NCHRP

REPORT 474

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters

Volume 2: Practitioner's Handbook

TRANSPORTATION RESEARCH BOARD

OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters

Volume 2: Practitioner's Handbook

THOMAS V. DUPUIS
CH2M HILL
Boise, ID

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Christopher Hedges
Staff Officer
Transportation Research Board

This report presents guidance for practitioners in assessing the impacts of bridge deck runoff on receiving waters and, if necessary, identifying the most appropriate method of mitigation as part of an overall management plan. The first volume, *Final Report,* includes the findings of a literature review, a survey of current highway agency practice, stakeholder consultation, and biological testing at both freshwater and saltwater sites. The second volume, the *Practitioner's Handbook*, presents the assessment process that was developed on the basis of the findings reported in the *Final Report.* The *Practitioner's Handbook* guides the user through a step-by-step process that begins with the collection of some basic data and the identification of the main areas of concern. Following these initial steps, the *Handbook* helps the user select the most appropriate analysis method, conduct an assessment of the results, and develop a management plan. Use of the *Handbook* and accompanying *Final Report* should be particularly helpful for practitioners (especially those responsible for structural, hydraulic, and water quality design and evaluation) in making sound, scientifically defensible decisions concerning the need for water runoff controls on new, replacement, or existing structures.

Although there are a number of analysis methodologies to predict and assess the impacts of highway storm water runoff on receiving waters, they have not proven to be appropriate for bridges, which have very different characteristics and constraints. As a result, to comply with permits and regulations, some projects have been required to include installation of costly enclosed drainage systems on bridges.

A need was therefore identified for a process to assist practitioners in making decisions on the need for, and the extent of, control of bridge deck runoff in both new and retrofit applications. The process would encompass consideration of runoff constituents (e.g., metals, sediments, and nutrients); types of bridge runoff management designs; impacts on receiving waters and aquatic biota; and other potential runoff impacts. The process would also include risk assessment for special potential problems (such as hazardous materials spills), benefit/cost-effectiveness assessments, and other elements of a strong management process for the consideration of runoff concerns within the project development process.

Under NCHRP Projects 25-13 and 25-13(01), a research team from CH2M HILL developed a rational process to identify, assess, and manage bridge deck runoff that may adversely impact the beneficial uses of receiving waters. When warranted, the process addresses a range of mitigation alternatives that may include on-site control of bridge deck runoff, off-site watershed-based mitigation, or pollution trade-off opportunities. Where on-site control is proposed, appropriate new bridge design parameters for runoff and opportunities for existing bridge retrofits are considered along with nonstructural best management practices. The process is appropriate for both coastal and inland settings and permits consideration of direct impacts on a project basis, as well as consideration of cumulative impacts to the receiving water.

Both the *Practitioner's Handbook* and *Final Report* are also available in portable document format (PDF) on CRP's website (www4.trb.org/trb/crp.nsf).

CONTENTS

ASSESSING THE IMPACTS OF BRIDGE DECK RUNOFF CONTAMINANTS IN RECEIVING WATERS

SUMMARY

This report documents the results of NCHRP Project 25-13, "Assessment of Impacts of Bridge Deck Runoff Contaminants on Receiving Waters" in two volumes. The first volume is the project final report (*Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 1: Final Report*) and the second volume is a handbook for practitioners (*Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 2: Practitioner's Handbook*). The project included the following:

- A critical review of scientific and technical literature on water quality impacts and assessment methods associated with bridge deck runoff, maintenance practices, and spills (see *Final Report*);
- A survey of state and provincial highway agencies to obtain information on mitigation measures being used or considered for bridge runoff, maintenance, and spills (see *Final Report*);
- Development and testing of biological studies including a time-variable bioassay methodology, field monitoring of the benthic macroinvertebrate community, and chemical analyses of runoff and sediments at two bridge sites: I-85/Mallard Creek, North Carolina, and the San Francisco-Oakland Bay Bridge (see *Final Report*); and
- The design of a process to evaluate the impact of bridges on water quality and to develop, if necessary, strategies for mitigating impacts on water quality (see *Practitioner's Handbook*).

The results of the literature review, survey, and biological studies demonstrate that consideration of the unique characteristics of each bridge is crucial to effective evaluation of the potential impacts of bridge deck runoff on receiving waters. Bridge deck length, width, runoff chemical concentrations, traffic volume, and receiving water type (e.g., river, lake, or estuary) are a few of the characteristics of any bridge deck and receiving water environment that must be considered in an evaluation of the potential impacts of bridge deck runoff on receiving waters. The results of NCHRP Project 25-13 also show that three factors have been central in the consideration of bridge deck mitigation systems: (1) state and federal regulatory requirements; (2) state and federal regulatory

agency and interested party concerns with the impact of the bridge (e.g., water quality, spills, and endangered species); and (3) receiving water characteristics and designated uses, particularly with high-quality and Outstanding Natural Resource Waters. The results of NCHRP Project 25-13 were incorporated into a process that practitioners can use to analyze the characteristics of a particular bridge deck and receiving water environment, decide whether mitigation is needed, and, if necessary, choose a mitigation strategy. This process, developed with extensive input from stakeholders, is documented in the *Practitioner's Handbook.* A more detailed discussion of the study's conclusions, as well as recommendations for additional research, can be found in Chapter 4 of the first volume, *Final Report.*

CHAPTER 1

INTRODUCTION

PROJECT AND HANDBOOK PURPOSE

The objective of National Cooperative Highway Research Program (NCHRP) Project 25-13 was to develop a rational process for identifying, assessing, and managing bridge deck runoff that may adversely affect designated uses of receiving waters. The process that was developed addresses on-site and off-site mitigation options, including watershed-based considerations and pollution trading. It is also applicable to inland and coastal settings and addresses project-specific and cumulative receiving water impacts.

This "practitioner's" process is designed to guide the transportation agency and other stakeholders through the appropriate level of analysis needed to address three questions: (1) whether, given a particular circumstance, bridge deck storm water runoff will affect the receiving water; (2) if runoff does have an impact, whether mitigation is necessary; and (3) if mitigation is necessary, what kind is needed. As presented in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report, four factors have been responsible for the consideration of bridge deck mitigation systems: (1) state and federal regulatory requirements; (2) state and federal regulatory agency and interested party concerns with the impact of the bridge—for example, water quality, spills, and endangered species; (3) receiving water characteristics and designated uses, particularly high-quality waters and Outstanding National Resource Waters; and (4) bridge deck characteristics. These four factors ultimately combine to make every bridge deck discharge condition unique, requiring customized analysis to address the question of whether a proposed, existing, or reconstructed bridge may affect the multiple uses of a receiving water.

The process documented here provides the practitioner with guidance on which methods to use, depending on the issues that have to be addressed to successfully deal with stakeholder concerns and interests. To select appropriate methods of analysis from the array of options provided here, the individual practitioner must use common sense and judgment and be cognizant of state- and locality-specific storm water programs and issues.

It is not the intent of the NCHRP Project 25-13 research team that all, or even most, of the details and steps of the process be followed in all cases. Many stakeholders do not consider small bridges, rural low-traffic highways (and their bridges), or bridges in major urban areas (where pollutant loads from other sources are preponderant or receiving waters are degraded for other reasons) to be of high priority or even of any concern at all. The literature review in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report indicated that FHWA's conclusion that low-traffic rural highways do not cause significant adverse effects on aquatic biota has not been invalidated by subsequent studies. Similarly, many highway agencies do not oppose avoiding direct discharge of storm water to receiving waters in cases in which bridges are small enough or conveniently enough configured for that to be accomplished at a reasonable cost and without compromising public safety. Again, the research team does not propose that the process described here should supersede such rational, commonsense approaches, nor should it cause the practitioner to employ a more complicated process than necessary to come to a judgment.

It is also not intended that the process supersede existing or future storm water regulations or programs that clearly specify what actions must be taken. For example, the United States Environmental Protection Agency (U.S. EPA) storm water National Pollutant Discharge Elimination System (NPDES) regulations specify that entities that are required to have municipal permits must comply with the requirement to control discharge of pollutants to the "maximum extent practicable" (MEP). MEP is defined in the *Federal Register* (U.S. EPA, 1999, p. 68754). This document says that "Compliance with the conditions of the general permit and the series of steps associated with identification and implementation of the minimum control measures will satisfy the MEP standard." Minimum control measures are defined in the *Federal Register* as (1) public education and outreach, (2) public participation/involvement, (3) illicit discharge detection and elimination, (4) construction site runoff control, (5) postconstruction runoff control, and (6) pollution prevention/good housekeeping. However, postconstruction runoff control may not always be necessary or practicable for all bridges. In cases in which MEP or other storm water policies are clearly defined by regulation and applicable to bridges, the process points the practitioner to that understanding. In most such cases, use of the specified control measure(s) avoids the need to consider other analyses or measures in the process. Of course, the practitioner can also use the process, or elements of it, to help define MEP or demonstrate that existing definitions or other regulatory requirements are unnecessary or inappropriate and advocate for regulatory or policy changes.

The research team believes that the NCHRP Project 25-13 process is most needed in situations in which large bridges are to be newly built or reconstructed over sensitive or highly valued receiving waters, and in which federal, state, and/or local regulations and policies are ambiguous or may need to be reconsidered. Although it is not an issue that has been frequently encountered in the past, it is possible that existing bridges also may be identified or perceived as impacting water quality problematically. The process allows the practitioner to address this kind of situation.

BACKGROUND AND GENERAL CONSIDERATIONS

Historically, bridge engineers have designed storm water drainage systems to drain directly to receiving waters through scupper systems or simply through open-rail drainage. This was the low-cost, practical way to get water off the bridge quickly and maintain safe driving conditions. Virtually all bridges constructed in the United States still use these drainage methods. The quality of the storm water and its potentially adverse effects on receiving waters have now fully emerged as issues and are major planning and design considerations.

Apart from one's position on whether all, or even most, newly constructed bridges should be designed to preclude direct discharge, questions remain concerning what to do with existing bridges and what to do in cases in which avoiding direct discharge is impractical, excessively costly, or provides little actual environmental benefit. Consequently, there is a need for a reliable process that highway designers and planners can use in the very early stages of scoping new bridge projects and also to make sound, commonsense decisions about the need to retrofit existing bridges.

Although there is an extensive body of information regarding highway runoff quality, receiving water impacts, assessment methods, and mitigation measures, bridges need to be addressed separately. Bridges have unique characteristics and constraints that require an analysis methodology that can stand alone. Bridge design and retrofit are constrained by the following physical features at the receiving water crossing:

- There is no flexibility regarding the size of the footprint. In other words, there is no lateral right-of-way (ROW) on which to build mitigation measures. Mitigation measures can be located on the bridge only at substantial cost, or storm water must be gravity-drained back to land.
- The topography and approach slope at some bridge locations preclude design or retrofit for gravity drainage back to land.
- The additional load of storm water piping must be considered for retrofit and in new bridge design.
- The length and slope of some bridges preclude gravity drainage to land. For floating bridges, storm water cannot be routed to land without pumping assistance.
- Maintenance may be difficult, and additional safety measures may need to be considered for bridges that are retrofitted with storm water control measures.

As reported in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report, most states do not anticipate construction of many new bridges where none exist today, particularly not the large bridges that tend to be most controversial. Instead, most major bridge projects will involve reconstruction or replacement of existing bridges that have exceeded their design or useful life and require replacement or significant modification for structural or capacity reasons.

Most states noted that they have neither funds nor reason, in most cases, to consider bridge retrofit exclusively for water quality purposes. The NCHRP Project 25-13 survey (see the first volume of this report) revealed only one case in which an existing bridge was thought to be causing a water quality problem and was retrofitted to correct it. This was the I-5 Bridge over the Snohomish River in Everett, Washington. Washington, in fact, was the only state identified as having an active policy regarding highway retrofit for water quality purposes, funds permitting. The Washington State Department of Transportation (WSDOT) has developed a priority rating system for best management practices (BMPs) retrofits. The NCHRP 25-13 research team concluded that the WSDOT priority rating scheme was sound and included it, with some modification for bridges only, as an option for the practitioner (see Method 18 in the Appendix to this volume).

The elements of the main process can also be used to address water quality issues at existing bridges. For example, desktop calculation and field methods can be used with an existing bridge and for a replacement bridge with characteristics that are similar to the existing bridge. For a totally new bridge, the desktop, or more complex modeling approaches, would be required during planning and design unless a surrogate bridge and receiving water can be identified. In some cases, after the new bridge is built, it may be appropriate to use the identified field evaluation methods to validate the predictions made during the planning process. For example, stakeholders may have agreed up front that mitigation measures did not appear to be warranted, but there was enough uncertainty in the methodologies used that the highway agency agreed to postconstruction monitoring. In these cases, it is likely that the bridge design would have either allowed for postconstruction addition of a water quality BMP, or there would have been some other remediation or mitigation measures specified (e.g., mitigation banking) if later shown to be appropriate by monitoring.

Thus, the practitioner's process is compatible with new, replacement, and existing bridges for which water quality mitigation or BMPs are being considered or requested by some entity. The process is also compatible with design-build projects in which permitting for regulatory compliance must be accomplished in conjunction with project design development.

Any process developed specifically for bridges must be flexible enough to fit into a broader analysis for a larger highway project, or even within the context of large-scale watershed planning. Highways typically constitute a very small fraction of a watershed's total drainage area, and bridges often constitute a small portion of the highway drainage area. Thus, highways often, but not always, contribute a small fraction of the overall pollutant load to a given receiving water body, and bridges contribute even less. This provides mitigation opportunities for considering and implementing commonsense solutions, such as providing enhanced pollutant removal somewhere else in the ROW, or even somewhere else in the watershed (i.e., off-site mitigation or pollutant trading). Although it is recognized that site-specific effects must be thoroughly considered in any watershed or trading concept, there are mitigation opportunities related to a variety of storm water pollutants, including nutrients, bacteria, sediments/solids, and even metals or organics, if the pollution problem is not localized near the bridge site (e.g., metals accumulations in sediments in a downstream reservoir that is subject to metals inputs from a variety of sources). This approach of compensatory off-site mitigation was used for the Hood Canal floating bridge replacement in the state of Washington. Mitigation was provided for an adjacent section of highway in place of constructing conveyance and off-site BMPs for the Hood Canal floating bridge. The U.S. EPA, some states, and even many local governments have moved, or are moving rapidly, toward watershed-scale planning for water quality protection and enhancement, including pollutant trading. Highway agencies should logically be a part of that process.

NCHRP Project 25-13 focused on developing a process that state departments of transportation (DOTs) can use to make sound, scientifically defensible decisions on the need for, and the extent of, control of bridge deck runoff in both new and retrofit applications. The *Practitioner's Handbook,* as one of eight tasks included in Project 25-13, incorporates elements from all eight tasks in an effort to synthesize the results and knowledge gained over the course of the project. Results from the first two tasks of the project (a literature review and a survey of mitigation practices and current studies) are provided in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report.

Project 25-13 is one of several other NCHRP highway runoff research projects:

- Project 25-1: Effects of Highway Runoff on Wetlands
- Project 25-9: Environmental Impact of Construction and Repair Materials on Surface and Ground Waters
- Project 25-12: Wet Detention Pond Design for Highway Runoff Pollution Control

These projects are cross-referenced when appropriate.

CHAPTER **2**

HOW TO USE THIS HANDBOOK

It is assumed that practitioners with varying levels of experience will be using the process that is described in this handbook. However, the level of expertise needed to address the concerns identified by the practitioner may be dependent on the complexity of the bridge deck configuration, the existing regulatory environment, and the nature of the receiving water. This handbook is designed to guide practitioners through a process that first identifies concerns and then suggests strategies and analysis methods appropriate to the specific bridge deck runoff conditions they face.

USING THE HANDBOOK

Figure 1 provides an overview of the *Practitioner's Handbook* process and how the handbook can be helpful in making decisions about managing bridge deck runoff. As can be seen in Figure 1, the recommended process includes the following core steps:

- Collect Basic Information
- Define Process Drivers and Identify Potential Analysis Methods
- Select Appropriate Analysis Methods
- Perform Analysis and Assess Results for the Development of a Plan

These steps will guide the practitioner toward a better understanding of bridge deck runoff characteristics and potential solutions that could be implemented in a management plan. When solutions are being implemented, the practitioner can also turn to the methods in this handbook to reevaluate the management plan.

The Practitioner's Handbook will guide the user toward a better understanding of bridge deck runoff characteristics and potential solutions for implementation.

DESCRIPTION OF SECTIONS

The steps described above coincide with the chapters (and Appendix) of the *Practitioner's Handbook.* Brief summaries of these sections are included here to supplement the process depicted in Figure 1.

Chapter 3: Basic Information

Chapter 3 provides a brief description of the pollutants common to highway runoff and the parameters that affect the magnitude of their presence. Additionally, U.S. EPA water quality criteria for some metals are given in this chapter. These criteria are meant only to give guidance and a sense of context about the relative concentrations generally allowed for each pollutant. A checklist of basic questions for bridge analysis has been developed to guide practitioners in developing a descriptive profile of the proposed bridge project. If the unique characteristics of the bridge have already been assessed and the practitioner is familiar with the basic pollutants common to bridge deck runoff, the practitioner may wish to skip Chapter 3.

Chapter 4: Identifying Process Drivers

Screening questions are provided in Chapter 4 to assist the practitioner in identifying potential concerns about bridge deck runoff. This chapter organizes concerns and links them with methods that may be used to address the concerns. Drivers have been organized into three general groups: (1) regulatory considerations, (2) special conditions such as the potential for hazardous spills, and (3) BMP feasibility. Tables are provided in this chapter to identify potential analysis methods for application to the practitioner's situation.

Chapter 5: Using the Process—Case Study Example

It is anticipated that an assessment of impacts of bridge deck runoff will follow an iterative process such as the one depicted in Figure 1. After basic project information has been reviewed and process drivers or concerns have been identified (screening questions), the practitioner is encouraged to review a series of methods provided in this handbook that can be used to address these concerns. After analysis methods have been chosen and used, a plan should be developed and stakeholder involvement solicited. A case study of the San Francisco-Oakland Bay Bridge (SFOBB) is presented in Chapter 5 as an example of how this process could be used to address bridge deck runoff issues. Other case study exam-

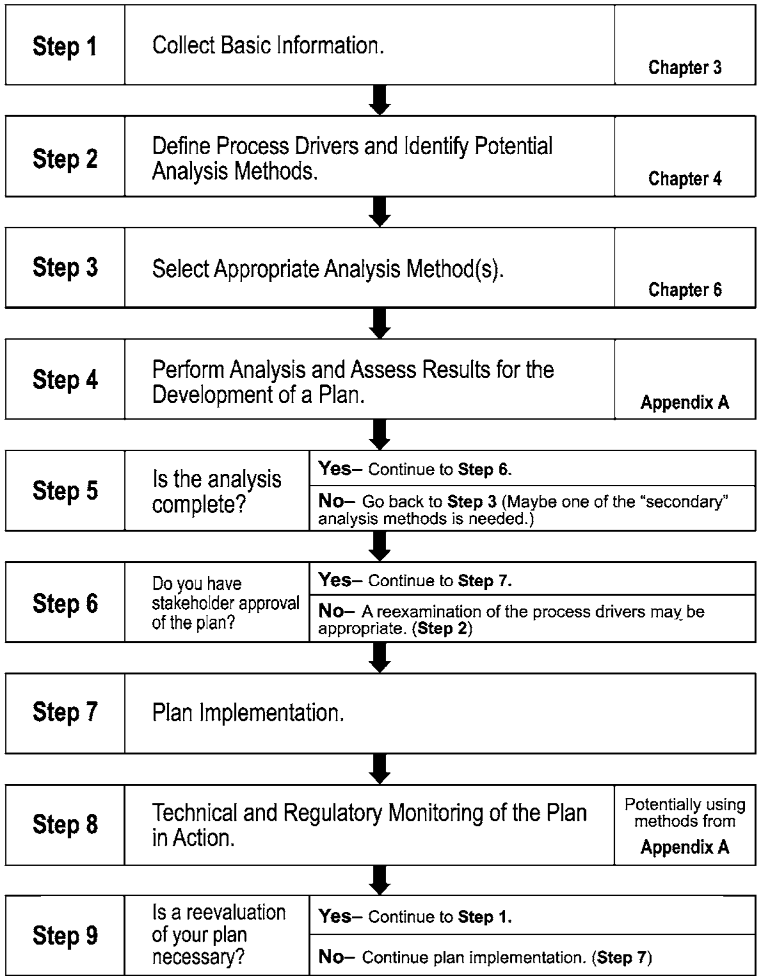

Figure 1. Practitioner's Handbook process steps.

ples are presented with the applicable methods in the Appendix to this volume.

Chapter 5 is a case study of how the Handbook's process could be used with the San Francisco-Oakland Bay Bridge as an example.

Chapter 6: Methods Summaries

After identifying the process drivers and using the tables provided in Chapter 4 to determine potential analysis methods applications, the practitioner can go to Chapter 6 to read a summary of each method. If the method does not appear to be appropriate for the particular situation, a graphical summary of the methods presented in Chapter 4 can be used as a "quick-finder" for candidate analysis methods (primary or secondary) that apply to a specific area of concern. The Appendix to this volume provides complete descriptions of each method.

Although this *Practitioner's Handbook* is not intended to guide practitioners through the public involvement process, stakeholder involvement is very important. A helpful screening test to aid this process of stakeholder involvement includes the following three steps:

- Identify the designated uses of the receiving waters,
- Identify those proposed actions that will prevent or mitigate any adverse impact, and
- Identify those pollutants in bridge deck runoff that could adversely impact any designated use of the receiving waters.

These three steps will provide the basic information for stakeholders to make an informed decision on the project. When the plan is met with stakeholder approval, it is ready for implementation. Implementation may involve actions such as postconstruction monitoring or compliance assessment—steps that could lead to the need to reconsider various elements of the process that were followed in this handbook.

CHAPTER **3**

BASIC INFORMATION

This chapter presents some basic ideas and information to consider when working on a bridge deck runoff problem. Topics discussed are pollutant sources, bioavailability of metals, water quality criteria, and bridge characteristics.

POLLUTANT SOURCES

As described in FHWA's *Effects of Highway Runoff on Receiving Waters–Volume IV Procedural Guidelines for Environmental Assessments* (Dupuis and Kobringer, 1985), several parameters affect the magnitude of pollution in highway runoff. Parameters are grouped into the following general categories:

- *Traffic characteristics*—speed, volume, vehicular mix (cars/trucks), congestion factors, and state regulations controlling exhaust emissions;
- *Highway design*—pavement material, percentage impervious area, and drainage design;
- *Maintenance activities*—road cleaning, roadside mowing, herbicide spraying, road sanding/salting, and road repair;
- *Accidental spills*—sand, gravel, oils, and chemicals.

FHWA also described the common highway runoff pollutants and their primary sources (see Table 1). The pollutants most frequently scrutinized for impact assessments are metals (e.g., acute and chronic toxicity to aquatic life); particulates (e.g., "carriers" of other pollutants and sedimentation effects on aquatic habitat); nutrients (e.g., eutrophication); and salts (e.g, aquatic life toxicity and drinking water supply taste). More recently, polycyclic aromatic hydrocarbons (PAHs) have also been investigated from a toxicity perspective (Dupuis et al., 1985b; Hewitt and Rashed, 1992; Hoffman et al., 1985; Ishimaru et al., 1990; Perry and McIntyre, 1987; Yamane et al., 1990).

The chemical characteristics of bridge deck runoff have not been extensively documented. Although only a few studies have focused specifically on bridge deck runoff (Dupuis et al., 1985b; Kszos et al., 1990; Yousef et al., 1984), others have documented the characteristics of highway runoff from impervious sites, which may be directly comparable with bridge deck runoff (Gupta et al., 1981; Kobriger and Geinopolos, 1984).

NCHRP Report 448 evaluated the chemical characteristics and potential toxicity of leachates of construction and repair materials, including recycled and waste material used as amendments (Nelson et al., 2001). In general, commonly used construction and repair materials were not toxic. The few materials that were toxic included the wood preservatives, ammoniacal-copper-zinc-arsenate and creosote, and municipal solid waste bottom ash. The toxicity of these materials was reduced or eliminated when incorporated into portland cement concrete or asphalt cement concrete. A chemical fate and transport model, using inputs from the leaching studies, was developed in this study to predict the concentration of leachates originating from construction and repair materials and the effect of removal mechanisms such as soil sorption on the concentration of pollutants in runoff.

A brief discussion is warranted on the terminology used to describe the content of storm water runoff. The content of storm water such as metals, salts, solids, organic compounds of anthropogenic origin, and nutrients can be described as toxicants, pollutants, or constituents. The word "constituent" is the most general descriptor of the content of runoff, whereas "pollutant" suggests that the concentration of a substance is above natural or background levels because of human influence. The word "toxicant" is more specific and describes pollutants with a toxic effect. In the context of runoff from bridges, the primary concern is with constituents with elevated levels. Therefore, "pollutant" is used in this handbook to describe the content of storm water. The use of this term does not imply that all bridge deck runoff constituents will be elevated but is used for simplicity in terminology.

For simplicity in terminology in this handbook, "pollutant" is used to describe the content of storm water.

BIOAVAILABILITY OF METALS

Over the last several years, the U.S. EPA and many states have reevaluated their approach to metals toxicity (Prothro, 1993). The key element of this reevaluation is the recognition by U.S. EPA that the dissolved metal fraction should be used in establishing criteria. This approach has since been further recognized by many in the scientific community

TABLE 1 Common highway runoff pollutants and their primary sources

Pollutants	Primary Source(s)
Particulates	Pavement wear, vehicles, atmosphere, maintenance of roadway
Nitrogen, phosphorous	Atmosphere, roadside fertilizer application
Lead	Tire wear, lubricating oil and grease, bearing wear
Zinc	Tire wear, motor oil, grease
Iron	Auto body rust, steel highway structures (for example, guard rails), moving engine parts
Copper	Metal plating, bearing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, brake lining wear, asphalt paving
Manganese	Moving engine parts
Cyanide	Anticake compound used to keep deicing salt granular
Sodium, calcium	Deicing salts, grease
Chloride	Deicing salts
Sulfate	Roadway beds, fuel

(Bergman and Dorward-King, 1997) and codified in U.S. EPA's National Toxic Rule (NTR) (U.S. EPA, May 4, 1994).

The dissolved fraction was selected because there is a standard analytical protocol for its determination (i.e., filtration through a 0.45-μm filter). For most metals even the "dissolved" fraction may overestimate toxicity because some metal complexes smaller than 0.45 μm exert minimal toxicity. Many receiving waters contain naturally occurring substances that bind to metals and reduce their bioavailability. Typical dissolved metals concentrations in highway runoff are substantially lower than total metal concentrations. However, most of the metals data for highway runoff collected to date have been in the total or total recoverable forms. This makes the comparison of historical metals concentrations to current metals criteria difficult.

In general, caution is needed when using available data on metals because there may not be adequate information regarding the form or species of the metal or the dissolved fraction. This information is critical regarding the toxicity of the metal and its bioaccumulation in organisms.

WATER QUALITY CRITERIA

In December 1998, the U.S. EPA published a compilation of its national water quality criteria for 157 pollutants (U.S. EPA, 1998). These recommended criteria provide guidance for states and tribes in adopting water quality standards. Table 2 provides the U.S. EPA recommendations for some of the pollutants listed previously in Table 1. These criteria pertain to protection of aquatic life and are intended to be protective of the vast majority of the aquatic communities in the United States. Criteria for other uses, such as the protection of wildlife, or human health criteria related to public water supply and ingestion of organisms, are available as well and may be appropriate for the specific analytical needs of a particular bridge. As noted above, these U.S. EPA criteria are guidance values. Each state is required to adopt its own criteria into its water quality standards and may even adopt criteria on a site-specific basis for some water bodies. The practitioner should review the state water quality standards directly applicable to the specific receiving water for the bridge(s) in question.

The practitioner should review the state water quality standards directly applicable to the specific receiving water for the bridge(s) in question.

BRIDGE CHARACTERISTICS

The list of questions in Table 3 is intended to assist the practitioner in developing a descriptive profile of a bridge being assessed. This checklist highlights many of the relevant concepts described in detail throughout this document.

TABLE 2 National recommended water quality criteria for priority toxic pollutants[a]

Priority Pollutant	Freshwater[b] CMC (μg/L)[c]	Freshwater[b] CCC (μg/L)[c]	Saltwater CMC (μg/L)[c]	Saltwater CCC (μg/L)[c]
Cadmium[d]	2.0	0.25	40	8.8
Chromium III	570	74	—	—
Chromium VI	16	11	1,100	50
Copper	13	9.0	4.8	3.1
Lead	65	2.5	210	8.1
Nickel	470	52	74	8.2
Zinc	120	120	90	81

[a] The document that these criteria were taken from can also be found on the Internet at the following address: http://www.epa.gov/fedrgstr/EPA-WATER/1998/December/Day-10/w30272.htm.
[b] Criteria for metals are expressed in terms of the dissolved metal in the water column. All pollutants listed in this table, with the exception of Chromium VI, have freshwater-dissolved criteria that are hardness dependent. The criteria were calculated using a hardness of 100 mg/L as $CaCO_3$ for illustrative purposes only.
[c] The values provided in Table 2 are for the Criteria Maximum Concentration (CMC) and Criterion Continuous Concentration (CCC). The CMC protects against short-term (acute) effects (i.e., lethality), whereas the CCC protects against long-term exposure (chronic) effects such as significant reductions in growth or reproduction.
[d] New cadmium criteria were published by U.S. EPA in April 2001 (U.S. EPA, 2001).

TABLE 3 Basic questions for bridge analysis

Issues to Consider	Comments
Is the project a new bridge, replacement bridge, or a retrofit?	Some methods do not apply to new bridge construction.
What is the Average Daily Traffic (ADT)? What fraction of ADT is trucks? What is the truck accident rate per million vehicle miles?	These factors affect runoff characteristics and spill risk. May have to estimate ADT for new bridges to calculate spill risk.
What is the bridge length, width, and total area that contributes to runoff?	Bridge length is a factor in determining whether drainage is needed as well as the amount of pollutant runoff and hazardous spill risk.
What are the designated uses of the receiving water?	Water quality criteria are assigned according to designated uses.
What are the basic hydrologic characteristics of the receiving water?	Lake size, stream flow, estuary flow and tide considerations.
Is the reach of waterway near the bridge designated as an Outstanding National Resource Water (ONRW) or other special status?	These special designations or classifications impose potentially critical constraints.
Is the reach of waterway near the bridge included as an impaired water on the 303(d) list of waters in need of a Total Maximum Daily Load Plan (TMDL)? For which pollutant(s)?	The TMDL process will require overall reductions in pollutant loads, leading to both constraints and opportunities (e.g., via pollutant trading) for new or existing discharges.
Is the bridge located in an urban or rural watershed?	This may affect the concentration of pollutants upstream of the bridge deck.
Is the bridge listed on the National Register of Historic Places?	Section 106 of the National Historic Preservation Act may restrict some retrofits to existing bridges.

CHAPTER **4**

IDENTIFYING PROCESS DRIVERS

SCREENING QUESTIONS

The screening questions listed below are designed to provide insight into the contents of the process driver sections of this chapter and guide the practitioner to the methods that will benefit him or her the most. Tables in the chapter provide a list of the general concerns involved for each driver and can be used to identify analysis methods that are appropriate and potentially a good fit for application by the practitioner. Two types of analyses are described: "preliminary" and "secondary." The preliminary analyses are good for early investigation of potential bridge deck runoff problems because they are relatively easy to use. If a preliminary analysis determines that a problem does exist, or could exist, a secondary analysis may be helpful to verify or better characterize the problem.

Are regulatory considerations such as storm water requirements or pollutant-specific criteria involved? Users of the *Handbook* should turn to the section of this chapter called "Regulatory Considerations" for guidance on managing bridge deck runoff in cases in which regulations governing water column or sediment pollutant concentrations or National Environmental Policy Act (NEPA) requirements affect a bridge project. The section on regulatory considerations also provides guidance on what types of highway runoff pollutant categories need to be addressed in an environmental impact statement (EIS).

Does the action/project involve new potential impacts or changes affecting special resource waters or sensitive habitat? This question is often addressed as part of a project's environmental review process. The section on regulatory considerations can provide some special guidance in this area regarding topics such as pollutant loading to a drinking water source or Outstanding Natural Resource Waters.

Do special circumstances creating the potential for hazardous spills exist? What is the potential impact of repair or construction activities? The users should turn to the section of this chapter titled "Special Conditions" to determine whether heavy truck traffic volumes or high spill potentials apply to the bridge in question, or if repair or construction activities may have an effect on runoff contaminants.

What are the Best Management Practices (BMPs)? The up-front application of BMPs may address certain project situations. Some BMP issues and questions that should be reviewed are the following:

- Is drainage to land encouraged or required?
- For reconstruction, what is the existing bridge drainage system? Does it satisfy any BMPs?
- Is a nonstructural or institutional BMP appropriate?
- Are there opportunities for project impact offsets or "trading" through institutional BMPs such as mitigation banking, pollutant trading, or similar programs?
- For an existing bridge, is it structurally feasible to add a storm water conveyance system to the bridge?

Users should turn to the section of this chapter titled "Best Management Practices" to determine if a BMP will address specific problems of the bridge in question.

REGULATORY CONSIDERATIONS

Table 4 lists some typical regulatory consideration topics a practitioner may encounter and potential analysis methods for each topic. In addition to new, reconstructed, or replacement bridges, potentially any activity or work on existing bridges could lead to regulatory considerations. Table 3 presents several major areas of concern regarding the regulatory considerations of bridge deck runoff. They range from general water quality standards to long-term pollutant loading. In Table 4, appropriate analysis methods are given for each of the topics. The questions listed below can help guide the practitioner in identifying the potential regulatory environment for bridge deck runoff.

Does your bridge need to meet storm water regulation requirements? Most states are now authorized to run U.S. EPA's NPDES storm water permit program. U.S. EPA requires permits for certain kinds of industrial activity, construction activity, and governmental entities (such as state DOTs) discharging to certain municipal separate storm sewer systems (MS4s). Phase I of the storm water program, starting in 1992, required NPDES storm water permits for 10 general categories of industrial activity, construction disturbing greater than 5 acres, and runoff from cities (MS4s) with populations

TABLE 4 Analysis methods for regulatory considerations

Concerns	Details	Preliminary Analysis Methods	Method Number	Second-Stage Analysis Methods	Method Number
General water quality standards	Acute water quality criteria	Mass balance at zone of initial dilution (ZID)	1, 2	Bioassay	4
	Chronic water quality criteria	Mass balance or default dilution	2	Biosurvey	5
	Human health and wildlife criteria	Mass balance or default dilution	2	Great Lakes Water Quality Initiative (GLI) methods, bioaccumulation model	6, 9
	Sediment criteria	Sediment pollutant accumulation model, sample sediment	3, 8	Sample sediment, advanced model	8, 9
	Nutrient criteria	Mass balance calculation	2	Eutrophication model	10
	Human health and aquatic life criteria	Mass balance or default dilution	2	GLI methods, bio-accumulation modeling	6, 9
	Chronic water quality criteria	Average concentration at shellfish bed, decay model	2, 7	Advanced model	9
	Conventional pollutant (for example, bacteria) criteria	Mass balance and decay models	2, 7	Advanced model	9
Storm water requirements	Meet percentage removal requirements	Nonstructural and structural BMP evaluation	13	None	—
	Meet required structural BMPs	Nonstructural and structural BMP evaluation	13	None	—
	Storm water pollution prevention plan	Nonstructural and structural BMP evaluation	13	None	—
Nutrient loading as part of formalized Total Maximum Daily Load (TMDL)	Nitrogen or phosphorus loading rate limits/allocation	Bridge deck loading	11	Gather site-specific runoff field data	12
Input to drinking water reservoir	Allocated loading	Bridge deck loading	11	Gather site-specific runoff field data, fate and transport model	12, 9
Long-term pollutant loading	Sediment criteria	Sediment pollutant accumulation model	3	Sample sediment, advanced model	8, 9
	Relative loading	Comparison of bridge deck loading to other sources	15	None	—
Degraded receiving water (303d)/urban environment	Pollutant inputs from bridge deck	Calculation of bridge deck and other sources loadings	15	Determine impact of storm water inputs upon biology of receiving water with biosurvey or bioassay	5, 4
		Gather site-specific runoff field data	12	None	—

TABLE 4 (Continued)

Concerns	Details	Preliminary Analysis Methods	Method Number	Second-Stage Analysis Methods	Method Number
High quality water/ outstanding national resource water	Acute water quality criteria	Mass balance at ZID	1, 2	Bioassay	4
	Chronic water quality criteria	Mass balance or default dilution	2	Biosurvey	5
	Human health and wildlife criteria	Mass balance or default dilution	2	GLI methods, bioaccumulation model	6,9
	Sediment criteria	Sediment pollutant accumulation model, sample sediment	3, 8	Sample sediment, advanced model	8,9
	Nutrient criteria	Mass balance calculation	2	Eutrophication model	10
	Restrictions on new or increased discharges	Antidegradation analysis	19	None	—

greater than 100,000. Many state DOTs were required to obtain MS4 permit coverage in areas where their highways ran through these Phase I cities. Starting in early 2003, Phase II of the storm water program will require permits from smaller cities and construction disturbing 1 to 5 acres. State DOTs may need to expand their MS4 permit coverage to add state highways in these Phase II cities. Additional information on U.S. EPA's storm water program, with links to state storm water programs, can be found at http://cfpub.epa.gov/npdes/.

The U.S. EPA sets the national storm water regulatory standards, yet the requirements within each authorized state will differ according to the water quality objectives set forth by that state. Construction of new bridges will probably require an NPDES construction storm water permit. Existing bridges, however, are probably covered by the state DOT's statewide MS4 permit. Some industrial facilities managed by the state DOT, such as vehicle maintenance yards, could require a separate industrial storm water permit.

Storm water permits typically set the general requirements but allow the permittee to decide exactly how to meet those requirements.

Storm water permits typically set the general requirements that must be met but allow the permittee to decide exactly how to meet those requirements and which BMPs to use. For bridges that need to meet storm water regulation requirements, this handbook identifies approaches for meeting percentage removal, BMP, and pollution prevention plan requirements in Method 13. See Chapter 6 for a summary and applicable references for those methods, or look in the Appendix to this volume for the full descriptions of each method.

Are water quality criteria or special receiving waters a source of concern? This chapter provides guidance for issues involving specific water quality criteria, such as sediment or bacteria, and more general regulatory concerns such as Total Maximum Daily Loads (TMDLs). Receiving waters for bridge deck runoff often have special features that give them certain regulatory designations. These waters are often a source of drinking water or may be given a special management classification such as Outstanding National Resource Water. In recent years, new regulatory emphasis has been placed on the TMDL program (http://www.epa.gov/owow/tmdl). TMDLs set pollutant-specific water quality targets for a water body. These targets create opportunities for the analysis of appropriate BMPs, a topic that is covered in Method 13. However, to best select BMPs, the analyses listed in the "Special Considerations" section of this chapter are often required beforehand.

Another area of concern when examining the regulatory considerations of bridge deck runoff is applicability to regulations of the National Environmental Policy Act (NEPA). FHWA (Dupuis and Kobringer, 1985) provides guidance for addressing highway runoff pollutant categories in an EIS. Table 5 shows the suite of highway runoff pollutant categories to be discussed in an EIS as they pertain to designated uses of water bodies.

Is the bridge identified as a historic property? Resources that are considered to be of historic value are protected by Section 106 of the National Historic Preservation Act. Section 106 requires that impacts to historic properties, defined as those eligible or potentially eligible for listing on the National Register of Historic Places (NRHP), be considered prior to implementation of a federal agency undertaking. For assistance in determining whether a bridge is eligible or potentially eligible for the NRHP, consultation with the State Historic Preservation Officer (SHPO) or the Advisory Council on Historic Preservation (ACHP) is recommended.

If, in consultation with the SHPO and the ACHP, a determination of "adverse effect" to the bridge is declared, an action may proceed as planned only when a Memorandum of

TABLE 5 Highway runoff pollutant categories that should be addressed in an environmental impact statement (EIS) for specific receiving water types and designated uses[a]

	Highway Runoff Pollutant Category				
Receiving Water Type and Designated Use	Deicing Salts	Toxic Materials	Microorganisms (Coliforms)	Solids (Siltation)	Nutrients (Eutrophication)
Rivers and Streams					
Water supply	X	X	X		X
Aquatic life	X	X		X	X
Recreational		X	X		X
Lakes or Reservoirs					
Water supply	X	X	X		X
Aquatic life	X	X		X	X
Recreational		X	X		X
Coastal Systems					
Estuaries	X	X	X	X	X
Marine	X	X	X		

[a] Adapted by CH2M HILL from FHWA guidance.

Agreement is created, which outlines agreed-on measures that the agency will take to avoid, minimize, or mitigate the adverse effects to the bridge. In some cases, the consulting parties may agree that no such measures are possible, but that the adverse effects must be accepted in the public interest. The implementing regulations for Section 106 (36 CFR 800) outline the criteria for an adverse effect and provide guidance on Section 106 issues.

SPECIAL CONDITIONS

The potentially unique characteristics of a bridge vary widely, making it difficult to capture all of the special conditions a practitioner may be interested in analyzing. This chapter provides analysis techniques for some of the typical bridge deck runoff concerns, including acute and chronic toxicity, cases of multiple bridges, hazardous spills, and construction and repair activities. Multiple bridges are a concern when there may be a nearby bridge that contributes to the background levels of a pollutant. As previously discussed, the toxicity of materials used in the construction and repair of highways and bridges has been evaluated (Nelson et al., 2001) and the effects of these activities on receiving waters may need to be evaluated using methods developed in NCHRP Project 25-9.

Table 6 presents the preliminary and secondary methods that may be most applicable to the issues of multiple bridges and other special conditions.

INTEGRATING WATER QUALITY AND BIOLOGICAL DATA

Answering the question of whether bridge deck runoff will impair the aquatic life of the receiving water body is the primary purpose of gathering water quality data, performing biological analysis, and evaluating biological data. Impairment can only be judged against the capacity of a water body to support aquatic life. Rivers, lakes, coastal estuaries, and ephemeral streams, for example, have vastly different indigenous aquatic life and hence are given separate designations. Water quality criteria for aquatic life are applied to these designations to protect indigenous biota; therefore, criteria can be used to evaluate the potential of bridge deck runoff to impair a water resource. Other considerations include what pollutants exceed criteria, and the magnitude and frequency of the exceedance.

With this in mind, the comparison of pollutants in runoff with established criteria (generally accounting for dilution and other fate and transport mechanisms in the receiving water body) can be used to make an initial determination of the potential for impairment. However, if criteria are consistently exceeded, additional evaluation is warranted. Time-variable and continuous whole effluent (bridge deck runoff) toxicity tests and biosurveys can be performed to further evaluate the potential for impairment (Methods 4 and 5, summarized in Chapter 6 and described in detail in the Appendix to this volume). Ultimately, it will be useful or even necessary for the practitioner to be able to develop an integrated assessment of available physical, chemical, and biological data.

The Water Environment Research Foundation (WERF) published technical guidance that included a recommended approach for such an integrated assessment (Novotny et al., 1997). Central to the WERF approach is the concept of attainment. The following are three conditions of attainment:

- All three groups of indices (that is, physical, chemical-toxicological, and biological) indicate attainment;

TABLE 6 Analysis methods for special conditions

Concerns	Details	Preliminary Analysis Methods	Method Number	Second Stage Analysis Methods	Method Number
Acute toxicity	Bridge deck runoff toxicity (that is, multiple pollutants)	Bioassay	4	In situ toxicity test	15
Hazardous materials spill	Human health and acute aquatic life criteria or other toxicological endpoints	Calculate concentration of hazardous chemical at drinking water intake, or other point of concern	16, 17	Advanced computer model	18
Chronic toxicity	Bridge deck runoff toxicity (that is, multiple pollutants)	Biosurvey, bioassay	5, 4	In situ toxicity test	15
Construction and repair	Toxicity of construction and repair materials	Mass balance or default dilution	1,2	None	—
Multiple bridges	Cumulative impacts	Mass balance or default dilution, sediment accumulation, decay model, comparison of loadings from bridges to other sources	1-3, 7, 16	Advanced model	9

- Only statistics of chemical group of indices (water and sediment) indicate nonattainment, but monitoring data do not indicate consistent exceedances of the criteria, meaning the chemical criteria are not exceeded frequently or to the magnitude that biological impairment would occur; and
- Only biological indices indicate nonattainment, but impairment is due to past adverse effects of pollution or habitat disruption, and a designated use may be attained if there is a trend toward recovery within a reasonable time period.

Evidence of nonattainment includes the following three conditions:

- Only biological indices indicate nonattainment,
- Statistics of chemical indicators indicate nonattainment, and
- Two or more groups of indicators indicate nonattainment.

One of the historical difficulties with biological assessments is that they often do not specifically identify the cause or source of impairment/nonattainment. A commonsense approach to this constraint is presented in U.S. EPA's *Stressor Identification Guidance Document* (SIGD) (U.S. EPA, 2000). This approach could be used to link together the use of criteria, whole effluent bioassays, biosurveys, and other relevant data. The SIGD proposes a series of steps to identify the cause of a detected or suspected biological impairment. The steps presented in the SIGD are (1) list candidate causes, (2) analyze evidence, and (3) characterize causes. A particularly important concept that was developed in the SIGD was "strength of evidence" analysis. Because a bridge's region of influence is small compared with other watershed influences, it is important to determine if there is enough evidence to identify the bridge as the cause of impairment or, if impairment is not evident, to determine if the bridge could cause impairment.

Linking stressors with an effect, strength of evidence analysis makes use of six causal considerations that are relevant to bridge deck runoff: (1) co-occurrence, (2) temporality, (3) biological gradient, (4) consistency of association, (5) consistency of evidence, and (6) coherence of evidence. The first three considerations link the placement of a bridge in a watershed to localized effects near the bridge. Determining consistency of association involves considering whether the level of pollutants discharged from a bridge is consistent with the level of effects noted near the bridge. Determining the consistency and coherence of evidence involves considering whether the use of methods such as time-variable bioassays, continuous exposure chronic bioassays, and biosurveys consistently points to the bridge deck as the source of impairment. In this regard, timescale issues are critical. Continuous chronic bioassays are not appropriate for receiving waters such as rivers, where storm water is quickly flushed and aquatic organisms are exposed only for a short duration. In this case, time-variable bioassays would more accurately reflect the exposure duration. Conversely, toxicity for one time-variable bioassay alone should not lead to the conclusion of impairment. The evidence needed to identify impairment could be improved by performing additional bioassays during several seasons and/or by performing additional analysis such as a biosurvey. If a biosurvey identifies

TABLE 7 Analysis methods for best management practices (BMPs)

Concerns	Details	Preliminary Analysis Methods	Method Number	Second-Stage Analysis Methods	Method Number
Input to drinking water reservoir	Percent removal required/needed	BMP evaluation	13	None	—
Maintenance	Bridge cleaning, painting, and resurfacing	BMP evaluation	13	None	—
Pollutant reduction	Nonstructural, institutional, and structural BMPs	BMP evaluation	13	None	—
Bridge design considerations	Bridge storm water conveyance systems	BMP evaluation	13	None	—

localized effects, the link to the bridge deck as the source of impairment would be more conclusive. The outcome of these assessment methods and others (e.g., water quality criteria and enrichment of metals in sediment and biota) should be evaluated from a "strength of evidence" viewpoint.

In addition to assessing the chemical and biological integrity of a water body, practitioners should assess its physical integrity. The physical integrity of a stream, for example, can be affected by a road running along it that restricts normal stream flow and hydrology. It can also be affected by urbanization that causes greater hydraulic loads and scouring, or channelization. Any assessment of the potentially adverse effects of bridge deck runoff should include a consideration of physical integrity along with chemical and biological measurements.

Any assessment of the potential adverse effects of bridge deck runoff should include a consideration of physical integrity along with chemical and biological measurements.

Finally, the methods and assessments discussed so far in this chapter will in some cases lead to the logical conclusion that the promulgated numeric water quality criterion may not be appropriate for a specific water body. In many cases, site-specific factors affect the bioavailability of a pollutant to aquatic organisms. The U.S. EPA and most states have recognized this and have provisions and approved methods for development of site-specific criteria. Of particular relevance to bridge runoff is the Water Effect Ratio procedure designed for site-specific criteria development for metals that are not bioaccumulative (see the first volume of this report). The Water Effect Ratio of pollutants is the ratio of toxicity to aquatic organisms in natural waters to toxicity to aquatic organisms in laboratory waters. This procedure has seen fairly widespread use in recent years, especially for common and ubiquitous metals such as copper, lead, and zinc.

BEST MANAGEMENT PRACTICES

BMPs are a common implementation tool and are used to bridge the gap between the results of an analysis and implementation of a solution. As can be seen in the two previous process driver sections, BMPs can apply to nearly all bridge deck runoff problems. To address concerns, or to achieve water quality goals, the three types of BMPs that may need to be considered are structural, nonstructural, and institutional BMPs. Nonstructural and institutional BMPs offer cost-efficient and alternative approaches to reducing pollutant loads when the physical features of an existing or proposed bridge make it difficult to construct storm water conveyance systems for off-bridge treatment.

The three types of BMPs that may need to be considered include structural, nonstructural, and institutional BMPs.

Table 7 presents the preliminary methods that may be most applicable when considering BMPs.

Early in the planning process, the feasibility of constructing storm water conveyance systems associated with structural BMPs for bridge deck runoff must be considered. The integrity of existing bridges and the structural design of proposed bridges will be affected by the additional weight imposed by the system and by the various conflicts the system will have with the structural members (see Method 13 for additional discussion).

CHAPTER 5

USING THE PROCESS—CASE STUDY EXAMPLE

The SFOBB offers a unique example of how the process described in this handbook can be used to evaluate a complex bridge deck runoff environment. Evaluation of the SFOBB in this case study follows the procedure outlined in Figure 1 (see Chapter 2). The process starts with the review of basic project information, moves to the identification of process drivers or issues, and concludes with the use of analysis methods to develop a plan. Except when noted otherwise, the application of the specific methods described in this chapter were conducted by the NCHRP Project 25-13 research team, with issue identification and some relevant data provided by the California Department of Transportation (Caltrans).

PROJECT INFORMATION AND PROCESS DRIVERS

The SFOBB consists of two spans, the existing west span (between San Francisco and Yerba Buena Island) and the existing east span (from Yerba Buena Island to Oakland). The east span is up for replacement because of concerns over its ability to withstand an earthquake. The proposed reconstruction of the bridge triggered interest in mitigating storm water runoff from the new and existing spans. The bridge has two decks with a total area of 43.5 acres and an average daily traffic (ADT) volume of approximately 274,000 vehicles per day. Storm water is currently discharged directly to the San Francisco Bay via a series of scupper drains.

Using the screening questions (see Chapter 4) the NCHRP Project 25-13 research team identified the process drivers or issues as (1) regulatory, primarily water quality as related to potential impacts on aquatic life; (2) special conditions, primarily the risk of spills; and (3) BMP feasibility. The primary stakeholders in this process are Bay Area citizens, environmental groups, the San Francisco Bay-Regional Water Quality Control Board (SFB-RWQCB), and Caltrans.

SELECTING METHODS/ PERFORMING ANALYSIS

Regulatory Issues (Water Quality/Aquatic Life)

Storm water discharges in the Bay Area are regulated by the NPDES storm water permitting system. A specific regulatory environment exists for the San Francisco Bay. The SFB-RWQCB has adopted water quality objectives that set forth pollutant limits in the Bay according to designated uses. For the Bay Area in the vicinity of the SFOBB, the designated uses are sport fishing, estuarine habitat, industrial service, fish migration, fish spawning, preservation of rare and endangered species, water contact recreation, noncontact recreation, shellfish harvesting, and wildlife habitat. Water quality objectives are set to protect these designated uses, and the concentration of pollutants in SFOBB runoff is compared with the objectives. The current policy of the SFB-RWQCB is that storm water discharged into the Bay Area cannot contain concentrations of pollutants that exceed these objectives.

However, comparing pollutant concentrations in undiluted storm runoff to numeric criteria associated with the ambient receiving water does not provide a complete or rigorous analysis. As discussed in earlier sections of this handbook, potential effects on aquatic life are generally best evaluated using several different methods, when practicable, and developing a conclusion based on an integrated "strength of evidence" or "weight of evidence" analysis. This is the case particularly with bridges like the SFOBB, which cross large water bodies, because such large areas of water are likely to provide substantial dilution and other fate and transport processes.

A "strength of evidence" or "weight of evidence" analysis approach can be used to assess effects of bridge deck runoff on a receiving water.

Other water quality/aquatic life issues are also important in this case. For example, the San Francisco Bay is on the 303(d) list of impaired waters and will likely be the subject of a TMDL study. The U.S. EPA has identified copper and nickel for inclusion in a TMDL process. Both of these metals are found in bridge deck runoff. Sediment quality is also regulated by narrative criteria (i.e., non-numeric criteria) that state that the sediment load shall not cause a detrimental increase in sediment concentration of a toxicant.

Methods from this handbook used to address regulatory issues related to water quality and protection of aquatic life included the following:

- Method 4—Bioassay Method
- Method 5—Biosurvey

- Method 8—Sediment Sampling
- Method 11—Pollutant Loading
- Method 12—Collection of Site-Specific Runoff Quality Data
- Method 15—Comparison of Bridge Deck Loading to Other Source Loadings in Watershed

Evaluation of the potential effect of SFOBB runoff prior to construction of the new east span required an estimate of the pollutant concentrations that would enter the San Francisco Bay from the bridge. Runoff data were available for a nearby highway (I-80) that abuts the San Francisco Bay and had an ADT (246,000 to 263,000) that was similar to the expected ADT of the new SFOBB. Therefore, runoff data from I-80 were expected to be comparable with SFOBB runoff data. These I-80 runoff data were compared with the water quality objectives (see Table 8) for the San Francisco Bay. It was clear from this preliminary analysis that concentrations of several metals in the runoff from SFOBB were likely to exceed the San Francisco Bay water quality objectives. Monitoring of storm water from the SFOBB performed under NCHRP Project 25-13 largely confirms this earlier data review (although the concentrations of copper and zinc were significantly greater at the SFOBB than I-80).

Although water quality objectives were exceeded in the bridge runoff for a number of metals, substantial mixing will occur in the San Francisco Bay because of the free-fall energy of runoff discharging through scupper drains and subsequent tidal dispersion and flushing. A dye study could be performed, or a number of mixing models reviewed in Method 1 could be used, to estimate the zone in which pollutant concentrations exceed the objectives as a result of bridge runoff and the spatial extent of such pollutant concentration exceedances. In most states, such a limited area is provided as a "mixing zone" in which criteria exceedances are allowed under specified conditions. In this case, even though the SFB-RWQCB apparently does not allow a mixing zone, it may be worthwhile to evaluate the mixing and dispersion processes anyway. The area of the impacted zone could be used in a pollutant trading program in which a similar or larger-sized impact zone located near the bridge, or in another part of the watershed, could be mitigated through the use of a BMP (see Method 13). Such analyses were not undertaken for this case study because the application of other methods (described below) strongly indicated that aquatic life in the immediate vicinity of the bridge has not been adversely affected by storm water runoff.

Most states provide for a "mixing zone" in which criteria exceedances are allowed under specific conditions.

Acute aquatic toxicity was also evaluated using runoff from I-80. Runoff was not toxic to *Pimephales promelas* (fathead minnows) during 96-hour tests (Caltrans, 1998a). Therefore, acute toxicity was not a dominant issue surrounding SFOBB runoff (Pilgrim, 2001).

The potential acute and chronic toxicity of runoff from the SFOBB was evaluated using the time-variable method presented in this handbook (see Method 4 in the Appendix to this volume) and in the first volume of this report. A saltwater test organism, *Mysidopsis bahia* (mysid shrimp), was exposed to SFOBB runoff at various dilutions for a period of time equal to the storm duration. The test organisms were then transferred to laboratory control water (i.e., "clean" water) for the remaining duration of the standard test to evaluate potential delayed effects (total duration of 48 hours for acute response and 7 days for chronic). Both acute and chronic tests were conducted. Acute results are expressed as percent survival and chronic results are expressed as the

TABLE 8 Runoff quality for I-80 and the San Francisco-Oakland Bay Bridge (SFOBB) and water quality objectives

Pollutant (µg/L)	I-80[a]		SFOBB[b]		Water Quality Objectives	
	Min.	Max.	Min.	Max.	4-Day Average	1-Hour Average
Arsenic	<2.0	<2.0	—	—	36	69
Cadmium	—	—	1.3	2.8	9.3	43
Chromium	<10.0	24	7.8	40	50	1100
Copper	9.3	58	130	270	—	4.9
Lead	6.5	64	51	160	5.6	140
Nickel	28	31	15	36	7.1 (24-hour)	140 (inst. max)[c]
Zinc	34	190	360	760	58 (24-hour)	170 (inst. max)

[a] Caltrans, 1998a.
[b] See first volume of this report.
[c] instantaneous maximum.

TABLE 9 Saltwater time-variable bioassay results for San Francisco-Oakland Bay Bridge (SFOBB) deck runoff

Event (Runoff duration)	April 16, 2000 (382 minutes)	May 7, 2000 (340 minutes)	May 14, 2000 (93 minutes)	April 6, 2001 (351 minutes)
Percent runoff	**Acute Test Results (Mean Percent Survival in 48 hours)**			
0 (Control)	100	97.5	95	100
6.25	97.5	97.5	100	97.5
12.5	97.5	97.5	95	97.5
25	97.5	90	92.5	95
50	97.5	95	95	100
100	95	80	100	100
	Chronic Test Results (IC_{25} over 7 days)			
Percent runoff causing a 25 percent reduction in growth compared to the control (IC_{25})	97.9	>100	>100	>100

25 percent inhibition concentration, as defined in Method 4. Table 9 presents the results of the bioassays.

The time-variable tests with runoff from the SFOBB showed runoff was not acutely toxic for three of the four events at concentrations up to 100 percent. The other event showed no significant acute toxicity at runoff concentrations as high as 50 percent, with some toxicity evident at 100 percent runoff. Similarly, the tests showed that there was no significant chronic toxicity for three of the four events. For one event, a 25 percent reduction in growth was predicted at a runoff concentration only slightly lower than 100 percent. Concentrations of some metals also exceeded national water quality criteria in SFOBB runoff samples (e.g., copper values from 130 to 270 μg/L and zinc values from 360 to 760 μg/L). Yet the time-variable toxicity tests showed either no toxicity or low levels of toxicity. These tests also showed that relatively low levels of receiving water dilution would eliminate the marginal effects seen at 100 percent runoff. More specifically, these particular tests showed that a dilution factor of only one part San Francisco Bay water to one part runoff (i.e., 50 percent runoff) is the most that would be needed to eliminate all significant toxicity.

The potential long-term impairment of aquatic life below the bridge was further evaluated with sediment quality and biosurvey data. According to a benthic biosurvey performed beneath the SFOBB as part of NCHRP Project 25-13, benthic biota in the bridge vicinity have not been impaired by the historical operation of the existing bridge (see example under Method 5 in the Appendix to this volume, or see the first volume of this report). This outcome is further supported by a 1996 evaluation of the concentration of pollutants in sediment (Method 8) taken from beneath the SFOBB (see the first volume of this report), in multiple locations in the San Francisco Bay (Yerba Buena Island, Horseshoe Bay, Richardson Bay, Point Isabel, and Red Rock [SFEI, 1996]), and in solids deposited in drain inlets located on the bridge deck (Caltrans, 1998b) (see Table 10). These data show that, although solids from the drain inlets have elevated concentrations of copper and zinc, the sediments immediately below the bridge are more comparable to those elsewhere in the San Francisco Bay.

An integrated assessment of the application of the above methods relating to water quality and aquatic life can be developed using the WERF "weight of evidence" (Novotny et al., 1997) and U.S. EPA "strength of evidence" (U.S. EPA, 2000) approaches described in Chapter 4.

- **Weight of Evidence**—The exceedance of numeric objectives at the "end-of-pipe" (without dilution or fate and transport considerations) provides only the suggestion (but not evidence) of potentially adverse effects from SFOBB runoff. This suggestion of potential impact is outweighed by the fact that time-variable toxicity tests (with minimal dilution considered), benthic biosurveys, and sediment quality data all show that aquatic life uses are not significantly affected by bridge runoff. This suggests that end-of-pipe application of water quality objectives is not warranted in this case, or that site-specific numeric criteria for several pollutants may be appropriate. In either case, the weight of evidence shows that the bridge is not causing impairment (i.e., nonattainment).
- **Strength of Evidence**—This analysis is intended to systematically identify stressor(s) given a determination that there is biological impairment in an aquatic ecosystem. In this case, the only suggestion that the bridge may be causing adverse aquatic life impacts is that "end-of-pipe" concentrations of some pollutants exceed numeric water quality objectives for the San Francisco Bay. Again,

TABLE 10 Concentration of metals in sediment on the bridge deck of the San Francisco-Oakland Bay Bridge (SFOBB), from beneath the SFOBB, and in Central San Francisco Bay

Pollutant (mg/kg)	Sediment Source		
	Below SFOBB[a]	SFOBB Bridge Deck[b]	Regional Monitoring Program-Central Bay[c]
Cadmium	<0.22	1.6	0.15
Chromium	75	52	79
Copper	46	445	29
Nickel	43	50	71
Zinc	78	632	91

[a] Average of Project 25-13 data.
[b] Source: Caltrans, 1998b.
[c] Source: SFEI, 1996.

the results of the time-variable bioassay tests (with minimal dilution considered), the benthic biosurveys, and sediment quality data all strongly indicate that there is no significant biological impairment near the bridge. Therefore, there is no compelling reason to evaluate stressor(s) that may be associated with bridge runoff.

Regulatory Issues (TMDL/Pollutant Loadings)

As previously noted, the San Francisco Bay is on the 303(d) list of impaired waters and is likely the subject of a TMDL analysis. The result of monitoring activities, toxicity testing, and input from stakeholders led to the identification of pollutant loading from the SFOBB as the primary issue related to bridge runoff. As a result, the relative loadings from the SFOBB compared with the other sources contributing listed pollutants to the bay will be a critical element of the TMDL. Not only will the relative load from the SFOBB provide perspective, it could also serve as a basis for offsets or pollutant trading, if such programs are established for the San Francisco Bay as a result of the TMDL process. Caltrans has developed a relationship between rainfall intensity and pollutant loading (see Intensity-Correlation Method under Method 11 in the Appendix to this volume) from a runoff monitoring study performed for I-80 near the SFOBB (Caltrans, 1998a). As an example, the NCHRP 25-13 research team, using the intensity-correlation method and precipitation data from 2000, performed a loading estimate for the SFOBB. This estimate was then compared with a loading estimate using the simple method (also described in Method 11), which uses annual precipitation, bridge deck area, and the runoff sampling data collected for the SFOBB (see Table 8). A comparison of these loading estimates is presented in Table 11. Largely because of higher runoff concentrations at the SFOBB, the loading estimate from the I-80 intensity-correlation study was far lower than the loading estimate based on four monitoring events at the SFOBB. Although four events may not necessarily provide a large enough database for definitive conclusions, the discrepancies in the loading methods' predictions suggest that site-specific data collection, when practicable, may be preferable to transference of data from other sites.

A pair of analyses from Method 11 that utilize rainfall data were compared with each other in the case study (see Table 11).

Special Conditions (Risk of Hazardous Materials Spills)

According to Caltrans (Pilgrim, 2001), during the fiscal years 1993/1994 to 1996/1997 there were 10 spills in the vicinity of the SFOBB: 7 at the toll plaza and 3 on the bridge.

TABLE 11 Estimated loading from San Francisco-Oakland Bay Bridge (SFOBB) for selected metals

	Loading (lbs/year)			
	Chromium	Copper	Lead	Zinc
Intensity Correlation	2.8	6.6	3.7	31.6
Simple Method	4.7	48	26	137

Hence, the risk of a spill on the bridge was slightly less than once each year.

Using the methodology provided in Method 16 in the Appendix to this volume, the risk of a spill on the SFOBB can also be calculated with the following equation and national risk estimates:

$$Risk = TAR \times FracHaz \times RelProb \times Length \times \frac{ADTT \times 365}{1,000,000}$$

where

Truck Accident Rate per million vehicle miles (**TAR**)	=	2.09
Fraction of trucks involved in accidents carrying hazardous materials (**FracHaz**)	=	0.04
Fraction of hazardous material accidents with a spill (**RelProb**)	=	0.33
Length of the bridge in miles (**Length**)	=	4.1
Average Daily Truck Traffic (**ADTT**)	=	27,400

Assuming that truck traffic was 10 percent of total ADT (274,000), the risk of a spill was 1.13 spills per year, or one spill every 11 months, a calculation in very close agreement with Caltrans historical spills data.

BMP Evaluation

The evaluations of the SFOBB presented so far suggest that BMPs need not be considered with respect to potentially adverse aquatic life effects in the vicinity of the bridge because it is unlikely that long-term historical operation at very high ADT levels has caused such effects. However, if the San Francisco Bay is indeed being adversely affected by overall loadings of some pollutants, as suggested by the 303(d) listing and TMDL processes, then it might be anticipated that reductions in these loadings may be needed to address the larger-scale issues in the watershed. To address the pollutant loading issue, Caltrans evaluated potential BMPs for storm water runoff management (Pilgrim, 2001). Caltrans performed a review of BMPs similar to the BMP method presented in this handbook (Method 13). This analysis of BMPs also has to involve common sense and design considerations, such as whether the structural capacity of a bridge can withstand the additional weight of a storm water conveyance system (as described under Method 13 in the Appendix to this volume). The Caltrans analysis identified high-efficiency, vacuum-type street sweeping as the most effective BMP for the SFOBB (with respect to cost and pollutant removal efficiency). However, the east span of the SFOBB has not yet been constructed, and the use of street sweeping for the bridge is still under consideration.

Regarding the spills issue, the historical level of risk was not considered large enough by Caltrans to warrant the construction of a conveyance system to contain spills (Pilgrim, 2001). There was additional concern that a gasoline spill could cause an explosion hazard if it were retained in piping used to convey storm water runoff. The result of these analyses was that the conveyance of runoff through piping to an off-site BMP was not considered a practical option for spill control.

CHAPTER **6**

METHODS SUMMARIES

Each of the 19 methods is briefly summarized in this chapter and is described in detail in the Appendix to this volume. Figure 2 shows how the unique regulatory and environmental climate associated with a bridge project logically leads the practitioner toward a suite of analytical methods to evaluate potential impacts and BMPs to mitigate for them. The preliminary methods, many of which are “desktop” analyses, are provided in the circles. Secondary methods are given in the triangles. It is possible for one analysis method to be both preliminary and secondary depending on the level of detail and effort expended on the method.

Some of the methods in this handbook involve the use of models to predict the fate of storm water pollutants in a receiving water. Historically, most water quality models have been developed for continuous point source inputs; however, the episodic nature of storm water inputs requires innovative approaches to modeling. In those cases in which innovative modeling approaches may be needed, suggestions are provided in the methods. These suggestions, however, are not meant to exclude other approaches to storm water modeling.

The remaining portion of this chapter provides a summary for each of the 19 methods described in this *Practitioner’s Handbook.*

METHOD 1: CALCULATION OF IN-STREAM POLLUTANT CONCENTRATION AT THE ZONE OF INITIAL DILUTION

This method provides a conservative approach to calculating in-stream concentrations of pollutants within a limited region in which storm water and receiving water mix. The mixed concentration is calculated at the edge of this mixing region, generally called the zone of initial dilution (ZID). State water quality standards usually provide methodologies for the determination of ZID size. Some states do not allow ZIDs and instead compare acute criteria to end-of-pipe concentrations, which in this case would be direct storm water from the bridge. Acute criteria protect against short-term, lethal effects. Chronic criteria protect against longer-term effects such as growth and reproduction impairment.

Another option for states that do not use a ZID concept for acute criteria is to assume complete mixing with a design stream flow specific to acute criteria. In these cases, the complete-mix approach (see Method 2) should be used. If the estimated undiluted runoff concentration for a given parameter is less than the applicable in-stream criterion, there is no reason to undertake mass balance calculations. If the background concentration exceeds the criterion, the practitioner should proceed to methods for cases in which sources of pollutants other than the bridge need to be considered (e.g., Methods 11 and 15).

METHOD 2: FULLY MIXED IN-STREAM POLLUTANT CONCENTRATION

Method 2 is applicable to analysis of any situation in which it is assumed that the discharge is fully mixed with the receiving water or some specified fraction thereof. This situation could include acute and chronic aquatic life (e.g., acute effects are short-term lethality, and chronic effects are impairment of growth and reproduction), wildlife, and human health toxicity criteria. Method 2 also is applicable to other water quality standards (i.e., substances such as salts and color).

Calculations of fully mixed in-stream pollutant concentrations have been traditionally used to determine whether pollutants from a continuous point source such as a municipal or industrial discharge exceed chronic or human health water quality criteria. Because storm water discharges are intermittent, aquatic organisms as well as humans will experience intermittent exposure to pollutants. Hence, calculation of in-stream pollutant concentrations from average or peak storm water flows will overestimate (and thus provide a conservative estimate of) the potential for runoff to have a toxic/human health effect. Although this method generally is very conservative, it will nonetheless often demonstrate minimal likelihood of toxicity from specific chemicals in runoff from a bridge deck. If this method predicts an exceedance of one or more criteria, it does not necessarily mean that there will be a real impact in the receiving water. Biological test methods (Methods 4 and 5) can also be used to assess toxicity and may be preferable.

Detailed calculation methodologies for each receiving water type (streams and rivers, coastal areas, lakes, wetlands, and reservoirs) are provided for Method 2 in the Appendix to

Process Drivers

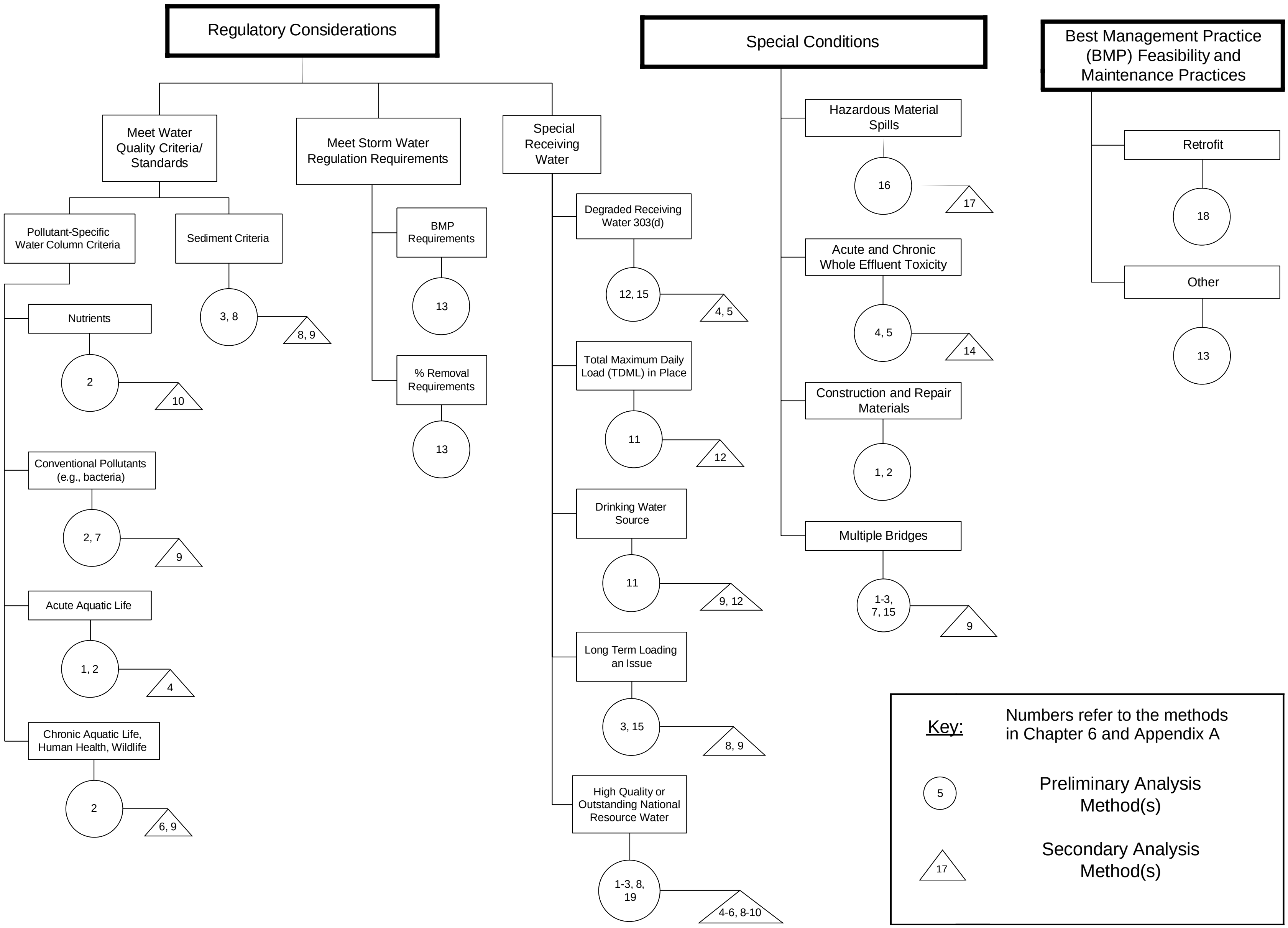

Figure 2. Handbook analysis methods chart.

this volume, along with considerations for chloride discharge and multiple bridges.

METHOD 3: SEDIMENT POLLUTANT ACCUMULATION MODEL

One ultimate sink for pollutants is sediment. Once incorporated in sediments, pollutants can either bioaccumulate or cause toxicity to organisms that live in or near the sediment layer. Therefore, comparing sediment criteria to sediment pollutant concentrations near the bridge can identify potential long-term impacts of the bridge.

This method describes relatively simple models for the calculation of sediment pollutant concentrations downstream from, or near, bridge deck storm water discharges. A loading estimate is required for each of the models described in this method. The models assume that the loading is continuous; therefore, appropriate adjustments are necessary to account for the intermittent nature of bridge discharges. As in Method 2, the models apply to streams and rivers, coastal systems, lakes, wetlands, and reservoirs.

The U.S. EPA is in the process of developing sediment quality criteria, and some states (such as Washington) have criteria. Until such time as these criteria, as well as implementing procedures, are published and widely adopted into state water quality regulations, it can reasonably be argued that practitioners should not be expected to evaluate sediment impacts.

METHOD 4: BIOASSAY METHOD

This method does not generally apply to new bridge construction unless an existing bridge is used as a surrogate for the new bridge.

The potential for adverse effects on receiving waters is often related to storm duration, volume, time between storms (in some cases), traffic volume, and mixing with the receiving water. The area of a receiving water that is potentially affected by toxicity is also a function of mixing. If the runoff is funneled to a single point discharge, the amount of mixing in the receiving water will be less efficient than if the runoff were discharged from multiple points across the bridge deck (analogous to a diffuser).

The objective of this test method is to determine if bridge deck runoff has the potential to be acutely or chronically toxic to freshwater or marine organisms under simulated runoff conditions. To meet this objective, a sampling and toxicity testing program has been developed specific to bridge deck runoff that will assess the toxicity of runoff for time-variable exposures.

The laboratory bioassay methods described here will provide a scientifically sound and fairly low-cost way to assess the toxicity of bridge runoff to aquatic organisms. Although the methods suggested and organisms to be used are mostly consistent with standard U.S. EPA testing protocols, several deviations are needed to address the time-variable component of storm events. The methods and materials needed for this test are described in detail in the Appendix to this volume.

METHOD 5: BIOSURVEY METHOD

This method does not generally apply to new bridge construction unless an existing bridge is used as a surrogate for the new bridge.

Two integral factors in assessing potential impacts from bridge deck runoff are the intermittent nature of rain events and the initial concentrations of contaminants. As described in Methods 1 through 3, conservative models of pollutant concentrations rely on an assumption of continuous point source input. The biosurvey method, like Method 4, takes into consideration the intermittent nature of rain events and the initial concentrations of contaminants in receiving waters. Method 4 is better suited for assessment of potential impact within an event and for the total event. Method 5 is better for measurement of potential long-term impact.

The U.S. EPA and specific state documents should be consulted before conducting a biosurvey program. Methods are generally organism specific, each having advantages and disadvantages. The biosurvey methods presented in this handbook rely solely on the use of benthic macroinvertebrates as the indicator organisms of choice. For a list of the advantages of using these organisms, see the full description of the biosurvey method in the Appendix to this volume.

METHOD 6: RECALCULATION OF HUMAN HEALTH AND WILDLIFE CRITERIA WITH SITE-SPECIFIC DATA

The U.S. EPA's Great Lakes Water Quality Initiative (GLI), promulgated in March 1995, provides a method by which bioaccumulation is directly incorporated into ambient water quality criteria for protection of human health and wildlife (U.S. EPA, 1995a). The U.S. EPA considered the bioaccumulation concepts and methodologies in the GLI to be reflective of the most current science available for criteria development.

In general, the numeric criteria developed by U.S. EPA can be used without site-specific modification. In the event that site-specific modification is warranted, the GLI provides guidance on procedures and data requirements for that purpose. Additionally, the GLI describes in detail how human health and wildlife criteria are to be derived for both organic and inorganic substances and provides default values for key parameters, such as food chain multipliers, that are to be used in the absence of substance-specific or site-specific data.

The GLI also explicitly identifies 22 substances that are considered to be both persistent and bioaccumulative, referring to them as Bioaccumulating Chemicals of Concern (BCCs). For a complete list of the BCCs, turn to the full description of this method in the Appendix to this volume. Note that the typical pollutants of highway runoff, including metals such as lead, cadmium, copper, zinc, nickel, and chromium, are not identified BCCs.

The U.S. EPA also has developed computer models that can be used by the practitioner for food chain bioaccumulation assessment (see Method 9).

METHOD 7: FIRST-ORDER DECAY MODELS

The term "decay" normally refers to the loss, reduction, or attenuation of a nonconservative pollutant in a receiving water by assimilative processes such as bacterial decomposition. The simple first-order decay approach is widely used and described in numerous water quality evaluation texts and relevant U.S. EPA guidance documents. FHWA describes this approach for the highway practitioner.

The first-order decay method will often need to be combined with the simple dilution calculations described in Methods 1 and 2. First-order decay processes are included in most of the computerized fate and transport models described in Method 9, but the analyses can also be readily performed with a calculator or spreadsheet.

For the case of multiple bridges, the first-order decay model, again usually combined with dilution calculations, can be used to determine if there is a need to consider cumulative impacts (e.g., whether pollutant concentrations reach background levels before the next downstream bridge is reached).

METHOD 8: SEDIMENT SAMPLING

This method does not generally apply to new bridge construction unless an existing bridge is used as a surrogate for the new bridge.

Two main types of devices are used to collect sediment samples: grab samplers and core samplers. Both devices can be used in toxicity testing and in evaluating chemical and physical properties of the sediment. Core sampling can also be used to evaluate historical sediment records.

Location of sites for taking samples will depend on the objectives of the study. However, samples are typically taken from an area of potential contamination and a reference area.

METHOD 9: FATE AND TRANSPORT MODELS

If a more rigorous analysis of fate and transport of pollutants is warranted (i.e., for long-term pollutant loading effects and sediment accumulation), a more complex water quality modeling program can be used to assess the effects of short- or long-term loadings on a receiving water. This type of analysis requires significantly more effort than a basic steady-state model or equation approach. However, the results from this type of analysis can be much more accurate and precise in terms of effects on sediment and water column, as well as in terms of potential effects on water intakes.

Several U.S. EPA-supported fate and transport models are available from the Center for Exposure Assessment Modeling (CEAM). A description of the most applicable models is provided in the full method description in the Appendix to this volume.

METHOD 10: LAKE MODELS

There are many computer-modeling techniques available to predict the effects of storm water runoff discharges on receiving waters. In the case of lakes, a simplifying complete-mix assumption can be used to predict pollutant concentrations. An equation for doing so is provided in the Appendix to this volume. That equation and the procedures described for lakes, reservoirs, and wetlands in Methods 1 and 2 focus on conservative substances such as metals and salts.

In some cases, bridge runoff effects on eutrophication of these types of water bodies will need to be addressed by practitioners. In these cases, methods outlined by FHWA for highways will be suitable for bridges (Young et al., 1996). However, these water bodies will almost always be subject to nutrient loads from sources other than bridges. Thus, the relative loading analyses, pollutant trading, and storm water banking options are all viable approaches for nutrients (see Methods 11 and 13).

METHOD 11: POLLUTANT LOADING

Two methods of calculating pollutant loads from a bridge deck are described under Method 11 in the Appendix to this volume. These are a simple method and an intensity-correlation method. Both require knowledge of pollutant concentrations in runoff.

The NCHRP Project 25-13 literature review revealed only a limited number of studies of bridge deck runoff quality; however, the pollutant concentrations reported may be comparable with storm water quality data for totally impervious highways—that is, studies in which storm water was monitored directly from pavement. Therefore, impervious highway runoff quality data likely can be used to supplement bridge deck runoff quality data. Although a comprehensive and edited database of bridge and impervious highway runoff quality does not currently exist, multiple sources of highway runoff quality data do exist. These include reports from FHWA, the U.S. Geological Survey (USGS), and state DOTs; academic publications; and state DOT monitoring studies that were performed for compliance with federal and state NPDES storm water permit requirements.

METHOD 12: COLLECTION OF SITE-SPECIFIC RUNOFF QUALITY DATA

If a more precise, site-specific pollutant concentration and loading is desired, field data can be collected for an existing bridge, or a surrogate bridge with similar attributes as the bridge in question. In 1985, the FHWA published a guidance manual for highway runoff and receiving water monitoring (Dupuis et al., 1985a). In general, the methods described remain valid and applicable today. In addition to their previous studies, the FHWA has recently sponsored development of an updated monitoring guidance document for highway runoff.

METHOD 13: NONSTRUCTURAL AND STRUCTURAL BMP EVALUATION

If it has been determined that some type of BMP may need to be implemented for bridge deck runoff, an evaluation to determine the most suitable type of BMP should be conducted. Nonstructural, structural, or institutional BMP approaches, or a combination thereof, could be implemented. Many factors must be considered in selecting a BMP approach, including the BMP capabilities and limitations, appropriateness for the site, pollutant loading benefits, maintenance requirements, and cost. This method provides a sampling of BMP types and analyses that can be used to determine the most appropriate BMP for a particular bridge situation.

METHOD 14: IN SITU TOXICITY TESTING

This method does not generally apply to new bridge construction unless an existing bridge is used as a surrogate for the new bridge.

In situ toxicity studies use a unique method in which organisms that occur as natural populations within the system under study are used as test organisms. In these studies, the endpoint is usually some measure of survival (percentage alive compared with a reference/control group).

METHOD 15: COMPARISON OF BRIDGE DECK LOADING TO OTHER SOURCE LOADINGS IN WATERSHED

Comparison of the pollutant loading from a bridge deck with other sources in the watershed can provide an idea of the relative impact from the bridge. Additionally, information needed for pollutant trading, off-site mitigation, and storm water banking programs can be obtained through such an analysis.

Loadings from the bridge deck can be determined by use of Methods 11 and 12, whereas loadings from other sources can be obtained in a variety of ways. The preferred approach is to obtain these estimates from an agency or entity that has already developed them for other reasons (e.g., a local TMDL program).

METHOD 16: ASSESSMENT OF HAZARDOUS MATERIAL SPILLS

Spills on bridges obviously have the potential to adversely affect aquatic life in the receiving water. Given that most highway spills are of limited volume and duration, the primary concern is acute (i.e., mortality) effects. Oregon has developed documentation of a hazardous material spill risk assessment (Kuehn and Fletcher, 1995) that applies to drinking water supplies. The Oregon document and other studies were used to develop a hazardous material spill risk assessment methodology that consists of three parts. The assessment methodology can be found in the full description of Method 16 provided in the Appendix to this volume and applies to any numeric water quality criterion, whether it be drinking water or acute aquatic life.

Another topic relevant to the mitigation of hazardous material spills is “restoration-based compensation,” in which the timing of a restoration project in relation to a hazardous material spill is important. For instance, if a restoration project is performed after a spill, the “time value” of the spill must be considered in determining the extent of the project. By the same token, if restoration is prior to the spill, a certain amount of credit becomes available the longer the time is between restoration and the spill event.

METHOD 17: MICROCOMPUTER SPILL MODELING

In rare situations, a bridge project may warrant a more sophisticated assessment of the effects of a spill. In these cases, the practitioner (or consultant) can use a software package such as the Spills Analysis Workstation (SAW) developed by the Danish Hydraulics Institute in Denmark or other specialized programs.

METHOD 18: RETROFIT PRIORITIZATION METHODOLOGY

This method does not generally apply to new bridge construction unless an existing bridge is used as a surrogate for the new bridge.

Retrofitting bridges with structural storm water BMPs is technically difficult and can be very costly. Therefore, it is likely that this method would be used on only a limited number of existing bridges. A prioritization method can be used to identify the bridges where bridge deck runoff is substantially affecting the receiving water and where the greatest benefit could be gained by retrofitting. Retrofitting can include the construction of new structural BMPs or modifications to existing BMPs.

WSDOT developed a storm water outfall prioritization system, which uses a rating system to compare the impacts of one outfall to another and makes an assessment of their overall impacts to determine when retrofitting is warranted

(WSDOT, 1996). WSDOT's outfall prioritization methodology has been modified in Method 18 to address prioritization of bridge deck runoff discharges only.

METHOD 19: ANTIDEGRADATION ANALYSES

All states are required by the Clean Water Act to have an antidegradation policy in their water quality standards. The policy is especially intended to protect high-quality waters from new or increased sources of pollution. Additionally, state waters are not allowed to degrade from their existing condition without appropriate analysis, justification, and public input.

Although no standardized national protocols exist for antidegradation analyses, many states have specific procedures and methods that must be followed for new or increased discharge of pollutants. The practitioner is thus advised to investigate these restrictions very early in the bridge-planning process.

APPENDIX

METHODS

CONTENTS

METHOD **1**

CALCULATION OF IN-STREAM POLLUTANT CONCENTRATION AT THE ZONE OF INITIAL DILUTION

State water quality criteria for the protection of aquatic life are typically designated as acute and chronic. Acute criteria protect against short-term, lethal effects, whereas chronic criteria protect against longer-term effects such as growth and reproduction impairment. Criteria are applied to the receiving water body and signify maximum acceptable levels of pollutants in the water body. State water quality standards include definitions and policies applicable to mixing zones; these are areas of the receiving water in which discharges mix with ambient water. States recognize that acute and/or chronic criteria can be exceeded within these zones because they are limited in size, and thus the overall aquatic resource of the receiving water is protected.

In this method, steps are provided for the calculation of in-stream concentrations of pollutants within a limited region in which storm water and receiving water mix; these concentrations should be compared with acute criteria. The mixed concentration is calculated at the edge of this mixing region, generally called the zone of initial dilution (ZID). State water quality standards usually provide methodologies for the determination of ZID size. Some states do not allow ZIDs and instead compare acute criteria to end-of-pipe concentrations, which in the case of bridges would be direct storm water from a bridge. Some states also compare end-of-pipe concentrations to the final acute value (FAV), which is generally the acute criterion multiplied by 2.

Some states do not use a ZID concept for acute criteria but instead assume complete mixing with a design stream flow specific to acute criteria. In these cases, the complete-mix approach (Method 2) should be used.

Calculation of pollutant concentrations at the ZID has been traditionally used to determine whether pollutants from a continuous point source, such as a municipal or industrial discharge, exceed acute water quality criteria. Because storm water discharges are intermittent, aquatic organisms will also experience intermittent exposure to pollutants. Hence, calculation of in-stream pollutant concentrations from average or peak storm water flows will overestimate (and thus provide a conservative estimate of) the potential toxic effect of runoff. The U.S. EPA and many states recognize the need to develop wet weather criteria, but formal criteria have not been developed to date. One approach, recommended by FHWA, is to compare in-stream pollutant concentrations after mixing with both the existing acute criteria and "threshold effect" levels developed by U.S. EPA under the National Urban Runoff Program (NURP) (Driscoll et al., 1990). Methods 1 and 2 are provided to the practitioner because in many cases even this very conservative approach will demonstrate minimal likelihood of acute toxicity from specific chemicals in runoff from a bridge deck. If this method predicts an exceedance of one or more criteria, this does not necessarily mean there will be a real acute impact in the receiving water. Biological test methods (Methods 4 and 5) can also be used to assess acute toxicity and may be preferable until such time as promulgated wet weather criteria are available.

Site-specific monitoring data, data from a representative site, or data from a national database of highway storm water runoff quality can be used to calculate pollutant concentrations at the ZID. The latest compendium of highway runoff data was compiled by FHWA (Driscoll et al., 1990), but the metals data should be used with caution for reasons discussed in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report. ***The NCHRP 25-13 research team recommends that the practitioner attempt to obtain more current metals data whenever possible. Recent metals data for highway or bridge runoff may be available from published literature and state or local highway agencies. Evaluation of these data may be assisted by review of U.S. Geological Survey (USGS) documentation regarding the quality control assessment of highway runoff data (Granato et al., 1998).***

Method 1 can also be used to estimate the concentration of pollutants at the ZID that are due to leaching from construction and repair materials commonly used on highways. Nelson and colleagues (2001) applied a leachate and toxicity testing screening procedure to a series of construction and repair materials to identify materials that were potentially harmful to aquatic life. The leachate results of Nelson and colleagues (2001) may be used as an estimate of storm water pollutant concentrations under this method.

Note that if the estimated undiluted runoff concentration for a given parameter is less than the applicable in-stream criterion, there is no reason to undertake the mass balance calculations described below. Also note that, if the background concentration exceeds the criterion, the practitioner should proceed to other methods in this handbook that deal with cases in which sources of pollutants other than the bridge need to be considered (e.g., Methods 11 and 15).

PROBABILISTIC CONCENTRATIONS AND FLOWS

In-stream pollutant concentrations resulting from storm water discharges are dependent on the following four factors: (1) receiving water hydrology (i.e., stream flow), (2) storm water flow, (3) background pollutant concentrations, and (4) storm water pollutant concentrations. Each of these is highly variable but can be characterized with simple statistics such as a mean and standard deviation. Depending on the level of conservatism required, the mean and standard deviation can be used to calculate probabilistically an estimate of in-stream concentrations.

For example, to calculate a conservative in-stream concentration, one may want to use input parameters that are greater than 95 percent of the monitored data (known as the 95th percentile). Assuming a log normal distribution, the 95th percentile corresponds to 1.65 standard deviations above the mean (from a standard normal distribution table). For rivers, the 95th percentile value would be used for storm water, stream concentrations, and storm water flow. The 5th percentile (1.65 standard deviations below the mean) would be used to calculate the stream low flow. The stream low flow and the high storm water flow would then be used as dilution model inputs to determine dilution at the ZID. Examples of dilution models that can be used for surface discharges are PDS and CORMIX (U.S. EPA, 1991; U.S. EPA, 1993).

Existing dilution models do not directly account for mixing that would occur because of the free-fall energy of storm water from bridge to receiving water. Use of these models, therefore, would also be conservative. For an existing bridge, the dilution factor can also be developed with a fairly simple field dye study. A fluorescent dye, Rhodamine WT, can be added to storm runoff and tracked in the receiving water using a fluorometer.

Standard hydrologic procedures (Chow et al., 1988) or the SYNOP or SYNOP II program (Strecker et al., 1990) can be used to calculate the volume, duration, and intensity of storms from a historical precipitation record. These values can then be used to calculate runoff rates for each storm event. Runoff rate calculations for a bridge deck are generally straightforward, using direct translation of bridge deck surface area to each drain and rainfall intensity. The probabilistic method can also be used for lakes and coastal systems.

CALCULATING POLLUTANT CONCENTRATIONS AT THE ZID

The mixed concentration of runoff and receiving water pollutants at the ZID can be calculated using average or probabilistic estimates.

The concentration of pollutants in the receiving water at the ZID where ambient (upstream or background) water quality data are available is calculated by:

$$C = \left(\frac{1}{D} C_{sw}\right) + \left(1 - \frac{1}{D}\right) C_{rw}$$

The concentration of pollutants in the receiving water at the ZID where receiving water concentration is unknown or assumed to be zero is calculated by:

$$C = \left(\frac{1}{D}\right) C_{sw}$$

where

C = concentration at the ZID
D = dilution at the ZID
C_{sw} = runoff concentration (average or probabilistic estimate)
C_{rw} = receiving water concentration (average or probabilistic estimate)

The following procedure can be used to calculate a probabilistic estimate of a mixed runoff and receiving water pollutant concentration at the ZID:

1. Calculate the log normal average and standard deviation for each of the following factors: storm water and stream flow, and storm water and upstream pollutant concentrations.
2. Calculate the 95 percent storm water concentration level for each pollutant.
3. Calculate the 95 percent upstream concentration.
4. Define dilution (D) at the acute mixing zone boundary using a mixing zone model or a default value that is derived from state water quality standards or professional judgment. Dilution at the ZID will be different for average and probabilistic estimates. For a probabilistic estimate, the 95 percent runoff flow and 5 percent stream flow will be used as inputs to the dilution model. Average flow values can be used as inputs when using average pollutant values.

Potential data and equipment requirements that may be needed for Method 1 include the following:

- Historical record of rainfall intensity and duration;
- Stream flow record;
- Bridge deck runoff pollutant data;
- Stream pollutant data;
- Bridge deck characteristics needed to calculate runoff such as length, width, slope, roughness, and number of drains and their locations;

TABLE A-1 Runoff monitoring data and natural logarithm transformed values for two highways

Mallard Creek (I-85)[a] Copper µg/L			Milwaukee (I-94)[b] Lead µg/L		
Sampling Date	Normal Value	Natural Log Values	Sampling Date	Normal Value	Natural Log Values
09/25/2000	27	3.30	03/13/1979	50	3.91
11/07/2000	75	4.32	03/30/1979	200	5.30
11/09/2000	63	4.14	04/11/1979	100	4.61
04/03/2001	64	4.16	04/25/1979	50	3.91
			01/11/1980	200	5.30
			01/16/1980	50	3.91
			02/22/1980	200	5.30
			03/10/1980	200	5.30
			03/14/1980	100	4.61
			03/15/1980	400	5.99
			03/16/1980	100	4.61

[a] See first volume of this report.
[b] From Driscoll et al. (1990).

- Water body characteristics such as depth, width, flow rate, salinity, and temperature;
- Mixing zone boundary;
- Rhodamine WT dye; and
- Fluorometer.

PROBABILISTIC RUNOFF POLLUTANTS AT I-85 AND MALLARD CREEK IN NORTH CAROLINA AND I-94 IN MILWAUKEE, WISCONSIN

This section presents an example calculation of the probabilistic procedure described in this method. Table A-1 shows runoff monitoring data and the logarithmically (natural logarithm) transformed data for two highway monitoring sites.

The 95 percent and the 5 percent copper and lead concentrations ($C_{95\%}$ and $C_{5\%}$) are calculated with the following formulas and descriptions:

$$C_{\%} = e^{(U + ZS_d)}$$

U = mean of the natural log transformed values
S_d = standard deviation of the natural log transformed values
e = base e (or approximately 2.718) raised to the power shown

The Z statistic can be obtained from a standard normal distribution table. For $C_{5\%}$, Z is –1.65 and for $C_{95\%}$, Z is 1.65. Using the equations above and data from the table, the $C_{95\%}$ and $C_{5\%}$ values are

Copper (Cu): $C_{95\%}$ = 115 µg/L, and $C_{5\%}$ = 25 µg/L

Lead (Pb): $C_{95\%}$ = 383 µg/L, and $C_{5\%}$ = 38 µg/L

Note that the $C_{95\%}$ estimate for copper is substantially above the largest sampled copper concentration. This demonstrates that the use of a limited runoff database can lead to less realistic probabilistic estimates.

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METHOD **2**

FULLY MIXED IN-STREAM POLLUTANT CONCENTRATION

Method 1 provided analyses for evaluating acute toxicity effects on the basis of a dilution factor obtained from dispersion modeling or state default values. Method 2 provides an analysis applicable to any situation in which it is assumed that the discharge is fully mixed with the receiving water or some specified fraction thereof. This could include acute and chronic aquatic life (e.g., acute effects are short-term lethality, and chronic effects are impairment of growth and reproduction), wildlife, and human health toxicity criteria. The method also is applicable to other water quality standards (i.e., substances such as salts and color).

Calculation of fully mixed in-stream pollutant concentrations has been traditionally used to determine whether pollutants from a continuous point source such as a municipal or industrial discharge exceed chronic or human health water quality criteria. Because storm water discharges are intermittent, aquatic organisms and humans will experience intermittent exposure to pollutants. Hence, calculation of in-stream pollutant concentrations from average or peak storm water flows will overestimate (and thus provide a conservative estimate of) the potential toxic/human health effect of runoff. The U.S. EPA and many states recognize the need to develop wet weather criteria, but formal criteria have not been developed to date. One approach recommended by FHWA is to compare in-stream pollutant concentrations after mixing with both the existing acute criteria and "threshold effect" levels developed by U.S. EPA under the NURP program (Driscoll et al., 1990). Methods 1 and 2 are provided to the practitioner because in many cases even this very conservative approach will demonstrate minimal likelihood of acute toxicity from specific chemicals in runoff from a bridge deck. If this method predicts an exceedance of one or more criteria, this does not necessarily mean there will be a real acute impact in the receiving water. Biological test methods (Methods 4 and 5) can also be used to assess acute toxicity and may be preferable until such time as promulgated wet weather criteria are available.

Another difficulty is that criteria associated with chronic aquatic life, wildlife, and human health are intended to protect against long-term effects and assume long-term continuous exposure. Because storm water discharges are intermittent, such long-term effects may not be relevant. Nonetheless, there will be cases in which concerns about these effects will be of importance for bridge projects. Consequently, this method may be needed, but the original FHWA approach for acute effects needs to be modified to reflect long-term effects. As with acute toxicity, biological test methods (Methods 4 and 5) can also be used to assess chronic aquatic life toxicity and also may be preferable until such time as promulgated wet weather criteria are available.

There is an additional margin of safety built into this method because it assumes the pollutant is "conservative" and not subject to decay, die-off, settling, volatilization, and other forms of attenuation that occur in the receiving water. This assumption is close to reality for salts but not for most other pollutants.

Storm water and receiving water quality data used in the following calculations can be from site-specific monitoring data, another representative site, or a national database of highway storm water runoff quality. The latest compendium of highway runoff data was compiled by FHWA (Driscoll et al., 1990), but the metals data should be used with caution for reasons discussed in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report. ***The NCHRP 25-13 research team recommends that the practitioner attempt to obtain more current metals data whenever possible. Recent metals data for highway or bridge runoff may be available from published literature and state or local highway agencies. Evaluation of these data may be assisted by review of U.S. Geological Survey (USGS) documentation regarding the quality control assessment of highway runoff data (Granato et al., 1998).***

Note that, if the estimated undiluted runoff concentration for a given parameter is less than the applicable in-stream criterion, there is no reason to undertake the mass balance calculations described below. Also note that, if the background concentration exceeds the criterion, the practitioner should proceed to other methods in this handbook that deal with cases in which sources of pollutants other than the bridge need to be considered (e.g., Methods 11 and 15).

This method presents a probabilistic technique for streams and rivers developed by FHWA (Driscoll et al., 1990) that will provide an estimate of fully mixed in-stream concentrations. The methods for lakes and coastal systems use a similar, but more simple, probabilistic technique for the calculation of input variables to accompanying water quality models. Detailed calculation methodologies for each receiving water type are provided in upcoming sections.

STREAMS AND RIVERS

The FHWA methodology (Driscoll et al., 1990) was designed to probabilistically determine fully mixed in-stream concentrations in rivers. It considers 10 common pollutants in highway runoff, including several toxic metals. For metals, the methodology was intended to be used only to address potential acute toxicity effects. This method is somewhat data intensive and requires an intermediate level of calculation effort. The FHWA has developed an interactive computer program for the procedure (Strecker et al., 1990). However, the formulas can be readily input into a spreadsheet for the repetitive calculation of multiple storm water pollutants.

The key to this procedure is the choice of an appropriate level of conservatism. An example of a high level of conservatism is the calculation of the 95th percentile in-stream pollutant concentration level. What this means is that for 95 percent of all storm events the fully mixed in-stream concentration would be less than the calculated concentration. This is essentially a prediction of the highest anticipated in-stream pollutant concentration resulting from a bridge deck storm water discharge. This prediction may be appropriate for acute criteria; however, state water quality standards and/or reasonable judgment usually suggest that a long-term average in-stream concentration is more appropriate for comparison with chronic, wildlife, and human health criteria, as well as other criteria. The geometric mean is generally used for background in the Great Lakes states. In the absence of specified statistical values in state regulations or guidance, the 50th percentile values should be used for these criteria or the applicable stream design flows (e.g., U.S. EPA and many states now use the long-term "harmonic" mean river flow for human health criteria). In addition, the long-term storm water flow should reflect inter-event periods, either by using average or median annual rainfall volume to calculate flow or properly adjusting calculated event flows for inter-event periods.

The values used for background concentrations can be extremely important to the analysis. The quality and representativeness of the data must be carefully considered. Data that are 5 years old or less, and that were collected within reasonable proximity to the bridge, would be most preferable. The sampling and analytical techniques and quality assurance/quality control procedures should be critically examined, regardless of the source of the data. This is particularly true for metals data for reasons discussed previously.

There are also a number of programs available to evaluate a historical precipitation database and calculate the duration and intensity of rain events. SYNOP is a simple program developed by FHWA (Strecker et al., 1990) that can calculate storm event length and runoff intensity. Although SYNOP is referenced in this methodology, other programs or manual calculations are equally acceptable.

The following are the input data requirements for the probabilistic FHWA methodology:

- Rainfall intensity and duration for a historical record of precipitation events (for the monitoring station closest to the bridge);
- Drainage area for the bridge deck and the river;
- Historical record of stream flow; and
- Storm water and upstream (background) receiving water pollutant concentrations.

The following are the basic steps of the probabilistic FHWA methodology:

1. Use the SYNOP program to calculate rainfall intensity and duration for each storm event.
2. Calculate storm water flow for each event from rainfall intensity and bridge deck drainage area.
3. Calculate the mean, standard deviation, and coefficient of variation for the storm water and stream flow record, and the storm water and stream pollutant concentrations.
4. Calculate in-stream concentration after mixing and compare to appropriate criteria.

SPECIAL CONSIDERATION FOR CHLORIDE

If salt may be applied to the bridge deck in the winter, it may result in the discharge of chloride to the receiving water. Chloride concentrations are calculated with respect to the amount and the type of salt applied to the bridge deck. The calculation of in-stream concentrations should follow these general steps:

1. Determine the water-equivalent volume for each storm in a historical record of snowstorms and calculate the average storm volume (assume all the snow melts).
2. Determine the length of each snowstorm and calculate the average length.
3. Assuming all the snow melts, use Steps 1 and 2 to calculate the average storm water flow (average volume/average time).
4. Estimate the weight of salt applied to the bridge during a typical snowstorm.
5. Calculate the concentration of chloride in the discharge of an average storm event (mass/volume).
6. Calculate the average stream flow from a historical record of winter stream flows.
7. Calculate in-stream chloride concentration using the equation below:

$$C = \frac{(Q_{rw}C_{rw}) + (Q_{sw}C_{sw})}{Q_{rw} + Q_{sw}}$$

where

C = in-stream chloride concentration (mg/L)
Q_{rw} = average stream flow in cubic feet per second (cfs)

C_{rw} = average upstream chloride concentration (mg/L)
Q_{sw} = average runoff flow (cfs)
C_{sw} = average runoff chloride concentration (mg/L)

Note that chloride concentrations are not calculated using a probabilistic method. This is due to the lack of precise salting data available. In some cases, only an average annual salting weight per mile of roadway is available. The variable C_{sw} can be determined by monitoring bridge deck runoff or by calculating expected chloride concentrations from annual salt application data as follows:

$$C_{sw} = \frac{S_{ar}}{nV_{sw}}$$

where

S_{ar} = annual salt application mass
n = estimated number of winter storms with deicing
V_{sw} = average storm runoff volume

Calculated in-stream concentrations should be compared with applicable chloride criteria.

LAKES, WETLANDS, AND RESERVOIRS

The calculation of receiving water pollutant concentrations (for comparison with applicable criteria) for lakes and reservoirs is similar to the procedure developed for acute toxicants (Method 1). Most states regulate continuous point source discharges of chronic pollutants within a given mixing zone. A default dilution factor is often provided, or the discharger can demonstrate dilution within the mixing zone using models and/or dye studies. To calculate concentrations of pollutants for comparison with criteria in which the dilution factor (D) is specified, follow the procedure in Method 1 for lakes, wetlands, and reservoirs. The only difference between the two methods is the allowable level of dilution. When a dilution factor is not specified or determined with a site-specific mixing analysis, it can be calculated as follows:

$$D = \frac{Q_{sw}T}{(Q_{sw}T) + V_{rw}} = \frac{V_{sw}}{V_{sw}V_{rw}}$$

where

D = dilution factor
Q_{sw} = storm water flow
T = runoff duration
V_{rw} = volume of receiving water
V_{sw} = volume of runoff

Alternatively, the practitioner can calculate the complete-mix concentration of a conservative pollutant in a lake, wetland, or reservoir. Assuming the bridge is the only source of pollutants to the lake, the expected pollutant concentration in the lake after a storm event would be as follows:

$$C = \frac{Q_{sw}TC_{sw}}{V} + C_0$$

where

C = concentration of pollutant in the lake after mixing
C_0 = initial concentration of pollutant in lake before the storm event
C_{sw} = concentration of pollutant in the storm water
Q_{sw} = storm event flow into lake
T = runoff duration
V = volume of water in lake

If the pollutant is conservative and does not settle, the long-term equilibrium concentration in the lake is:

$$C_{eq} = \frac{W}{Q_{out}}$$

where

C_{eq} = equilibrium lake concentration
W = annual pollutant loading from the bridge
Q_{out} = annual outflow from the lake

The number of years it will take for the long-term equilibrium pollutant concentration to be established can be calculated by solving for T in the following equation (e = base e [or approximately 2.718] raised to the power shown):

$$C_{eq} = \left(\frac{W}{Q_{out}}\right)\left\{1 - e^{-\left(\frac{Q_{out}}{V}\right)T}\right\}$$

Because it will take a large number of years to reach equilibrium, it may be more appropriate to estimate the number of years it will take to reach 90 or 95 percent of the equilibrium value.

COASTAL SYSTEMS

Simple and complex models currently available can predict the dispersion and, if needed, the decay of point source inputs to an estuarine system. Modeling techniques, averaging times, runoff hydrology, and runoff pollutant concentrations used as model inputs should correspond to the timescale of the pollutant's effect. Chronic, wildlife, and human health toxicants elicit an effect only during long exposure periods. These criteria, then, should be compared with long-term pollutant concentrations in an estuary. The models recommended by the research team for this task are a simple model, the dispersion-advection model (Mills et al., 1985, p. 207; Thomann and Mueller, 1987, p. 106), and the more complex one-dimensional finite segment estuary model (Thomann and Mueller 1987, p. 123). The dispersion-advection model assumes the cross-sectional area, flow, and depth in the estuary is constant, and the storm water is completely mixed in the estuary at the point of entry. This model determines pollutant concentrations in the estuary at fixed distances from the point of storm water entry. The finite segment model breaks an estuary into different segments with different volumes and estimates the dispersion of pollutants by simulating the exchange of pollutants between segments. Both models were developed for continuous point source discharges and may overestimate in-stream pollutant concentrations unless corrected for the intermittent nature of storm water discharges (sum a year of storm water discharges and average the flow for a year). Also, because both models are designed to estimate pollutant concentrations in an estuary over multiple tidal cycles, average input values rather than probabilistic ones should be used in the model.

The primary data requirements for the two models are the following:

- Estuary area and volume,
- Freshwater flow near the discharge,
- Net nontidal velocity (freshwater flow velocity through estuary),
- Dispersion coefficient,
- Storm water flow rate,
- Storm water pollutant concentrations,
- Estuary background pollutant concentration, and
- Dye study or salinity data to determine the dispersion coefficient (see Thomann and Mueller 1987, p. 115).

MULTIPLE BRIDGES

The case of multiple bridges can be addressed in several ways. First, if the bridges are close enough together, they can be addressed using the methods already discussed by simply considering the multiple loads (i.e., flows and pollutant concentrations) together as a single source. This could also be done for simple, complete-mix analyses for relatively small lakes or wetlands. If the bridges are more remote, the decay or die-off of pollutants between bridges can be determined using Method 7, 9, or 10. If these methods indicate that receiving water concentrations reach background before the next downstream bridge is reached, then they can be addressed separately. If this is not the case, the upstream bridge's contribution can be factored into the "background" concentration for the downstream bridge (see formulas in Method 2). If, as one moves downstream, the collective inputs from the bridges exceed criteria at some point, the practitioner must then consider the cumulative effects in more detail, using other applicable methods. See Methods 11, 15, and Table A-5 in Method 9.

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METHOD **3**

SEDIMENT POLLUTANT ACCUMULATION MODEL

The impact of pollutant loadings over the lifetime of a bridge is often a concern. Because one ultimate sink for these pollutants is sediment, the effect of long-term loadings can be accounted for by examining sediment concentrations. Once incorporated in sediments, pollutants can either bioaccumulate or cause toxicity to organisms that live in or near the sediment layer. Hence, comparing sediment criteria with sediment pollutant concentrations near a bridge can identify the potential long-term impacts of the bridge. This method describes relatively simple models for the calculation of sediment pollutant concentrations downstream or near bridge deck storm water discharges. A loading estimate is required for each of the models presented below. The models assume that the loading is continuous; therefore, appropriate adjustments are necessary to account for the intermittent nature of bridge discharges.

As discussed in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report, the U.S. EPA is in the process of developing sediment quality criteria. Until such time as these criteria are published with implementing procedures and adopted into state water quality regulations, it can reasonably be argued that practitioners should not be expected to evaluate sediment impacts. The procedures described herein can be used to address stakeholder concerns, but the practitioner should keep in mind that this exercise is currently voluntary.

The question of which criteria to use in the interim period until promulgated criteria are available remains a matter of judgment for the practitioner. Sediment criteria for protection of aquatic life have been developed for marine and estuarine sediments (Long et al., 1995) and for Lake Ontario (Persaud et al., 1993). In addition, a number of states have identified sediment quality criteria applicable to dredging and disposal operations. Still others have developed information on sediment quality at reference sites (i.e., those reference sites minimally impacted by human activities) (Jones, 1994). These publications and criteria provide a useful perspective but should not be construed at this time as regulatory mandates.

STREAMS AND RIVERS

The simple model presented by Thomann and Mueller (1987, pp. 524–527) is best suited to estimate sediment pollutant concentrations at various distances downstream of a bridge deck. Data requirements are the following:

- *Stream characteristics.* Characteristics include velocity, depth, sediment porosity, water column particulate concentrations upstream and downstream of the bridge, pollutant loading upstream of the bridge, solids settling and resuspension rates, and downstream flow.
- *Chemical parameters.* Chemical parameters include sediment/water partition coefficients for each pollutant, the ratio of the solid phase pollutant concentration in sediment to water, and pollutant diffusion rates.
- *Storm water pollutant loading.* A fundamental assumption of the model is that there is no additional sediment input from other sources downstream of a bridge. This model can be used for conservative and nonconservative substances. Site-specific measurements can be taken to improve on the accuracy of input variables, and average loading and flow parameters (adjusted for inter-event considerations) should be used as model inputs. If desired, upstream loading can be considered in this model.

LAKES, WETLANDS, AND RESERVOIRS

The chosen model for lakes, wetlands, and reservoirs is similar to the model presented for rivers and is described by Thomann and Mueller (1987, pp. 516–522). The model assumes the receiving lake is completely mixed, which leads to an underestimate of sediment concentrations located near a bridge deck. However, this can be overcome by using a lake volume corresponding to the region of influence of the storm water discharge. The primary data requirements include storm water pollutant loading; pollutant diffusion between sediment and the water column; lake area and depth (volume); lake outflow rate; sediment porosity; particulate settling and resuspension rates; and dissolved pollutant fraction in the water column. For organic pollutants, chemical and physical properties (such as Henry's constant) may also be required to account for the volatilization of these chemicals to the atmosphere. The primary difference between this model and the one for rivers and streams is that sediment pollutant concentrations are estimated for the period in which discharges enter the lake (time) rather than at various locations downstream of the outfall (distance). The time element of the model (in total loading, outflow, inflows, and pollutant removal rates) should equal the lifetime of the bridge. If desired, the effect of background concentrations can be considered in model predictions. It is recommended that average loading and flow parameters, again adjusted for inter-event considerations, be used as model inputs.

COASTAL SYSTEMS

The coastal system model (Thomann and Mueller, 1987, pp. 527–528) is similar to the river model in that sediment pollutant concentrations are estimated a given distance from the outfall (in the coastal model, estimates are upstream and downstream of the outfall). Data requirements include the following:

- *Estuary characteristics.* Characteristics include velocity, depth, flow, sediment porosity, water column particulate concentrations, solids settling and resuspension rates, downstream flow, and estuary dispersion coefficient.
- *Chemical parameters.* Parameters include sediment water partitioning coefficients for each pollutant, the ratio of the solid phase pollutant concentration in sediment to water, and pollutant diffusion rates.
- *Storm water pollutant loading.* Background concentrations are not considered in this model. It is recommended that average loading and flow parameters be used as model inputs.

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METHOD **4**

BIOASSAY METHOD

INTRODUCTION

The NCHRP 25-13 research team believes that the laboratory bioassay methods described here will provide a scientifically sound and fairly low-cost way to assess the toxicity of bridge runoff to aquatic organisms. Although the methods suggested and organisms to be used are mostly consistent with standard U.S. EPA testing protocols, there are several deviations needed to address the time-variable component of storm events.

As described in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report, the volume and duration of runoff from a bridge are a function of several factors. These include the duration of the storm; precipitation volume and intensity; and bridge deck area, slope, and drainage methods. The potential for adverse effects on receiving waters is often related to storm duration, volume, time between storms (in some cases), traffic volume, and mixing with the receiving water.

It can be inferred from previous studies that the potential for the most toxic conditions could occur for bridges with high traffic volumes and low dilution potential in the receiving water. The antecedent dry period has been shown to be important for urban runoff but may be less important for highways and bridges, where pollutants are partially derived from the washoff from vehicular traffic during a storm.

The area of a receiving water that has the potential to be affected by toxicity is also a function of mixing. If the runoff is funneled to a single point discharge, the amount of mixing in the receiving water will be less efficient than if the runoff were discharged from multiple points across the bridge deck (analogous to a diffuser).

OBJECTIVE

The objective of this test method is to determine if bridge deck runoff has the potential to be acutely or chronically toxic to freshwater or marine organisms under simulated runoff conditions. To meet this objective, a bridge deck runoff sampling and toxicity testing program has been developed that will assess the toxicity of runoff for time-variable exposures. To provide reasonable assurance that the samples collected represent worst case conditions, they should be collected for a storm of moderate volume, intensity, and duration. Samples collected from too large an event would tend to dilute pollutants, whereas samples from too small an event may not have the force and volume to convey pollutants or have an effect. Samples should be collected from a site with high enough average traffic and at a time of day when vehicular traffic is substantial. For the results to be conservative, the antecedent dry period with no precipitation greater than 0.1 inch should be at least 72 hours (even though this may not be as important for bridges).

METHODS AND MATERIALS

Collection of Samples

Grab samples should be collected at appropriate time intervals from representative bridge storm drain locations for the duration of the runoff event. These samples should be composited into six equal time intervals for the duration of the runoff event. For example, if a runoff event lasted 6 hours and samples were collected every 15 minutes, each composite sample for testing would consist of four grab samples.

To calculate the volume of runoff sampled for each time interval, a manual or recording rain gauge should be used. The volume for each time interval should be calculated from the bridge deck area and volume of precipitation during the sampling interval.

Procedures

The organisms and procedure used for the test are based on those used for whole effluent toxicity tests when testing for National Pollutant Discharge Elimination System (NPDES) compliance.

Current whole effluent toxicity tests for NPDES compliance use a continuous exposure of one to three samples over the time of the test, 48 to 168 hours (2 to 7 days). Bridge deck runoff events are short-term (i.e., less time than the conventional test length) intermittent events with time-variable concentrations of toxicants.

One potential methodology would be to set up in situ flow-through tests to assess the toxicity of bridge deck runoff for different events. Alternatively, a series of laboratory tests could be set up with organisms continuously exposed for the duration of the test to a single composite sample, or separate laboratory tests could be set up on grab samples collected throughout the runoff event. Neither one of these time or sample exposures would provide a realistic exposure scenario. For example, the first 15 minutes of runoff might be the most toxic, but organisms in the receiving water would never be exposed to first-flush runoff continuously for 2 to 7 days. In this case, the potential toxicity could be severely overestimated. If a single composite sample representing the entire runoff event were tested, the high concentrations that might be present at specific times would be diluted, and toxicity might be underestimated.

The proposed methodology is a combination of these exposure scenarios. In this methodology, grab samples should be collected during a runoff event. These samples would then be composited in groups. For example, if grab samples were taken every 15 minutes for 6 hours, four grab samples from every hour of the storm could be used to make six composites. The organisms would then be exposed to each of the six composites for the total duration of the storm (i.e., 6 hours). At the end of the exposure period, organisms would be transferred to control water and the test run for an additional 48 hours or 7 days. To determine the effect of dilution on toxicity, the runoff would be mixed with control waters from 6.25 percent to 100 percent runoff (see Table A-2). Table A-2 shows the time of exposure for a hypothetical 6-hour storm with equal exposure times for each storm water sample.

Test Organisms

Freshwater Receiving Water

The commonly accepted and most widely used organisms for acute and chronic freshwater tests are *Ceriodaphnia dubia* (a water flea) and fathead minnows.

Toxicity for individual pollutants published by U.S. EPA, and the NCHRP Project 25-13 research team's experience with whole effluent toxicity tests with point source effluents suggest that *C. dubia* (or a closely related species) are among the freshwater organisms most sensitive to metals and other toxicants for both the acute and chronic tests. Therefore, *C. dubia* should be used for both acute and chronic testing. The test protocols will generally follow the standard procedures except for the time-variable exposure to different samples.

For freshwater toxicity testing of bridge deck runoff, hardness can be of particular concern because the toxicity of metals is inversely related to hardness. The control water used (also used as dilution water for the runoff concentrations tested) should be at the hardness of the receiving water at the time of sampling. The hardness of rainwater is generally low. To assess the potential toxicity of metals in 100 percent runoff caused by low hardness, an additional 100 percent continuous exposure sample should be adjusted to the hardness of the receiving water.

Marine Receiving Water

Commonly accepted acute tests for marine organisms include the mysid shrimp, *Cyprinodon variegatus* (sheepshead minnow), *Menidia beryllin* (silverside minnow), sea urchins, and mussel tests. The difficulty with marine bioassays is that there are no organisms sensitive to the wide variety of pollutants that may be present in bridge deck runoff. Mysid shrimp, sheepshead minnows, and silverside minnows are not very sensitive (acute or chronic) to metals but are fairly sensitive to oils, grease, or other substances that can clog their gills.

Mussels are very sensitive to metals. However, the mussel test is an embryo development test that requires having adult mussels in reproductive condition on hand. It is very difficult

TABLE A-2 Time of exposure (hours) for an acute test lasting 48 hours and a runoff event lasting 6 hours

	Concentration of Runoff Tested (percent runoff)						
Sample	**6.25**	**12.5**	**25**	**50**	**100**	**Control**	**Transfer Control[a]**
Sample 1 (hr)	1	1	1	1	1	0	1
Sample 2 (hr)	1	1	1	1	1	0	1
Sample 3 (hr)	1	1	1	1	1	0	1
Sample 4 (hr)	1	1	1	1	1	0	1
Sample 5 (hr)	1	1	1	1	1	0	1
Sample 6 (hr)	1	1	1	1	1	0	1
Control Water (hr)	42	42	42	42	42	48	42

[a] Organisms transferred from control water to control water to serve as a control for the physical act of transferring organisms.

to maintain adults in reproductive condition in the laboratory at all times. This difficulty presents the logistical problem of having organisms to test when samples are collected. In addition, the mussel tests are embryo development tests lasting 48 hours. The physical act of moving microscopic embryos from concentration to concentration for a time-variable exposure without harming the developing embryos could be difficult. The sensitivity of mussels to oils and grease is unknown.

Sea urchins, like mussels, are sensitive to metals. Their sensitivity to oils and grease is unknown. The sea urchin test is an embryo fertilization with a 2-hour exposure duration. Because of the short duration of the test and the problems with the physical act of moving fertilized, microscopic embryos, it is inappropriate to use the sea urchin test for a time-variable exposure. However, because the test is of such a short duration, the potential acute toxicity of individual samples taken throughout a runoff event could be assessed.

The commonly accepted marine chronic tests use mysid shrimp and sheepshead minnows. Of these tests, the mysid shrimp test tends to be more sensitive to a wider variety of pollutants.

For marine organisms, individual acute tests should be done with each sample from the runoff event using the acute test and a time-variable exposure test using mysid shrimp. The chronic tests should be done using time-variable exposure and the mysid shrimp.

Storm water runoff, of course, is freshwater, and the organisms being tested require saline water. Prior to testing, commercial sea salts (e.g., Instant Ocean, or Tropic Marine) should be added to each sample to adjust the salinity to a level appropriate for the organism being tested. The laboratory control water (and dilution water) should be an artificial seawater sample prepared with sea salts added to laboratory water.

Methodology Development

Prior to testing actual bridge runoff, a reference toxicant sample of cadmium chloride should be prepared, and the time-variable exposure methodology should be tested. Cadmium chloride was selected as the reference toxicant because of the large body of literature available on toxicity of cadmium with continuous exposure and the availability of results of some limited time-variable exposure tests to cadmium.

Data Analysis and Report

The proper endpoint for each test will be calculated. Possible endpoints include the following:

- IC_{25}—the concentration of runoff that will cause a 25 percent reduction in test organism reproduction or growth,
- LC_{50}—the concentration of runoff that is lethal to 50 percent of test organisms,
- NOEC—no observed effect concentration (the concentration of runoff at which no toxicity occurs), and
- LOEC—lowest observed effect concentration.

The results will be interpreted in relation to each bridge and storm event tested with respect to the potential for toxicity in the receiving water caused by bridge deck runoff.

Additional Guidance on Timescale Toxicity Issues

The procedure described in this method specifically applies to evaluations of the toxicity of bridge deck runoff to aquatic organisms. A guidance document has been developed to evaluate timescale effects of storm water discharges from local to watershed-size environments (Herricks and Milne, 1998). Issues of sampling frequency, toxicity evaluation, organism selection, precision, and the integration of short-term acute toxicity findings with long-term chronic effects are covered.

TIME-VARIABLE BIOASSAYS FOR TWO BRIDGES

The exposure of aquatic organisms to storm water constituents varies over time. To evaluate how this variability affects bridge deck runoff's toxicity to aquatic organisms, time-variable bioassays were performed. Bioassays were done, according to the procedures outlined in this method, with storm water collected from bridges crossing a freshwater site (I-85 at Mallard Creek, North Carolina) and a saltwater site (the San Francisco-Oakland Bay Bridge, California). Both bridges have high traffic volumes, but the San Francisco-Oakland Bay Bridge (SFOBB) has a much higher average daily traffic (ADT) volume (274,000) than the I-85 bridge (74,000). Mysid shrimp (*Mysidopsis bahia*) and a type of water flea (*C. dubia*) were chosen as the test organisms for the saltwater and freshwater sites, respectively. Bioassay results for individual storm events are summarized in this example; the complete results and a detailed description of the tests are given in the first volume of this report.

To mimic the exposure of aquatic organisms to runoff pollutants during a storm event, the duration of organism exposure in runoff for each bioassay was set equal to the duration of each storm event. The organisms were then placed in laboratory control water (i.e., "clean" water) for the remaining duration of the standard test to evaluate potential delayed effects (total duration of 48 hours for acute tests and 7 days for chronic tests). Both acute and chronic tests were conducted. Acute results are expressed as percent survival, and chronic results are expressed as the 25 percent inhibition concentration. Table A-3 presents the results of the bioassays.

TABLE A-3 Freshwater and saltwater time-variable bioassay results for bridge deck runoff

Freshwater (I-85)[a]			
Event (Runoff duration)	**November 7, 2000 (30 minutes)**	**November 9, 2000 (75 minutes)**	**April 3, 2001 (75 minutes)**
Percent runoff	**Acute Test Results (Mean Percent Survival in 48 hours)**		
0 (Control)	100	100	100
6.25	100	100	100
12.5	100	100	100
25	100	100	100
50	100	100	100
100	100	100	100
	Chronic Test Results (IC_{25} over 7 days)		
Percent runoff causing a 25 percent reduction in reproduction compared to the control (IC_{25})	>100	>100	>100

Saltwater (SFOBB)[b]				
Event (Runoff duration)	**April 16, 2000 (382 minutes)**	**May 7, 2000 (340 minutes)**	**May 14, 2000 (93 minutes)**	**April 6, 2001 (351 minutes)**
Percent runoff	**Acute Test Results (Mean Percent Survival)**			
0 (Control)	100	97.5	95	100
6.25	97.5	97.5	100	97.5
12.5	97.5	97.5	95	97.5
25	97.5	90	92.5	95
50	97.5	95	95	100
100	95	80	100	100
	Chronic Test Results (IC_{25} over 7 days)			
Percent runoff causing a 25 percent reduction in growth compared to the control (IC_{25})	97.9	>100	>100	>100

[a] I-85 at Mallard Creek, North Carolina
[b] San Francisco-Oakland Bay Bridge

The runoff from I-85 at Mallard Creek did not cause significant acute toxicity effects in time-variable bioassays for any of the events, even at test concentrations as high as 100 percent runoff. Similarly, no significant chronic effects were evident from the bioassays. Concentrations of some metals in the runoff samples were higher than the U.S. EPA's national water quality criteria for both acute and chronic effects (e.g., copper values from 63 to 75 µg/L and zinc values up to 570 µg/L), and thus the time-variable bioassay tests suggest that these criteria may not be good indicators of actual toxic effects from this bridge's storm runoff.

The time-variable tests with runoff from the SFOBB showed that runoff was not acutely toxic for three of the four events at runoff concentrations up to 100 percent. The other event showed no significant acute toxicity at runoff concentrations as high as 50 percent, with some toxicity evident at 100 percent runoff. Similarly, the tests showed that there was no significant chronic toxicity for three of the four events. For one event, a 25 percent reduction in growth was predicted at a runoff concentration only slightly lower than 100 percent. Concentrations of some metals also exceeded national water quality criteria in SFOBB runoff samples (e.g., copper values from 130 to 270 µg/L and zinc values from 360 to 760 µg/L). Yet the time-variable toxicity tests showed either no toxicity or low levels of toxicity. They further showed that relatively low levels of receiving water dilution would eliminate the marginal effects seen at 100 percent runoff. More specifically, these particular tests showed that a dilution factor of only one part San Francisco Bay water to one part runoff (i.e., 50 percent runoff) is the most that would be needed to eliminate all significant toxicity.

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METHOD **5**

BIOSURVEY METHOD

INTRODUCTION

Two integral factors in assessing potential impacts from bridge deck runoff are the intermittent nature of rain events and the initial concentrations of contaminants. Any characterization of potential impacts should take a time series/timescale approach. In a timescale approach, methods of assessment must integrate the potential impact within an event (intra-event), the impact of a total event, and a long-term impact. Method 4 can be used to assess intra-event and total event impacts whereas the biosurvey method is best suited to long-term impacts.

RAPID BIOASSESSMENT PROTOCOL

Rapid Bioassessment Protocols (RBPs) are designed as inexpensive screening tools for determining whether a water body is supporting or not supporting a designated aquatic life use. Many states have developed RBPs to determine the status of a water resource, to evaluate the cause of a degraded water resource, to assess the effectiveness of water resource restoration, and to measure the success of water resource management plans. The procedures described in this method generally follow suggested methods for specific water resource types. U.S. EPA and specific state documents should be consulted before conducting a biosurvey program. Methods are generally organism-specific, and each has advantages and disadvantages (U.S. EPA, 1996).

The following methods rely solely on the use of benthic macroinvertebrates as the indicator organisms of choice for the following reasons (U.S. EPA, 1996):

- Macroinvertebrate assemblages have been shown to be good indicators of the water quality of localized conditions. These organisms are generally sessile in nature or have limited migration patterns; therefore, they are particularly well-suited for assessing site-specific impacts.
- Macroinvertebrates integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately 1 year or more. Sensitive life stages will respond quickly to stress; the overall community will respond more slowly.
- Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear, and has no detrimental effects on the resident community structure.
- Benthic macroinvertebrates are abundant in most streams.
- Most state water quality agencies that routinely collect biosurvey data focus on macroinvertebrates; therefore, many already have background macroinvertebrate data.

Streams and Rivers

The general protocol assesses benthic macroinvertebrate population characteristics (metrics) above and below a bridge within a potentially impacted area. The characteristics are compared with a reference or background condition. In some states, reference locations have been developed within each watershed or major river basin and should be used as the reference condition. The reference location could be an upstream site or a designated state reference location.

The size of the area to be assessed and the number and kinds of samples collected will depend on the physical size of the river and the type of habitat. An accepted approach to determining the area is to define “the sampling reach.” This involves determining the spatial scale on which to assess the biological component and habitat characteristics. The primary determinant of the length of the sampling reach is the presence of repetitions of two geomorphic channel units such as a sequence of pool, riffle, pool, and riffle. Only those geomorphic channel units (riffle, run, and pool) that cover more than 50 percent of the active channel width are considered when determining the length of the reach. When repetitions of geomorphic channel units are not present (large laminar flow rivers), or occur at intervals of more than 1,000 meters, then the length of the reach is determined to be 20 times the channel width (based on the width of the channel at the boundary of the reach) (Meador et al., 1993). As a rule of thumb, minimum and maximum acceptable lengths are 150 meters and 300 to 500 meters, respectively, for wadable sites. Minimum and maximum acceptable lengths are 500 meters and 1,000 meters, respectively, for nonwadable sites.

Habitat Assessment

Habitat measurements need to be assessed prior to biological assessment. Habitat measurements are used to assess the impacts of habitat on biota, and hence the impacts of habitat on the interpretation of changes in biota. Habitat must be taken into account to make accurate comparisons between the potentially impacted area and the reference condition. The habitat experienced by aquatic organisms consists of the water and the substrate, including structure and pollutant chemicals. Water quality is considered a component of habitat. Likewise, the assessment of habitat will play an important role in determining how the benthic macroinvertebrate community is sampled.

The habitat assessment is accomplished by characterizing selected physicochemical parameters. Physical parameters of importance are predominant surrounding land use, local watershed erosion, local watershed nonpoint source pollution, estimated stream/river width, estimated stream/river depth, high water mark, velocity, the presence of a dam, channelization, canopy cover, sediment odors, sediment oils, sediment deposits, inorganic substrate components, and organic substrate components.

In addition, conditions that may significantly affect aquatic biota need to be documented. Such documentation should include current weather conditions and general water quality parameters such as temperature, dissolved oxygen (DO), pH, conductivity, hardness, total suspended solids (TSS), total organic carbon, stream type, water odors, water surface oils, and turbidity. A prescribed protocol for habitat assessment can be found in the U.S. EPA Office of Water's "Revisions to Rapid Bioassessment Protocols for Use in Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish" (U.S. EPA,1996).

Sampling Methods

Many types of sampling equipment and types of techniques have been developed for the collection of benthic macroinvertebrate samples. The choice of sampling equipment and technique will depend on the water depth, current velocity, and type of bed material to be sampled (Cuffney et al., 1993). The approach described in the rest of this section is suggested for the assessment of bridge deck runoff and is based on accessibility and substrate composition.

Frequency of sampling will depend on the overall objectives of a study. A minimum sampling frequency would consist of one sample event during a stable flow period when benthic macroinvertebrate community structure is most stable. An optimum study design would evaluate seasonal variations.

Wadable Streams and Rivers: Coarse-Grained Substrates. Disturbance-removal sampling techniques are the most appropriate method for sampling wadable coarse-grained substrates (dominated by medium gravel, cobbles, boulders, or bedrock) with current velocities greater than 5 centimeters per second (Cuffney et al., 1993). These techniques involve defining a specific area and disturbing the substrate within that area to dislodge invertebrates into a sampler or downstream net. Examples of such samplers are the Hess sampler, the Surber sampler, the kick net, the box sampler, and the D-frame net.

Wadable Streams and Rivers: Fine-Grained Substrates. Grab sampling devices are the most appropriate method for use in shallow, fine-grained substrates (e.g., silts, sands, and fine gravel). The Eckman grab sampler is best for fine sands and silts, whereas the Ponar grab sampler is best for fine-gravel substrates. Grab samplers are lowered carefully to the stream bottom and released to avoid disturbing the sediments prior to contact and to aid in establishing a uniformity of substrate penetration (Cuffney et al., 1993). Each sample taken may be analyzed individually or composited depending on the assessment objectives. Samples to be composited should be taken within the same in-stream habitat type but at sufficient distances apart to avoid interference among samples.

Nonwadable Streams and Rivers: Coarse-Grained Substrates. Coarse substrates in water deeper than approximately 0.5 meter cannot be effectively sampled using most disturbance-removal type samplers. Although diver-operated samplers are an option, cost and logistics may require other alternatives. Artificial substrates, such as rock-filled barbecue baskets, may be the best option for sampling coarse substrates in nonwadable areas. The baskets are filled with indigenous rocks that have been cleaned of any organisms or uniform substrates such as unlapped porcelain balls (Mischuk and Rades, 1985). Filled baskets are placed on the bottom of the river, within the appropriate in-stream habitat type, and tied to floats or streamside vegetation. The baskets are allowed to colonize for 3 to 6 weeks (depending on season, stream flow, temperature, and latitude), and then are removed (with the aid of a 425-μm-mesh net to catch organisms dislodged during transfer of the baskets to the surface). After retrieval, the contents of the baskets and the collection net are emptied into a bucket, and the associated organisms are removed by scrubbing the substrate with one's hands, a small fingernail brush, or forceps. The samples can be analyzed separately or composited, depending on the assessment objectives. Artificial substrates do have limitations that need to be factored into their use:

1. They require two trips to the sampling site (installation and removal) separated by an interval of time to allow for colonization of the substrates;
2. They are susceptible to loss and vandalism;
3. They are biased towards species that are actively colonizing at the time of placement; and
4. They may not accurately depict the type or relative abundance of benthic macroinvertebrates at a site.

Although these samplers may exclude certain organisms, they collect sufficient diversity of benthic fauna to be useful in assessing water quality in this habitat type.

Nonwadable Streams and Rivers: Fine-Grained Substrates. Grab samplers such as Ponar, Petersen, Van Veen, or Shipek grabs, can be used from boats to obtain samples from deep rivers with fine-grained substrates. All samples are sieved through a 425-µm-mesh screen or smaller to remove extraneous material and consolidate the sample. Individual samples can be analyzed or composited, depending on the assessment objectives. Samples to be composited should be taken within the same in-stream habitat type but at sufficient distances apart to avoid interference among samples.

Wadable and Nonwadable Streams and Rivers: Woody Debris–Dominated Substrates. Where the dominant substrate material is woody debris, an alternative to the above-mentioned sampling techniques is the use of Hester-Dendy multiplate samplers. These sampling devices mimic the woody debris and provide a uniform area for assessing community parameters on a per-area basis. As with coarse-grained substrates, the samplers must be installed and allowed to colonize before they are retrieved. After retrieval, the samplers are disassembled, placed in a suitable container with their attached organisms, preserved, and returned to the laboratory for processing. These samplers are subject to the same limitations as the coarse substrate samplers.

Sample Processing and Taxonomic Analysis

Procedures for laboratory sample processing and level of taxonomic analysis will depend on the objectives of the assessment. A detailed description for benthic macroinvertebrate RBP protocol can be found in the U.S. EPA Office of Water's "Revisions to Rapid Bioassessment Protocols for Use in Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish" (U.S. EPA, 1996).

Data Analysis and Interpretation

The analysis and interpretation of benthic macroinvertebrate data depend on the objectives of the assessment. In general, most assessments will revolve around a simple null hypothesis of impairment to the community used as an indicator. The simplest design will rely on the development of an index from a set of metrics (community characteristics) and a comparison with a reference condition. Many benthic metrics have been proposed for the analysis and interpretation of benthic macroinvertebrate data. These include the Invertebrate Community Index (ICI) (De Shon, 1995); Rapid Bioassessment Protocols (RBPs) (Barbour et al., 1992; 1995; Hayslip, 1993; Plafkin et al., 1989; Shackleford, 1988); and the benthic Index of Biotic Integrity (IBI) (Kearns and Karr, 1994). Many state agencies have developed specific metrics to be used on waters within each state. It is recommended that state agency protocols be consulted before conducting a biosurvey. In the absence of a state protocol, it is suggested that the procedures of Plafkin and colleagues (1989) or the U.S. EPA (1996) be used. In such cases, statistical procedures that equate changes in biological measures to human disturbance or ecological condition should be employed. Because there are many approaches to summarizing and testing biological data, one should consult a good biostatistics book before proceeding.

Lakes and Reservoirs

Procedures used for the assessment of lakes and reservoirs also rely on the measurement of multiple attributes or metrics that incorporate pollution tolerance, diversity, and ecological functions. The described approach defines an array of measurements, each of which represents a measurable characteristic of the biological assemblage that changes in a predictable way with increase or decrease in environmental stress.

Biological assessment of lakes and reservoirs may be implemented in a tiered approach. The approach for the assessment of bridge deck runoff will focus on using benthic macroinvertebrates as the biological indicator assemblage, for reasons mentioned earlier in this method description.

Before the potential impact of bridge deck runoff to a lake or reservoir system can be evaluated, the reference condition with which a site-specific assessment will be compared needs to be defined. States may classify lakes and reservoirs into categories. State resource agencies should be consulted before proceeding to develop a reference condition. Lakes vary widely in size, shape, and ecological characteristics; therefore, a single reference condition for all lakes would be misleading. States may classify lakes into similar groups in order to reduce biological variability within classes and to maximize variability among classes. The intent of classification is to identify groups of lakes that under ideal conditions would have comparable biological communities.

For the purpose of bioassessment, a lake is any inland body of open water with some minimum surface area free of rooted vegetation and an average hydraulic retention time of more than 7 days (U.S. EPA, 1995b). These characteristics distinguish lakes from small ponds and wetlands, and from riverine pools that retain their lotic character. The distinction between lake and small pond is arbitrary, and a resource agency must set the minimum size for a body of water to be considered a lake.

Habitat Assessment

The habitat of a lake or reservoir needs to be assessed prior to biological assessment. Habitat must be taken into account to make accurate comparisons between the potentially impacted area and the reference condition. The habitat experienced by aquatic organisms consists of the water and the substrate, including structure and chemical constituents. Water quality is considered a component of habitat. In-lake habitat includes both the physical and chemical environment experienced by biota and is influenced by the watershed through runoff and loadings. Habitat measurements consist of both watershed and in-lake observations and have two purposes. First, habitat measurements assist in placing a lake into a category determined by a classification scheme. Second, habitat measurements can help identify anthropogenic disturbances and exposure that might be responsible for biological degradation. Habitat measurements fall into three categories: (1) watershed habitat, (2) physical and chemical parameters, and (3) lakeshore habitat. The U.S. EPA provides a summary of measurements (1995b).

Sampling Methods

The unit of assessment and sampling (the sampling unit) is a definable, relatively self-contained basin of a lake. Most lakes have a single basin and thus will consist of a single sampling unit. Larger lakes, and often reservoirs, have embayments, arms, and basins that are hydrologically isolated from the main body of water. Each isolated basin is considered a separate sampling unit because of restricted water flow between basins. Large lakes can thus comprise several sampling units. Therefore, on a large lake, an isolated basin can be used as a reference site. A reference lake with the same habitat and lake classification as the potentially impacted lake may be needed when the potentially impacted lake is small and without any isolated bays.

Reservoirs are further divided into three zones—riverine, transitional, and lacustrine—to reflect differences among these zones. Each zone is a separate sampling unit; in large reservoirs, zones might be represented in each major arm (TVA, 1994). Therefore, the potentially impacted zone will need to be identified and an appropriate reference site located.

Lake and reservoir surveys may require sampling of the benthic macroinvertebrate biological assemblage and habitat in one or more field visits, depending on assessment objectives. The number of transects, the number of sampling sites, and the frequency of sampling will vary, depending on the potential area of impact.

In a minimal sampling design, the preferred sampling area would consist of available substrate located in the sublittoral zone. The sublittoral zone is the preferred area because of its relatively stable nature. The choice of sampling equipment used would depend on the substrate available: submerged aquatic vegetation (dip net), rocks or gravel (dome sampler), sand (Van Veen, Peterson, Ponar grabs), mud (Ponar, Eckman grabs), or clay (Peterson, Van Veen grabs). The preferred sampling period would be late summer, which is generally the most stressful in most regions of the country. Sampling would consist of two to three grab samples at three to five sublittoral transects within the potentially impacted area and the reference location, respectively. Each transect ends in a macroinvertebrate sample site. Grabs could be composited on transects or kept as replicates of an in-lake variance estimate. Samples would be sieved through a 595-µm-mesh screen (U.S. No. 30 sieve) to remove extraneous material and consolidate the sample.

Sample Processing and Taxonomic Analysis

Procedures for laboratory sample processing and level of taxonomic analysis will depend on the objectives of the assessment. A detailed description for the benthic macroinvertebrate RBP protocol can be found in the U.S. EPA Office of Water's "Revisions to Rapid Bioassessment Protocols for Use in Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish" (U.S. EPA, 1996).

Data Analysis and Interpretation

The analysis and interpretation of benthic macroinvertebrate data depends on the objectives of the assessment. In general, most assessments will revolve around a simple null hypothesis of impairment to the community used as an indicator. The simplest design will rely on the development of an index from a set of metrics (community characteristics) and a comparison with a reference condition. Many benthic metrics have been proposed for analysis and interpretation of benthic data. These include the ICI (De Shon 1995); RBPs (Barbour et al., 1992; 1995; Hayslip, 1993; Plafkin et al., 1989; Shackleford 1988); and the benthic IBI (Kearns and Karr, 1994). Many state agencies have developed specific metrics to be used on waters within each state. It is recommended that state agency protocols be consulted before conducting a biosurvey. In the absence of a state protocol, it is suggested that the procedures of Plafkin and colleagues (1989) or the U.S. EPA (1996) should be used. It may be of interest to develop some measure of variability in a metric or index. In such cases, statistical procedures that equate changes in biological measures to human disturbance or ecological condition should be employed. Because there are many approaches to summarizing and testing biological data, one should consult a good biostatistics book before proceeding.

Estuarine and Coastal Systems

Procedures used for the assessment of estuaries and coastal marine areas are based on the classification of the environment into physical and geographic characteristics that are not subject to anthropogenic perturbations. The classifications reduce the array of physical and geographic characteristics to the smallest number of classes that represent comparable biological communities. A set of multiple reference sites are then selected from within each coastal or marine class. The reference sites selected should be those understood to be the least impaired by anthropogenic sources and those that are characteristic of the biological communities of interest represented by that class.

As with previously discussed biosurvey approaches, this one concentrates on measurement of multiple attributes or metrics that incorporate the pollution tolerance, diversity, and ecological functions of one biological assemblage—benthic infaunal macroinvertebrates. The reasons for the selection of this assemblage have been stated previously. Within each estuarine or coastal classification, both physical habitat characteristics and biological assemblage are surveyed using standardized methods.

Habitat Assessment

Habitat characterization is essential to accurately assessing the conditions of the biological assemblage. Estuarine and coastal systems need to be classified into categories such as coastal plain estuary, lagoon, or fjord before traditional physical and chemical properties are determined. The geomorphic type that is potentially impacted will dictate the reference type for comparison of biological assemblages. Traditional physicochemical parameters, needed in the characterization, will act as secondary determining factors (U.S. EPA, 1992b; 1994).

Sampling Methods

Sampling approaches and methods will depend on the objectives of the assessment and the type of habitat. Different techniques are available for sampling organisms in hard- or soft-bottom habitats. It is essential that the techniques used be standardized between locations so information and subsequent data interpretation are not confounded by methods variability.

Hard-Bottom Habitat

Benthic surveys of hard-bottom (e.g., rock outcrop and coral reefs) habitats usually preclude the use of remote sampling devices like nets and grabs. Generally, divers or remotely operated vehicles perform these surveys. The diver or submarine collects specimens directly for positive taxon identification. The linear point intercept method appears to be efficient and yields species abundance estimates similar to the true habitat (Ohlhorst et al., 1988). Underwater photographs can be used to confirm the information obtained by the divers and as reference documents for temporal comparisons. The number and length of transects will depend on the potential area of impact.

Soft-Bottom Habitat

Traditional sampling devices such as grab samplers, core samplers, and trawls can be used to sample the benthic organisms of the soft-bottom habitat. Because benthic macroinvertebrate spatial distribution may vary both horizontally and vertically, samples are required incorporating these differing scales. A preliminary survey may be required to determine the most appropriate technique for the site and the optimal balance between the information required and/or samples needed and subsequent analysis.

Sample Processing and Taxonomic Analysis

The 1.0-mm-mesh sieve is commonly used in impact studies to consolidate the sample and remove extraneous material. The level of identification will depend on the monitoring program objectives, sample size, and number of study sites. In general, the lowest level of taxonomy will be driven by sample costs and information needed to achieve detection of anthropogenic disturbances.

Data Analysis and Interpretation

The analysis and interpretation of benthic macroinvertebrate data depend on the objectives of the assessment. In general, most assessments will revolve around a simple null hypothesis of impairment to the community used as an indicator. The simplest design will rely on the development of an index from a set of metrics (community characteristics) and a comparison with a reference condition. Many benthic metrics have been proposed for the analysis and interpretation of infaunal benthic macroinvertebrate data. Some state agencies in coastal areas have developed specific metrics to be used in marine/estuarine environments. It is recommended that state agency protocols be consulted before conducting a biosurvey. In the absence of a state protocol, it is suggested that the procedures provided in “CWA Section 403: Procedural and Monitoring Guidance” (U.S. EPA, 1994) be used. In such cases, statistical procedures that equate changes in biological measures to human disturbance or ecological condition should be employed. Because there are many approaches to summarizing and testing biological data, one should consult a good biostatistics book before proceeding.

BIOSURVEY AT THE SAN FRANCISCO-OAKLAND BAY BRIDGE

The potential long-term effect of storm water pollutant loading from the SFOBB on aquatic life was evaluated by sampling benthic fauna below the bridge. The presence or absence of impairment was determined by comparing the number of taxa, abundance, and specific species below the SFOBB with the taxa, abundance, and species at a reference site evaluated by the San Francisco Estuary Institute. Table A-4 shows a summary of the data, and Figures A-1 and A-2 illustrate the bridge and sampling locations. A more detailed account of these results is presented in the first volume of this report.

At the SF02 sampling site, the number of taxa was below the minimum number of taxa (14) that were at the reference site. However, the benthic infauna at the reference site and at the SFOBB were comparable, suggesting that there had been few long-term, localized effects from the bridge operation to date.

The results of this study indicated no discernable impact on benthic community structure below the bridge drainage system. This conclusion is based on several factors: comparisons of the benthic infaunal community structure below the bridge with a reference condition described by Thompson and Lowe (2000), extensive studies of benthic infauna conducted in the San Francisco Bay, knowledge of the life histories of many of the organisms present as described in the literature, and professional judgment.

TABLE A-4 Results of biosurvey for the San Francisco-Oakland Bay Bridge (SFOBB)

Site	Number of Taxa	Total Abundance	Amphipod Abundance	Oligochaete Abundance	*C. capitata* Abundance	Number Out of Reference Range
SF 01	18	511	149	1	0	0
SF 02	11[a]	297	73	1	0	1
SF 03	16	491	169	5	2	0
SF 04	16	318	196	1	0	0
SF 05	19	235	130	2	0	0
SF 06	16	235	157	6	0	0
SF 07	23	290	156	1	0	0
SF 08	33	321	89	16	2	0
SF 09	25	191	74	3	3	0
SF 10	17	147	43	3	1	0
SF 11	21	449	187	0	0	0
SF 12	20	131	21	7	0	0
SF 13	25	274	18	3	0	0
SF 14	21	195	26	2	0	0
SF 15	29	354	35	3	4	0

[a] Below the reference range

Reference Ranges for Marine Muddy Benthic Sub-assemblages

	Minimum	Maximum	Mean
Number of taxa	14	66	35
Total Abundance	77	4,022	940
Amphipod Abundance	2	3,693	604
Oligochaete Abundance	0	259	16
Capitella capitata Abundance	0	7	1

Criteria Number of Indicators Outside Reference Range	
0-1	Unimpacted
2	Slightly Impacted
3	Moderately Impacted
4 -5	Severely Impacted

Figure A-1. Oakland side of San Francisco-Oakland Bay Bridge.

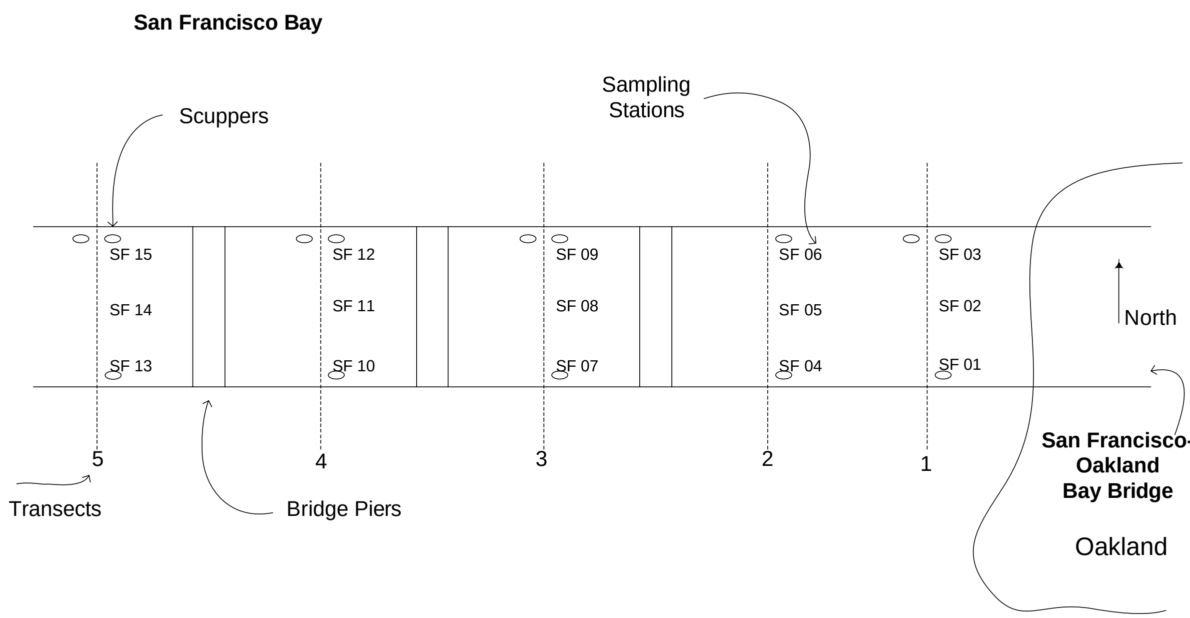

Figure A-2. Schematic of San Francisco-Oakland Bay Bridge sampling stations.

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METHOD **6**

RECALCULATION OF HUMAN HEALTH AND WILDLIFE CRITERIA WITH SITE-SPECIFIC DATA

The U.S. EPA's Great Lakes Water Quality Initiative (GLI), promulgated in March 1995, provides a method by which bioaccumulation is directly incorporated into ambient water quality criteria for protection of human health and wildlife (U.S. EPA, 1995a). The U.S. EPA considered the bioaccumulation concepts and methodologies in the GLI to be reflective of the most current science available for criteria development.

The numeric criteria developed by U.S. EPA have subsequently been adopted by Great Lakes states, as they were required to do to be consistent with the GLI. These criteria can be used directly by practitioners of the NCHRP Project 25-13 process without site-specific modification. In general, the NCHRP Project 25-13 research team does not anticipate that practitioners will find it necessary or useful to undertake the effort or research necessary to establish site-specific data. In the event that site-specific modification is warranted, the GLI provides guidance on procedures and data requirements for that purpose.

In addition, the GLI describes in detail how human health and wildlife criteria are to be derived for both organic and inorganic substances and provides default values for key parameters, such as food chain multipliers, that are to be used in the absence of substance-specific or site-specific data. Thus, if the practitioner encounters concern about a specific chemical that may be in bridge runoff, but a promulgated numeric criterion does not exist for that substance, the general GLI bioaccumulation methods can be used to provide insight into the likelihood of an impact from that chemical. In fact, the GLI includes a process to develop what are referred to as "Tier II" criteria. These are criteria that can be established for substances that lack the complete toxicological database needed for Tier I values. Other default data that are needed include octanol-water partitioning values, currently available to the practitioner from a variety of sources (Young et al., 1996).

One additional useful aspect of the GLI is that it explicitly identified 22 substances that are considered to be both persistent and bioaccumulative, referred to as Bioaccumulating Chemicals of Concern (BCCs). Below is a list of BCCs.

- Chlordane
- 4,4′-DDE; p,p′-DDE
- Dieldrin
- Hexachlorobutadiene; hexachloro-1,3-butadiene
- Alpha-Hexachlorocyclohexane; alpha-BHC
- beta-Hexachlorocyclohexane; beta-BHC
- Mercury
- Octachlorostyrene
- Pentachlorobenzene
- 2,3,7,8-TCDD; dioxin
- 1,2,3,4-Tetrachlorobenzene
- 4,4′-DDD; p,p′-DDD; 4,4′-TDE; p,p′-TDE
- 4,4′-DDT; p,p′-DDT
- Hexachlorobenzene
- Hexachlorocyclohexanes; BHCs
- delta-Hexachlorocyclohexane; delta-BHC
- Lindane; gamma-hexachlorocyclohexane; gamma-BHC
- Mirex
- PCBs; polychlorinated biphenyls
- Photomirex
- 1,2,4,5-Tetrachlorobenzene
- Toxaphene

The GLI listed other substances that do not have significant potential to bioaccumulate. These substances are listed below.

- Acenaphthene
- Acrolein; 2-propenal
- Aldrin
- Anthracene
- Arsenic
- 1,2-Benzanthracene; benz[a]anthracene
- Benzidine
- 3,4-Benzofluoranthene; benzo[b]fluoranthene
- 1,12-Benzoperylene; benzo[g,h,i]perylene
- bis(2-Chloroethoxy)methane
- bis(2-Chloroisopropyl)ether
- 4-Bromophenyl phenyl ether
- Cadmium
- Chlorobenzene
- Chlorodibromomethane
- 2-Chloroethyl vinyl ether
- 2-Chloronaphthalene
- 4-Chlorophenyl phenyl ether
- Chromium
- Copper
- 2,4-D; 2,4-Dichlorophenoxyacetic acid
- Diazinon
- Dibutyl phthalate; di-n-butyl phthalate
- 1,3-Dichlorobenzene
- 3,3′-Dichlorobenzidine

- 1,1-Dichloroethane
- 1,1-Dichloroethylene; vinylidene chloride
- 2,4-Dichlorophenol
- 1,3-Dichloropropene; 1,3-dichloropropylene
- 2,4-Dimethylphenol; 2,4-xylenol
- 4,6-Dinitro-o-cresol; 2-methyl-4,6-dinitrophenol
- 2,4-Dinitrotoluene
- Dioctyl phthalate; di-n-octyl phthalate
- Endosulfan; thiodan
- beta-Endosulfan
- Endrin
- Ethylbenzene
- Fluorene; 9H-fluorene
- Guthion
- Heptachlor epoxide
- Hexachloroethane
- Isophorone
- Malathion
- Methyl bromide; bromomethane
- Methyl chloride; chloromethane
- Nickel
- 2-Nitrophenol
- N-Nitrosodimethylamine
- N-Nitrosodipropylamine; N-nitrosodi-n-propylamine
- Pentachlorophenol
- Phenol
- Pyrene
- Silver
- Tetrachloroethylene
- Toluene; methylbenzene
- 1,1,1-Trichloroethane
- Trichloroethylene; trichloroethene
- Vinyl chloride; chloroethylene; chloroethene
- Acenaphthylene
- Acrylonitrile
- Aluminum
- Antimony
- Asbestos
- Benzene
- Benzo[a]pyrene; 3,4-benzopyrene
- 11,12-Benzofluoranthene; benzo[k]fluoranthene
- Beryllium
- bis(2-Chloroethyl)ether
- Bromoform; tribromomethane
- Butyl benzyl phthalate
- Carbon tetrachloride; tetrachloromethane
- p-Chloro-m-cresol; 4-chloro-3-methylphenol
- Chloroethane
- Chloroform; trichloromethane
- 2-Chlorophenol
- Chlorpyrifos
- Chrysene
- Cyanide
- DEHP; di(2-ethylhexyl)phthalate
- 1,2:5,6-Dibenzanthracene; dibenz[a,h]anthracene
- 1,2-Dichlorobenzene
- 1,4-Dichlorobenzene
- Dichlorobromomethane; bromodichloromethane
- 1,2-Dichloroethane
- 1,2-trans-Dichloroethylene
- 1,2-Dichloropropane
- Diethyl phthalate
- Dimethyl phthalate
- 2,4-Dinitrophenol
- 2,6-Dinitrotoluene
- 1,2-Diphenylhydrazine
- alpha-Endosulfan
- Endosulfan sulfate
- Endrin aldehyde
- Fluoranthene
- Fluoride
- Heptachlor
- Hexachlorocyclopentadiene
- Indeno[1,2,3-c,d]pyrene; 2,3-o-phenylene pyrene
- Lead
- Methoxychlor
- Methylene chloride; dichloromethane
- Naphthalene
- Nitrobenzene
- 4-Nitrophenol
- N-Nitrosodiphenylamine
- Parathion
- Phenanthrene
- Iron
- Selenium
- 1,1,2,2-Tetrachloroethane
- Thallium
- 1,2,4-Trichlorobenzene
- 1,1,2-Trichloroethane
- 2,4,6-Trichlorophenol
- Zinc

Note that the identified BCCs are not pollutants typical of highway runoff, whereas many of the highway runoff pollutants that do not tend to bioaccumulate, including metals such as lead, cadmium, copper, zinc, nickel, and chromium and a number of the PAHs, are those most frequently of concern from a water quality perspective.

The U.S. EPA also has developed computer models that can be used by the practitioner for food chain bioaccumulation assessment (see Method 9).

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METHOD **7**

FIRST-ORDER DECAY MODELS

The term "decay" normally refers to the loss, reduction, or attenuation of a nonconservative pollutant in a receiving water by assimilative processes such as bacterial decomposition. The simple first-order decay approach is widely used and described in numerous water quality evaluation texts and relevant U.S. EPA guidance documents (Mills et al., 1985; Thomann and Mueller, 1987). It is also described for the highway practitioner by FHWA (Young et al., 1996). The simple first-order decay approach is commonly used to predict the bacterial oxidation (i.e., nitrification) of organic and ammonia nitrogen, the predominant chemicals found in urea-based deicers, and is also the standard model for predicting the die-off of bacteria such as fecal coliforms that are common pollutants in highway runoff. First-order decay processes are included in most of the computerized fate and transport models described in Method 9, but the analyses can also be readily performed with a calculator or spreadsheet.

The first-order decay method will often need to be combined with the simple dilution calculations as described in Methods 1 and 2. For example, if a practitioner wants to predict the fecal coliform concentration in a river at a water supply intake some distance downstream of a bridge, the bacteria concentration immediately downstream can be estimated with the simple dilution model, and the concentration after die-off at the downstream intake can be calculated using first-order decay. Any intervening inflows between the bridge and the intake would be factored into the dilution calculation.

For the case of multiple bridges, the first-order decay model, again usually combined with dilution calculations, can be used to evaluate whether there is a need to consider cumulative impacts (e.g., whether or not bacteria concentrations reached background levels before the next downstream bridge is reached).

The steady-state first-order decay model for a stream or river is as follows (Young et al., 1996):

$$C_x = C_0 e^{-K\left(\frac{x}{U}\right)}$$

where

C_x = concentration downstream at distance x
C_0 = initial complete-mix concentration at the point of discharge
K = decay rate
U = stream velocity
e = base e (or approximately 2.718) raised to the power shown

For a completely mixed lake, the steady-state first-order decay model is:

$$C = \frac{W}{Q + KV}\left\{1 - e\left[-\left(\frac{Q}{V} + K\right)T\right]\right\} + C_0 e\left[-\left(\frac{Q}{V} + K\right)T\right]$$

where

C = fully-mixed lake concentration
C_0 = initial lake concentration
W = pollutant load during time interval
Q = lake inflow and outflow
V = lake volume
K = decay rate constant
e = base e (or approximately 2.718) raised to the power shown
T = time

Typical decay rates for different organisms in freshwater and saltwater are provided in various texts and documents (e.g., Bowie et al., 1985; Mills et al., 1985; Thomann and Mueller, 1987, p. 235).

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METHOD **8**

SEDIMENT SAMPLING

Two main types of devices are used to collect sediment samples. The choice of sampler to be used for a particular study depends on the nature of the sample needed. Grab samplers such as Ponar, Eckman dredge, Peterson dredge, or Shipek sediment samplers are designed to obtain discrete samples of surface sediments no greater than 8 inches in depth. Core samplers such as the Ballcheck corer, the KB corer, the Ogeechee sand corer, and piston corers are designed to sample to a greater sediment depth (depending on the depth of water above the sediments). Grab samplers and core samplers can be used in toxicity testing and in evaluating the chemical and physical properties of the sediment. Core sampling can also be used to evaluate historical sediment records. The USGS provides guidance on sediment sampling for highway runoff studies (Breault and Granato, 2000).

Location of sample sites will depend on the objectives of the study. For streams and rivers, sediment samples should be taken from both the reference area (could be upstream of the bridge) and downstream of the bridge. For lakes and reservoirs, samples should be taken from reference areas within the lakes, or from other reference lakes, and also from the lake or sampling unit affected by bridge runoff. In estuaries, sediment samples should be taken from the area of potential contamination and a reference area.

Equipment should be thoroughly cleaned between samples, using prescribed decontamination techniques to prevent cross-contamination. The proper number of Quality Control/Quality Assurance (QA/QC) samples should also be collected when appropriate.

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Breault, R. F., and Granato, G. E., “A Synopsis of Technical Issues for Monitoring Trace Elements in Highway and Urban Runoff.” U.S. Geological Survey Open-File Report 00-422 (2000).

METHOD **9**

FATE AND TRANSPORT MODELS

If a more rigorous analysis of fate and transport of pollutants is warranted (i.e., for long-term pollutant loading effects and sediment accumulation), a more complex water quality modeling program can be used to assess the effects of short- or long-term loadings on a receiving water. This type of analysis requires significantly more effort than a basic steady-state model or screening-level approach. For example, the preliminary methods described earlier (Methods 1, 2, 3, and 7) would normally be expected to take several days to several weeks of effort, whereas more complicated fate and transport modeling can be expected to take hundreds or even thousands of hours of effort. However, the results from the more advanced analyses are generally more accurate and precise in terms of assessing effects on sediment and water column and the potential effects on water intakes.

U.S. EPA's Water Quality Analysis Simulation Program (WASP) is one example of a complex fate and transport model that is available to practitioners (Ambrose et. al., 1988). WASP is a generalized modeling framework for contaminant fate in surface waters. Based on the flexible compartment modeling approach, WASP can be applied in one, two, or three dimensions, given the transport of fluxes between segments. WASP can be used to study biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination.

WASP is capable of simulating water column-sediment interactions (i.e., resuspension, settling, and diffusion). First- or second-order kinetics can be used for all significant organic chemical reactions. Sediment exchanges include pore-water advection, pore-water diffusion, and deposition/scour. Net sedimentation and burial rates can be specified or calculated. General data requirements include water body hydrogeometry, advective and dispersive flows, settling and resuspension rates, boundary concentrations, pollutant loadings, and initial conditions. Segment volumes, connectivity, and type (e.g., surface water, subsurface water, surface benthic, subsurface benthic) must be specified.

Table A-5 summarizes the features of WASP and several other dynamic models that may be suitable for storm water evaluations.

Other U.S. EPA-supported complex fate and transport models that may be useful to the practitioner in some cases are (1) MINTEQ, an equilibrium metals speciation model (Brown and Allison, 1987); (2) FGETS, a fish bioaccumulation model for nonpolar organic compounds (Barber et al., 1988); and (3) FCM2, a generalized model of the uptake and elimination of chemicals by aquatic organisms (Connolly and Thomann, 1985). FGETS and FCM2 can be run separately or as postprocessors for the WASP model. These models are available from the U.S. EPA Center for Exposure Assessment Modeling (CEAM). The CEAM model distribution coordinator can be contacted at (706) 355-8400.

TABLE A-5 Descriptions of fate and transport models

Model	Model Description	Model Processes	Method/Techniques	Input Data Requirements	Outputs	Limitations	Source
WASP5	One-, two-, or three-dimensional, unsteady flow, general purpose modeling system for assessing the fate and transport of conventional and toxic pollutants in surface waterbodies	Dissolved Oxygen-Biochemical Oxygen Demand (DO-BOD), temperature, salinity, nitrogen cycle, phosphorus cycle, phytoplankton growth, first-order decay, process kinetics, equilibrium sorption, resuspension, deposition	Flexible compartment modeling approach	Water body dimensions, flow, loads, boundary concentrations, and initial concentrations for each state variable	Time-variable chemical concentrations for every segment at the specified time interval	Requires separate hydrodynamic model, advanced technical expertise required	U.S. EPA
CE-QUAL-RIV1	One-dimensional fate and transport model, can model unsteady conditions for streams, advective and dispersive transport, far field modeling capabilities	Temperature, first-order decay, DO-BOD, nitrogen cycle, phosphorus cycle, phytoplankton growth	Simulates transient water quality conditions associated with highly unsteady flows, allows simulation of dynamically coupled and branched river systems with multiple control structures	River geometry and boundary conditions, location of control structures, streambed elevations, river cross-sections, metrologic data, withdrawals, rate coefficients	Water surface elevations, velocities, temperatures, DO, Carbonaceous Biochemical Oxygen Demand (CBOD), organic nitrogen, ammonia nitrogen, nitrate nitrogen, orthophosphate, dissolved iron, dissolved manganese, coliform bacteria	For one-dimensional flow conditions only	U.S. Army Corps of Engineers
CE-QUAL-W2	One- or two-dimensional, unsteady flow, advective-dispersive hydrologic and water quality model	Temperature, salinity, DO-carbon balance, nitrogen cycle, phosphorus cycle, silicon cycle, phytoplankton and bacterial growth, first-order decay	Coupled hydrodynamic and water quality routines that incorporate 21 constituents and constituent reactions	Watershed geometry, bathymetry, and boundary conditions, horizontal and vertical dispersion coefficients for momentum and temperature, 60 parameters required for water quality simulations	Water surface elevations, velocities, and temperature, all selected water quality constituents	Suited for relatively long and narrow waterbodies, significant technical expertise in hydrodynamics and limnology required	U.S. Army Corps of Engineers
CE-QUAL-ICM	One-, two-, or three-dimensional, unsteady flow, advective-dispersive hydrologic and water quality model	Temperature, salinity, DO-carbon balance, nitrogen cycle, phosphorus cycle, silicon cycle, phytoplankton and bacterial growth, first-order decay	Improved finite difference method used to solve mass conservation equation, detailed algorithms for water quality kinetics	Detailed algorithms for water quality kinetics, geometric data to define finite difference representation, 140 parameters needed to specify kinetic interactions, initial and boundary conditions need to be specified	Temperature, salinity, inorganic suspended solids, phytoplankton, dissolved, labile, and refractory components of particulate organic carbon, DO, chemical oxygen demand (COD), dissolved silica, particulate biogenic silica, nitrogen and phosphorus speciation	Limited to data availability for calibration and verification, significant technical expertise in aquatic biology and chemistry required	U.S. Army Corps of Engineers
HSPF	Dynamic, one-dimensional hydrologic and water quality model with best management practice (BMP) evaluation component	Water balance, sediment, temperature, nitrogen and phosphorus cycle, DO-BOD, phytoplankton, bacteria, pH and inorganic carbon, first-order kinetics for all biochemical processes	Hydrolysis, oxidation, photolysis, biodegradation, volatilization, sorption, transfer and reaction processes, sub-surface pollutant loads from watershed and routes them through surface waters	Meteorologic data, stream rating curves, land use, land cover, point source data, more than 400 parameters are required for performing specific HSPF functions	Time series of runoff flow rate, sediment and bacteria loads, nutrient and pesticide concentrations	Large amount of water quality data required for calibration, limited to well mixed systems, highly trained staff required for model application	U.S. EPA

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METHOD **10**

LAKE MODELS

There are many computer-modeling techniques available to predict the effects of storm water runoff discharges on receiving waters. These methods have been documented extensively (Mancini et al., 1983; Young et al., 1996, pp. 133–140). Thermal stratification of a lake can affect its mixing ability and the resulting water quality. Computer-modeling techniques, or the use of computer models such as MINLAKE (Riley and Stefan, 1988) that consider the exchange of pollutant between stratified layers, must be used to accurately assess the effects of discharges on stratified lakes.

A complete-mix assumption can be used for a simplified approach to predicting concentrations of a pollutant in a receiving water. For very large or complex lakes, this assumption would not be valid. Simple models that use the completely mixed assumption are presented in Methods 2 and 7.

If a complete-mix assumption is not valid, because of the size of the lake or current patterns, a mixing model may be run to predict the amount of mixing that occurs with the receiving water. Many models are available to predict mixing of discharges in receiving waters, including both rivers and lakes (U.S. EPA, 1991; 1993). These references should be consulted if this type of analysis is warranted.

The above discussion and the procedures described for lakes, reservoirs, and wetlands in Methods 1 and 2 focus on conservative substances such as metals and salts. In some cases, bridge runoff effects on eutrophication of these types of water bodies will need to be addressed by practitioners. In these cases, methods outlined by FHWA for highways will be suitable for bridges (Young et al., 1996). The BATHTUB model has also been used fairly extensively for lake eutrophication analysis (Walker, 1999). In most cases, these water bodies will be subject to nutrient loads from sources other than bridges. Thus, the relative loading analyses, pollutant trading, and storm water banking options are all viable approaches for nutrients (see Methods 11 and 13).

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METHOD **11**

POLLUTANT LOADING

SIMPLE METHOD

Annual or storm event loading can be calculated simply, using literature values for the mean concentration of the pollutant. Because nearly all precipitation that falls on a bridge deck will become storm water runoff (although there are losses at expansion joints and paving notches), the equation for calculating load can be simplified:

$$Load = P \times C \times A$$

where

P = rainfall depth over the desired time interval (annual or event)
C = mean concentration of the pollutant of concern
A = contributing area of the bridge deck (width × length)

Many of the methods in this Appendix require an estimation of bridge deck storm water runoff quality for multiple pollutants. There are a variety of references that can be consulted to estimate a typical pollutant concentration from highway runoff, as discussed in *NCHRP Research Results Digest 235* (Dupuis et al., 1999), the first volume of this report, and other FHWA publications (e.g., Driscoll et al., 1990; Young et al., 1996). However, these FHWA documents do not focus exclusively on bridge decks, or even exclusively on totally impervious highway drainage areas. In addition, there may be aspects of data from these references that are not reflective of current highway runoff quality. This is especially true for metals such as lead, as discussed in the first volume of this report. Consequently, it may be useful to develop national or site-specific databases for bridge runoff evaluation. An approach to developing such a database will be discussed in the section "Developing a Storm Water Pollutant Database for Bridge Decks."

INTENSITY-CORRELATION METHOD

One of the potential limitations of the simple method is that it does not account for the effect of rainfall intensity on pollutant concentrations in runoff, often referred to as the "first flush" effect. High intensity storms have a greater potential to wash off particles on the bridge deck and increase the concentration of pollutants in runoff. The intensity-correlation method correlates rainfall intensity with constituent loading. This method requires hourly rainfall and pollutant concentration data and may necessitate extensive monitoring of bridge decks or adjacent highways to establish a reliable rainfall intensity–mass loading relationship. Use the following procedure to develop a rainfall intensity–loading relationship:

1. Select monitoring location and define the contributing runoff area.
2. Monitor rainfall intensity and pollutant concentrations in 1-hour increments during several storm events.
3. Calculate the mass loading (M) in 1-hour increments for each pollutant analyzed.

$$M = A \times I \times C$$

where

M = mass loading
A = contributing area
C = runoff concentration
I = rainfall intensity

4. Perform a regression between the calculated 1-hour mass loading values (y-axis) and rainfall intensity (x-axis) and define the slope (m) and intercept (b).
5. Obtain hourly rainfall data for an appropriate time period (1 year or more).
6. Calculate the expected mass loading for each hour of precipitation in the rainfall record according to the following formula:

$$M = (m \times I) + b$$

7. Sum the calculated mass loadings for each storm during a year to estimate annual pollutant loads, and multiply the annual loading estimate by the ratio of the bridge deck area to the area monitored for storm water runoff.

The accuracy of this method can be evaluated for each runoff pollutant with a standard measure of the goodness of fit (R^2) of the regression.

DEVELOPING A STORM WATER POLLUTANT DATABASE FOR BRIDGE DECKS

The literature review described in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report revealed only a limited number of studies of bridge deck runoff quality; however, the pollutant concentrations reported may be comparable to storm water quality data for totally impervious highways, that is, studies in which storm water was monitored directly from pavement. Hence, impervious highway runoff quality data likely can be used to supplement bridge deck runoff quality data. Although a comprehensive, edited database of bridge and impervious highway runoff quality does not currently exist, multiple sources of highway runoff quality data do exist: FHWA, USGS, and state DOT reports; academic publications; and state DOT monitoring studies performed for compliance with federal and state NPDES storm water permit requirements.

A bridge runoff quality database could be developed by gathering, editing, and statistically summarizing monitoring data for impervious highway and bridge surfaces. The literature review and state DOT survey tasks for NCHRP Project 25-13 identified multiple storm water monitoring studies. Currently, only a few FHWA documents consist of compiled and edited monitoring data. For example, Driscoll and colleagues (1990) summarized monitoring data for 31 FHWA sites, 12 of which were completely impervious and are applicable to bridge decks. The USGS has gathered highway-monitoring reports (under contract with FHWA) and has published an easily accessible reference list of the reports that is available on their website.

The largest effort in developing a national database would involve the collection of monitoring data gathered by state DOTs for the purpose of NPDES storm water compliance. This task will be simplified for the practitioner if monitoring of bridge or impervious highway surface runoff has been conducted in the state in which the bridge is located.

Once the monitoring data are compiled, qualitative and quantitative tools can be applied to evaluate the data and to examine whether certain data points, specific storms, or entire monitoring studies are unusable and should be removed from the dataset. It may be useful to consult USGS guidance (Breault and Granato, 2000) on evaluating the acceptability of highway storm water runoff data. Once unusable data are removed, the dataset should be classified into groups on the basis of traffic volume, region, urban versus rural environments, or a combination of these. It should be noted that the 1990 FHWA study was unable to develop a predictive model of pollutant load based on highway characteristics such as traffic volume (Driscoll et al., 1990). They ultimately chose to divide the database into urban and rural highways, as defined by an ADT cutoff of 30,000.

POLLUTANT LOADING IN WISCONSIN

The Wisconsin DOT (WisDOT) used Method 11 to calculate pollutant loading for a bridge in Wisconsin. The results of their analysis are provided below and compared with the results of monitoring data that WisDOT had previously collected (Tables A-6 and A-7).

Pollutant loading was calculated using the formula and parameters listed below.

$$Load = P \times C \times A$$

where

P = rainfall depth over the desired time interval (annual or event)
C = mean concentration of the pollutant of concern
A = contributing area of the bridge deck (width $\times$ length)

Parameters for the Wisconsin bridge were the following:

- Length of bridge deck = 2,375 feet
- Width of bridge deck = 48 feet
- Area of bridge deck = 114,000 square feet
- Rainfall depth (year) = 31.58 inches
- Event rainfall depth = 1.5 inches

TABLE A-6 Comparison of calculated mean concentrations with mean concentrations from monitoring data

Pollutant	From Literature Values (FHWA)	From Monitoring Data
Mean TSS[a] concentration	100 mg/L	120 mg/L
Total copper concentration	54 µg/L	58 µg/L
Total zinc concentration	329 µg/L	200 µg/L
Total lead concentration	400 µg/L	28 µg/L
Total cadmium concentration	45 µg/L	0.8 µg/L
Total phosphorous concentration	3 mg/L	0.107 mg/L

[a] total suspended solids

TABLE A-7 Comparison of literature-based annual pollutant loading values (Driscoll et al., 1990) versus pollutant loading estimates from Wisconsin DOT (WisDOT) monitoring data

	Calculated Pollutant Loading Values (lb) from FHWA Literature		Pollutant Loading Estimates (lb) from WisDOT Monitoring Data	
Pollutant	**Annual**	**Event**	**Annual**	**Event**
TSS[a]	69.158	3.2849	82.990	3.9419
Copper	0.037	0.0018	0.040	0.0019
Zinc	0.228	0.0108	0.138	0.0066
Lead	0.277	0.0131	0.019	0.0009
Cadmium	0.031	0.0015	0.001	0.0000
Phosphorus	2.075	0.0985	0.074	0.0035

[a] Total suspended solids

As can be seen in Tables A-6 and A-7, some of the calculated loadings derived from the FHWA values (Driscoll et al., 1990) are comparable to the estimates determined from local monitoring data. The results also show that in the case of lead, cadmium, and phosphorus, the literature-based calculations were conservative.

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METHOD **12**

COLLECTION OF SITE-SPECIFIC RUNOFF QUALITY DATA

If site-specific pollutant concentration and loading are desired, field data can be collected for an existing bridge, or a surrogate bridge or highway with similar attributes to the bridge in question. Although using site-specific data may be preferable in some cases to using literature or national database values, it is generally advisable to sample a minimum of three storm events to even out any storm event anomalies and to address the inherent variability in runoff quality. The cost of collecting site-specific chemical data will have to be weighed against the benefits.

FHWA developed a guidance manual for highway runoff and receiving water monitoring (Dupuis et al., 1985a). More recent guidance on runoff monitoring for highways has been developed for FHWA by the USGS (Breault and Granato, 2000). This guidance covers container selection, clean monitoring techniques, QA/QC recommendations, and analytical considerations, as well as providing some data on the ratio of dissolved to total metals in highway runoff. Most sampling studies also require precipitation monitoring for storm water flow measurements. The USGS also has guidance on precipitation monitoring for highway runoff studies (Church et al., 1999). Another resource available for highway runoff and receiving water monitoring is a new sampling device, the development of which was sponsored by the FHWA (GKY and Associates, Inc., 2000). Although not written specifically for highways, a U.S. EPA monitoring guidance for nonpoint source controls, which describes topics such as developing a monitoring plan, biological monitoring, data analysis, and QA/QC, could be useful for monitoring highway and bridge runoff (U.S. EPA, 1997).

As discussed in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report, the practitioner should consider more recent “clean” sampling and analysis methods for metals, particularly for receiving water sampling (U.S. EPA, 1995c). In addition, sampling runoff from bridge decks in many cases will present unusual challenges. For example, bridges with simple open-rail drainage may require special methods to block several openings so that runoff can be concentrated at a discrete location. In addition, open-ended scupper drains or open holes in the deck may be difficult or dangerous to access at the higher elevations along the bridge. For bridges with multiple scupper drains or other storm water outlets, the issue of obtaining samples representative of the entire bridge will also have to be included in the study design. Normally, only scuppers readily accessible to sampling would be used (i.e., those at the lower elevations on either side of the bridge), and generally, these will be representative of the other nonsampled locations.

Storm water flows at each sampling location over the course of an event can generally be accurately determined by rainfall monitoring and knowledge of the bridge deck area draining to the sampling location(s). Two previous studies of bridge runoff used large plastic garbage pails to retain runoff from open-ended scupper drains (Buchholz, 1986; Dupuis et al., 1985b). This allows runoff to be collected without the sampling crew being present at the start of the event. If this method is used, the sampling pail should be shrouded with plastic sheeting of some kind to minimize atmospheric inputs prior to the event.

CASE STUDIES

Michigan DOT Storm Water Runoff Study

The Michigan Department of Transportation (MDOT) conducted a storm water runoff quality study that concentrated on metal pollutants in runoff (CH2M HILL, 1998). MDOT data on concentrations of metals in runoff and FHWA published values for bridges above and below 30,000 ADT are shown in Table A-8. As can be seen in the table, MDOT results for lead concentrations are lower than the values in the FHWA literature, supporting the results of the Wisconsin study referenced in Method 11. This comparison of site-specific results with FHWA published values demonstrates how highway runoff databases for metals need to be revisited. Sampling and analytical procedures continue to be improved, and leaded gasoline has been phased out, limiting the value of older studies especially with regard to lead.

Collection of Runoff to Evaluate the Effect of Deicer Chemicals (Minnesota DOT)

The Minnesota DOT (Mn/DOT) took samples of runoff from the Bong Bridge between Duluth, Minnesota, and Superior, Wisconsin, from February 1987 to May 1989. The purpose of the runoff sampling was to determine the potential water quality impact from using an experimental deicer.

TABLE A-8 Metals database comparison—Michigan DOT (MDOT) data and FHWA published values for bridges with average daily traffic above and below 30,000

Pollutant (microgram per liter)	Average Daily Traffic less than 30,000		Average Daily Traffic greater than 30,000	
	MDOT Mean	FHWA Median	MDOT Mean	FHWA Median
Copper	14	22	41	54
Zinc	104	80	187	329
Lead	14	80	25	400

TABLE A-9 Estimated concentration of sampled parameters in the St. Louis River based on mass loadings from deicing chemicals on the Bong Bridge. Samples taken during the winter months[a]

Pollutant Parameter	Units	River Concentration Based on 7-Day, 10-Year Low Flow (7Q10)			
		Mean	Median	Minimum	Maximum
Chloride	mg/L	3.69	0.1457	.0003	39.29
Sulfate	mg/L	0.0482	0.0067	0.0001	0.4613
Sodium	mg/L	0.2761	0.1118	0.0003	1.20
Total Phosphorous	mg/L	0.0137	0.0025	0.0000	0.1085
Total Solids	mg/L	5.76	0.4334	0.0012	60.65
Zinc	μg/L	17.48	0.7053	0.0165	145.2

[a] 12 samples taken, November through April.

Mn/DOT attached a 30-gallon, plastic-sealed drum to a bridge downspout to measure runoff flows and to direct runoff to an automatic sampler. A weighing bucket rain gauge was also installed at the site. The drainage area of the bridge downspout was approximately 3,000 square feet. Sampling was conducted throughout the year, with the non-winter months (May–October) serving as a control for runoff when deicers were not applied.

Storm water pollutants monitored during the study include chloride, sodium, zinc, and TSS. The summation of the masses for each parameter in a given sampling event were converted to mass/square foot for the 3,000-square-foot drainage area and then extrapolated to the total surface area of the bridge receiving the deicing chemical. It was assumed that the total mass of the deicing material applied to the bridge would wash into the receiving water (the St. Louis River). The average 7-day low flow expected on a 10-year periodicity (7Q10) was used to estimate the effect of the loading to the river. It was further assumed that the total mass washed from the bridge would be instantaneously mixed with the total 1-day flow. This value was expressed as a concentration.

The calculated mass loading of each pollutant was used to determine an estimated concentration of the pollutant in the St. Louis River per runoff event. Mn/DOT, in conjunction with the Minnesota Department of Health, analyzed runoff samples for chemical characteristics and concentrations. Data for several events were collected and compared with concentration limits for certain metals in receiving waters. Table A-9 presents some of the study results.

Estimated mean loadings were found to be well within the concentration limits in almost all cases (Minnesota DOT, 1990). After conducting the study, Mn/DOT discontinued the runoff monitoring. The data were used to set upper limits for usage of the experimental deicer over any 24-hour period.

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METHOD **13**

NONSTRUCTURAL AND STRUCTURAL BMP EVALUATION

If it has been decided, on the basis of either regulatory or receiving water needs, that some type of BMP may need to be implemented for bridge deck runoff, an evaluation to determine the most suitable type of BMP will need to be conducted. The BMP could consist of nonstructural, institutional, or structural BMPs, or a combination of them. Many factors must be considered in selecting a BMP approach including the BMP capabilities and limitations, appropriateness for the site, pollutant loading benefits, maintenance requirements, and costs. Consideration should also be given to the effect of BMP choice on the safety of maintenance workers. For example, snoopers will be used to maintain below deck piping, and a confined space entry will be required to maintain piping that is located within the bridge deck structure.

BMPs can consist of structural techniques (e.g., detention ponds, infiltration ditches, and grassed swales) or nonstructural methods (e.g., source control and pollution prevention practices). Source control to reduce pollutant loading from bridge deck runoff could include more effective street sweeping or more appropriate deicing practices in winter. Institutional BMPs, such as pollutant trading or mitigation banking, can also be considered.

A simplified evaluation process is provided here to lead the practitioner through the BMP selection process.

- *Step 1.* Define the need (e.g., heavy metals concentration reduction, discharge elimination).
- *Step 2.* Define the constraints (e.g., site, cost, and organizational and physical constraints).
- *Step 3.* Eliminate obviously inappropriate techniques (e.g., if the concern is hazardous material spills only, street sweeping will not address the concern).
- *Step 4.* Begin evaluation of nonstructural BMPs. One by one, determine the benefit and cost of each technique and answer the following: Will the technique achieve the required water quality benefit in whole or in part? Project benefits are based on projected pollutant reduction and/or projected flow reduction. Determine costs for BMPs using literature values or other internal estimates, as appropriate. Nonstructural BMPs that are potentially applicable to bridges include:
  – Street sweeping,
  – Inlet box/catch basin maintenance,
  – Maintenance management,
  – Deicing controls, and
  – Traffic management (e.g., high occupancy vehicle lanes, and mass transit).
- *Step 5.* If one or a combination of several nonstructural BMPs would not achieve the required benefits, begin evaluation of institutional BMPs (i.e., pollutant trading and mitigation banking). Evaluate whether either of these techniques, or a combination of any techniques evaluated up to this point, would achieve the desired water quality benefit. Determine costs of the institutional BMPs.
- *Step 6.* If the nonstructural and institutional BMPs cannot provide enough of the desired water quality benefit/protection, structural BMPs should be evaluated to determine which methods are appropriate and to assess the cost-effectiveness of potential methods. A critical component of the BMP analysis includes engineering evaluations related to the type of drainage and storm water conveyance needed, and the effects these systems could have on the structural design of the bridge. Structural BMPs have been evaluated by many researchers (e.g., Schueler, 1987; Young et al., 1996). FHWA has also developed a review of BMPs appropriate for use in urban areas with limited land availability (Shoemaker et al., 2000). For information on structural BMP effectiveness, the American Society of Civil Engineers (ASCE) is developing a National Storm Water BMP Database to allow users to access data on BMP performance (http://www.bmpdatabase.org). In selecting an appropriate BMP, required pollutant removal benefits, site constraints, maintenance constraints, and potential environmental or aesthetic enhancements need to be considered (Dorman et al., 1996; Shoemaker et al., 2000; Young et al., 1996, Table 33). Once a narrowed list of BMPs is selected, the costs for each should be calculated (see Table 9 in the first volume of this report) and an appropriate economic analysis made (Brown and Schueler, 1997). A list of structural BMPs that have been applied or considered, and may be appropriate methods for controlling bridge deck runoff, are described in *NCHRP Research Results Digest 235* (Dupuis et al., 1999) and the first volume of this report. These include simple drainage back to land for relatively small bridges

in cases in which this is practical. In most cases, the drainage would be to a grassy area or pond prior to discharge to the receiving water. Other systems have included enclosed piping or open-trough drainage back to land, again, with some form of treatment on land such as swales or ponds. In one case, a series of collection trays or pans along the bridge deck that were periodically vacuum-cleaned were used. Another example is drainage to treatment systems below the bridge This could include oil-water separators or Storm-ceptors. NCHRP Project 25-12 investigated wet detention pond technology for highway storm water runoff. Practitioners should review this information.

NONSTRUCTURAL BMPs

Nonstructural mitigation techniques should always be considered before structural measures because they are cost-effective and sometimes more efficient pollutant removers. Nonstructural techniques for bridge decks include source control and management methods.

Street Sweeping

Research conducted in the past few years has demonstrated that street sweeping can effectively reduce pollutant loads from roadways. This contradicts studies conducted in the late 1970s and early 1980s under NURP that concluded that street sweeping was ineffective at reducing pollutant loading in urban runoff. Recent studies have demonstrated that NURP conclusions are no longer valid today (Sutherland and Jelen, 1997). The two primary reasons for this change are improvements in equipment and improvements in sweeping methods.

Mechanical sweepers (broom and conveyer belt) are now more effective at picking up fine solids than they were in the early 1980s. Also, the introduction of vacuum-assisted and regenerative air sweepers (which blow air onto the pavement and immediately vacuum it back to entrain and filter out accumulated solids) has greatly increased effectiveness, particularly with fine particles. In addition, improved methods such as tandem sweeping (i.e., mechanical sweeping followed immediately by a vacuum-assisted machine) have shown marked increases in percent pollutant reductions (Sutherland and Jelen, 1997).

In recent studies (Sutherland and Jelen, 1997), a new type of street-sweeping machine called the Enviro Whirl (which combines a broom with a powerful vacuum in one unit) was found to be most effective, reducing TSS loading up to 90 percent for residential streets and up to 80 percent for major arterials. The actual percent reduction also depended on the number of cleanings per year, with the maximum numbers reported for weekly cleanings. Results for biweekly cleanings are about 70 percent for both residential and major arterials (Sutherland and Jelen, 1997).

The costs of the high-end cleaners, such as the regenerative air sweepers or the Enviro Whirl sweepers, can be from 2 to 2.5 times the cost of a traditional street sweeper. Operation costs and service life are comparable.

Timing and frequency of street sweeping have been shown to be critical for obtaining high removal rates. Often, the time of peak material on the road, such as just after snowmelt in early spring, is missed because of the street-sweeping schedule. The Massachusetts Department of Environmental Protection (DEP) reports that a better-planned schedule of street sweeping could increase the pollutant reduction substantially (1997). The Massachusetts DEP also reports that infrequent sweepings (less than 20 times per year) with conventional mechanical sweepers result in average TSS removal efficiencies no greater than 20 percent.

Catch Basin Cleaning

Inlet box and catch basins should be cleaned out regularly if these are present on the bridge deck. As with street sweeping, the efficiency of the program is dependent on the frequency and consistency of the cleaning. It is critical to remove the sediment accumulated during the winter months before spring rains.

Deicing Controls

Winter deicing activities add substantially to the pollutant loading off of bridge decks. Some alternative practices that can reduce the loading include using alternative deicing compounds (e.g., calcium chloride or calcium magnesium acetate), designating “low salt” areas on bridges over sensitive receiving waters, and reducing deicing applications through driver education, training, and equipment calibration.

Traffic Management

In a few cases, in which protection of a critical receiving water is a priority, traffic routing of large trucks and hazardous material haulers away from critical bridges could be considered. Limiting the number of large trucks on critical bridges would lower the incidence of accidents. This traffic management technique is discussed in greater detail in Method 16.

Maintenance Practices

Necessary maintenance activities on bridges can adversely affect water quality in the receiving waters beneath the bridges. Maintenance activities include bridge painting, substructure repair, drainage structure repair, and pavement repair or repaving.

Bridge painting is probably the most common bridge maintenance practice and the one with potentially the greatest adverse effects on the receiving water. Painting activities contribute blasting abrasives and paint chips (often leaded paint) into the receiving waters below the bridge. Surveys have indicated that up to 80 percent of the bridges repainted each year were previously painted with lead paint. These surveys have also indicated that substantial amounts of used abrasives can be lost to the environment if appropriate containment practices are not used (Young et al., 1996). Paint overspray and solvents also may be toxic to aquatic life if they reach the receiving water (Kramme, 1985).

The NCHRP Project 25-13 survey also revealed that metal bridge cleaning is a significant water quality issue in some states, particularly in Washington, Tennessee, and Oregon (see *NCHRP Research Results Digest 235* [Dupuis et al., 1999] and the first volume of this report). According to the survey, the cleaning process produces a water solution, which generally needs to be tested and/or treated before being either discharged to the receiving water or otherwise controlled and managed off-site.

Several techniques can be implemented to reduce the impacts of maintenance activities on receiving waters. These include containment of wastes, recovery of wastes, and training of painters to increase their awareness of potential impacts on receiving waters. Containment of blasting abrasives and paint chips can be accomplished using shrouding, total structural enclosures, and negative pressure containment systems. Recovery of blasted materials and other residue can be accomplished by vacuuming at the point of surface application, placing barges below the bridges, using containment booms in the receiving water, and funneling the debris in the enclosed container to a disposal truck or storage compartment. Workers can be trained in practices that reduce the impacts of bridge painting. These practices would include not allowing paint to enter surface waters, hanging drip tarps to catch drippings and dropped brushes, mixing paint or other substances away from the water, having a plan for accidental spills, and using appropriate cleaning procedures. (Young et al., 1996). The use of airless sprayers and the elimination of the use of solvents would greatly reduce the toxicity-related concerns associated with chemicals entering the receiving water directly (Kramme, 1985).

NCHRP Synthesis of Highway Practice 176 notes that fully enclosed containment structures are capable of recovering 85 to 90 percent of abrasive, paint particles, and dust for simple spans; however, this type of containment is not feasible for high trusses or other complex structures (Appleman, 1992).

The costs of implementing these measures to reduce the effects of bridge painting on receiving water quality have been estimated at an additional 10 to 20 percent for containment techniques and an additional 10 to 15 percent for waste disposal (Young et al., 1996). Management practices associated with retraining workers would also add an undefined cost.

The effects of construction and repair materials on surface and groundwater were evaluated under NCHRP Project 25-09 by Nelson and colleagues (2001) for their potential to cause toxicity as a result of chemical leaching. A screening test identified materials that had a potential to cause toxic effects to aquatic life. The leaching and toxicity results from this study can be used to estimate the impact of leached materials.

INSTITUTIONAL BMPs

The specific elements of the various types of pollutant trading, off-site mitigation, and mitigation banking programs are unique to each program. Thus, no specific guidance on applicability, criteria, economic benefit, or methodology can be provided here. The practitioner is advised to determine if institutional BMPs such as these exist in the appropriate geographic context (i.e., usually within the watershed) of the bridge project. If none exist, it may be beneficial to consider establishing one. Based on the results of the survey and explicit trends within the U.S. EPA and many states, the NCHRP Project 25-13 research team believes that these institutional approaches will be progressively more available to the practitioners of this process over time. Approaches such as these have already been developed for highway and/or bridge storm water runoff in several states (e.g., Washington and Delaware). The details and potential benefits of these programs are very specific to each state or watershed. As a starting point for identifying opportunities in such programs, the practitioner can contact the U.S. EPA (www.epa.gov/owowwtr1/watershed).

STRUCTURAL BMPs

A large number of structural BMPs are available to effectively reduce storm water runoff volume and/or pollutant loading. Several techniques are used for storm water runoff disposal from bridge decks:

- Discharging runoff through multiple open scuppers directly into the receiving water.
- Discharging runoff through piping down from the bridge deck directly into the receiving water.
- Conveying the storm water runoff over the surface of the bridge to one or both ends for BMP treatment or discharge.
- Conveying the storm water runoff via piping or open troughs over to one or both ends of the bridge for BMP treatment or discharge.
- Detaining and treating the storm water under the bridge deck.

Bridge Design Considerations Associated with Drainage and Conveyance Systems

Background

A first step in the engineering evaluation would be to determine if the bridge requires deck drain strictly from a drainage perspective. An example of such an analysis, performed by Mn/DOT, is given toward the end of this method. In some cases, a system will be required to convey storm water from the bridge deck to a treatment system located off the bridge. The details of this conveyance system must be considered during the bridge design. The structural design of the bridge will be affected by the additional weight imposed by the system and by the various conflicts the system will have with the structural members.

The following discussion is applicable whether the conveyance is designed for traditional hydraulic concerns or for storm water treatment.

Various guidelines (USDOT, 1984; 1986) are of assistance in the design of bridge deck drainage systems. These documents typically discuss the hydraulic concerns such as application of the Rational Method, gutter flow, and inlet design but do not address either the conveyance system or the structural aspects of the system.

This section addresses the structural issues associated with placing conveyance systems on bridges.

System Configurations

Typically, a storm water conveyance system is comprised of a number of deck inlets each connected to lateral pipe running transversely to the bridge. This lateral pipe conveys deck runoff to a main trunk line running longitudinally along the length of the bridge. The trunk line exits the bridge at the abutments and connects to a treatment system located nearby.

The details of the conveyance will depend on the type of bridge under consideration. Given the large number of bridge types, there will be a wide variety of piping layouts, inlet sizes, and support systems.

Bridge Load

If large diameter piping will be required to convey the storm water, the additional load to the bridge must be considered early in the bridge design. The AASHTO Bridge Design Specifications do not specifically mention this load; therefore, the designer will need to apply project-specific criteria to evaluate this load in combination with other bridge loads.

Inlets

Although inlets for bridge deck drainage systems are typically much smaller than inlets on roadway drainage systems, they can create substantial conflicts with the structural design of the bridge.

The inlet typically is cast into a concrete deck. This creates a conflict with the transverse and longitudinal deck-reinforcing steel; therefore, additional reinforcing may be required in these locations. Large inlets in positive longitudinal bending locations may necessitate analyzing the bridge deck using a reduced section modulus determined by subtracting the portion of the deck lost to the inlet.

Decks with posttensioning steel require special consideration. Inlets can create conflicts with both longitudinal and transverse posttensioning. Relocation of longitudinal posttensioning in the field may not be possible. Anchorage zones for transverse posttensioning may be adversely affected because inlets are typically placed at the edge of the deck where the anchorage stresses are highest. These details must be considered at the design stage to avoid construction difficulties.

Inlet design must consider the deck grooving and grinding typically performed on bridge decks. This may necessitate casting the inlet below the top of deck level.

Some agencies specify a minimum spacing of 10 feet for inlets.

Piping

The piping for bridge storm water conveyance is typically much smaller than piping used for roadway drainage systems, in which the minimum pipe diameter is often 18 inches or 24 inches. Bridge deck drainage systems typically incorporate 6-inch-minimum-diameter pipes.

Piping is usually located within the depth of the bridge to satisfy vertical clearance requirements. From an aesthetic standpoint, locating the pipes between the girders and thereby hiding them from view is beneficial. Piping is usually located inside of box girder bridges for the same reasons.

To reduce clogging, large radius sweeps are used at bends in the piping (3-foot radius bends on 6-inch pipes is common). The designer should verify that sufficient space exists for these sweeps, otherwise the piping will conflict with girders or penetrate below the bridge depth. Because of the sweeps and the limited headroom available within the bridge, pipe slopes are essentially restricted to the bridge slope. Piping located near the top of vertical curves may have very slight slopes and small flow capacities.

Care must be taken to avoid conflicts between the piping and the other utilities on the bridge.

For durability and maintenance concerns, the piping must be strong. Welded steel pipe is commonly used.

Structural analysis of the piping system is required to verify the pipe supports and to verify that the pipe can span between these supports.

Conflicts with Structural Members

The following structural members can be adversely affected by the conveyance system:

- *Girder Webs.* Penetrations in the girder webs are often necessary for the pipe laterals, because the inlets are usually at the edge of the deck and the trunk piping is usually between the girders. These penetrations must be carefully detailed and reinforced. For prestressed girders or posttensioned bridges, the penetration must be located to avoid the prestressing, which may be at the middepth of the member.

- *Intermediate Diaphragms and Cross-Frames.* The longitudinal trunk line may conflict with these transverse members.
- *Bent Caps.* Integral concrete caps are typically highly reinforced and will have additional steel at the column/cap joint for joint shear requirements. Because piping often is directed down columns at the bents, the sweeping turns in the piping make this a difficult area to avoid reinforcing. Often the column transverse and main reinforcing are spaced more tightly than the diameter of the piping.
- *Columns.* Pipes conveying storm water down concrete columns typically exit the face of the column just above the footing. When a fixed connection between the column and the footing exists, the pipe will conflict with the transverse and main longitudinal column steel just as it does at the bent cap. This necessitates additional analysis and detailing.
- *Hinges.* In concrete bridges, hinges in the superstructure are highly reinforced and experience high bending and shear stresses. Large diameter trunk lines are difficult to fit in this area.

Expansion Joints. Bridges with expansion capability at the abutments or in the spans will require compatible pipe expansion joints. These joints are typically of much larger diameter than the connecting pipe and are difficult to maintain. On very large bridges, the joint may be expected to move over 1 foot under temperature movements alone. Designing expansion joints for such large movements is difficult.

An alternative to providing a mechanical joint at abutments is to construct a gapped system in which the piping directs storm water downward from the superstructure into a small rectangular funnel-shaped reservoir located in the abutment seat. In this manner, the piping in the superstructure moves with the expansion or contraction of the bridge above the small receiving reservoir, which is sized to always accept water from the piping.

Maintenance. Bridge storm water conveyance systems, because of their small diameter piping and the nature of highway debris, create a challenge for maintenance staff. Repairing or replacing damaged or worn piping and components is difficult. This is especially true in enclosed box girder bridges because of restricted access, low working headroom, and low-light conditions.

Access hatches or manholes are required in the top or bottom slab of box girder bridges, creating more locations for conflicts with rebar and posttensioning steel. Cleanouts may be necessary in complex piping systems and should be made accessible from safe locations.

Access to expansion joints is especially important for their maintenance.

Maintenance Travelers. On bridges incorporating maintenance travelers, the travelers will have to be designed to access the pipes and not to conflict with them. Coordination is required with compressed air piping to avoid conflicts with these systems.

Vents on Box Girder Bridges. Vents are provided on box girder bridges to allow air to circulate inside the bridge. Often these vents are only 4 inches in diameter. Designers should resize the vents or provide additional vents to pass the flow of a broken trunk line pipe within the bridge. For large diameter piping, a steel grate, similar to that used on bridges with pressure pipe water utilities, may be necessary.

Roadway Design

Consideration of bridge drainage and conveyance issues during the geometric design of the roadway will lead to simplified conveyance systems. Most importantly, avoiding sag curves and super-elevation reversals on the bridge will greatly reduce the number of inlets and the diameter of piping. Locating the high point of the bridge near the middle of its length may negate the need for inlets and piping on the bridge.

Constant width bridges have simpler piping systems than tapered bridges and less likelihood of girder conflicts. All the flow upstream of the bridge should be intercepted to limit bypass flow from entering the bridge and having to be conveyed through the less-reliable bridge conveyance system.

Cost and Benefit Analyses

Popular BMP methods used at the ends of bridges are wet and dry extended detention ponds, wet ponds, wetlands, and grassed swales. The costs of ponds are dependent on the storage volume required. Costs developed in the 1980s were recently updated (Brown and Schueler, 1997). The following formula was developed for calculating the relationship of total pond or wetland volume to total construction cost (based on 38 pond/wetland systems in the Mid-Atlantic region):

$$TC = 23.07 \times V_x^{0.705}$$

where

TC = total construction cost (1996 dollars)
V_x = total storage volume, cubic feet

This total cost includes 32 percent allowance over base construction cost for design, permitting, and other contingencies (Brown and Schueler, 1997). Availability of sufficient land for a pond is a critical element.

The cost-volume relationship for bioretention practices (e.g., grassed swales or vegetative strip), based on 12 bioretention facilities in the Mid-Atlantic region, is:

$$TC = 6.88 \times WQV^{0.991}$$

where

TC = total construction cost (1996 dollars)
WQV = water quality volume, cubic feet

One important consideration in calculating cost is to estimate the annual maintenance costs for structural BMPs, which in some cases can be significant. BMPs that are not maintained can quickly lose any pollutant removal capabilities. Furthermore, a BMP that is not maintained could pose a hazard to the highway or bridge where lack of maintenance has reduced the BMP's capacity to handle the volume of runoff planned.

The effectiveness of ponds, swales, and vegetative strips for removing pollutants is summarized in various sources and is being collected as part of the ASCE National Storm Water BMP Database (Dorman et al., 1996; Schueler, 1987; Young et al., 1996, Tables 34 and 36; Yu, 1993). NCHRP Project 25-12 has included extensive evaluation of wet detention basins for highway storm water runoff (final report not available as of this printing).

The analyses listed below could be considered for evaluating the benefits and costs of mitigative measures. With the exception of production theory analysis, the various economic methods described reflect common engineering practice and are not unique to the NCHRP Project 25-13 process (e.g., White et al., 1977). Consequently, bridge engineers and designers are generally already knowledgeable about these methods. Methods that directly consider operation and maintenance costs over the life of the bridge are recommended to ensure that this often critical cost is not overlooked in the analysis. Consult the FHWA document on BMPs in an urban setting (Shoemaker et al., 2000) for an extensive review of cost estimates for structural BMPs.

Present Value Analysis

Present value analysis, which is a component of most of the methods discussed below, provides a framework for comparing the direct costs and benefits of project alternatives by accounting for the "time value" of money. The discounting process rests on the assumption that a dollar today is worth more than a dollar tomorrow because of opportunity costs (the cost of giving up the opportunity to use or invest the resource). Net present value, which includes the present value of all direct costs and benefits, can be used to compare the results of project or program options. However, because net present value combines the effects of costs and benefits, it would not be as useful as benefit/cost analysis in estimating the relative efficiency of various projects.

Benefit/Cost Analysis

Benefit/cost analysis focuses on the efficiency of project alternatives. It is a basis for comparing and ranking projects with different goals or varying scales. Benefit/cost analysis also includes an estimate of the relationship of all benefits and costs to society by translating indirect costs and benefits into dollars (the sum of all direct and indirect costs borne by or accrued to everyone). If all costs and benefits were direct, net present value and benefit/cost analyses would yield identical results. Using dollars as a common denominator allows conflicting objectives to be compared. Because benefits and costs often accrue in different patterns over time, it is usually necessary to discount them to a present value. The cost parameters associated with the alternatives can be defined to include both initial investment costs and the present value of maintenance costs anticipated over the life of the facilities.

Cost-Effectiveness Analysis

Cost-effectiveness analysis is primarily useful when comparing the costs (and determining the least-cost approach) of different ways of achieving the same measurable goal. This method rests on the assumption that any additional benefits beyond meeting the goal and any nonmonetary costs are insignificant. If those benefits or costs are significant, a technique that focuses on efficiency, such as benefit-cost analysis, would be preferred. Cost-effectiveness analysis would, therefore, be most useful in evaluating situations in which a single goal exists rather than multiple goals. One important consideration for all projects is the economic quantification of environmental value. Many stakeholders view economic quantification of environmental resources as controversial. For storm water BMPs, the common cost-effectiveness metric is the BMP cost per unit mass of pollutant removed (Brown and Schueler, 1997).

Life Cycle Cost Analysis

Life cycle cost analysis takes into consideration the total cost of constructing and implementing a facility for its useful life. Historical cost curves, useful lives, replacement costs, and operating cost histories for similar facilities are used to aid decision making. In some cases, this type of analysis might identify bridges that should be retrofitted to help establish prioritization of limited funds. Understanding the life cycle stage of retrofit projects competing for highway agency dollars makes it possible to consider such factors as these in the resource allocation process:

- Projected changes in annual maintenance costs throughout the remainder of the useful life of the equipment or structure.

- Opportunities to extend the useful life of the facility through early restoration or rehabilitation.
- Risk of significant increases in the cost of implementing the mitigative measures if they are delayed 1 year, 5 years, or some other interval of time.

Analysis of life cycle cost can be combined with benefit/cost analysis or other related methods in developing components for evaluating mitigative strategies.

Production Theory Optimization

CH2M HILL has developed a storm water BMP economic optimization method based on production theory and marginal benefits and costs. The methodology has been used for a number of combined sewer overflow and storm water control projects. Production theory optimization analysis is a quantitative method of comparing candidate BMPs to arrive at an optimal solution. It relies on information developed in the technologies evaluation steps, including performance (i.e., pollutant removal effectiveness), cost, and interactions of individual BMPs. It is most useful in cases in which multiple BMPs are considered. CH2M HILL has developed a computerized program (BEST) that simplifies what otherwise would be a laborious evaluation process. This approach may be applicable to larger bridge projects in which the potential costs and benefits warrant this degree of sophistication.

BMP Ranking Procedure

The objective of using a BMP is often to protect aquatic life or prevent spills from entering a receiving water. When faced with limited resources to protect receiving waters, it may be worthwhile to evaluate BMPs with regard to pollutant removal efficiency and cost. A series of steps and formulas were developed by Caltrans (Pilgrim, 2001), similar to CH2M HILL's production theory optimization concept, to rank a list of proposed BMPs by evaluating the ratio of cost to effectiveness for each BMP. The Caltrans method is different than production theory optimization in that a numerical evaluation of BMP removal efficiency is weighted by giving greater value to the removal of pollutants that are of particular concern. Once the optimal BMP is identified, it can be compared with mitigating storm water with similarly evaluated BMPs at other sites in the watershed (e.g., mitigation banking, pollutant trading). Hence, this procedure can also be used to identify when treatment of bridge runoff is not practical—that is, if significantly greater benefits could be realized by treating runoff, for the same or lower costs, from impervious areas that discharge into other locations within the same body of water or watershed.

BMPs are ranked by calculating a selection value according to the following formula:

$$SV = \frac{(C + M + E)}{AF}$$

where

SV = selection value (lowest value = best BMP option)
C = BMP cost
M = present worth of maintenance cost (10 years used by Caltrans)
E = present worth of environmental monitoring costs (10 years used by Caltrans)
A = area of watershed treated by BMP
F = pollutant removal factor

The pollutant removal factor is a composite value for several storm water runoff constituents and spills and is based on the following equation:

$$F = f_1 p + f_2 p + f_3 p + \cdots f_i + f_{spills}$$

where

f_{1-i} = weighting factor for each pollutant of interest
f_{spills} = weighting factor for spills
p = pollutant removal efficiency (% removal/100)

There are a number of potential approaches to developing weighting factors. Professional judgment could be used to assign f values for each pollutant of interest. For example, if sediment is considered the most problematic pollutant, a large f value (e.g., 100) would be assigned to sediment. If aquatic toxicity was the primary concern, large f values could be assigned to metals such as copper and zinc (e.g., 100), whereas lower values (e.g., 40) would be assigned to sediment. Clearly, street sweeping would not be a viable option for spill containment, and in this case, the pollutant removal factor (p) would be zero. A more quantitative method would be to use monitoring data and water quality criteria to identify the problematic pollutants. In this case, the f factor could be calculated as the frequency, in percent, with which a particular runoff pollutant exceeds water quality criteria. This would link the f factor to the protection of the designated use of the receiving water body. The f factor for spills may be based on professional judgment and might include consideration for the risk of spills, downstream drinking water sources, and the nature of the receiving water (i.e., how quickly it flushes).

For the cost of constructing off-site BMPs such as ponds and swales, see the beginning of the section "Cost and Benefit Analysis." For the cost of constructing bridge deck containment and treatment systems, see Table 9 in the first volume of this report. The pollutant removal efficiency of BMPs has been reviewed by a number of authors (Schueler et al., 1992; Shoemaker et al., 2000; Sutherland and Jelen, 1997).

CASE STUDIES

Minnesota DOT—Maximum Bridge Length Required Before Deck Drains Are Necessary (For Drainage Purposes Only)

It may be worthwhile to examine whether a newly proposed bridge will need deck drains. Mn/DOT performed some preliminary calculations to determine how long a bridge can be before deck drains are needed. The following variables were used:

- Longitudinal slope (0.005 foot per foot);
- Cross-slope (0.025 foot per foot);
- Spread (10 feet);
- Bridge deck roughness (0.016);
- Gutter depression (0.025 inch);
- Gutter width (2 feet);
- Bridge width (18 feet); and
- Rainfall intensity (6 inches per hour).

The first six variables were put into the FHWA program "HY22-Urban Drainage and Design Program" to determine the storm water flow rate for a bridge with the characteristics itemized in the bullet list above. This rate is the maximum storm water flow that can run off a bridge deck. Using the discharge rate and a given rainfall intensity (e.g., 100-year storm), the maximum length that a bridge can be without drainage was calculated with the following equations:

$$Area \times (Runoff\ Coefficient \times Rainfall\ Intensity) = Flow$$

$$Maximum\ Distance\ within\ Drain = \frac{Area}{Bridge\ Width}$$

Mn/DOT performed calculations for a hypothetical bridge and determined that 0.43 acre (18,800 square feet) was the maximum bridge deck area that could handle a 6-inch-per-hour rainfall. With that information, it was then possible to determine a maximum bridge length by assuming various bridge deck widths. For instance, assuming a bridge deck with one 12-foot lane and a 6-foot shoulder, the maximum bridge deck length (with the given slope and spread characteristics) without a drain was determined to be 1,044 feet (18,800 square feet divided by 18 feet).

Maine DOT—Promoting BMPs Across Multiple State Agencies

In 1997, the Maine DOT developed a revised "Best Management Practices for Erosion and Sedimentation Control" manual for the storm water–related issues of transportation projects in the state. Although this manual alone does not have any regulatory authority or provide any specifications, it does contain a compilation of structural and nonstructural BMPs appropriate to Maine's transportation projects.

Recognizing the value of this manual, the Maine DEP, the Maine Turnpike Authority, and the Maine DOT agreed that the Maine DOT manual was the most feasible guide to controlling storm water in a manner consistent with the state standards set out by the DEP. The three agencies signed a Memorandum of Agreement in 1998 in which the Maine DOT and the Maine Turnpike Authority agreed to apply the Maine DOT manual BMP standards to all projects in the organized territory, with a few exceptions. In return, all Maine DOT and Maine Turnpike Authority roads, railroads, and associated facilities constructed pursuant to the requirements of the Memorandum of Agreement are not required to obtain a permit or DEP approval pursuant to the DEP's storm water management rules.

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METHOD **14**

IN SITU TOXICITY TESTING

In situ toxicity studies present a unique method in which organisms that occur as natural populations within the system under study are used as test organisms. Likewise, the organisms are incubated in the system under study as opposed to laboratory studies. Although this type of test presents many logistical problems, it allows one to obtain real-time data under real field conditions.

Test organisms are generally species that are available at the time the study is conducted and can represent several phylogenetic groups. Examples include zooplankton (*Daphnia*), aquatic insects (mayflies [*Ephemeroptera*], damselflies [*Odonata*]), algal microcosms (periphyton), and fish (perch). Many species have been used and can be used in these in situ studies. A typical design would consist of flow-through chambers that allowed exchange of chamber water with the surrounding ambient water. Many different designs of chambers can be used to isolate the test organisms. Test chambers can be placed in reference locations away from the influence of the bridge deck runoff to act as controls. Test chambers for the study may be placed at locations near runoff points or at intervals away from runoff points that represent varying degrees of dilution. In these studies, the endpoint is usually some measure of survival (percentage alive compared with the reference/control group).

Interpretation of data from in situ studies requires knowledge of the ecological requirements of the organisms used, the life cycle of the organisms used, and the environmental conditions (physical and chemical conditions that may influence the results) at the time of the test. Using organisms of known age that have been acclimated to the reference condition will reduce the level of uncertainty.

Length of incubation will depend on the objectives of the study, study design, and test organism used.

METHOD **15**

COMPARISON OF BRIDGE DECK LOADING TO OTHER SOURCE LOADINGS IN WATERSHED

It will generally be useful to be able to compare the anticipated or predicted pollutant loads from the bridge deck with those from other sources in the watershed. This not only places the impact of the bridge in a relative context, but it also can provide the information needed for pollutant trading, off-site mitigation, and storm water banking programs. The loading from the bridge can be estimated using Methods 11 and 12.

Obtaining estimates of pollutant loadings from other sources in the watershed can be done in a variety of ways. The preferred approach is to obtain these estimates from an agency or entity that has already developed them for other reasons; however, when these data are inadequate, the responsible agency may consider implementing a water quality monitoring program. With the recent increase in watershed-based programs, including TMDLs (see *NCHRP Research Results Digest 235* [Dupuis et al., 1999]), there will be a rapidly expanding database on sources and loads for receiving waters in the United States. Some data will be specific to a particular watershed; other data will be statewide or regional and cover a variety of land uses. These will become increasingly accessible to the practitioner, as evidenced by U.S. EPA's *Surf Your Watershed* Internet access database (http://www.epa.gov/surf). Other sources of applicable water quality information may include USGS, watershed councils, or university extension offices. Such watershed-specific information will be superior to nonspecific literature values for particular land use types that have often been used in the past (Dupuis et al., 1985b). This is particularly true for agricultural sources, which vary widely because of differences in climate and agricultural practices.

Other methods available to the practitioner range from the very simple (e.g., export coefficients) to sophisticated watershed models (Lahlou et al., 1996; U.S. EPA, 1992a). For most bridge projects, simpler methods should suffice in cases in which loadings data are not already available from other agencies.

If a more in-depth modeling approach is indeed appropriate, a recommended starting point would be U.S. EPA's BASINS modeling framework (http://www.epa.gov/ostwater/BASINS/), which is based on a geographic information system (GIS). According to U.S. EPA's BASINS web page (http://www.epa.gov/ostwater), BASINS, originally released in 1996, addresses three objectives: (1) to facilitate the examination of environmental information; (2) to provide an integrated watershed and modeling framework; and (3) to support analysis of point and nonpoint source pollution management alternatives. It supports the development of TMDLs, which require a watershed-based approach that integrates both point and nonpoint sources. BASINS can support the analysis of a variety of pollutants at multiple scales, using tools that range from simple to sophisticated.

The heart of BASINS is its suite of interrelated components essential for performing watershed and water quality analysis. These components are grouped into five categories: (1) national databases; (2) assessment tools (TARGET, ASSESS, and Data Mining) for evaluating water quality and point source loadings at a variety of scales; (3) utilities including local data import, land use and DEM reclassification, watershed delineation, and management of water quality observation data; (4) watershed and water quality models including PLOAD, NPSM (HSPF), SWAT, TOXIROUTE, and QUAL2E; and (5) postprocessing output tools for interpreting model results. BASINS' databases and assessment tools are directly integrated within an ArcView GIS environment. The simulation models run in a Windows environment, using data input files generated in ArcView. The capabilities of various watershed loading models are briefly summarized in Table A-10.

TABLE A-10 Models for developing watershed loading estimates

Types of Models	Time Step	Non-point Sources		Point Sources	GIS[a] Linkage	Integrated BMP[b] Evaluation	Data Requirement	Linked to Ground Water	In-Stream and Lake Modeling	Calibration and Verification
		Urban	Rural							
Screening										
EPA Screening	Annual	Yes	Yes	No	No	No	Minimal	No	No	Minimal
PLOAD	Annual	Yes	Yes	Yes	Yes	Yes	Minimal	No	No	Minimal
WMM	Annual	Yes	Yes	Yes	No	Yes	Minimal	No	Yes	Minimal
SLOSS/PHOSPH	Annual	No	Yes	No	No	No	Minimal	No	No	Minimal
Mid-Range										
GWLF	Continuous	Yes	Yes	Yes	No	No	Moderate	No	No	Moderate
AGNPS	Event	No	Yes	Yes	No	No	Moderate	No	No	Moderate
P8-UCM	Continuous	Yes	No	No	No	No	Moderate	No	No	Moderate
SLAMM	Continuous	Yes	No	No	No	Yes	Moderate	No	No	Moderate
Detailed										
HSPF	<Daily and Continuous	Yes	Yes	Yes	Yes	Yes	High	Yes	Yes	High
SWMM	<Daily and Continuous	Yes	Yes	Yes	No	Yes	High	No	Yes	High
SWAT	Daily and Continuous	Yes	Yes	Yes	Yes	Yes	High	No	Yes	High
ANN-AGNPS	Daily and Continuous	No	Yes	No	No	No	High	No	No	High

[a] Geographic Information System.
[b] Best management practice.

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METHOD **16**

ASSESSMENT OF HAZARDOUS MATERIAL SPILLS

According to NCHRP Project 25-13 survey recipients, the potential of hazardous material spills to contaminate drinking water sources is one of the primary drivers behind the construction of enclosed storm water containment systems. Spills obviously also have the potential to adversely affect aquatic life in the receiving water. Given that most highway spills are of limited volume and duration, the primary concern would be acute effects (i.e., mortality). In any case, the assessment techniques described herein can be applied to any numeric water quality criterion, whether it be drinking water or acute aquatic life.

The Oregon DOT developed documentation of a hazardous material spill risk assessment (Kuehn and Fletcher, 1995). This document describes a risk methodology used by the Oregon DOT to assess the potential impact of a hazardous material spill from Highway 101 to Clear Lake, a drinking water supply in Oregon. The Oregon DOT document also provides references to documents that contain national risk assessment methodologies and statistics. These include key FHWA documents (FHWA, 1987; 1990; 1994) and "Truck Accident Rate Model for Hazardous Materials Routing" in *Transportation Research Record 1264* (Harwood et al., 1990).

These and other documents were used to develop a hazardous material spill risk assessment methodology that consists of three parts: (1) calculation of the risk of a hazardous material spill for a bridge, (2) modeling of the concentration of pollutants at the drinking water intake for comparison to drinking water criteria, and (3) residence time of the spill chemicals. The methodology for Part 1 is the same for the three receiving water categories (streams and rivers; lakes, wetlands, and reservoirs; and coastal systems), whereas for Parts 2 and 3 the methodology depends on receiving water type.

The outcome of all three parts should be used to develop an understanding of the vulnerability of the drinking water source to contamination from hazardous material transport on the bridge. Part 1 provides an estimate of the risk of a hazardous material spill on a bridge. Regardless of the risk determination, it is worth knowing whether drinking water standards are exceeded at the intake (Part 2) and, if so, for how long (Part 3). Part 3 provides methods to determine how long the spill contaminants will remain in the drinking water supply.

The risk determination of Part 1 will determine whether the findings of Parts 2 and 3 are significant. The key question, of course, is: What level of risk is acceptable in which circumstances? The answer, of course, is: It depends. It depends on the sensitivity of the receiving water uses, stakeholder opinions, and other intangibles. There is no regulatory standard under the Clean Water Act that is directly applicable, although insight and perspective can be provided by the following considerations:

- U.S. EPA guidance on water quality criteria for protection of aquatic life, used as the basis for most promulgated state standards, recommends that acute and chronic toxicity criteria not be exceeded more often than once every 3 years (the rationale being that aquatic systems can recover within that timeframe). Additional information on recovery times for various types of aquatic systems can be found in the scientific literature.
- Major hydrologic events (e.g., severe droughts and floods that can significantly impact aquatic life and drinking water supplies) typically recur with somewhat predictable frequencies. These recurrence intervals can be compared with spill probabilities to provide additional perspective. Severe droughts commonly occur at least once every decade or two, and severe floods generally occur at least once every century or so.

Other important questions relevant to the risk analysis that need to be answered are the following:

- Which chemical(s) exceed drinking water standards and what are the toxicological properties of these chemicals? Effects of some chemicals are manifested only with long exposure periods (e.g., carcinogens). If the drinking water criterion for one of these chemicals is exceeded, a qualitative risk estimate should consider the magnitude of the exceedance (Part 2) and the residence time of the chemical (Part 3), which is essentially the exposure period.
- What is the water treatment plant's capacity to reduce the spilled chemical below drinking water standards, and what is the cost of alternative or supplemental drinking water sources in comparison with spill containment (structural mitigation)?

The practitioner also should be aware of "restoration-based" methods that have been developed in recent years to address

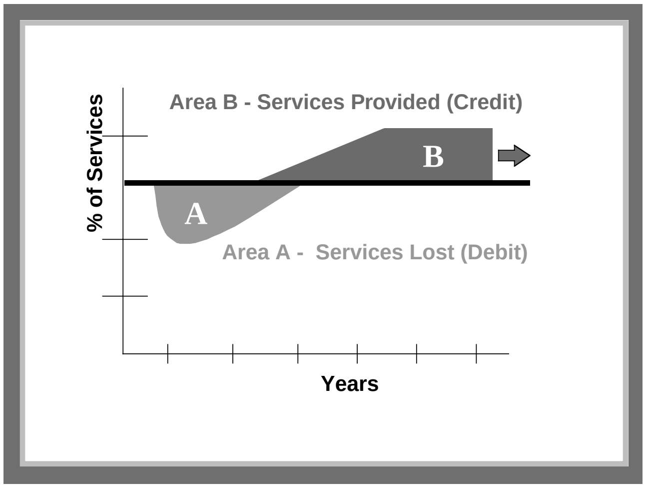

Figure A-3. Restoration-based compensation.

the ecological impacts of a possible spill from a bridge. In Figure A-3, the potential damage caused by a spill would be Area A. It could be quantified in area of benthic habitat affected, number of fish affected, reduced fish spawning area, reduction in zooplankton, loss of emergent vegetation, and so forth. If there were only a 10 percent probability of the spill event occurring, the value of "A" could be adjusted accordingly. Area B is the credit derived from a restoration project either at the site of the damage (after the fact) or in an area that could benefit from restoration (as determined by stakeholders). With a restoration approach, it is common practice to apply "interest." Therefore, if the restoration occurs after the spill, more restoration is required. In contrast, if the restoration were performed in advance, credit would accrue so that if a spill did occur, it would be "precompensated."

In practice, the approach might be implemented by

- Determining the area of A, based on likelihood of a spill and amount of potential damage.
- Working with stakeholders to determine a desirable restoration project within the potentially affected watershed.
- Scaling the restoration project so that with the ecological benefit of having the credit in place in advance of any damage, the damage would be fully compensated within the planning period.
- Comparing the cost and probability of success of the scaled restoration project with the cost and probability of success (and potential for need) of spill prevention measures.

PART 1: RISK OF A HAZARDOUS MATERIAL SPILL

The risk of a hazardous material spill on a bridge should be calculated using the following formula:

$$Risk = TAR \times FracHaz \times RelProb \times Length \times \frac{ADTT \times 365}{1{,}000{,}000}$$

where

Risk = risk probability of hazardous material spill during a year
TAR = truck accident rate, that is, the number of large truck accidents per million vehicle miles
FracHaz = fraction of trucks (that carry hazardous materials) involved in accidents (as decimal)
RelProb = fraction of hazardous material accidents with a spill (as decimal)
Length = length of the bridge in miles
ADTT = average daily truck traffic
365 = converts risk probability to an annual basis
1,000,000 = conversion factor to million vehicle miles

The calculated value *Risk* is the probability of a hazardous material spill occurring during a year. The inverse of *Risk* (1/*Risk*) is the probabilistic estimate of the time in years between hazardous material spills. For the Oregon study at Clear Lake, it was estimated that a hazardous material spill would occur once every 247 years if no improvements were made to the roadway.

Statistics for *TAR*, *FracHaz*, and *RelProb* used in the example at the end of this method are from an FHWA fact sheet. The fact sheet provides a national average for *TAR*, but the crash rate on a bridge can be affected by the configuration of on ramps and off ramps and deceleration and acceleration lanes (Bauer and Harwood, 1997). Crash rates on bridges can vary significantly. Crash rates studied for four bridges (Berry Creek, Mill Basin, Tappan Zee, and Willis Avenue) in the New York City metropolitan area ranged from 186 to 896 crashes per 100 million vehicle miles (MVM) (Retting et al., 2000). Crash rates on the approach roads ranged from 56 to 243 crashes per 100 MVM. High crash rates (825 crashes per 100 MVM) at the Willis Avenue bridge were explained by merging activity to access a major roadway. This study demonstrates that statewide or site-specific data can improve the overall risk estimate.

The risk estimate formula presented here is conservative in that it includes all hazardous material spills, whereas, for a particular drinking water source or type of aquatic life to be endangered, a spill must be of a certain size and involve certain chemicals. For example, half of all hazardous materials transported are petroleum products, which float on water and can be contained. Hence, the variable *FracHaz* can be reduced by 50 percent if the primary interest is in spills that would be difficult to contain.

Hazardous material content data are available from the FHWA or local state agencies. If these sources are not adequate, hazardous material content can be more accurately defined by monitoring and recording the content of hazardous material–carrying trucks at inspection stations near the bridge.

Spill statistics reported by the FHWA and state agencies include both large and small spill events. It is worthwhile to separately calculate the *Risk* factor for large catastrophic events and small (all other) spill events. Large catastrophic events are defined as involving 10,000 gallons (a conservative value for the volume that a tractor trailer truck, hauling a double-tank rig, can legally haul over bridges in most states). Risk for small and large spills should be calculated as follows:

$$RiskSmall = Risk \times FractSmall$$

$$RiskLarge = Risk \times FractLarge$$

where

Risk = risk probability of hazardous material spill during a year
FractSmall = fraction of small spills to total spills
FractLrg = fraction of large spills to total spills

It should also be noted that the risk of a spill event can be reduced with safety enhancements such as lane and shoulder widening, good drainage, and speed reduction. The calculated risk factor can be used to determine the relative risk of a spill among many bridges for purposes of identifying which drinking water supplies are at risk of contamination from bridges, or it can serve as an absolute measure of risk.

PART 2: HAZARDOUS CHEMICAL CONCENTRATION AT DRINKING WATER INTAKE

This part requires four steps: (1) identify in detail the hazardous chemicals that will be carried across the bridge, (2) determine the volume and concentration of each hazardous chemical carried by trucks, (3) identify the safe drinking water maximum contaminant level criteria or the drinking water equivalent level for each chemical, and (4) gather receiving water data and calculate the concentration at the drinking water intake. The primary shortfall of this analysis is the large number of chemicals that may be potentially transported across a bridge and the lack of complete FHWA or state data. For example, hazardous chemicals carried by a given truck may contain multiple pollutants, and FHWA data do not provide this level of detail. Therefore, a national or site-specific study may need to be undertaken to better quantify truck-carried hazardous material and the transported chemicals. The research team's recommended approach to fill this data gap is presented at the end of this method.

The human health effect of a spill is dependent on two timeframes, short and long. The short timeframe considers dilution before complete mixing, whereas the long timeframe considers dilution after complete mixing. If a drinking water intake is close enough to a bridge deck that complete mixing will not occur, a dilution model should be used to calculate chemical concentrations at the intake immediately following the spill (short timeframe). These concentrations should then be compared with drinking water criteria. If any criteria are exceeded, proceed to Part 3 to calculate the residence time of the chemicals (to estimate how long the body of water will be impacted). If the intake is far enough removed from the bridge deck to allow complete mixing of the spill, use the long-term dilution modeling methods. Provided below are methods to calculate pollutant concentrations for the long-term time period. Short-term methods require the use of computer models such as UDKHDEN, PLUMES, or other mixing models. It is recommended that the most conservative assumptions be used in these models. For example, if a drinking water intake is 2,000 feet from a bridge, assume that the currents point in the direction of the intake.

Streams and Rivers

The model used for streams and rivers is presented by Thomann and Mueller (1987, pp. 72–76). It allows the user to calculate the peak concentration of each pollutant of a completely mixed chemical spill at a given distance (drinking water intake) downstream of the spill. Primary data requirements include river characteristics (use average velocity and flow), length of time the spill discharges to the river, the initial fully mixed chemical concentration, and distance downstream to the drinking water intake. If greater accuracy is required, a field dye study involving the discharge of rhodamine dye to the river could be used to calibrate the model or to simulate a hazardous material spill. It should be pointed out that the suggested model is conservative in that it does not account for removal of pollutants by volatilization, sediment removal, or decay.

Lakes, Wetlands, and Reservoirs

This method simply involves the calculation of the chemical concentration in the body of water (mass/volume). Modeling methods are not available to determine the length of time between a spill and complete mixing. This may need to be determined empirically by injecting Rhodamine WT dye (in a manner such that it mimics a spill) and measuring dye concentrations in the body of water for a given number of days after the spill.

Coastal Systems

The long-term model for coastal systems is provided by Thomann and Mueller (1987, pp. 116–117). The primary drawback (leads to a conservative estimate) of this model is the assumption that the entire spill contents enter the receiving water instantaneously after the spill event. Primary data requirements include estuary dimensions and velocity, distance from the bridge to the point of concern, estuary dispersion coefficient, and volume of the spill (loading). Because an estuary moves upstream and downstream, the chemical concentration at the point of interest will vary with time. This will require the practitioner to calculate the pollutant concentration at the point of interest for sufficiently small time increments after the spill to identify the worst-case concentration peak.

PART 3: RESIDENCE TIME OF THE HAZARDOUS CHEMICAL

Chemical residence time calculations should be performed to identify how long the drinking water source is not useable. This part should be completed only if the long-term, fully mixed, in-stream chemical concentrations are above drinking water criteria.

Streams and Rivers

The model used for streams and rivers is the same as in Part 1 and is presented by Thomann and Mueller (1987, pp. 72–76). This model can be used to predict concentrations downstream of the source at given time intervals. Hence, by executing the model for a range of time steps, a curve can be developed that shows an increase in chemical concentrations with time, a maximum, and a decrease. A comparison of this curve to the drinking water standard will provide an estimate of how long the standard is exceeded, and in turn, how long the drinking water source is unusable after a hazardous material spill.

Lakes, Wetlands, and Reservoirs

The appropriate model for this task is presented by Thomann and Mueller (1987, pp. 180–188). This model begins with the chemical concentration after complete mixing with the body of water and accounts for volatilization, sedimentation, and decay over time. The model can be used to predict the length of time it takes for concentrations to fall below a given level, which is also how long the drinking water source is unusable. Data requirements for this model include water body volume, inflow and outflow, chemical decay rates, and pollutant settling rates.

Coastal Systems

The long-term model for coastal systems is the same as in Part 2 and is provided by Thomann and Mueller (1987, pp. 116–117). The primary drawback (leads to a conservative estimate) of this model is the assumption that the entire spill contents enter the receiving water instantaneously after the spill event. Nonetheless, executing this model for a range of time steps allows the development of a curve that relates each pollutant concentration at the point of interest to time after the spill. The time period in which a given pollutant concentration exceeds a criterion provides an estimate of how long the use is impacted. Primary data requirements include estuary dimensions and velocity, distance from bridge to the point of interest, estuary dispersion coefficient, and volume of the spill (loading).

CASE STUDIES

Probability of a Bridge Chemical Spill in Minnesota

Mn/DOT provided calculations to determine the probability of a highway chemical spill occurring on a bridge in Minnesota. Data used to complete this analysis included:

- Accidents of all types occurring on bridges in Minnesota that involved semi-trailer trucks annually for 5 years (1991 to 1995).
- The number of bridges in Minnesota in the four major highway classifications (Interstate, U.S. Highway, State Highway, County State Aide Highway).
- Proportion of trucks carrying hazardous materials over a bridge.

The average number of semi-trailer accidents on bridges in Minnesota was 133 per year. Given that there are 9,139 bridges in Minnesota (of which 7,699 are over water), the number of semi-trailer accidents per bridge was lower than 0.02. The proportion of trucks carrying hazardous material was difficult to determine; in this case, nationwide data from the 1993 Commodity Flow Survey (U.S. Census Bureau, 1996) were used (see below for how WisDOT handled this issue). Those data indicated that there were 864.9 billion ton-miles of freight hauled by trucks. Less than 1 percent of that total (0.124 billion ton-miles) were hazardous materials. Comparing the two numbers (semi-trailer accidents per bridge and proportion of hazardous freight) reveals that the probability of a bridge chemical spill is very small in Minnesota.

The data used in the above analyses are general in nature and are difficult to apply to the specific circumstances of one bridge. Because of the lack of data, no consideration is made for differences in the amount of hazardous material carried on an Interstate versus a County State Aide Highway or in an urban versus rural area. Inclusion of such considerations, when possible, would help to improve the analysis for a bridge of concern.

Hazardous Material Spill Risk Assessment for the Hudson Bridge (Wisconsin–Minnesota)

WisDOT used the assessment procedure provided in this method to determine the risk of a hazardous material spill on the Hudson Bridge between Wisconsin and Minnesota.

The following equation was used to determine the risk:

$$Risk = TAR \times FracHaz \times RelProb \times Length \times \frac{ADTT \times 365}{1{,}000{,}000}$$

Please see above for the definition of each parameter. The calculated value *Risk* is the probability of a hazardous material spill occurring during a year if no improvements were made to the roadway. The inverse of *Risk* (1/*Risk*) is the probabilistic estimate of the time in years between hazardous material spills. The risk estimate formula presented here is conservative in that it includes all hazardous material spills, whereas for a particular drinking water source or type of aquatic life to be endangered, a spill must be of a certain size and involve certain chemicals.

For the Hudson Bridge, WisDOT used the following data to calculate the risk (data on truck and hazardous material accidents were obtained from FHWA):

$TAR = 2.09$
$FracHaz = 0.04$
$RelProb = 0.33$
$Length = 0.45$ mile
$ADTT = 4{,}860$ (on the newly reconstructed eastbound bridge)

Using these numbers in the risk estimate formula above yields a probabilistic estimate of approximately 45 years between hazardous material spills. As previously discussed, a similar assessment was performed by the Oregon DOT (see above) to assess the potential impact of a hazardous material spill from Highway 101 to Clear Lake, a drinking water supply. The Oregon DOT estimated that a hazardous material spill would occur once every 247 years if no improvements were made to the roadway.

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METHOD **17**

MICROCOMPUTER SPILL MODELING

In rare situations, a large coastal bridge project may warrant a more sophisticated assessment of the effects of a spill. In these cases, the practitioner (or consultant) can use a software package such as the Spills Analysis Module of MIKE 21 (developed by the Danish Hydraulics Institute) or other specialized programs.

MIKE 21 is a comprehensive two dimensional modeling package for marine systems. Coupled with a hydrodynamic database and measurements of currents, the MIKE 21 Spills Analysis Module can forecast oil slick locations, the amount of oil left on the sea surface, slick mobility, and the evolution of the physicochemical properties of the oil. The Spills Analysis Module can also be used to evaluate spill scenarios and aid the development of contingency plans.

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METHOD **18**

RETROFIT PRIORITIZATION METHODOLOGY

Retrofitting bridges with structural storm water BMPs is technically difficult and can be very costly. Therefore, this method would likely be used on only a limited number of existing bridges. A prioritization method can be used to identify the bridges where bridge deck runoff is causing substantial impacts on the receiving water and situations in which the greatest benefit could be gained by retrofitting. Retrofitting can include the construction of new structural BMPs or modifications to existing BMPs.

WSDOT developed a storm water outfall prioritization system, which compares the impacts of one outfall with another and makes an assessment of their overall impacts to determine cases in which retrofitting is warranted (WSDOT, 1996). WSDOT's outfall prioritization methodology has been modified here to address prioritization of bridge deck runoff discharges only.

The first step in the prioritization process is to inventory all bridges in the state and to divide the bridges into high-, medium-, and low-priority categories, based on the professional judgment of the inventory crews. The bridges in the high-priority category would then be ordered according to the surface area of road drained, pollutant loading, and/or uses and sensitivity of the receiving water body.

The prioritization equation developed by WSDOT is presented below. Following the equation are summaries of each element of the equation. Table A-11 follows the summaries and provides a comprehensive listing of the point values for each element in the equation.

WSDOT PRIORITIZATION EQUATION

The equation developed by WSDOT to prioritize outfalls is:

$$Score = (A + B) + (C1 \times D) + C2 + [(E1 + E2 + E3 + E4) \times E5] + E6 + F$$

where

A = type and size of receiving water body
B = designated uses of receiving water body
C = pollutant loading
D = percentage contribution of highway runoff to watershed
E = cost/pollution benefit
F = values trade-off

Each element (A–F) is assigned a value based on the characteristics of the element and a predetermined ranking system.

Element Description for the WSDOT Equation

Element A. Type and Size of Receiving Water

The ranking system developed by WSDOT was established on the assumption that storm water pollutants would have a greater effect on a small stream than on a large stream because the amount of dilution in the large stream would be greater. A small stream would be assigned a higher impact value than a large stream, with the maximum point designation for water body type being 10.

WSDOT defined a small stream as an intermittent, or unnamed, tributary or creek less than 5 miles in length. These may be channelized or piped in urban areas. A large stream is defined as being generally greater than 5 miles in length. A river is defined as a named river as represented on maps. A small lake or pond is defined as less than 300 acres in surface area; a large lake is defined as greater than 300 acres in surface area. Wetlands were identified using wetlands inventory maps; a sensitive wetland was defined as having unique or rare characteristics (such as those found in a bog) or containing rare, endangered, or threatened species.

Element B. Designated Uses of Receiving Water

This category is used to determine how the receiving water is being used and to assign a ranking based on the importance of the use. Receiving water uses can be obtained from the state water quality agency or from city or county water resources reports. Receiving water uses were valued on a scale from 1 to 20. The uses were designated either as prevention or standards violated, with a higher value assigned if a receiving water had already violated standards.

Elements C1 and C2. Pollutant Loading

This category is a measure of the amount of pollutants that could be potentially present in the storm water runoff. The ranking value ($C1$) is based on the ADT volume, with the assumption that higher levels of traffic produce greater

TABLE A-11 Washington State DOT (WSDOT) equation element values

Element A. Type of Receiving Water Body	Value (A)
Groundwater	10
Small stream	8
Small lake	6
Sensitive wetland	6
Large stream	5
Large lake	3
River	2
Wetlands	2
Tidelands	2
Element B. Designated Uses of Receiving Water Body	**Value (B)**
Drinking water standards violated (SV)	20
Drinking water prevention	18
Public health SV	16
Public health prevention	14
Fisheries SV	12
Fisheries prevention	10
Aesthetics	4
Flood protection	4
Element C. Pollutant Loading	**Value (C1)**
Very high	4
High	3
Medium	2
Low	1
Element D. Percentage Contribution of Highway Runoff to Watershed	**Value (D)**
Less than 5%	5
2 to 5%	4
1 to 2%	3
0.5 to 1%	2
Less than 0.5%	1
Element E1 through E6. Cost/Pollution Benefit	
Element E1. Right-of-Way Cost	**Points (E1)**
DOT-owned land	4
Rural (low cost)	3
Suburban/transitional	2
Urban (high cost)	1
Prohibitive	0

TABLE A-11 (Continued)

Element E2. Best Management Practice (BMP) Capital Cost	Points (E2)
No cost	5
Low	4
Medium	3
High	2
Very high	1
Element E3. Conveyance Structure	**Points (E3)**
Impermeable (pipe/asphalt)	4
Soil	3
Vegetation	1
Element E4. Water Quality of Receiving Water Body	**Points (E4)**
303(d) listed	5
305(b) listed	5
Sensitive groundwater	5
Class B or equivalent low classification	4
Class A or equivalent mid-level classification	3
Class AA, marine, or equivalent high classification	2
Element E5. Water Quality Multiplier	**Points (E5)**
Discharge to marine, large lake, low classification wetland	0.5
Discharge to all other surface waters, Class I or II wetland, or sensitive groundwater system	1.0
Element E6. Future Construction Plans	**Points (E6)**
Outfall is within the boundaries of a planned construction project	3
No projects planned in the area, the BMP would be a stand-alone project	1
Element F. Values Trade-Off	**Points (F)**
Site presents a cost-sharing opportunity with another agency	4
Site falls within a DOT permitting jurisdiction for a National Pollutant Discharge Elimination System (NPDES) permit	4
Court decision has mandated water quality standards for the receiving water	4
Outfall has been identified as a problem in a Watershed Action Plan	3
Governmental or nongovernmental entity is providing active financial support for watershed improvement	2
BMP retrofit is in a highly visible location, allowing for signs to be erected to explain the benefits of BMPs to the public	2
BMP will not exacerbate other problems, would complement local government actions or plans or other watershed action plans, or could have other designated uses, such as community open space or recreation	1
BMP conflicts with local government direction or other watershed action plans	0
BMP is a nonconforming or conflicting use, such as a BMP requiring a security fence in a residential neighborhood	0

amounts of contaminants in runoff. The actual traffic volumes for each category would vary by state.

One point could be added to the overall score (*C*2) if there were significant off-site pollutant loading.

Element D. Percentage Contribution of Highway Runoff to the Watershed

This element is a measure of the proportion of runoff contributed by the bridge deck as compared with the entire contributing area of the receiving water. The contributing area from the bridge deck is calculated as the deck width multiplied by the length of road contributing runoff to the discharge points. The total watershed area is multiplied by a land use coefficient (e.g., rural-0.5, suburban/urban-0.9, and highway-1.0) before calculating the percentage of highway runoff to the watershed.

As the percentage that the bridge deck contributes increases, the pollutant loading of the bridge deck runoff becomes more critical. Conversely, if the bridge deck contributes a larger fraction of the total drainage area, the amount of pollutants delivered by the bridge deck is more critical.

Element E1 through E6. Cost/Pollution Benefit

This factor weighs the overall cost of the BMP retrofit against its benefit to the receiving water. It incorporates a right-of-way cost (*E*1), BMP cost (*E*2), type of conveyance structure (*E*3), water quality of the receiving water (*E*4 and *E*5), and future construction plans (*E*6).

Right-of-WayCost (*E*1). Prohibitive costs would include those areas that are completely developed and areas where real estate prices are high. Purchasing land could mean buying buildings, as well.

BMP Cost (*E*2). Low-cost BMPs might include biofiltration swales or retrofitting an existing BMP to improve its performance. A low cost would be assigned when nonstructural BMPs are selected. A medium-cost BMP could be a wet pond with a biofiltration swale. High-cost BMPs could include a large wet pond with a biofiltration swale. Finally, a very high-cost BMP could be a vault or a very large wet pond with a biofiltration swale.

Type of Conveyance Structure (*E*3). The type of conveyance structure affects the amount of loading that enters the receiving water. The best type of conveyance structure is vegetation, which would filter out pollutants and reduce the peak flow.

Water Quality of the Receiving Water (*E*4 and *E*5). The type and quality of the water body as reflected by designated uses and other special assessments are important considerations. Designated uses and other special assessments might include being on a 303(d) list and in need of a TMDL, or being listed in a 305(b) report as not fully supporting designated uses.

Future Construction Plans (*E*6). The future construction plans ranking is based on the assumption that it is less expensive to construct a retrofit BMP while other construction is underway.

Element F. Values Trade-Off

Local environmental and societal issues also can exert an effect on BMP construction or retrofit. This factor assesses the overall impact of these intangible issues. After all the factors for each bridge/BMP retrofit are assimilated, the score can be calculated. The highest scores should be given first priority for retrofitting.

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METHOD **19**

ANTIDEGRADATION ANALYSES

All states are required by the Clean Water Act to have an antidegradation policy in their water quality standards. The principal intent of an antidegradation policy is to protect high-quality waters from degradation resulting from new or increased discharges. The policy also ensures that all waters are not degraded from existing conditions without appropriate analysis, justification, and public input. In no case can waters be allowed to degrade below existing designated uses and associated promulgated water quality criteria. At present, these restrictions generally apply only to those discharges governed by the NPDES program.

For the most part, states have adopted a multitiered approach to antidegradation classifications that generally includes (1) Outstanding National Resource Waters, which usually include water bodies in national wildlife refuges and national parks, wild and scenic rivers, important nursery areas, and water bodies with pristine watersheds and water quality conditions; (2) exceptional and/or high-quality waters; and (3) all other waters. For Outstanding Natural Resource Waters, the antidegradation policy usually prohibits all new or increased discharges, with a very limited number of exceptions. For the mid-tier classifications, restrictions on new or increased discharges are usually required, although they are not as strict as they are for Outstanding Natural Resource Waters. For the last level, degradation below existing conditions is allowed, but new or increased discharges cannot violate water quality criteria or impair designated uses. New or increased discharges usually must be justified on the basis of cost-effectiveness considerations and an alternatives analysis.

Each state has its own antidegradation requirements, and many states have specific procedures and methods that must be followed for new or increased discharge of pollutants. The practitioner is thus advised to investigate these restrictions very early in the bridge-planning process.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ACHP: Advisory Council on Historic Preservation
ADT: average daily traffic
ASCE: American Society of Civil Engineers
BCC: bioaccumulating chemicals of concern
BMP: best management practice
Caltrans: California Department of Transportation
CEAM: Center for Exposure Assessment Modeling
cfs: cubic feet per second
DEP: Department of Environmental Protection
DO: dissolved oxygen
DOT: department of transportation
EIS: environmental impact statement
FAV: final acute value
GIS: geographic information system
GLI: Great Lakes Water Quality Initiative
IBI: Index of Biotic Integrity
IC_{25}: the concentration of runoff that will cause a 25 percent reduction in test organism reproduction or growth
ICI: Invertebrate Community Index
LC_{50}: the concentration of runoff that is lethal to 50 percent of test organisms
LOEC: lowest observed effect concentration
MDOT: Michigan DOT
MEP: maximum extent practicable
Mn/DOT: Minnesota DOT
MS4: municipal separate storm sewer system
MVM: million vehicle miles
NEPA: National Environmental Policy Act
NOEC: no observed effect concentration (the concentration of runoff at which no toxicity occurs)
NPDES: National Pollutant Discharge Elimination System
NRHP: National Register of Historic Places
NTR: National Toxic Rule
NURP: National Urban Runoff Program
PAH: polycyclic aromatic hydrocarbon
QA/QC: quality control/quality assurance
RBP: Rapid Bioassessment Protocol
ROW: right-of-way
SAW: Spills Analysis Workstation
SFB-RWQCB: San Francisco Bay-Regional Water Quality Control Board
SFOBB: San Francisco-Oakland Bay Bridge
SHPO: State Historic Preservation Officer
SIGD: Stressor Identification Guidance Document
TMDL: total maximum daily load
TSS: total suspended solids
U.S. EPA: U.S. Environmental Protection Agency
USGS: U.S. Geological Survey
VPD: vehicles per day
WASP: Water Quality Analysis Simulation Program
WERF: Water Environment Research Foundation
WisDOT: Wisconsin Department of Transportation
WSDOT: Washington State Department of Transportation
ZID: zone of initial dilution

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation