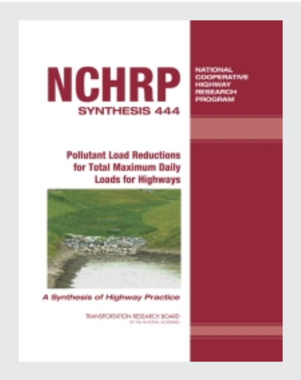

Pollutant Load Reductions for Total Maximum Daily Loads for Highways

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 444

Pollutant Load Reductions for Total Maximum Daily Loads for Highways

A Synthesis of Highway Practice

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Cover figure: Biofiltration swale. *Credit:* Alex Nguyen, Washington State Department of Transportation.

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We would like to thank Joe Battiata of the Center for Watershed Protection and Roger Kilgore of Kilgore Consulting and Management for assistance in developing this report. We also thank the NCHRP Topic Panel 20-05 for helpful feedback and comments on draft versions of this synthesis.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Program Director
Transportation
Research Board

Increasingly, state departments of transportation (DOTs) are being required to meet water quality goals for stormwater run-off from their highway assets. These goals are characterized as "Total Maximum Daily Loads" (TMDL) by the U.S. Environmental Protection Agency. TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards. To meet TMDL goals, the DOTs must often employ best management practices (BMPs) for mitigating the impacts of stormwater pollutants.

This report presents information on the types of structural and non-structural BMPs currently being used by DOTs, including performance and cost data. Information was gathered by an extensive literature review and phone interviews with staff from 12 selected DOTs.

S. Ali Abbasi and Antti Koskelo, EA Engineering, Science, and Technology, Inc., Hunt Valley, Maryland, collected and synthesized the information and wrote the report. The members of the topic panel overseeing this work are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

POLLUTANT LOAD REDUCTIONS FOR TOTAL MAXIMUM DAILY LOADS FOR HIGHWAYS

SUMMARY

The intent of this synthesis is to collect information on the types of best management practices (BMPs) currently being used by state departments of transportation (DOTs) for meeting total maximum daily load (TMDL) water quality goals for stormwater runoff. The study approach includes two major components: interviews with 12 state DOTs to identify the existing state of the practice as it relates to TMDL implementation, and a review of selected literature sources based on the criteria of highways, TMDLs, BMP performance, and BMP cost to stay consistent with the goals of this synthesis. In particular, detailed quantitative BMP performance and cost data, including life-cycle costs, are presented, which builds significantly on previous studies of this nature.

The impetus for this study was to help fill in a significant information gap on what types of BMPs are cost-effective for *specific* use in linear highway applications for TMDL implementation purposes. Even with the advent of new low-impact development/green infrastructure practices, there remain a lack of effective BMP technologies and nonstructural controls (e.g., source control and water quality credit trading) for DOTs to implement for National Pollutant Discharge Elimination System permit compliance. This problem will only grow larger as new TMDLs are continually being developed, and many DOTs are unprepared both technically and economically to cope with the additional requirements (some states already have 60+ TMDLs in which they are a named stakeholder).

In an effort to help state DOTs with TMDL implementation, a simple user-friendly BMP matrix/toolbox with quantitative performance and, where available, life-cycle cost data for various structural and nonstructural BMPs is presented. Some of the more common TMDL pollutants of concern (sediment, nutrients, fecal coliform, and metals) are focused to maximize applicability for state DOTs. The performance and cost data were derived from numerous literature sources including the International Stormwater BMP Database, which currently consists of more than 400 studies. This study is designed to help promote information exchange and technology transfer among DOTs for the mutual benefit of all highway managers faced with TMDL implementation. Conclusions from this synthesis are briefly highlighted here by general topic area, with more details provided in chapters four and five.

Performance for structural BMPs varied by pollutant and BMP type; however, certain trends did emerge from the literature review. In general, total suspended solids (TSS) appear to be relatively easy to treat with a broad range of BMPs, including infiltration basins, sand filters, and bioretention. Nutrients (especially total nitrogen) can be more challenging to remove; nonetheless, some BMPs (e.g., Austin sand filters for total nitrogen and infiltration basins for total phosphorus) showed some promise. Fecal coliform data were limited; however, several BMPs were documented as being effective, including infiltration basins, and infiltration trenches, among others. Additional BMP performance data from the International Stormwater BMP Database support the view that media filters and retention ponds are consistently effective for a wide variety of TMDL pollutants, including TSS, nutrients, fecal coliform, and total metals. This conclusion is based on statistics that show that median concentrations of these pollutants were statistically lower in effluent concentrations compared with influent concentrations based on a large number of studies from around the country (although not all highway related). Overall, while these BMPs may be generally effective across a range

of environmental conditions, obtaining local site-specific BMP monitoring data would be preferable for developing individual state DOT TMDL programs.

Performance data are also presented for nonstructural practices such as street sweeping, catch basin cleaning, and tree planting. Quantitative performance data are generally lacking in the literature for these types of BMPs. The limited information found suggests that street sweeping and catch basin cleaning may potentially be effective strategies for reducing TSS, nutrients, and metals provided they are performed frequently enough and the right technology is used (in the case of sweeping). Tree planting and stream restoration were documented as having some water quality benefits for nutrients. Notably, anti-icing management has been successfully demonstrated in New Hampshire, where a 20% reduction in chlorides was achieved by upgrading the technology on snow plows in response to a chloride TMDL.

In addition to performance, life-cycle cost data are presented where available. However, the cost information could not be adequately synthesized owing to differences in cost estimating approaches, reporting units, variability in costs among states and regions, and inconsistencies in BMP naming conventions. This also prevented a true cost-benefit analysis. However, numerous sources of life-cycle cost data, as well as sources for individual cost elements such as design, construction, and operation and maintenance, are provided where the interested reader may obtain more detailed information. Given the differences in cost from one region to another, the reader is encouraged to obtain cost data that are most relevant to their state. Hyperlinks are provided in the BMP matrix/toolbox where one may access examples of reports with detailed life-cycle cost data, and numerous additional cost sources are cited throughout the section on Highway Best Management Practices in chapter three.

There appear to be several common elements to developing an effective TMDL implementation program, all of which have the potential to benefit DOTs by helping them receive a more equitable waste load allocation and developing a more manageable TMDL program. The key elements are listed here (although not all may apply to every DOT):

- **Increase awareness and training within the DOT** on TMDL issues, especially in cases where the DOT is named a stakeholder in only a few TMDLs (or none).
- **Develop off-site watershed partnerships and collaborate with other stakeholders** to ensure cost-effective approaches based on economies of scale and to promote information sharing and technology transfer among stakeholders.
- **Collaborate with the state regulatory agency during the TMDL development process, especially early in the process**.
- **Estimate pollutant loads** generated within the DOT right-of-way (either through water quality monitoring or modeling) and predict potential load reductions from various BMP implementation scenarios.

Although some DOTs had relatively successful TMDL programs, others clearly faced a number of challenges. The primary challenges were limited financial resources, a lack of effective BMP technologies for linear highway applications, and difficulties in navigating complex regulatory environments where TMDL-related requirements were either inconsistently enforced or restricted the flexibility of the DOT in implementing BMPs of their choice.

Further research is suggested on the following topics: long-term adverse environmental and cultural aspects of BMP implementation; new and innovative BMP technologies suitable for the highway environment; more studies on BMP longevity, life-cycle costs, and maintenance costs and standards; and alternative and creative solutions to addressing emerging TMDLs for less traditional pollutants such as biological integrity, sediment toxicity, and organic compounds (e.g., vehicle source control, water quality trading). Finally, more research is needed on the use of different BMP design terms in the literature, which are often confusing and vary from state to state.

CHAPTER ONE

INTRODUCTION

OBJECTIVE

This synthesis was designed to acquire information on the types of best management practices (BMPs) currently being implemented by state departments of transportation (DOTs) to meet total maximum daily load (TMDL) water quality goals for stormwater runoff. It seeks to establish the existing "state of knowledge" of DOTs as it relates to TMDL implementation strategies to facilitate information sharing and technology transfer for the mutual benefit of all DOTs. The results of DOT interviews and highlights from key research studies are summarized; challenges and successes that DOTs have experienced have been identified; and this information has been organized, evaluated, and documented into usable categories for the benefit of DOT officials responsible for managing TMDL programs. This synthesis will ultimately provide a summary of key information on effective and practical BMPs for highway TMDL implementation. This study is not intended to cover all literature sources, but rather highlight the most important information from a select group of sources specifically related to highways, TMDLs, BMP performance, and BMP cost. Throughout the text there are references to sources where the interested reader may obtain more detailed information.

TOTAL MAXIMUM DAILY LOADS AND THE REGULATORY FRAMEWORK FOR STORMWATER MANAGEMENT

TMDLs are a requirement under §303(d) of the Federal Water Pollution Control Act (Clean Water Act or CWA) of 1972. Under that law, states are required to develop lists of water body segments impaired by a pollutant and needing a TMDL. A TMDL is a technical calculation of the maximum load of a pollutant a water body can receive and still meet water quality standards. A TMDL addresses the sum of all point source loads (waste load allocation) and loads associated with nonpoint sources (load allocation) (EPA 2009).

$$TMDL = WLA + LA + MOS$$

Where:

WLA = waste load allocation (amount of pollutant from existing point sources; e.g., sewage treatment plant, industrial facility, stormwater);
LA = load allocation (amount of pollutant from existing nonpoint sources and natural background; e.g., farm runoff and atmospheric mercury); and
MOS = margin of safety (part of TMDL allocated to uncertainty in analysis).

TMDLs are generally developed by states or the EPA. Some have also been developed by third parties in conjunction with states. The development process is based on the loading capacity of the water body (i.e., the maximum amount of loading that a water body can assimilate and still meet water quality standards) and the pollutant reductions needed to meet the loading capacity. In this way, TMDLs are an important link between watershed pollution control actions and the attainment of water quality standards (EPA 2012a, b).

TMDLs are generally implemented at the watershed scale through WLAs incorporated into DOT's National Pollutant Discharge Elimination System (NPDES) permits for stormwater discharges from municipal separate storm sewer systems (MS4s) and construction permits. From a DOT perspective, TMDLs are an emerging issue and some DOTs confront increasing economic and technical challenges associated with TMDL implementation. DOTs face unique challenges because roads are linear entities that often cross many watersheds and therefore the DOT may be named a stakeholder in multiple TMDLs. Effectively addressing TMDLs requires watershed modeling tools to calculate baseline pollutant loads within and adjacent to the DOT right-of-way (ROW) and to predict the pollutant load reductions associated with BMP implementation.

In addition to TMDLs, many regulatory requirements affect DOT stormwater management activities. Historically, DOTs have been effective at addressing drainage and hydraulic issues related to the maintenance of the transportation infrastructure (FHWA 1979). This includes design standards that (1) ensure that stormwater runoff is conveyed away from the road surface quickly and efficiently, and (2) minimize maintenance needs by ensuring self-cleansing velocities in pipes and ditches while also avoiding excessive velocities that would require repeated repair of grass-lined channels. In some states (e.g., Virginia), the increases in peak flow rates resulting from these policies have resulted in state- or watershed-driven requirements to manage stormwater discharges to minimize downstream channel erosion and flooding.

Some states such as Maryland and Virginia have also established statewide regulations that require DOTs to implement post-construction stormwater quality and quantity BMPs on new and widening road projects. These requirements have generally been the result of either specific watershed initiatives [e.g., the Chesapeake Bay and the Neuse River (North Carolina)] or other resource or habitat protection goals (e.g., salmon).

Finally, the EPA's development of NPDES MS4 permits has regulated the quality of stormwater discharges from the DOT drainage system. These MS4 permits are generally updated every 5 years to include any additional requirements of local TMDLs. However, in some cases permits may be updated more frequently (e.g., Washington State, where they are updated at least every 18 months) or less frequently (in some states permits are 10 or more years old). In the absence of a TMDL pollutant of concern, the NPDES MS4 permit requires general post-construction stormwater treatment for runoff generated by the newly constructed ROW, as well as a program for identifying and eliminating illicit (nonstormwater) discharges to the ROW. Therefore, many DOTs are implementing both programmatic (e.g., illicit discharge detection and elimination) and technical water quality improvement projects within all or limited areas of their states.

The development of TMDLs adds specificity to the DOT's MS4 permits in terms of specific pollutants and/or specific compliance requirements. In addition, incorporating the requirements of the TMDL into the MS4 permit provides an additional CWA enforcement provision to the TMDL, which is a relatively new element of the MS4 permits.

PROBLEM STATEMENT

Because TMDL implementation is generally new for DOTs, BMP strategies tend to rely on traditional end-of-pipe treatment approaches. However, there are several drawbacks to these types of BMPs, including (1) there are possible public safety issues, (2) they are expensive to design and construct, (3) they have a large construction footprint in a ROW that is often needed for other purposes, (4) they require intensive maintenance to ensure continued performance, and (5) they may not be effective at removing certain pollutants. Although some DOTs have added a new class of higher-performing and smaller footprint BMPs to their stormwater quality toolboxes (e.g., infiltration, bioretention, and filter strips), as well as some innovative BMPs and even low impact development/green infrastructure practices, there is still a need for information on what practices are *specifically* effective for TMDL implementation for highways. Further, there appears to be little awareness of the types of design standards, operation and maintenance requirements, monitoring and performance objectives (especially types of TMDL pollutants treated), and BMP costs that are needed to meet TMDL water quality goals *beyond* the normal compliance framework to meet MS4 permit requirements. TMDLs require many DOTs to face unprecedented challenges to achieve target reduction goals. Further, TMDLs are generally increasing in number across the country and in some states potentially hundreds of additional TMDLs will be developed in which the DOT may be named a stakeholder.

To help fill in these information gaps, this synthesis will summarize current effective and practical methods for DOTs to meet TMDL requirements for highways, particularly given the land and budget constraints that DOTs often face. Although there exist many studies on BMP performance, and some on BMP costs, there is limited information on the types of BMPs that are applicable to the linear highway environment and even fewer reports that address TMDL implementation issues. Because this study will synthesize all of these topics, it focused on using the criteria of highways, TMDLs, BMP performance, and BMP cost to refine our approach and meet the goals of this synthesis. Our research is not intended to be comprehensive, but rather present highlights from key sources that meet the previous criteria and would be most relevant to DOT managers. Information will also be obtained on potential opportunities to form off-site (i.e., outside the ROW) partnerships (or any barriers to such partnerships) to reduce external inputs of pollutants onto the DOT's stormwater system on a watershed-wide basis. This type of approach may potentially be more cost-effective (and potentially more credit-worthy) than BMPs implemented strictly within the DOT ROW where space is limited, especially in ultra-urban areas. Finally, this study will develop a matrix/toolbox of some of the more common structural and nonstructural BMPs employed by DOTs for TMDL implementation within the unique highway environment. We hope this study will provide new and practical information for the benefit of DOT highway practitioners who are developing their TMDL programs.

REPORT ORGANIZATION

This synthesis report is divided into five chapters. The first chapter presents introductory background material. The second chapter includes the basic study approach, including methods for conducting the literature review and the state DOT interviews. The third chapter includes the major findings of the literature review and interviews and synthesizes them into usable categories (e.g., BMP design, maintenance, and cost), and provides several detailed examples of individual state DOT implementation plans. Chapter four presents a BMP matrix/toolbox that provides performance and life-cycle cost data for structural BMPs used by DOTs in the highway environment, as well as performance data for nonstructural BMPs. Finally, chapter five draws conclusions based on the accumulated information and identifies areas for further research.

CHAPTER TWO

STUDY APPROACH

The approach to this study includes two major components: (1) a review of the literature on highway BMP performance, BMP costs, and TMDL implementation plans; and (2) interviews with various state DOTs to gather current information on their TMDL programs. The literature review is designed to establish background information on highway BMPs, especially those used by DOTs, and TMDL implementation strategies. The interviews are intended to gather information on the DOT's "state of knowledge" as it relates to stormwater management activities for achieving TMDL requirements. By combining these two approaches, a broader and more comprehensive picture of DOT stormwater practices and TMDL program elements is presented.

LITERATURE REVIEW APPROACH

The literature on BMPs as tools for stormwater management is considerable; however, the number of studies that relate to highway BMP performance and cost for TMDL implementation is relatively small. The synthesis process initially identified approximately 30 sources encompassing state and federal agencies, research organizations, nonprofits, universities, and peer-reviewed articles. However, through an adaptive approach, additional sources were added to present a broader view of DOT practices and TMDL strategies.

The large list of sources was filtered through our criteria of highways, TMDLs, BMP performance, and BMP cost to identify those studies that are most consistent with the goals of this synthesis. These criteria helped narrow the sources to primarily DOT publications, which we found most useful for this study. In addition, through the interview process, the state DOTs provided additional documents related to their TMDL programs, including website links with further information and studies.

STATE DEPARTMENT OF TRANSPORTATION INTERVIEW APPROACH

Phone interviews were conducted with stormwater managers at 12 selected state DOTs in April and May 2012. These DOTs were California, Colorado, Delaware, Georgia, Kansas, Minnesota, New Hampshire, New York, North Carolina, Ohio, Virginia, and Washington State. These particular DOTs were selected based on the following criteria: (1) they represented a broad geographic area to identify issues related to different climates, ecosystems, and regulatory environments across the United States (see Figure 1); (2) they represented a range of maturity in their TMDL programs; and (3) they were named as an existing or potential stakeholder in one or more TMDL(s) as identified by AASHTO (2010). Final selection of DOTs was determined in consultation with the NCHRP topic panel.

The interview questions were developed to establish a dialogue with the individual DOTs to identify TMDL implementation strategies (or in some cases the state of development of implementation strategies) that build on the recommendations of McGowen et al. (2009) and AASHTO (2010). These strategies include, for example, how DOTs are managing the TMDL process internally (i.e., organizational procedures and responsibilities) and the extent of DOT collaboration with state agencies and other stakeholders, and early participation in the TMDL development process. Questions were also directed toward the selection of BMPs and the efforts being made to identify the most cost-effective structural and nonstructural practices through performance monitoring and tracking of capital, operations & maintenance (O&M), and life-cycle costs. Finally, questions were also targeted to determine if DOTs are implementing watershed scale strategies with partners or other TMDL stakeholders.

Each interview was conducted using interview guides previously developed as part of the Stage 1 deliverables. The questionnaire covered a range of topics related to the DOT's TMDL program including but not limited to the following:

TMDL Compliance Strategies:

- Is your DOT named or expected to be named a stakeholder in a TMDL?
- What organizational units are responsible for compliance on this TMDL?
- Did the DOT participate in the development of any TMDL?
- Has the DOT implemented a policy of participating in the development process of current or future TMDLs?
- Did the DOT provide data to support the LA or WLA?
- Do you estimate pollutant loads from DOT ROWs for purposes of predicting, tracking, and reporting reductions?

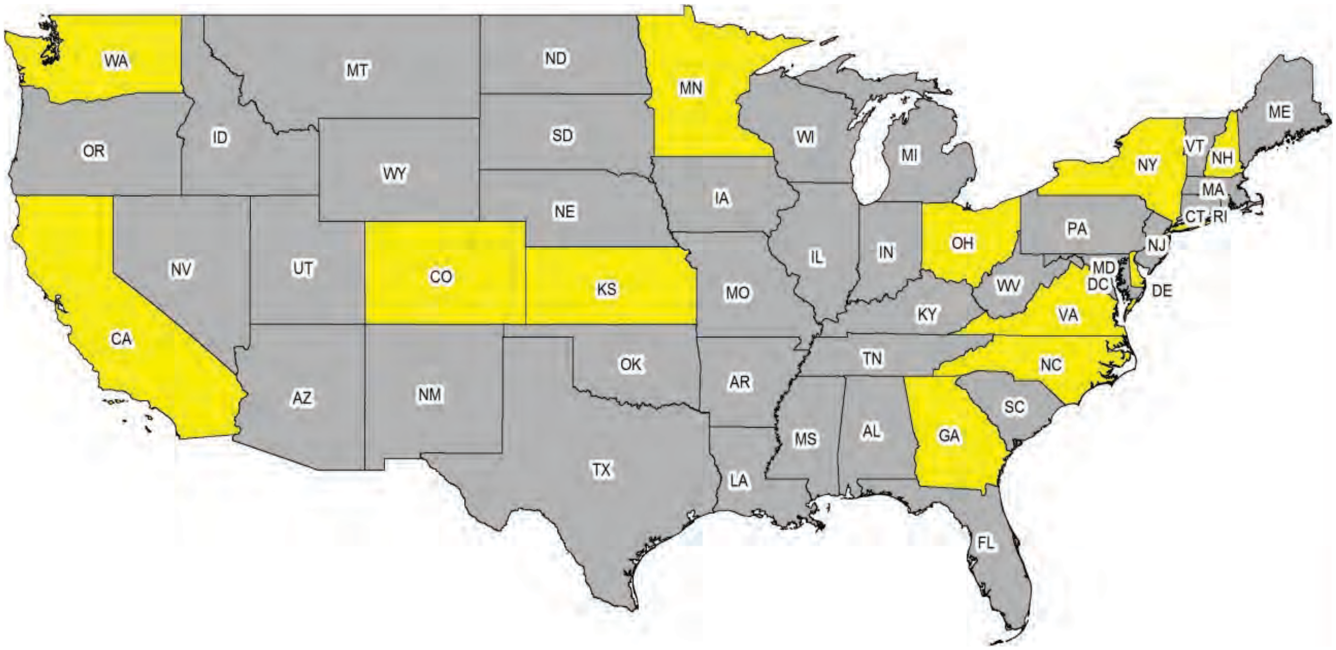


FIGURE 1 Location of the 12 state DOTs interviewed in April and May 2012 (unshaded).

- Have you developed a long-term policy for TMDL participation and compliance?

Effective and targeted structural and nonstructural BMPs:

- What types of structural and nonstructural BMPs have you most utilized for stormwater treatment and pollutant reduction?
- What are the costs associated with BMP implementation? What kinds of costs do you track; for example, capital, O&M, land acquisition, life-cycle?
- Does your state use field measurements and/or sampling to gauge BMP effectiveness?
- Have you conducted any systematic observations of any BMPs located within the ROW to help predict the projected service life (maintenance interval)?
- Do you participate in or provide any funding for research on highway-specific stormwater BMP performance?

Watershed Partnerships:

- Do you have a standard policy for initiating collaboration with other parties, such as a local government, adjacent property owners, watershed groups, etc., to address stormwater requirements?
- Do you have formal agreements with partners to implement the strategies?
- What are the barriers to developing partnerships?

The questions were provided well in advance of the interviews to allow DOT contacts to coordinate with various departments within their organization. The full questionnaire is provided in Appendix A.

CHAPTER THREE

RESULTS AND SYNTHESIS

The literature review provided key information on state TMDL programs including the types of BMPs being implemented, their effectiveness, design standards, and associated costs. The literature review findings supplemented the information obtained during the interviews and provided a greater level of detail to present a more comprehensive picture of TMDL and BMP implementation strategies. However, a clear difficulty with the literature is that it describes a variety of different study approaches, BMP terminologies, and reporting methods and it is difficult to compare data directly from separate studies. In some cases, results are conflicting and/or may only apply within certain geographic areas or climates (e.g., BMPs in arid climates may not work in temperate climates). An attempt is made to synthesize the findings to the extent possible, although there is a need for further research in standardizing BMP naming conventions (see chapter five for more details).

The interviews with the 12 state DOTs were informative and helped establish the current state of knowledge as it relates to TMDL programs around the country. In many cases, several DOT representatives were available from a variety of divisions (e.g., environmental, design, maintenance, and engineering) to provide information on different aspects of their stormwater programs. Following each interview, a brief summary was prepared to capture the primary discussion points. Only ten DOTs were required to be interviewed (in accordance with EA 2012) and the top ten most relevant DOT interviews were summarized and reported. These summaries were sent back to the DOTs for review and all ten responded with comments that were then incorporated into the text. The interview summaries are provided in Appendix B.

Because the findings of the literature review and interviews complement each other (and in some cases overlap), the results from the two approaches are combined. These combined results are presented throughout this chapter and are ultimately synthesized into common patterns and themes, a BMP matrix/toolbox and idealized timeline for the overall TMDL and NPDES permit development process, and a series of conclusions and areas for further research. In cases where the information provided in the interviews was insufficient or not detailed enough, supplemental results are presented from the literature review. However, in cases where the interviews were *more* informative than the literature review (e.g., on the topics of DOT institutional structures or DOT participation in TMDL development), the results of the interviews are the primary source.

TOTAL MAXIMUM DAILY LOADS BY STATE

The number of TMDLs in which the interviewed DOT was a named stakeholder varied widely depending on the state. There is some conflicting information in the literature on the exact numbers of TMDLs in which the DOTs are a named stakeholder versus the numbers provided in the DOT interviews. For simplicity, the information from the interviews was assumed to be the most up to date. Table 1 summarizes the number of TMDLs in which the DOT is a named stakeholder, the associated pollutants of concern, some basic information on how TMDLs are implemented in the state, and other related issues (e.g., construction permits, 401 certifications). As shown, some states are not named in any TMDLs (e.g., Kansas) and some have a large number of TMDLs and a vast array of TMDL pollutants of concern (e.g., California). This range of involvement in TMDLs reflects the intentional selection of DOTs with differing maturity levels in their TMDL programs. Where the DOT is a named stakeholder, TMDLs are implemented in various ways such as through NPDES MS4 permits [or variants such as State Pollution Discharge Eliminations System (SPDES) permits in New York or Transportation Separate Storm Sewer System (TS4) permits in North Carolina] and/or through Construction General Permits. DOTs may be assigned a specific WLA in cases where they are identified as a significant contributor to the water body impairment and/or the WLA may be shared with other stakeholders. More details are provided in Table 1. It is outside the scope of this synthesis to address all the TMDLs listed in the table. However, we highlight certain TMDLs and present detailed implementation plans for select states (see Total Maximum Daily Load Implementation Plans).

INSTITUTIONAL PRACTICES FOR TOTAL MAXIMUM DAILY LOAD IMPLEMENTATION

In this section, some DOT institutional practices for TMDL implementation are described. Institutional practices are defined here as any nonstructural DOT practices, policies, and organizational strategies that are used to help the DOT manage its stormwater program to meet TMDL target reduction goals.

TABLE 1
NUMBER OF TMDLs WHERE THE STATE DOT IS NAMED AS A STAKEHOLDER, THE ASSOCIATED POLLUTANTS OF CONCERN, INFORMATION ON HOW TMDLs ARE IMPLEMENTED, AND OTHER RELATED ISSUES

State DOT	No. of TMDLs Where the DOT Is Named as a Stakeholder	TMDL Pollutants of Concern	Comments
Kansas	0	N/A	KDOT does not foresee TMDLs being implemented in the near future; it focuses on temporary construction stormwater BMPs only (no retrofits).
Ohio	0, but approximately 40 new ones are expected	N/A	ODOT is indirectly affected by TMDLs through watershed-specific Construction General Permits (CGP) that apply to projects disturbing more than 1 acre of land.
Georgia	0, but some are expected soon	N/A	GDOT must monitor outfalls to 303(d) streams in its MS4 permit areas to determine if the roadway is a significant contributor to the impairment. GDOT expects the monitoring will identify it as a significant contributor, potentially naming it as a stakeholder in new TMDLs.
Colorado	2, but many more TMDLs are expected	sediment	TMDL WLAs are divided into different sources of sediment, but all are assigned to CDOT since their assets are typically the only man-made structures in remote mountainous TMDL watersheds. TMDL goals are driven by comparison with reference watersheds in pristine wilderness areas.
New Hampshire	4	chloride/salt	TMDL WLAs are allocated among NHDOT (10%), municipalities (35%), and private property owners (55%) based on salt application data provided to the state by each discharger. The initial chloride TMDL study (funded by NHDOT) was the result of a 401 Certification of a Wetland Permit for the I-93 expansion project.
New York	5	nitrogen, phosphorus, pathogens	TMDLs are implemented through the State Pollutant Discharge Elimination System (SPDES) General Permit for MS4s, which requires a percent load reduction (unique for each TMDL).
Virginia	8 in current MS4 permit, with more than 20 expected in the next permit cycle (2013–2018), including the Chesapeake Bay TMDL	sediment, nitrogen, phosphorus, PCBs, bacteria, flow	TMDLs are implemented through the MS4 permit and VDOT is typically listed under an aggregated WLA with other stakeholders. VDOT only addresses TMDLs in watersheds where they have been designated as having responsibility for the discharge from an MS4 or a construction site.
Delaware	21	nutrients, bacteria, PCBs, TSS	TMDLs are implemented through the state regulations for sediment and stormwater control, through MS4 permits, and in the case of the Chesapeake Bay TMDL, as a blanket requirement across the state. DelDOT is assumed to meet all requirements if they follow the state regulations. DelDOT also develops pollution control strategies to reduce nutrients in certain watersheds to the level required by TMDLs.
Washington State	26, with possibly 17 more in the next MS4 permit	fecal coliform, temperature, TSS/turbidity, dissolved oxygen, pH, mercury, arsenic, pesticides, PCBs	TMDLs are listed in WSDOT’s MS4 permit; the permit may be modified every 18 months to add any new TMDLs that name WSDOT as a stakeholder. WSDOT’s TMDL requirements and specific action items to address the TMDLs are spelled out in the permit.
Minnesota	approximately 40–50 approved and pending	dissolved oxygen, biota, chloride, fecal coliform, nutrients, turbidity, etc.	TMDLs usually have a WLA for construction stormwater (implemented through a CGP) and a WLA for MS4s (implemented through an MS4 permit). Construction stormwater BMPs are required by the CGP, TMDLs, and by requirements of watershed districts and management organizations. If MnDOT complies with the CGP, it is assumed to have met its construction stormwater WLA.

(*continued on next page*)

TABLE 1
(*continued*)

State DOT	No. of TMDLs Where the DOT Is Named as a Stakeholder	TMDL Pollutants of Concern	Comments
California	62, with approximately 200 additional in the near future	trash, bacteria, metals, selenium, nutrients, dissolved oxygen, chlorophyll A, toxics, pesticides, PCBs, sediment toxicity, PAHs, etc.	TMDLs are developed and enforced by numerous regional water quality control boards (regulatory agencies). Caltrans is actively implementing about 40 high-priority TMDLs in cases where they are discharging a pollutant of concern from the roadway with the potential to impact water quality.
North Carolina	estimated more than 100, although DOT not named in all	fecal coliform, nutrients, turbidity, biological integrity, etc.	TMDLs are implemented through a TS4 permit that reflects the unique nature of the transportation corridor. The permit describes a step-by-step process for meeting the TMDL requirements in cases where NCDOT is assigned a specific WLA. Additional "TMDL-like" requirements occur in select coastal estuaries and drinking water supply reservoirs that require nutrient management strategies, so there are BMPs being implemented in both TMDL watersheds and (similarly regulated) non-TMDL watersheds.

N/A = not available; PCBs = polychlorinated biphenol; PAH = polycyclic aromatic hydrocarbons.

One example of an institutional practice is a collaborative approach with the state regulatory agency to TMDL development. As recommended in McGowen et al. (2009), active participation is key because many source and treatment reduction approaches will benefit from economies of scale. They also recommend that DOTs participate early in the process to help ensure that WLAs are valid and equitable. The DOT interview questions probed this issue to evaluate if DOTs are engaging in this process and what, if any, benefits are being realized.

The interview results indicated that the level of collaboration with state regulatory agencies on TMDL development varied widely. Some DOT participation was limited to simply commenting on the draft TMDL during the public comment period; others took a more proactive approach by providing data and expertise to the regulatory agency and in some cases working with them to help define the DOT's contribution to the WLA or to develop specific DOT action items for TMDL implementation.

Overall, the message from the DOTs was clear: four of the DOTs that participated in the development of the TMDLs indicated that the most significant success in their TMDL program was the relationship they developed with the state regulatory agency through early participation and collaboration. The benefits were measurable in terms of the greater level of understanding on the part of the regulatory agency translating into more appropriate and achievable compliance goals. It also helped to educate the other stakeholders on the actual impact of the DOT ROW in order to establish more realistic expectations for the role of the DOT in the compliance strategy.

Brief state-by-state summaries of DOT participation in the TMDL development process are provided here (further details are available in the interview summaries in Appendix B):

- Delaware does not participate in the development of TMDLs owing to a lack of scientific expertise. However, it does comment on draft TMDLs during the public comment period and participates in the development of pollution control strategies and watershed implementation plans.
- New York does not participate in TMDL development except during the public comment period.
- Colorado does participate in TMDL development by providing data on sand application rates to address a sediment TMDL.
- California does not participate in TMDL development; however, it does provide a wealth of data to the regional water quality control boards (the regulatory agencies) that are responsible for developing the WLA and enforcing the TMDL. The California DOT (Caltrans) also comments on draft TMDLs during the public comment period.
- Washington State does participate in TMDL development to the best of its ability, but is limited by a lack of manpower (currently only one full-time employee is dedicated to the development process). The Washington State DOT (WSDOT) reviews and provides comments during the public comment stage. It does not currently provide data to the state agency, but may in the future as monitoring efforts are increasing as part of the its new MS4 permit. WSDOT works with the state regulatory agency to ensure that realistic action items for TMDL requirements are written into its MS4 permit.
- Minnesota participates in TMDL development by providing data and commenting during the public comment

period. The Minnesota DOT (MnDOT) requests an individual WLA for smaller TMDLs as governed (in part) by a Memorandum of Understanding with the state regulatory agency, which outlines the procedure for providing the agency with data (acres in ROW) and reviewing/commenting on TMDLs.

- Virginia participates in TMDL development through its environmental division and MS4 consultant; however, the bulk of its analysis comes after the TMDL is approved through characterization studies. These studies verify the ROW acreage and estimate baseline pollutant loads and potential load-reduction strategies using a modeling approach.
- New Hampshire participates in TMDL development by providing data on salt application rates to the state regulatory agency (for chloride TMDLs). The DOT also provided funding for a TMDL study along I-93 resulting from a wetland mitigation permit.
- North Carolina is probably the most proactive interviewed DOT in terms of participation in the TMDL development process. The North Carolina DOT (NCDOT) typically provides data, expertise, and sometimes funding to the state regulatory agency to ensure that the process is based on accurate and scientific assessments. However, the state uses its own modeling tools to develop the WLA. NCDOT's proactive collaborative approach has provided many benefits including the ability to help define the DOT's contribution to the WLA and form a reasonable TMDL strategy. Further, this approach has helped inform the development of a TS4 permit, the first of its kind in the country. The TS4 permit reflects the unique characteristics of the linear highway (as opposed to a municipal network) and an understanding of the transportation corridor within the urban setting.

Another institutional TMDL implementation strategy is the development of watershed partnerships outside of the DOT's ROW. The watershed partnerships are based on the concept that there are multiple land owners and sources of pollutants within a watershed. TMDL implementation strategies, therefore, must address pollutant loads from all sources to improve the chances of successfully meeting the TMDL.

One major impetus for developing watershed partnerships is that pollutant loadings from highway surfaces may be relatively insignificant compared with those from the broader TMDL watershed, especially in cases where the DOT's assets comprise only a small fraction of the watershed. In these cases, even if the impervious highway surface converts a greater fraction of the rainfall to runoff (e.g., 75%–80%) and often carries higher concentrations of specific pollutants compared with other land uses, the pollutant loads generated by the highway are still minor compared with loads from other land uses within the watershed (Driscoll et al. 1990). These authors even suggest that where typical highway pollutant concentrations are significantly lower, as with nutrients, highway runoff could essentially be excluded from the analyses in cases where water quality issues are related to nutrient loads. In support of this, a study by Hon et al. (2003) concluded that highways are an insignificant source of mass loadings of fecal coliform, total phosphorus, total nitrogen, and pathogens because the runoff volume from the highways is so small compared with the runoff from other watershed land uses. Similarly, a report by the East–West Gateway Coordinating Council (2000) suggests that land uses *surrounding* the highway facility have a far greater impact on the characteristics of the stormwater runoff from highway surfaces.

Based on this evidence, developing watershed partnerships would appear to be a more cost-effective TMDL strategy, particularly if the ROW is too constrained for BMP implementation (e.g., in ultra-urban corridors) or in cases where BMP implementation within the ROW is insufficient to achieve the required pollutant load reductions. A more distributed watershed approach to stormwater management would allow managers to acquire a more complete understanding of the overall water quality conditions in a receiving stream and the stressors that affect those conditions; in addition, a watershed approach can save managers time and money (Oregon State University et al. 2006), especially in cases where design, construction, and maintenance costs can be shared among partners.

One example of an off-site partnership is stream restoration. This practice may be an important opportunity for DOTs to achieve sediment load-reduction goals. In Maryland, the Maryland State Highway Administration has worked with the Maryland Department of the Environment (the state regulatory agency) to increase the efficiency credits of such activities to at least 310 lb of sediment per 100 linear feet of stream restored. Furthermore, this number does not consider floodplain connectivity as part of the stream restoration efforts, which may provide additional benefits in terms of nutrient and TSS reductions.

Based on the interviews, it was found that a majority of the DOTs believed that their current efforts do not represent the most cost-effective strategies, and most indicated that they believed watershed partnerships with other stakeholders are important for achieving watershed scale requirements through the development and implementation of cost-effective TMDL strategies. However, only 6 of the 12 DOTs had a standard policy for initiating collaboration with other parties (e.g., local governments, adjacent property owners, and watershed groups) to address stormwater requirements. In some cases, these partnerships already exist as standard operational agreements between the state and local DOTs for the operation and maintenance of the joined highway systems, such as the entrances to limited access Interstates and primary collectors, tunnel facilities, and bridges. For example, an Inter-Jurisdictional Agreement (IA) between New Castle County, Delaware, and the Delaware DOT (DelDOT) outlines the roles and responsibilities of each party in inspecting, repairing, and maintaining MS4s, bridges, stormwater management basins and ponds, etc., within their respective jurisdictions. In particular, the IA states that the county and DelDOT shall consider TMDLs and various pollution control strategies as provided in a consent decree. For more details on the IA, see DelDOT (2001).

Not all DOTs, however, are interested in entering into watershed partnerships. For example, NCDOT interview responses indicated caution when considering a partnership that may potentially leave them beholden to another entity for achieving on-going compliance with a WLA assigned to the DOT system. However, they also indicated that the cost-effectiveness of practices available to other watershed partners such as exclusion fencing of streams to keep cattle from eroding stream banks and introducing pathogens is significantly greater than traditional DOT practices. On the whole, though, there were more examples of successful partnerships; for example, the New Hampshire DOT's (NHDOT's) technology transfer with private and local salt applicators; and MnDOT's, Colorado DOT's (CDOT's), and DelDOT's Cooperative Agreements with other stakeholders.

LITERATURE REVIEW ON HIGHWAY BEST MANAGEMENT PRACTICES PERFORMANCE STUDIES

This section provides key information from the literature review on highway BMP performance studies. The literature on BMP performance studies is considerable, but here the focus is only on those studies that met the criteria matrix. In general, BMP performance is difficult to measure. There are several potential metrics to use, some more scientifically valid than others, but there is no standardized way of reporting BMP performance in the literature. Further, the selection of a performance metric may have a pronounced bearing on how a BMP's performance is perceived (Lenhart and Hunt 2011).

Percent removal has been a common metric for BMP performance. Although there are drawbacks to using this metric (Wright Water Engineers and Geosyntec Consultants 2007), it is in part relied on because it is ubiquitous. However, we also present results from the literature that utilize other metrics, such as effluent quality (a more scientifically valid approach according to Wright Water Engineers and Geosyntec Consultants 2007) and load reduction to present a more comprehensive picture of BMP effectiveness.

Texas DOT Study (Hon et al. 2003)—Process Framework for Identifying and Prioritizing Water Quality Improvement for Meeting TMDLs in Texas

A Texas DOT study by Hon et al. (2003) documents a process framework for identifying and prioritizing water quality improvement for meeting TMDLs in Texas. As part of this study, existing BMPs were assessed for their effectiveness in treating highway runoff. A summary of their results is presented in Table 2. It shows the relative ranking of BMP effectiveness (low, medium, or high) based on pollutant removal efficiencies.

Hon et al. (2003) concluded that most of the BMPs analyzed are effective at removing TSS and certain metals from

TABLE 2
RELATIVE RANKING OF BMP EFFECTIVENESS FOR VARIOUS CONSTITUENTS BASED ON POLLUTANT REMOVAL EFFICIENCIES

	TSS	TKN	Nitrate	TP	Total Zinc	Fecal Coliform
Sand Filters:						
Austin Sand Filter	High	Medium	Low	Medium	Medium	Medium
Delaware Sand Filter	High	Medium	Low	Medium	High	High
Extended Detention Basin	Medium	Low	Low	Medium	High	Low
Wet Basin	High	Low	Medium	Low	High	High
Infiltration Basin	High	High	High	High	High	High
Infiltration Trenches	High	High	High	High	High	High
Vegetated Swales	Low	Medium	Low	Low	High	Low
Vegetated Buffer Strips	Medium	Low	Low	Low	High	Varied

From Hon et al. (2003).
Rankings are defined as follows. For TSS, low = 0%–50%, medium = 51%–75%, and high = >75%. For all other constituents, low = 0%–30%, medium = 31%–65%, and high = >65%.
TKN = total Kjeldahl nitrogen; total phosphorus.

highway runoff but are less effective at removing nutrients and bacteria. In some cases, the BMPs most likely exported nutrients as a result of fertilizer applications in vegetated BMPs and nitrification in filtration BMPs. A second analysis of the data from the same report examined vegetated filter strips at the edge of the pavement in California and Texas even when those strips were not designed as BMPs. The study concluded that the vegetated filter strips achieve a substantial reduction in pollutant concentrations (similar to engineered systems) in highway runoff. However, the reductions in bacteria and nutrient concentrations in vegetated BMPs were not sufficient; that is, the concentrations did not meet water quality standards for the main causes of water quality impairments in Texas, which are bacteria and low dissolved oxygen. Other conventional stormwater controls were equally ineffective at treating bacteria and nutrients. Table 3 shows the vegetated filter strip data for a variety of constituents.

Caltrans Studies: BMP Retrofit Pilot Program Final Report, Phase I–IV Gross Solids Removal Devices Pilot Studies

A BMP retrofit pilot program study by Caltrans (2004) evaluated the performance of various structural BMPs for treating stormwater runoff from existing Caltrans facilities. The study is part of a pilot study that installs and implements a range of BMPs along freeways. Although several difficulties were encountered along the way, the program was largely a success, and several successful BMPs are now operating throughout many portions of urban southern California. All of the tested devices (except for inlet inserts) were successfully sited without compromising the safety of the traveling public or Caltrans personnel.

In terms of BMP performance, the results are summarized as the expected effluent quality for TSS, total phosphorus, and total zinc that would be achieved if each of the BMPs were subject to runoff with influent concentrations equal to that observed during the study (see Table 4). Expected effluent concentrations of 0 are assumed for infiltration devices that have no discharge to surface waters.

As indicated in Table 4, total phosphorus concentrations in the effluent were greater than influent concentrations for the wet basin, biofiltration swale, and biofiltration strips. For the wet basin, the Caltrans (2004) report does not offer an explanation for the lack of nutrient removal. However, in the case of the biofiltration swale and strips, the higher effluent concentrations were attributed to natural leaching of phosphorus during the dormant season from the salt grass vegetation used in these BMP types. The report suggests that a mixture of drought-tolerant native grasses is preferable to a salt grass monoculture. The report also presents pollutant removal efficiencies for the pilot study BMPs based on a comparison of the expected effluent concentrations with the Water Quality Design Storm Concentrations [event mean concentration (EMC) for pilot study]. These results are summarized in Table 5.

Finally, the Caltrans (2004) report presents a series of graphs that compare the predicted effluent concentration and load reductions (including the effects of infiltration) for various BMP technologies for treatment up to the design capacity (i.e., design storm). The BMPs are presented across a range of relative life-cycle costs. The life-cycle costs were developed by adding the present value (assuming a 20-year life cycle and a 4% discount rate) of normalized expected operation and maintenance costs to the normalized adjusted construction costs. The term "normalized" in this instance means that the costs were normalized by the water quality volume. The construction costs were adjusted to allow for additional site-specific and ancillary costs that may be encountered during future BMP retrofits. Note that infiltration trenches and infiltration basins are assumed to have an effluent concentration of zero and a 100% load reduction

TABLE 3
COMPARISON OF HIGHWAY MEDIAN EVENT MEAN CONCENTRATIONS (EMCs) AND VEGETATED AREA EMCs FOR VEGETATED FILTER STRIPS IN CALIFORNIA AND TEXAS AT THE EDGE OF THE PAVEMENT

Constituent	Highway Median EMC (mg/L)	Vegetated Area EMC (mg/L)	Difference (%)
TSS	100	20	80
NO_3	1.2	0.8	33
TKN	2.1	1.3	38
Total N	3.3	2.1	36
Total P	0.27	0.18	33
Zinc	120	30	75
Fecal Coliform (cfu/100 mL)	2,500	800	68

Hon et al. (2003).
NO_3 = nitrate; TKN = total Kjeldahl nitrogen, N = nitrogen; P = phosphorus.

TABLE 4
EXPECTED EFFLUENT CONCENTRATIONS FOR BMP TYPES

Device	TSS (Influent 114 mg/L)	Total Phosphorus (Influent 0.38 mg/L)	Total Zn (Influent 355 ug/L)
Austin Sand Filter	7.8	0.16	50
Delaware Sand Filter	16.2	0.34	24
EDB unlined	36.1	0.24	139
EDB lined	57.1	0.31	132
Wet Basin	11.8	0.54	37
Infiltration Basin	0	0	0
Infiltration Trench	0	0	0
Biofiltration Swale	58.9	0.62	96
Biofiltration Strip	27.6	0.86	79
Storm-Filter™	78.4	0.30	333
MCTT	9.8	0.24	33
CDS®	68.6	0.28	197

From Caltrans (2004).
EDB = extended detention basin; MCTT = multi-chambered treatment train; CDS = continuous deflection separator.

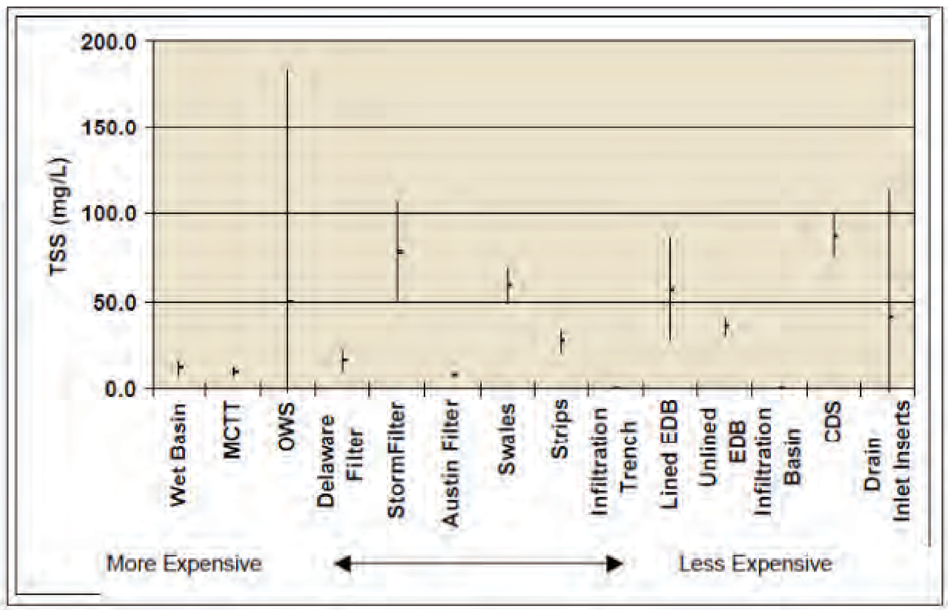
TABLE 5
REPRESENTATIVE POLLUTANT REMOVAL EFFICIENCIES (Percent)
FOR PILOT STUDY BMPs

BMP Type	TSS	TN	TP	TZn	TCu	TPb
Infiltration Basin	N/A	N/A	N/A	N/A	N/A	N/A
Infiltration Trench	N/A	N/A	N/A	N/A	N/A	N/A
Extended Detention Basin (Lined)	40	14	15	54	27	30
Extended Detention Basin (Unlined)	72	14	39	73	58	72
Wet Basin	94	51	5	91	89	98
Austin Sand Filter	90	32	39	80	50	87
Delaware Sand Filter	81	9	44	92	66	85
Multi-Chambered Treatment Train (MCTT)	75	0	18	75	35	74
Storm-Filter™	40	13	17	51	53	52
Biofiltration Strip	69	10	N/A	72	65	65
Biofiltration Swale	49	30	N/A	77	63	68
Drain Inlet Insert	N/A	N/A	N/A	N/A	N/A	N/A
Oil-Water Separator	N/A	N/A	N/A	N/A	N/A	N/A

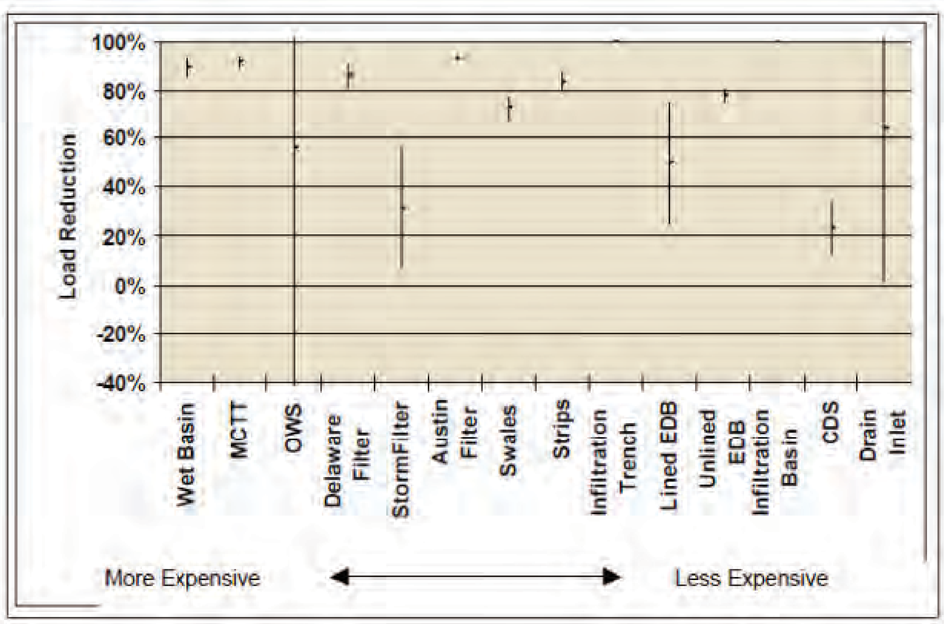
From Caltrans (2004).
TN = total nitrogen; TP = total phosphorus; TZn = total zinc; TCu = total copper; TPb = total lead; N/A = not available.

for the water quality design storm because they have no effluent discharge. An example graph for TSS is shown in Figure 2. Similar plots for nitrate, total Kjeldahl nitrogen, dissolved P (phosphorus), particulate P, particulate Zn (zinc), dissolved Zn, particulate Cu (copper), dissolved Cu, particulate Pb (lead), and dissolved Pb are provided in the report (Caltrans 2004).

Another study by Caltrans examined Gross Solids Removal Devices (GSRDs), a nonproprietary device to capture trash, vegetation, and debris of relatively large size (collectively "gross solids") (Caltrans 2005a). GSRDs can be incorporated into existing or future highway drainage systems. Along with other strategies, they have been used successfully in California to address trash TMDLs.



(a)



(b)

FIGURE 2 Predicted TSS effluent concentration (*a*) and TSS load reduction (*b*) for various BMP technologies across a range of relative 20-year life-cycle costs. MCTT = multi-chambered treatment train; OWS = oil-water separator; EDB = extended detention basin; CDS = continuous deflection separator. Error bars indicate the reliability of the estimated effluent concentrations and load reductions (from Caltrans 2004). Infiltration trenches and infiltration basins have TSS concentrations of 0 and load reductions of 100% because they have no discharge to surface waters.

TABLE 6
PERCENT REMOVAL FOR A SEDIMENTATION/FILTRATION SYSTEM FOR ONLY THE RUNOFF ENTERING THE SYSTEM (i.e., excluding bypass)

Constituent	Influent EMC (mg/L)	Influent Load (kg)	Effluent EMC (mg/L)	Effluent Load (kg)	Removal (%)
TSS	204	5705	3.50	94.0	98
Turbidity	53.0	750	4.60	62.6	92
COD	90.6	2474	11.0	286	88
TOC	32.0	692	12.6	261	62
Nitrate	1.24	20.6	0.474	7.40	64
TKN	1.59	33.8	0.591	11.9	65
Phosphorus	0.356	7.96	0.126	2.72	66
Zinc	0.143	3.85	0.008	0.214	94
Iron	3.25	70.2	0.175	3.71	95

From Keblin et al. (1998).
EMC = event mean concentration; COD = chemical oxygen demand; TOC = total organic carbon; TKN = total Kjeldahl nitrogen.

This study (Caltrans 2005a) is one of several pilot studies (Phases I–IV) that test the effectiveness of GSRDs of varying configurations and slopes. In this case, the Phase IV GSRD had a 35 degree slope and captured approximately 44% of the gross solids by volume during the first storm season. The low capture efficiency was primarily the result of the large momentum of the stormwater runoff, which forced the gross solids out of the GSRD. As a result, the Phase IV GSRD did not meet the TMDL criteria or Caltrans goals. Other results from Phases I–III of the pilot study, however, with different configurations of the GSRDs, showed much better capture efficiencies of generally >85% based on either wet weight or wet volume of gross solids. The interested reader is referred to Caltrans 2003a, b, and 2005b for more details.

Keblin et al. (1998)—The Effectiveness of Permanent Highway Runoff Controls: Sedimentation and Filtration Systems

A study by Keblin et al. (1998) focused on the performance of a sedimentation and filtration treatment system in the Edwards Aquifer Recharge zone in Texas. The study includes (1) monitoring and evaluating a single sedimentation/filtration facility in Austin, Texas; and (2) evaluating the factors that affect sedimentation in a prototype detention basin. The results are summarized in terms of influent EMC and load, effluent EMC and load, and the percent removal, and pertain only to the runoff that entered the system (i.e., bypass was excluded, see Table 6). They also calculated the percent removal based on the total runoff that drained from the watershed (Table 7).

TABLE 7
PERCENT REMOVAL FOR A SEDIMENTATION/FILTRATION SYSTEM BASED ON THE TOTAL RUNOFF FROM THE WATERSHED

Constituent	Watershed Load (kg)	Bypass + Final Effluent Load (kg)	Removal (%)
TSS	7132	1520	79
Turbidity	937	250	73
COD	3092	905	71
TOC	865	434	50
Nitrate	25.7	12.5	51
TKN	42.2	20.3	52
Phosphorus	9.95	4.71	53
Zinc	4.81	1.18	76
Iron	87.8	21.3	76

The total includes the runoff entering the system plus the bypass water.
From Keblin et al. (1998).
COD = chemical oxygen demand; TOC = total organic carbon; TKN = total Kjeldahl nitrogen.

The total included the runoff entering the system plus the bypass water in order to identify the total load to the receiving waters. As shown, accounting for the bypass reduces the performance (i.e., percent removal) of the sedimentation and filtration system owing to the poorer hydraulic performance (compare Tables 6 and 7).

The results from the sedimentation and filtration facility suggest the following:

1. Sedimentation and filtration is an excellent form of treatment for runoff captured in the system; however, the poor hydraulic performance of this particular (sand) filter reduces the facility's capture capacity and increases the quantity of untreated runoff that bypasses the system.
2. Results from the prototype experiments show that detention time is more important than outlet design for achieving satisfactory removal of constituents in runoff.
3. Treatment by sedimentation alone is comparable to sedimentation and filtration when adequate and consistent detention times are achieved.

In addition, the Keblin et al. (1998) report summarizes removal efficiencies for seven dry detention ponds from a range of geographic locations across the United States (Table 8). Although direct comparison of these data is not possible because of different methodologies and pond designs, the efficiencies provide an idea of the range of performance for dry detention ponds. In particular, the detention ponds are most effective at removing particulate constituents (e.g., TSS) in runoff and less effective at removing soluble constituents (e.g., NO_3-N) (Keblin et al. 1998). This is supported by the data in Table 8, which show that removal efficiencies on average are among the highest for TSS and among the lowest for NO_3-N.

International Stormwater BMP Database

The International Stormwater BMP Database, first developed in 1996 by ASCE and available at www.bmpdatabase.org, is an important source of scientifically based BMP performance monitoring and reporting protocols. Currently, the database features more than 400 studies from approximately 150 data providers from around the country including universities, municipalities, state agencies, private entities, and others. The database is continually being updated. Not all of these studies are related to highway applications. However, through the website the user may retrieve studies by individual data providers, which includes about ten transportation-related agencies. Much of the highway-specific data in the database are from Caltrans, although other state DOTs (e.g., Florida, Delaware, North Carolina, Texas, Minnesota, and Washington State) have also provided data.

For this synthesis, we provide an overview of performance results for various BMP categories from the most recent analysis of the database by Geosyntec Consultants and Wright Water Engineers (2012). As noted in the analysis report, a variety of screening criteria were applied to make sure that the data sets and BMP designs are reasonably representative (see full report for details). The report presents a large amount of data. In the interest of space and applicability to highways, the data tables from the report were tailored and condensed to make the information more user-friendly for highway managers. For example, we focused only on the most prevalent TMDL pollutants of concern for state DOTs [TSS, total nitrogen (TN), total phosphorus (TP), fecal coliform, and metals] (see Table 1) and excluded BMPs that are not considered relevant for highways (green roofs) or lack specificity (composite and treatment train BMPs). We also present only the median influent and effluent concentrations, the 95% confidence interval, and the statistical significance (increase or decrease) between the inflow and outflow median concentrations. The interested reader is referred to the report for additional statistics and information.

The results are presented in Table 9. Here we assume that "effective" BMP performance is synonymous with statistically significant decreases between median influent and effluent concentrations. Significant differences are in dark shaded bold (decrease) and light shaded italic (increase) to help the reader quickly assess the relative effectiveness of

TABLE 8
REMOVAL EFFICIENCIES FOR SEVEN DRY DETENTION PONDS (%)

Detention Pond	TSS	TOC	TN	NO_3-N	TP	Pb	Zn
Lakeridge, VA	14	—	10	9	20	—	−10
London, VA	29	—	25	—	40	39	24
Stedwick, MD	70	—	24	—	13	62	57
Maple Run, Austin, TX	30	30	35	52	18	29	−38
Oakhampton, Baltimore, MD	87	—	—	−10	26	—	—
Lawrence, KS	3	−3	—	20	19	66	65
Greenville, NC	71	10	26	−2	14	55	26

From Keblin et al. (1998); after Stanley (1996).
TOC = total organic carbon; TN = total nitrogen; TP = total phosphorus; Pb = lead; Zn = zinc.

TABLE 9
INFLUENT/EFFLUENT SUMMARY STATISTICS FOR TOTAL SUSPENDED SOLIDS (TSS), TOTAL NITROGEN (TN), TOTAL PHOSPHORUS (TP), FECAL COLIFORM (FC), TOTAL ZINC (TZN), TOTAL COPPER (TCU), AND TOTAL LEAD (TPB) AS ADAPTED FROM GEOSYNTEC CONSULTANTS AND WRIGHT WATER ENGINEERS (2012). DATA ARE FROM THE INTERNATIONAL STORMWATER BMP DATABASE (www.bmpdatabase.org).

	Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*	
BMP Type	TSS In mg/L	TSS Out mg/L	TN In mg/L	TN Out mg/L	TP In mg/L	TP Out mg/L	FC In # / 100 mL	FC Out # / 100 mL	TZn In ug/L	TZn Out ug/L	TCu In ug/L	TCu Out ug/L	TPb In ug/L	TPb Out ug/L
Grass Strip	43.1 (36.0, 45.0)	**19.1 (16.0, 21.5)**	1.34 (1.06, 1.50)	1.13 (1.00, 1.23)	0.14 (0.11, 0.15)	***0.18 (0.15, 0.20)***	NA	NA	103.3 (86.0, 120.0)	**24.3 (16.0, 26.0)**	24.52 (19, 26)	**7.30 (6.4, 7.9)**	8.83 (6.6, 11.5)	**1.96 (1.30, 2.20)**
Bioretention	37.5 (29.2, 45.0)	**8.3 (5.0, 9.0)**	1.25 (1.06, 1.35)	**0.90 (0.74, 0.99)**	0.11 (0.08, 0.12)	0.09 (0.07, 0.10)	NA	NA	73.8 (62.0, 83.5)	**18.3 (7.7, 25.0)**	17.0 (11.0, 23.0)	**7.67 (4.60, 9.85)**	3.76 (2.49, 5.5)	2.53 (2.50, 2.50)
Bioswale	21.7 (16.2, 26.0)	**13.6 (11.8, 15.3)**	0.75 (0.60, 0.92)	0.71 (0.63, 0.82)	0.11 (0.09, 0.12)	***0.19 (0.17, 0.20)***	4720 (2120, 5500)	5000 (2600, 6200)	36.2 (30.0, 40.0)	**22.9 (20.0, 26.6)**	10.86 (8.70, 13.20)	**6.54 (5.7, 7.7)**	3.93 (2.80, 5.00)	**2.02 (1.80, 2.29)**
Detention Basin	66.8 (52.3, 76.1)	**24.2 (19.0, 26.0)**	1.40 (1.03, 1.57)	***2.37 (1.75, 2.69)***	0.28 (0.25, 0.30)	**0.22 (0.19, 0.24)**	1480 (789, 1900)	1030 (500, 1900)	70.0 (40.0, 95.0)	**29.7 (17.1, 38.2)**	10.62 (7.78, 14.00)	**5.67 (4.0, 6.8)**	6.08 (3.86, 8.0)	3.10 (2.15, 4.30)
Manufactured Device	34.5 (30.0, 36.8)	**18.4 (15.0, 19.9)**	2.27 (1.98, 2.65)	2.22 (1.90, 2.41)	0.19 (0.16, 0.22)	**0.12 (0.10, 0.13)**	NA	NA	87.7 (79.0, 95.0)	**58.5 (52.8, 63.5)**	13.42 (11.90, 14.70)	**10.16 (7.94, 11.0)**	8.24 (6.77, 9.56)	**4.63 (3.80, 5.16)**
Manufactured Device-F**	NA	NA	NA	NA	NA	NA	478 (200, 1300)	1890 (200, 3000)	NA	NA	NA	NA	NA	NA
Manufactured Device-P**	NA	NA	NA	NA	NA	NA	2210 (900, 3000)	2750 (1400, 5000)	NA	NA	NA	NA	NA	NA
Media Filter	52.7 (45.9, 58.2)	**8.7 (7.4, 10.0)**	1.06 (0.85, 1.25)	**0.82 (0.68, 0.99)**	0.18 (0.16, 0.19)	**0.09 (0.08, 0.10)**	1350 (725, 2300)	**542 (200, 625)**	77.3 (68.2, 86.0)	**17.9 (15.0, 20.0)**	11.28 (10.0, 12.68)	**6.01 (5.1, 6.6)**	10.5 (8.02, 11.79)	**1.69 (1.30, 2.00)**
Porous Pavement	65.3 (45.0, 80.3)	**13.2 (11.0, 14.4)**	NA	NA	0.15 (0.12, 0.16)	**0.09 (0.08, 0.09)**	NA	NA	57.6 (49.6, 66.0)	**15.0 (12.5, 16.8)**	13.07 (11.45, 15.3)	**7.83 (6.80, 8.10)**	4.30 (3.28, 5.47)	**1.86 (1.38, 2.21)**
Retention Pond	70.7 (59.0, 79.0)	**13.5 (12.0, 15.0)**	1.83 (1.60, 1.98)	**1.28 (1.19, 1.36)**	0.30 (0.27, 0.31)	**0.13 (0.12, 0.14)**	1920 (970, 2650)	**707 (200, 1160)**	53.6 (49.0, 59.0)	**21.2 (20.0, 23.0)**	9.57 (8.0, 10.0)	**4.99 (4.06, 5.0)**	8.48 (6.80, 9.41)	**2.76 (2.00, 3.00)**
Wetland Basin	20.4 (16.6, 24.4)	**9.06 (7.0, 10.9)**	1.14 (1.04, 1.28)	1.19 (1.04, 1.21)	0.13 (0.11, 0.14)	**0.08 (0.07, 0.09)**	13000 (5080, 21000)	6140 (230, 11800)	48.0 (40.6, 53.2)	**22.0 (16.7, 24.3)**	5.61 (4.36, 6.34)	**3.57 (3.00, 4.00)**	2.03 (1.57, 2.24)	**1.21 (1.00, 1.55)**
Wetland Channel	20.0 (17.0, 22.0)	**14.3 (10.0, 16.0)**	1.59 (1.38, 1.78)	1.33 (1.05, 1.56)	0.15 (0.13, 0.17)	0.14 (0.13, 0.17)	NA	NA	23.0 (16.0, 30.0)	15.6 (11.0, 20.0)	4.52 (3.80, 5.10)	4.81 (3.61, 5.2)	2.94 (1.90, 4.20)	2.49 (1.40, 3.11)

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993).

**For bacteria, manufactured devices are broken down into inlet insert/filtration (Manufactured Device – F) and physical settling/straining devices (Manufactured Device – P).

NA = Limited or no data available.

<values> (green) Hypothesis testing shows statistically significant **decreases** for this BMP category.

<values> (red) Hypothesis testing shows statistically significant **increases** for this BMP category.

one BMP versus another. However, these results should be used cautiously. As stated previously, the results are not necessarily all derived from highway studies. Furthermore, the statistics may not be meaningful in cases where the influent concentrations are already relatively clean to begin with or in cases where the results include many nondetects (although this is more of an issue for dissolved metals, which are not included here) (Geosyntec Consultants and Wright Water Engineers 2012). Nonetheless, the results present a reasonable basis for appraising the general performance of different BMP categories for TMDL planning purposes.

As shown in Table 9, the data support the view that TSS and total metals are relatively easy to treat with almost any type of BMP. This was also generally the case in the other literature sources reviewed (e.g., see Table 20 in chapter four). Note, however, that this may not necessarily be the case with dissolved metals, which are generally more difficult to remove. Similarly, nutrients are also relatively difficult to treat. In some cases the BMP may be a net contributor of nutrients (e.g., grass strips and bioswales show a statistically significant increase in total phosphorus) (Table 9). Media filters and retention ponds were the only BMPs effective at treating both nitrogen and phosphorus. Fecal coliform concentrations were highly variable, which is typical of bacteria in surface waters during storm flows. The database provides two additional manufactured device options for fecal coliforms: inlet insert/filtration devices ("F") and physical settling/straining devices ("P"). Neither is effective at treating fecal coliform; however, media filters and retention ponds showed a statistically significant reduction in fecal coliform median concentrations. Overall, media filters and retention ponds appear to be effective for all of the TMDL pollutants assessed, including TSS, nutrients, fecal coliform, and total metals.

Other Studies

Several other studies were identified with highway BMP performance data, mostly related to specific innovative practices being developed and utilized in certain areas of the country. For example, two reports, one each by Barrett (n.d.) and Eck et al. (2012), show significant pollutant reductions from permeable friction courses, a roadway material 25 to 50 mm thick that is applied on top of regular impermeable pavement to enhance driving safety during wet weather conditions and improve water quality. The Barrett (n.d.) study found statistically significant concentration reductions of 92% for suspended solids, 90% for total lead, 51% for total copper, and 74% for total zinc relative to a conventional asphalt surface in Texas. The Eck et al. (2012) study found similar reductions in suspended solids (90%) and lower effluent concentrations of phosphorus, copper, lead, and zinc for permeable friction courses in Texas and North Carolina. The water quality benefits were similar in both states and lasted through the design life of the pavement.

A study by WSDOT (2006) examined an ecology embankment (sometimes referred to as a media filter drain) test system located along a highway shoulder in western Washington State. Ecology embankments are linear flow-through treatment devices designed for highway side-slopes, medians, borrow ditches, or other linear depressions, particularly in areas with a limited ROW. The monitoring results showed that treatment goals for total suspended solids (80% removal) and total phosphorus (50% removal) were generally met or exceeded for the sampled storm events. In addition, the ecology embankment was found to provide "enhanced treatment" of dissolved zinc (median removal of 80% to 90%) and dissolved copper (median removal of about 40%), meaning that it performed better than basic treatment facilities. The median removal for total zinc was 85% to 90% and the median removal for total copper was 86%.

Finally, a comprehensive study by MnDOT (2005) provides performance data for total suspended solids and total phosphorus for a variety of BMPs. Although they present removal efficiencies similar to the previous studies, they also provide estimates of TSS and phosphorus removed over 20 years as a function of water quality volume for dry detention basins, wet basins, constructed wetlands, infiltration trenches, bioinfiltration filters, and sand filters. An example is shown in Figure 3. Further details are available in the report (MnDOT 2005).

NONSTRUCTURAL BEST MANAGEMENT PRACTICE PERFORMANCE

Nonstructural BMPs for decades have been qualitatively recognized as having the potential to contribute to water quality improvements, but quantification of those contributions remains elusive. Nonstructural BMPs may be considered as source controls rather than as treatment facilities because their application is generally distributed throughout a watershed and their intent is to prevent pollutants from entering the watershed drainage system rather than removing them once they are moving with stormwater or snowmelt runoff.

Nonstructural BMPs are programmatic in the sense that their successful implementation requires ongoing efforts to identify implementation opportunities, select appropriate technologies, develop implementation plans, and budget the necessary resources to sustain the plans. Nonstructural BMPs that may be applicable to transportation environments include the following:

- Street sweeping
- Catch basin cleaning
- Naturescaping and tree planting
- Stream restoration and reclamation
- Vegetation management
- Anti-icing management
- Downspout disconnection (rest areas, maintenance facilities, etc.)
- Erosion control on construction sites

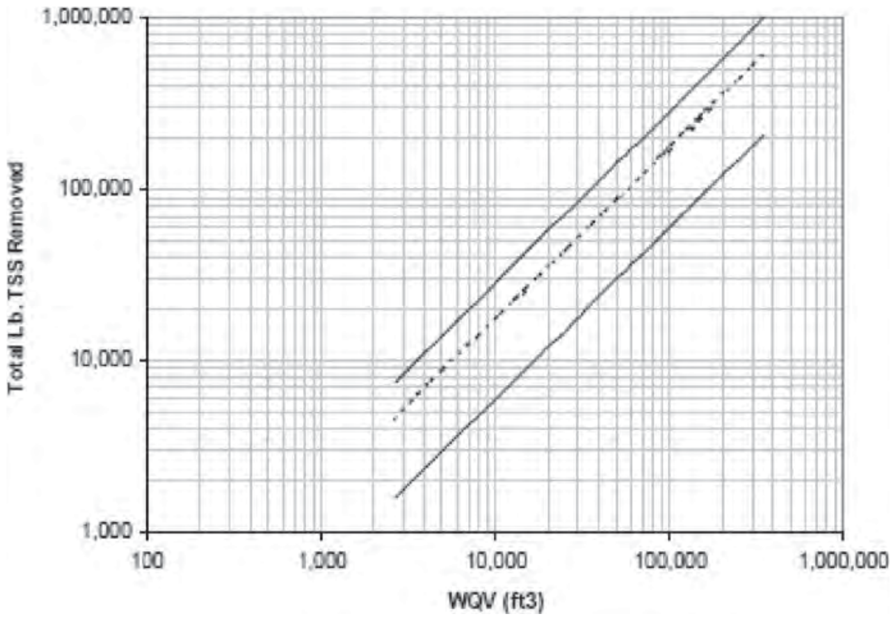


FIGURE 3 Estimated TSS removed in 20 years for dry detention basins with the 67% confidence interval (from MnDOT 2005).

- Spill prevention and response plans
- Education/awareness for the public and employees.

Effectiveness of any of these BMPs depends on a number of factors that have been recognized for over a decade (NVPDC 1996). These include how widely applicable the BMP can be applied, how widely the BMP is applied, how long the BMP is sustained, the effectiveness of the technology used, watershed characteristics, and site-specific hydrology. Because each of these can vary widely by transportation agency, watershed, and state, quantification of performance for TMDLs is challenging.

Table 10 summarizes the quantitative performance metrics identified in the literature search. None of these metrics appear to be broadly transferable nationwide largely because of the variations in conditions mentioned previously. However, they do provide reference points on how quantification has been addressed to date and the challenges that remain.

Street sweeping effectiveness is highly variable and dependent on sweeping technology and sweeping frequency (NVPDC 1996; HECI 2006). Generally, sweeping technologies have improved and older studies tend to report less effective performance. Climate, including frequency and magnitude of rain storms and the extent of a winter season affected by snowfall, will also affect performance. One study in Table 10 showed a range of annual load reduction for TSS, phosphorus, and metals. The differences in reductions reflect, in part, the effectiveness in picking up different size fractions to which the other pollutants may be attached. A spreadsheet model estimated that load reductions though the source of these estimates was not apparent (HECI 2006). One limitation of metrics that simply measure the mass of material removed is that trash is generally included in that measurement, but may not contribute to TSS or other pollutant TMDLs (assuming there is not a separate TMDL for trash). The cost-effectiveness of street sweeping in a transportation context, with frequency a major driving variable, was not addressed.

The effectiveness of catch basin cleaning has been both measured and modeled as shown in Table 10. In one modeling effort, reductions in annual loads were tied to cleaning frequency with virtually no reduction with infrequent cleaning (every 5 years) and up to 45% reduction in loading when cleaning every three months. Removal effectiveness is tied to the size of the solids storage and the rate at which the storage fills. As the storage approaches its capacity, previously captured material is more likely to be resuspended with larger storms. Other assessments shown in the table measure performance in terms of mass removed. As with street sweeping, trash is generally included in these measurements. The state of Maryland has developed performance metrics in terms of an equivalency to structural BMPs. It is beyond the scope of this synthesis to evaluate this methodology, but it does represent an agreement between the Maryland State Highway Administration (MDSHA) and the regulatory authorities regarding the effectiveness of this nonstructural BMP.

Documentation of the effectiveness of tree planting, or more generically "naturescaping," is limited. An older report provided examples of the reduction in runoff concentrations for nutrients with a program of reforestation (NVPDC 1996). The specific numerical values are intended to be illustrative of what may be achieved by converting an

TABLE 10
NONSTRUCTURAL BMP PERFORMANCE MEASURES

BMP/Study	TSS	Nutrients (phosphorus, nitrogen)	Metals (copper, lead, zinc)
Street Sweeping			
Performance modeled with sweeping frequency from twice weekly to biweekly (HECI 2006)	45 to 70% reduction in annual loads	35 to 60% reduction in phosphorus annual loads	25 to 60% reduction in annual loads
Spreadsheet model assuming sweeping frequency of 6 to 12 times per year (HECI 2006)	25 to 35 lb removed per lane mile per year	<0.1 lb phosphorus removed per lane mile per year	<0.1 lb removed per lane mile per year
Catch Basin Cleaning			
Spreadsheet model with cleaning frequency from every 3 months to once in 5 years (HECI 2006)	0 to 45% reduction in annual loads		
Alameda County study with cleaning frequencies from monthly to annual (HECI 2006)	8 to 70 lb removed per cleanout; generally a decline in removal per cleanout with higher frequency		
Spreadsheet model with frequency ranging from every 4 days to every 40 days (HECI 2006)	35 lb removed per cleanout; constant regardless of frequency	0.00003 lb phosphorus removal per catch basin per cleaning	0.0000012 to 0.0000064 lb removal per catch basin per cleaning
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	2000 lb removed by cleaning is equivalent to 0.4 impervious acres of structural BMP treatment		
Tree Planting			
Reforestation (NVPDC 1996)		Nonpoint source runoff concentrations for phosphorus reduced from 0.205 to 0.15 mg/L and for nitrogen reduced from 0.139 to 0.078 mg/L as examples	
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	1 acre of planting is equivalent to 0.38 impervious acres of structural BMP treatment		
Stream Restoration			
Site-specific evaluation (CCBWQA 2011)		90–220 lb phosphorus immobilized per mile per year	
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	100 linear feet of restoration is equivalent to 1 impervious acre of structural BMP treatment		

urbanized land use back to a more natural landscape. Tree planting is also included in the Maryland Accounting Protocol (MDSHA 2012).

Stream restoration is considered a nonstructural BMP because it can reduce the loading of excess sediment and, potentially, other pollutants by reducing erosion and by providing the means to capture sediment in riparian vegetation and the floodplain. One site-specific study in the Denver, Colorado, area estimated that 90 to 220 pounds of phosphorus is immobilized per mile of stream reclamation every year (CCBWQA 2011). That is, by reducing the erosion and unraveling of the stream the sediment and corresponding phosphorus remained in the stream banks and bed, while a reconnection to the floodplain allows capture of phosphorus from upstream sources. Stream restoration is also included in the Maryland Accounting Protocol (MDSHA 2012).

Quantitative measures of other nonstructural BMPs were limited or not found in the literature review. Vegetation management efforts are targeted at not over-fertilizing or irrigating vegetated areas and reducing pesticide use within the transportation corridor, thereby reducing avoidable discharges of nutrients and pesticides. Similarly, anti-icing management efforts are targeted to reducing over-application of sand and chemicals while protecting the public safety. One excellent example of anti-icing management is a pilot project implemented by NHDOT. The pilot project tests advanced technology to measure the temperature of the road surface and automatically manage the rate of salt application. Early results were described during the interview as very promising in terms of reducing the amount of salt applied (20% reduction), thereby reducing the chloride loads to receiving streams and water bodies. The next phase of this effort is intended to apply this technology to private snow removal operations, which are significantly greater in terms of total impervious cover (local roads and parking lots) and total material applied to the pavement surface. Downspout disconnection effectiveness is limited in a transportation context because the area covered by roofs is limited.

Erosion control at construction sites and spill prevention and response plans are generally already covered under MS4 requirements and other permitting programs. Further cost-effective practices in these areas beyond existing requirements may be identified for TMDL compliance, but may be limited.

Education and awareness campaigns for the general public and state transportation employees may have some benefits, but these have not been quantified. For example, campaigns encouraging driving habits that result in the reduced deposition of pollutants related to cars on the roadway may improve water quality. However, response rates to public education campaigns may be as low as 1.5% to 8% (HECI 2006).

Effective strategies for TMDL compliance may include application of multiple structural and nonstructural BMPs. Among the greatest needs for TMDL managers is not only how to measure effectiveness of individual measures, but how to account for measure interactions.

BEST MANAGEMENT PRACTICE DESIGN STANDARDS

BMP design standards have generally evolved slowly for DOTs. The original stormwater quality BMPs developed in the mid-1980s (Schueler 1987) are similar to those being implemented today. Some new practices have been introduced (e.g., bioretention) and some of the older practices are now being recognized as providing a water quality benefit (e.g., street sweeping) (EPA 2011; MDE 2011a, b). However, while several of the DOTs indicated some use of new or innovative structural or nonstructural BMPs on DOT ROWs such as biochar, iron filings, polyacrylamide, etc., the majority of BMPs being implemented are detention and extended detention basins, grass swales, and infiltration. Nonetheless, within the past 5 years the pace of change in BMP design standards as implemented by most state stormwater programs has begun to accelerate. This coincides with the EPA's accelerated implementation of the NPDES permit program and local TMDL development.

As stated previously, DOTs have traditionally used practices designed to reduce the peak runoff rate (Oregon State University et al. 2006). These practices were the first to evolve and included BMPs such as an extended detention to allow for settling of solids. All the DOTs interviewed included detention and extended detention basins on the list of the most common BMPs. However, research is generally revealing these practices to be limited in their ability to address many of the TMDL pollutants of concern; for example, nutrients and metals (Hon et al. 2003).

Nine of 12 DOTs (New Hampshire, New York, Colorado, Delaware, Washington State, California, Georgia, North Carolina, and Virginia) indicated that they have a drainage and/or BMP design manual, either developed specifically for the DOT applications, modified from the state stormwater agency manual to fit DOT ROW applications, or adopted directly from the state stormwater agency. In some cases, the DOTs indicated that the state is in the process of adopting or has recently adopted new BMP design standards as a result of TMDLs and NPDES permits; for example, Virginia, Maryland, Delaware, and New York. The changes in BMP standards are incorporating runoff volume reduction as a new BMP performance metric consistent with the EPA's adoption of the recommendations of the National Research Council report *Urban Stormwater Management in the United States* (NRC 2008). Achieving volume-reduction goals is intended to replicate the pre-development (i.e., before new urban structures, not before human disturbance) runoff characteristics in terms of volume and duration of flows. The greatest challenge noted by many DOTs during the interviews is to establish which of these new BMPs are appropriate for linear ROW application.

BEST MANAGEMENT PRACTICE MAINTENANCE

Maintenance of the stormwater infrastructure and stormwater BMPs is a fundamental element of long-term compliance with TMDLs and local stormwater management programs. Ensuring on-going maintenance of the growing inventory of structural BMPs is both a financial and an administrative challenge for state stormwater programs. No DOTs indicated that they were experiencing maintenance audits or enforcement pressure from their respective state programs or the EPA. However, all the states are required to ensure that the MS4 permittees, including the DOTs, are meeting the substantial requirements for maintenance (EPA 2007).

Another consideration is the ability to manage the routine maintenance of BMPs as part of the regular maintenance practices already programmed into the DOT budgets. Regular ROW maintenance including grass mowing and litter pick-up has served to meet the routine maintenance needs of the traditional detention and retention basins. The new generation of water quality BMPs, such as bioretention and other vegetated practices with subsurface components, require a different though generally similar level of effort for routine maintenance. Based on the DOT interviews, it is the uncertain financial and manpower estimates associated with the infrequent maintenance and the potential for major overhaul of the BMPs that in part fuels the resistance of implementing the new practices.

Routine maintenance is generally described as procedures expected to be performed on a regular basis to maintain the proper working order of a BMP, such as vegetation management, trash and debris removal, and minimal grading and repairs. Infrequent maintenance activities are described as those tasks anticipated to be performed periodically but less frequently than routine maintenance. Examples of infrequent maintenance include accumulated sediment removal and disposal; soil media, mulch, and riprap replacement; and larger scale grading and repairs.

Only four DOTs (Delaware, California, Georgia, and Minnesota) indicated that they conducted any systematic observations of BMPs located within the ROW to help predict the projected service life or maintenance interval. This would be considered a very inexpensive form of monitoring that can support the adaptive management format of evaluating BMPs to help inform the location and design of the practices. This effort would also serve to identify the potential need for the infrequent maintenance before it reaches the more expensive overhaul stage.

Four of the 12 DOTs (Georgia, Washington State, North Carolina, and California) indicated having a maintenance procedure manual that addresses stormwater BMPs. NCDOT, for example, has developed a *Stormwater Control Inspection and Maintenance Manual* that identifies routine and emergency maintenance procedures, reporting and record keeping protocols, and specific activities and checklists for each BMP approved for use on the DOT ROW. One DOT indicated that a maintenance procedure manual is under development with a specific section dedicated to stormwater BMPs, and two DOTs indicated that they are adapting a standard DOT drainage system maintenance guide to address routine BMP maintenance.

Aside from BMP maintenance, the primary drivers of DOT maintenance expenditures are related to pavement failure (Arika et al. 2006). The two leading causes of pavement failure are (1) traffic volume (the pavement surface is no longer able to absorb and transmit the wheel loading to the subgrade because of increases in traffic and/or traffic loads), and (2) poor drainage (the surface and subsurface drainage system must keep the surface and subsurface water sufficiently below the pavement and subgrade). Although DOTs are not able to reduce traffic volume, they can control the management of runoff and groundwater. This was described by several DOTs during the interviews as a significant concern with using stormwater retention BMPs, which by definition retain water within or adjacent to the ROW despite design standards that promote the opposite, namely directing the runoff away from the road surface and ROW as quickly as possible.

HIGHWAY BEST MANAGEMENT PRACTICES COSTS

Based on the DOT interviews, BMP implementation costs (capital, O&M, land acquisition, life cycle) are generally not closely tracked. In some instances, they are not tracked at all, or are difficult to track, owing to the lack of an adequate tracking system. Some DOTs were clearly better at tracking than others. They typically tracked capital costs and/or O&M costs only (only two of the 12 DOTs interviewed tracked land acquisition costs and only one tracked life-cycle costs). However, none of the costs were assessed at the individual BMP level. Capital and/or O&M costs were often rolled into project budgets or larger programmatic budgets (e.g., NPDES or TMDL implementation).

North Carolina and Washington State were probably the two most comprehensive cost trackers. The NCDOT tracks design, capital, and O&M costs for retrofit projects because of an aggressive retrofit requirement in their TS4 permit (70 retrofits required over the 5-year permit cycle). The WSDOT completes an Environmental Mitigation Cost Study every 3 years that tracks capital, design, and land acquisition costs for BMP implementation. A copy of the latest study is available in WSDOT (2009). WSDOT is also developing a Highway Activity Tracking System that will include some tracking of O&M costs. NPDES compliance budgets, if known, were typically in the $2 to 4 million range for the smaller states and about $90 million for Caltrans.

Actual cost data on highway BMPs are difficult to obtain as they are not reported systematically and may have limited application in other areas owing to differences in BMP design standards, materials costs, and other project-specific elements. Nonetheless, through the literature review, some cost data were located.

One goal is to ultimately provide life-cycle cost information that refers to the total project cost across the life span of a BMP, including design, construction, and O&M costs (Arika et al. 2006). In this context, the term “life-cycle” refers to 10-year and 20-year cost estimates over the service life of the BMP. In the following sections we present design, construction, and O&M costs individually and then summarize the information at the end with life-cycle cost estimates that include all of the components mentioned previously. There is some overlap, as life-cycle costs *include* design, construction, and O&M costs. However, the intent is to build up from individual cost elements to a more comprehensive picture of total life-cycle costs for the benefit of DOT managers who may wish to focus either on a particular cost element or on the broader life-cycle costs. Several reports are highlighted here; however, the reader is encouraged to refer to the full reports for additional details.

Design Costs

There was generally little information available in the literature on design costs. Here we present highlights from URS Corporation (2010), which is a study of stormwater control measures (SCMs) (i.e., BMPs) related to bridge infrastructure for the NCDOT. The report determines the cost of implementing effective treatments for existing and new bridges over waterways in North Carolina. SCMs are grouped into four main categories: Level I treatment, Level II treatment, design-related, and maintenance. Level I treatment SCMs remove pollutants that enter stormwater runoff as it travels over the bridge deck (i.e., pavement abrasion, atmospheric deposition, leaching of metals from vehicles), and Level II treatment SCMs reduce erosion by stabilizing soil, dissipating energy, and promoting diffuse flow of bridge runoff. Here we focus on Level I and II treatment SCMs as they are the most relevant to DOTs (URS Corporation 2010). Although the study relates specifically to bridges, it is also reasonable to consider these costs as generally reflective of the financial resources needed to retrofit the nonbridge highway environment, as well (Andrew McDaniel, NCDOT, personal communication, July 19, 2012).

In the report, SCM design costs are expressed as a percentage of construction costs and are based on the cost of retrofits. The retrofits are expected to incur higher SCM design and construction costs than larger newer construction projects because of the need for additional site visits, surveying, and utilities investigations. The report concludes that design costs for SCMs associated with new construction projects were approximately 40% of the design costs for SCM retrofit projects. Based on this assumption, the design budgets were adjusted to yield new construction SCM design costs, which were compared with preliminary construction cost estimates to assess the relationship between design and construction costs. This relationship, which is based on a variety of Level I SCMs, is presented in Figure 4.

Construction Costs

Data on construction costs are available in three reports by URS Corporation (2010), Arika et al. (2006), and Caltrans (2004). In the URS Corporation (2010) report, construction costs for Level I SCMs are based on actual costs from previously constructed NCDOT SCM projects or preliminary construction estimates for planned and ongoing projects. These costs are presented in Table 11.

The relationship between the construction costs and the corresponding water quality volume (represented as impervious acres) was used to develop regression equations for predicting construction costs based on impervious drainage area. An example of a regression equation is presented in Figure 5 for a bioretention basin. Additional plots for dry detention basins, filtration basins, stormwater wetlands, level spreaders, and environmental site design–dry detention basins can be found in the report (URS Corporation 2010) and the equations are summarized in Table 11 (additional equations available in the report for level spreader and dry detention environmental site design).

The second report (Arika et al. 2006) presents construction costs for common BMPs as a series of equations based on data from MnDOT (2005):

- Dry Pond $CC = 97.338 \cdot WQV^{-0.3843}$
- Wet Pond $CC = 230.16 \cdot WQV^{-0.4282}$
- Constructed Wetland $CC = 53.211 \cdot WQV^{-0.3576}$

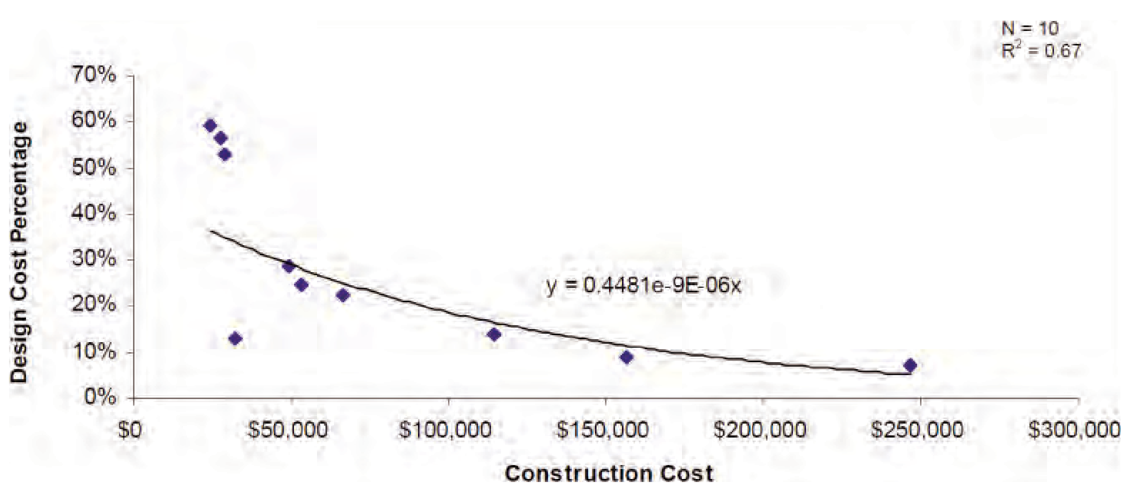


FIGURE 4 Comparison of design cost percentage to construction cost for a variety of stormwater control measures (from URS Corporation 2010).

TABLE 11
SCM CONSTRUCTION COST DATA

BMP	Number of Systems Analyzed	Average Cost	Equation (y = total construction cost, x = impervious drainage area in acres)
Bioretention Basin	$n = 9$	$76,748	$y = 27903x + 48785$
Dry Detention Basin	$n = 5$	$41,541	$y = 1064.5x + 39592$
Filtration Basin	$n = 7$	$107,650	$y = 30959x + 46156$
Stormwater Wetlands	$n = 3$	$75,407	$y = 25157x – 7191$
Swales	$n = 2$	$12,483	N/A

From URS Corporation (2010).
N/A = not available.

- Infiltration Trench $CC = 44.108 \cdot WQV^{-0.1991}$
- Sand Filter $CC = 389.00 \cdot WQV^{-0.3951}$
- Bioretention $CC = 0.0001 \cdot WQV + 9.00022$
- Grass Swales $CC = 21.779 \cdot \ln(A) - 42.543$

Where *CC* is the construction cost expressed in dollars per unit of water-quality volume (*WQV*) or BMP area *A* (ac). The *WQV* is defined as the volume of water the facility will treat and can be calculated as follows:

$$WQV = \left(\frac{43560}{12}\right) * P * Rv * A$$

Where *P* is the design precipitation depth (in.), *Rv* is the ratio of runoff to rainfall in the watershed, and *A* is the watershed area (acres).

Arika et al. (2006) also present a graph showing the construction costs as a function of *WQV* for various BMPs (Figure 6).

The report by Caltrans (2004) presents site-specific BMP costs that were reviewed by a technical work group to develop "generic" retrofit costs that could reasonably be applied to other BMP retrofit projects. The costs were developed by reviewing the specific construction items for each site, eliminating those that were atypical, and reducing the costs that were considered to be in excess of what would "routinely" be encountered in a retrofit situation. Construction costs were adjusted to account for ancillary site-specific costs based on the discussions of the technical work group. Construction costs were also normalized to the water quality volume (i.e., cost per *WQV* or \$/m^3). The results are presented in Table 12. For more details, see Caltrans (2004).

The Caltrans (2004) report also presents mean unit construction costs (\$/m^3 of *WQV*) calculated by a third party cost work group from data collected in a nationwide survey. One set of columns lists the statistics from the Caltrans pilot study (Caltrans 2004), a second set lists statistics of all nationwide data (excluding Caltrans), and a third set gives statistics only from BMP construction by the MDSHA (see Table 13). The MDSHA BMP projects were selected for comparison because the costs are combined with broader highway reconstruction costs and therefore are thought to represent greater cost savings than retrofit programs in other states. However, the Caltrans (2004) authors noted a number of limitations to the MDSHA dataset such as (1) the lack of separate line-item costs for these BMPs, which implies the

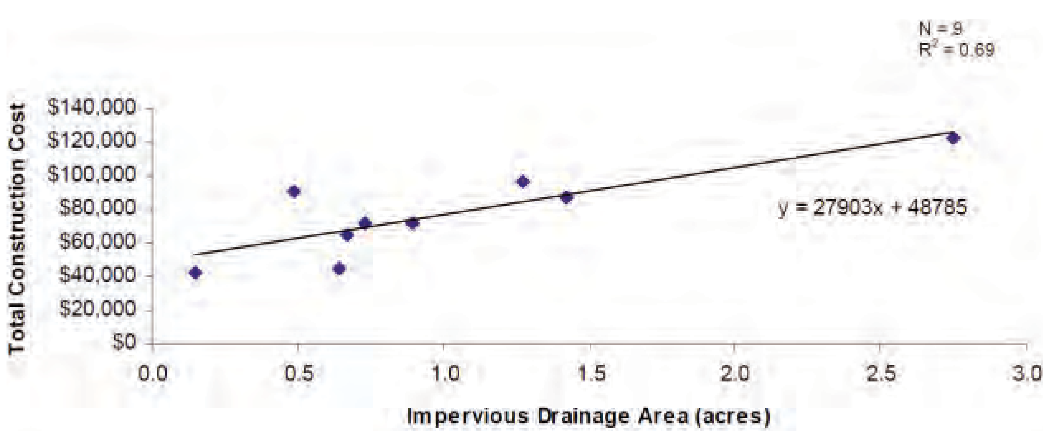


FIGURE 5 Comparison of bioretention basin construction cost to impervious drainage area (from URS Corporation 2010).

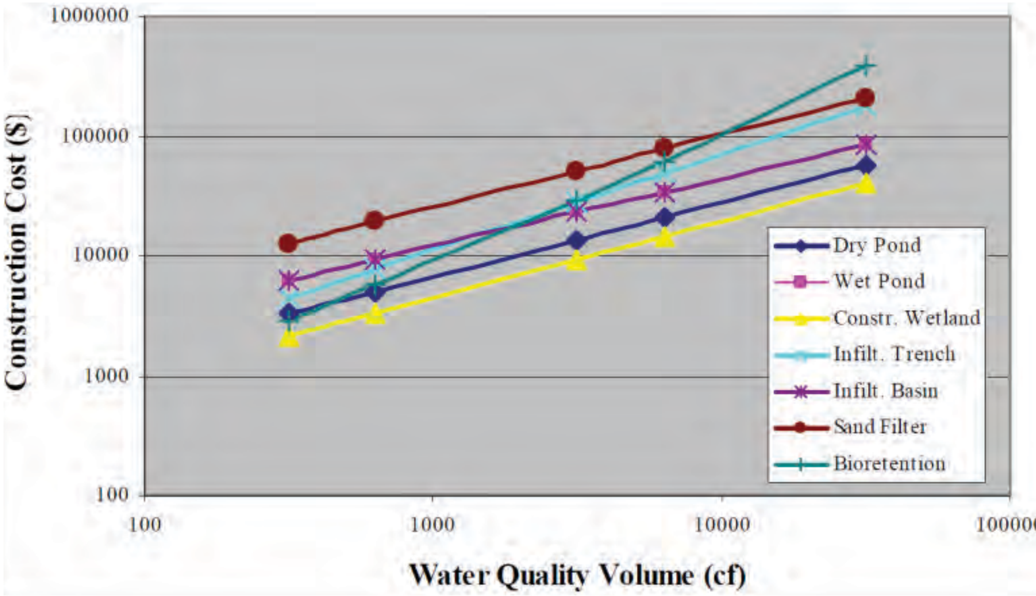


FIGURE 6 Construction cost for selected stormwater BMPs (from Arika et al. 2006).

data could not be independently verified; and (2) the cost database is small and only contains between one and five examples of each BMP type.

As shown in the table, MDSHA costs are much lower than the Caltrans pilot study costs and are generally similar to nationwide costs. Despite the limitations of the Maryland dataset, the data support the view that integrating BMP implementation costs into larger highway projects does result in significant cost savings. In addition, the water quality volumes for the MDSHA sites are substantially larger than the Caltrans pilot study sites, suggesting that the drainage area of the BMP can be a significant source of cost savings owing to economies of scale (Caltrans 2004).

Operation and Maintenance Costs

O&M costs are those post-construction costs necessary to ensure or verify the continued effectiveness of a BMP (Arika et al. 2006). These costs are summarized in several reports highlight here. In the URS Corporation report (2010), O&M costs are estimated to include both routine maintenance and infrequent maintenance. Routine maintenance is based on procedures expected to be performed on a regular basis to maintain the proper working order of an SCM, such as vegetation management and trash and debris removal. Infrequent maintenance includes, for example, sediment removal; soil media, mulch, and riprap replacement; and larger scale grading and repairs. Typical routine and infrequent maintenance costs are provided in Table 14 for various Level I and II treatment SCMs.

In Arika et al. (2006), maintenance costs are expressed as a fraction of construction cost, which varies depending on the BMP type. EPA (2004) presents maintenance costs as an annual percentage of construction costs for common BMPs as follows:

- Dry Pond <1%
- Wet Pond 3% to 6%
- Constructed Wetland 3% to 6%
- Infiltration Trench 5% to 20%
- Infiltration Basin 1% to 3%
- Sand Filter 11% to 13%
- Bioretention 5%

Figure 7 shows the maintenance costs for various BMPs as related to the WQV treated using a period of analysis of 20 years and a discount rate of 7% from EPA (2004).

Caltrans (2004) summarizes annual maintenance in terms of equipment and materials cost and average labor hours performed for each of the tested devices during a retrofit pilot study. Labor hours were generally high for all devices; however, they do not correspond to the effort that would routinely be required to operate the piloted BMPs or reflect the design lessons learned during the course of the study. The largest maintenance item for each of the BMPs was generally vegetation management. Maintenance costs are summarized in Table 14. Note that sand filters were relatively cheap to maintain because (unlike the other BMPs) they were constructed of concrete. This conflicts with the relatively expensive maintenance costs of sand filters from Arika et al. (2006) (see Figure 6), which may reflect geographic differences between the Arika study (from Minnesota) and the Caltrans study, and/or differences in maintenance procedures in these two states.

TABLE 12
ADJUSTED CONSTRUCTION COSTS BY BMP TYPE (1999 Dollars)

BMP Type		Adjusted Construction Cost $	Adjusted BMP Cost per WQV, $/m^3
EDB (4)	Avg	172,737	590
	High	356,300	1,307
	Low	91,035	303
IB (2)	Avg	155,110	369
	High	171,707	397
	Low	138,512	340
WB		448,412	1,731
MFSTF		305,356	1,572
MFSD		230,145	1,912
MFSA (5)	Avg	242,799	1,447
	High	314,346	2,118
	Low	203,484	746
MCTT (2)	Avg	275,616	1,875
	High	320,531	1,895
	Low	230,701	1,856
BSW (6)	Avg	57,818	752
	High	100,488	2,005
	Low	24,546	182
BSTRP (3) [a]	Avg	63,037	748
	High	67,099	1,237
	Low	58,262	384
IT/STRP (2)	Avg	146,154	733
	High	156,975	775
	Low	135,333	691
OWS		128,305	1,970
CDS® (2)	Avg	40,328	264
	High	42,875	353
	Low	37,782	174
DII (6) [b]	Avg	370	10
	High	371	21
	Low	369	2

[a] Unit costs for strips varied widely because the unit loading ratio, or tributary area/treatment area, varied significantly in the study, ranging from 4 at the I-605/SR-91 biofilter strip in District 7 to 43 at the Altadena Maintenance Station in District 7.

[b] Unit cost for drain inlet inserts varied widely because the treatment area varied significantly.

From Caltrans (2004).
The number of BMPs are shown in parentheses; e.g., EDB (4). EDB = extended detention basin; IB = infiltration basin; WB = wet basin; MFSTF = media filter, storm filter; MFSA = media filter sand Austin type; MCTT = multi-chambered treatment train; BSW = biofiltration swale; BSTRP = biofiltration strip; IT/STRP = infiltration strip.

Life-Cycle Costs

As stated earlier, life-cycle costs represent the sum total of design, construction, and O&M. Life-cycle costs are generally not well documented. However, four reports by Arika et al. (2006), URS Corporation (2010), King and Hagan (2011), and Caltrans (2004) were identified with some comprehensive life-cycle costs and methodologies for calculating them. It can be noted that these reports use different approaches for life-cycle cost estimating and generally assess different types of BMPs. Therefore, a direct comparison of the data from all four reports is not possible. However, in a few cases, the reports examine the same BMP type and the cost estimates can be variable. As an example, construction costs for swales range from $12,000 to $57,818 (compare Tables 14, 15, and 16). This variability is likely the result of the different calculation methods used in the reports and perhaps real differences in costs by geographic region (these studies include four different states: California, Maryland, Minnesota, and North Carolina). Highlights from each report, including summary tables and cost equations, are presented here. As discussed previously, there is some overlap with the previous sections as life-cycle calculation includes design, construction, and O&M cost elements.

In Arika et al. (2006), life-cycle costs are provided for dry ponds, wet ponds, constructed wetlands, infiltration trenches,

TABLE 13
COMPARISON OF MEAN UNIT CONSTRUCTION COSTS AND WQVs FROM NATIONWIDE SURVEY TO ADJUSTED MEAN UNIT CONSTRUCTION COSTS AND WQVs IN CALTRANS RETROFIT PILOT PROGRAM (1999 dollars)

BMP	Pilot Study		Nationwide[a]		MD SHA[b,e]	
	Adjusted Cost $/m³	WQ Volume m³	Cost $/m³	WQ Volume m³	Cost $/m³	WQ Volume m³
Austin sand filter	1,447	168	82	12,123	32.81[c]	1,140[c]
Delaware sand filter	1,912	120	200	1,836		
Extended-detention basin	590	293	5.25	99,537	18.37	32,279
Infiltration trench	733	199	46	2,485	11.48	4,304
Biofiltration swale	752	748	8.86[c]	2,066[c]		
Wet pond	1,731	259	7.55	44,833	9.19	20,391
Wetland			4.59	416,695	3.94	4,877
Storm-Filter™	1,572	194	19[d]	2,350[d]		

[a] Means for all entries in the Third Party Cost nationwide survey where water quality volume is available.
[b] Means for all Maryland State Highway Administration BMPs where water quality volume is available.
[c] Based on a single installation.
[d] Based on compost filters in nationwide survey.
[e] MD SHA had a retrofit policy that capped retrofit costs at $12,000 per acre.

From Caltrans (2004).

TABLE 14
BMP ACTUAL ANNUAL MAINTENANCE EFFORT FOR CALTRANS BMP RETROFIT PILOT PROGRAM

BMP	Equipment & Materials, $	Average Labor Hours
Sand Filters	872	157
Extended Detention Basin	958	188
Wet Basin	2,148	485
Infiltration Basin	3,126	238
Infiltration Trench	723	98
Biofiltration Swales	2,236	246
Biofiltration Strips	1,864	233
Storm-Filter™	308	106
Multi-Chambered Treatment Train	2,812	299
Drain Inlet Inserts	563	121
Oil-water Separator	1,066	139
Continuous Deflective Separator	785	254

From Caltrans (2004).
Maintenance is mainly for vegetation management except for sand filters, which are concrete.

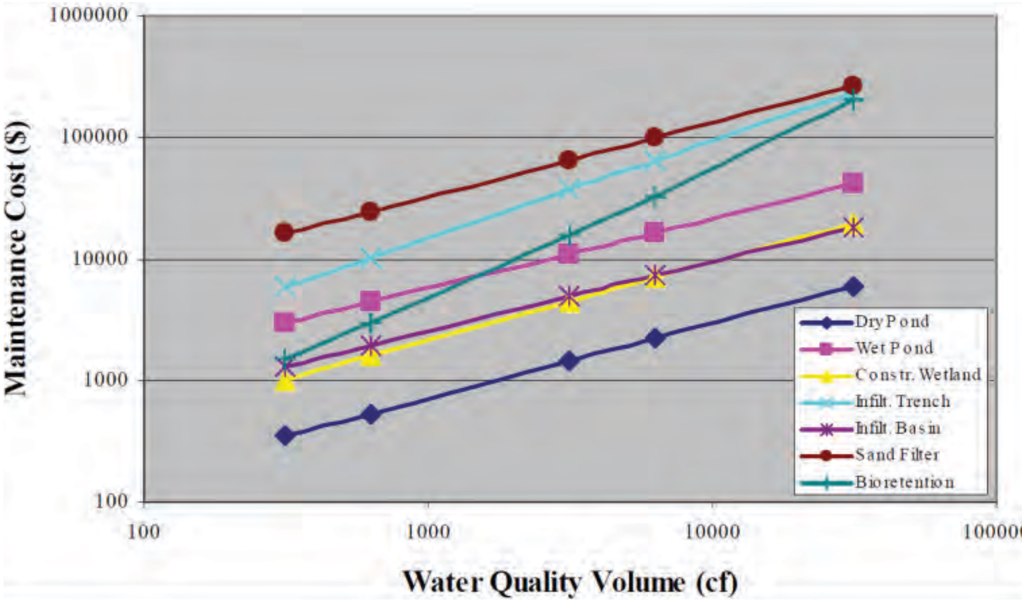


FIGURE 7 Present worth annual maintenance costs as a function of water quality volume for various BMPs. References can be found in Arika et al. (2006).

infiltration basins, sand filters, bioretention areas, and vegetated swales. The life-cycle costs are presented as a series of equations where they are the sum of construction costs and design costs, which include design, permitting, erosion control, and contingency costs. Additional equations are provided for computing (1) the construction cost as a function of the Water Quality Volume (or Qv in this case), (2) the maintenance cost as a function of the construction cost and the multi-year discount factor, and (3) the multi-year discount factor over a specific period of analysis. In addition, individual cost data (i.e., construction costs, design costs, maintenance costs, etc.) are presented for a variety of drainage area sizes. A sample of the life-cycle cost data is presented in Figure 8. For life-cycle cost estimates for other BMP types see the full report (Arika et al. 2006).

A report by the URS Corporation (2010) also presents life-cycle cost estimates based on a 10-year BMP service

BASIC DATA AND EQUATIONS

$$LFC = CC + DC + MC$$

LFC is the life cycle cost ($)
CC is the construction cost ($)
DC is the design, permitting, erosion control, and contingency cost ($)

$$CC = 97.338\ Qv^{-0.3872}$$

CC in $/cf **DC** = 32% CC

$$MC = 1\%\ CC \times MDF$$

MDF is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

i is the discount rate (fraction)
t is the period of analysis (year)

	DRAINAGE AREA				
COST TYPE	0.5 ac	1 ac	5 ac	10 ac	50 ac
Qv (cf)	315	630	3151	6302	31511
CC ($)	3306	5056	13556	20730	55582
DC ($)	1058	1618	4338	6634	17786
MC ($)	350	536	1436	2196	5888
LCC ($)	4715	7210	19330	29560	79257

FIGURE 8 Life-cycle cost estimates for a dry pond. References can be found in Arika et al. (2006).

TABLE 15
TYPICAL COSTS FOR LEVELS I AND II TREATMENT STORMWATER CONTROL MEASURES (SCMs) FOR APPLICATION TO BRIDGES

	Capital Cost			Operating Cost					
SCM Type	Construction Cost[a]	Design Cost[b]	Total Capital Cost	Annual Inspect. Cost[c]	Routine Maint. Cost[d]	Annualized Infrequent Maint. Cost[e]	Total Annualized Operating Cost	Total 10-year Operating Cost	10-year Total Cost
Level I Treatment SCMs									
Bioretention basin	$77,000	$17,000	**$94,000**	$100	$600	$1,200	$1,900	**$19,000**	**$113,000**
Catch basin insert	$1,000[f]	$0	**$1,000**	$0[g]	$1,900[h]	$300	$2,200	**$22,000**	**$23,000**
Dry detention basin	$42,000	$13,000	**$55,000**	$100	$500	$1,400	$2,000	**$20,000**	**$75,000**
Filter strip[i]	-	-	-	-	-	-	-	-	-
Filtration basin	$108,000	$18,000	**$126,000**	$100	$200	$600	$900	**$9,000**	**$135,000**
Infiltration basin	$52,000[j]	$15,000	**$67,000**	$100	$200	$1,400	$1,700	**$17,000**	**$84,000**
Stormwater wetland	$75,000	$17,000	**$92,000**	$100	$500	$3,100	$3,700	**$37,000**	**$129,000**
Swale	$12,000	$5,000	**$17,000**	$100	$200	$400	$700	**$7,000**	**$24,000**
Level II Treatment SCMs									
Energy dissipators and preformed scour holes[k]	$3,000	$0[l]	**$3,000**	$100	$200	$100	$400	**$4,000**	**$7,000**
Level spreader (and filter strip)[i]	$17,000	$7,000	**$24,000**	$100	$700	$800	$1,600	**$16,000**	**$40,000**

See text for definition of Level I and Level II (from URS Corporation 2010).

life. Typical 10-year life-cycle cost estimates include capital costs (construction plus design) and operating costs (which includes maintenance). A summary of the 10-year cost data is provided in Table 15 for Level I and II treatment SCMs (as defined earlier). Notes and references associated with the table can be found in URS Corporation (2010).

Comprehensive life-cycle cost data are provided in a report by King and Hagan (2011). They present planning level unit cost estimates per acre of impervious area treated. The data are designed for use in Maryland to assist counties in comparing the effectiveness of BMP implementation strategies based on costs as well as their potential contributions to meeting county TMDL targets. Therefore, the data may be of limited use outside of Maryland, but the report provides a basis for extrapolating to other areas and presents a method for devising similar life-cycle cost estimates in other localities [for full details, see King and Hagan (2011)]. A summary from the report is presented in Table 16, which presents both the total costs over a 20-year BMP service life and the average annualized cost over 20 years. Costs are further broken down into pre-construction costs, construction costs, land costs (i.e., land acquisition), and post-construction costs. Table references and assumptions used are available (see King and Hagan 2011).

Additional life-cycle cost estimates are presented in Caltrans (2004). In this report, life-cycle costs include construction costs and O&M costs assuming a 20-year BMP service life and a 4% discount factor. As discussed previously, construction costs (and in this case O&M costs) were adjusted to account for ancillary site-specific costs, and life-cycle costs are normalized by water quality volume (i.e., cost/*WQV* or $/m^3). The cost data are presented in Table 17. Additional details are available in the Caltrans report (2004).

TOTAL MAXIMUM DAILY LOAD IMPLEMENTATION PLANS

A number of state DOTs, although not all, have developed TMDL implementation plans to address their WLA requirements. This section provides some detailed examples of implementation plans from California, Washington State, Colorado, and New York to address a variety of TMDL pollutants of concern (metals, toxics, fecal coliform, dissolved oxygen, temperature, PCBs, sediment, nutrients, pathogens, etc.). It is outside the scope of this synthesis to address the TMDL implementation plans in all 12 of the interviewed states; however, by presenting selected highlights, we hope to identify some key patterns and themes common to all implementation plans.

California—Los Angeles River Metals TMDL

Caltrans is a named stakeholder in a Los Angeles River metals TMDL issued in 2005. Its implementation plan is described in Caltrans (2010a). The TMDL assigns a wet weather WLA specifically to Caltrans, while the dry weather WLA is aggregated among all the permittees under a joint

TABLE 16
SUMMARY UNIT PLANNING LEVEL STORMWATER COST ESTIMATES PER IMPERVIOUS ACRE TREATED

Stormwater Management Practice	Pre-Construction Costs[1]	Construction Costs[2]	Land Costs[3]	Total Initial Costs	Total Post-Construction Costs[4]	Total Costs over 20 Years	Average Annual Costs over 20 Years
Impervious Urban Surface Reduction	$ 8,750	$ 87,500	$ 50,000	$ 146,250	$ 885	$ 163,957	$ 8,198
Urban Forest Buffers	$ 3,000	$ 30,000	$ -	$ 33,000	$ 1,210	$ 57,207	$ 2,860
Urban Grass Buffers	$ 2,150	$ 21,500	$ -	$ 23,650	$ 870	$ 41,057	$ 2,053
Urban Tree Planting	$ 3,000	$ 30,000	$ 150,000	$ 183,000	$ 1,210	$ 207,207	$ 10,360
Wet Ponds and Wetlands (New)	$ 5,565	$ 18,550	$ 2,000	$ 26,115	$ 763	$ 41,368	$ 2,068
Wet Ponds and Wetlands (Retrofit)	$ 21,333	$ 42,665	$ 2,000	$ 65,998	$ 763	$ 81,251	$ 4,063
Dry Detention Ponds (New)	$ 9,000	$ 30,000	$ 5,000	$ 44,000	$ 1,231	$ 68,620	$ 3,431
Hydrodynamic Structures (New)	$ 7,000	$ 35,000	$ -	$ 42,000	$ 3,531	$ 112,620	$ 5,631
Dry Extended Detention Ponds (New)	$ 9,000	$ 30,000	$ 5,000	$ 44,000	$ 1,231	$ 68,620	$ 3,431
Dry Extended Detention Ponds (Retrofit)	$ 22,500	$ 45,000	$ 5,000	$ 72,500	$ 1,231	$ 97,120	$ 4,856
Infiltration Practices w/o Sand, Veg. (New)	$ 16,700	$ 41,750	$ 5,000	$ 63,450	$ 866	$ 80,770	$ 4,039
Infiltration Practices w/ Sand, Veg. (New)	$ 17,500	$ 43,750	$ 5,000	$ 66,250	$ 906	$ 84,370	$ 4,219
Filtering Practices (Sand, above ground)	$ 14,000	$ 35,000	$ 5,000	$ 54,000	$ 1,431	$ 82,620	$ 4,131
Filtering Practices (Sand, below ground)	$ 16,000	$ 40,000	$ -	$ 56,000	$ 1,631	$ 88,620	$ 4,431
Erosion and Sediment Control	$ 6,000	$ 20,000	$ -	$ 26,000	$ 10	$ 26,207	$ 1,310
Urban Nutrient Management[5]	$ -	$ 61,000	$ -	$ 61,000	$ 31	$ 61,620	$ 3,081
Street Sweeping[6]	$ -	$ 6,049	$ -	$ 6,049	$ 451	$ 15,079	$ 754
Urban Stream Restoration	$ 21,500	$ 43,000	$ -	$ 64,500	$ 891	$ 82,320	$ 4,116
Bioretention (New - Suburban)	$ 9,375	$ 37,500	$ 3,000	$ 49,875	$ 1,531	$ 80,495	$ 4,025
Bioretention (Retrofit - Highly Urban)	$ 52,500	$ 131,250	$ 3,000	$ 186,750	$ 1,531	$ 217,370	$ 10,869
Vegetated Open Channels	$ 4,000	$ 20,000	$ 2,000	$ 26,000	$ 610	$ 38,207	$ 1,910
Bioswale (New)	$ 12,000	$ 30,000	$ 2,000	$ 44,000	$ 931	$ 62,620	$ 3,131
Permeable Pavement w/o Sand, Veg. (New)	$ 21,780	$ 217,800	$ -	$ 239,580	$ 2,188	$ 283,347	$ 14,167
Permeable Pavement w/ Sand, Veg. (New)	$ 30,492	$ 304,920	$ -	$ 335,412	$ 3,060	$ 396,603	$ 19,830

From King and Hagan (2011).

TABLE 17
LIFE-CYCLE COST OF BMP TECHNOLOGIES (1999 dollars)

BMP Type (No. of installations)	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m³ of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m³	Life-Cycle[a] Cost/m³
Wet Basin (1)	$ 448,412	$ 1,731	$ 16,980	$ 452	$ 2,183
Multi-chambered Treatment Train (2)	$ 275,616	$ 1,875	$ 6,410	$ 171	$ 2,046
Oil-Water Separator (1)	$ 128,305	$ 1,970	$ 790	$ 21	$ 1,991
Delaware Sand Filter (1)	$ 230,145	$ 1,912	$ 2,910	$ 78	$ 1,990
Storm-Filter™ (1)	$ 305,355	$ 1,572	$ 7,620	$ 204	$ 1,776
Austin Sand Filter (5)	$ 242,799	$ 1,447	$ 2,910	$ 78	$ 1,525
Biofiltration Swale (6)	$ 57,818	$ 752	$2,750	$ 74	$ 826
Biofiltration Strip (3)	$ 63,037	$ 748	$2,750	$ 74	$ 822
Infiltration Trench (2)	$ 146,154	$ 733	$ 2,660	$ 71	$ 804
Extended Detention Basin (5)	$172,737	$590	$ 3,120	$ 83	$ 673
Infiltration Basin (2)	$ 155,110	$ 369	$ 3,120	$ 81	$ 450
Drain Inlet Insert (6)	$ 370	$ 10	$1,100	$ 29	$ 39

[a] Present value of operation and maintenance unit cost (20 yr @ 4%) plus construction unit cost.

NPDES MS4 permit. Within the Los Angeles River watershed, Caltrans operates and maintains 275.5 road miles and a number of park-and-ride facilities and maintenance stations. Together, these assets comprise only 1.3% of the watershed area. The general TMDL approach includes implementation of (1) structural BMPs, (2) maintenance activities, (3) source control, and (4) special studies and monitoring plans. These four approaches are described individually here.

Structural BMPs are widely implemented throughout the Los Angeles River watershed. As of October 2010, 115 structural BMPs had been completed, including 101 GSRDs, three biofiltration swales, an EDB, a sand filter, and an infiltration device. An additional 72 structural BMPs were in progress, including 65 GSRDs, five Austin sand filters, and an infiltration basin. Another 481 BMPs are in the planning phase, including 241 GSRDs, 98 media (sand) filters, 64 biofiltration swales, 41 biofiltration strips, 24 infiltration basins, 11 detention basins, and one infiltration trench. Pollutant load reductions are calculated based on the following assumptions: (1) the average drainage area for each BMP is 1 acre; (2) the annual rainfall is 14.78 inches, which is used to determine the WQV to be treated annually; and (3) BMP removal efficiencies are the same as those identified in the DOT's BMP Retrofit Study (Caltrans 2004). Structural BMPs are selected based on a list of approved treatment BMPs identified in the Statewide Stormwater Management Plan (Caltrans 2003b). The list is continually expanded through Treatment BMP Technology Reports (e.g., Caltrans 2010b) that identify and evaluate new BMP technologies for potential use in the highway environment. An additional 287 treatment BMPs are planned for implementation in the Los Angeles River Basin based on corridor studies that identify potential BMP opportunity sites along the roadway corridor.

Caltrans also implements maintenance activities to comply with the Los Angeles River metals TMDL. These include stenciling of storm drain inlets to help educate the public about stormwater runoff pollution. For the dry weather WLA, the DOT conducted a study to identify dry weather runoff from its facilities. In total, 61 instances of dry weather flows were observed in the Los Angeles River watershed, mostly in cases where commercial and residential properties outside of the DOT ROW were contributing dry weather run-on. Caltrans is coordinating with municipalities to eliminate these sources. Most dry weather flows attributed to the DOT were the result of broken irrigation lines. Overall, Caltrans produces little to no dry weather flow and is currently meeting the dry weather WLA for metals.

Caltrans also participates in source control to address the TMDL. These include brake pad partnerships, roadside landscape measures, annual element (a soil stabilization protocol), and enhanced street sweeping. The brake pad partnership is funded by Caltrans and others including municipal stormwater permittees, brake pad manufacturers, environmental groups, government agencies, and community members and designed to reduce copper in vehicle brake pads. Current brake pads contain up to 20% copper, but following state legislation signed in 2010 (SB 346), copper is being phased out in brake pads to no more than 5% by 2021, and no more than 0.5% by 2025. Effective in 2014, the law also restricts cadmium, hexavalent chromium, lead, mercury, and asbestos, which will substantially reduce other metals entering the Los Angeles River. Roadside landscape measures include the use of vegetation for erosion control, which helps trap sediments and their attached metals at the source. Annual element, a soil stabilization protocol, is another practice to prevent erosion, typically using rock riprap, willow planting, ice plant planting, pavement, and mulching. Enhanced street sweeping is currently being considered to reduce the amount of metals. However, the amount of metals removed during street sweeping is not known, but is likely to be highly variable based on site conditions.

Finally, Caltrans has partnered with other watershed stakeholders to develop special studies and monitoring plans. The purpose of the special studies is to evaluate water quality objectives and ensure that the WLAs are appropriate for site-specific conditions. Special studies cover such topics as recalculating metals criteria using new data, analyzing metal loads deposited through atmospheric deposition, and developing a water effects ratio [a ratio of the toxicity of metals in laboratory dilution water to the toxicity of metals in site water (EPA 1994)] to revise the WLA targets. Results from these studies are submitted to the regulatory agency during the re-opening of the TMDL. For an example of a special study, see Larry Walker Associates (2008). A Coordinated Monitoring Plan was also developed by Caltrans and other stakeholders to collect data to evaluate the uncertainties and assumptions made during development of the TMDL, assess compliance with the WLAs, and evaluate potential management scenarios. The monitoring program has a three-tiered TMDL implementation approach: long-term monitoring (Tier I), targeted monitoring of tributaries with repeated exceedances (Tier II), and monitoring of source control efforts (Tier III). Data collected at ambient monitoring stations are used to gauge the effectiveness of TMDL implementation efforts. For more details of the Coordinated Monitoring Plan, see Los Angeles River Metals TMDL Technical Committee (2008).

In summary, Caltrans implements four basic strategies to comply with the Los Angeles River metals TMDL: (1) structural BMPs, (2) maintenance activities, (3) source control, and (4) special studies and monitoring plans. Using all of these approaches, Caltrans expects to meet the wet weather WLA by 2028.

California—Marina Del Rey Harbor Toxics TMDL

Caltrans is also a named stakeholder in a toxics TMDL for the Marina del Rey Harbor. Its implementation plan is documented in city of Los Angeles et al. (2011). The plan was jointly developed with two other municipalities. The DOT's assets comprise only 1% of the watershed. The plan proposes a two-pronged approach including institutional BMPs (vehicle brake pad product replacement, enhancing street sweeping, education and outreach, catch basin cleaning, and downspout retrofits) and structural BMPs (mainly infiltration practices for housing developments). The watershed also has a bacteria TMDL, for which the county of Los Angeles installed three low flow diversions and five tree wells; and a trash TMDL, for which approximately 100 catch basin opening screen covers are to be installed by 2011 (it is not clear if they have been actually installed). Many of these BMPs also serve the dual purpose of reducing toxics. Although Caltrans does not play a major role in the TMDL implementation plan, the plan is a good example of a collaborative watershed-based approach in which BMPs have multi-pollutant benefits to address multiple TMDLs.

Caltrans has many additional TMDL implementation strategies for a wide variety of pollutants as they are currently named in more than 60 TMDLs. It is outside the scope of this synthesis to address them all. However, the interested reader is referred to CDM (2007), an implementation plan for the Malibu Creek bacteria TMDL; a report by Sobelman et al. (n.d.) that documents trash management strategies for compliance with trash TMDLs in Ballona Creek and the Los Angeles River; and finally to the Caltrans interview summary in Appendix B, which presents additional information on TMDL implementation strategies.

Washington State

For WSDOT, the implementation plan is written directly into its NPDES municipal stormwater permit, which lists all of the TMDLs and the associated "action items" for each along with implementation timelines. The action items represent requirements above and beyond the permit obligations. WSDOT actively works with the state regulatory agency [State of Washington Department of Ecology (SWDE)] to ensure that the action items and timelines are appropriate and effective for meeting TMDL goals. The current NPDES permit, last modified in March 2012, lists 26 TMDLs and numerous associated action items (see Appendix 3 in SWDE 2012). Most of the TMDLs are for fecal coliform; however, other pollutants addressed include temperature, TSS, dissolved oxygen, pH, mercury, arsenic, polychlorinated biphenyls (PCBs), and chlorinated pesticides. TMDLs are grouped into two basic categories: (1) those TMDLs for which compliance with the action items constitutes compliance with the assigned WLA, and (2) those TMDLs for which compliance with the permit obligations that address TMDL listed pollutants constitutes compliance with the WLA. Some examples of action items from the current NPDES permit as described in SWDE (2012) are provided here:

- For the Nisqually River tributaries fecal coliform and dissolved oxygen TMDL, WSDOT is required to install a pet waste station, maintain WSDOT controlled tide gates every other year, and participate in annual adaptive management meetings.
- For the Teanaway River temperature TMDL, WSDOT is required to maintain roads and roadside stormwater conveyance ditches to prevent entry of sediment into area waterways.
- For the Walla Walla River watershed fecal coliform, PCBs, chlorinated pesticide, temperature, pH, and dissolved oxygen TMDL, WSDOT is required to (1) reroute 97% of the traffic volume on US-12 to a plateau located well above the Walla Walla River, (2) implement infiltration and/or dispersion BMPs to address the pollutants covered under this TMDL, and (3) follow the current Integrated Roadside Vegetation Management Plan (IRVM) (South Central Region, Area 4) (WSDOT 2012) within the Walla Walla TMDL boundary. The IRVM is designed to enhance roadside vegetation by providing stable, sustainable plant communities; reduce maintenance costs; and improve weed control. For more details on the IRVM, see WSDOT (2012).
- For the Spokane River watershed dissolved oxygen TMDL, WSDOT is required to conduct a stormwater discharge inventory within its ROW and inside the NPDES coverage area, as well as identify phosphorus and ammonia sources. If phosphorus and ammonia sources are found, WSDOT will apply BMPs from their Stormwater Management Program Plan or SWMPP (see Appendix 7 of SWDE 2012) or perform remediation to eliminate the sources.

A common theme running through all of the WSDOT action items for fecal coliform TMDLs is the implementation of a programmatic approach. This approach was developed by WSDOT to systematically address fecal coliform TMDLs; it includes activities such as fecal coliform source identification, inventory of highway discharge locations, illicit discharge detection and elimination, and identification of fecal coliform maintenance issues within the TMDL boundary. A flow chart of the programmatic approach is provided on page 53 of the current NPDES permit (SWDE 2012). If the programmatic approach finds bacteria discharges within WSDOT's ROW that are above natural background levels, WSDOT will implement BMPs from its SWMPP or perform remediation to remove the bacteria source. For run-on sources of bacteria from outside the ROW, WSDOT will notify SWDE and work with them, the local jurisdiction, and any other parties involved to resolve the issue. It can be noted, however, that WSDOT does not generally consider itself a source of bacteria (other than minor contributions from pet walking areas at rest stops and bird roosting areas under bridges), but rather a conveyance of bacteria (WSDOT 2011a). For a more detailed listing of WSDOT's TMDL action items, see Appendix 3 of the current NPDES permit (SWDE 2012).

WSDOT is also unique among state DOTs in that its *Highway Runoff Manual* (WSDOT 2011b) has specific TMDL considerations for 21 of the most commonly used runoff treatment BMPs available for highway applications. These are broadly grouped into infiltration, dispersion, biofiltration, wet pool, oil control, and phosphorus control BMPs. For example, one type of wet pool BMP, a constructed stormwater treatment wetland, is listed as the "preferred" BMP for reducing dissolved metals and TSS/turbidity, but is to be avoided for reducing fecal coliform. In general, infiltration BMPs (e.g., infiltration pond, infiltration vault, drywells, and permeable pavement) and dispersion BMPs (natural dispersion and engineered dispersion) are considered the most desirable for TMDL situations because they are effective across a broad range of pollutants, including fecal coliform, nutrients, oil and grease, dissolved metals, TSS/turbidity, polycyclic aromatic hydrocarbons (PAHs), and several others. For more details, see WSDOT's *Highway Runoff Manual* (WSDOT 2011b).

Colorado—Straight Creek Sediment TMDL

The Colorado DOT (CDOT) is a named stakeholder in two sediment TMDLs. One of the TMDLs is for Straight Creek in a pristine mountainous area west of Denver near I-70, where it passes through the Eisenhower Memorial Tunnel. The TMDL was developed in 2000 by the state regulatory agency [the Colorado Department of Public Health and the Environment (CDPH&E)]. It identifies two main sources of sediment: wash-off of applied traction sand on I-70 and erosion of the cut and fill slopes of the I-70 approach to the Tunnel (CDPH&E 2000). The load allocation compliance strategy for CDOT is written directly into the TMDL and consists of (1) revegetating at least 70% of the cut and fill slopes to 70% potential cover; (2) cleaning and maintaining of 12 existing sedimentation basins, a holding pond, and sediment control structures on the I-70 roadway; and (3) removing at least 25% of the traction sand applied yearly to the I-70 roadway within the TMDL boundaries (CDPH&E 2000). In addition, the TMDL study specifies several water quality targets designed to protect aquatic life. These include (1) increasing the median particle substrate size, (2) decreasing the in-stream pool volume filled with fine sediment, (3) protecting the morphology of the stream, and (4) showing an improvement in the Brook Trout population.

Sediment control activities have been ongoing in the Straight Creek watershed for decades and pre-date the development of the TMDL in 2000 (CDOT 2002). Therefore, it is difficult to distinguish between specific TMDL strategies and continuation of previous sediment clean-up efforts. According to CDOT's *Sediment Control Action Plan* developed in 2002, CDOT implemented a Straight Creek Erosion Control Project in 2000–01 (one of several erosion control projects dating back to 1979), which included seeding and mulching of 107 acres on cut and fill slopes, planting 1,000 tree tublings, cleaning 7,466 tons of sand and sediment off the highway, and paving approximately 2,000 linear feet of ditches to reduce erosion and provide a surface for sweeping. The *Sediment Control Action Plan* also proposes several sediment mitigation strategies, all of which would fulfill the Straight Creek TMDL requirements. The most rigorous scenario includes implementation of an enhanced maintenance program as well as nonstructural controls (e.g., removal of sand deposits, semi-annual sweeping and ditch cleaning, cleanup of sediment basins and traps, and revegetation) and structural controls (e.g., basins and traps to capture sediment, paving of shoulder areas, and valley pan drains to control and route highway runoff). In addition, a Straight Creek Clean Up Committee that includes representatives from CDOT met eight times between 1998 and 2000 to satisfy issues on the TMDL goals, targets, and implementation, with meetings scheduled at least once annually beyond that (CDPH&E 2000). There has also been a significant change in CDOT's winter road maintenance materials, with a trend away from the use of salt and sand in the 1990s toward sand/slicer mixtures and liquid deicer salts in the 2000s (CDOT 2011).

However, despite these efforts, a 2008 compliance evaluation of the Straight Creek Sediment TMDL by the U.S. Forest Service and the EPA concluded that Straight Creek was not meeting the water quality goals of the TMDL although many of the required sediment control practices had been completed (CDOT 2011). Specifically, as outlined in the report, the TMDL water quality targets related to median particle size and fisheries populations had either not been attained or evaluations of the data have not been conclusive. Further, the shift to sand/slicer mixture and liquid deicer salts has resulted in increased chloride concentrations and loads in Straight Creek. The current TMDL data collection and evaluation is underfunded and inconsistent, making it difficult to quantify improvements and assess if water quality goals are being met (CDOT 2011). The report makes several recommendations for achieving TMDL objectives: (1) a coherent monitoring and evaluation plan, (2) consistent annual funding, and (3) nonparametric analysis to address high annual variability when seeking trends. CDOT's own nonparametric analysis of data from 1992–1998 versus 1999–2006 has shown some improvement in aquatic life support categories over time; however, this analysis was not accepted by the U.S. Forest Service and state regulators (Holly Huyck, personal communication, May 9, 2012).

New York

NYSDOT is a stakeholder in several TMDLs for nitrogen, phosphorus, and pathogens. The TMDLs were developed by the New York State Department of Environmental Conservation (NYSDEC) and are referenced in the current SPDES General Permit for MS4s (available in Appendix C of NYSDOT 2012). Stormwater retrofit programs (an implementation strategy for all TMDLs) must demonstrate pollutant reductions in accordance with the SPDES Permit or, in one case (the New York City East of Hudson River TMDL for

TABLE 18
TMDL IMPLEMENTATION STRATEGIES BY NEW YORK STATE DOT TO ADDRESS PHOSPHORUS, PATHOGEN, AND NITROGEN TMDLs

TMDL Watershed	TMDL Pollutant	TMDL Implementation Strategies
New York City East of Hudson River Watershed	Phosphorus	Map the drainage system to help track suspected illicit discharges, develop a stormwater retrofit program that demonstrates phosphorus reductions, inspect and maintain the MS4 drainage features, remediate degradation sites where the MS4 creates a potential for adverse impacts to NYC's drinking water supply[1]; implement a standardized turf management and procedures policy
Greenwood Lake Watershed	Phosphorus	Develop a stormwater retrofit program that demonstrates phosphorus reductions; implement a standardized turf management practices and procedures policy
Onondaga Lake Watershed	Phosphorus	Create a poster to help educate the public on ways to reduce phosphorus in the watershed[2], develop a stormwater retrofit program that demonstrates phosphorus reductions; implement a standardized turf management practices and procedures policy
Oyster Bay Watershed	Pathogens	Develop a stormwater retrofit program that demonstrates pathogen reductions
Peconic Bay Watershed	Pathogens	Develop a stormwater retrofit program that demonstrates pathogen reductions
27 Long Island Shellfishing Impaired Embayments	Pathogens	Develop a stormwater retrofit program that demonstrates pathogen reductions
Peconic Bay Watershed	Nitrogen	Develop a stormwater retrofit program that demonstrates nitrogen reductions; implement a standardized turf management practices and procedures policy

[1]NYSDOT worked with NYSDEC and the New York City Department of Environmental Protection (NYCDEP) to remediate these sites, mostly through stabilization efforts or redirection of drainage to reduce or eliminate direct stormwater discharges into water bodies. Examples of BMPs utilized included swales, check dams, re-grading, sediment basins, slope stabilization (include soil bioengineering), outlet protection, and the removal of paved or concrete swales.

[2]Poster is available here: https://www.dot.ny.gov/divisions/engineering/environmental-analysis/repository/PHOSPHORUS_POSTER.pdf.

phosphorus, see Table 18), in accordance with the *Croton Watershed Phase II Phosphorus TMDL Implementation Plan.* Stormwater retrofit program plans are required to be submitted to NYSDEC to meet permit requirements. A brief summary of general TMDL implementation strategies for each TMDL is presented in Table 18.

In addition, NYSDOT has developed two main policies for phosphorus TMDLs: (1) all new development projects must have erosion and sediment control plans in accordance with NYSDOT specifications, and (2) post-construction stormwater management practices must be consistent with the *New York State Stormwater Management Design Manual, Chapter 10—Enhanced Phosphorus Removal Standards* (CWP 2010). [For more details on NYSDOT's stormwater management program to address TMDL requirements, see NYSDOT (2012), pp. 50–57].

Maryland—Chesapeake Bay TMDL

MDSHA is working to meet the requirements of the Chesapeake Bay TMDL, issued December 29, 2010. The requirements are established in Maryland's Watershed Implementation Plan for the Chesapeake Bay Total Maximum Daily Load (WIP I), issued December 3, 2010. SHA has land coverage in three sectors: (1) minor processed wastewater, (2) septic, and (3) regulated urban stormwater.

MDSHA has coordinated with two state agencies responsible for establishing the TMDL [Maryland Department of the Environment (MDE) and the Department of Natural Resources] as well as the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the EPA. Because the vast majority of the state of Maryland is in the Chesapeake Bay watershed, a statewide perspective is essential. As resources have permitted, MDSHA has also participated in workshops, webinars, and meetings with county and other local officials, as well as local watershed groups to identify partnering activities to achieve the TMDL

No specific requirements have been imposed on MDSHA for non-MS4 areas. However, specific WLAs (see Table 19) have been issued by the MDE for MDSHA compliance with the Chesapeake Bay TMDL and are the MDSHA components of the overall limits of pollutants in regulated urban stormwater to meet water quality standards by 2025. The 2017 SHA target load is 60% of the reduction requirement based on the MDE 2009 baseline progress scenario. The impervious surfaces goal in the table specifies the proportion of impervious surface area that must be treated by BMPs in the Phase I and Phase II counties by 2017. The WLAs are expressed as "delivered" (DEL) or "edge-of-stream" (EOS). The EOS load is the amount of pollutant that enters a stream near a pollutant source; DEL loads are the proportion of the EOS load that ultimately discharges to the Chesapeake Bay. The DEL load is generally lower than the EOS load because of losses of the pollutant (e.g., the result of deposition, removal by algae and plants, and denitrification) during transport by means of streams and rivers.

Requirements for regulated urban stormwater represent the largest TMDL challenges for MDSHA. The department

TABLE 19
SHA WLA AND IMPERVIOUS TREATMENT REQUIREMENTS FOR REGULATED URBAN STORMWATER SECTOR

WLA	TN (lb/yr)	TP (lb/yr)	TSS (lb/yr)	Impervious Surfaces (I/II)
SHA Phase I/II MS4 WLA (DEL)	433,358	25,336	—	—
SHA Phase I/II MS4 WLA (EOS)	764,772	43,574	27,270,536	—
2017 SHA Target Load (EOS) (60% WLA Reduction)	825,095	50,611	30,782,560	30%/20%

DEL = delivered; EOS = edge of stream.

maintains MS4 permit coverage for the SHA roadway storm drain systems in nine Maryland MS4 Phase I counties and in two MS4 Phase II counties. The WIP only applies to these counties. The Maryland Assessment Scenario Tool, a Geographic Information System (GIS)-based watershed planning software, is used to forecast and evaluate MDSHA's progress in achieving the overall limits of pollutants (TSS, phosphorus, and nitrogen) that can be discharged to the bay and still meet water quality standards.

SHA has phased implementation of TMDL responsibilities over several milestones with the ultimate goal of achieving the requirements by 2025. Achievement will be evaluated, in part, using MDE guidance: *Accounting for Stormwater Waste Load Allocations and Impervious Acres Treated* (draft, June 2011), otherwise referred to as the NPDES Accounting Protocol. The milestones include implementation of a combination of structural and nonstructural BMPS by 2013, 2017, and 2025 for 10%, 60%, and 100% implementation, respectively.

BMPs include bioretention/rain gardens, dry detention, extended detention, stormwater retrofits, catch basin cleaning, urban filtering, urban infiltration, stream restoration, tree planting, vegetated open channels, wet ponds, wetlands, bioswales, forest conservation, and outfall stabilization. Quantitative goals for each measure for each milestone have been established. For structural BMPs, the measure is expressed in terms of the drainage area restored. For nonstructural BMPs, the measure is uniquely defined for each BMP. For example, goals for catch basin cleaning are expressed as pounds of material collected and goals for stream restoration are expressed as linear feet of stream restored.

For the nonstructural BMPs, Maryland Assessment Scenario Tool incorporates equivalencies from the NPDES Accounting Protocol to convert BMP implementation quantities to impervious areas treated. For example, the accounting protocol defines 1 ton of material collected from catch basin cleaning as equivalent to 0.4 impervious acre treated by structural BMPs. Similarly, it defines 100 linear feet of stream restoration as equivalent to 1 impervious acre treated by structural BMPs.

MDSHA is also developing a custom application in a GIS environment that will track and generate reports for various parameters. Some potential reports may include TMDL 2-year milestone progress, MS4 database annual delivery, the MDSHA business plan data, bay expenditures data, and implementation status. The application will be housed in the SHA Enterprise GIS environment.

Part of the rationale for developing a custom application is that MDSHA would like to address several technical discrepancies it believes exist in currently available tracking and assessment tools. One of the areas being addressed is the method of accounting for nutrient credits for various nonstructural BMPs such as street sweeping and catch basin cleaning. The department is collaborating with MDE on these issues as it moves forward with its TMDL responsibilities.

Internally, SHA has convened a workgroup/oversight committee to bring all design, construction and operations functions within the SHA together to discuss the requirements, develop strategies, and address programmatic and funding gaps. Training was developed and given to all seven SHA district offices including design, construction, and maintenance managers, and TMDL liaisons have been designated for each district to address local implementation and coordination.

Budget needs for this TMDL are estimated to be $508.2 million for the fiscal years 2012 through 2016. However, prior to the start of fiscal 2012, only $78.2 million had already been planned for this period leaving a large gap in funding. MDSHA represents one of the transportation modes within the Maryland DOT, which estimates that the cost for all modes will be $1.5 billion. Maryland DOT recognizes TMDL implementation as a top priority, but also balances the safety of the traveling public in funding the implementation.

CHAPTER FOUR

MATRIX/TOOLBOX

BACKGROUND

Based on the results of the literature review as discussed in the previous chapter, a BMP matrix/toolbox was developed to provide state DOTs with easy access to TMDL-related BMP performance and cost data. The matrix/toolbox is presented in Tables 20–23. Table 20 includes relative performance categories (high, medium, low, and negative) for some of the more common structural highway BMPs based on pollutant removal efficiencies (i.e., percent pollutant removed). This performance metric was chosen because it is ubiquitous in the literature and is accepted by many state and federal regulatory agencies. The categories are defined as follows: high = >65%, medium = 31%–65%, low = 0%–30%, and negative = <0% (i.e., the BMP is exporting the pollutant). The performance data were derived from ten different sources that are provided in the table as hyperlinks where the reader may obtain more detailed information. Five life-cycle cost data sources are also provided in the table. However, cost data could not be adequately synthesized because the source reports use different methods of cost estimating and different reporting units. In addition, they do not assess the same types of BMPs. Therefore, direct comparison was not possible. For the purposes of this table, the cost sources were grouped with certain BMP types based on certain assumptions [e.g., "filtering practices (sand) above and below ground" from King and Hagan (2011) is equivalent to Austin and Delaware sand filters from Caltrans (2004)]. This was necessary because BMP naming conventions are not standardized nationwide. BMP definitions are generally provided in the source reports; however, they may not be consistent or grouped in a similar fashion. In addition to the hyperlinks, the full web addresses for all of the sources used in Table 20 is provided in the References at the end of this report.

The second table in the BMP matrix/toolbox (Table 21) is a companion to Table 20; it provides definitions of the BMPs listed in Table 20. Sources were specifically chosen from the same state as the sources in Table 20 to avoid mixing naming conventions and definitions from different states as discussed earlier. Tables 22 and 23 are repeated from earlier sections in this report: Table 22 is the same as Table 9 in International Stormwater BMP Database in chapter three and Table 23 is the same as Table 10 in Nonstructural Best Management Practice Performance in chapter three. They are repeated here to present all the information in one place for easier viewing and accessibility for the reader. Table 22 presents more detailed quantitative performance data (beyond low, medium, and high categories) from the International Stormwater BMP Database, including influent/effluent concentrations and summary statistics. Note, however, that these data are not necessarily all from highway applications, although several DOTs contribute data to the database. Table 23 provides quantitative performance data for nonstructural BMPs to the extent that data were available in the literature. In general, the BMP matrix/toolbox focuses on the more prevalent TMDL pollutants of concern (TSS, nutrients, fecal coliform, total metals) based on our impression of the most pressing needs of the DOTs. Many other TMDL pollutants of concern exist (e.g., biological integrity, PCBs, polycyclic aromatic hydrocarbons, pesticides; see Table 1); however, little to no information was found on the ability of highway BMPs to address these pollutants.

The intention of the report is to provide a user-friendly compendium of information with both qualitative and quantitative data on structural and nonstructural highway BMPs. The matrix is considered to be reasonably comprehensive in that it derives information from 13 unique sources (10 for performance and 5 for costs, with 2 sources overlapping). Although some details have been omitted for clarity, the interested reader is encouraged to access the complete reports by means of hyperlinks. Additional information is available in several places: (1) the earlier sections of this report (see Institutional Practices for Total Maximum Daily Load Implementation and Total Maximum Daily Load Implementation Plans in chapter three for nonstructural practices, and Literature Review on Highway Best Management Practices Performance Studies in chapter three for structural BMPs); (2) the References section at the end of this report, which includes almost 70 sources; and (3) the state DOT interview summaries in Appendix B. Finally, the reader is referred to an ongoing NCHRP study (25-40) entitled, "Long-Term Performance and Life-Cycle Costs of Stormwater Best Management Practices."

TIMELINE OF TOTAL MAXIMUM DAILY LOAD AND NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM PERMIT DEVELOPMENT PROCESS

In addition to the BMP matrix/toolbox, an idealized timeline is also presented summarizing actions by states or the EPA and DOTs during the TMDL and NPDES permit development process. The timeline is not specific to any state, but rather is intended as a generic sequence of events that could apply anywhere. The objective of the timeline is to show how

TABLE 20
RELATIVE PERFORMANCE CATEGORIES (high, medium, low, and negative; see footnote c for definitions) OF SOME COMMON STRUCTURAL HIGHWAY BMPs BASED ON PERCENT REMOVAL EFFICIENCY

Common Structural BMPs Used by DOTs	Life-Cycle Cost Sources	TSS	TN	TP	Fecal Coliform	Total Zn	Total Cu	Total Pb	Performance Source(s)
Infiltration Basin[a]	[1], [8], [9], [10][b]	High[c]	—	High	High	High	—	—	[2][b]
EDB lined	[1], [10]	Medium	Low	Low	—	Medium	Low	Low	[1]
EDB unlined	[1], [10]	High	Low	Medium	—	Medium–High	Medium	High	[1]
Infiltration Trench	[1], [5], [8], [10]	High	—	High	High	High	—	—	[2]
Biofiltration Strip	[1], [9]	High	Low	Negative	—	High	Medium	Medium	[1]
Biofiltration Swale	[1], [5], [9]	Medium	Low	Negative	—	High	Medium	High	[1]
Austin Sand Filter	[1], [5], [8], [10]	High	Medium	Medium	Medium	Medium–High	Medium	High	[1], [2]
Delaware Sand Filter	[1], [5], [8], [10]	High	Low	Low–Medium	High	High	High	High	[1], [2]
Wet Basin	[1], [5], [8], [10]	High	Medium	Negative–Low	High	High	High	High	[1], [2]
Vegetated Buffer Strips	—	Medium–High	Negative	Negative–Medium	Variable	High	—	—	[2]
Dry Detention Pond	[5], [9] , [10]	Variable	Low–Medium	Low–Medium	—	Variable	—	Variable	[3], [4]
Vegetated Swales	[8], [10]	Low–Medium	—	Low	Low	High	—	—	[2]
Bioretention	[8], [9], [10]	High	—	High	—	—	—	—	[5]
Constructed Wetland	[5], [8], [9], [10]	High	Low–Medium	Medium–High	—	Medium	Medium	High	[5], [6], [7]
Permeable Friction Course	—	High	—	—	—	High	Medium	High	[11], [12]
Media Filter Drain/Ecology Embankment	—	High		Medium	—	High	High	—	[13]

Performance and life-cycle cost data sources are provided as hyperlinks (hit Control + Left Click).
[a]Definitions of BMPs are provided in Table 21.
[b]Sources: [1] = Caltrans (2004): http://www.dot.ca.gov/hq/oppd/stormwtr/Studies/BMP-Retro-fit-Report.pdf; [2] = Hon et al. (2003): http://www.utexas.edu/research/ctr/pdf_reports/0_4252_1.pdf; [3] = Keblin et al. (1998): http://ntl.bts.gov/lib/24000/24700/24753/2954_1.pdf; [4] = Oregon State University et al. (2006): http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_565.pdf; [5] = MnDOT (2005): http://www.lrrb.org/pdf/200523.pdf; [6] = Farrell and Scheckenberger (2003): http://www.cawq.ca/cgi-bin/journal/pdf_view.cgi?language=english&article=84; [7] = Yu et al. (n.d.): http://www.northinlet.sc.edu/training/media/resources/Constructed%20Wetlands%20SW%20Mgmt.pdf *and* http://www.northinlet.sc.edu/training/media/resources/Constructed%20Wetlands%20SW%20Mgmt.pdf; [8] = Arika et al. 2006: http://www.lrrb.org/pdf/200549A.pdf; [9] = URS Corporation (2010): Transportation Oversight Committee, prepared for North Carolina Department of Transportation, July 2010 [Online]. Available: https://connect.ncdot.gov/resources/hydro/Stormwater%20Resources/Stormwater%20Runoff%20from%20Bridges%20-%20May%202012.pdf; [10] = King and Hagan (2011): http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/King_Hagan_Stormwater%20Cost%20Report%20to%20MDE_Final%20Draft_12Oct2011.pdf; [11] = Barrett (n.d.): http://www.rmc-foundation.org/images/PCRC%20Files/Hydrological%20&%20Environmental%20Design/Stormwater%20Quality%20Benefits%20of%20a%20Permeable%20Friction%20Course.PDF [12] = Eck et al. (2012): http://ascelibrary.org/action/showAbstract?page=174&volume=138&issue=2&journalCode=joeedu; [13] = WSDOT (2006): http://www.wsdot.wa.gov/NR/rdonlyres/3D73CD62-6F99-45DD-B004-D7B7B4796C2E/0/EcologyEmbankmentTEER.pdf. Control + Left Click on hyperlinks to access report.
[c]Removal efficiencies are defined as follows: High = >65%, Medium = 31%–65%, Low = 0%–30%, Negative = <0% (i.e., net export of pollutant).

TABLE 21
DEFINITIONS OF STRUCTURAL BMPs USED IN TABLE 20

BMP Type	Definition	Source
Infiltration Basin	An infiltration basin is a depression used to detain stormwater for short periods until it percolates to the groundwater table. It functions as a BMP through filtration of runoff and adsorption of pollutants using site vegetation and soils.	Caltrans (2010b)
Extended Detention Basin	An extended detention basin is an empoundment lined with either vegetated soil or concrete. Stormwater runoff is conveyed from freeways to these basins through the storm drain system. Stormwater collects in the basins and the outlet allows water to drain slowly, while sediment and other particulate forms of pollutants settle out.	Caltrans (2007)
Infiltration Trench	An infiltration trench is typically a long and narrow excavation that is lined with filter fabric and backfilled with stone aggregate or gravel to form an underground basin. Runoff is diverted to the trench and infiltrates into the soil.	Caltrans (2010a)
Biofiltration Strip	Biofiltration strips are relatively flat, vegetated areas that accept stormwater runoff as sheet flow.	Caltrans (2010a)
Biofiltration Swale	Biofiltration swales are vegetated conveyance channels that concentrate flow.	Caltrans (2010a)
Austin Sand Filter	The Austin Sand Filter includes a sedimentation basin and a filtration basin. The sedimentation basin captures and detains the design water quality runoff volume (typically for 24 h) prior to discharge to the filtration basin. The sedimentation basin removes floatable debris and coarse suspended solids, and prevents premature clogging of the filter media surface. The sedimentation chamber effluent discharges to the filtration basin typically through a perforated riser. In the filtration basin, the water first passes through a sand layer, then through a geotextile layer, and finally into a gravel underdrain.	Caltrans (2010a)
Delaware Sand Filter	The Delaware unit consists of separate sedimentation and filter chambers, but differs from the Austin design in that a permanent pool is maintained in the sedimentation chamber. Ideally, runoff enters the sedimentation chamber as sheet flow. As runoff enters the chamber, water remaining in the device from previous storms is displaced and flows over a weir into the sand filter chamber.	Hon et al. (2003)
Wet Basin	A wet basin holds a permanent pool of water designed to detain and treat a runoff water quality volume. The basin supports plant species that provide constituent removal by biological processes. In addition, the vegetation may help reduce erosion of the side slopes and trap sediments. Sedimentation processes also occur in the basin. Wet basins are usually deep enough to prevent resuspension of particles, and should be sited where a permanent pool of water can be maintained from a dry weather flow source.	Caltrans (2010a)

(*continued on next page*)

TABLE 21
(*continued*)

BMP Type	Definition	Source
Vegetated buffer strip	Vegetated buffer strips differ from vegetated swales (see below) in that runoff occurs as sheet flow rather than being conveyed as concentrated flow in a channel. Vegetated buffer strips usually are densely vegetated and have a uniformed slope.	Hon et al. (2003)
Dry Detention Pond	The primary purpose of a dry detention pond is to control the peak flow associated with the runoff from a watershed. Reduction in the rate of flow can limit the frequency of occurrence of erosion, thereby reducing the sediment load to the receiving waters. The secondary purpose of the pond is to temporarily store runoff to allow the removal of particulate material by settling.	Keblin et al. (1998)
Vegetated Swale	Biofiltration swales or vegetated swales are broad, shallow channels that are lined with dense vegetation on the side slopes and channel bottom to aid in pollutant removal. Swales are designed to convey storm water with an appropriate amount of detention time to allow for pollutants to be trapped, promote infiltration, and also reduce the velocity of the flow.	Hon et al. (2003)
Bioretention	Bioretention systems are essentially landscaped depressions to which stormwater runoff is diverted and stored. Once in the depression, the landscaped trees, shrubs, and other vegetation help to remove the water through uptake, while the runoff infiltrates into the soil below. The underlying soil may consist of the original soil or it may be nonnative soil such as sand that is installed during construction. Also, depending on the permeability of the underlying soil, a bioretention system may include a perforated underdrain that collects and removes infiltrated water.	MnDOT (2005)
Constructed Wetland	Constructed wetland systems are similar to retention and detention systems, except that a major portion of the water surface area contains wetland vegetation.	MnDOT (2005)
Permeable Friction Course	Roadway material 25–50 mm thick applied over regular impermeable pavement	Barrett (n.d.)
Media Filter Drain/Ecology Embankment	Linear flow-through treatment devices designed for highway side-slopes, medians, borrow ditches, or other linear depressions in areas of limited right-of-way.	WSDOT (2006)

DOTs can respond to specific actions by states/EPA during the process to help them develop an effective TMDL implementation program. From the state/EPA side, the timeline begins with the inclusion of the water body on the 303(d) list of impaired waters and the development of the draft and final TMDL, and continues with proposing an NPDES permit with TMDL-related requirements and then finalizing the NPDES permit. On the DOT side, the actions highlight the need to submit data and engage with the regulatory agency *early on* in the TMDL development process (before the TMDL modeling process). An additional DOT action is to review and comment on the draft TMDL and NPDES permit in order to negotiate a position that is favorable to the DOT, especially as related to TMDL requirements. The overall process is summarized in a timeline graphic in Figure 9.

There are some excellent examples of DOTs that follow this general approach. For example, NCDOT collaborates with the regulatory agency early on in the TMDL development process (typically providing data, expertise, and sometimes funding) to ensure the process is based on the best available science. This has translated into tangible benefits for the DOT, including the ability to help define its WLA and form a reasonable TMDL implementation strategy, and a recognition and understanding by the state that highway environments are unique entities that require a unique TS4 permit. Another example is WSDOT, which negotiates with its regulatory agency to develop reasonable "action items" to address TMDL requirements in their NPDES permit; these action items are developed by a single full-time equivalent working with the regulatory agency.

TABLE 22
INFLUENT/EFFLUENT SUMMARY STATISTICS FOR TOTAL SUSPENDED SOLIDS (TSS), TOTAL NITROGEN (TN), TOTAL PHOSPHORUS (TP), FECAL COLIFORM (FC), TOTAL ZINC (TZN), TOTAL COPPER (TCU), AND TOTAL LEAD (TPB) AS ADAPTED FROM GEOSYNTEC CONSULTANTS AND WRIGHT WATER ENGINEERS (2012)

BMP Type	Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*		Median (95% Conf. Interval)*	
	TSS In mg/L	TSS Out mg/L	TN In mg/L	TN Out mg/L	TP In mg/L	TP Out mg/L	FC In # / 100 mL	FC Out # / 100 mL	TZn In ug/L	TZn Out ug/L	TCu In ug/L	TCu Out ug/L	TPb In ug/L	TPb Out ug/L
Grass Strip	43.1 (36.0, 45.0)	**19.1 (16.0, 21.5)**	1.34 (1.06, 1.50)	1.13 (1.00, 1.23)	0.14 (0.11, 0.15)	***0.18 (0.15, 0.20)***	NA	NA	103.3 (86.0, 120.0)	**24.3 (16.0, 26.0)**	24.52 (19, 26)	**7.30 (6.4, 7.9)**	8.83 (6.6, 11.5)	**1.96 (1.30, 2.20)**
Bioretention	37.5 (29.2, 45.0)	**8.3 (5.0, 9.0)**	1.25 (1.06, 1.35)	**0.90 (0.74, 0.99)**	0.11 (0.08, 0.12)	0.09 (0.07, 0.10)	NA	NA	73.8 (62.0, 83.5)	**18.3 (7.7, 25.0)**	17.0 (11.0, 23.0)	**7.67 (4.60, 9.85)**	3.76 (2.49, 5.5)	2.53 (2.50, 2.50)
Bioswale	21.7 (16.2, 26.0)	**13.6 (11.8, 15.3)**	0.75 (0.60, 0.92)	0.71 (0.63, 0.82)	0.11 (0.09, 0.12)	***0.19 (0.17, 0.20)***	4720 (2120, 5500)	5000 (2600, 6200)	36.2 (30.0, 40.0)	**22.9 (20.0, 26.6)**	10.86 (8.70, 13.20)	**6.54 (5.7, 7.7)**	3.93 (2.80, 5.00)	**2.02 (1.80, 2.29)**
Detention Basin	66.8 (52.3, 76.1)	**24.2 (19.0, 26.0)**	1.40 (1.03, 1.57)	***2.37 (1.75, 2.69)***	0.28 (0.25, 0.30)	**0.22 (0.19, 0.24)**	1480 (789, 1900)	1030 (500, 1900)	70.0 (40.0, 95.0)	**29.7 (17.1, 38.2)**	10.62 (7.78, 14.00)	**5.67 (4.0, 6.8)**	6.08 (3.86, 8.0)	3.10 (2.15, 4.30)
Manufactured Device	34.5 (30.0, 36.8)	**18.4 (15.0, 19.9)**	2.27 (1.98, 2.65)	2.22 (1.90, 2.41)	0.19 (0.16, 0.22)	**0.12 (0.10, 0.13)**	NA	NA	87.7 (79.0, 95.0)	**58.5 (52.8, 63.5)**	13.42 (11.90, 14.70)	**10.16 (7.94, 11.0)**	8.24 (6.77, 9.56)	**4.63 (3.80, 5.16)**
Manufactured Device-F**	NA	NA	NA	NA	NA	NA	478 (200, 1300)	1890 (200, 3000)	NA	NA	NA	NA	NA	NA
Manufactured Device-P**	NA	NA	NA	NA	NA	NA	2210 (900, 3000)	2750 (1400, 5000)	NA	NA	NA	NA	NA	NA
Media Filter	52.7 (45.9, 58.2)	**8.7 (7.4, 10.0)**	1.06 (0.85, 1.25)	**0.82 (0.68, 0.99)**	0.18 (0.16, 0.19)	**0.09 (0.08, 0.10)**	1350 (725, 2300)	**542 (200, 625)**	77.3 (68.2, 86.0)	**17.9 (15.0, 20.0)**	11.28 (10.0, 12.68)	**6.01 (5.1, 6.6)**	10.5 (8.02, 11.79)	**1.69 (1.30, 2.00)**
Porous Pavement	65.3 (45.0, 80.3)	**13.2 (11.0, 14.4)**	NA	NA	0.15 (0.12, 0.16)	**0.09 (0.08, 0.09)**	NA	NA	57.6 (49.6, 66.0)	**15.0 (12.5, 16.8)**	13.07 (11.45, 15.3)	**7.83 (6.80, 8.10)**	4.30 (3.28, 5.47)	**1.86 (1.38, 2.21)**
Retention Pond	70.7 (59.0, 79.0)	**13.5 (12.0, 15.0)**	1.83 (1.60, 1.98)	**1.28 (1.19, 1.36)**	0.30 (0.27, 0.31)	**0.13 (0.12, 0.14)**	1920 (970, 2650)	**707 (200, 1160)**	53.6 (49.0, 59.0)	**21.2 (20.0, 23.0)**	9.57 (8.0, 10.0)	**4.99 (4.06, 5.0)**	8.48 (6.80, 9.41)	**2.76 (2.00, 3.00)**
Wetland Basin	20.4 (16.6, 24.4)	**9.06 (7.0, 10.9)**	1.14 (1.04, 1.28)	1.19 (1.04, 1.21)	0.13 (0.11, 0.14)	**0.08 (0.07, 0.09)**	13000 (5080, 21000)	6140 (230, 11800)	48.0 (40.6, 53.2)	**22.0 (16.7, 24.3)**	5.61 (4.36, 6.34)	**3.57 (3.00, 4.00)**	2.03 (1.57, 2.24)	**1.21 (1.00, 1.55)**
Wetland Channel	20.0 (17.0, 22.0)	**14.3 (10.0, 16.0)**	1.59 (1.38, 1.78)	1.33 (1.05, 1.56)	0.15 (0.13, 0.17)	0.14 (0.13, 0.17)	NA	NA	23.0 (16.0, 30.0)	15.6 (11.0, 20.0)	4.52 (3.80, 5.10)	4.81 (3.61, 5.2)	2.94 (1.90, 4.20)	2.49 (1.40, 3.11)

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**For bacteria, manufactured devices are broken down into inlet insert/filtration (Manufactured Device – F) and physical settling/straining devices (Manufactured Device – P).

NA = Limited or no data available.

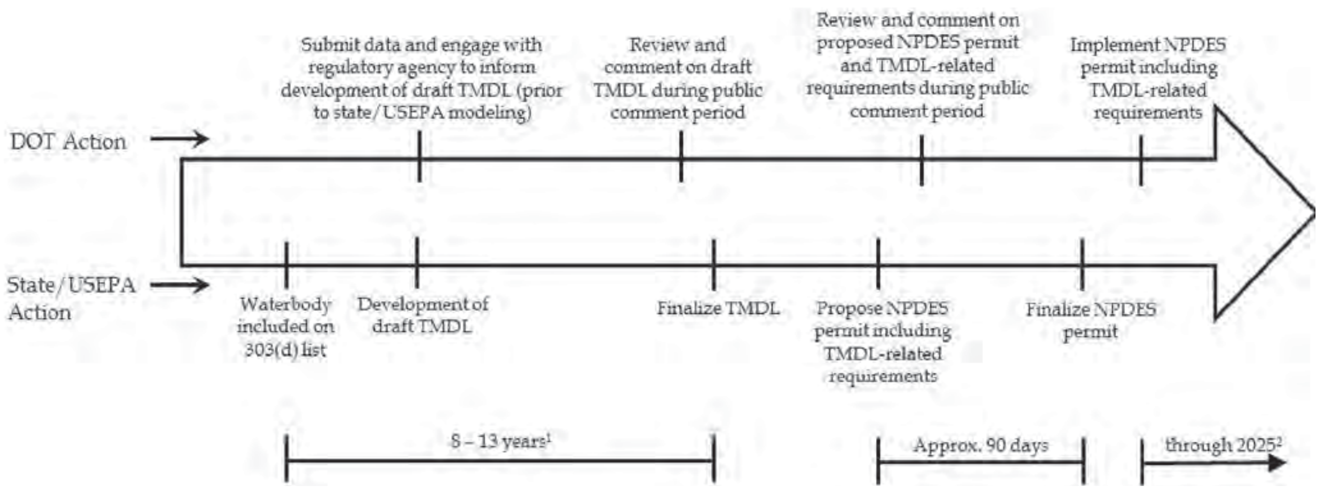
<values> Hypothesis testing shows statistically significant **decrease** in median concentration for this BMP type.

<Values> Hypothesis testing shows statistically significant **increase** in median concentration for this bmp type.

Data are from the international stormwater bmp database (www.bmpdatabase.org).

TABLE 23
NON-STRUCTURAL BMP PERFORMANCE MEASURES

BMP/Study	TSS	Nutrients (phosphorus, nitrogen)	Metals (copper, lead, zinc)
Street Sweeping			
Performance modeled with sweeping frequency from twice weekly to biweekly (HECI 2006)	45 to 70% reduction in annual loads	35 to 60% reduction in phosphorus annual loads	25 to 60% reduction in annual loads
Spreadsheet model assuming sweeping frequency of 6 to 12 times per year (HECI 2006)	25 to 35 lb removed per lane mile per year	<0.1 lb phosphorus removed per lane mile per year	<0.1 lb removed per lane mile per year
Catch Basin Cleaning			
Spreadsheet model with cleaning frequency from every 3 months to once in 5 years (HECI 2006)	0 to 45% reduction in annual loads		
Alameda County study with cleaning frequencies from monthly to annual (HECI 2006)	8 to 70 lb removed per cleanout; generally a decline in removal per cleanout with higher frequency		
Spreadsheet model with frequency ranging from every 4 days to every 40 days (HECI 2006)	35 lb removed per cleanout; constant regardless of frequency	0.00003 lb phosphorus removal per catch basin per cleaning	0.0000012 to 0.0000064 lb removal per catch basin per cleaning
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	2000 lb removed by cleaning is equivalent to 0.4 impervious acres of structural BMP treatment		
Tree Planting			
Reforestation (NVPDC 1996)		Nonpoint source runoff concentrations for phosphorus reduced from 0.205 to 0.15 mg/L and for nitrogen reduced from 0.139 to 0.078 mg/L as examples	
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	1 acre of planting is equivalent to 0.38 impervious acres of structural BMP treatment		
Stream Restoration			
Site-specific evaluation (CCBWQA 2011)		90–220 lb phosphorus immobilized per mile per year	
MD NPDES Accounting Protocol (specifics on pollutants not given) (MDSHA 2012)	100 linear feet of restoration is equivalent to 1 impervious acre of structural BMP treatment		



[1]From EPA (2009).
[2]Example from Chesapeake Bay TMDL implementation plan, but varies from state to state.

FIGURE 9 Idealized timeline of TMDL and NPDES permit development process. DOT actions are shown on the top of the arrow and state/EPA actions are shown on the bottom.

CHAPTER FIVE

CONCLUSIONS AND FURTHER RESEARCH

Based on the information presented in the previous chapters, the following conclusions were drawn. They are grouped into four general topic areas: (1) best management practice (BMP) performance and cost, (2) effective total maximum daily load (TMDL) implementation strategies, (3) main challenges, and (4) further research.

BEST MANAGEMENT PRACTICES PERFORMANCE AND COST

Our BMP matrix/toolbox identified relative performance rankings (high, medium, low) based on percent removal efficiency for a wide variety of structural highway BMPs. Many of the BMPs had a high ranking for total suspended solids (TSS) indicating >65% removal; for example, infiltration basins, sand filters, bioretention, permeable friction course, and others (see Table 20). Nutrients, on the other hand, were more difficult to treat, especially total nitrogen for which none of the structural BMPs had a high performance ranking. Austin sand filters and wet basins appear to be the most promising for removing total nitrogen; both had a medium ranking (31%–65% removal). The apparent inability of most BMPs to treat nitrogen is most likely the result of the complex nature of the nitrogen cycle and the many site-specific factors that affect the transformation of nitrogen species, such as microbes, and the extent of aeration. Total phosphorus results were highly variable depending on the BMP, ranging from negative (net export) to high. However, infiltration basins, infiltration trenches, and bioretention each had a high ranking for total phosphorus removal.

Fecal coliform performance data were limited; however, several of the BMPs were identified as having a high ranking, including infiltration basins, infiltration trenches, Delaware sand filters, and wet basins. Finally, for metals, performance is difficult to evaluate as it tends to vary depending on the analyte and in many cases data were not available for total copper and total lead. However, the Delaware sand filter and the wet basin stood out as having a high performance ranking for total zinc, total copper, and total lead.

Regarding costs, several sources of life-cycle cost data are presented in the matrix/toolbox for structural BMPs. However, a true cost–benefit analysis was not possible owing to differences in cost estimating approaches and reporting units, variability in costs by region, and inconsistencies in BMP naming conventions in the source reports. The reader is encouraged to access the complete reports (provided as hyperlinks in Table 20) to obtain cost data that are most relevant for their state/region.

More detailed quantitative performance data are also presented from a large number of studies from the International Stormwater BMP Database. The data are reported as influent/effluent concentrations with the 95% confidence interval and statistical significance. Based on these data, TSS and metals (total zinc, total copper, and total lead) appear to be relatively easy to treat with many types of BMPs (e.g., grass strips, wetland basins, etc.; see Table 22), whereas nutrients and fecal coliform are relatively difficult to remove. This is generally consistent with the findings of the literature review. Media filters and retention ponds stood out as being effective at treating all of the TMDL pollutants of concern examined (TSS, nutrients, fecal coliform, and metals), where effectiveness is defined as having a statistically significant reduction in pollutant concentrations.

As for nonstructural BMPs, quantitative performance data tend to be sparse and performance metrics vary widely and/or may not be transferable nationwide. Therefore, deriving numerical load reductions for TMDL purposes continues to be a challenge. However, some studies were identified with performance data that are summarized in Table 23. Based on these findings, street sweeping and catch basin cleaning have the potential to be moderately effective at removing TSS, nutrients, and metals provided they are performed frequently (weekly to biweekly for sweeping, every three months for catch basin cleaning) to prevent build-up of pollutants; also, in the case of sweeping, the technology must be suitable to maximize pollutant removal. Other nonstructural practices are not as well quantified for the range of TMDL pollutants examined in this report; however, tree planting and stream restoration have been documented as providing water quality benefits for nutrients. The Maryland State Highway Administration has also developed a method to convert acres of tree planting and linear feet of stream restoration to equivalent acres of impervious area treated. Other practices such as anti-icing management are difficult to quantify. However, one very successful example was noted in New Hampshire where the department of transportation (DOT) has demonstrated a 20% reduction in chloride loads by upgrading the technology of their salt application fleet.

EFFECTIVE TOTAL MAXIMUM DAILY LOAD IMPLEMENTATION STRATEGIES

Developing an effective TMDL strategy begins with *awareness and education within the DOT on TMDL issues,* which may be challenging in cases where the different DOT divisions (design, maintenance, environmental, etc.) are not integrated. Based on our findings, we found that awareness of TMDLs ranged from basically no awareness at all in states where the DOT was not named in any TMDLs, to full awareness and very active participation in implementing strategies in states where the DOT was named a stakeholder in a large number of TMDLs. Awareness and training will become especially important as TMDLs continue to emerge nationwide; in some states, hundreds more are expected to be implemented where the DOT may be named a contributor.

Collaboration with other stakeholders and jurisdictions is key to developing an effective TMDL strategy. A prime example is Delaware, where the DOT shares a joint National Pollutant Discharge Elimination System MS4 permit with other stakeholders, which facilitates collaboration among the co-permittees to implement BMPs on a watershed-wide basis rather than just within the DOT right-of-way. Another example of collaboration is in New Hampshire where the DOT reduced the application of road salts by 20% to address chloride TMDLs by upgrading their fleet of plows and applicators with the latest technologies for salt application. These technologies were shared with private and municipal operators through a collaborative approach known as the Technology Transfer program through the University of New Hampshire.

Another key element of an effective TMDL strategy is *early and active participation in the TMDL development process.* North Carolina is an ideal DOT in this regard. It has a strong working relationship with its regulatory agency and in most cases contributes data and scientific expertise to help define its own contribution to the waste load allocation (WLA) and ensure a realistic TMDL strategy. The Washington State DOT also actively participates in TMDL development and it works with the regulatory agency to write specific action items into their National Pollutant Discharge Elimination System permits. *Proper estimation of loads* is also important to developing an effective TMDL strategy. Calculating baseline pollutant loads and predicting potential load reductions from various BMP implementation scenarios is critical to a successful TMDL program. This procedure has two main advantages. First, it provides a decision support system to assist highway managers in developing the most cost-effective TMDL strategy. Second, the data generated may be provided to the state regulatory agency during the TMDL development process and may help define the DOT's contribution to the WLA, potentially resulting in a more targeted and effective TMDL strategy. In North Carolina, this process has helped inform the development of a unique TS4 permit, which represents recognition by the regulatory agency that permits need to address specific DOT concerns given the unique nature of their linear highway assets. Transportation Separate Storm Sewer System (TS4) permits may be a useful model for other states with traditional Municipal Separate Storm Sewer System (MS4) permits.

Based on the state DOT interview responses, five of the 12 states (Colorado, Delaware, New Hampshire, New York, and Virginia) use some type of modeling tool(s) to estimate loads. The Simple Method was the most common model cited (used by New Hampshire, New York, Delaware, and Virginia); others included SELDM (Stochastic Empirical Loading and Dilution Model, used by Colorado and New York), WinSLAMM (Source Loading and Management Model for Windows, by New York), PLOAD (Pollutant Loading, by Delaware), and the Watershed Treatment Model (by Virginia). The California DOT (Caltrans) uses a water quality planning tool with embedded calculations to estimate loads; however, it is intended primarily for designers. North Carolina DOT uses the Simple Method to develop their nutrient management strategies, but do not use any models for TMDL purposes. However, the state regulatory agency in North Carolina (the North Carolina Department of Environment and Natural Resources) uses several modeling tools such as HSPF (Hydrological Simulation Program FORTRAN), LSPC (Loading Simulation Program in C++), load duration curves, and others.

MAIN CHALLENGES

Although some states had relatively successful TMDL programs, many states noted significant challenges to developing an effective implementation strategy. A common theme across most DOTs was a *lack of manpower and financial resources.* In addition, several DOTs cited *the lack of effective BMP technologies for linear highway applications,* and some expressed *difficulties in navigating the complex regulatory environments within their state.* For example, several states with multiple regulatory agencies and other government entities noted a number of challenges including (1) inconsistent enforcement and interpretation of TMDL requirements among the state regulatory agencies that prevented the DOT from developing comprehensive TMDL strategies, (2) requirements placed on DOTs by regulatory agencies on which BMPs the DOT can use, and (3) communication challenges between the DOT and state regulatory and federal agencies.

FURTHER RESEARCH

More research is needed on long-term adverse environmental and cultural impacts related to BMP implementation. For example, in arid climates where BMP vegetation is difficult to grow, soil degradation (wind and erosion loss, decreased organic addition to soils), human health effects from dust, and adverse impacts of decreased grass surface on water infiltration and stormwater movement may be an issue. Some DOTs also noted that fire hazards were a concern for some

BMPs in arid regions; others cited mosquitoes and West Nile Virus in wet pool BMPs as potential threats to human health and safety. A few DOTs were also concerned about groundwater pollution impacts for infiltration BMPs.

Many DOTs cited the need for new and innovative BMP technologies designed for linear highway applications, especially in ultra-urban corridors. Although the list of BMP types is continually expanding, there have been relatively few studies on which BMPs are *specifically* effective for TMDL implementation for highways. Traditional DOT practices are typically ineffective for TMDL pollutants such as nitrogen, bacteria, and pathogens.

There need to be more studies conducted on BMP longevity, life-cycle costs, and maintenance costs and standards. Some life-cycle cost data are available (see Life-Cycle Costs in chapter three and Table 20); however, in general the cost estimating approaches, reporting units, and BMP naming conventions are not consistent, which prevents adequate synthesis of the information and negates the ability to conduct a cost–benefit analysis. Greater standardization of maintenance practices would benefit DOTs by ensuring continued performance of BMPs.

Entirely new TMDL strategies may be needed to address some of the less common pollutants of concern (e.g., biological integrity, sediment toxicity, organic compounds, or "surrogate" pollutants such as flow). To ensure permanent reduction of these pollutants from the right-of-way, more research is needed on alternative strategies (e.g., source control, institutional controls, and water quality trading).

Finally, there needs to be more standardization of BMP naming conventions in the literature. For example, what is called a "bioswale" in some states is called a "bioinfiltration swale" in others. Some states distinguish between Austin and Delaware sand filters (typically those in the western United States), while others lump them together as "sand filters" or "media filters" (which may or may not include sand). Similarly, bioretention practices are sometimes called "rain gardens" even though the design is essentially the same. Glossaries do exist with standardized BMP types and descriptions [e.g., see MDE (n.d.)], but tend to be specific to that state or region.

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APPENDIX A

Interview Questionnaire

NCHRP Topic 43-06 Interview Questionnaire
April 2012

Agency: ____

Address: ____

____

City: ____ State: ______ ZIP:________

Questionnaire Contact: ____

Position/Title: ____

In case of questions and for NCHRP to send you a link to the final report, please provide:

Tel: _______________________ E-mail: _______________________

1. Is your DOT named or expected to be named a stakeholder in a TMDL? Yes/No/Not sure

2. What organizational units are responsible for compliance on this TMDL? Yes/No

3. How many TMDLs is your DOT participating in? 1–3, 4–7, 7–10, >10 /Not sure

4. Did the DOT participate in the development of any TMDL? Yes/No/Not sure

5. If you answered Yes to number 4 above, which of the following best describes why you participated in the development of the TMDL?

   a. Stormwater discharges are regulated under NPDES Stormwater Permits (including discharges from Phase I or Phase II MS4 and construction activities);

   b. Stormwater discharges are regulated under Consent Decree Agreement; or

   c. Other……

6. Has the DOT implemented a policy of participating in the development process of current or future TMDLs? Yes/No/Not sure

7. Provide a short description of the DOT's policy for participating on local TMDLs. Please briefly describe the program evolution if participation has increased (or decreased) over time.

8. Do you have a TMDL waste load allocation or WLA for a pollutant or pollutants assigned specifically to your discharges? Yes/No/Not sure

9. Are your TMDL WLAs aggregated under a watershed-wide total WLA for a particular pollutant? Yes/No/Not sure

10. Did the DOT provide data to support the Load Allocation (LA) or WLA? Yes/No/Not sure

11. Do you estimate pollutant loads from DOT rights-of way for purposes of predicting, tracking and reporting reductions? Yes/No

12. Do you use standardized software to estimate baseline pollutant loads and reductions for TMDL compliance? Yes/No

13. If Yes to number 12 above, do you use a standardized computational procedure or software?

    a. Simple method (Spreadsheet)

    b. SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration Model)

    c. SELDM (Stochastic Empirical Loading and Dilution Model)

    d. WinSLAMM (Source Loading and Management Model for Windows)

    e. WTM (Watershed Treatment Model from the Center for Watershed Protection)

    f. Other ……

14. If Yes to number 12 above, which of the following best describes the role of the regulatory agency in the use of this standardized procedure or software?

    a. Procedure/software was approved by regulatory agency

    b. Procedure/software was imposed by regulatory agency

    c. Regulatory agency did not play any role in the use of the procedure/software

    d. Other ……

15. Have you developed a long-term policy for TMDL participation and compliance? Yes/No

16. If you answered Yes to number 14, what are some of the strategies you are using to implement your TMDL compliance plan?

    a. On-site structural stormwater control program for new location projects, and/or expansion and upgrade of existing projects

    b. Nonstructural practices

    c. DOT construction of offsite regional controls through partnership with local or state programs

    d. Participation in the construction of offsite/regional controls by others

    e. Offset and/or Nutrient Credit Trading. If so, please describe the process

    f. Other ……..

17. Which of the above is the most effective in your view in the long run: a, b, c, d, e, or f?

18. Does your DOT have a BMP inventory program?

19. List specific strategies or BMPs that you use to target the following pollutants.

    a. Nitrogen ………………………………………

    b. Phosphorus …………………………………

    c. Zinc …………………………………………..

    d. Copper ………………………………………

    e. Bacteria ……………………………………

f. Chloride ……………………………………

g. Temperature ………………………………

h. Sediments …………………………………

i. Trash………………….

j. Other …………………

20. What types of structural BMPs have you most utilized for stormwater treatment and pollutant reduction? Answer all that apply:

a. Bioretention

b. Permeable pavement

c. Stormwater wetlands

d. Detention and extended detention basins

e. Grass swales

f. Media (sand) filters

g. Infiltration

h. Other ……

21. What types of nonstructural BMPs have you utilized for stormwater treatment and pollutant reduction? Answer all that apply:

a. Sheet flow to vegetated filter strip

b. Sheet flow to conservation area

c. Street sweeping

d. Public education

e. Maintenance activities to protect or enhance water quality

f. Innovative BMPs. Please list: ________

g. Other source controls……

22. What are the costs associated with BMP implementation? What kind of costs do you track? e.g., capital, O&M, land acquisition, life-cycle.

23. Do you have or use a BMP design criteria or standard? If so please specify; e.g., state design manual, FHWA manual, etc. ……………..

24. What BMP performance measures do you use to gauge effectiveness?

a. Runoff volume reduction

b. Pollutant mass reduction

c. Pollutant concentration reduction

d. Other …..

25. Does your state utilize published BMP treatment efficiencies or pollutant removal rates? If so cite sources ….

26. Does your state utilize field measurements/sampling to gauge BMP effectiveness?

27. How does your DOT track maintenance needs and life-cycle costs?

28. Do you use a BMP maintenance standard? If so, please specify; e.g., state design manual, FHWA manual, etc. ……………..

29. Have you conducted any systematic observations of any BMPs located within the right-of-way to help predict the projected service life (maintenance interval)?

a. Bioretention

b. Permeable pavement

c. Stormwater wetlands

d. Detention and extended detention basins

e. Grass swales

f. Sand filters

g. Other media filters

h. Infiltration

i. Other…..

30. Do you participate in or provide any funding for research on highway-specific stormwater BMP performance? Yes/No. If Yes, please list…..

31. What strategies are you using to reduce external or offsite inputs of pollutants?

a. Watershed partnerships

b. Periodic connection permits review

c. Collaboration with adjoining property owners

d. Collaboration with adjoining MS4

e. Collaboration with the auto industry

f. IDDE inspections

g. Other…..

32. Do you have a standard policy for initiating collaboration with other parties, such as a local government, adjacent property owners, watershed groups, etc., to address stormwater requirements? If so, then please provide the policy language.

33. Do you have formal agreements with partners to implement the strategies?

34. What are the roles and responsibilities of your partners for the offsite BMPs?

    a. Planning

    b. Design

    c. Construction

    d. Maintenance

    e. Financing

    f. All of the above

    g. None of the above

35. What are the barriers to developing partnerships?

    a. Institutional

    b. Regulatory

    c. Legal

    d. Other, specify ……………

36. What are the most significant challenges in implementing your TMDL program?

    a. Regulatory

    b. Technological

    c. Financial

    d. Institutional capability/capacity

    e. Inter-agency coordination

37. Are there any unique challenges to implementing your TMDL program in your geographical area/climate?

38. Are there any long-term adverse environmental or cultural impacts related to stormwater BMPs?

39. What are your most significant successes in implementing your TMDL program? Please describe.

40. What systemic changes do you feel are needed to ensure permanent reductions of pollutants originating from the right-of-way? (such as the following as suggestions to prompt answers):

    a. Education and training of DOT designers and contractors

    b. Research and development on alternative BMPs (manufactured BMPs targeted for specific parameters)

    c. Watershed based approach

    d. Maintenance standards

    e. Other …..

41. What are your most significant future needs to develop an effective TMDL compliance program?

42. What other groups or agencies would be useful to contact for further information on this topic? Please provide a contact name, if possible.

a. Within the state DOT?

b. In state resource agencies?

43. Would you be willing to be contacted for further information about your agencies' TMDL compliance program? Yes/No

44. Do you have a website or any reports with additional information that you would be willing to share?

Glossary

Consent decree
: Also referred to as a Consent Order, is a judicial decree expressing voluntary agreement between parties to a suit.

Loading capacity
: The greatest amount of a pollutant that a receiving water body can assimilate and still meet water quality standards.

Load or loading
: The total amount of pollutants entering a water body from one or multiple sources, measured as a rate, as in mass per unit time or per unit area.

Load allocation (LA)
: The portion of the loading capacity attributed to (1) the existing or future nonpoint sources of pollution and (2) natural background sources. Wherever possible, nonpoint source loads and natural loads should be distinguished.

Total maximum daily load (TMDL)
: The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, and a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Wasteload allocation (WLA)
: The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution (e.g., permitted waste treatment facilities).

APPENDIX B

Department of Transportation Interview Summaries

Virginia Department of Transportation
April 16, 2012
Tracey Harmon, Environmental Division; Roy Mills, Location and Design; Morris Walton, Maintenance

The Virginia Department of Transportation has, like most DOT's, a very complex organizational structure, with each division operating within its own silo in terms of budgets, communication, roles and responsibilities, etc. In fact, one of the greatest accomplishments to date noted by the interviewees has been the increased awareness of the DOT's responsibility with regard to compliance with the MS4 Permit requirements including compliance with the growing number of TMDLs being developed across the Commonwealth. Further, the agency dedicated general operating budget to the MS4 program requirements for the first time in 2010. The interviewees were quick to note that this dedicated budget of $3M is barely adequate to address the growing list of current requirements, without consideration for what is on the horizon (overall estimates of the cost of TMDL compliance for Virginia DOT is $1B, although there was no specific breakdown of the estimate). The general response to the question of the most pressing needs was additional staff and financing.

The Virginia DOT program is implemented through a partnership of multiple divisions; however, the Environmental, Location and Design, and Maintenance Divisions take on the bulk of the responsibilities. The Environmental Division is responsible for the initial participation in any TMDL development process with the other watershed stakeholders, manages the Characterization Studies through a consultant, and then manages the development of the implementation strategies to be carried out by other divisions. VDOT is currently addressing 8 TMDLs, with another 20 plus expected to be approved by the next MS4 Permit cycle beginning 2013 (including the Chesapeake Bay TMDL). It is important to note that VDOT is only addressing the TMDLs in watersheds where they (and the local jurisdiction) have been designated as having responsibility for the discharge from an MS4. (There are currently 13 Urban Areas in the Commonwealth of VA).

Once a TMDL has been approved, the Characterization Study includes an analysis of the watershed and the VDOT right-of-way or property (in some cases VDOT may own a nonlinear facility such as a rest area, or maintenance area or district headquarters). The analysis verifies the assumptions of the VDOT owned acreage, and overall drainage area assessment and hydrologic analysis, estimates of baseline pollutant loads (using the Simple Method, Watershed Treatment Model, and other off-the-shelf methods) in order to estimate the baseline pollutant loads and evaluate potential load reduction strategies. The strategies (still in development) include a cost-based hierarchy that starts with on-site nonstructural BMPs utilizing the existing infrastructure of vegetated right-of-way to manage sheet flow from the road surface where possible, grass swales (if they meet the various design criteria), and any other available opportunities. Next is the use of off-site nonstructural practices such as community outreach, carcass removal programs, nutrient management plans for facilities, etc. (although there are still questions about how these practices will be credited toward compliance). And finally, on-site structural controls for new location and widening projects, and the retrofit of existing BMPs on existing right-of-way if located in a TMDL watershed. It is important to note that the agency has more confidence in the long-term compliance of on-site structural and nonstructural controls as they are able to maintain these practices and ensure continued performance.

Historically, the use of structural BMPs on VDOT right-of-way has been limited to detention and extended detention basins, primarily because the State stormwater program has required quality and quantity controls, making it relatively simple to address both requirements in a single facility. While this typically requires the purchase of right-of-way, the long-term O&M is contained with a single accessible location. As TMDLs are developed, the trend is expected to shift to linear treatment practices. While VDOT is not aggressively pursuing research of new or innovative practices, they do work with the Virginia Center for Transportation Innovation and Research to conduct research as funding is available. The VCTIR is scheduled to evaluate an LID/GI roadway project currently proposed in Northern Virginia.

Finally, VDOT does not have a formal policy for partnering with other watershed dischargers; however, they have in the past entered into agreements with localities and adjacent land owners to share responsibilities for managing stormwater: in some cases VDOT will build a facility and turn it over to the locality or private land owner for long-term O&M; in other cases VDOT will pay into a regional stormwater BMP program developed by the local jurisdiction. VDOT expects this opportunistic approach to continue on a case by case basis.

Ohio Department of Transportation
April 19, 2012
Jeffrey E. Syar, Becky Humphreys, Hans Gucker

TMDLs in Ohio are currently implemented through the State's NPDES construction stormwater permit program through the development of watershed specific Construction General Permits (CGPs) for the release of construction stormwater into targeted watersheds – rather than the statewide Construction General Permit. A statewide Construction General Permit addresses stormwater releases to nonspecific watersheds. Compliance on ODOT land disturbing activities within the designated TMDL watershed is triggered with the adoption of the watershed specific general permit as developed by Ohio EPA. There are currently only 2 watersheds covered by these watershed-specific CGPs, both happen to be developed for designated High Quality Watersheds, and both address sediment (TSS), with one also addressing temperature. ODOT estimates that approximately 40 new TMDLs are on the horizon; however, there is no set schedule for the development of the watershed specific Construction General Permits for these watersheds.

ODOT complies with the conditions of these watershed specific CGPs on any new location or expansion project that disturbs greater than 1 acre of land. Compliance generally includes developing and implementing an Erosion and Sediment Control Plan (or SWPP) in accordance with the Permit. There are no WLAs assigned to ODOT within the MS4 areas of these 2 watersheds, nor are there LAs outside the MS4 areas.

ODOT does not currently participate directly in TMDL development; however, they do provide comments through the public comment period of adopting a new CGP. It is anticipated that participation in the development of future TMDLs will be necessary if ODOT is assigned a specific WLA or if specific pollutants for post construction discharges are identified. Further, ODOT does not currently develop or provide data to support the development of LAs or WLAs, or for tracking or reporting reductions.

ODOT's Stormwater Program (within the Office of Hydraulic Engineering) is responsible for compliance with the TMDLs, and is responsible for informing and directing policies to other ODOT Divisions and offices as needed, including the Office of Construction Administration, Office of Maintenance Administration, Office of Facilities, Office of Training, Local Technical Assistance Program (LTAP), and Office of Environmental Services; all of which have stormwater quality activities and policies they manage under the MS4 permit (within the MS4 Urban Areas).

ODOT's Location and Design Manual, Volume 2, Drainage Design includes the typical menu of post-construction structural BMPs (Infiltration trench/Basin, Exfiltration Trench, Extended Detention, Retention Basin, Bioretention Cell, Constructed Wetlands, Manufactured Systems, and Vegetated Biofilters). Grass Swales, Exfiltration Trenches, and Manufactured BMPs were indicated as the most common structural practices in use, and Street Sweeping as the only nonstructural BMP in use (however, street sweeping is not implemented as a water quality BMP).

ODOT is currently developing a BMP inventory program (BMPs are currently tracked to some degree at lower divisions of operation, e.g., residencies and district maintenance; the new inventory program will likely consolidate the current processes being implemented individually). Also, ODOT has developed a Maintenance Administration Manual; however, there is no systematic process of tracking BMP O&M or life-cycle costs, nor is BMP performance tracked. Although exfiltration trenches were noted as being utilized to address post-construction stormwater, they were also noted as requiring very high maintenance efforts due to clogging. Research is being conducted at Ohio University on exfiltration trenches and vegetated biofilters (however, the interview indicated that exfiltration may be dropped from the preferred list of practices due to maintenance issues).

ODOT conducts an IDDE program within the MS4 area, and tracks any new connections to the drainage system statewide. However, it was specifically noted that there is very little legal authority to prevent pollutants from entering the right-of-way. There is no formal policy for partnering with local stormwater groups or other adjacent land owners; however, ODOT is open to the opportunity on a case by case basis. In fact, utilizing a watershed approach in partnership with other watershed stakeholders was identified as one of the systematic changes needed to ensure permanent reductions of pollutants originating from the right-of-way. Education and training of ODOT designers and contractors was also noted as an important need for TMDL compliance.

The most significant challenge to TMDL implementation and compliance noted by ODOT was the lack of a method to credit pollutant load reduction strategies for pollutants other than sediment. ODOT did, however, indicate a desire to develop a working relationship with State regulators in order to develop credits for these other pollutants. The lack of the system of crediting BMPs removes the incentive to spend resources on proactive TMDL compliance, relying solely on addressing specific permit requirements as those permits are developed. The lack of financial resources and institutional capacity were also noted as significant challenges (ODOT does not have any operating budget dedicated to TMDL compliance.)

New Hampshire Department of Transportation
April 19, 2012
Mark Hemmerlein, Water Quality/NPDES Specialist

The New Hampshire DOT is currently addressing 4 chloride TMDLs. There are no nutrient or other parameter TMDLs that identify the DOT as a source at this time; however, there is an expectation that nutrients will eventually be targeted. Recent efforts to address total nitrogen were deferred over the cost for wastewater treatment plant upgrades.

The chloride TMDL WLA is divided among three categories of dischargers identified as applicators of road salts: the NHDOT, municipalities, and private property owners. Allocation of the waste load is 10%, 35%, and 55%, respectively, and is determined based upon salt application data provided by NHDOT, towns, and estimates of private applicators. The NH Department of Environmental Services (NHDES) develops TMDLs, and the initial chloride TMDL was the result of a 401 certification of a wetland permit for a specific project (I-93) – the USEPA utilized the need for a permit in the impaired watershed to press for the development of the chloride TMDL.

A TMDL Implementation Plan or compliance strategy for the chloride TMDLs was developed through a pilot study paid for by the NHDOT. The study included the collection of load data. The strategy utilizes the latest road sensing salt application technology on the fleet of NHDOT plows and applicators. Through these nonstructural BMPs, NHDOT was able to reduce the application of road salts by 20%. The application of salt represents a significant expense so the result of the effort allows NHDOT to continue to provide for highway safety as well as recognize cost savings, while also protecting adjacent surface and ground water. Compliance is reported back to NHDES through 'salt' reports. The initiative has been received well by the public because the amount of salt application has been reduced without compromising road safety.

The overall development of other TMDLs in New Hampshire has been hampered by a lack of funding. Approximately 70% of the rivers and water bodies in the state are on the 303(d) list; however, there is limited funding to develop the corresponding TMDLs. As such, the NHDOT does not anticipate a need to ramp up compliance efforts other than to continue to implement the salt reduction strategies developed for the chloride TMDL. Therefore, there has been limited effort in terms of policies and/or BMP implementation although structural BMPs are required under state law. However, it is important to note that the NHDOT salt application technology development and implementation work may serve as a resource for all DOTs.

Post-construction water quality practices for new location and widening projects are implemented on projects in accordance with Section 401 Water Quality Certifications and State Law. NHDES has developed a stormwater manual that includes accepted structural and nonstructural BMPs and corresponding pollutant removal efficiencies (TP, TN, and TSS). NHDES recommends the Simple Method for nutrient load and load reduction estimates; however, NHDOT does not perform baseline nutrient (or other pollutant) loads or expected reduction computations unless required by a 401 Water Quality Certification.

The micro-pool wet extended detention basin was noted as the most common practice due to its cost-effective construction and maintenance (currently used in non-TMDL regulated MS4 areas); gravel wetlands have been used on projects with no-net loading requirements resulting from the 404 certification; however, they are noted for their high cost of construction. Nonstructural practices include street sweeping (however, it is not applied as a pollutant reduction practice), and a public education and outreach program through the MS4 permit (New Hampshire is a nondelegated NPDES state, so the permit is managed by EPA, and NHDOT is still operating under the 2003 permit). NHDOT has implemented an IDDE program and has mapped its urban area outfalls.

The NHDOT has implemented a BMP Inventory program. The BMP O&M costs are not tracked other than as part of the overall right-of-way maintenance budget (basins are estimated for budgeting purposes at $400–$600/year), and this generally includes routine maintenance. The NHDOT is relatively small and as such is able to readily communicate BMP construction and maintenance issues from the respective work units back to the design section. Some innovative BMPs (permeable pavement at park & ride lots, and pervious median barrier) have been installed and are still being observed (there is no flow or water quality monitoring being conducted).

NHDOT participates in the Technology Transfer (T2) at UNH which allows the sharing of the road salt application technology with private and municipal operators. Alternatively, there are no formal (or informal) partnerships with adjacent property owners as there are limitations on the ability to apply DOT funds to private properties. There have been cases of MOAs with community associations to address specific project issues.

The most significant challenge in implementing the TMDL program is related to the only TMDL currently in place: salt application. The application of salt leads to the degradation of aquatic resources; however, a reduction in salt application can lead to increased liability related to highway safety. The current road salt application technology being applied as a result of the TMDL, and the balance between NHDOT's transportation mission and environmental protection, is considered a significant success of the TMDL program. Similarly, the use of the T2 program to leverage those results is likewise considered a success.

Kansas Department of Transportation
April 23, 2012
Scott Shields, Environmental Scientist; Anthony Menke

The Kansas DOT is not currently named in any TMDLs. In general, KDOT does not foresee TMDLs being implemented in the near future by the local state agency, KDHE (Kansas Department of Health and the Environment). Kansas DOT does not have an official TMDL policy in place at this time; however, they are interested in learning about other TMDL programs across the country. Any upcoming Waste Load Allocations would be imposed on KDOT by the state, either aggregated or not (not known at this time).

Currently, KDOT focuses on implementing temporary construction BMPs to control sediment runoff which is strictly regulated through their NPDES permit renewed in 2012. These BMPs include silt fences, sediment basins, rock check dams, erosion control blankets, and bio-logs. There is no single preferred BMP; typically the most cost-effective option is selected during the contractor bidding process which includes the development of a SWPP plan. There are no nonstructural BMPs in place aside from a popular Adopt-a-Highway program for trash control. The cost for BMPs is tracked through the bidding process and usually includes capital cost and labor (no life-cycle tracking).

There is a standard manual developed by the state with erosion control design specifications for construction BMPs which KDOT has modified for their purposes. Design standards are enforced through bid specifications; however, KDOT has had problems with correct installation of BMPs by contractors. BMPs are maintained and inspected weekly by contractors and monthly by KDOT (and after any > 0.5″ rain event). Baseline pollutant loads from the roadway and BMP pollutant reductions are not quantified as there is no water quality monitoring requirement in the NPDES permit. KDOT does partner with the Texas DOT through the TTI program (Texas Tech Institute) which conducts research on erosion control blankets. The most effective blankets are then put on a list of approved products but there is no official list of approved BMPs, although all BMPs must meet ASTM standards. Along interstate highways, KDOT has a large heavily vegetated ROW and the assumption is that this buffers sediment runoff from the agricultural fields. Most BMPs are temporary (during construction only), and there is no retrofitting of post-construction BMPs. Only 1–2% of sediment basins and a slightly higher percentage of rock check dams are left in place as permanent structures.

In the future, KDOT sees benefits to including the agricultural community in the regulatory process as there is a lot more land area dedicated to agriculture than to construction in commercial areas. However, this is not likely in the near future.

Delaware Department of Transportation
April 23, 2012
Randy Cole, Vince Davis, Rob McCleary, Marianne Walch

The state agency of Delaware (Delaware Department of Natural Resources and Environmental Control or DNREC) has developed TMDLs for most watersheds in the state amounting to 29 TMDLs overall. The TMDLs target a variety of parameters—mostly nitrogen, phosphorus, and bacteria but also zinc, PCBs, and TSS. DNREC is also developing dissolved oxygen and habitat TMDLs. DelDOT does not participate in the development of the TMDLs as they do not have the scientific expertise; however, they do comment on them during public comment stage and participate in the development of pollution control strategies and watershed implementation plans (WIPS). DelDOT also actively works with other state DOTs as part of a stormwater practitioners group under AASHTO where TMDL compliance issues are discussed.

In general, TMDLs in Delaware are implemented in three ways: through the state regulations for sediment and stormwater control, through NPDES MS4 permits, and in the case of the Chesapeake Bay TMDL, as a blanket regulation across the state. Although DelDOT does not have an official TMDL compliance policy, the assumption is that if they follow the state regulations, they are in compliance with all regulations. DelDOT is currently negotiating a new NPDES MS4 permit (old permit expired in 2006) in which they are a co-permittee with New Castle Counties (the primary permittees) and six other municipalities. An aggregated WLA has been assigned in the permit although it is not being enforced. DelDOT is not specifically named at this time, and it is unclear how the loads will be split among the permittees. For compliance purposes, the permittees operate independently such that the failure of any one entity does not affect the others. In general, Delaware has some unique geographic challenges when it comes to implementing a TMDL program such as a high water table (especially in Kent & Sussex Counties), poor drainage off the landscape, and slope restrictions due to the flat topography. Additional challenges for DelDOT include financial limitations, the lack of BMP technology to address certain pollutants (e.g., bacteria, nitrogen), a fragmented institutional structure (stormwater management programs located across multiple divisions), restricted space in ultra-urban areas, and general awareness issues within DelDOT.

On the positive side, Delaware has a unique delegation of authority system where DelDOT is given relatively broad authority by the state (7 Del. Code, Ch. 40) to implement a permit program for its capital transportation improvement projects. This program includes implementation of erosion and sediment control during construction and permanent stormwater management BMPs for quantity and quality control based on the control of post-project conditions to pre-project levels. Delaware also implements its NPDES MS4 Permit Program in New Castle and Kent Counties. This involves implementation of multiple pollution control strategies within their ROW under the Phase I and Phase II permit programs stormwater retrofits, structural, and nonstructural BMPs such as sand filters, grass swales, bioretention, street sweeping, public education, pet waste campaigns, Adopt-a-Highway programs, and many others. They are open to new technologies and have an active BMP research program through the University of Delaware which is exploring other options such as biochar (an additive to increase nutrient removal) and pesticide reduction strategies along guard rails.

In some cases, DelDOT collaborates with other partners outside their ROW through inter-jurisdictional agreements which are facilitated by the collective permitting system. The trend is toward increased collaboration on a watershed-wide basis where BMPs are dispersed across the landscape (not just within the ROW). An example of this collaboration is the Anchorage Canal Project in which (through cooperative agreements between DelDOT, DNREC, municipalities, and advocacy organizations in the watershed) funds were pooled to build many BMPs. Some of them are in the DelDOT right-of-way for which routine maintenance (e.g., mowing and litter collection) is provided by the municipalities and major maintenance is provided by DelDOT. Indeed, DelDOT sees this as the most effective approach in terms of water quality benefits. A Stormwater Quality Banking agreement fashioned after the Maryland 1980-90 banking agreement has been in effect since 1996. Revisions to that banking agreement are being drafted to accommodate new language pertinent to TMDL requirements. The agreement covers treatment of stormwater quality based on impervious area.

Several BMP performance measures are used to gauge effectiveness including runoff volume reduction, pollutant mass and concentration reduction, and peak flow reduction; these are all based on values published by DNREC. In addition, DelDOT is conducting some field sampling studies of individual BMPs. However, in general, DelDOT does not estimate pollutant loads from their ROW or track reductions, although they expect to begin using the PLOAD model (based on the simple method) to accomplish this. The costs of BMP implementation are difficult to track. Capital costs for structural controls generally come out of the project budget while O&M costs are wrapped into the overall NPDES budget of $2.07 M a year. DelDOT does not track life-cycle costs but are interested in doing so.

In general, DelDOT is in a unique situation in that they share a joint MS4 permit with other jurisdictions and have relatively broad authority to develop pollutant reduction strategies. There are few barriers to developing partnerships in such a small state and the general view is that collaboration will increase in the future particularly in the area of TMDL compliance.

California Department of Transportation
April 24, 2012
Keith Jones P.E., Environmental Engineering Liaison

Caltrans is specifically named in 62 TMDLs across the state of California. However, they are actively implementing approximately 40 high priority TMDLs at this time, typically in cases where they are discharging a pollutant of concern from the roadway with the potential to impact water quality. The entire department is responsible for compliance. California's TMDLs are generally prepared by the local Regional Water Quality Control Boards which lists Caltrans as one of several stakeholders and provides an estimation of the waste load allocation (WLA). Caltrans does not participate in the TMDL development process; however, with their wealth of water quality monitoring data, they do provide data to Regional Water Quality Control Boards which are responsible for developing the WLA and enforcing the TMDLs. In some cases, TMDLs are implemented in which the WLA may over-estimate the roadway contributions by applying the edge-of-pavement loadings to the entire ROW, including pervious areas. Some TMDLs were developed in response to Consent Decrees brought about by third party litigation, for example in the Los Angeles Basin. Caltrans does not have an official written policy for participating in the TMDL development process. However, they do review and comment on new TMDLs during the regulatory development process. There are expected to be about 200 new TMDLs in the near future.

Caltrans uses a number of strategies as part of their TMDL compliance program, including a combination of structural controls, nonstructural practices, and off-site regional controls. Specific BMPs include (for example) slope armoring, LID, swales, media filters, detention basins, infiltration devices, gross solids removal devices (GSRDs), street sweeping, and many others. Guidance for selecting and designing pollution prevention and structural treatment BMPs is provided in the Project Planning and Design Guide (PPDG). Watershed (off-site) regional controls have the potential to be an effective strategy; for example, the Statewide Advance Mitigation Initiative (SAMI) addresses off-site mitigation solutions such as wetland restoration and conservation banks. For the Public Education permit requirement, Caltrans successfully implemented a public awareness campaign known as "Don't Trash California" which resulted in behavior change contributing to significant trash reduction to comply with the Los Angeles area TMDLs. Caltrans also has an active BMP development program with help from universities such as the University of California and the University of Texas. Individual BMP effectiveness monitoring is not generally measured in the field; however, Caltrans has conducted pilot studies across a broad spectrum of BMP types which have helped to determine treatment efficiencies. In addition, Caltrans participates in group monitoring efforts in a number of TMDL watersheds in cooperation with other stakeholders. They do have a Water Quality Planning Tool with the ability to determine receiving water objectives and impairments, Caltrans tributary area within the watershed, etc. Costs for BMP implementation are currently tracked only at the programmatic level. Caltrans does not currently track life-cycle costs but is in the process of quantifying the parameters involved. The budget for state-wide NPDES management is about $90 M which is divided between Capital Outlay Support ($45 million) and an overall operation and maintenance program ($45 million), which includes BMP maintenance and other practices such as street sweeping and waste management.

Caltrans has a number of unique challenges in implementing their TMDL program. The number one problem identified is a lack of financial resources; in particular, there is a perception that the DOT should share a commensurate level of funding with other stakeholders, yet they are typically only a minor part of a watershed (<5%). Second, due to the size of the state, the regulatory community consists of 10 water quality control boards (nine regional and one state level), each having a unique approach to enforcing and interpreting permit and TMDL requirements. The large number of TMDLs and diversity in regulatory standards make it difficult to develop comprehensive strategies. In some cases, TMDLs are adopted sequentially for multiple pollutants in the same basin (e.g., first trash, then metals), which forces the DOT to change strategies mid-course, or daisy-chain treatment controls. California also has some unique ecological challenges due to the large variety of ecosystems. Vegetative BMPs are not feasible in drier areas because of the lack of water to grow the vegetation. In addition, any standing water (such as in a stormwater wetland or in a structural treatment device) is considered a potential vector breeding concern, which must be abated. To ensure permanent reductions of pollutants, the major systemic changes identified were 1) the need for a watershed based approach, 2) a recognition that highways were built long before stormwater controls and cannot be fixed overnight, and 3) regulatory reform.

North Carolina Department of Transportation
April 25, 2012
Matthew Lauffer, Andrew McDaniel,
NCDOT Hydraulics Section

NCDOT has been named in numerous TMDLs, and in some cases they have been assigned a specific WLA. The Hydraulics Unit is responsible for managing the DOT's compliance with TMDLs and implements a very proactive strategy. This strategy has evolved in part due to NCDOT's status as a statewide NPDES MS4 Phase I permittee which potentially involves them in every TMDL developed in North Carolina. A key part of this proactive strategy is the DOT's statewide MS4 permit, now in its 3rd 5-year cycle, which has evolved into a DOT specific Transportation Separate Storm Sewer System (TS4) permit, the first of its kind in the country. The governing elements of the CWA NPDES Permit have not changed, as much as the language and implementation approach reflects the very unique characteristics of the linear highway (as opposed to a municipal network) and an understanding of the transportation corridor within the urban setting.

Specifically, the section of the Permit that identifies Total Maximum Daily Load Assessment (Part III Section C) spells out a step by step process for the DOT's compliance in cases where they are assigned a specific WLA and identified as a significant contributor of the pollutant of concern. This process includes an Assessment and Monitoring Plan, infrastructure and outfall data collection, and ultimately a Report of Findings that includes a strategy and implementation schedule for meeting the DOT's WLA. This somewhat prescriptive approach defines the DOT's role and serves to limit the potentially unrealistic expectations that the other stakeholders may have in terms of what NCDOT will do to address the TMDL. Further, NCDOT reports that the proactive approach has helped to support the TMDL implementation process with data, expertise, and in some cases funding, in order to ensure that the process is based on accurate and scientific assessments, and in some cases, help define the DOT's contribution to the WLA and form the compliance strategy.

This TMDL compliance approach has not yet been adopted as a formal written policy; however, the process has become institutionalized and kept the level of effort manageable with current staff and resources (approximate budget of $3 million for NPDES program management overall). NCDOT acknowledged, however, that the pace of TMDL development could easily exceed the resources in time.

The DOT does provide data to NC's TMDL development process; however, the State resource agency implements its own modeling tools (HSPF, LSPC, load duration curves, or surface area in cases of impervious cover TMDLs). NCDOT provides input data in some form on most TMDL development. Most TMDL compliance is in the form of on-site structural and nonstructural practices. There is a nutrient trading program between point sources in North Carolina; i.e., bubble trading among WWTPs; however, there is currently no program framework to facilitate trading which is allowable by various state rules among the different source sectors and between regulated NPDES permittees (WLAs) and unregulated permittees (LAs). While there have been some instances of partnering with offsite stakeholders, and NCDOT recognizes the increased value of implementing load reductions on lands outside the right-of-way in select situations, there is no standard state-level framework for TMDL compliance partnerships at this time.

Additional (non-TMDL) requirements associated with select coastal estuaries and drinking water supply reservoirs require nutrient management strategies, so there are numerous BMPs being implemented in both TMDL watersheds and (similarly regulated) nutrient limited non-TMDL watersheds. NCDOT developed a Stormwater BMP Toolbox (2008) that includes design specifications as well as a Stormwater Control Inspection and Maintenance Manual (2010). BMP selection is typically based first on right-of-way limitations (available space, topography, geotechnical, and safety considerations, etc.) and then on the specific pollutant being targeted. BMP selection for rest areas and park-and-rides (green roofs, permeable pavement, bioretention, cisterns) is typically very different than that for the transportation right-of-way (grass swales, basins) due to differing requirements, available space, safety, and aesthetic considerations. NCDOT is preparing a guidance document, available later this year, to aid in the evaluation of retrofit BMP sites potentially suitable for WLA compliance. Common nonstructural practices include road salt application controls, fertilizer management (soil testing, nutrient applicator training, incorporating the fertilizer into the soil rather than broadcasting for ground cover establishment), an Adopt-a-Highway program for trash, etc. NCDOT does not routinely conduct analytical monitoring of BMP pollutant removal performance using NCDOT staff; however they do have a Research and Analysis Program which utilizes UNC system university staff to examine specific topics identified by the Hydraulics Unit. Major research topics include BMP pollutant removal performance and pollutant loading characterization from roadways, rest areas, and NCDOT industrial facilities.

The tracking of specific BMP costs (aside from costs tracked as pay items on construction projects) has been on retrofit projects. NCDOT has a very aggressive retrofit requirement in their TS4 Permit – construct a minimum of 5 retrofits per year, with a total of 70 required over the 5-year permit cycle. The experience of retrofitting will likely be very valuable for TMDL compliance. Individual BMP life-cycle costs are not tracked, though NCDOT does have a BMP inventory and an aggressive inspection and maintenance program that includes an independent audit and an internal inspector training program. As noted above, analytical monitoring is not routinely performed on every BMP; however, visual monitoring for operation and maintenance helps to feed an adaptive management process which is communicated through an annual conference that brings together the design, construction, and maintenance personnel.

NCDOT utilizes an Encroachment Permitting process which requires that any adjacent property applying for a NCDOT permit to connect to the transportation stormwater system be certified as properly permitted (e.g., NPDES stormwater permit or state stormwater permit) under applicable laws and rules. This Encroachment Permitting process is a requirement of NCDOT's NPDES permit. This permit does not require NCDOT to enforce the provisions of the applicant's stormwater permit issued by the resource agency. There are instances of partnerships that transfer maintenance of BMPs to adjacent land owners when the site specific conditions make it advantageous to the property owner to utilize the BMP.

The most significant challenge to NCDOT is the potential for escalating costs. The proactive program has kept those costs manageable to date; however, there is some concern as the TMDL list continues to grow. NCDOT wants to stay involved in this process since they recognize their obligation to protect the environment, and they have considerable expertise in addressing compliance issues. Another challenge is the sheer size of the NCDOT roadway and facility system spread across 3 physiographic regions, each with their own specific challenges. Long-term issues include the evolution of BMP strategies (groundwater influences, stream impacts, today's preferred BMP may become tomorrow's problem BMP, etc.). An important significant success was described as the proactive approach that has allowed NCDOT to develop the only TS4 permit to date (it is expected that other DOTs will duplicate the NCDOT model). Another success of the proactive approach is the ability to avoid group compliance, allowing NCDOT to implement a compliance strategy developed specifically for the DOT's capabilities and resources (while supporting other watershed stakeholders as needed or able).

Georgia Department of Transportation
April 26, 2012
Brad McManus, Design Group Manager;
Eugene Hopkins, Manager, Env. Compliance Bureau

The Georgia state agency, the Environmental Protection Division, has several hundred TMDLs listed on their website, mostly for fecal coliform and sediment. However, the Georgia DOT has not been named a stakeholder in any TMDLs, nor have they been assigned a specific WLA or been aggregated into a watershed-wide total WLA at this time. GDOT is not involved in the TMDL development process but they are required to monitor outfalls within their MS4 permit area when the roadway is named a significant contributor to the impairment. It is expected that this monitoring will likely identify the DOT as a significant contributor. The monitoring constituents are driven by the pollutants of concern specified in the TMDLs, including fecal coliform, oils and grease, and metals. However, the main concern is sediment. The monitoring language written into their new statewide NPDES permit (issued January 2012) was developed by GDOT in conjunction with EPD and provides flexibility for the DOT. GDOT does not have an official policy for participating in the development of future TMDLs but they do monitor forthcoming TMDLs closely.

GDOT uses both structural and nonstructural BMPs for stormwater treatment and pollutant reduction. The number one structural BMP is enhanced grass swales (dry and wet). Sand filters and stormwater wetlands are also used. On construction projects, PAM is typically mixed into the soil for control of sediment runoff. For nonstructural BMPs, GDOT maintains vegetated buffers along streams and utilizes sheet flow to vegetated filter strips. In general, BMPs with the lowest maintenance requirements and longest service life are preferable as they are easier to budget for. The DOT also participates in public education as required by the EPD. BMP design criteria and treatment efficiencies are based on the Georgia stormwater manual ("Blue Book"). GDOT currently only uses "applicable parts" of the Blue Book, which is not designed specifically for highway environments. GDOT also has an active BMP research program through Georgia Tech which examines the effectiveness of some BMP types (though not all). Additional monitoring is ramping up with the new NPDES permit, including IDDE inspections and monitoring downstream of BMPs located near 303d listed streams. GDOT does not currently estimate pollutant loads from their right-of-way. BMP implementation costs are also not tracked, although there has been some interest in tracking life-cycle costs. The overall MS4 compliance budget is generally about $4 M a year which covers some maintenance, design, and the IDDE program. Capital costs for construction of BMPs are rolled into project budgets, and there is also a separate maintenance budget handled by the maintenance office.

GDOT has a number of unique challenges to implementing their TMDL program. Currently, there appears to be relatively little collaboration with other stakeholders to specifically address water quality issues due to the lack of financial resources. Georgia also has a diversity of physiographic provinces which can present challenges to successful BMP implementation, especially in remote mountainous areas with severe terrain limitations. The number one challenge to implementing their TMDL program was a lack of financial resources. Several systemic changes were identified to ensure permanent reduction of pollutants from the roadway, including the need for more education and training of DOT designers and contractors (and the general public), additional research and development of alternative BMPs with fewer maintenance requirements, and the need for a BMP maintenance standard. On the positive side, GDOT has flexibility in their new NPDES permit to develop a water quality management plan in cooperation with EPD. In addition, they have already demonstrated successful BMP implementation in mountainous terrain, for example with the Canton Creek project where sand filter beds were utilized to capture roadway runoff and protect a local endangered species.

Washington Department of Transportation
May 4, 2012
Jana Ratcliff, TMDL Lead, Environmental Services Office

The Washington Department of Transportation (WSDOT) is currently named as a stakeholder in 26 TMDLs, which are listed in the WSDOT MS4 Permit. The MS4 permit can be modified at least once every 18 months to add any newly approved TMDLs that name WSDOT as a stakeholder (the current permit was effective March 2009, and was modified in 2010 and 2012). Approximately 17 TMDLs are currently being developed and could potentially be added in the next modification cycle. The TMDLs currently listed in WSDOT's NPDES MS4 Permit generally include a WLA specifically assigned to WSDOT although some assign an aggregate WLA to all NPDES municipal permittees. WSDOT is finding many TMDL studies do not include any reference to stormwater runoff sampling data from WSDOT facilities. To be consistent with regulations and guidelines used to establish TMDLs, WSDOT feels numeric waste load allocations (WLAs) should only be assigned when there is credible, site-specific data/information indicating that WSDOT facilities are a meaningful source or contributor of the pollutant of concern. WSDOT feels, in the absence of site-specific stormwater outfall data, a numeric WLA assigned to WSDOT is presumptuous and without just cause. TMDLs often calculate WLAs based on: national averages, data collected elsewhere in Washington State, in stream data inappropriately used to represent stormwater discharge contributions, or reference general water quality standards as the basis for the WLA.

WSDOT's TMDL-related requirements are described in Section S6 of the WSDOT NPDES MS4 Permit. Required actions specific to the TMDLs are found in Appendix 3 of the Permit. Compliance with these actions constitutes presumptive compliance with TMDL WLAs assigned to WSDOT. Appendix 3 is split into two general categories (or parts): Part 1 consists of specific action items assigned to WSDOT that go above and beyond Permit implementation; Part 2 is for those TMDLs located partially or wholly within the Phase I/II MS4 permit urban area. For this category, compliance with WSDOT's NPDES MS4 Permit obligations that address the TMDL-listed pollutants constitutes presumptive compliance with TMDL WLAs assigned to WSDOT. This can include monitoring or other provisions as outlined in WSDOT's MS4 permit.

WSDOT's policy for participating in TMDL development is an informal policy best described as a triage approach, where the participation is prioritized based on 1) compliance with NPDES MS4 permit requirements to the MEP; 2) prioritized participation in the development of the TMDL based on Washington Department of Ecology (WDOE), the local state agency, and WSDOT input; or for TMDLs considering a surrogate pollutant (e.g., flow); and 3) TMDLs where WSDOT is not considered the source of the pollutant (such as bacteria). This third tier TMDL is typically addressed with a Programmatic Approach spelled out in the MS4 permit (the current MS4 Permit includes a Programmatic Approach for addressing fecal coliform). WSDOT's participation in TMDL development has gradually increased over time; however, it appears to be constrained by available manpower (currently there is only 1 FTE within WSDOT Environmental Services Office dedicated to the tracking and participatory development process). WSDOT does not currently provide any data to WDOE during the TMDL development process. WDOE may potentially use WSDOT data in the future as data become available from WSDOT's monitoring program, which is described in Section S7 of WSDOT's MS4 permit.

Several compliance strategies are used by WSDOT to comply with their MS4 permit and *Highway Runoff Manual* requirements relating to treatment, flow control, and stormwater retrofits. These include structural BMPs (infiltration ponds, vaults, trenches, media filter drain, compost amended biofiltration, compost amended filter strip, wet pond, constructed stormwater treatment wetland, combined wet/detention pond, and bioretention) and nonstructural BMPs (natural and engineered dispersion, DOT staff training and education). To date, only one TMDL has assigned a specific action to WSDOT to perform a stormwater retrofit. Two TMDLs have assigned WSDOT an action item to install pet waste stations. WSDOT has developed a BMP design and maintenance manual: the *Highway Runoff Manual*, which includes 303(d)/TMDL considerations relating to the selection of specific BMPs for specific pollutants for TMDL compliance purposes. The BMP pollutant removal efficiency presumptions are those established by WDOE. The cost of implementation of BMPs is not directly tracked; however, WSDOT does conduct an Environmental Mitigation Costs Study on a 3-year cycle that tracks capital costs, design, and land acquisition (this report tracks project-specific mitigation for all environmental mitigation, including erosion control, stormwater, wetlands, stream, noise, etc.). BMP operation and maintenance costs are not currently tracked; however, WSDOT is developing a tracking system: Highway Activity Tracking System (HATS) that will track BMP maintenance activities and some cost information. Annual maintenance is required for BMPs, and generally includes a process for visually verifying that the practices are functioning; it is expected that the HATS system will also identify long-term operation and maintenance trends and the adequacy of the currently prescribed maintenance frequency.

There has been some limited BMP performance research on grass swales, permeable pavement, and a few other select practices; however, a more rigorous process of monitoring highway runoff and measuring BMP efficiency is ramping up. Section S7 of the latest WSDOT MS4 permit includes a much more robust monitoring program with prescriptive requirements for monitoring data quality objectives, QA/QC, QAPPs, etc. Additional research on BMP performance is anticipated in collaboration with the WSU Puyallup Research & Extension Center.

WSDOT also collaborates with the neighboring municipalities on various issues related to stormwater. Maintenance of BMPs on roads in urban areas is typically turned over to the municipality through a standard agreement (that is modified as needed based on the specific project or location). Overall, however, numerous obstacles are cited as barriers to engaging in more involved permit compliance related partnerships, the most significant being compliance liability issues. One of the biggest obstacles to the TMDL program implementation in general was identified as the limited data and technology for developing accurate WLAs (although the newer permit language referencing presumptive compliance has reduced this as an issue). Another implementation challenge in Washington is the wide range of climatic and physiographic characteristics (especially between eastern and western portions of the state), requiring a wide range of compliance strategies. The biggest implementation successes were identified as 1) the development of a collaborative relationship between WSDOT and WDOE during the development and on-going implementation of the current NPDES permit, and 2) the development of the Programmatic Approach for complying with certain TMDLs. The biggest changes needed for moving forward were identified as 1) training of personnel, 2) increased research to expand the list of BMP options that are applicable to the right-of-way environment, 3) nonstructural practices for source control (brake pad materials, galvanized [zinc] coatings on downspouts, etc.), and 4) additional manpower and funding resources.

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MnDOT has been named a stakeholder in approximately 40–50 approved and pending TMDLs. There are currently >3,000 impaired waters in Minnesota and >2,000 TMDLs; therefore, it is expected that hundreds of additional TMDLs will be coming down the pipeline in which MnDOT will likely be a stakeholder. MnDOT prioritizes TMDLs based on 1) those within urban MS4 areas, 2) those that have pollutants of concern associated with highway runoff, 3) those that potentially impact the NPDES Construction General Permit (CGP), and 4) those that are outside the MS4 but may potentially establish a precedent for addressing pollutants of concern, and 5) those that will potentially become urbanized. TMDLs usually have multiple WLAs, for example one for construction stormwater and one for MS4s. For smaller TMDLs, MnDOT requests an individual WLA (as written in a Memorandum of Understanding with the local state agency, the Minnesota Pollution Control Agency [PCA]). For larger TMDLs that cover huge watersheds (e.g., South Mississippi River, Minnesota River), MnDOT tends to have a categorical (aggregated) WLA with other MS4 permittees. Several organizational units within MnDOT are responsible for TMDL compliance, including the Office of Environmental Stewardship at the headquarters level; and the Water Resources Engineering maintenance, construction, design, and planning units of the Metro district (one of 8 districts in Minnesota, and the one with the most TMDLs that MnDOT has participated in). MnDOT's participation on TMDL development is governed (in part) by the MOU with the PCA which outlines the procedure for providing PCA with data (acres in right-of-way) and reviewing/commenting on TMDLs.

Construction stormwater BMPs implemented by MnDOT are required by the CGP, TMDLs, and by requirements established by Watershed Management Organizations and Watershed Districts (there are 34 watersheds in the Metro area). Generally, the nutrient and turbidity TMDLs can be met by the CGPs. The assumption is that if MnDOT is in compliance with the construction permit, they have met their construction stormwater WLA. Structural BMPs include (for example) infiltration practices, filtration practices, detention and extended detention basins, iron filings (which are mixed into filtration material to enhance phosphorus removal), proprietary controls, and grit chambers for sediment control known as structural pollution control devices. Nonstructural BMPs include street sweeping, public education, and enhanced maintenance and research activities. MnDOT is generally locked into structural practices (especially infiltration for volume control) due to the requirements implemented by the Watershed Districts and Management Organizations. Design standards are generally mandated by the watershed organizations as well as the construction permit; it is presumed that if these design standards are met, and the practice is being maintained, then the BMP is working effectively (i.e., in accordance with PCA published efficiencies). Per its MS4 General Permit, MnDOT also conducts periodic visual inspections of BMPs to identify maintenance needs. Monitoring of BMPs has generally been limited to date; however, MnDOT is starting to implement infiltrometers to measure the effectiveness of existing infiltration practices (as well as verify the efficacy of placing new ones). The new NPDES permit expected in the fall is not likely to have additional monitoring requirements (beyond visual inspections). MnDOT also has an active BMP research program through the University of Minnesota which examines the effectiveness of (for example) grass swales and sump manholes. Pollutant loads from the ROW have not been estimated by MnDOT. They are done by consultants for PCA with mixed results. BMP costs are not generally tracked.

The number one challenge identified by MnDOT in implementing their TMDL program was regulatory, specifically the lack of flexibility in BMP selection afforded by the watershed organizations and the PCA. The primary focus is on volume control which essentially restricts MnDOT to a limited set of infiltration BMPs. MnDOT would like to see a more expanded set of options, specifically nutrient credit trading and the use of iron filings; however, there appears to be little impetus to develop these further at the current time. Another difficulty is meeting the TMDL WLAs which are not seen as meaningful numbers because of the lack of a framework to measure success, particularly in cases where the DOT's impact is so insignificant within a much larger watershed. Other challenges unique to Minnesota include the sheer volume of impaired water bodies and the magnitude of TMDLs being implemented, some of which (e.g., IBI TMDLs) the DOT has little experience with. There are also challenges in karst areas where infiltration may not be appropriate, and there is a general concern that infiltration of pollutants simply re-directs the problem to groundwater which can be especially problematic in rural areas where wells are not tested. BMPs are also seen as being less effective during the harsh winters in Minnesota. The primary success identified by the DOT was the ability to meet the construction permit requirements and hence meet the TMDL construction stormwater WLA for nutrient and turbidity TMDLs. Several systemic changes were identified to ensure permanent reductions of pollutants from the ROW. These include continued education and training of DOT designers and contractors, additional research on BMPs that are easier to implement and maintain (and less expensive in the long run), maintenance standards with funding to implement them, and greater control of off-site water running onto the ROW.

Abbreviations used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation