced, if necessary to achieve water quality standards;
- Evidence that voluntary approaches structured similarly have succeeded in other jurisdictions.

Regulatory Context. According to U.S. EPA guidelines for TMDLs under the existing regulations issued in 1992, if a TMDL is developed for waters impaired by point sources only, the issuance of an NPDES permit provides the reasonable assurance that the wasteload allocations contained in the TMDL will be achieved. This is because 40 CFR 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 wasteload allocation is based on an assumption that nonpoint source load reductions will occur, U.S. EPA's 1991 TMDL Guidance states that the TMDL should provide reasonable assurances that nonpoint source control measures will achieve expected load reductions for the TMDL to be approvable (U.S. EPA, 1991a). This information is necessary for the agency to determine that the TMDL, including the load and wasteload allocations, has been established at a level necessary to implement water quality standards.

U.S. 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 (U.S. EPA, 1997a). However, U.S. EPA cannot disapprove a TMDL for nonpoint source-only impaired

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waters, which do not have a demonstration of reasonable assurance that load allocations will be achieved, because such a showing is not required by current regulations.

Current state approaches. The majority of reasonable assurances reviewed consist of a listing of existing competitive grants and applicable regulations. These may or may not be good reasonable assurances, depending on how specific they are (in the case of regulations) or how likely the funding is to be secured (in the case of grants). For example, a description of a potential grant may be a good reasonable assurance if the grant process gives priority to addressing impaired waters. In the reasonable assurance provisions reviewed, there are typically no signed agreements by sources or local government agencies that specified actions will be undertaken; no link between funding sources and specific actions; and no evidence that funding has been secured. The exceptions are the agreements that some states have with federal or state land management agencies, such as the U.S. Forest Service, to develop and execute TMDL implementation plans.

States are struggling with development of reasonable assurances that are practical, affordable, and effective. Some of the challenges states described include the following.

- How to identify and request reasonable assurances from individual sources (e.g., agricultural land owners) in a "user-friendly" and effective way.
- How to design pilot projects, which can provide reasonable assurances by, for example, gauging the effectiveness of selected BMPs, such that results can be extrapolated to the widest range of circumstances possible (e.g., TMDLs for other geographic locations).
- How to make the best use of nonpoint source funding to provide reasonable assurances. For example, one state official described their nonpoint funding approach as "nonpoint" in nature: it is scattered across various projects and geographic locations and not concentrated effectively. One state official has found that sources are increasingly aware of and relying on Section 319 and other grant funding, such that the threatened loss of such funding can be an effective tool in encouraging sources to take action if they are failing, or are slow, to do so.
- How to realistically ensure that other agencies, with whom an agreement may be in place to execute a portion of the implementation plan, follow-through on implementation (e.g., in light of possible funding cuts at that agency).

States are still in the early stages of developing and testing how to use and rely on reasonable assurances. The effectiveness of reasonable assurances, as an alternative to enforceable mechanisms, is unproven at this time. Over the longer term, as more TMDLs are completed, implemented, and given time to achieve improvements in water quality, state officials will be in a better position to evaluate the effectiveness of relying on reasonable assurances to help attain water quality standards.

12.5.5 States that have regulatory tools to address nonpoint sources are better positioned to address water quality problems.

Enforceable mechanisms are an important part of the institutional framework for successfully implementing nonpoint source TMDLs, according to most of those interviewed. Such mechanisms, of which there are a wide variety, provide a state with "more tools in the toolbox" to help attain water quality standards.

At the same time, most of the states reported that they continue to rely primarily (but not exclusively) on a voluntary approach to nonpoint source control. The value of having enforceable mechanisms "on the books" for these states is as an important motivating influence for sources. Sources are often more cooperative if the potential exists of having existing enforcement authority exercised against them or having new authorities come on line, according to those interviewed.

According to the Environmental Law Institute study, Enforceable State Mechanisms for the Control of Nonpoint Source Water Pollution (portions of which are paraphrased below), nearly all states have some general statutory authority to deal with nonpoint source discharges that are shown to result in water quality problems (ELI, 1997). The Institute defines an enforceable mechanism as consisting of a standard applicable to an identified entity or entities; a sanction such as a civil, criminal, or administrative penalty, loss of license, or performance of required remedial action; and a process for applying the standard and imposing the sanction.

The different categories of enforceable mechanisms states are using include: 1) general discharge prohibitions; 2) prohibiting the causing of pollution or contributing to the exceedance of water quality standards; and 3) requiring operating standards and practices through targeted laws.

General discharge prohibitions are of two major types, but most are parts of states' water pollution control laws. One type prohibits the discharge of any substance (or pollutant or waste) without a permit. This is broad authority and can serve either as the basis for adopting a permitting program by regulation or for enforcement against discharges on a case-by-case basis.

More states have provisions that simply prohibit the causing of "pollution," or causing or contributing to the exceedance of water quality standards. These provisions allow states to impose sanctions and obtain compliance in relatively clear-cut cases. Provisions in state public health and fish and game laws, typically enforced as petty criminal offenses, also may prohibit specific kinds of discharges that detrimentally affect public waters, impair public health, or kill fish.

The largest category of states includes those that apply enforceable mechanisms to require operating standards and practices through targeted laws, such as erosion control laws, forest practices laws, and agricultural conservation laws. Enforceable erosion and sediment control laws provide one significant area of control. Some of these programs are statewide in application; many are delegable to local governments or conservation districts. Forest practices laws play a role in establishing enforceable nonpoint source pollution controls in about a dozen states, primarily on the west coast and in New England, which have forestry laws with enforceable statewide standards. These states require the preparation and approval of harvest plans incorporating state standards of prescribed BMPs.

Enforceable regulation of agriculture is the most problematic area; many laws of general applicability have exceptions for agriculture. Nevertheless, about a fifth of the states have some statewide sediment requirements, and about a fourth of the states authorize individual soil and water conservation districts to adopt enforceable "land use regulations" for the control of erosion and sedimentation.

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The following provides examples of enforceable nonpoint source control mechanisms in place in individual states.

- California has the authority to regulate nonpoint source discharges. The agency can issue permits under its waste discharge requirements (which do not differentiate between point and nonpoint sources) or can waive them if the source meets certain requirements. According to the state representative interviewed, this gives the state a "greater degree of comfort" that standards can be attained.
- Washington reports making "active use" of several of its enforceable mechanisms, including its septic system inspection and enforcement provisions; dairy nutrient management inspection program, and management plan development requirements; and its Forest Practices Act BMP planning requirements.
- Kansas provides for registration of confined animal feeding operations. The registration is used to determine the need for any significant water pollution potential or separation distance requirements. If such requirements are identified, then a permit is required.
- Massachusetts, California, and Washington provide opportunities for prospective review of state actions that may produce nonpoint source pollution (e.g, highway maintenance and operation) and require implementation of identified mitigation measures and minimization of adverse environmental impacts.

States have relatively little experience with actually carrying out implementation plans, so it is unclear what role enforceable mechanisms will play over the long term. If sources are not following implementation plan requirements, or if implementation plan requirements are not specific enough, enforceable mechanisms may be needed to ensure water quality standards are attained.

12.5.6 Greater attention to and funding for monitoring is needed to evaluate the effectiveness of implementation.

Monitoring is the "weak link" in implementation according to most of the states interviewed. There is a lack of appropriate monitoring assistance, in the form of staff time and funding, which impedes the ability to measure program effectiveness and make necessary adjustments. As an Oregon Department of Environmental Quality guidance document states, "the failure to adequately fund and carry out monitoring is nearly as serious as the failure to implement the plan itself."

- The 1998 FACA Report on the TMDL program recommends that a monitoring plan include the following minimum components to determine the effectiveness of the implementing actions and whether allocations are met:
- A plan for assessing whether management measures/control actions are being implemented as planned;
- A plan for assessing whether allocations are sufficient to attain water quality standards;
- A plan for assessing the improvement in water quality conditions (reflecting time necessary to ensure that water quality standards are met);
- A plan for assessing whether milestones are being met; and
- A plan for assessing the effectiveness of management measures/control actions.

In addition, the implementation plan should indicate who will carry out (and pay for) the monitoring activities (U.S. EPA, 1998a).

U.S. EPA's 1991 document, Guidance for Water Quality-Based Decisions: The TMDL Process (U.S. EPA 440/4-91-001), recommends a monitoring plan to track the effectiveness of a TMDL, particularly when it involves both point and nonpoint sources and the wasteload allocation is based on an assumption that nonpoint source load reductions will occur. Such a 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.

Based on the review of 176 TMDLs, 90% of them required follow-up monitoring. The monitoring plans reviewed, however, vary widely. None had all of the specific elements recommended by the FACA. Most included at least a brief description of "who, what, and when"; which agency was responsible for monitoring; the monitoring objectives (e.g., BMP effectiveness by monitoring acres of land pretreatment implemented over time); and the monitoring schedule (e.g., monthly, annually).

Like the implementation plans themselves, the level of specificity varies widely among monitoring plans. Some plans appear detailed and ready to be implemented, by including elements such as funding sources, sampling protocols, and sampling locations, while others are a statement of monitoring needs rather than planned actions. Some of the states reviewed provide guidance to staff on the elements that a monitoring plan should contain (e.g., Oregon's guidance recommends nine elements, from identification of the monitoring objectives to how the monitoring program will be funded).

While the content and specificity of the monitoring plans vary, in all cases states interviewed indicated they are struggling with how to adequately fund TMDL implementation monitoring. One state representative characterized it as "writing monitoring plans with our fingers crossed," hoping but not knowing if funding will be obtained to fully implement the plan. States are findings some ways to help bridge the funding gap:

- Many states reported relying increasingly on other agencies (primarily land management agencies such as the U.S. Forest Service, state departments of natural resources, etc.) for much of the data collection and analysis. Washington, for example, estimated that other agencies collect up to 80% of water quality-related data used for TMDL monitoring. These other agencies typically already are collecting and analyzing relevant data, and it is a matter of developing partnerships with them (if they are not already a designated lead agency for TMDL implementation) to determine if they can meet TMDL-related monitoring needs. State representatives interviewed emphasized that while cost-effective, partnering with other agencies to conduct monitoring requires a substantial investment in terms of providing technical assistance and training to the partner agencies.
- Most states interviewed rely to some degree on citizen volunteer monitoring as a part of the overall monitoring plan. Volunteers must be adequately trained and equipped, and their data subjected to quality assurance checks to ensure that the data collected is

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useful, according to those interviewed. Massachusetts has hired monitoring coordinators to oversee and train both citizen volunteers and other agencies on monitoring objectives, methods, and data handling to ensure data quality and avoid duplication of efforts. Several states, including Massachusetts, California, and Oregon, have detailed monitoring guidance for citizen volunteers.

While creative ways to bridge the funding gap are important, state agencies are clearly not in a position to provide for adequate TMDL implementation monitoring on their own or through partnerships with other agencies and citizen volunteers, according to those interviewed. With declining federal resources, state legislatures will most likely need to providing greater funding if monitoring plans are to be fully implemented.

12.6 Summary

States generally are in the early stages of TMDL implementation, and some TMDLs examined have no implementation plans associated with them at this point. States are developing implementation plans in a variety of program contexts and are employing a variety of approaches. At this time there is considerable inconsistency, in terms of implementation plan content and specificity, both within and among states. This is not surprising, given states' focus to date on TMDL development and the evolving regulatory landscape with respect to implementation planning. However, the importance of implementation to the overall value and success of the TMDL program cannot be over-emphasized.

States interviewed offered observations on keys to effective implementation planning based on their experience to date. Chief among these was the observation that the more specific and detailed an implementation plan is, the greater confidence state officials have that the plan will be implemented and water quality standards will be attained. State officials also emphasized that TMDL implementation plans should not be developed in isolation and, in fact, can help direct and link together many discrete program activities (such as traditional NPDES permitting, urban wet weather management, and ambient monitoring) that states are striving to integrate to better achieve program goals and watershed protection. States are also experimenting with ways to accelerate the overall pace of TMDL implementation by, for example, encouraging stakeholders to contribute funding and technical assistance where appropriate.

Many implementation planning challenges remain. States are still in the early stages of testing how to use and rely on reasonable assurances. Their effectiveness, in the absence of enforceable mechanisms, remains to be seen. The role enforceable mechanisms will play over the long-term is also unclear; most states continue to rely on voluntary approaches to nonpoint source implementation.

A key area for improvement is in TMDL implementation monitoring. Monitoring is needed to ensure implementation is occurring and that expected water quality improvements are being achieved. All states interviewed consider this the "weak link" in implementation. States report that they are unable to adequately fund TMDL implementation monitoring. Like implementation plans themselves, the specificity and content of monitoring plans vary widely. Further, while most states interviewed agree with the concept of "adaptive management,"

modifying the TMDL or implementation plan as necessary in cases of uncertainty or lack of success in achieving standards, only a small percentage of implementation plans reviewed contained adaptive management provisions (see Chapter 14.0). States will likely need to direct greater funding to monitoring if TMDLs are to be fully and appropriately implemented.

At this time, TMDLs, in some cases, can readily spur recovery of impaired waters (e.g., where point sources dominate, where nonpoint source are among the strongest, where all stakeholders are highly motivated). In other cases states need to strengthen certain program elements to ensure that TMDLs are fully implemented. Research into how these program elements can be strengthened would be valuable. These elements include stronger program integration (e.g., TMDL and nonpoint sources); better communication of TMDL information and mobilization of stakeholders; and more staff/funding for monitoring and follow-up.

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CHAPTER 13.0

PUBLIC INVOLVEMENT

An in-depth review of public participation in the TMDL program was beyond the scope of this project. However, any report related to the TMDL program would be lacking if it failed to highlight the importance of public participation. This chapter provides a brief summary of sources of information related to this topic, and highlights the topics that were investigated though this research project that addressed public participation in some way.

13.1 Issues Identification

In the review of stakeholder comments on proposed TMDL regulations and through other forums (Section 2.2), a wide range of views were expressed related to public participation. Some expressed concern that short deadlines may restrict public involvement, while others support that limits be set and additional requirements not be imposed on the TMDL process. Many comments related to public accessibility to data, and information on how the data are used in the TMDL. During the closing session of the TMDL Science Issues Conference in 2001 (WEF, 2001a), participants stressed that scientists need to learn to communicate with stakeholders effectively, particularly with respect to the technical details of the TMDL process, including conveying modeling results.

13.2 Available Guidance

The report of the Federal Advisory Committee on the TMDL Program describes public participation requirements for the TMDL program as "generally described in Clean Water Act regulations at 40 CFR Part 25 and are expanded on in §303(d) program specific regulations and guidance." The regulations state, in part, that environmental agencies should actively solicit data and information relevant to §303(d)(1) list development from local, state, and federal agencies, members of the public, and academic institutions. Public notice is required prior to submittal of a list or TMDL to U.S. EPA for approval, and §303(d) program guidance also requires that states provide for "adequate public participation" in list development, priority ranking, and TMDL development activities. U.S. EPA must complete the public participation process for any lists and TMDLs it develops (U.S. EPA, 1998a).

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The FACA Report emphasizes that "meaningful and well-timed public participation is a cornerstone of a successful TMDL process." Some selected recommendations related to enhancing public participation include:

- States should actively solicit public comment on all proposed 303(d) lists and TMDLs;
- States should hold periodic informal public meetings;
- States should consider listing waters nominated by the public and other agencies;
- In cases where best professional judgment is utilized, a clear explanation should be made available to the public; and
- States and U.S. EPA should encourage and support a substantial role for stakeholders in TMDL development, particularly related to data collection and implementation.

U.S. EPA's 1991 "Guidance for Water Quality Based Decisions: The TMDL Process" (U.S. EPA, 1991a) states that, in accordance with its Water Quality Planning and Management Regulations (40CFR Part 130), and as described in a state's Continuing Planning Process (CPP), TMDLs should be made available for public comment. The guidance discusses the importance of involving the public in identifying water quality-limited waterbodies, and in the development of TMDLs. U.S. EPA's protocols for developing TMDLs (U.S. EPA, 1999d, 1999e, 2001c) also highlight the importance of stakeholder involvement. These documents state that communication with the public and promoting public input into the 303(d) listing and TMDL process is critical.

13.3 Research

Although this project did not address public participation directly, many of the research investigations described in this report address stakeholder involvement in the TMDL process. For example, the chapter on modeling in the TMDL process (Chapter 8.0) stresses the importance of clearly explaining and documenting modeling details to allow stakeholders and decision-makers to fully understand the utility and limitations of the model. In the discussion of allocation of loads (Chapter 10.0), a key observation was that many states rely on stakeholder processes to recommend or determine allocations, and that most states view public involvement as the key to the success of the TMDL, including the acceptability of the allocation. In the discussion of Best Management Practices (Chapter 11.0), community acceptance and public support is listed as a key factor in BMP success. All states interviewed for the implementation planning investigation (Chapter 12.0) consider stakeholder involvement a vital aspect of TMDL development and implementation. Chapter 12.0 includes a discussion of how engaging stakeholders, including other agencies and jurisdictions, is a challenging fact of life in TMDL implementation and, to be successful, requires a different set of skills and interactions from those required for TMDL development. In the discussion of adaptive watershed management (Chapter 14.0), it is emphasized that stakeholders who have a vested interest in the problem and its solution should be involved throughout the entire process, from formulating and revising objectives to choosing controls.

13.4 Conclusions

Existing TMDL regulations and guidance are specific about the essential role of public participation in a successful TMDL process. While this research project did not address this topic explicitly, the importance of public involvement in many specific components of TMDLs is highlighted throughout this report.

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CHAPTER 14.0

ADAPTIVE WATERSHED MANAGEMENT

The development and implementation of many TMDLs is significantly hindered by limited data, high uncertainty, and unproductive debate over the efficacy of proposed controls to achieve water quality standards. The result is often ineffective or overly stringent TMDLs, or alternatively, a total lack of any water quality progress as the TMDL is under critical debate. Adaptive watershed management can provide an improvement on the conventional TMDL process for many of these situations. This chapter provides a conceptual overview of this approach as proposed for use in developing TMDLs. It combines features of adaptive management (Walters and Holling, 1990) with watershed management (Freedman et al., 1994) to meet TMDL requirements, or in some cases, to supersede the TMDL.

In certain situations, the successful implementation of the TMDL program is fundamentally hindered by too little time, resources, data, and knowledge. The dilemma in TMDL development is how to establish a definitive allowable loading limit as needed to meet water quality standards when too much is unknown or uncertain. Herein is where Aristotle's wisdom comes into play. Aristotle in the fourth century B.C. simply said:

> *"The mark of an educated mind is to rest satisfied with the degree of precision which the nature of the problem permits and not seek an exactness where only an approximation of the truth is possible."*

This statement well characterizes the modern day TMDL dilemma (Freedman, 2001): how to develop a singular and precise loading limit for a water body with limited understanding of everything from the numeric endpoints to quantifying the loads to understanding the receiving water quality. This chapter discusses this dilemma and recommends a non-prescriptive, alternative approach—adaptive watershed management—that provides a process to be progressively implemented over a specific timeframe, until water quality standards are achieved.

The chapter addresses the problem context (Section 14.1), provides a definition of adaptive watershed management (14.2) and the types of TMDLs it is well-suited for (14.3); describes the history of the use of adaptive management (14.4), presents the current use of adaptive management in TMDLs (14.5), provides case study examples (14.6); and summarizes recent calls for integration of adaptive management into the TMDL program (14.7). This is followed by a discussion of additional elements that need to be considered before adaptive management is

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integrated into the TMDL program (14.8), an identification of the obstacles to doing this (14.9), and the research team's conclusions (14.10).

14.1 Problem Context

The conventional TMDL (without adaptive watershed management) is a methodic process relying on very quantitative definitive assessments (Figure 14-1). It starts with setting the TMDL targets based on water quality standards. An analysis (often modeling) is then conducted and numeric allocations for point and nonpoint sources are established along with a corresponding margin of safety (MOS). After the TMDL is developed, controls are implemented and the waterbody is monitored. If water quality standards are attained, then the state will determine future monitoring provisions but the TMDL process is complete. However, if standards are not attained but are expected to be attained with reasonable certainty, the water quality agency continues to implement the TMDL as proposed with further monitoring. However, if the uncertainty in achieving attainment is high, then the water quality agency may decide to revisit the TMDL, but recognize this is not intrinsic to the TMDL process or regulatory approval.

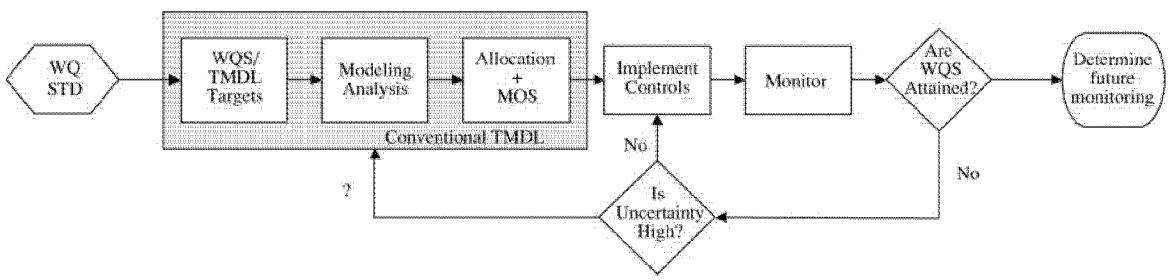

Figure 14-1. The Conventional Approach to Establishing a TMDL.

This conventional approach works well for situations where the conditions and recommendations can be confidently quantified. It is particularly applicable where the stressors and loads are well known and well quantified, the relationships to water quality response are well defined, the proposed controls are clear and known to be effective, and the water quality objectives are explicitly linked to the impaired uses. However, this conventional approach is deficient for many sites, including those dominated by nonpoint source loads, those with limited data and a high level of uncertainty, or those with high costs and other obstacles that hinder implementation. The conventional approach can also be deficient for sites with narrative water quality standards, when the linkage between the TMDL target and use attainment is unclear. In many of these situations, water quality progress is essentially halted while unproductive debate over the TMDL continues often without end in sight.

These challenging TMDL situations are not uncommon, as documented in Freedman (2001) and by other researchers:

- Nearly half of the needed TMDLs involve narrative standards where the TMDL targets are unclear (U.S. EPA, 2000b);

- 43% of the 303(d) impaired waters are solely impacted by nonpoint sources, and another 47% by a combination of both nonpoint and point sources (U.S. EPA, 2000b);
- In a General Accounting Office (2000) investigation, only three of 50 states admitted to having the majority of data needed to identify and quantify nonpoint source loads, let alone the effectiveness of proposed controls;
- The level of uncertainty in TMDL determinations is rarely well-defined and often exceedingly large (NRC/NAS, 2001);
- Annual pollution control costs are estimated to range between $1 billion and $4.3 billion, depending on whether states choose to allocate reductions to sources with lower costs vs. requiring equivalent reductions among all sources (U.S. EPA, 2001b).

The findings of the issues identification phase of this research project (Chapter 4.0) support many of the observations listed above, and highlight others. For example:

- 15 of 22 states surveyed indicated that there were insufficient data to characterize nonpoint sources;
- 21% of reviewed TMDLs never estimated current nonpoint source loads, so there was no way of knowing the feasibility of reducing those loads;
- Almost one-fifth of the reviewed TMDLs did not calculate assimilative capacity, let alone use a model to conduct the calculation; and
- 42% of the reviewed TMDLs did not explicitly define an MOS. Of those that did, all but one defined it arbitrarily.

Other supporting evidence is provided in the various chapters of this report.

These challenging situations suggest the need for an alternative approach that does not rely on such a definitive assessment. Adaptive watershed management as described herein is one such approach that can be useful in many situations.

Specifically, there is a need for an alternative TMDL approach that addresses the problems caused by high levels of uncertainty in the TMDL process related to:

- Assessing whether water quality standards will be met
- Defining standards and TMDL targets
- Quantifying loads and stressors, especially nonpoint sources
- Quantifying the link between stressors and water quality responses
- Defining the feasibility and effectiveness of control actions

Adaptive management has been proposed as an approach that, when faced with the above problems, can help initiate progress in water quality improvement and also meet TMDL program needs. When deciding whether adaptive management can be appropriate for use in development of TMDLs, one basic fundamental question needs to be asked first:

> *"As a result of the TMDL analysis, can you be reasonably confident that the proposed controls will be implemented, are cost-effective, and can be expected to result in restoration of uses as defined in the water quality standards?"*

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A TMDL, by legislative definition, needs to provide reasonable expectation that water quality standards will be met. If the answer is yes, then the conventional TMDL approach is likely sufficient. If the answer is no, or unknown, as shown in Figure 14-2, then an alternative approach may be preferred. More information should be collected, the applicability of the water quality standards should be reevaluated, or the TMDL development delayed until better data and/or more appropriate standards are adopted. Depending on the level of certainty and the water quality agency's program, an agency could choose to proceed with adaptive watershed management within the TMDL process, or defer the TMDL while other environmental programs proceed. More on the applicability of adaptive management is provided in subsequent sections.

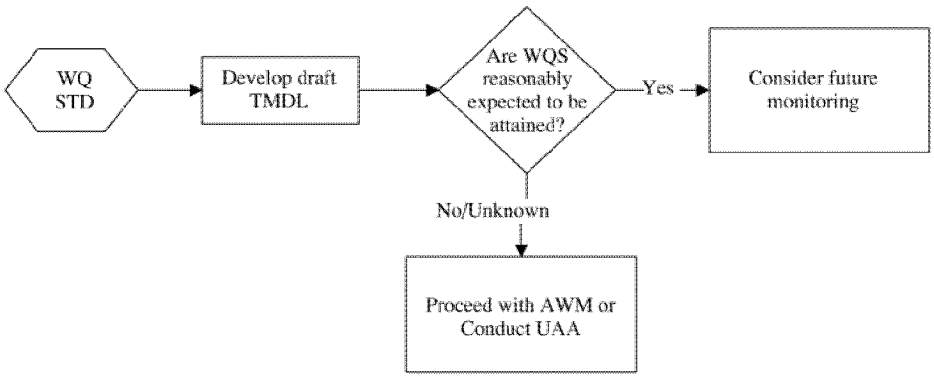

Figure 14-2. Decision Tree for Deciding When to Apply Adaptive Management.

14.2 What Is Adaptive Watershed Management?

Proposed herein is an adaptive management process entitled adaptive watershed management. It is a combination of terms and concepts from adaptive management and watershed management as applied in the TMDL context. This process must be viewed in conjunction with Figure 14-2. For example, natural background conditions or air deposition might preclude attainment of the standards regardless of the point source or nonpoint source controls generated by the TMDL. This conclusion could be reached during the modeling analysis or during the allocation stage. In those cases, managers might decide to defer development of the TMDL and/or implementation of priority controls until water quality standards are reevaluated and new TMDL targets are established.

As shown in Figure 14-3, adaptive watershed management addresses the various uncertain elements in a TMDL by a process to be progressively implemented over a specific timeframe, until water quality standards are attained. The TMDL is then viewed more in context of the process, not just a singular number. An iterative or adaptive process updates the elements as more information is obtained and thereby addresses the uncertainty in the various steps.

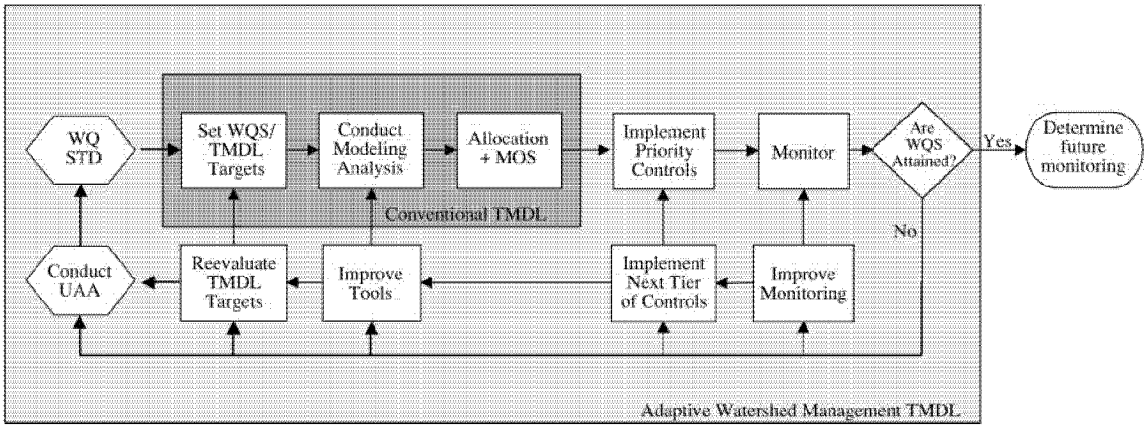

Figure 14-3. The Adaptive Watershed Management TMDL Approach Is Built Upon the Conventional TMDL Framework.

With the conventional TMDL framework, the waterbody can be delisted after the allocation is determined (U.S. EPA, 2001). However, for a TMDL employing adaptive watershed management, only the initial steps are the same as in the conventional TMDL (Figure 14-1). Managers are allowed to proceed with a preliminary allocation, and implementation of controls occurs in a progressive manner as understanding of the system improves. In this manner, the TMDL is not held up by unproductive and irresolvable debate over uncertainty in the numeric value of the TMDL or the efficacy of final recommended controls.

In this adaptive approach, initial priority controls or management actions are those that stakeholders and water quality professionals agree are necessary and will be cost-effective. They are best undertaken through voluntary participation as agreed through stakeholder participation in watershed management planning. Monitoring is then intended to determine the next steps, and evaluate if water quality standards can be attained. Many subsequent adaptive paths can then be taken if monitoring shows that water quality standards are not being met (or are not expected to be met) after implementation of initial priority controls.

In this proposal for adaptive watershed management, a structured approach is used to continually update the TMDL through refined monitoring, additional controls, improved tools, and/or changes in the TMDL endpoints or water quality standards. This framework not only facilitates, but requires the progressive adaptation and improvement in the TMDL and continual progressive steps towards water quality improvement. This is different from both the existing TMDL program and adaptive management because the process requires an explicit and structured framework of implementation with monitoring and continual review and adaptation until specific water quality standards are achieved. The process additionally employs all the holistic and iterative steps intrinsic to watershed management planning (Freedman et al., 1994), with a focus on how the adaptive process can meet TMDL program needs. Some may view this as going beyond the legislative scope of the TMDL process, while others may view it as keeping the focus on the waterbody until standards are met. Individual states and tribes will need to determine what role adaptive management should play within their water quality assessment programs.

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If water quality standards are not attained after initial controls, then several choices (which are not necessarily sequential or linked) are available by employing adaptive watershed management. For example, managers may choose to adapt and improve the TMDL process through any of the boxes shown at the bottom of Figure 14-3:

- ***Improve monitoring:*** Additional monitoring may be needed to determine whether standards have been attained or to provide better information for the various steps within the adaptive framework.
- ***Implement next tier of controls:*** Priority controls may prove to be more or less effective than originally anticipated. In this case, managers may choose to implement the next level of controls identified in the TMDL without revisiting the TMDL.
- ***Improve tools:*** The original TMDL analysis may have been preliminary or imprecise because of lack of data, resources, or time. Based on new data and/or resources, improved models can be developed and the TMDL revisited.
- ***Reevaluate TMDL targets:*** The target that was used as a surrogate for the water quality standard may have been poorly chosen or improperly assigned because of a lack of sufficient information, requiring that the TMDL be revisited using a revised target.
- ***Conduct a Use Attainability Analysis:*** Subsequent data and analysis may have demonstrated that the water quality standard is unattainable, therefore requiring a change in the water quality standard, and subsequent revision of the TMDL (U.S. EPA, 1983; Novotny et al., 1997). The issue of unachievable water quality standards is a prominent complaint in the TMDL process (NRC/NAS, 2001) and needs to be addressed.

In sites using adaptive watershed management, adding explicit elements in the process beyond what is currently required in the conventional TMDL program helps better ensure that water quality standards are achieved. Elements to consider include:

- Implementation plan and schedule
- Plan for follow-on monitoring and refinement of tools
- Comprehensive watershed management plan
- Funding strategy
- Stakeholder involvement
- Decision framework

By including these elements in adaptive watershed management, the goals and requirements of the TMDL program are better assured. By including specific requirements for monitoring, additional measures, review and revision of the TMDL, adaptive watershed management can meet the ultimate goal and regulatory requirements of the TMDL program without absolute knowledge. Several states have also recognized the difficulty of establishing quantitative wasteload allocations and load allocations for qualitative objectives like riparian improvements. In these cases, they have turned to adaptive watershed management, such as with the Nestucca Bay TMDL for temperature in Oregon (see Section 14.6.6).

14.3 What Types of TMDLs Qualify for Adaptive Watershed Management?

Adaptive watershed management is not well suited to all TMDL sites, and should be used only for certain conditions. Sites where conventional TMDLs can be developed and implemented with reasonable certainty would be inappropriate. Also excluded would be sites involving primarily regulated sources, where regulatory controls would have to be imposed based on uncertain or adaptive analyses.

Adaptive watershed management is best suited to sites dominated by nonpoint sources, where uncertainty is often largest. Other considerations for adaptive watershed management include sites:

- Having very limited data,
- Having high levels of uncertainty in the TMDL,
- Involving many complex stressors,
- Having severe obstacles to implementation of controls,
- With strong stakeholder cooperation, and
- Where voluntary actions can be implemented.

Individual states need to establish policies establishing which of the above considerations or others are necessary and sufficient to warrant the use of adaptive watershed management.

The application of the adaptive watershed management in TMDL can be applied in TMDLs using both quantitative and qualitative approaches. However, other constraints are still relevant.

Quantitative TMDLs involving a large range of uncertainty are good candidates. In these situations, the TMDL has been calculated with a fair degree of certainty, but the value and levels of control are bounded by an uncertain range. In these cases, the initial priority controls represent the lower end of the range expected to meet water quality standards, and the adaptation follows to determine where in the range actual attainment will be achieved.

Qualitative TMDLs can also be candidates. In these situations, sufficient data are not available to quantify the load reductions needed to achieve water quality objectives, but stakeholders and professionals agree on controls necessary to meet water quality objectives. In these cases, monitoring is used to assess compliance and to more quantitatively determine any additional controls that are needed.

There is considerable debate as to the regulatory acceptance of TMDLs that do not define a specific numeric loading level. Nonetheless, many TMDLs have been developed and previously approved based on a course of action and not a specific load allocation. Adaptive watershed management is well suited to these situations, but the regulatory adequacy without a specific load limit is still subject to considerable debate and perhaps brings those approved TMDLs into question. Therefore, some states and tribes may choose to defer the TMDL (Figure 14-2) rather than proceed with a qualitative TMDL. States and tribes can argue that, in both cases above, the adaptive feedback loop and structured approach provides the assurance that water quality standards will be met and provides the Margin of Safety required in the TMDL.

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States and tribes will of course tailor these adaptive concepts to their program needs. For example, they may submit a TMDL and a comprehensive water quality management plan at the same time, as is done by Oregon. Others may use adaptive management but prefer to characterize it as a TMDL in the process of being developed, or say that the TMDL will be deferred, or not even list the waterbody on the 303(d) list. States and tribes may also choose to list these waters in a separate category, recognizing impairment but not requiring development of a TMDL (Washington ECY, 2002). Some might characterize these situations as ongoing TMDLs and associate a timeframe (10-50 years) for implementation and continued refinement of the TMDL. Others may indicate that progress is being made within the watershed, that monitoring will be conducted, and that it may be shown that a TMDL is unnecessary. Still others may want to indicate that a voluntary control program is in place, or that water quality problems are being addressed by other programs (e.g., 319 grants, Farm Plans, or comprehensive water quality management plans). Finally, some may focus on delaying full TMDL development until water quality standards are revisited through use attainability analyses or the triennial review of water quality standards.

14.4 History of Adaptive Management

Active adaptive management is "learning by doing" despite the existence of uncertainty (Walters and Holling, 1990). Policies are implemented as "experiments" with the results used to create more experiments as progress proceeds towards a goal. Adaptive management promotes learning to a high priority and implies revised ends as well as novel means (Lee, 1999). This distinguishes adaptive *management* from adaptive *assessment*. Adaptive assessment means continually reassessing the process, keeping the same endpoint in mind. Adaptive management implies also being willing to embrace changing the *endpoint* if necessary.

Adaptive management embraces uncertainty and recognizes that models used for decision-making are only approximations and that there is never enough data or resolution about uncertainty. In particular, Walters (1986) notes that for adaptive management to be successful, two myths about modeling need to be dispelled: 1) "if models are to be useful they must be capable of detailed and/or precise quantitative predictions" (that is, models with high uncertainty have little value); and 2) "modeling is a substitute for experience" (that is, one does not need to learn by doing). The adaptive process allows decision-makers to proceed with initial decisions based on modeling (or other analyses), and then update forecasts and decisions as experience and knowledge improve.

The use of adaptive management as a resource management technique took root in the 1970s (Holling, 1978). A prime early example of adaptive management was a series of management experiments in fisheries that the Australian Commonwealth Scientific & Industrial Research Organisation in Tasmania began in 1988 and completed a decade later (Lee, 1999). In this example, adaptive management resulted in modified fisheries regulations (Peterman and Peters, 1998). Adaptive management has also been used to balance hydropower needs and fisheries protection in the Columbia River (Lee and Lawrence, 1986), balance fisheries' needs and downstream water uses on the Feather River (BuRec et al., 2001), integrate habitat conservation plans with TMDLs (NOAA, 2002), restore riparian habitat in the Glen Canyon Dam (DOI,

2002), balance agricultural and other uses (Oregon DEQ, 2002), and develop stormwater management plans (U.S. EPA, 2000a). These applications of adaptive management recognize that changes targeted at solving one problem may have unanticipated, undesirable effects, and therefore allow testing before proceeding with additional controls.

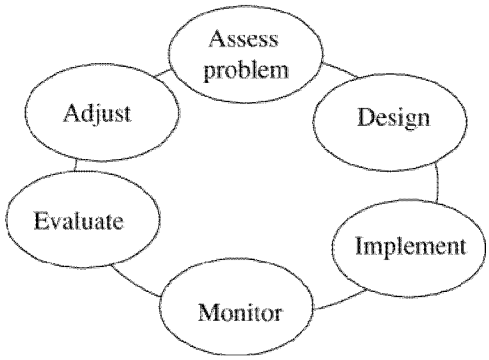

Figure 14-4. The Adaptive Management Process (BC Forest Service, 2000).

The adaptive management process has six fundamental element steps (Figure 14-4) (British Columbia Forest Service, 2000). The Forest Service emphasizes that managers must implement all the steps to be successful. These steps are iterative and not necessarily sequential. All stages of the process can be adapted based on monitored results. Furthermore, stakeholders who have a vested interest in the problem and its solution should be involved throughout the entire process, from formulating and revising objectives to choosing controls. Stakeholders will be more willing to experiment if they are allowed to phase in less costly controls with low risk or limited high-cost controls if results are monitored before additional controls are required (Lee, 1999).

14.5 Current Use of Adaptive Management in TMDLs

Adaptive management has not been explicitly incorporated into the TMDL program. Components of adaptive management were included in the "phased approach" for TMDLs (U.S. EPA, 1991), but that approach has alternatively been promoted and sometimes criticized. There are several examples where adaptive assessment/management is called for or is being used in the TMDL program, but the success of these approaches is not yet known, and the approaches, so far, are not always as comprehensive as envisioned under adaptive watershed management.

In the context of the TMDL program, U.S. EPA's 1991 guidance includes a "phased approach" for TMDLs for situations that are not straightforward or are complex. These include situations where:

- data and predictive tools are inadequate to characterize and analyze the pollution problem with a known level of uncertainty;
- the wasteload allocation will be based on a load allocation (LA) for which nonpoint source controls need to be implemented; or

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- states and tribes desire to collect additional data to verify expected load reductions, evaluate effectiveness of control measures, and ultimately determine whether a TMDL needs to be revised.

U.S. EPA indicated that if a phased approach was pursued, the TMDL should establish a schedule for the installation and evaluation of source controls, additional monitoring, assessment for water quality standards attainment, and if needed, additional predictive modeling. It also indicated that states and tribes should establish a procedure for reviewing and revising BMPs in TMDL documentation (U.S. EPA, 1991a).

The phased approach set the stage, so to speak, for a more comprehensive use of adaptive management in the TMDL program. Phased TMDLs are similar to the process envisioned under adaptive watershed management, but often do not consider revision of the water quality standards, do not incorporate a significant process for continued stakeholder involvement, and do not have sufficient structure to ensure implementation of the adaptive plans. In the mid 1990s, this "phased approach" became less popular; however, the concept is now coming back into favor as identified in a subsequent section. For example, the Final Water Quality Guidance for the Great Lakes System (*Federal Register*; March 23, 1995; Vol. 60:15366-15425) calls for a "phased approach, where appropriate" and the associated regulatory relief to accommodate this phasing.

Besides the phased TMDL approach, other U.S. EPA guidance speaks to the adaptive approach. The Draft Guidance for Water Quality-based Decisions: The TMDL Process, Second Edition (U.S. EPA, 1999b) advocates use of an "adaptive management plan" including implementation monitoring (of controls) and effectiveness monitoring (of response) to determine whether the TMDL should be revised or whether the water body can be delisted. The guidance also indicates that a follow-on monitoring plan should be used to evaluate TMDL progress and to determine whether targets, load estimates, and modeling tools need refinement as additional monitoring data are collected. The Protocol for Developing Pathogen TMDLs: First Edition (U.S. EPA, 2001d) indicates that the adaptive management component of the TMDL should discuss when and how the TMDL will be reviewed and describe the criteria that will be used, if possible. The Protocol for Developing Sediment TMDLs: First Edition (U.S. EPA, 1999b) provides an example of using adaptive management to determine if additional data and controls are needed, by presenting a hypothetical TMDL for watersheds dominated by infrequent, high-magnitude runoff events that make it difficult to quantify sediment impacts, sources, and controls.

14.6 Example TMDLs with Adaptive Management

Some U.S. EPA Regional Offices and states are currently including elements of adaptive management in the TMDL process and other water quality programs with encouraging results and acceptance. For example, Region 10 defines adaptive management as "a strategy for addressing pollutant load uncertainty that emphasizes taking near term actions to improve water quality. It can be employed when data only weakly quantifies links between sources, allocations and in-stream targets. Adaptive management identifies site-specific actions leading toward water quality standards attainment; future data collection and analysis; and reassessment of appropriate actions" (U.S. EPA, 2000c).

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The Washington Department of Ecology includes adaptive watershed management in its Listing Methodology guidance (Washington ECY, 2002). Adaptive management is specifically referenced for two subcategories of category: *"4. Impaired But Does Not Require a TMDL."* Under the subcategory *"a. Has a TMDL,"* Ecology considers that a TMDL is *"successful so long as an adaptive management process is being fully used to respond to new information or changed conditions and progress on water quality improvement is being made."* Ecology reviews all segments covered by existing TMDLs during each five-year assessment cycle, thereby ensuring that water quality improvements are occurring. Under subcategory *"b. Has a Pollution Control Plan,"* adaptive management is a required criterion for the plan (e.g., Habitat Conservation Plans).

When the Oregon Department of Environmental Quality submits a TMDL, it also submits a comprehensive water quality management plan to U.S. EPA (Oregon DEQ, 2001a). The Oregon agency defines adaptive management as setting an interim target; monitoring indicators, water quality, and implementation of water quality management plans over time; re-analyzing and refining the TMDL, the water quality management plan for the watershed and the indicator if necessary; and ultimately developing an indicator allocation (Oregon DEQ, 2001b).

Idaho Department of Environmental Quality guidance recognizes that a phased approach to developing TMDLs is typically needed when nonpoint sources contribute a significant portion of the total load (IDEQ, 1999) or the level of complexity is significant. The guidance also makes specific reference to adaptive management for TMDLs when surrogate measures are used for endpoints. Idaho couples these TMDLs to adaptive management so that regular future monitoring feeds back into adjustment of pollutant source controls. It includes an approach of "ramping up" of implementation to control more obvious sources of pollution first, and scheduling more difficult and less cost-effective controls later. The agency divides the TMDL into a three-step process: 1) sub-basin assessment, 2) loading analysis, and 3) implementation plan. The guidance requires that the implementation plan be developed within 18 months of the approval of the TMDL.

Although adaptive management has not been explicitly incorporated into the national TMDL program, many states are already using elements of adaptive management in their individual TMDLs. Below are eight examples where elements of adaptive management have been incorporated into TMDLs. They have been selected to represent a broad spectrum of water quality impairments and TMDL issues. They are not presented as "model" case studies that fully demonstrate the adaptive watershed management approach outlined herein. Rather, they are presented as illustrations of how adaptive management concepts are currently being used in the TMDL program, and they illustrate some of the attributes that have been discussed herein. This section presents only a brief sketch of the case studies, but more details can be obtained in the noted references.

14.6.1 Georgia: Savannah River Mercury TMDL

This example illustrates a phased TMDL where the dominant source of mercury was atmospheric loading, and other non-water programs were to provide the source control. The effectiveness of these programs was uncertain, as was the ability to meet the water quality objectives. In the Savannah River TMDL (U.S. EPA, 2001c), atmospheric sources of mercury contributed 99% of the loads causing elevated fish levels and violations of fish consumption

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advisories. Point source reductions were targeted through numeric water quality-based permit limits and implementation of mercury minimization plans. However, control of atmospheric mercury sources was to be realized through existing and future Clean Air Act requirements plus various voluntary programs. Attainment of the proposed reductions and achievement of water quality objectives was highly uncertain; hence, a phased TMDL was approved with a revisit in 2004 when better data would be available. The waterbody was subsequently dropped from the 303(d) list by the state when the water quality standard for mercury was revised.

14.6.2 Washington: Bellingham Bay Sediment Contamination TMDL

This TMDL illustrates a site where adaptive management was employed focusing initially on high-priority sources and then revisiting the controls as more knowledge is gained about their effectiveness to reduce toxicity. A TMDL was established to address impairments from potential toxic effects from contaminated sediments in Bellingham Bay, but the actual causes were uncertain (Washington ECY, 2001). Wasteload allocations were assigned to a paper company and municipal combined sewer overflows. A range of near-term remedial actions that address high-priority sediment cleanup/source control sites was also identified by a work group of the Bellingham Bay Demonstration Pilot Project, and actions were to be enforced under the Model Toxics Control Act. The Washington adaptive implementation strategy consists of the cleanup activities and source control, followed by monitoring to evaluate effectiveness of controls to meet sediment quality objectives and to determine the need for additional controls.

14.6.3 Idaho and Oregon: Snake River-Hell's Canyon Nutrient TMDL

This TMDL illustrates use of adaptive management involving two states where not only the effectiveness of the proposed TMDL was under question but also the TMDL water quality target. In the Snake River, excess phosphorus levels from wastewater plants, municipal and industrial storm water discharges, agriculture, tributary inflows, and natural sources are creating excessive nuisance algal blooms. The Idaho and Oregon Departments of Environmental Quality established a draft TMDL that includes seasonal, instream phosphorus targets of 0.07 mg/L (Idaho DEQ and Oregon DEQ, 2001). This target was established based on background levels, correlation with chlorophyll *a*, and modeled improvements in dissolved oxygen. An allocation strategy was developed that relies on technology-based controls and companion general water quality management plans providing each state's proposed approach. The implementation plans include five-year periodic reviews of progress, costs, benefits, and validity of assumptions. The plans indicate that adaptive management is required because the states will likely develop new nutrient criteria that would necessitate changes to the TMDL targets. Long-term (20-year) monitoring and modeling will be used to assess attainment of intermediate targets and confirm or modify interim targets.

14.6.4 Montana: Flathead Lake Nutrient TMDL

In this TMDL, a two-phase adaptive management approach was employed because insufficient data were available to establish a reliable linkage between sources and impacts, and there was debate as to the appropriate TMDL nutrient target. The Montana Department of Environmental Quality developed an adaptive management TMDL for nutrients in Flathead Lake with an interim reduction in total nitrogen and phosphorus loads of 15% (Montana DEQ, 2002). Poor understanding of the source/response relationships and complexities from highly variable environmental conditions led to a two-phased load reduction strategy with 25% reductions targeted for high-priority sources considered an immediate threat to the lake. Phase II of the

TMDL consisted of monitoring to reevaluate the relationships, development of a new model, evaluation other sources and additional controls, and also development of new nutrient criteria. The TMDL also includes a Water Quality Restoration Plan for the entire Flathead Basin to guide a Voluntary Nutrient Reduction Program.

14.6.5 Vermont: Lake Champlain Phosphorus TMDL

This TMDL involves two state programs and the need to monitor the initial effectiveness of nonpoint source controls and revise the TMDL with improved data and modeling. The draft TMDL for Lake Champlain was based on preliminary loading targets developed for each segment of the lake in a 1996 basin plan (Vermont DEC and New York DEC, 2002). The TMDL focuses on controlling nonpoint source loads, which account for 71% of the nutrient loading. The TMDL includes an implementation plan that includes monitoring of BMP performance, river input and lake monitoring, mapping of land use changes every five years, and fate and transport modeling of sediment and phosphorus loads to refine the TMDL. Vermont and New York included an adaptive implementation plan in this TMDL to provide more information to refine the actions needed to control nonpoint sources based on new data, modeling and updated land uses. Reasonable assurance of TMDL effectiveness was provided by the states' basin planning processes and an inter-state Lake Champlain Basin Program Steering Committee.

14.6.6 Oregon: Nestucca Bay Sedimentation TMDL

This TMDL includes elements that address many of the components of adaptive management, including the reevaluation of the effectiveness of nonpoint source controls and the need to reevaluate surrogate TMDL targets. Nestucca Bay spawning areas are impaired by excessive sediment loadings, which are governed by narrative water quality standards. For the development of a TMDL, Oregon established a goal of 20% reduction in streambed sediment fines in riffle and glide reaches (Oregon DEQ, 2002). To achieve this goal, it targeted BMPs for land use practices associated with forestry, roads, and agricultural clearing and maintenance of riparian areas that are managed by multiple agencies. It is employing a Water Quality Management Plan that will use long-term monitoring and adaptive management to evaluate the goal over time. Specific requirements of Oregon's adaptive management include a five-year periodic review of the progress of the TMDL and the management plan. Oregon's Department of Environmental Quality also expects that each management agency will establish benchmarks, will monitor and document progress, and will revise the components of the management plan to address any deficiencies identified in the long term monitoring. In consultation with the management agencies, the department will revise the TMDL if it determines that the load reductions are ineffective or if the TMDL surrogate targets are infeasible or ineffective.

14.6.7 Colorado: Boulder Creek Un-ionized Ammonia

Although not a formal TMDL, the Boulder Creek un-ionized ammonia problem has been included as a case study for the TMDL program (U.S. EPA, 2002b). Adaptive management has been used to address impairments caused by un-ionized ammonia from a wastewater treatment plant. A use attainability analysis showed that high temperature and pH were contributing to excursions of the un-ionized ammonia standard. Monitoring and simplified modeling were used to determine that the best solution was a combination of treatment plant upgrades, habitat restoration and BMPs. Adaptive management was employed to permit monitoring and evaluation of phased controls. A trading program was established and allowed the City of Boulder to pay for a multitude of nonpoint source improvements, and has served as a case study in effluent

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trading saving the city approximately $5 million (Reason, 2002). The combination of these improvements and controls has been more cost-efficient than through intensive point source controls only. The creek is still listed on Colorado's 303(d) list, but additional data are being collected to confirm that water quality standards have been achieved (CO DPHE, 2002).

14.6.8 North Carolina: Neuse River Estuary Nitrogen TMDL

This TMDL illustrates a phased TMDL for total nitrogen that addresses uncertainty. The first phase, conditionally approved in 1999, called for a 30% reduction in loading (NCDNR, 2001). The TMDL has large uncertainty since three different models used in the TMDL analysis indicated significantly different required reductions. This was complicated by extreme environmental variability during the data collection period. As a result, the Division of Water Quality of the North Carolina Department of Environment and Natural Resources will employ an adaptive phased approach that will include monitoring the effectiveness of initial nonpoint source controls and model refinement to establish if loading targets and water quality objectives are being achieved. Existing data indicate a load reduction effectiveness of between 0 and 30%, while Neuse Estuary nitrogen criteria are currently exceeded less than 10% of the time. Updated data and modeling will be used to quantify the load allocation under the initial TMDL and as needed to develop a revised TMDL, revised load reductions, and/or revised water quality criteria.

Additionally there are numerous water bodies on the 303(d) list of impaired waters that will require TMDLs, but the formal process has been delayed while better information is collected and adaptive management is being employed to begin the restoration. Prominent examples include the Everglades (U.S. EPA, 1998) and the Chesapeake Bay (U.S. EPA, 2001a).

14.7 Calls for Adaptive Management Use in TMDLs

As U.S. EPA was developing new TMDL regulations in 1998 and 1999, there were several calls for adaptive management to be incorporated into the program (Kitzhaber & Gering, 1999; Hammerschmidt, 2000). The Western governors pointed out that particularly for nonpoint sources, it is not possible to know in advance that initial controls will achieve water quality standards. The governors were requesting that EPA incorporate adaptive management so that these TMDLs could be submitted and approved.

At the request of Congress, the National Research Council of the National Academy of Sciences evaluated the scientific basis of the TMDL program (NRC/NAS, 2001). Its findings concluded that adaptive management and use attainability analysis processes should be incorporated into the TMDL program:

> *[W]aterbodies exist inside watersheds that are subject to constant change. For this reason, and others, even the best predictive capabilities of science cannot assure that an action leading to attainment of designated uses will be initially identified. Adaptive management will allow the TMDL program to move forward in the face of these uncertainties.*

Water quality standards are the benchmark for establishing whether a water body is impaired; if the standards are flawed (as many are), all subsequent steps in the TMDL process will be affected.

The NRC/NAS identified several obstacles that must be addressed before adaptive management can be incorporated into the TMDL program:

If Congress and EPA want to improve the scientific basis of the TMDL program, then the policy barriers that currently inhibit adoption of an adaptive implementation approach to the TMDL program should be addressed. This includes the issues of future growth, the equitable distribution of cost and responsibility among sources of pollution, and EPA oversight.

Appropriate use designation for a state's waterbodies is a policy decision that can be informed by technical analysis. However, a final selection will reflect a social consensus made in consideration of the current condition of the watershed, its predisturbance condition, the advantages derived from a certain designated use, and the costs of achieving the designated use.

U.S. EPA recently developed a guide for its researchers who can help improve the scientific basis for restoring and protecting impaired waters (U.S. EPA, 2002a). In this document, it summarized the TMDL science needs identified by the NRC, states and tribes, U.S. EPA national and regional TMDL programs, the private sector, and others. The recommendation to develop adaptive implementation approaches for doing TMDLs was included as one of twenty recommendations to improve the TMDL program. The report notes that *"EPA researchers might develop or evaluate adaptive management strategies, or focus on related tools such as recovery forecasting models, post-implementation monitoring methods, and alternative futures analysis."*

The current challenges of the TMDL program justify a call for adaptive watershed management (Freedman, 2001). The TMDL program is often fundamentally hindered by inadequate standards, insufficient data, inaccurate models, and uncertain effectiveness of controls. As a result, the nation's current efforts are often misguided in pursuing precise TMDLs. In TMDLs with a high level of uncertainty, adaptive watershed management is better suited. As Aristotle said, we should not seek a precision that the problem does not permit. "Learning by doing" is preferable to relying on imprecise models to determine an exact number for the wasteload allocations, load allocations and Margins of Safety. Adaptive watershed management is well suited for such situations where information is limited and exactness is not feasible.

14.8 Additional Considerations

Adaptive watershed management for use in the TMDL program needs consideration of additional elements than a conventional TMDL because of the required adaptive loops and the absence of definitive loading limits. The TMDL program does not currently require a comprehensive implementation plan or follow-on monitoring and other adaptive steps (U.S. EPA, 1992). Therefore, several important considerations include:

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Implementation Plan and Schedule: This would provide a sequence of actions. Immediate actions could be implemented first, allowing progress towards attainment. Other controls could be phased in after improvements were assessed. The implementation plan would include a schedule for periodic review and reevaluation of the TMDL. Specific milestones with specific dates are important. This can be addressed through the State 303(e) Continuing Planning Process.

Monitoring and Modeling Plan: This plan would identify a schedule and assign responsibilities for collection of additional monitoring data and improved modeling tools so that improvements in the TMDL analysis could be realized. The objectives herein would be to learn from actions implemented, collect data, improve understanding, and refine tools for developing more recommendations.

Watershed Management Plan: A comprehensive watershed management plan would ensure that the TMDL is put in context with the rest of the watershed planning, and that water quality goals established by stakeholder consensus can be reasonably attained. It would also address the potential for unintended consequences as a result of the TMDL, and facilitate discussion about the appropriateness of the designated uses. Both impacts from pollutants and pollution would be considered.

Funding Strategy: For the adaptive watershed management TMDL to be successful, a funding strategy is necessary, particularly in the early stages. This would ensure that the plans for monitoring and subsequent adaptations of the TMDL would be implemented. The funding strategy should identify sources of funding, agencies, and specific programs.

Stakeholder Involvement Plan: Adaptive watershed management requires extensive stakeholder involvement in decision-making from the selection of initial controls to decisions about any changes in water quality standards (uses and criteria). A comprehensive plan on how stakeholders will maintain a voice in all these matters is important, as well as how to proceed if there is disagreement.

Decision Plan: This would define the process that would be used for the program managers to make decisions during the TMDL. It would facilitate communication between stakeholders and managers, ensuring that both are involved in every decision from the specification of initial controls to the need for site-specific standards or a use attainability analysis. The decision plan would outline the nature and timing of required decisions to ensure continual progress in water quality improvements and maintenance of the TMDL requirements.

Water Quality Standards Review/Revision Plan: Many TMDLs are confounded by unachievable water quality standards (NRC/NAS, 2001). A successful adaptive watershed management TMDL process must include a way to resolve this dilemma.

By including the above elements in the adaptive watershed management TMDL, managers are held accountable for implementing the TMDLs.

14.9 Obstacles to Using Adaptive Watershed Management

The use of adaptive watershed management even in select conditions may encounter criticism. The primary objections can be addressed through four categories, as follows:

Effectiveness: Many might argue that employing adaptive watershed management in TMDLs will just delay progress in water quality improvement and will not ensure that standards will be achieved. Properly employed, however, the adaptive management process actually can provide *better assurance*, because it outlines a continual adaptive process that monitors and updates planning of additional water quality controls. Setting a poorly supported TMDL value does not necessarily ensure that water quality standards will be met, especially if the determination of the number is grossly uncertain and/or implementation of needed controls is infeasible or impractical. By employing an adaptive process, objections that often halt a TMDL and related controls can be avoided. Concerns about effectiveness can be addressed with a clear description of the process intended to meet water quality standards, including the considerations given previously and providing an expected timeline with checkpoints to ascertain whether the adaptive watershed management process is meeting objectives.

Equity: Many in the regulated community are concerned that in using adaptive approaches, states and tribes will too often choose NPDES controls first because they are easy to identify and regulate. However, in the proposal herein, initial actions should focus on implementing controls that stakeholders agree are likely to provide significant benefit. This may mean that the most promising actions are voluntary, as opposed to regulatory. As such, adaptive watershed management is well suited to nonpoint source-dominated systems, where continued reductions in point source loads are unlikely to provide significant benefit. In addition, the use of watershed management planning ensures that water quality improvement is viewed holistically, considering all stressors, not just regulated sources.

Regulatory: The absence of a specific definitive loading limit and Margin of Safety is viewed as a regulatory deficiency by many and is the biggest regulatory obstacle to the broad use of adaptive watershed management. Previously, U.S. EPA has approved many TMDLs without a specific numeric allocation, but with descriptive implementation plan. Adaptive watershed management seems well suited for these, but needs to be reconsidered in the context of current regulatory interpretations. Additionally, there are approved TMDLs where there is considerable uncertainty in the load estimates, or the load reductions are interim. Further, other approved TMDLs include an implicit Margin of Safety or one that is not well quantified. In these applications, use of adaptive watershed management can provide better assurance that water quality standards will be met than for a simple conventional TMDL because of the emphasis on continual monitoring and improvements. Adaptive watershed management can be a powerful tool to insure that water quality standards are attained for certain difficult situations. In looking to the future and possible regulatory and legislative changes, there needs to be consideration of how to provide the flexibility to effectively employ adaptive watershed management within the TMDL regulations. This issue must be evaluated by states and tribes and resolved by U.S. EPA and/or the courts, before the adaptive watershed management approach discussed herein can have widespread use for employing qualitative courses of action without quantitative allocation.

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Resources: The resources required to employ adaptive watershed management involve subsequent monitoring and continual review and re-examination of the TMDL. Some states and tribes may be reluctant to make this long-term commitment and may prefer to do "quick and dirty" TMDLs and accept their weaknesses. From a resource standpoint, however, this is actually shortsighted. Weak TMDLs are often challenged in court, and approval, as well as implementation, can be bogged down by objections. Addressing these objections can be more resource-intensive than establishing an adaptive process. Furthermore, imposing unnecessary and/or ineffective controls is, from a societal point of view, resources wasted or poorly spent. For adaptive watershed management to be successful, states and tribes must identify the resources that will be dedicated for continued monitoring and refinement of the TMDL.

14.10 Conclusions

The use of adaptive watershed management for TMDL analysis is proposed for situations that are nonpoint source dominated, that have very limited data and a high level of uncertainty, or where high costs and other obstacles hinder implementation. Both adaptive management and watershed management concepts are employed and directed at meeting the TMDL program requirements. The non-prescriptive concept involves an iterative process of goal setting, stressor identification, initial control actions, and monitoring, followed by review and revision of everything from goals to tools to control actions as necessary to meet water quality objectives. These same principles can be applied outside the TMDL program. For example, adaptive watershed management can be used to achieve attainment of water quality standards for watersheds that are impaired by pollution (Category 4c of the Integrated List). Watershed management concepts are emphasized wherein all watershed stressors (from both pollutants and pollution) are evaluated and all stakeholders are actively involved in goal setting and prioritization of actions.

This approach differs from the conventional TMDL approach because it requires progressive implementation and allows initial progress to proceed while information is insufficient to definitively assign a TMDL number or specify final control actions. Adaptive watershed management ensures that water quality standards will be met by instituting a specific process and schedule to progressively implement improvements, reevaluate, and then update additional actions until uses are restored. Future research efforts should be focused on further exploration and refinement of the adaptive watershed management concept, and address obstacles to implementation.

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APPENDIX A

LIST OF REVIEWED TMDLS

State	Waterbody Name	# of TMDLs	Pollutant	Source of Pollutant	Author	Date of Approval
Alaska	Duck Creek	1	Debris	Mix	EPA, Region 10	Sept-00
Alaska	Jewel Lake	1	Bacteria	Nonpoint	EPA	Sept-97
Alaska	King Cove	1	Settleable solids residue	Point	Alaska DEC EPA, Region 10	Sept-98
Arizona	Lower Colorado River	1	Nutrients (Nitrogen & Phosphorus)	Mix	ADEQ, City of Yuma, Carollo Engineers	Jan-92
Arizona	Nutrioso Creek	1	Turbidity	Nonpoint	Arizona Dept. of Envir. Quality (ADEQ)	ca. Jul-00
Arizona	Pena Blanca Lake	1	Mercury	Nonpoint	Tetra Tech	Oct-99
Arizona	Stoneman Lake	1	Dissolved oxygen	Nonpoint	ADEQ	Sept-00
Arizona	Stoneman Lake	1	pH	Nonpoint	ADEQ	Sept-00
Arizona	Stoneman Lake		Nutrients	Nonpoint	ADEQ	Sept-00
California	Redwood Creek	1	Clean sediment	Nonpoint	EPA & RWQB	Dec-98
California	San Diego/ Newport Bay	1	Clean sediment	Nonpoint	EPA, Region 9	Apr-98
Colorado	Box Canyon Creek	1	Clean sediment	Nonpoint	State Agency	Jun-00
Colorado	Wisp Creek	1	Total residual chlorine	Point	CDHE	Aug-98
Colorado	Wisp Creek	1	Bacteria	Point	CDHE	Aug-98
Colorado	Wisp Creek	1	Ammonia	Point	CDHE	Aug-98
Delaware	Indian River, Indian Bay and Rehoboth Bay	4	Nutrients (Nitrogen & Phosphorus)	Mix	DNREC	Dec-98
Delaware	Nanticoke River and Broad Creek	3	Total nitrogen	Mix	DDNR & Tetra Tech	Dec-98
Delaware	Nanticoke River and Broad Creek	3	Total phosphorus	Mix	DDNR & Tetra Tech	Dec-98
Delaware	Nanticoke River and Broad Creek	2	Dissolved oxygen	Mix	DDNR & Tetra Tech	Dec-98
Delaware	Nanticoke River and Broad Creek	3	Bacteria	Mix	DDNR & Tetra Tech	Dec-98
District of Columbia	Hickey Run	1	Chlordane	Mix	District of Columbia	Jan-98
District of Columbia	Hickey Run	1	Oil & grease	Mix	District of Columbia	Jan-98
District of Columbia	Hickey Run	1	PCB	Mix	District of Columbia	Jan-98
Florida	Blackwater River (downstream segment)	1	Bacteria	Mix	EPA, Region 4	Feb-01
Florida	Lake Thonotosassa	1	Nutrients (Total N, Total P)	Mix	State of Florida	Jun-98

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State	Waterbody Name	# of TMDLs	Pollutant	Source of Pollutant	Author	Date of Approval
Florida	Tampa Bay	10	Nitrogen	Mix	Tampa Bay National Estuary Program	Jun-98
Georgia	Lake Jackson	1	PCBs	None	State of Georgia	NA
Georgia	Lazar Creek	1	Bacteria	Mix	GA EPA (?);ND	ND
Georgia	Mill Creek	1	Bacteria	Nonpoint	ND	ND
Idaho	Coeur d'Alene River, Tribs, Lake & Spokane River	3	Metals (Dissolved cadmium, lead, zinc)	Mix	EPA & IDEQ	Aug-00
Idaho	Upper Lapwai Creek	1	Clean sediment	Nonpoint	State of Idaho	Feb-99
Idaho	Upper Lapwai Creek	1	Nutrients	Nonpoint	State of Idaho	Feb-99
Idaho	Upper Lapwai Creek	1	Temperature	Nonpoint	State of Idaho	Feb-99
Idaho	Upper Lapwai	1	Bacteria	Nonpoint	State of Idaho	Feb-99
Idaho	Winchester Lake	1	Clean sediment	Nonpoint	State of Idaho	Feb-99
Idaho	Winchester Lake	1	Nutrients	Nonpoint	State of Idaho	Feb-99
Idaho	Winchester Lake	1	Bacteria	Nonpoint	State of Idaho	Feb-99
Idaho	Winchester Lake	1	Dissolved oxygen	Nonpoint	State of Idaho	Feb-99
Idaho	Winchester Lake	1	Temperature	Nonpoint	State of Idaho	Feb-99
Iowa	Corydon Reservoir	1	Toxics (atrazine)	Nonpoint	Iowa DNR	Nov-00
Kansas	Arkansas River	6	Boron	Nonpoint	ND	ND
Kansas	Buffalo Creek	6	Chloride	Mix	ND	ND
Kansas	Clinton Lake	3	Nutrients (P & N)	Nonpoint	ND	ND
Kansas	Middle Republican River	4	Bacteria	Nonpoint	Kansas	ND
Kansas	Ninemile Creek	3	Metals (zinc)	Nonpoint	ND	ND
Kansas	Upper Wakarusa	2	Clean Sediment	Mix	ND	ND
Kentucky	Elijahs & Gunpowder Creeks	2	Dissolved oxygen related to de-icing fluids (ethylene glycol, propylene glycol, urea)	Point	KDOW	ND
Kentucky	Fleming Creek and tributaries	11	Bacteria	Mix	Kentucky Division of Water	ca. Apr-01
Kentucky	Unnamed Tributary to South Fork Russell Creek	1	Chlorides	Mix	Kentucky DOW	Dec-00
Louisiana	Bayou Cocodrie	1	Metals (Dissolved copper)	Point	Louisiana DEQ	22-Dec-99
Maine	Cobbossee Lake	1	Total P	Nonpoint	Maine DEP	Oct-99
Maryland	Back River	1	Chlordane	Nonpoint	Maryland Department of the Environment	ca. Jul-99
Maryland	Baltimore Harbor	1	Chlordane	Nonpoint	Maryland Department of the Environment	20-Mar-01

State	Waterbody Name	# of TMDLs	Pollutant	Source of Pollutant	Author	Date of Approval
Maryland	Tony Tank Lake	1	Phosphorus	Nonpoint	Maryland Department of the Environment	ca. Sept-99
Maryland	Tony Tank Lake	1	Clean sediment	Nonpoint	Maryland Department of the Environment	ca. Sept-99
Michigan	Ore Lake	1	Phosphorus	Mix	MDEQ	18-Feb-00
Mississippi	Bayou Cumbest/ Bangs Lake	1	Bacteria	Nonpoint	MS State University	5-May-00
Mississippi	Bayou Pierre	1	Bacteria	Mix	Mississippi Department of Environmental Quality	ca. 15-Dec-99
Mississippi	Tallahala Creek	1	BOD	Mix	MDEQ	Jul-99
Mississippi	Okatibbee Creek	2	Bacteria	Mix	MS DEQ	15-Dec-99
Missouri	Goose & Saline Creek	4	Metals (Dissolved nickel & cobalt)	Mix	MDNR	1-Dec-99
Missouri	James River	3	Nutrients	Mix	Missouri Dept. of Natural Resources	ca. May-01
Missouri	Piney Creek	1	Chlorine	Point	Missouri DNR	Jan-01
Montana	Elk Creek	1	Clean sediment	Nonpoint	Montana DEQ	Dec-98
Nebraska	Pawnee Reservoir	1	Clean sediment (siltation)	Nonpoint	ND	Feb-01
Nebraska	West Fork Big Blue River	1	Bacteria	Mix	Nebraska DEQ	Feb-01
New Mexico	Jemez River & Rio Guadalupe	2	Clean sediment (stream bottom deposits)	Nonpoint	State of New Mexico	Dec-99
New Mexico	Jemez River & Rio Guadalupe	2	Turbidity	Nonpoint	State of New Mexico	Dec-99
New Mexico	North Ponil Creek	1	Temperature	Nonpoint	State of New Mexico	Nov-99
New Mexico	Rio Grande	1	Phosphorus	Point	ND	ND
New Mexico	Rio Grande	1	Ammonia	Point	ND	ND
New Mexico	Rio Grande	1	Bacteria	Point	ND	ND
Ohio	Middle Cuyahoga River	1	Dissolved oxygen	Mix	Ohio EPA	ca. Mar-01
Oklahoma	Arkansas River	1	Dissolved oxygen	Point	OKDEQ	Aug-97
Oregon	Bear Creek	1	Dissolved oxygen, UBOD	Mix	ODEQ	Mar-92
Oregon	Bear Creek	1	Ammonia	Mix	ODEQ	Mar-92
Oregon	Bear Creek	1	Phosphorus	Mix	ODEQ	Mar-92
Oregon	Columbia Slough	3	Toxics (DDE & DDT, PCBs, dieldrin, lead)	Point	ODEQ	Nov-98
Oregon	Columbia Slough	1	Phosphorus	Point	ODEQ	Nov-98
Oregon	Columbia Slough	1	Bacteria	Mix	ODEQ	Nov-98
Oregon	Coquille River & Estuary	3	Dissolved oxygen, UBOD	Mix	ODEQ	Jul-96
Pennsylvania	Bald Eagle Creek	1	Temperature	Point	PA DEP	ca. Apr-98

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State	Waterbody Name	# of TMDLs	Pollutant	Source of Pollutant	Author	Date of Approval
Pennsylvania	Brandywine Creek	1	Nonpoint	Chlordane	PA DEP	ca. Feb-99
Rhode Island	Scrabbletown Brook	1	Nonpoint	Bacteria	RIDEM	Feb-01
South Carolina	Grassy Run Branch	1	Bacteria	Nonpoint	SC DHEC	Jul-99
South Carolina	Mill Creek	1	Bacteria	Nonpoint	SC DHEC	Jan-00
South Carolina	Sanders Branch & Coosawhatchie River	2	Dissolved oxygen, CBOD, NBOD	Point	SC DHEC	Aug-98
South Dakota	Big Sioux River	1	Ammonia	Mix	SD DENR	Apr-99
South Dakota	Lake Hiddenwood	1	Clean sediment	Nonpoint	SD DENR	Feb-99
South Dakota	Lake Hiddenwood	1	Nutrients	Nonpoint	SD DENR	Feb-99
South Dakota	McCook Lake	1	Clean sediment	None	SD DENR	ca. Feb-99
Texas	Clear Fork Trinity	11	Toxics (Chlordane, DDT, dieldrin, PCBS)	Mix	Texas Natural Resource Conservation Commission	Nov-00
Virginia	Muddy Creek	1	Nitrate	Mix	University of Virginia	Jun-00
Virginia	Muddy Creek	1	Bacteria	Mix	Tetra Tech, Inc. for Commonwealth of Virginia & EPA, Region 3	ND
Washington	Lower Nooksack River	4	Bacteria	Nonpoint	Washington St. Dept. of Ecology	Unknown
West Virginia	Anderson Run	1	Bacteria	Nonpoint	Tetra Tech	Feb-98
West Virginia	Blackwater River	1	Dissolved oxygen, CBOD, NBOD	Mix	EPA, Region 3	Feb-98
West Virginia	Buckhannon River	1	Metals (Iron)	Mix	EPA, Region 3	ND
West Virginia	Ten Mile Creek	1	Metals, pH (delisted for pH)	Mix	EPA, Region 3	ND
West Virginia	Tomlinso Run Lake	1	Clean sediment	Mix	EPA, Region 3	Oct-98

ND = No date provided.

APPENDIX B

ANNOTATED BIBLIOGRAPHY: BEST MANAGEMENT PRACTICES

General BMP Effectiveness

U.S. EPA. January 1993b. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA-840-B-93-001c Available at: http://www.epa.gov/owow/nps/MMGI/ .

EPA developed management measures, which are synonymous with BMPs. The purpose of each management measure, appropriateness of the measure, measure selection process, information on the effectiveness of the measure, and cost information for the measure is provided. The effectiveness of each measure is dependent upon the pollutant of concern, types of BMPs being considered, and the site-specific conditions in which the BMPs will be implemented. In addition, national and some state costs where noted are provided for a number of measures. Several case studies are also included. Chapters are divided by subject including urban, forestry, and agricultural BMPs.

U.S. EPA National Menu of Best Management Practices for Storm Water Phase II http://www.epa.gov/npdes/menuofbmps/menu.htm

U.S. EPA recommends the use of measurable goals (BMP design objectives) that can quantify the performance on BMPs under the NPDES permitting process. They recommend several ways to document the measurable goals including: tracking implementation over time, measuring progress in implementing the BMP, tracking total numbers of BMPs implemented, tracking program/BMP effectiveness, tracking environmental improvement. EPA also recommends that the measurable goals include: the BMP of interest, a scheduled date of completion, and a quantifiable number to evaluate progress and effectiveness of the BMP. They also recommend the following considerations when selecting measurable goals: consider the objective for each BMP, review existing programs, select BMPs that are complimentary, develop a schedule for each BMP (mark the start of implementation, evaluate and legal or funding issues, decide how progress will be monitored, choose if the success is a reduction or a targeted level) determine how BMP effectiveness will be measured, derive measurable goals for the selected evaluation methods for effectiveness.

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Urban BMPs

American Society of Civil Engineers (ASCE) National Stormwater Best Management Practices Database. http://www.bmpdatabase.org/.
ASCE developed a BMP database in recognition of the wealth of information on BMP effectiveness, and the lack of standardization in data collection procedures, reporting and performance protocols. The database tracks site location characteristics, watershed characteristics, BMP design parameters, monitoring location and instrumentation, cost, precipitation, flow, and water quality data. This database was recently updated to include 39 new BMPs from California and Washington. Other states in the database include Washington, California, Michigan, Illinois, Ohio, Texas, Florida, North Carolina, Virginia, Maryland, and Minnesota.

American Society of Civil Engineers. National Stormwater Database. Master BMP Bibliography Used to Develop the Database. http://www.asce.org/pdf/bibl2.pdf_
Several files are provided by the ASCE that provide bibliographic references for studies in several categories including: structural BMPs (e.g., infiltration, filtration, and detention), nonstructural BMPs (e,g, planning, post-development), BMP and water quality monitoring programs, water quality models, NPS pollution sources/loads, structural and nonstructural BMPs. For each reference a topic, author(s), date of publication, title, source, and abstract (when available) are documented.

Atlanta Regional Commission. First Edition 2001. Georgia Stormwater Management Manual Volume 2: Technical Handbook.
Design criteria for pollutant removal efficiencies for structural stormwater controls are discussed. They recommend several steps in the screening process: overall applicability including stormwater management suitability, water quality performance, site applicability, and implementation considerations. In addition they detail factors to be considered including physiograhic factors, soils, and any special watershed or stream considerations (e.g., primary trout streams, swimming/shellfish etc.). For each BMP key considerations are the design criteria, advantages/benefits, disadvantages/limitations, and maintenance requirements. Stormwater management suitability (water quality, channel protection, flood protection), and feasibility considerations (land requirement, capital cost, maintenance burden) , and pollutant removal are considered. They also discuss why a BMP is recommended for limited use only based on all of the above factors.

Catalog of Stormwater Best Management Practices. For Idaho Cities and Counties.
Idaho Department of Environmental Quality. Available on-line at:
http://www2.state.id.us/deq/water/stormwater_catalog/index.asp
The catalog of Stormwater Best Management Practices for Idaho Cities and Counties provides technical guidance for BMP selection. They provide a step-by-step procedure for site design that can be coupled with the stormwater BMP selection suitability decision tree. Temporary (construction) BMPs, permanent (post-construction) BMPs, and other structural controls are discussed. Steps include evaluation of site conditions, review of local requirements, development of a conceptual site design, characterization of stormwater flows, followed by an evaluation of BMPs. They provide a general sense of nonstructural and structural BMPs that may be appropriate. This is based on expected pollutant effectiveness, drainage area, maximum slope, minimum depth to bedrock, depth to high water table, SCS soil type, use of BMP with freeze and

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thaw cycles, whether the BMP can provide drainage and flood control. Once the appropriate BMP has been selected the user can prepare a preliminary project design and the preliminary landscape design. They also provide guidance for the completion of the design and submission of the final plan and permit process.

Center for Watershed Protection. A Stormwater Design Manual Builder. The Stormwater Managers' Resource Center.
The SMRC stormwater design manual has several useful tools to assist the user with the development of a stormwater treatment practice manual: procedures for reviewing stormwater plans, basic sizing criteria, list of acceptable STPs, performance criteria, guidance on STP selection, stormwater credits, design example, construction specifications and checklists for construction and maintenance inspection. Detailed design examples are provided for practices, ponds, infiltration, filtering systems and open channels.

Center for Watershed Protection. 1997. Stormwater BMP Design Supplement for Cold Climates. Center for Watershed Protection. Ellicott City, Maryland. http://www.cwp.org/cold-climates.htm
This manual provides BMP information for small-urban sites in a cold climate setting. Cold climate design challenges include pipe freezing, ice formation on the permanent pool, reduced biological activity, reduced oxygen levels in bottom sediments, reduced setting velocities, frost heave, reduced soil infiltration, short growing season, high runoff volumes during spring melt, high pollutant loading during the spring melt, and snow management. In addition to the typical pollutants of concern, cold climates need to pay more attention to pollutants in snowmelt such as sand (sediments), salt (chlorides), PAHs, cyanide, as well as trash and debris. Applicability of BMPs to cold climates conditions are detailed in a series of tables.

City of Boise. Stormwater Management: A Design Manual. Available on-line at: http://www.ci.boise.id.us/public_works/services/water/storm_water/manual/des
City of Boise defines minimum requirements, standards, and procedures. Removal rates of BMPs are detailed for all types of BMPs including dry and wet detention ponds, dry and wet extended detention ponds, evaporation ponds, biofiltration swales, sand and organic filters, catch basin inserts, sediment traps, grass buffer strips, and/water separators. In addition, they have a sliding scale for TSS and required TSS removal efficiency that designers should use to determine TSS removal rates. This is based on the % of parcel area that is impervious and the % TSS removal efficiency required.

City of Knoxville Engineering Department Stormwater Engineering Division. March 2001. Best Management Practices (BMP) Manual.
City of Knoxville draft online erosion and sediment control manual provides information on the design, inspection, and maintenance of structural and nonstructural BMPs that are used in the City of Knoxville, TN. They document that the objectives in pollution prevention vary for each site. They state that a comprehensive understanding of pollution risks for each location is imperative when selecting and implementing BMPs during construction. After a review of the characteristics of the site and the type of construction or industrial activity proposed, the risks should be defined. This information should be reviewed early in the design process. Then specific BMP objectives should be selected. The BMP objectives for a typical construction project

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or industrial activity follow: maintain the integrity of the original, minimize disturbance to surrounding areas, stabilize disturbed site, protect slopes and channels, control site perimeter, control internal erosion and drainage.

Claytor, R., and T. Brown July 27, 2000 (Center for Watershed Protection). Memorandum to Vermont Stormwater Management Handbook Steering Committee. Re: Phase 1 Task 1 Deliverable – Review of Stormwater Management Strategies from Other Regions of the Country.
The Center for Watershed Protection (CWP) conducted a detailed evaluation of existing stormwater manuals and handbooks in an effort to evaluate the level of designed criteria and performance goals being implemented in programs across the nation. This detailed review of the programs and manuals were intended to assist with the prioritization of issues in the development of the Vermont BMP manual. The screening process included a review of evaluation criteria considered to be necessary components of an effective stormwater management program, including:

- Defines acceptable stormwater treatment practices for region
- Establishes performance criteria for treatment practices
- Provides design guidance and specifications and meaningful details and sketches for stormwater treatment practices
- Provides guidance on stormwater treatment practices selection
- Allows for innovative stormwater treatment practices with a proven effectiveness
- Incorporates nonstructural practices
- Provides maintenance guidance (e.g., does the program provide criteria and design guidelines for the long term operation and maintenance of stormwater treatment practices? Is there a mechanism in place to assign responsibility for maintenance?)

Three programs (Maryland, Massachusetts, and North Carolina) were chosen to be the most comprehensive documents after an intensive screening process of the various states program.

Center for Watershed Protection. Comparative Pollutant Removal Capability of Stormwater Treatment Practices. Article 64. Technical Note Number 95. Watershed Protection Techniques. 2(4): 515-520.
A study comparing pollutant removal capabilities of stormwater treatment practices was conducted. They caution cross comparisons of stormwater management practices as studies may compute removal efficiencies by different methods, sample sizes may differ, regional differences in soil type may exist, and the size of land use may vary. One of the important things to consider is the removal percentages may be influenced by the inconsistency of pollutant concentrations in the incoming stormwater. Box and whisker plots were developed to portray the statistical distribution of removal rates. Pollutants studied include total phosphorus, total nitrogen, soluble phosphorus, nitrate and nitrite nitrogen, total suspended solids, zinc, total organic carbon, copper, and trace metals, bacteria and hydrocarbons. Removal rates are included in the document and are synthesized in Table X. Wetlands pollutant removal appears to be more variable than other practices, (e.g., ponds). Infiltration practices were seen to have the best removal capabilities of any group, whereas dry extended detention ponds and ditches seem to have very limited removal capabilities.

Determining Urban Stormwater Best Management Practice (BMP) Removal Efficiencies. Task 3.4 - Final Data Exploration and Evaluation Report. U.S. EPA Assistance Agreement Number CX 824555-01 - Task 3.4. Prepared by GeoSyntec Consultants, Urban Drainage and Flood Control District, URS and Urban Water Resources Research Council (UWRRC) of ASCE.
This report details the initial dataset used for Version 1 of the national Stormwater Best Management Practices Database. Thus paper attempts to evaluate the efficiency and effluent quality of the data. An overview of the results of the efficiency calculations are presented by BMP type and parameter. Other variables' influence on efficiency (e.g., design, climatic, etc) are also assessed. Several limitations and conclusions are discussed based on the evaluation.

URS Greiner Woodward Clyde, Urban Drainage and Flood Control District and Urban Water Resources Research Council (UWRRC) of ASCE. 1999. Development of Performance Measures. Task 3.1 – Technical Memorandum. Determining Urban Stormwater Best Management Practices (BMP) Removal Efficiencies. Developed in cooperation with Office of Water U.S. EPA.
This document provides an excellent overview of methods for evaluating efficiency, performance, and effectiveness of best management practices. They provide BNP types and implication for calculation efficiency as well as a nice review of commonly used efficiency calculation methods. The methods documented include efficiency ration, summation of loads, regression of loads, mean concentration, efficiency of individual storm loads, reference watersheds and before/after studies They also document that BMP studies are usually conducted to obtain information regarding the following objectives:

"What degree of pollution control does the BMP provide under typical operating conditions?

- Does performance vary from pollutant to pollutant?
- Does performance vary with various input concentrations?
- Does performance vary with large or small storm events?
- Does performance vary with rainfall intensity?
- Do design variables affect performance?
- Does performance vary with different operational and/or maintenance operations?
- Does performance improve, decay, or remain stable over time?
- How does the BMP's performance compare relative to other BMPs?
- Does the BMP reduce toxicity to acceptable levels?
- Does the BMP cause an improvement in downstream biotic communities?
- Does the BMP have potential downstream negative impacts?"

Effectiveness of BMPs for Stormwater. Management Center for Transportation and the Environment North Carolina state University. National Teleconference Series. Program No. TC-22. http://www.itre.ncsu.edu/cte/tc22bib.htm
The Bibliography from conference has not yet been posted. This reference will be updated as soon as the information is posted.

Center for Watershed Protection. Irreducible Pollutant Concentrations Discharged from Stormwater Practices. Article 65. Technical Note Number Watershed Protection Techniques. 2 (2): 369-372.
Traditionally, the way to evaluate the performance of BMPs has been through the measurement of load reduction. The pollutants entering a practice are compared against the mass leaving it. Tables were developed documenting irreducible concentrations in wastewater wetlands and

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BMPs. Although this study is based on only two studies, it is evident that a limit to stormwater treatment efficiency does exist. In their expert opinion, surface flow wastewater wetlands cannot reduce sediment and nutrient concentrations beyond the already low level documented in this paper. Parameters evaluated include total suspended solids, total phosphorus, total nitrogen, nitrate-nitrogen, and TKN. In addition, they document that it doesn't matter how much more surface area or treatment volume is provided, the levels will not go below this limit. While this limit is low, it should be recognized when conducting restoration and watershed programs.

Massachusetts Department of Environmental Protection, Massachusetts of Coastal Zone Management, and United States Environmental Protection Agency. March 1997. Stormwater Management Volume I, Stormwater Policy Handbook. Available on-line at: http://www.state.ma.us/dep/brp/stormwtr/stormpub.htm
Massachusetts suggests considering the following questions when considering BMP implementation. What is the best system to meet standards effectively? Is it possible to meet standards, stormwater recharge, and peak discharges at the same time? Will comprehensive site planning minimize the needs for structural controls? Are there areas of concern adjacent to the site? Does the project involve SW discharge from an area with a higher pollutant load? Are there physical site constraints? Is the future maintenance possible for the BMP? Is the BMP cost effective? They also document that one of the biggest problems is the construction of BMPs without well thought out maintenance. They also recommend that various maintenance requirements, costs, and public acceptance issues should also be taken into consideration. Calculations to address water quality and volumetric standards are also included in this document.

Maine Department of Environmental Protection. November 1995. Stormwater Management for Maine- Best Management Practices.
Physical suitability, applicability of the BMP measure for achieving management objectives and capability of achieving pollutant removal capabilities. Highway runoff BMP selection is included in this document. A series of questions are presented to the user, depending upon the response, the user is referred to a specific BMP.

Manuals of Storm Water Quality Best Management Practices for: I. Construction Activities – 2nd Edition (June 1999) II. Residential/Commercial Land Uses – Original Edition.
The book offers several sections on the Stormwater Management Program, Best Management Practices Selection, and Source Control BMP Fact Sheets. Specifically, guidance is provided in the selection of the most appropriate BMPs for various types of land use including residential and commercial land use. In addition, each of the fact sheets includes a description and approach, cost considerations, regulatory considerations and more.

Maryland Department of the Environment in cooperation with the Maryland Department of Natural Resources Coastal Zone Management Program. Maryland Stormwater Design Manual, Volume I.
The Maryland document offers six general categories for stormwater control: stormwater ponds, stormwater wetlands infiltration practices, filtering practices, open channel practices, and non-structural practices. Comprehensive performance criteria are provided for each category. They determine that a BMP can be used as a stand alone BMP, if and only if, the following are satisfied: capturing and treating the required water quality volume, removing 80% of TSS and 40% of TP, as well as having an adequate longevity rate. Those that do not satisfy the

above requirements or have inadequate testing should not be used as stand alone BMPs. The structural BMPs that fall into this category include: catch basin inserts, dry extended detention ponds, water quality inlets and oil/grit separators, hydro-dynamic structures, filter strips, grass channels, street sweeping, deep sump catch basin, dry wells, and on-line storage in the storm drain network.

Maryland also mentions stormwater "hotspots". They define a hotspot as "a land use or activity that generates higher concentrations of hydrocarbons, trace metals, or toxicants that are found in typical stormwater runoff, based on monitoring studies." Recommendations for managing stormwater at "hotspot" sites are provided. The document also provides tables for BMP selection for watershed, terrain, stormwater treatment suitability, physical feasibility, community and environmental factors as well as location and permitting factors. Maryland has a commitment to update the acceptable BMP practices as new monitoring research is conducted and new technologies are tested.

Barr Engineering Company. 2001. Minnesota Urban Small Sites BMP Manual. Stormwater Best Management Practices for Cold Climates. Prepared for the Metropolitan Council.
Cold climate design challenges include pipe freezing, ice formation on the permanent pool, reduced biological activity, reduced oxygen levels during ice cover, reduced setting velocities, frost heave, reduced infiltration, short growing season, high runoff volumes during spring snowmelt, high pollutant loading during the spring snowmelt, snow management, and special maintenance. They also provide an excellent resource with an annotated bibliography of stormwater manuals. The bibliography includes 18 general stormwater manuals, 13 region specific stormwater BMP manuals, 4 BMP performance and performance enhancement manuals. This manual also includes information on 40 BMPs that are focused on cold climate setting urban areas.

Minnesota Pollution Control Agency. Protecting Water Quality in Urban Areas Manual. Best Management Practices for Dealing with Stormwater Runoff from Urban, Suburban, and Developing Areas of Minnesota. Available on-line at:
http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html
Prioritizes BMPs by avoidance of adverse impacts, minimizing unavoidable impacts, and lastly mitigating unavoidable adverse impacts. This manual follows the first practice of avoiding adverse impacts. They follow BMP selection options including the characteristics of the protected resource, the ease of implementation, public demands, and governmental regulations. Selection consideration includes temperature, aesthetics, effect on other resources, physical site suitability, maintenance requirements, and cost effectiveness. They suggest the development of watershed plans, followed by on-site assessment plans, refining of the stormwater treatment system design, implementation and maintenance.

New Jersey Department of Agriculture, New Jersey Department of Community Affairs, New Jersey Department of Environmental Protection, and New Jersey Department of Transportation. Fifth draft May 3, 2000. Revised Manual for New Jersey: Best Management Practices for Control of Nonpoint Source Pollution from Stormwater
Estimated percent pollutant concentration reductions are discussed. Effectiveness of BMP monitoring approaches include measurement of pollutants, stream temp monitoring, and environmental indicators (e.g., benthic macroinvertebrates, fish assemblages, toxicity testing or organisms).

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Center for Watershed Protection for the New York State Department of Environmental Conservation. New York State Stormwater Management Design Manual. Chapter 7 Stormwater Management Practices Selection.
BMPs include stormwater ponds, stormwater wetlands, infiltration practices, filtering practices, open channel practices. They were selected based on the following criteria: capable of capturing the full water quality volume, capable of 80% TSS removal and 40% TP removal, have acceptable longevity in the field and have pretreatment mechanism. NY uses the same evaluation approach as Georgia including reasons for limited use, design considerations, stormwater management suitability, and any special applications. The screening factors include land use (rural, residential, roads and highways, commercial development, hotspot land uses, ultra-urban sites), physical feasibility (soils, water table, drainage area, slope, and head), watershed/regional factors (sensitive streams, aquifers, lakes, reservoirs, estuary/coastal, cold climates), stormwater management capability (water quality, channel protection, flood control) and community and environmental factors (ease of maintenance, community acceptance, affordability, safety, and habitat. During the screening process a series of matrices are used to evaluate the factors.

North Carolina Department of Environment and Natural Resources. Division of Water Quality. Water Quality Section. April 1999. Stormwater Best Management Practices.
North Carolina Department of Environment and Natural Resources assessed several stormwater BMPs and the assumed TSS removal efficiencies for each BMP including: wet detention basins (85%), extended detention wetlands (85%), pocket wetlands (35%), sand filters (85%), bioretention areas (85%), grassed swales (35%), extended dry detention (50%), filter strips (25-40%), and infiltration devices (85%). BMPs in this guidance are recommended alone or in combination to achieve the goal of 85% removal of TSS. Advantages and disadvantages to each BMP, design requirements, and operation and maintenance costs are also documented for each practice.

Northern Virginia Planning District Commission and Engineers and Surveyors Institute. November 1992. Northern Virginia BMP Handbook. A Guide to Planning and Designing Best Management Practices in Northern Virginia.
The handbook is designed to provide guidance for the design and review of BMPs in Northern Virginia. They recommend a screening for physical site attributes including soil suitability, depth to water table, depth to bedrock, slopes, and watershed area to be served. In addition, proximity to water sources and foundations, land availability, recreational use potential, aquatic and terrestrial wildlife habitat values, and maintenance. Outside of the general guidance they recommend taking into account aesthetics or stormwater management consideration as well. They also suggest that designers should consult their local jurisdiction for local regulations and or requirements for BMP screening. They also provide reviews of phosphorus removal calculation methods to be used for local jurisdictions. BMP facility planning considerations are also discussed.

Oregon Department of Land Conservation and Development. October 2000. Water Quality Model Code and Guidebook. http://www.lcd.state.or.us/coast/waterguidebook/watergb.html_
A BMP matrix is provided, a series of tables for nonstructural BMP solutions for designated pollution factors are deemed effective or inconclusive. Pollutant removal effectiveness is also included.

Pennsylvania Association of Conservation Districts Inc. Pennsylvania Handbook of Best Management Practices for Developing Areas.
This handbook documents that the components of an effective BMP program include carefully prepared site layouts and designs, effective runoff control measures, and effective control of soil erosion and sedimentation during land disturbing activities. They also indicate that developers need to consider the market factors affected by BMPs (e.g., green thinking, permitting requirements, liability concerns), the costs and cost savings of BMPs, and the technology transfer limitations to BMPs.

Sargeant, D., S. O'Neal, and W. Ehinger. April 2002. Chehalis Best Management Practices Evaluation Project, Final Report for Water Quality Sites. Washington State Department of Ecology. Publication Number 02-03-015. http://www.ecy.wa.gov/biblio/0203015.html
Washington State Department of Ecology conducted water quality and benthic macroinvertebrate monitoring to assess and evaluate the efficiency of BMPs installed in three sub-basins of the upper Chehalis basin. As part of the sampling plan, monitoring was performed before and after BMPs were installed upstream and downstream of the studied area during both the dry and wet seasons. BMPs included fencing agricultural riparian corridors, implementation of dairy waste management plans; and revegetation of riparian areas. Other types of BMPs, implemented for erosion and sediment control, were also evaluated. Water quality data collected from "the Beaver Creek sub-basin" showed large reduction of fecal coliform and ammonia-nitrogen concentrations resulting from BMPs implemented on a large dairy farm. However, the concentrations of these parameters must be reduced further to meet water quality standards and the load allocation required in the TMDL. Water quality improvements for fecal coliform were documented at Deep Creek and Bunker Creek. However, due to improper maintenance of the BMP, fecal coliform levels increased again. Fecal coliform levels measured in the Berwick Creek were reduced after agricultural fencing was installed and properly maintained. The main point from this study is that proper maintenance of BMPs is a very critical factor to improve BMP effectiveness.

Center for Watershed Protection. Stormwater Strategies for Arid and Semi-Arid Watersheds. Article 66. Watershed Protection Techniques. 3(3): 695-706.
This article presents stormwater strategies for Arid and Semi-Arid watersheds including: lower rainfall depths, higher evaporation rates, greater pollutant concentrations in stormwater, sparse vegetative cover in the watershed, greater sediment movement, rare dry weather flow and essentially different aquatic resources and management objectives. The authors provide examples of pollutant concentrations and a number of samples in the areas of Arizona, Idaho, Colorado, California, and Texas. They recommend four principles for designing "western" stormwater practices, including the careful selection of STPs for arid and semi-arid areas, such as extended detention dry ponds, sand filters, rooftop infiltration, etc. Several other BMPs are suggested for limited use or not recommended at all. They also recommend to minimize the need for irrigation in STPs, protect groundwater resources and encourage recharge, reduce downstream channel erosion and protect upland sediment.

The authors also review the performance of vegetated swales in semi-arid climates (swales are rarely used in arid climates) for TSS,COD, TP, TKN, Nitrate, Zinc, and Lead. While there

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have been mixed results of pollutant performance of swales in arid and semi-arid conditions, Table 6 indicates the excellent pollutant removal rates in two Austin Texas highway vegetated swales without the use of irrigation (Barret et al., 1998).

Strecker, E., M. Quigley, and B. Urbonas. 2000. Determining Urban Stormwater BMP Effectiveness. In: National Conference on Tools for Urban Water Resource Management and Protection Proceedings. February 7-10, 2000. Chicago, IL. EPA 625-R-00-001 Technology Transfer and Support Division, National Risk Management Research Laboratory, Office of Research and Development U.S. Environmental Protection Agency, Cincinnati, OH 45268.
http://www.epa.gov/ORD/WebPubs/nctuw/Strecker2.pdf
In the EPA document "National Conference on Tools for Urban Water Resource Management and Protection Proceedings" Strecker et al (2000) document the need for consistency with methods and constituents utilized for assessing BMP effectiveness in their "Determining Urban Stormwater BMP Effectiveness" paper. They also indicate that BMP performance data collected at a specific site should not only be useful for that site, but should be comparable for assessing studies of similar and different types of BMPs in other locations. They cite that most past BMP effectiveness studies have limited data. They assess some of the issues in the past effectiveness studies in an effort to create more comparability studies. They document ways to collect data to facilitate the assessment of factors that might have contributed to the performance levels achieved.

In addition, Strecker et al. (2000) document that after a careful of review of the numerous studies that have assessed the ability of BMPs to reduce pollutant concentrations and loadings, it is recognized that the inconsistent study methods and reporting create major difficulties in making larger-scale assessments. Further they document that these studies have used significantly different sample collection techniques, water quality constituents, data reporting on tributary watershed and BMP design characteristics, effectiveness estimation techniques, and statistical validation of results. Based on this assessment, ASCE is developing protocols for BMP monitoring and reporting, developing a database on BMP performance studies, as well as performing an assessment of existing information to assist U.S. EPA in providing guidance to the regulating community.

Statewide Stormwater Quality Task Force. Sponsored by the Texas Chapter of, American Public Works Association. (no date available as it is a website) Texas Nonpoint Source Book. Urban Nonpoint Source Management 101 & Runoff Quality Best Management Practices
http://www.txnpsbook.org/SiteMap.htm Selecting the Right BMP — Guidance for Beginners & Interactive BMP Selector.
Texas has two documents, Urban Nonpoint Source Management 101 and Runoff Quality Best Management Practices. They also have an interactive BMP selector. This tool will prompt the user to select the level of annual precipitation, BMP category (e.g., pollution prevention, source control, and treatment control), pollutant removal effectiveness, type of application, soil type, and whether the materials are toxic. Pollutant removal efficiencies are given for nutrients, oxygen demand, bacteria and viruses, heavy metals, toxic materials, sediment, and floatable materials. Capital costs, maintenance level, operation and maintenance costs, and training costs are also available, however they are not part of the BMP selection criteria. High, low, medium rankings are assigned to cost and effectiveness categories.

Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices. 2001. Guide for Best Management Practice (BMP) Selection in Urban Developed Areas. Sponsored by Environmental and Water Resources Institute of ASCE.
The authors cite several factors that should be considered when selecting BMPs including land availability, types of pollutants to be removed, groundwater levels, soil types, BMP costs, maintenance costs, desired pollutant removal efficiency. Several BMPs are evaluated and described within the guide. BMPs include ponds, aluminum injection systems, constructed wetlands, media filters, baffle boxes, inlet devices, buffer strips, and infiltration/exfiltration trenches. A BMP selection guide is presented which allows the user to consider site constraints, costs, and pollutant removal efficiencies.

U.S. Department of Transportation, Federal Highway Administration. June 1996. Evaluation and Management of Highway Runoff Water Quality. FHWA-PD-96-032.
DOT developed a manual with three components, a literature review on existing studies, interviews with highway practitioners, and a synthesis of all of these results into one manual. It is a comprehensive document with extremely useful information. In an effort to assist the user interpret limitations, pollutant removal efficiencies, and site-specific considerations for the BMPs a series of tables have been included.

U.S. Department of Transportation, Federal Highway Administration. May 2000. Ultra-Urban Best Management Practice Assessment and Analysis Best Management Practices System User's Guide and Ultra-Urban Best Management Practice Database.
DOT ultra-urban database provides design criteria and monitoring results on BMPs from the US and other countries. It provides information on successful and unsuccessful BMP implementation, level of effectiveness, reference information, study information, specific information for BMPs, BMP cost and maintenance data, and study results. Selection criteria include a series of yes/no questions including "Is it considered an ultra-urban setting?" Performance independent of soil conditions, minimum effective life, capital costs, maintenance costs, drainage area, area set-aside for BMPs, and minimum pollutant removal efficiencies are included. BMP types include detention/retention, biofiltration/bioretention, infiltration/filtration, and system BMPs. Once factors are selected the BMPs will be returned that fit the selection criteria.

U.S. Department of Transportation, Federal Highway Administration. May 2000. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. FHWA-EP-00-002.
DOT prepared a manual to accompany the database. Summary tables of site consideration, management considerations, and pollutant removal effectiveness were developed. Detailed information regarding each practice includes the applicability of the BMP, effectiveness, site design and consideration, maintenance considerations, cost considerations. They also address cost-effectiveness, management and public acceptance issues. Case studies are provided for Florida, Virginia, Washington, Oregon, and Texas. They also prepared a User's Guide titled "Ultra-Urban Best Management Practice Assessment and Analysis Best Management Practices System User's Guide." This manual presents a table of selection criteria and their associated ranges.

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U.S. EPA. October 1993. Guidance Manual for Developing Best Management Practices (BMP). EPA Number 833-B-93-004. Washington DC.
This manual is designed to provide guidance to NPDES permittees in the development of BMPs for facilities. BMP regulatory history, BMP applicability, types of BMPs, selection factors affecting BMP performance are included. While this book is directed toward point sources it may provide additional guidance when selecting nonpoint source BMPs.

U.S. EPA. January 2001. Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures. Urban. EPA 841-B-00-007. Washington DC. http://www.epa.gov/owow/nps/urban2.html
EPA (2001) conducted statistical analyses of BMP effectiveness data and found that removal efficiencies are not very useful at characterizing performance, resulting in a recommendation that BMP performance requirements not be specific in terms of removal. They also reported that some BMPs are cited as less effective due to cleaner influent. However, this does not cover more complex questions about the performance of the BMP such as the relationship between design and performance. They recommend consistent formatting of the data, clearly identified QA/QC results, and standardized comparisons to water quality results. They also recommend two critical factors: the reporting of tributary watershed characteristics, and BMP design information.

In addition the authors found that a wide variety of pollutant removal effectiveness estimations have been employed. They provide a comparison of BMP pollutant removal efficiency techniques. They recommend evaluating the use of effluent data when attempting to compare design criteria, as BMPs may be able to only treat a given concentration, which would create differing results if clean water is entering a BMP versus greater polluted water. Methods to monitor BMP effectiveness are documented. The typical method is to collect and analyze water quality samples. While efficiency is important to monitor, the hydraulic performance of the BMP is also monitored. Another method they used is to evaluate the quality of water receiving runoff. The authors provide some helpful references for monitoring BMP effectiveness, including Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls (U.S. EPA 1997a). This document provides a comprehensive review of guidance documents including the full reference, contents, main focus, and a brief description of the document.

Washington State Department of Ecology. Stormwater Management Manual for Western Washington .http://www.ecy.wa.gov/programs/wq/stormwater/manual.html
Washington State Department of Ecology developed a stormwater manual that contains several volumes of information. Volumes of the manual include minimum technical requirements and site planning, construction stormwater pollution prevention, hydrologic analysis and flow control design BMPs, source control BMPs, and runoff treatment BMPs. This manual was recently updated to include additional data and includes more areas throughout western Washington whereas the last manual was limited to Puget Sound.

Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE) 1998. Urban Runoff Quality Management. WEF Manual of Practice No 23. ASCE Manual and Report of Engineering Practice No. 87. Alexandria, VA, and Reston, VA.
This manual addresses urban runoff effects and control requirements, best management practices, and water quality parameters. Various BMPs are discussed in two chapters of this book.

Design objectives for BMPS are addressed, and general guidance for the selection of stormwater best management practices are discussed. Ranking criteria are suggested for selecting source controls. The effectiveness of pollutant removal, public acceptance of the control, implementation, institutional constraints, and costs are the main factors considered. They also take into account public education and participation as a method by which to implement BMPs.

Winer, R. June 2000. National Pollutant Removal Performance Database for Stormwater Practices 2nd Edition. Prepared by Center for Watershed Protection for U.S. EPA Office of Science and Technology in association with Tetra Tech Inc.
This database developed by the Center for Watershed Protection builds upon Brown and Schueler's (1997) National Database of BMP Pollutant Removal Performance. The second edition includes 147 performance-monitoring studies. The database consists of two components a dynamic PC database and a succession of STP pollutant removal efficiencies. Pollutants analyzed include Phosphorus, nitrogen, suspended sediment, carbon, metals, bacteria, hydrocarbons, etc. BMPs include filtering practice, infiltration practice, open channel practice ditch, open channel practice dry swale, open channel practice grass channel, open channel practice grass swale, stormwater pond, and stormwater wetland.

Forestry BMPs

Arkansas Forestry Commission. 2002. Arkansas Forestry Best Management Practices for Water Quality Protection. http://www.forestry.state.ar.us/bmp/bmp_final.pdf
Arkansas presents the reader with some general guidelines for planning to meet with landowners and/or foresters to determine the most appropriate BMP. BMPs including streamside management zones, active roads, inactive roads, harvesting, mechanical site preparation, forest chemicals and reforestation are discussed. General guidance is given to make each BMP more effective.

Field Guide to Best Management Practices for Timber Harvesting in Kentucky.
http://www.ca.uky.edu/agc/pubs/for/for69/intro.htm
Kentucky developed a guide for timber harvesting operations, which includes minimum specifications of BMPs in Kentucky. A quick reference for determining timber harvesting BMPs is included. It provides a series of questions and depending on the answer the user is directed to a specific BMP. Guidance for planning road, trail and landing placement are provided to assist with BMP implementation and can maximize their intended effectiveness. Determination of control points (e.g., highway access points, water courses, sinkholes) should be considered as they affect the placement of roads, trails, and landings. They also recommend using maps and conducting a walk-through to determine the location of control points. Then the planning of the location of roads and landings can be conduced. Some general recommendations to increase the effectiveness of the process are provided including recommendations for slope measurement, slope distance. They provide minimum requirements for each BMP based on the Kentucky Forest Practice Guidelines for Water Quality Management (1997). This document details BMPs for reforestation and fire control issues. This document was revised in 2001. Each BMP has specifications, spacing, and maintenance, issues and each BMP has minimum requirements.

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Georgia Forestry Commission January 1999. Georgia's Best Management Practices for Forestry. http://www.gfc.state.ga.us/Publications/RuralForestry/GeorgiaForestryBMPManual.pdf
Georgia presents BMP guidance in a somewhat unique fashion. While planning for water quality the various BMPs are discussed. They present the user with a series of what to avoid, what is mandated law or requirement. Streamside management zones, special management areas, road location, construction, stream crossings, maintenance and retirement as well as timber harvesting, site preparation and reforestation, management and protection are discussed.

Montana Department of Natural Resources and Conservation Water Quality BMPs for Montana Forests. http://www.dnrc.state.mt.us/forestry/ServiceForestryPrograms/BMPmanual.htm
Montana developed a very useful guide for BMP applicability for streamside management, roads, stream crossings, soil, timber harvesting, reforestation, winter planning, and clean up. General guidance and site selection criteria area also provided.

Nebraska Forest Service, University of Nebraska. 1998. Forestry Best Management Practices for Nebraska. http://www.ianr.unl.edu/pubs/forestry/nfs/nfs-1.htm
Nebraska State Guidelines provide general guidelines to follow when implementing and selecting forestry BMPs, including a guideline for sizing culverts.

Ohio Department of Natural Resources. August 1999. Evaluation of Logging Best Management Practices on Private Forest Lands in Ohio.
In Ohio, the Silvicultural Nonpoint Source Pollution Plan was developed in the early 1990s to address pollution from logging and other silvicultural activities. 110 logging sites on private lands were sampled. These sites were identified through contact with the public, industry, and private consulting foresters. Sites were evaluated for overall use and effectiveness of BMPs. 80% of logging sites were rated with a passing score; 62% of those rated good to excellent. A direct correlation was found between the use and effectiveness of BMPs and forrester assistance on harvests. When loggers trained in BMPs were used on harvest activities, compliance ratings were significantly higher than on those where non-trained loggers were used. "Failing" ratings were the result of lack of proper application of BMPs on skid trails and SMZs.

Prud'homme B.A., and John G. Greis AQUA-4: Best Management Practices in the South. Region 4, US Environmental Protection Agency and Southern Region, USDA Forest Service. Prud'homme et al. reviewed scientific literature from 13 states including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Twelve states measured BMP implementation but did so with varying techniques. An effort to develop consistency between states has been underway. They found that BMP implementation was greatest on public land, forest industry land, corporate non-industrial land, and private non-industrial land. Findings indicate that professional forestry assistance increase the proper implementation of the BMPs.

General guidelines from early research are presented. They cite several examples of BMP effectiveness monitoring and the related outcomes. BMP effectiveness was also measured on the Ouachita National Forest in Arkansas and Oklahoma. Clinginpeel (1989) and Neihardt (1992) both researchers concluded that the forestry BMPs effectively maintained water quality within state standards. Sediments were measured in both studies as well as turbidity, nutrients, and

several metals. Clinginpeel (1993) conducted another study from 89-92 and found that BMPs tested effectively protecting water quality and fisheries.

Rashin, E., J. Bell, and C. Clishe. June 1993. Effectiveness of Forest Road and Timber Harvest Best Management Practices with Respect to Sediment-Related Water Quality Impacts, Interim Report No. 1. Ecology Report No. 94-27. TFW-WQ8-93-001. (Abstract available on-line at http://www.ecy.wa.gov/biblio/9427.html) & Rashin, E., C. Clishe, and A. Loch. January 1994. Effectiveness of Forest Road and Timber Harvest Best Management Practices with Respect to Sediment-Related Water Quality Impacts, Interim Report No. 2. Ecology Publication No. 94-67. TFW-WQ8-94-001. (Abstract available on-line at http://www.ecy.wa.gov/biblio/9467.html) & Rashin, E. May 1999. Effectiveness of Forest Road and Timber Harvest Best Management Practices with Respect to Sediment-Related Water Quality Impacts (Abstract available on-line at http://www.ecy.wa.gov/biblio/99317.html).
Washington's Department of Ecology studied the effectiveness of forest road and timber harvest BMPs to assess whether state sediment-related water quality standards could be achieved during the first 1-3 years following BMP implementation. 90 examples of BMPs were implemented, including road construction practices, road maintenance practices, and timber harvesting practices. Several BMPs were found to be ineffective, however, many were effective, including streamside buffers, road drainage BMPs, and fillslope construction.

Rashin, E., and C. Graber July 1992. Effectiveness of Washington's Forest Practice Riparian Management Zone Regulations for Protection of Stream Temperature. TFW-WQ6-92-001. Ecology Publication No. 92-64. Prepared for Timber/Fish/Wildlife Cooperative Monitoring, Evaluation, and Research Committee, Water Quality Steering Committee (Abstract available at http://www.ecy.wa.gov/biblio/9264.html)
Washington's Department of Ecology studied the effectiveness of BMPs at achieving water quality standards for temperature in areas affected by timber harvesting. BMPs were considered effective at 5 of the 13 sites studied. (At two of the sites, maximum allowable temperature was exceeded but determined to be caused by factors other than timber harvesting; three of the sites met temperature criteria.) BMP effectiveness was influenced by site elevation, post-harvest shade levels, groundwater flux within the reach, and stream morphology.

Stringer, J.W., and T.R. Queary. Kentucky's Timber Harvesting BMP Implementation Study: Preliminary Results. Forestry FORFS 97-4. Abstract available at http://www.uky.edu/Agriculture/Forestry/FS97-41.HTM
A study was conducted by the Kentucky Division of Water to determine the effectiveness of BMPs in reducing nonpoint source pollution from timber harvesting activities. Of the sites sampled, BMPs were needed and installed in 46%. Of those, over 60% experienced reduced nonpoint source runoff due to BMPs, 21% partially reduced runoff, and 17% saw no reduction due to improper implementation. (Note these were 28%, 10%, and 8% of the total sites sampled, respectively.)

Tennessee Department of Agriculture, Division of Forestry. 1993. Guide to Forestry Best Management Practices. Available on-line at: http://www.state.tn.us/agriculture/forestry/bmpmanual.html
Forestry BMPs are designed to be economical and easily applicable to all forestry operations. The BMP guide for Tennessee can be used as a tool to facilitate each aspect of BMP installation

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for the user from forest road design, timber harvesting and site preparation, construction and maintenance, streamside management, and wetland control. Some specific BMPs for Forestry include steering clear of stream channels, steep slopes, unstable slopes, unnecessary stream crossings and wet areas during the planning design and location phase. BMPs also recommend avoiding disruption of stable road surfaces through road construction during wet periods. BMP implementation and effectiveness rating systems are also discussed. Sample ratings scales used by various states including Indiana, Montana, and South Carolina are also included.

Texas Forest Service. January 2000. Texas Forestry Best Management Practices. http://txforest-service.tamu.edu/forest_management/best_management_practices/bmp_handbook.html
Texas presents the reader with a guide to read the manual followed by some general guidelines for planning and development of BMPs. Guidelines documented in this manual relate to planning, road construction and maintenance, harvesting operations, locations of landings, skid trails, drainage, treatment of wastes and chemicals, and the protection of stream courses.

United States Department of Agriculture, Forest Service Pacific Southwest Region. September 2000. Water Quality Management for National Forest System Lands in California Best Management Practices. http://www.r5.fs.fed.us/water_resources/waterquality/water-best-mgmt.pdf
The U.S. Forest Service conducted a study of BMP effectiveness from 21 states in 1994. Again, proper implementation was the key for BMP success. Monitoring was also found to be quite important as it improves the understanding of the interaction of soils and topography with BMP implementation. QA/QC procedures should be used in the monitoring process

USDA Forest Service, Soil and Water Conservation Handbook, Alaska Region Amendment. FSH 2509.22, R-10 Amendment 2509.22-96-1 Also known as "Best Management Practices". http://www.fs.fed.us/r10/ref_reports/bmp/
They detail the steps of an effective BMP process, which might be helpful to others. There are 6 steps including BMP design, BMP implementation and application, BMP monitoring, evaluation, reporting, and feedback. Step 1 "BMP design" advises the identification of beneficial uses, identify goals and objectives, physical conditions, BMP alternatives, feasibility, risk, final BMP design. Step 2, "BMP Implementation and application" recommends documenting requirements for BMP, ensure the process is implemented and the BMPs are designed according to any necessary site-specific conditions. Step 3 "BMP Monitoring" is important for three phases - implementation, effectiveness, and validation. Implementation is concerned with the application and models being designed as planned, effectiveness is concerned with protecting beneficial uses, meeting goals and objectives, and finally the validation phase which involves deeming a site as adequate if the water quality standards are met. Steps 4 and 5, "Evaluate and Report" evaluate and summarize BMP monitoring data in an annual monitoring report type of format. And finally Step 6, "Feedback" is a critical step as this can improve future management decisions. The last step in this process is refinement. If goals are not being met, then an adjustment or modifications to the current BMP need to be implemented. Information for mining and minerals management in the forestry practice is also discussed.

U.S. EPA Office of Water. August 2000. DRAFT National Management Measures to Control Nonpoint Source Pollution from Forestry. Prepared by Tetra-Tech. Available online at http://www.epa.gov/owow/nps/forestrymgmt/

U.S. EPA developed management measures, explanation of the management measures purpose, documentation for when the measures are appropriate, basis for selection of the measure, information on the effectiveness of each measure, and cost information for the measure. The effectiveness of the measure is dependent upon the pollutant of concern, types of BMPs being considered, and the site-specific conditions in which the BMPs will be implemented. In addition, national and some state costs where noted are provided for a number of measures.

U.S. EPA Office of Water. Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures – Forestry
http://www.epa.gov/owowwtr1/NPS/forestry/index.html_
This manual is intended to assist the user (e.g., state or local environmental professionals) in assessing the implementation and success of forestry BMPs in controlling NPS pollution. The authors provide methods for sample site selection, sample size estimation, sampling, and result evaluation and presentation. This guidance highlights the necessary statistical approaches to adequately collect, analyze, and monitor BMPs.

Vowell, J.L. March 2002. Florida Division of Forestry. Results of Florida's 2001 Silviculture BMP Compliance Survey. Available on-line at: http://www.fl-dof.com/Conservation/hydrology/2001_survey/index.html &
Vowell, J.L. Using Best Management Practice Monitoring as a Measure of Forest Resource Sustainability. http://www.srs.fs.fed.us/sustain/conf/abs/vowell.htm
Vowell (2001) evaluated the effectiveness of Florida's BMPs during intensive forestry operations in major eco-regions of Florida. All applicable BMPs were adhered to for treatments of clear-cut harvesting, intensive mechanical site preparation, machine planting, and chemical applications. Florida silvicultural BMPs were effective in protecting water quality, aquatic habitat, and stream ecosystem health. Division of forestry (DOF) also conducted a silviculture BMP compliance survey where 72% of all sites surveyed scored 100% compliance, with eleven sites scoring below 80%. The range of scores was between 42 to 100% (Florida Division of Forestry).

Wisconsin Forestry BMPs for Water Quality: The 1997 BMP Monitoring Report. Wisconsin Department of Natural Resources, Bureau of Forestry. PUB-FR-145-99.
Wisconsin DNR also reported a study during 1995-1997 that correctly applied BMPs 85% of the time. No adverse impacts were seen from BMP performance 99% of the time. Based upon some of the results, it was recommended that more emphasis be placed upon riparian management zones and forest roads. In addition, non-industrial private landowner education should be a priority as this group owns 57% of Wisconsin forestland.

Agricultural BMPs

Brown, L, K. Boone, S. Nokes, and A. Ward. Agricultural Best Management Practices, AEX-464-91. Ohio State University Extension Fact Sheet. The Ohio State University.
This fact sheet provides useful information fro the selection of agricultural BMPs to reduce water quality issues. They assessed the various practices for the associated effectiveness in reducing sediment, soluble nutrients, absorbed nutrients, soluble pesticides, absorbed pesticides, and

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oxygen demanding substances. Each BMP is assigned a ranking of A, (medium to high) B (low to medium), or C (no control to low) effectiveness.

Hatfield, J. L. Crop production BMP effectiveness and prediction of water quality improvements, USDA_ARS, National Soil Tilth Laboratory http://www.wef.org/pdffiles/TMDL/Hatfield.pdf
They assess the role of BMPs on soil water, since NPS pollution includes nutrients, pesticides, sediment, and pathogens and each vary in behavior in the soil profile. They document that there is strong evidence that BMPs may work in certain areas, however the system as a whole is lacking in an understanding of the variation that exists within and among agricultural watersheds. They document various BMPs and the pollutants they are targeted at controlling. They also present an example of the variation in BMPs. They find that water quality improvements are possible through BMPs that account for site-specific conditions at each watershed. They indicated that series of studies should be conducted across landscapes to better evaluate BMP effectives in reducing pollution.

Miller, M.A. Turtle Creek Priority Watershed: Bioassessment Final Report Wisconsin Department of Natural Resources Bureau of Water Resources Management
http://www.dnr.state.wi.us/org/water/wm/nps/tpubs/tutbio/tutbio.htm
While BMPs reduced pollution and soil loss in some areas of the Turtle Creek watershed in southeastern Wisconsin, land owners' poor land and livestock management practices and resistance to adopting BMPs reduced the overall effectiveness of BMPs in the watershed. Implementation of BMPs began in the spring of 1985 and were completed in December 1992 in the Turtle Creek watershed. The primary goal was to protect or improve the water quality of Turtle Creek and its tributaries by reducing sediment inputs that were causing excessive turbidity and siltation of streambeds. A secondary goal of the project was to slow the siltation and eutrophication rates of Lake Comus and Lake Delavan.

The effectiveness of BMPs in reducing nonpoint source pollution or improving riparian habitat was evident on a site-specific basis; however watershed-wide improvements were not discernible. The program was evaluated based on several factors including the proportion of BMPs implemented compared with the estimated effort needed to meet project goals; a barnyard inventory, aquatic insect samples, and weekly water quality samples. BMP implementation resulted in an estimated reduction in soil loss of 49,115 tons per year in Walworth County and 162,308 tons per year in Rock County. Low participation levels hindered the Turtle Creek Project in meeting its goals, and poor land and livestock management practices by a limited number of landowners continue to severely impact water quality in the Turtle Creek Watershed, that may mask benefits accrued by the BMPs implemented elsewhere in the watershed. Significant reductions in pollution have occurred, although it is difficult to detect BMP-associated changes. Long-term changes in attitudes of landowners is necessary for continued success. The main point from this study is that BMPs are not as effective when they are not consistently implemented by landowners.

Park, S.W., S. Mostaghimi, R.A. Cooke, and P.W. McClellan. BMP Impacts on Watershed Runoff Sediment, and Nutrient Yields. Water Resources Bulletin. 1994.

A procedure was developed for evaluating BMP effectiveness on a watershed scale. This process was then applied to the Nomini Creek watershed, located in Westmoreland County, Virginia. The effects of BMPs on the hydrology, sediment, and nutrient yields were evaluated.

U.S. EPA Office of Water. August 2000. DRAFT National Management Measures to Control Nonpoint Source Pollution from Agriculture. Prepared by NCSU Water Quality Group, as a sub-contractor to Tetra-Tech. Available online at http://www.epa.gov/owow/nps/agmm/index.html
U.S. EPA developed management measures, which are synonymous with BMPs. The purpose of each management measure (MM), appropriateness of the measure, MM selection process, information on the effectiveness of the measure, and cost information for the measure is provided. The effectiveness of each measure is dependent upon the pollutant of concern, types of BMPs being considered, and the site-specific conditions in which the BMPs will be implemented. In addition, national and some state costs where noted are provided for a number of measures. Several case studies are also included.

U.S. EPA Office of Water. Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures – Agriculture. http://www.epa.gov/owow/nps/agfinal.html
This manual is intended to assist the u*ser (e.g., state or local environmental professionals) in assessing the implementation and success of forestry BMPS in controlling NPS pollution. The authors provide methods for sample site selection, sample size estimation, sampling, and result evaluation and presentation. This guidance highlights the necessary statistical approaches to adequately collect, analyze, monitor BMPs. This guidance is meant to be a cost effective method for farms to assess BMP implementation.*

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Table B-1. Urban BMP Selection Factors.

BMP Selection Factors	Reference (Guidance Manuals that use these factors)
LAND USE	
Rural, residential, roads and highways, commercial development, hotspot land uses, ultra-EPA sites	S, K
Ultra-EPA setting (high density areas where space is a premium: space limits, economic considerations)	C, K, S, P
Hotspot (high concentrations of hydrocarbons, trace metals, etc.)	F, C, K, S, M, N, P
Land Use	F, K, N, P, S
Restricted Land Use	G
Land use in the drainage area	N
Future development and Land use in watershed	S
PHYSICAL FEASIBILITY/SITE CONSTRAINTS	
Soil suitability (type, condition, percolation rate, permeability)	A, L, K, M, H, P, E, F, D, C, B, G, S
Groundwater levels (ht of ground water above table)	A, J, L, S
Depth to bedrock	J, H, G
Depth to water table	J, M, H, P, S, G, B, C, K
Land availability/requirement	N, A, K, C, H, S
Size of drainage area	L, K, M, P, H, F, C, S
Slopes	J, H, P, S, E, F, G, B, C, K, M, N
Hydraulic Head	P, F, C, D, K, M, N
Proximity to water sources (e.g., drinking supply wells and intakes) and foundations	J, L, H, G, B,
Watershed area to be served	J, G, B, D, H
Area Required for BMP	D, F, N
Space Consumption	G
Geology/topography	S
Terrain Factors	M, E
Generated runoff volume in relation to the size of the BMP	L
Runoff volume and flow rate	S
Thermal Enhancement/No Thermal Enhancement	H, G
Watershed Factors	K, J, M, P, H
Sensitive streams, aquifers , lakes, reservoirs, estuary/coastal	P, K, M
Special watershed or stream considerations (e.g., primary trout streams, swimming/shellfish etc.)	P, C, K
Aquatic and terrestrial wildlife habitat values	J, G, K, M

[A] Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001)
[B] US Department of Transportation (1996)
[C] Atlanta Regional Commission (2001)
[D] US Department of Transportation (2000)
[E] City of Knoxville (2001)
[F] New Jersey Department of Agriculture, Dept. Community Affairs, Dept. Environmental Protection, Dept. of Transportation (2000)
[G] Maine Department of Environmental Protection (1995)
[H] Massachusetts Department of Environmental Protection, Coastal Zone Management, and US EPA (1997)
[J] Northern Virginia Planning District Commission and Engineers and Surveyors Institute (1992)
[K] Center for Watershed Protection - Stormwater Design Manual Toolbox
[L] City of Boise. Stormwater Management: A Design Manual
[M] Maryland Department of Environmental Protection (2000)
[N] Statewide Storm Wwater Quality Task Force. Sponsored by the Texas Chapter, American Public Works Association.
[P] CWP (2001)
[S] EPA (1999c)

Table B-1. Urban BMP Selection Factors. (cont.)

BMP Selection Factors	Reference (Guidance Manuals that use these factors)
STORMWATER MANAGEMENT CAPABILITY	
Stormwater management capability (water quality, channel protection, flood control)	C, N, P
Stormwater management suitability/treatment suitability	M, C, F
Recharge Capability	F, N
Available supplemental water to support vegetative BMPs	S
Water Quantity Control	F
Determine which BMPs require supplemental water	N, S
CLIMATE/ REGIONAL CONSIDERATIONS	
Climate	D
Cold climate	S, K, P
Arid/semiarid	K
Low relief	K, C, M
High Relief	C
Karst topography	K, C, F, M, S
Average rainfall, duration intensity	S, E
High rainfall	K
Susceptibility to freezing	S
POLLUTANTS	
Types of pollutants to be removed	A, J, L
Desired pollutant removal efficiency	K, A, C, N
Effective Life	D, F
COMMUNITY AND ENVIRONMENTAL FACTORS	
Community acceptance	P, S, F, H, G, M, P
Aesthetics	J, G, N
Affordability, safety, habitat	S, P, K, F, M, N
Ease of maintenance	F, M, P
Recreational use potential	J, G
COST CONSIDERATIONS	
Project Cost (capital and O&M)	A, C, D, F, M, N
Benefits and costs of the remaining BMP options	N
Cost effectiveness considerations	E, H, N

[A] Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001)
[B] US Department of Transportation (1996)
[C] Atlanta Regional Commission (2001)
[D] US Department of Transportation (2000)
[E] City of Knoxville (2001)
[F] New Jersey Department of Agriculture, Dept. Community Affairs, Dept. Environmental Protection, Dept. of Transportation (2000)
[G] Maine Department of Environmental Protection (1995)
[H] Massachusetts Department of Environmental Protection, Coastal Zone Management, and US EPA (1997)
[J] Northern Virginia Planning District Commission and Engineers and Surveyors Institute (1992)
[K] Center for Watershed Protection - Stormwater Design Manual Toolbox
[L] City of Boise. Stormwater Management: A Design Manual
[M] Maryland Department of Environmental Protection (2000)
[N] Statewide Storm Wwater Quality Task Force. Sponsored by the Texas Chapter, American Public Works Association.
[P] CWP (2001)
[S] EPA (1999c)

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Table B-1. Urban BMP Selection Factors. (cont.)

BMP Selection Factors	Reference (Guidance Manuals that use these factors)
MAINTENANCE REQUIREMENTS	
Locational/permitting factors, government regulations	J, M
Implementation considerations	C
Maintenance (e.g., requirements and burden)	J, C, S, D, F, N
Identification of BMP owner	H
Identification of Parties responsible for O&M	H
Identification of Sources of funding for O&M	H
Training	D
Schedule for Maintenance and inspections	H
Routine manageable maintenance tasks	H
Maintenance accessibility	S
Periodic and long-term maintenance/rehabilitation needs	S
TEMPORARY/CONSTRUCTION SELECTION FACTORS	
Location of concentrated flows, storm drains, and streams	E
Existing vegetation and ground cover	E
Type of construction activity	E
Construction schedules, construction sequencing, and phasing of construction	E
Size of construction project and area to be graded	E
Location of construction activity	E
Floodplain floodway and buffer requirements	E
Type of construction materials and potential pollutants	E

[A] Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001)

[B] US Department of Transportation (1996)

[C] Atlanta Regional Commission (2001)

[D] US Department of Transportation (2000)

[E] City of Knoxville (2001)

[F] New Jersey Department of Agriculture, Dept. Community Affairs, Dept. Environmental Protection, Dept. of Transportation (2000)

[G] Maine Department of Environmental Protection (1995)

[H] Massachusetts Department of Environmental Protection, Coastal Zone Management, and US EPA (1997)

[J] Northern Virginia Planning District Commission and Engineers and Surveyors Institute (1992)

[K] Center for Watershed Protection - Stormwater Design Manual Toolbox

[L] City of Boise. Stormwater Management: A Design Manual

[M] Maryland Department of Environmental Protection (2000)

[N] Statewide Storm Wwater Quality Task Force. Sponsored by the Texas Chapter, American Public Works Association.

[P] CWP (2001)

[S] EPA (1999c)

Table B-2. Urban BMP Site Constraints and Applicability.

Structural Control Category	Structural Control	Site Constraints & Applicability							
		Drainage Area (acres)	Area Typically Served (ha)	Space Req'd (% of tributary imp. area	Area Req'd (% of total drainage area)	Site Slope (%)	Site Requirements	Longitudinal Slope of BMP (%)	Minimum Head Required (m)
Stormwater Pond	Dry Retention Online Pond								
	Dry Offline Retention or Detention Pond								
	Extended Detention Pond	Moderate to Large[R]					Deep Soils[R]	*[B]	
	Extended Detention Basin	10+							
	Wet Detention Pond								
	Wet Detention Pond with Filtration								
	Underground Detention	<5[N]		0[N]		<15[N]			1.5-2.4[N]
	Detention Pond		0.8min[D];4min[H]		10-20[D]				0.9-1.8[D]
	Wet Pond	25min**[C,K,M,P]; Moderate to Large[R]		2-3[C]		15max[C,K,P];None[M]	Deep Soils[R]	*[B]	1.8-2.4[C,K,M,P]
	Wet ED Pond	25min**[C,K,P];>15[N]		2-3[C];<3[N]		15max[C,K,P];<15[N]			1.8-2.4[C,K,M,P];1.2-3[N]
	Pocket Pond	5max[K,M,P]				15max[K,P];None[M]			1.2[K,M,P]
	Multiple Ponds	25min**[C,K,M,P]		2-3[C]		15max[C,K,P];None[M]			1.8-2.4[C,K,M,P]
	Dry Detention Pond	Small or large sites[N]		2-3[N]		<15[N]			1.2-3[N]
	Dry Extended Detention Pond	>10[N]		<3[N]		<15[N]			1.8-2.4[N]
	Micropool ED	10min[C,K,M,P]				15max[K,P];None[M]			1.8-2.4[K,M,P]

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability								Management	
		Depth to Water Table (m)	Proximity to Wells (m)	Proximity to Buildings (m)	Buffer Requirements (m)	Normal Depth Range (m)	Climate a Significant Factor?	In Situ Soils	Land Area Needed	Capital Cost	Maintenance Cost
Stormwater Pond	Dry Retention Online Pond	0.6[A]							High[A]	High[A];0.5-1$/cf[S]	Medium[A]
	Dry Offline Retention or Detention Pond	0.6[A]							High[A]	High[A];0.5-1$/cf[S]	Medium[A]
	Extended Detention Pond	*[B]	*[B]	*[B]	*[B]	1.2[B]					
	Extended Detention Basin									Low to moderate[I]	Low[I]
	Wet Detention Pond	NA[A]						Deep Soils[R]	High[A]	High[A] 0.5-1$/cf[S]	Low[A]
	Wet Detention Pond with Filtration	NA[A]							High[A]	High[A]	High[A]
	Underground Detention										
	Detention Pond						No[D]	Independent[D]		Moderate[D];0.5-1$/cf[S]	Low[D]
	Wet Pond	*[B];0.6[C,K,P];1.2[M]	*[B]	*[B]	>7.6[B]	1-2.5[B]				Low[C]	Low[C]
	Wet ED Pond	0.6[C,K,P]								Low[C]	Low[C]
	Pocket Pond	Below WT[K,M,P]									
	Multiple Ponds	0.6[C,P];1.2[M]								Low[C]	Low[C]
	Dry Detention Pond	0.3[A]							High[A]	High[A];0.5-1$/cfS	Medium[A]
	Dry Extended Detention Pond							Deep Soils[R]			
	Micropool ED	0.6[J,P];1.2[M]									

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Management			Community and Environmental Factors			
		Effective Life (years)	Maintenance	Training[1]	Aesthetics	Habitat	Safety	Community Acceptance
Stormwater Pond	Dry Retention Online Pond							
	Dry Offline Retention or Detention Pond							
	Extended Detention Pond	High[R]						
	Extended Detention Basin	20+[I]						
	Wet Detention Pond							
	Wet Detention Pond with Filtration							
	Underground Detention				Moderate[N]	Worst[N]	Best[N]	
	Detention Pond	20-50[D]	Annual inspection[D]	Low[D]				
	Wet Pond	High[R]	Easy[M];Low[R]			Best[M]		High[M]
	Wet ED Pond	High[R]	Easy[M]		Best[N]	Best[N,M]	Worst[N]	High[M]
	Pocket Pond		Difficult[M]			Worst[M]		Medium[M]
	Multiple Ponds		Easy[M]			Best[M]		High[M]
	Dry Detention Pond				Moderate[N]	Worst[N]	Best[N]	
	Dry Extended Detention Pond	High[R]	Relatively high burdens[R]		Worst[N]	Moderate[N]	Best[N]	
	Micropool ED		Medium[M]			Moderate[M]		Medium[M]

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability							
		Drainage Area (acres)	Area Typically Served (ha)	Space Req'd (% of tributary imp. area	Area Req'd (% of total drainage area)	Site Slope (%)	Site Requirements	Longitudinal Slope of BMP (%)	Minimum Head Required (m)
Stormwater Pond	Quantity Control Pond								
	Stormwater Pond								
Chemical Treatment	Alum System								
	Alum Treatment		20-80[D]		<1[D]				0[D]
Wetland System	Wetlands		0.4min[D]		10[D]				0.3-2.4[D]
	Shallow Wetland	25min[C,M,P]		3-5[C]		8max[C,P]			0.9-1.5[C,M,P]
	Shallow Marsh	25min[K]				8max[K]			0.9-1.5[K,P]
	Pond/Wetland	25min[C,K,M,P]		3-5[C]		8max[C,K,P];None[M]			1.8-2.4[C];0.9-1.5[K,M,P]
	Pocket/Marsh	5max[K]				8max[K]			0.6-0.9[K]
	Pocket/Wetland	5min[C,M; 5max[P]		3-5[C]		8max[C,P];None[M]			0.6-0.9[C,M,P]
	ED Wetland	25min[C,K,M,N;>25[N]		3-5[C,N]		8max[C,K,P];None[M];<10[N]			0.9-1.5[C,K,M,N,P]
	Stormwater Wetland								
	Constructed Wetland	7min[K];Moderate to Large[R]					Poorly drained soils, space maybe limiting[R]	0[B]	
Wetland System	Gravel-Based Wetland	5max[N];<5[N]		3-5[N]		<15[N]			0.9[N]
	Submerged Gravel Wetland								
Bioretention	Bioretention Area	5max[C,K,M,P];<5[N]	0.4-20[D]	5[C,N]	4-10[D]	6max[C,K,P];None[M];<6[N]			1.5[C,K,M,N,P];0.6-1.2[D]

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability								Management	
		Depth to Water Table (m)	Proximity to Wells (m)	Proximity to Buildings (m)	Buffer Requirements (m)	Normal Depth Range (m)	Climate a Significant Factor?	In Situ Soils	Land Area Needed	Capital Cost	Maintenance Cost
Stormwater Pond	Quantity Control Pond										
	Stormwater Pond										
Chemical Treatment	Alum System	NA[A]								High[A]	Very High[A]
	Alum Treatment						No[D]	Independent[D]		Moderate[D]	Moderate[D]
Wetland System	Wetlands	0[A]					Yes[D]		High[A]	High[A];Moderate to High[D]	High[A];Moderate[D]
	Shallow Wetland	0.6[C];1.2[M]								Moderate[C]	Moderate[C]
	Shallow Marsh	0.6[K,P]									
	Pond/Wetland	0.6[C,P];1.2M								Moderate[C]	Moderate[C]
	Pocket/Marsh	Below WT[K]									
	Pocket/Wetland	Below WT[C,M,P]								Moderate[C]	High[C]
	ED Wetland	0.6[C,K,P];1.2[M]								Moderate[C]	Moderate[C]
	Stormwater Wetland										
	Constructed Wetland	*[B]	*[B]	*[B]	*[B]	0.15-0.30[B]				0.6-1.25$/cf[S]	Low to Moderate[I]
Wetland System	Gravel-Based Wetland										
	Submerged Gravel Wetland										
Bioretention	Bioretention Area	0.6[C,K,M,P]					Yes[D]	Independent[D]		Moderate[C,D];5.3$/cf[S]	Moderate[C];Low[D]

Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Management			Community and Environmental Factors			
		Effective Life (years)	Maintenance	Training[1]	Aesthetics	Habitat	Safety	Community Acceptance
Stormwater Pond	Quantity Control Pond							
	Stormwater Pond							
Chemical Treatment	Alum System							
	Alum Treatment	5-20[D]	Periodic chemical resupply[D]	Low[D]				
Wetland System	Wetlands	20-50[D]	Annual inspection/plant replacement[D]	Low[D]				
	Shallow Wetland		Medium[M]			Best[M]		High[M]
	Shallow Marsh							
	Pond/Wetland		Difficult[M]			Best[M]		High[M]
	Pocket/Marsh							
	Pocket/Wetland		Medium[M]			Moderate[M]		Low[M]
	ED Wetland		Medium[M]		Best[N]	Best[N,M]	Best[N]	Medium[M]
	Stormwater Wetland							
	Constructed Wetland	20+[I];High[R]	Annual harvesting of vegetation[R]					
Wetland System	Gravel-Based Wetland				Moderate[N]	Worst[N]	Best[N]	
	Submerged Gravel Wetland							
Bioretention	Bioretention Area	5-20, equipped with an underdrain system[D]	MediumM; Mowing/plant replacementD;Bi-annual or as neededS	Low[D]	Best[N]	Moderate[N]; Worst[M]	Best[N]	Medium[M]

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability							
		Drainage Area (acres)	Area Typically Served (ha)	Space Req'd (% of tributary imp. area	Area Req'd (% of total drainage area)	Site Slope (%)	Site Requirements	Longitudinal Slope of BMP (%)	Minimum Head Required (m)
Filter	Surface Sand Filter	10max[C,K,M,P];<10[N];Wide applicable[R]	0.8-2[D]	2-3[C,N]	2-3[D]	6max[C,K,P];None[M];<6[N]	Widely applicable[R]	0[B]	1.5[C,K,M,N,P];1.5-2.4[D]
	Perimeter Sand Filter	2max[C,K,M,P];<2[N];Wide Applicable[R]		2-3[C];3[N]		6max[C,K,P];None[M];<6[N]	Widely applicable[R]		0.6-0.9[C,K,M,P];0.9[N]
	Austin Sand Filter	Wide Applicable[R]					Widely applicable[R]		
Filter	D.C. Underground Sand Filter	Wide Applicable[R]					Widely applicable[R]		
	Underground Sand Filter	2max[K,M,P];<2[N]	0.8-2[D]	0[N]	2-3[D]	6max[K,P];None[M];<6[N]	Widely applicable[R]		0.3-2.4[D];1.5-2.1[K,M,P];1.8[N]
	Delaware Sand Filter	Wide Applicable[R]					Widely applicable[R]		
	Texas Vertical Sand Filter	Wide Applicable[R]					Widely applicable[R]		
	Pocket Sand Filter	5max[K,M];Wide Applicable[R]				6max[K];None[M]	Widely applicable[R]		0.6-1.5[K,M]
	Organic Sand Filter (Organic Media Filters)	5max[K,M,P];Wide Applicable[R]				6max[K,P];None[M]	Widely applicable[R]		0.6-1.2[K,M,P]
	Peat Sand Filter	Wide Applicable[R]					Widely applicable[R]		
	Washington Compost Filter System	Wide Applicable[R]					Widely applicable[R]		
	Alexandria Stone Reservoir Trench	Wide Applicable[R]					Widely applicable[R]		
	Organic Filter								
Baffle Box	Baffle Box								
Hydrodynamic Device	Gravity (oil-grit) separator		0.4-0.8[D];0-2[H]		<1[D]				0.9-1.8D

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability								Management	
		Depth to Water Table (m)	Proximity to Wells (m)	Proximity to Buildings (m)	Buffer Requirements (m)	Normal Depth Range (m)	Climate a Significant Factor?	In Situ Soils	Land Area Needed	Capital Cost	Maintenance Cost
Filter	Surface Sand Filter	*[B];0.6[C,K,M,P]	*[B]	*[B]	*[B]	0.46-1.81 (Filter medium)[B]	Yes[D]	Independent[D]		High[C,H];Moderate[D];3.00-6.00$/cf[S]	High[C,I];Moderate[D]
	Perimeter Sand Filter	0.6[C,K,M,P]								High[C]	High[C]
	Austin Sand Filter	0.6[A]							Medium[A]		High[A]
Filter	D.C. Underground Sand Filter								Medium[A]		High[A]
	Underground Sand Filter	0.6[K,M,P]					No[D]	Independent[D]		High[D]	High[D]
	Delaware Sand Filter	0.6[A]							Medium[A]		High[A]
	Texas Vertical Sand Filter	2.1[A]							Medium[A]		High[A]
	Pocket Sand Filter	0.6[M]									
	Organic Sand Filter (Organic Media Filters)	0.6[K,M,P]						Independent[D]			
	Peat Sand Filter								Medium[A]		High[A]
	Washington Compost Filter System	1.2[A]							200 sf/cfs[A]		High[A]
	Alexandria Stone Reservoir Trench								High[A]		High[A]
	Organic Filter										
Baffle Box	Baffle Box								Low[A]	Medium[A]	Medium[A]
Hydrodynamic Device	Gravity (oil-grit) separator						No[D]	Independent[D]		ModerateD	High[D]

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Management			Community and Environmental Factors			
		Effective Life (years)	Maintenance	Training[1]	Aesthetics	Habitat	Safety	Community Acceptance
Filter	Surface Sand Filter	5-20[D];20+[I];Low to moderate[R]	Biannual media cleanout[D];Frequent[I];Medium[M];Moderate[R];Annual or as needed[S]	Low[D]	Worst[N]	Worst[N,M]	Moderate[N]	Medium[D]
	Perimeter Sand Filter	Low to moderate[R]	Difficult[M];Moderate[R]		Moderate[N]	Worst[N,P]	Best[N]	High[M]
	Austin Sand Filter	Low to moderate[R]	Moderate[R]					
Filter	D.C. Underground Sand Filter	Low to moderate[R]	Moderate[R]					
	Underground Sand Filter	5-20[D];Low to moderate[R]	Annual media removal[D];Difficult[M];Moderate[R]	Moderate[D]	Moderate[N]	Worst[N,M]	Best[N]	High[M]
	Delaware Sand Filter	Low to moderate[R]	Moderate[R]					
	Texas Vertical Sand Filter	Low to moderate[R]	Moderate[R]					
	Pocket Sand Filter	Low to moderate[R]	Medium[M];Moderate[R]			Worst[M]		Medium[M]
	Organic Sand Filter (Organic Media Filters)	Low to moderate[R]	Medium[M];Moderate[R]			Worst[M]		High[M]
	Peat Sand Filter	Low to moderate[R]	Moderate[R]					
	Washington Compost Filter System	Low to moderate[R]	Moderate[R]					
	Alexandria Stone Reservoir Trench	Low to moderate[R]	Moderate[R]					
	Organic Filter	Low to moderate[R]	Moderate[R]					
Baffle Box	Baffle Box							
Hydrodynamic Device	Gravity (oil-grit) separator	50-100[D]	Frequent cleanout[D]	Moderate[D]				

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability							
		Drainage Area (acres)	Area Typically Served (ha)	Space Req'd (% of tributary imp. area	Area Req'd (% of total drainage area)	Site Slope (%)	Site Requirements	Longitudinal Slope of BMP (%)	Minimum Head Required (m)
Open Channel	Grassed Swale	Small[R]				15max[R]	Low-density areas with <15% slopes[R]	2-6[B]	
	Grass Swale, Low slopes with check dams		0-12.1[H]			<5[H]			
	Vegetated Swale		0.8-1.6[D]		10-20[D]				0.6-1.8[D]
	Dry Swale	5max[K,M,P];<5[N]		10-20[N]		4max[K,M];<2[N];6max[P]			0.9-1.5[K,M,N,P]
	Wet Swale	5max[K,M,P]				4max[K,M,P]			0.3[K,M,P]
	Enhanced Dry Swale	5max[C]		10-20[C]		4max[C]			0.9-1.5[C]
	Grass Channel	5max[K];<5[N]		7[N]		4[K];<2[N]			0.3[N,K]
Open Channel	Enhanced Wet Swale	5max[C]		10-20[C]		4max[C]			0.3[C]
Buffer Strip	Buffer Strip								
Biofilter	Filter Strip (Vegetated and others)	<2[N];Small[R]	<2[D,H]	50-100[N]	25[D]	<20[H];<6[N]	Low-density areas with low slopes[R]	<5[B]	Negligible[D];<0.3[N]
	Vegetated Rock Filter		0.8-2[D]		3-5[D]				0.6-1.2[D]
Biofilter	StormTreat System		0.8-2[D]		2[D]				1.2-1.8[D]
Porous Surface	Porous Pavement	Small[R]	0.8-1.6[D];0-2[H]			<5[H]	Deep permeable soils, low slopes, and restricted traffic[R]	<5[B]	NA[D]
Porous Surface	Porous Concrete	Small[R]					Deep permeable soils, low slopes, and restricted traffic[R]		
	Modular Porous Paver Systems								

Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability								Management	
		Depth to Water Table (m)	Proximity to Wells (m)	Proximity to Buildings (m)	Buffer Requirements (m)	Normal Depth Range (m)	Climate a Significant Factor?	In Situ Soils	Land Area Needed	Capital Cost	Maintenance Cost
Open Channel	Grassed Swale	0.3-0.6[B]	*[B]	>3[B]	*[B]	0.075-0.10[B]				0.5$/cfS	
	Grass Swale, Low slopes with check dams	0.3-0.6[H]		>0.3[H]		0.15-0.6[H]					
	Vegetated Swale	Low[A]					Yes[D]	Dependent[D]	Medium[A]	Medium[A];Low[D]	Low[A,D]
	Dry Swale	0.6[K,M,P]									
	Wet Swale	Below WT[K,M,P]									
	Enhanced Dry Swale	0.6[C]								Moderate[C]	Low[C]
	Grass Channel	0.6[K]									
Open Channel	Enhanced Wet Swale	Below WT[C]								High[C]	Low[C]
Buffer Strip	Buffer Strip	0.3-0.6[A]							Low[A]	Medium[A]	Low[A]
Biofilter	Filter Strip (Vegetated and others)	<1[B];0.3-0.6[H]	*[B]	*[B]	*[B]	<0.0125[B]	Yes[D]	Dependent[D]		Low[D];0.00-1.30[S]	Low[D]
	Vegetated Rock Filter						Yes[D]	Independent[D]		High[D]	High[D]
Biofilter	StormTreat System						Yes[D]	Independent[D]		Moderate[D]	Moderate[D]
Porous Surface	Porous Pavement	>1.2[B];0.6-1.2[H]	>30[B]	>30 (up gradient); >3 (down gradient)[B]	>6[B,H]	*[B];0.3-1.2[H]	Yes[D]	Dependent[D]		Low[D]	Moderate[D]
Porous Surface	Porous Concrete										
	Modular Porous Paver Systems										

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Management			Community and Environmental Factors			
		Effective Life (years)	Maintenance	Training[1]	Aesthetics	Habitat	Safety	Community Acceptance
Open Channel	Grassed Swale	High if maintained[R]	Low[R]; Annual or as needed[S]					
	Grass Swale, Low slopes with check dams							
	Vegetated Swale	5-20[D]	Mowing[D]	Low[D]				
	Dry Swale		Easy[M]		Moderate[N]	Moderate[N]; Worst[M]	Best[N]	High[M]
	Wet Swale		Easy[M]			Worst[M]		High[M]
	Enhanced Dry Swale							
	Grass Channel				Moderate[N]	Worst[N]	Best[N]	
Open Channel	Enhanced Wet Swale							
Buffer Strip	Buffer Strip							
Biofilter	Filter Strip (Vegetated and others)	20-50[D]; Low if poorly maintained[R]	Mowing[D];Low[R];Annual or as needed[R]	Low[D]	Moderate[N]	Moderate[N]	Best[N]	
	Vegetated Rock Filter	5-20[D]	Regular inspection and cleanout[D]	Low[D]				
Biofilter	StormTreat System	5-20[D]	Regular cleanout of accumulated sediment/ floatables[D]	Moderate[D]				
Porous Surface	Porous Pavement	15-20[D];Low[R]	Semi-annual vacuum cleaning[D];High[R]	Low[D]				
Porous Surface	Porous Concrete	High[R]	Moderate to High[R]					
	Modular Porous Paver Systems							

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability							
		Drainage Area (acres)	Area Typically Served (ha)	Space Req'd (% of tributary imp. area	Area Req'd (% of total drainage area)	Site Slope (%)	Site Requirements	Longitudinal Slope of BMP (%)	Minimum Head Required (m)
Infiltration	Infiltration Trench	5max[C,K,M,P]; Moderate[R]	0.8-1.6[D];0-4[H]	2-3[C]	2-4[D]	6max[C,H,K];15max[M,P]	Deep permeable soils[R]	<20[B]	0.3[C,M,K,P];0.9-2.4[D]
	Dry Well		0-2[H]	0[N]		<20[H];<6[N];15max[P]			0.3[N,P]
	Infiltration Pond								
Infiltration	Infiltration Basin	10max[M];Moderate to Large[R]	0.8-8[D];2-20.2[H]		2-4[D]	<6[H];15max[M]	Deep permeable soils[R]	<5[B]	0.9-1.2[D];0.9[M]
Inlet	Water Quality Inlet	<2[I];Small[R]	0-2[H]				Impervious catchments[R]	*[B]	
	Inlet Devices								
Catch Basin	Catch Basin Insert		<0.4[D]		None[D]				0.3-0.6[D]
Manufactured Systems	Manufactured Systems		0.4-4[D]		None[D]				1.2[D]
Detention Tank	Detention Tank		0.4-0.8[D]		0.5-1[D]				1.5-2.4[D]
Nonstructural	Streetsweeping								

[1] If confined space entry is required, then training is placed at a moderate level; otherwise, training requirements are low.

[A] Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001)

[B] US Department of Transportation (1996)

[C] Atlanta Regional Commission (2001)

[D] US Department of Transportation (2000)

[E] Winer (2000)

[F] City of Knoxville (2001)

[G] New Jersey Department of Agriculture, Dept. Community Affairs, Dept. Environmental Protection, Dept. of Transportation (2000)

[H] Maine Department of Environmental Protection (1995)

[I] Massachusetts Department of Environmental Protection, Coastal Zone Management, and US EPA (1997)

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Site Constraints & Applicability								Management	
		Depth to Water Table (m)	Proximity to Wells (m)	Proximity to Buildings (m)	Buffer Requirements (m)	Normal Depth Range (m)	Climate a Significant Factor?	In Situ Soils	Land Area Needed	Capital Cost	Maintenance Cost
Infiltration	Infiltration Trench	0.6-1.2[A];0.3-1.3[B];1.2[C,K,M];0.6-1.2[H];0.9[P]	>30[B,H]	>30 (up gradient); >3 (down gradient)[B]; >3[H]	>=6;>6[H]	1-2.5[B];0.6-1.5[H]	Yes[D]	Dependent[D]	Low[A]	Medium[A];High[C,I]; Moderate to High[D];4$/cf[S]	High[A,C,I];Moderate[D]
	Dry Well	0.3-0.6[H];0.9[P]	>30[H]	>3[H]	>6[H]	0.6-1.2[H]					
	Infiltration Pond										
Infiltration	Infiltration Basin	0.6-3B;0.6-1.2[H]	>30[B,H]	>30 (up-gradient); >3 (down-gradient)[B]; >3[H]	>=7.5[B];>6[H]	*[B];0.6-1.5[H]	Yes[D]	Dependent[D]		Moderate[D,I];1.3$/cf[S]	Moderate[D];High[I]
Inlet	Water Quality Inlet	*[B]	*[B]	*[B]	*[B]	1-2.4[B]				Moderate to High[I]	Moderate to High[I]
	Inlet Devices	NA[A]							None[A]	Low[A]	High[A]
Catch Basin	Catch Basin Insert						None[D]	Independent[D]		Low[D]	Moderate to High[D]
Manufactured Systems	Manufactured Systems						None[D]	Independent[D]		Moderate[D]	Moderate[D]
Detention Tank	Detention Tank						No[D]	Independent[D]		Moderate to High[D]	High[D]
Nonstructural	Streetsweeping						No[D]	Independent[D]		Moderate[D]	

[J] Oregon Department of Land Conservation and Development (2000)

[K] Center for Watershed Protection - A Stormwater Design Manual Builder

[L] Schueler (1997)

[M] Maryland Department of Environmental Protection (2000)

[N] Statewide Storm Water Quality Task Force. Sponsored by the Texas Chapter, American Public Works Association

[P] CWP (2001)

[R] EPA (1993a)
[S] EPA (1999c)

* Insufficient data / na = not applicable or available

**Smaller area acceptable with adequate water balance and anti-clogging device

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Table B-2. Urban BMP Site Constraints and Applicability. (cont.)

Structural Control Category	Structural Control	Management			Community and Environmental Factors			
		Effective Life (years)	Maintenance	Training[1]	Aesthetics	Habitat	Safety	Community Acceptance
Infiltration	Infiltration Trench	10-15[D]; High rates of failure within first five years[I]	Difficult[M];Sediment/debris removal[D];Annual or as needed[S]	Moderate[D]		Worst[M]		High[M]
	Dry Well				Moderate[N]	Worst[N]	Best[N]	
	Infiltration Pond							
Infiltration	Infiltration Basin	5-10 before deep tilling required[D]; High rates of failure within first five years[I];Low[R]	Medium[M]; Mowing[D]; High[R]; Annual or as needed[S]	Low[D]		Worst[M]		Low[M]
Inlet	Water Quality Inlet	20+[I];High[R]	Cleaned twice a year[R]					
	Inlet Devices							
Catch Basin	Catch Basin Insert	10-20[D]	Frequent cleanout[D]	Low[D]				
Manufactured Systems	Manufactured Systems	50-100[D]	Periodic cleanout[D]	Low[D]				
Detention Tank	Detention Tank	50-100[D]	Frequent cleanout[D]	Moderate[D]				
Nonstructural	Streetsweeping	4-8[D]		Low[D]				

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Table B-3. Cost and Relative Land Consumption by BMPs.

BMP Type	Typical Cost ($/BMP)[d]	Application[e]	Relative Land Consumption of BMP (% of Impervious Area)	Annual Maintenance Cost[f]	
				(% of Construction Costs)	References
Retention Basin	$100,000 (a)	50-Acre Residential Site (Impervious Cover 35%)	2 - 3% (b)		
Retention Basins and Constructed Wetlands				3 - 6%	Wiegand et al, 1986; Schueler, 1987; SWRPC, 1991
Detention Basins				<1% (c)	Livington et al, 1997; Brown and Schueler, 1997b
(Constructed) Wetlands	$125,000 (a)	50-Acre Residential Site (Impervious Cover 35%)	3 - 5% (b)	2% (c)	Livington et al, 1997; Brown and Schueler, 1997b
Infiltration Trench	$45,000 (a)	5-Acre Commercial Site (Impervious Cover 65%)	2 - 3% (b)	5 - 20%	Schueler, 1987; SWRPC, 1991
Infiltration Basin	$15,000 (a)	5-Acre Commercial Site (Impervious Cover 65%)	2 - 3% (b)	1 - 3% (c)	Livingston et al, 1997; SWRPC, 1991
				5 - 10% (c)	Wiegand et al, 1986; Schueler, 1987; SWRPC, 1991
Sand Filters	$35,000-70,000 (a)	5-Acre Commercial Site (Impervious Cover 65%)	0 - 3% (b)	11 - 13% (c)	Livingston et al, 1997; Brown and Schueler, 1997b
(Grass) Swales	$3,500 (a)	5-Acre Residential Site (Impervious Cover 35%)	10 - 20% (b)	5 - 7%	SWRPC, 1991
Bioretention	$60,000 (a)	5-Acre Commercial Site (Impervious Cover 65%)	5% (b)	5 - 7%	(Assumes the same as Swales)
Filter Strips	$0- 9,000 (a)*	5-Acre Residential Site (Impervious Cover 35%)	100% (b)	$320/ acre (maintained)	SWRPC, 1991
Porous Pavement			0% (b)		

Source: EPA 1999c

* Range is presented to account for design variations

(a) Adapted from Brown and Schueler (1997b) and SWRPC (1991)

d - Base costs do not include land costs

f - O&M estimated as a percent of base costs

(b) Claytor and Schueler, 1996. Represents the amount of land needed as a percent of the impervious area that drains to the practice to achieve effective treatment.

(c) Livingston et al (1997) reported maintenance costs from the maintenance budgets of several cities, and percentages were derived from costs in other studies

e - Application over land consumed per treatment volume depends on how much BMP treatment is underground & varies considerably.

NOTE: Regional cost Adjustment Factors must be taken into account, using EPA's rainfall zones. For example, rainfall region 1 has a factor of 1.12. Thus, all studies in the Northeastern United States are divided by 1.12 in order to adjust for this bias. [Modified by EPA from APWA (1992)]

Each Rainfall zone and the associated adjustment factor follows: 1[1.12], 2[0.90], 3[0.67], 4[0.92], 5[0.67], 6[1.24], 7[1.04], 8[1.04], and 9[0.76]

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs.

		Removal Efficiency (%)									
Structural Control Category	Structural Control	Sediments	Soluble Phosphorus	Total Petroleum Hydrocarbon	NO_3	Nitrate Nitrogen	Ammonia Nitrogen	Total Nitrogen	Total Phosphorus	Heavy metals	Cu
Stormwater Pond	Dry Pond										
	Dry Retention Online Pond							60-98[A]	60-98[A]	60-98[A]	
	Dry Offline Retention or Detention Pond							60[A]	85[A]	65-85[A]	
	Extended Detention Pond	68-90[B]						28-40[B]	42-50[B]	42-90[B]	
	Extended Detention Basin					0[G]			30[G]	40[G]	
	Dry Extended Detention Pond							31[E,L]	20[E,L]		29[E]
	Wet Detention Pond							40[A]	50[A]	25-70[A]	
	Wet Detention Pond with Filtration							25[A]	65[A]	60-85[A]	
	Detention Pond		0[L]		24-60[D];9[L]			28-50[D];5[L]	20-94[D];19[L]	24-89[D]	
	Pocket Pond							>30[P]		>60[P]	
	Micropool ED							>30[P]		>60[P]	
	Wet Pond	90[B]	62[E,L]		36[E,L]	30[G]	25[G]	48[B];30[C];32[E,L];10-90[J];>30[P]	65[B];50[C,G];49[E,L];20-90[J]	1[B];>60[G,P]	58[E]
	Wet Pocket (drainage area <10 acres)		65[E]		67[E]			28[E]	78[E]		55[E]
	Wet Regular (drainage area <=300 and >=10 acres)		70[E]		62[E]			32[E]	49[E]		58[E]
	Wet Regional (drainage area >300 acres)		42[E]		23[E]			37[E]	48[E]		55[E]
	Wet ED Pond		67[E,L]		63[E,L]			30[C];35[E,L];>30[P]	50[C];55[E,L]	>60[P]	44[E]
	Multiple Ponds		69[E]		87[E]			30[C];30[P]	50[C];76[E]	>60[P]	
	Dry Detention Pond							15[A];15-45[S]	25[A]15-45[S]	35-70[A];15-45[S]	
	Quantity Control Pond			0[E]	9[E]			5[E]	19[E]		10[E]

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)							
Structural Control Category	Structural Control	Pb	Zn	Organic carbon (BOD+COD+ TOC)	COD/BOD	Oil & Grease	Bacteria	Suspended Solids	Floating Trash Removal
Stormwater Pond	Dry Pond			25[E]				10[H]	
	Dry Retention Online Pond							60-98[A]	High[A]
	Dry Offline Retention or Detention Pond							90[A]	High[A]
	Extended Detention Pond				42-50/I[B]	I[B]	I[B]		
	Extended Detention Basin							70[G];55[H]	
	Dry Extended Detention Pond		29[E]					61[E,L]	
	Wet Detention Pond							85[A]	High[A]
	Wet Detention Pond with Filtration							85[A]	High[A]
	Detention Pond							46-98[D];7[L]	
	Pocket Pond						>70[P]		
	Micropool ED						35-70[P]	61[M]	
	Wet Pond		65[E]	43[E]	30/I[B]	I[B]	70[C,G];>70[P]	I[B];80[C,G];50-90[J];79[E,L];77[M]	
	Wet Pocket (drainage area <10 acres)		65[E]					87[E]	
	Wet Regular (drainage area <=300 and >=10 acres)		66[E]					80[E]	
	Wet Regional (drainage area >300 acres)		43[E]					70[E]	
	Wet ED Pond		69[E]				70[C];>70[P]	80[C,E,L];65-90[H];60[M]	
	Multiple Ponds						70[C];91[E];>70[P]	80[C];72[M]	
	Dry Detention Pond						<30[S]	70[A];30-65[S]	High[A]
	Quantity Control Pond		5[E]					3[E]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)									
Structural Control Category	Structural Control	Sediments	Soluble Phosphorus	Total Petroleum Hydrocarbon	NO_3	Nitrate Nitrogen	Ammonia Nitrogen	Total Nitrogen	Total Phosphorus	Heavy metals	Cu
Stormwater Pond	Stormwater Pond							30[C]	50[C]	50[C]	
	Dry detention basin, first flush held for 6 to 12 hours							20-40[F]	20-40[F]	40-60[F]	
	Dry detention basin, 1" runoff volume held for 24 hours							20-40[F]	40-60[F]	60-80[F]	
	Dry detention basin with shallow marsh and forebay, 1" runoff volume held for 24 hours							40-60[F]	60-80[F]	60-80[F]	
	Wet detention basin, permanent pool=0.5" per impervious acre							20-40[F]	40-60[F]	20-40[F]	
	Wet detention basin, permanent pool=2.5xmean storm runoff							20-40[F]	40-60[F]	60-80[F]	
	Wet detention basin, permanent pool=4.0xmean storm runoff							40-60[F]	60-80[F]	60-80[F]	
Chemical Treatment	Alum System							50[A]	90[A]	80-90[A]	
	Alum Treatment							60[C];78[D]	80[C];89[D]	75[C]	
Wetland System	Wetlands			85[E]				*[A];20[D]	*[A];25[D];40[G]	High[A];35-65[D];60[G]	
	Shallow Marsh		29[E,L]		73[E,L]			26[E,L]	43[E,L]		33[E]
	Shallow Wetland							30[C];>30[P]	40[C]	30-60[P]	
	Pond/Wetland		43[E,L]		40[E,L]			30[C];19[E,L];>30[P]	40[C];56[E,L]	30-60[P]	58[E]
	Pocket/Wetland		66[E]		67[E]			30[C];44[E];>30[P]	40[C];57[E]	30-60[P]	25[E]
	Wetland Regular (drainage area <=300 and >=10 acres)		37[E]		45[E]			15[E]	37[E]		60[E]

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)							
Structural Control Category	Structural Control	Pb	Zn	Organic carbon (BOD+COD+ TOC)	COD/BOD	Oil & Grease	Bacteria	Suspended Solids	Floating Trash Removal
Stormwater Pond	Stormwater Pond						70[C]	80[C]	
	Dry detention basin, first flush held for 6 to 12 hours				NA/40-60[F]			60-80[F]	
	Dry detention basin, 1" runoff volume held for 24 hours				NA/60-80[F]			80-100[F]	
	Dry detention basin with shallow marsh and forebay, 1" runoff volume held for 24 hours				NA/60-80[F]			80-100[F]	
	Wet detention basin, permanent pool=0.5" per impervious acre				NA/20-40[F]			60-80[F]	
	Wet detention basin, permanent pool=2.5xmean storm runoff				NA/60-80[F]			60-80[F]	
	Wet detention basin, permanent pool=4.0xmean storm runoff				NA/60-80[F]			80-100[F]	
Chemical Treatment	Alum System							90[A]	0[A]
	Alum Treatment						90[C]	90[C]	
Wetland System	Wetlands			18[E]			78[E];50[G]	High[A];65[D]	High[A]
	Shallow Marsh		42[E]					83[E,L]	
	Shallow Wetland						70[C];>70[P]	80[C];84[M]	
	Pond/Wetland		56[E]				70[C];71[E];>70[P]	80[C];71[L];72[M]	
	Pocket/Wetland		52[E]				70[C];>70[P]	57[E]80[C];76[M]	
	Wetland Regular (drainage area <=300 and >=10 acres)		36[E]					61[E]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)									
Structural Control Category	Structural Control	Sediments	Soluble Phosphorus	Total Petroleum Hydrocarbon	NO_3	Nitrate Nitrogen	Ammonia Nitrogen	Total Nitrogen	Total Phosphorus	Heavy metals	Cu
Wetland System	Wetland Regional (drainage area >300 acres)		35[E]		68[E]			35[E]	35[E]		57[E]
	Extended Detention Wetland		32[E,L]		35[E,L]			56[E,L]	39[E,L]		
	Shallow ED Wetland							30[C];>30[P]	40[C];32[L]	30-60[P]	
	Stormwater Wetland					0[G]	30[G]	30[C]	40[C,G]	50[C,G]	
	Constructed Wetland	V[B]						V[B];40-60[J];<30[S]	V[B];40-80[J];15-45[S]	V[B];40-80[J];50-80[S]	
	Submerged Gravel Wetland				81[E]			20[C];19[E]	50[C];64[E]	50[C]	21[E]
Bioretention	Bioretention Area			75[D]	16[E]		50[G]	50[C,D];49[E];>30[P]	60[C,G];50[D];65[E]	80[C,G];75-80[D];>60[P]	97[E]
Filter	Surface Sand Filter	70-90[B]	3[L]		0-23[D]			30-50[B];25[C];27-71[D];32[E];38[L];>30[P];<30[S]	50-70[B];50[G,C];27-80[D];59[E,L];15-45[S]	50-90[B];50[C];33-91[D];40[G];>60[P];50-80[S]	49[E]
	Vertical Sand Filter		21[E]					5[E]	45[E]		32[E]
	Perimeter Sand Filter		68[E]				70[G]	25[C];47[E];>30[P]	50[C];41[E];60[G]	50[G];>60[P]	25[E]
	Austin Sand Filter							31-47[A]	50-65[A]	20-84[A]	
	D.C. Underground Sand Filter										
	Underground Sand Filter							25[C];30-50[D];>30[P]	50[C];43-70[D]	50[C];22-91[D];>60[P]	
	Delaware Sand Filter							47[A]	41[A]	45.2[A]	
	Texas Vertical Sand Filter										
Filter	Organic Filter		30[E]					41[E];>30[P]	61[E]	>60[P]	66[E]
	Peat Sand Filter										
	Washington Compost Filter System							na	41[A]	75.8[A]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs (cont.)

		Removal Efficiency (%)							
Structural Control Category	**Structural Control**	**Pb**	**Zn**	**Organic carbon (BOD+COD+ TOC)**	**COD/BOD**	**Oil & Grease**	**Bacteria**	**Suspended Solids**	**Floating Trash Removal**
Wetland System	Wetland Regional (drainage area >300 acres)		52[E]					80[E]	
	Extended Detention Wetland							69[E,L];62[M]	
	Shallow ED Wetland						70[C];>70[P]	80[C;]	
	Stormwater Wetland						70[C]	80[C,G]	
	Constructed Wetland				V/V[B];	V[B]	V[B];Low[J];<30[S]	75[H];50-90[J];50-80[S]	
	Submerged Gravel Wetland		55[E]				70[C]	80[C];83[E]	
Bioretention	Bioretention Area		95[E]				****[C];75-98[D];>70[P]	80[C,G];75[D]	
Filter	Surface Sand Filter		80[E]		50-80/50-80[B]	I[B]	I[B];40[C,G];>70[P];<30[S]	80[C,G];75-92[D];87[E,L];83[M];60-95(80Avg)[R];50-80[S]	
	Vertical Sand Filter		56[E]					58[E]	
	Perimeter Sand Filter		69[E]				40[C];35-70[P]	80[C,G];79[E,M]	
	Austin Sand Filter							70-87[A]	na[A]
	D.C. Underground Sand Filter								na[A]
	Underground Sand Filter						40[C];35-70[P]	80[C];70-90[D]	
	Delaware Sand Filter							57[A]	na[A]
	Texas Vertical Sand Filter								na[A]
Filter	Organic Filter		89[E]				35-70[P]	88[E];81[M]	
	Peat Sand Filter								na[A]
	Washington Compost Filter System							95[A]	na[A]

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)									
Structural Control Category	Structural Control	Sediments	Soluble Phosphorus	Total Petroleum Hydrocarbon	NO_3	Nitrate Nitrogen	Ammonia Nitrogen	Total Nitrogen	Total Phosphorus	Heavy metals	Cu
	Alexandria Stone Reservoir Trench							47.2[A]	63-72[A]	**	
	Organic Filter							40[C]	60[C]	75[C]	
Baffle Box	Baffle Box							0	30[A]	unknown[A]	
Hydrodynamic Device	Gravity (oil-grit) separator		40[E]		47[E]			5[C];<10[D]	5[C];<10[D]	<10[D]	
Open channel	Grassed Swale	70[B]						25[B];0-40(10Avg)[R];15-45[S]	30[B];0-100(20Avg)[R];15-45[S]	50-90[B];15-45[S]	
	Grass Swale, Moderate slopes with no check dams							0-20[F]	0-20[F]	0-20[F]	
	Grass Swale, Low slopes with check dams							20-40[F]	20-40[F]	0-20[F]	
	Vegetated Swale							0-25[A];0-50[D]	29-45[A];20-85[D]	35[A];0-90[D]	
	Dry Swale		70[E]	75[J]	90[E];10-30[J]			92[E];>30[P]	83[E];20-40[J]	50[J];>60[P]	70[E]
	Enhanced Dry Swale							50[C]	50[C]	40[C]	
	Wet Swale			75[J]	31[E];10-30[J]			40[E];15-30[P]	28[E];20-40[J]	50[J];>60[P]	11[E]
	Enhanced Wet Swale							40[C]	25[C]	20[C]	
	Enhanced Swale					50[G]	50[G]		30[G]	40[G]	
	Ditch				24[E]						14[E]
	Grass Channel		40[E]					20[C]	25[C];29[E]	30[C]	42[E]
Buffer Strip	Buffer Strip							20-60[A]	20-60[A]	20-80[A]	
Biofilter	Filter Strip (vegetated and others)	70[B];27-70[D]				10[G]	20[G]	20-40[B,D];20[C];20-60[J];0-70(40Avg)[R];50-80[S]	40[B];20[C,G];20-40[D];30-80[J];0-95(40Avg)[R];50-80[S]	40-80[B];40[C,G];2-80[D];40-50[J];30-65[S]	
	Filter Strip, 20' wide turf strip							0-20[F]	0-20[F]	20-40[F]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)							
Structural Control Category	Structural Control	Pb	Zn	Organic carbon (BOD+COD+ TOC)	COD/BOD	Oil & Grease	Bacteria	Suspended Solids	Floating Trash Removal
	Alexandria Stone (Resevoir Trench)							79-84[A]	na[A]
	Organic Filter						50[C]	80[C]	
Baffle Box	Baffle Box							20-90[A]	low[A]
Hydrodynamic Device	Gravity (oil-grit) separator		17[E]			50-80[D]	****[C]	40[C];20-40[D];10[H]	
Open channel	Grassed Swale	3-100(70Avg)[R]	50-60(60Avg)[R]		25/I[B];25/NA[R]	75[B]	I[B];<30[S]	0-100(60Avg)[R];30-65[S]	
	Grass Swale, Moderate slopes with no check dams				NA/0-20[E]			0-20[F]	
	Grass Swale, Low slopes with check dams				NA/20-40[E]			20-40[F];35-50[H]	
	Vegetated Swale					75[D]		60-83[A];30-90[D];25-40[H]	Low[A]
	Dry Swale		86[E]			75[J]	35-70[P]	93[E,M];20-40[J]	
	Enhanced Dry Swale						****[C]	80[C]	
	Wet Swale		33[E]			75[J]	<35[P]	20-40[J];74[M,E]	
	Enhanced Wet Swale						****[C]	80[C]	
	Enhanced Swale							60[G]	
	Ditch		0[E]	18[E]			5[E]	31[E]	
	Grass Channel		45[E]					50[C];68[E]	
Buffer Strip	Buffer Strip							20-80[A]	Low[A]
Biofilter	Filter Strip (vegetated and others)	20-90(45Avg)[R]	30-90(60Avg)[R]		0-20/I[B]0-80(40Avg)[R]	****[B]	****B;<30[S]	50[C];68[E];60[G];40-90[J];20-80(65Avg)[R];50-80[S]	
	Filter Strip, 20' wide turf strip				NA/0-20[E]			20-40[F]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)									
Structural Control Category	Structural Control	Sediments	Soluble Phosphorus	Total Petroleum Hydrocarbon	NO_3	Nitrate Nitrogen	Ammonia Nitrogen	Total Nitrogen	Total Phosphorus	Heavy metals	Cu
	Filter Strip, 100' wide turf strip							40-60[F]	40-60[F]	80-100[F]	
	Vegetated Rock Filter							75[D]	82[D]	21-80[D]	
	StormTreat System								89[D]	65-98[D]	
Porous Surface	Porous Pavement	82-95[B]	10[E]					80-85[B,D];83[E];80-85(85Avg)[R];65-100[S]	65[B];60-71[D];65[E];65[R];30-65[S]	****[B];33-99[D];65-100[S]	
	Pervious Paving								50[G]	60[G]	
	Porous Concrete	b						65[C];65-100(90Avg)[R]	50[C];65-100(90Avg)[R]	60[C]	
	Modular Porous Paver Systems	b						80[C]	80[C]	90[C]	
Infiltration	Infiltration Trench		100[E]	75[D]	82[E]			45-70[A];60[C];45-70[D];42[E];50-100[J];>30[P];(55Avg)[R];50-80[S]	50-75[A];60[C];50-75[D];100[E];50-100[J];40-100(60Avg)[R];15-45[S]	75-99[A];75-99[D];>60[P];50-80[S]	
	Infiltration Structure w/ Filter Strip					25[G]	70[G]		60[G]	60[G]	
	Dry Well							>30[P];50-80[S]	80[G];15-45[S]	>60[P];50-80[S]	
	Infiltration Pond	75-99[B]						45-70[B]	50-75[B]	75-99[B]	
Infiltration	Infiltration Basin	75-99[B]		75[D]				45-70[B,D];45-100(60Avg)[R];50-80[S]	50-70[B,D];45-100(65Avg)[R];50-80[S]	50-90[B,D];50-80[S]	
	Infiltration Basin, Exfiltrates 0.5" per impervious acre							40-60[F]	40-60[F]	40-60[F]	
	Infiltration Basin, Exfiltrates 1" per impervious acre							40-60[F]	40-60[F]	80-100[F]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)							
Structural Control Category	**Structural Control**	**Pb**	**Zn**	**Organic carbon (BOD+COD+ TOC)**	**COD/BOD**	**Oil & Grease**	**Bacteria**	**Suspended Solids**	**Floating Trash Removal**
	Filter Strip, 100' wide turf strip				NA/60-80[E]			80-100[F]	
	Vegetated Rock Filter						78[D]	95[D]	
	StormTreat System						83[D]	95[D]	
Porous Surface	Porous Pavement	100[R]	99[E];100[R]		****[B];80[R]	****[B]	****[B]	82-95[D];95[E];60-90[J];80-95(90Avg)[R];65-100[S]	
	Pervious Paving							60[G]	
	Porous Concrete	65-100(90Avg)[R]	65-100(90 Avg)[R]		65-100(90Avg)[R]			65-100(90Avg)[R]	
	Modular Porous Paver Systems								
Infiltration	Infiltration Trench	45-100(65Avg)[R]	45-100(65 Avg)[R]		45-100(65Avg)/NA[R]		75-98[B,D];>70[P];65-100[S]	75-99[A];80[C];75-99[D,H];50-100[J];89[M]45-100(75Avg)[R];50-80[S]	High[A]
	Infiltration Structure w/ Filter Strip						60[G]	70[G]	
	Dry Well						>70[P];65-100[S]	80[G];75-99[H]50-80[S]	
	Infiltration Pond				I/70-90[B]	****[B]	75-98[B]		
Infiltration	Infiltration Basin	45-100(65Avg)[R]	45-100(65 Avg)[R]		45-100(65Avg)/NA[R]		75-98[B,D];65-100[S]	75-99[D,H];45-100(75Avg)[R];50-80[S]	
	Infiltration Basin, Exfiltrates 0.5" per impervious acre				NA/60-80[E]			60-80[F]	
	Infiltration Basin, Exfiltrates 1" per impervious acre				NA/60-80[E]			80-100[F]	

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)									
Structural Control Category	**Structural Control**	**Sediments**	**Soluble Phosphorus**	**Total Petroleum Hydrocarbon**	**NO_3**	**Nitrate Nitrogen**	**Ammonia Nitrogen**	**Total Nitrogen**	**Total Phosphorus**	**Heavy metals**	**Cu**
Inlet	Water Quality Inlet	20-40[B]						<10[B];5-55(20Avg)[R]	<10[B];5-10(5Avg)[R]	<10[B];10-25(15Avg)[R]	
	Inlet Devices							***[A]	***	Low[A]	
Catch Basin	Catch Basin Insert										
Manufactured Systems	Manufactured Systems										
Detention Tank	Detention Tank										
Riparian Forest Buffer						80[G]	40[G]		50[G]	60[G]	
Nonstructural	Streetsweeping							42-77[D]	40-74[D]	35-85[D]	

NOTES: V or *= highly variable I or ****= insufficient data
na or **=not applicable or not available
*** Traps particulate phosphorus and nitrogen in the form of leaves and grass - not effective for dissolved nutrients
b Due to potential for clogging, porous concrete and modular block paver systems should not be used for the removal of sediment or other coarse particulate pollutants

SOURCES:
[A] Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices (2001)
[B] US Department of Transportation (1996)
[C] Atlanta Regional Commission (2001)
[D] US Department of Transportation (2000)
[E] Winer (2000)
[F] City of Knoxville (2001) [Note: "trace metals" are placed under "heavy metals" in this table]

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Table B-4. Pollutant Removal Efficiencies of Specific Urban BMPs. (cont.)

		Removal Efficiency (%)							
Structural Control Category	**Structural Control**	**Pb**	**Zn**	**Organic carbon (BOD+COD+ TOC)**	**COD/BOD**	**Oil & Grease**	**Bacteria**	**Suspended Solids**	**Floating Trash Removal**
Inlet	Water Quality Inlet	10-25 (15Avg)[R]	5-10 (5Avg)[R]		<10/10[B];5-10(5Avg)/NA[R]	50-80[B]	****[B]	10[H];0-95(35Avg)[R]	
	Inlet Devices							Low-medium[A]	High[A]
Catch Basin	Catch Basin Insert					up to 90[D]			
Manufactured Systems	Manufactured Systems					up to 96[D]			
Detention Tank	Detention Tank								
Riparian Forest Buffer		20[R]						70[G]	
Nonstructural	Streetsweeping							55-93[D]	

[G] New Jersey Department of Agriculture, Dept. Community Affairs, Dept. Environmental Protection, Dept. of Transportation (2000)
[H] Maine Department of Environmental Protection (1995)
[I] Massachusetts Department of Environmental Protection, Coastal Zone Management, and US EPA (1997)
[K] Center for Watershed Protection - Stormwater Design Manual Toolbox
[L] Schueler (1997)

[M] Maryland Department of Environmental Protection (2000)
[N] Statewide Storm Water Quality Task Force. Sponsored by the Texas Chapter, American Public Works Association
[P] CWP (2001)
[R] EPA (1993a)

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Table B-5. Pollutant Removal Efficiencies by Urban General Best Management Practices.

	Measure	Infiltration Practices*	Retention Basins*	Constructed Wetland Systems**	Storm Water Filtration Systems*	Open Channel Vegetated Systems*
Soluble Phosphorus	N		20	12	2	8
	%		34	23	-31	11
Ortho-Phosphate	N			7		
	%			28		
TP	N	5	44	37	15	18
	%	65	46	46	45	15
Ammonia-Nitrogen	N	3	14	15	4	4
	%	83	23	33	68	3
Nitrate	N	3	27	18	13	13
	%	82	23	46	-13	11
Organic Nitrogen	N		6	7	2	3
	%		23	7	28	39
TN	N	2	24	11	9	10
	%	83	30	24	32	11
SS	N	2	43	26	15	18
	%	89	70	76	81	66
Bacteria	N		10	3	5	5
	%		74	78	37	-25
Organic Carbon	N	1	29	15	11	11
	%	82	35	28	57	23
Cadmium	N		5	6	1	6
	%		47	69	26	49
Chromium	N		5	3	2	5
	%		49	73	54	47
Copper	N		18	10	9	15
	%		55	39	34	41
Lead	N	1	34	17	11	19
	%	98	67	63	71	50
Zinc	N	1	32	16	15	19
	%	99	51	54	69	49

Adapted from: EPA 1999c

* Brown and Schueler, 1997

** Strecker et al (1992); Organic Carbon, Bacteria and Metals from Brown and Schueler, 1997

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Table B-6. Nonpoint Source Pollutants Resulting from Forestry Practices and Applicable BMPs for Nonpoint Source Reduction.

Activity	Access roads, Skid Trails, and Landings	Vegetative Establishment on Silviculturally Disturbed Areas	Streamside Management Zones	Sinkholes	Logging Debris	Proper Planting of Tree Seedlings by machine	Fertilization	Application of Pesticides	Site Preparation for Reforestation	Silviculture in Wetland Areas	Livestock Management	File Lines for Wildfire control	Prescribed Burning
Timber Harvesting	S	S	S, D	S, D	D								
Road, Skid, Trail, and Log Landing Construction & Management	S	S	S	S									
Activity in Streamside Corridors and Around Ponds and Lakes			S, W, D, P	F	D			P			S, A		
Activity Near Sinkholes				S, D, P, F	D		F	P			A		
Revegetation of Disturbed Areas		S					F						
Site Preparation and Forest Regeneration						S	F	P	S				

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Table B-6. Nonpoint Source Pollutants Resulting from Forestry Practices and Applicable BMPs for Nonpoint Source Reduction. (cont.)

Activity	Access Roads, Skid Trails, and Landings	Vegetative Establishment on Silviculturally Disturbed Areas	Streamside Management Zones	Sinkholes	Logging Debris	Proper Planting of Tree Seedlings by Machine	Fertilization	Application of Pesticides	Site Preparation for Reforestation	Silviculture in Wetland Areas	Livestock Management	File Lines for Wildfire Control	Prescribed Burning
Forest Wetland Activity	S	S	S				F	P		S, P, F			
Application of Fertilizers and/or Pesticides			F, P				F	P					
Woodland Grazing											S, A		
Fire Lines		S										S	
Prescribed Burning												S	S

Adapted from: Stringer (Revised 2001)

S = Sediment
D = Debris
W = Water temperature

P = Pesticides (include insecticides, herbicides, fungicides, rodenticides, nematodcides, etc.)
F = Fertilizer
A = Animal waste

Table B-7. Forestry BMP Cost by Region.

BMP	Northeast (a)	Southeast (b)	Midwest (c)	Rocky Mountains (d)	Northwest (e)	Southwest (f)	Alaska (g)
Broad-based dip		$40	$40-90	$50-60	$25-35	$100-130	$30-40
Waterbar		$20 (w/o labor)	$60-75 (on skid trails)	na	$100	$45-60	$25-35
Mulch		$71 (ton)	$20-80 (ton)	na	$1500 (ac) (hydromulch)	$400-500(ac)	$80-90(ton)
Seed	$1,000 (ac) (hydroseed)	$1-6 (lb)	$0.5-10 (lb)	$6 (lb)	$400-450 (ac)	$200-400 (ac)	7-10 (lb)
Riprap		na	$5-10 ($yd^3$)	$21($yd^3$)	$15-30 ($yd^3$)	na	$19-37($yd^3$)
Gravel		$6-10 (ton)		$35,000-40,000 (mile, 14'Wx4"D)	$16-26 ($yd^3$)	$30 ($yd^3$)	$18-22 ($yd^3$)
Culvert		$420	$500-2,000	$19 (ft,18" pipe)	$26 (ft, 24" pipe)	$24 (ft, 18" pipe)	$23 (ft, 18" pipe)
Straw Matting		$56 (roll, 7.5'x120')		na	$2 ($yd^2$)	$1-3 ($yd^2$)	$2.5 ($yd^2$)
Geotextiles		$378 (700 yd^2)	$2-6 (ft)	$8-12 (ft)	$1-2 (ft)		$14 (ft)
Hardwood Mats (pallets)	$120-200	$120-200	$170 (10'x12')	$120-200	$120-200	$120-200	$155 (10'12')
Turn-outs	$40-50	$50-70	$50-70	$50	$50	$40-50	$71
Silt Fence		$24 (24"Hx100'L)	not commonly used	not commonly used	$1.5 ($yd^2$)	$4 (ft)	$2 ($yd^2$)
Dust Control	$1,000 (mile, using calcium chloride)				$1,000-3,000 (mile, annually)	$190 (ton)	
Temporary Bridge		$500-20,000	$500-15,000	$200-25,000	$1,000-2,000 (ft)	na	$1,250-2,500 (ft)
Barge (Alaska)							$1,000 (hr)

Source: EPA (2001i)
(a) Schmid, 2000
(b) Holburg, 2000; Marzac, 2000
(c) Hansit, 2000; Gambles, 2000
(d) Taylor, 2000
(e) Dorn, 2000; Hulet, 2000; Wilbrecht, 2000; Yoder, 2000
(f) Leyba, 2000
(g) Jenson, 2000

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Table B-8. Estimation of Forestry BMP Cost in the Southeast and Midwest.

BMP	Average Cost ($)	Cost Range ($)
Planning/Savings from road design/location	385/mi (a)	
Planning/Savings in maintenance	231/mi (a)	
Streamside Management Area	3,996 (b)	
Road Construction		5,301/mi-42,393/mi (c)
		14,801-42,393 (b)
		229/mi-11,604/mi (d)
Construction Phase (as percent of total cost)	10% (equipment and material) (e)	
	20-25% (Clearing, grubbing, and slash disposal) (e)	
	20-25% (Excavation) (e)	
	10% (Culvert installation) (e)	
	30-40% (Rock surfacing) (e)	
Road Maintenance	2,205 - 3,941 (f)	
Mechanical Site Preparation	140/ac (g)	77-281/ac (g); 75-180/ac (h)
Regeneration	50/ac (g)	48-60/ac (g); 84-355/ac (i)
Revegetation	22,741 (b)	132-239/ac (h)
Prescribed Burning	13/ac (g)	10-19/ac (g)
Pesticide Application	102/ac (g)	56-138/ac (g)
Fertilizer Application	63/ac (g)	43-73/ac(g)

Source: EPA (2001i)

(a) Dissmeyer and Foster, 1987
(b) Lickwar, 1989
(c) Kockenderfer and Wendel, 1980
(d) Swift, 1984
(e) USDB-SCS, cited in Weaver and Hagans, 1994
(f) Dissmeyer and Frandsen, 1988
(g) Dubois et al., 1991
(h) Minnesota Department of Natural Resources, 1991
(i) Illinois Administrative Code, 1990

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Table B-9. Forestry BMP Costs.

Best Management Practice			Total Cost
Site Preparation (a)	Chemical		$67/acre
	Mechanical	Light (includes hand site preparation	$47/acre
		Heavy	$107/acre
	Chemical-Mechanical		$113/acre
Regeneration (a)	Planting	Softwoods (when purchased from State nurseries)	$21/100 seedlings planted
		Hardwoods (when purchased from State nurseries)	$29/100 seedlings planted
		Softwoods (when purchased from private nurseries)	$28/100 seedlings planted
		Hardwoods (when purchased from private nurseries)	$41/100 seedlings planted
		Shrubs	$40/100 seedlings planted
	Seeding (includes both purchase of seed and seeding)	Aerial seeding	$23/acre
		Cyclone seeding	$40/acre
		Hand or hot cap seeding	$53/acre
Revegetation	Tree Planting (trees and labor) (b)	No-cost planting stock	87.5/acre
		Purchased planting stock	212.5/acre
	Direct seeding (including seed collected or purchased plus labor and any machinery use) (b)		$50.0/acre
	Establishment of permanent cover (includes seedbed preparation, fertilizer, chemicals and application, seed, and seeding as prescribed in the plan (a)	Introduced grasses	$80/acre
		Native grasses	$147/acre
Erosion Control (c)	Dry seeding		$124/acre
	Plastic netting placed over seeded area		$5,662/acre

Source: EPA (2001i)
(a) Minnesota Department of Natural Resources, 1991
(b) Illinois Department of Conservation, 1990
(c) Megahan, 1987

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Table B-10. Forestry BMP Effectiveness for Erosion Control.

BMP	Portion of Road Treated	Percent Decrease in Erosion
Tree Planting	Fill slope	50 (a)
Hydromulch, straw mulch, and dry seeding	Fill slope	24 to 58 (b)
Grass and legume seeding	Road cuts	71 (c)
Straw mulch	Fill slope	72 (d)
Straw mulch	Road fills	72 (e)
Wood chip mulch	Road fills	61 (d)
Wood chip mulch	Fill slope	61 (e)
Excelsior mulch	Fill slope	92 (f)
Paper netting	Fill slope	93 (e)
Asphalt-straw mulch	Fill slope	97(e)
Straw mulch, netting, and planted trees	Fill slope	98 (a)
Straw mulch and netting	Fill slope	99 (d)
Gravel surface	Road tread	70 (f)
Asphalt-straw mulch	Fill slope	97 (e)
Straw mulch, netting, and planted trees	Fill slope	98 (a)
Straw mulch and netting	Fill slope	99 (d)
Gravel surface	Road tread	70 (f)
Dust oil	Road tread	85 (f)
Bituminous surfacing	Road treated	99 (f)
Terracing	Cut slope	86 (g)
Straw mulch	Cut slope	32 to 47 (b)
Straw mulch	Cut slope	97 (c)

Source: EPA 1993a - Adapted form Megahan (1987) and (1980)
(a) Megahan, 1974
(b) King, 1984
(c) Dyrness, 1970
(d) Bethlahmy and Kidd, 1966
(e) Ohlander, 1964
(f) Burroughs and King, 1985
(g) Unpublished data, Intermountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Boise, ID

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Table B-11. Agricultural BMP Capital Costs and Practice Life Span.

	Practice		Unit	Range of Capital Costs ($)	Practice Life Span (Years)	Median Annual Costs ($/acre/yr) (f)	Cost/Unit Construction (1997 $) (g)
Erosion Control	Diversions						2.38
		National	foot	1.97 - 5.51 (a, b, i)		52.09	
			ac	49.45 (d, j)			
		North Carolina	ac	120 (e, j)			
		Maryland	foot	2.25 - 3.12 (a, b, j)			
		Michigan	foot	3.75 (b, j)			
		Minnesota	foot	1.43 (b, j)			
		Wisconsin	foot	1.57 (b, j)			
		Virginia	foot	1.33 (b, j)			
	Terraces						
		National	foot	3.32 - 14.79 (b, i)		84.53	
			a.s.[2]	24.15 - 66.77 (c, i)			
			ac	91.43 (d, j)			
		Alabama	a.s.	45 (c, j))			
		Florida	a.s.	40 (c, j)			
		Georgia	a.s.	39 (c, j)			
		Minnesota	foot	2.25 (b, j)			
		North Carolina	a.s.	47 (c, j)			
		South Carolina	a.s.	17 (c, j)			
		Virginia	a.s.	39 (c, j)			
		Wisconsin	foot	10 (b, j)			
	Waterways						
		National	foot	5.88 - 8.87 (a, i)			
			ac	94.22 - 4257 (b, d, e, i)			
		Alabama	a.e.	1088 (c, j)			
		Florida	a.e.	1026 (c, j)			
		Georgia	a.e.	880 (c, j)			
		Maryland	foot	5.11 - 6.00 (a, b, j)			
		Michigan	ac	150 (b, j)			
		North Carolina	ac	72 (e, j)			
			a.e.	1232 (c, j)			
		South Carolina	a.e.	1442 (c, j)			
		Virginia	a.e.	1530 (c, j)			
		Wisconsin	ac	2880 (b, j)			

Table B-11. Agricultural BMP Capital Costs and Practice Life Span. (cont.)

	Practice	Unit	Range of Capital Costs ($)	Practice Life Span (Years)	Median Annual Costs ($/acre/yr) (f)	Cost/Unit Construction (1997 $) (g)
Erosion Control	Irrigation					
	Piping	foot		15 - 20		2.35 - 3.02
	Pumps	unit		15		2350 - 4700
	Sprinkler/Gun	unit		15		1180 - 4300
	Land Leveling			10		
	Canal and Ditch Lining			20		
	Head Ditches			1		
	Water Control Structure			20		
	Trickle Irrigation System			10		
	Surface Irrigation System			15		
	Pit or Regulation Reservoir			20		
	Subsurface Drain			20		
	Toxic Salt Reduction			1		
	Tailwater Recovery System			20		
	Irrigation Water Management			1		
	Underground Outlet			20		
	Contracted service to empty retention pond	1,000 gallon				3.68

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Table B-11. Agricultural BMP Capital Costs and Practice Life Span. (cont.)

	Practice		Unit	Range of Capital Costs ($)	Practice Life Span (Years)	Median Annual Costs ($/acre/yr) (f)	Cost/Unit Construction (1997 $) (g)
	Permanent Vegetative Cover				5	70.70	
		National	ac	69 - 270 (a, b, c, d, i)			
		Alabama	ac	98.78 (c, j)			
Erosion Control		Florida	ac	98.24 (c, j)			
		Georgia	ac	98.52 (c, j)			
		Maryland	ac	120 - 235.48 (a, b, i)			
		Michigan	ac	62.50 (b, j)			
		Minnesota	ac	233 (b, j)			
		North Carolina	ac	73.74 (c, j)			
		South Carolina	ac	121.54 (c, j)			
		Virginia	ac	101.36 - 133 (b, c, j)			
		Wisconsin	ac	70 (b, j)			
	Conservative Tillage		ac	9.50 - 63.35 (b, c, e, i)	1	17.34	
		Alabama	ac	19 (c, j)			
		Florida	ac	39 (c, j)			
		Georgia	ac	33 (c, j)			
		Maryland	ac	18 (b, j)			
		Michigan	ac	6.75 (b, j)			
		Minnesota	ac	13.40 (b, j)			
		North Carolina	ac	10 - 12 (c, e, j)			
		South Carolina	ac	27 (c, j)			
		Virginia	ac	16 - 29.30 (b, c, j)			
		Wisconsin	ac	27.55 (b, j)			
	Nutrient				3	2.40	
	Strip-cropping				5	11.60	
	Sediment Retention Water				10	89.22	
	Grassed Filter				5	7.31	
	Cover Crops				1	10.00	
	Reforestation of Crop and Pasture				10	46.66	
	Grassed				10	1.00/LF/yr	
	Animal Waste				10	3.76/ton/yr	
	Infiltration		acre				2980
	Manure Hauling		mile/4.5-ton load				2.64

Table B-11. Agricultural BMP Capital Costs and Practice Life Span. (cont.)

	Practice		Unit	Range of Capital Costs ($)	Practice Life Span (Years)	Median Annual Costs ($/acre/yr) (f)	Cost/Unit Construction (1997 $) (g)
Erosion Control	Dead Animal Composting Facility		cubic foot				5.96
	Retention Pond		cubic foot				0.37 - 3.08
	Settling Basin		cubic foot				1.29 - 5.08
Grazing Management	Forage improvement/ reestablishment						
		Alabama	acre	84 - 197 (j)			
		Nebraska	acre	45 - 47 (j)			
		Oregon	acre	27 (j)			
	Water Development						
		Alabama	each	1000 - 1500 (j)			
			foot	1.60 (j)			
		California	foot	0.28 (j)			
		Kansas	each	1239 - 1389 (j)			
		Maine	each	831 (j)			
		Nebraska	each	370 (j)			
			foot	1.31 (j)			
		Oregon	each	183 (j)			
			foot	0.20 (j)			
		Utah	each	200 (j)			
	Livestock Exclusion						
		Alabama	mile	2640 - 5808 (j)			
		California	mile	2000 (j)			
		Great Lakes	mile	2100 - 2400 (j)			
		Nebraska	mile	2478 (j)			
		Oregon	mile	2640 (j)			

Notes: **Date Source**: EPA 1993a

(i) 1998 dollars
(j) 1991 dollars

(a) Sanders et al., 1991
(b) Smolen and Humenik, 1989
(c) Russell and Christiansen, 1984
(d) Barbarika, 1987
(e) NCAES, 1982
(f) Camacho, 1991
(g) DPRA, 1992; USDA, 1998

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Table B-12. Agricultural BMP Pollutant Removal Effectiveness.

	Practice	Range of Reduction (%)									
		Pesticides	Average Pesticides	Total Phosphorus	Total Nitrogen	Sediment	Fecal Coliform	BOD5	TSS	Ammonium Nitrogen	COD
Pesticide Management	Ridge Till	-33 - 65	30 (a)								
	No-Till	-98 - 9	51 (a)								
		29 - 100	77 (b)								
		64 - 100	86 (c)								
		85 - 99	92 (d)								
		6 - 41	21 (e)								
		41	– (f)								
		100	– (g)								
	Contour Ridges	53 - 100	79 (h)								
	Incorporation	26 - 75	– (i)								
		24 - 36	30 (j)								
		7 - 79	52 (e)								
	Filter Strips	28 - 31	– (k)								
		4 - 14	– (l)								
		9 - 35	22 (i)								
		40 - 72	56 (m)								
		50 - 74	63 (n)								
		15 - 72	45 (o)								
Sediment Control	Filter Strips			75	70	65					
	Reduced Tillage Systems			45	55	75					
	Diversion Systems			30	10	35					
	Terrace Systems			70	20	85					
	Sediment Basins	75 - 95	87								
	Mini-basins	0 - 95	86								
	Buried Pipe Systems	75 - 95	83								
	Vegetative Filters	35 - 70	50								
	Placing Straw in Furrows	40 - 80	50								

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Table B-12. Agricultural BMP Pollutant Removal Effectiveness. (cont.)

	Practice	Range of Reduction (%)									
		Pesticides	Average Pesticides	Total Phosphorus	Total Nitrogen	Sediment	Fecal Coliform	BOD5	TSS	Ammonium Nitrogen	COD
Animal Feeding Operation Control	Animal Waste Systems			90	80	60	85				
	Diversion Systems			70	45	NA	NA				
	Filter Strips			85	NA	60	55				
	Terrace System			85	55	80	NA				
	Containment Structures			60	65	70	90				
	Confined Animal Feeding Operations			42	42			65	53	48	
	Constructed wetlands (Rush/Bulrush)				85 - 94						
	Constructed wetlands (Cattails/bur-reed)				81 - 94						
	Barnyard feedlot and runoff separation (p, q, r)			21 - 80	35 - 80 (TKN)				49 - 82 (TS)		51 - 85
	Runoff Control System			70-95 (s)					80-90 (s)		
	Grassed Waterways	-10 - 20 (t)									
	Cover Crops	-20 - 20 (t)									
	Crop Rotation	0 - 70 (t)									
	Pest-Resistant Varieties	0 - 60 (t)									
	Alternative Pesticides	0 - 95 (t)									
	Adequate Monitoring	40 - 65 (t)									

Source: EPA 1993a

(a) Baker and Johnson, 1979
(b) Glenn and Angle, 1987
(c) Hall et al., 1991
(d) Hall et al., 1984
(e) Franti et al., 1995
(f) Seta et al., 1993
(g) Isensee and Sadeghi, 1993
(h) Ritter et al., 1974
(i) Hall et al., 1983
(j) Baker and Laflen, 1979
(k) Asmussen et al., 1977
(l) Rhode et al., 1980
(m) Mickelson and Baker, 1993
(n) Misra et al., 1994
(o) Misra, 1994
(p) Edwards et al., 1986
(q) Edwards et al., 1983
(r) Dickey, 1981
(s) DPRA, 1986
(t) North Carolina State University, 1984

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Table B-13. Remining BMP Costs and Effective Life of the BMP.

BMP	Mine	Acres	Design Life (years)	Location	Cost (Date) ($)	Unit Cost ENR 6000 ($/ton)
Alkaline Addition/Lime Addition	PA (10)	28.6		Spoil	1,501 (2/90)	22.40
	PA (1)	26.1		Pit Floor	13,194 (3/90)	21.55
	PA (11)	61.3		Pit Floor	18,390 (9/89)	7.73
	PA (8)	22.68		Blast Holes, & Pit Floor	68,040 (2/93)	NA
	PA (19)	9.8			102,900 (12/97)	10.24
Alkaline Addition/Ash Addition	PA (2)	50			2608000 (8/88)	2.55
Anoxic Limestone Drains (ALDs)	TN (3)		40		NA	NA
	TN (5)		30		90,014 (5/94)	31.42
	TN (2)		10		230,000 (1995)	NA
Ash Fill Placement	PA (18)				3,750,000 (12/96)	0.26
Bactericides	PA (10)	13			27,300 (2/90)	2689[a]
Check Dams						Varies with the material used and width of the channel
Constructed Wetlands	TN (5)	3.45			21,559 (5/94)	23.93[b]
	VA (98)	14.2			284,000 (9/96)	299.84[b]
	TN (2)	4.35			21,000	23.03[b]
Daylighting	PA (6)	5			2,430 (9/89)	3.13[b]
	PA (1)	3.6			10,880 (4/90)	13.91[b]
	PA (7)	15.1			40,770 (10/89)	52.52[b]
	PA (11)	23.7			79,988 (10/93)	91.17[b]
	PA (9)	103.5			459,534 (8/94)	508.33[b]
	PA (3)	90			666,450 (12/88)	875.37[b]
Diversion Ditch	TN (5)				7,925 (5/94)	10.05[c]
Division Wells, Alkalinity Producing						11,000 each[d]
Drains, Pit Floor	PA (8)				132,000 (2/93)	60.31[c]
	PA (7)				12,060 (10/89)	15.545[b]

Table B-13. Remining BMP Costs and Effective Life of the BMP. (cont.)

BMP	Mine	Acres	Design Life (years)	Location	Cost (Date) ($)	Unit Cost ENR 6000 ($/ton)
Regrading of Abandoned Mine Spoil/Highwalls	PA (10)				34,171 (2/90)	43.76[b]
	PA (11)				48,150 (10/93)	54.88[b]
	KY (4)				76,039 (9/94)	83.91[b]
	PA (6)				88,829 (9/89)	114.42[b]
	PA (5)				133,575 (9/94)	147.76[b]
	PA (19)				160,688 (12/97)	164.58[b]
	PA (3)				981,552 (12/88)	1,289.25[b]
	PA (18)				2,600,000 (9/97)	2,661.21[b]
	PA (9)				3,484,350 (8/94)	3,854.37[b]
	WV (4)				3,630,000 (2/90)	4,648.88[b]
	KY (3)				3,950,378 (8/91)	4845.11[b]
	WV (9)				5,448,314 (10/81)	8997.24[b]
	WV (7)				5,848,000 (9/83)	8471.27[b]
	WV (10)				7,139,000 (3/85)	10,318.96[b]
	WV (2)				12,100,000 (1981)	20,537.48[b]
Revegetation	PA (7)	10			4,500 (10/89)	5.80[b]
	PA (10)	13			7,150 (2/90)	9.16[b]
	KY (4)	23.4			9,570 (9/94)	10.56[b]
	PA (6)	17			10,200 (9/89)	13.14[b]
	VA (6)	15			11,250 (10/91)	13.80[b]
	PA (11)	25.2			11,340 (9/89)	14.61[b]
	PA (8)	21			16,200 (12/94)	17.87[b]
Revegetation	PA (19)	30.3			19,695 (12/97)	20.17[b]
	PA (4)	45			36,000 (2/93)	42.60[b]
	KY (1)	195.7			69,264 (7/97)	69.60[b]
	PA (18)	500			500,000 (9/97)	512.73[b]
	KY (3)	1,215.70			497,221 (8/91)	609.84[b]

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Table B-13. Remining BMP Costs and Effective Life of the BMP. (cont.)

BMP	Mine	Acres	Design Life (years)	Location	Cost (Date) ($)	Unit Cost ENR 6000 ($/ton)
Sealing and Rerouting of Mine Water from Abandoned Workings/Highwal l Seal	PA (1)				8,222 (3/90)	10.52[b]
	PA (3)				40,000 (12/88)	52.54[b]
Sealing and Rerouting of Mine Water from Abandoned Workings/Clay Barrier	PA (10)				1,166 (9/96)	1.23[b]
Sealing and Rerounting of Mine Water from Abandoned Workings/Auger Holes	KY (4)				380 (9/94)	0.42[b]
	KY (3)				2,275 (8/91)	2.79[b]
Silt Fences					$6,000/Ft. (1992)	7.22[c]
Special Handling for Toxic and Acid Forming Materials	PA (11)				3,516 (9/89)	4.53[b]
	PA (19)				15,811 (12/97)	16.19[b]
	KY (7)				54,032 (6/88)	71.64[b]
	KY (3)				2,221,560 (12/88)	2,917.99[b]

Source: US EPA (2001a)

[a] Unit Cost ENR 6000 ($/acre)
[b] Cost ENR 6000 ($1,000)
[c] Unit Cost ENR 6000 ($/Ft.)
[d] Total Cost ENR 6000

Table B-14. Water Quality Results of Remining BMPs.

BMP		Chemical Parameters (% of discharges / # discharges)					
		Acidity	Iron	Sulfate	Manganese	Aluminum	Flow
Alkaline Addition > 100 tons/acre	Percent eliminated	36.4/4	45.5/5	45.5/5	16.7/1	0/0	36.4/4
	Percent significantly improved	27.3/3	9.1/1	9.1/1	0/0	0/0	27.3/3
	No difference	27.3/3	36.4/4	36.4/4	50/3	100/1	27.3/3
	Significantly degraded	9.1/1	9.1/1	9.1/1	33.3/2	0/0	9.1/1
Alkaline Addition < 100 tons/acre	Percent eliminated	16.9/11	21.7/13	20.9/14	20.5/8	19.2/5	20.9/14
	Percent significantly improved	16.9/11	15/9	16.4/11	12.8/5	7.7/2	13.4/9
	No difference	66.2/43	61.7/37	53.7/36	56.4/22	73.1/19	61.2/41
	Significantly degraded	0/0	1.7/1	9/6	10.3/4	0/0	4.5/3
On-site Alkaline Redistribution	Percent eliminated	83.3/5	66.7/2	66.7/4	100/4	100/3	66.7/4
	Percent significantly improved	0/0	0/0	16.7/1	0/0	0/0	16.7/1
	No difference	16.7/1	33.3/1	16.7/1	0/0	0/0	16.7/1
	Significantly degraded	0/0	0/0	0/0	0/0	0/0	0/0
Biosolids Application	Percent eliminated	0/0	50/3	33.3/2	60/3	66.7/2	33.3/2
	Percent significantly improved	83.3/5	16.7/1	50/3	0/0	33.3/1	50/3
	No difference	16.7/1	33.3/2	16.7/1	40/2	0/0	16.7/1
	Significantly degraded	0/0	0/0	0/0	0/0	0/0	0/0
Coal Refuse Removal	Percent eliminated	22.2/2	0/0	0/0	0/0	0/0	0/0
	Percent significantly improved	44.4/4	28.6/2	22.2/2	0/0	33.3/2	11.1/1
	No difference	33.3/3	57.1/4	77.8/7	83.3/5	66.7/4	88.9/8
	Significantly degraded	0/0	14.3/1	0/0	16.7/1	0/0	0/0
Construction of Special Water Facilities	Percent eliminated	22.7/5	30.4/7	26.1/6	26.3/5	18.2/2	26.1/6
	Percent significantly improved	27.3/6	17.4/4	17.4/4	21.1/4	9.1/1	21.7/5
	No difference	50/11	47.8/11	52.2/12	42.1/8	72.7/8	43.5/10
	Significantly degraded	0/0	4.3/1	4.3/1	10.5/2	0/0	8.7/2

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Table B-14. Water Quality Results of Remining BMPs. (cont.)

BMP		Chemical Parameters (% of discharges / # discharges)					
		Acidity	Iron	Sulfate	Manganese	Aluminum	Flow
Daylighting	Percent eliminated	17.1/28	17.3/27	16.6/28	19.4/21	18.5/17	16.5/28
	Percent significantly improved	23.8/39	22.4/35	19.5/33	21.3/23	14.1/13	20.6/35
	No difference	58.5/96	55.8/87	51.5/87	52.8/57	63/58	56.5/96
	Significantly degraded	0.6/1	4.5/7	12.4/21	6.5/7	4.3/4	6.5/11
Mining of Highly Alkaline Strata	Percent eliminated	25/3	23.1/3	15.4/2	0/0	0/0	15.4/2
	Percent significantly improved	41.7/5	15.4/2	30.8/4	50/2	0/0	46.2/6
	No difference	33.3/4	38.5/5	46.2/6	50/2	100/3	38.5/5
	Significantly degraded	0/0	23.1/3	7.7/1	0/0	0/0	0/0
Passive Treatment System Construction	Percent eliminated	0/0	50/1	0/0	100/1	0/0	0/0
	Percent significantly improved	0/0	0/0	50/1	0/0	0/0	50/1
	No difference	100/1	50/1	50/1	0/0	100/1	50/1
	Significantly degraded	0/0	0/0	0/0	0/0	0/0	0/0
Special Handling of Acid-Forming Material	Percent eliminated	14.1/11	15.7/11	13.8/11	23.5/12	15.8/6	13.8/11
	Percent significantly improved	21.8/17	21.4/15	18.8/15	15.7/8	15.8/6	20/16
	No difference	61.5/48	55.7/39	52.5/42	54.9/28	65.8/25	58.8/47
	Significantly degraded	2.6/2	7.1/5	15/12	5.9/3	2.6/1	7.5/6
Surface Regrading	Percent eliminated	19.5/30	24.1/33	17.4/27	18.9/21	16.7/14	16.7/26
	Percent significantly improved	26.6/41	18.2/25	20.6/32	20.7/23	20.2/17	26.9/42
	No difference	53.2/82	52.6/72	52.3/81	52.3/58	60.7/51	50/78
	Significantly degraded	0.6/1	5.1/7	9.7/15	8.1/9	2.4/2	6.4/10
Surface revegetation	Percent eliminated	20.1/35	25.3/40	19.3/34	20.5/26	17.3/17	18.6/33
	Percent significantly improved	26.4/46	18.4/29	22.7/40	19.7/25	20.4/20	26/46
	No difference	53.4/93	51.9/82	48.3/85	52.8/67	59.2/58	49.7/88
	Significantly degraded	0/0	4.4/7	9.7/17	7.1/9	3.1/3	5.7/10

Adapted from: U.S. EPA (2001a)

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