NCHRP

REPORT 474

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters

Volume 1: Final Report

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 1: Final Report

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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 AND RESEARCH APPROACH

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 would have to address on-site and off-site mitigation options, including watershed-based considerations and pollution trading. It would also have to be applicable to inland and coastal settings, and address project-specific and cumulative receiving water impacts. *Volume 1* of this report documents and discusses the results of the research done to develop a process for identifying, assessing, and managing bridge deck runoff. This research included a literature review, a survey of state and provincial highway agencies, and the development and testing of several biological methods.

BACKGROUND

Historically, bridge engineers have designed storm water drainage systems to drain directly into receiving waters through scupper systems or simply 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 have these types of drainage systems. The quality of the storm water, and potentially adverse effects on receiving waters, have now fully emerged as issues and are major planning and design considerations.

Today, it is often assumed that it is intrinsically better not to drain storm water runoff from bridges directly to a receiving water. Some state and local governments now encourage or require bridge drainage to land to allow for some form of active or passive improvement of the storm water before it is discharged to the receiving water or infiltrated into the ground without being directly discharged to the receiving water. To date, this policy has been implemented primarily for new construction projects rather than retrofit.

The U.S. Environmental Protection Agency (U.S. EPA) also has made several recommendations regarding management measures for bridges pursuant to Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) (U.S. EPA, 1993a). U.S. EPA recommends applying one or more of its recommended management practices, although it notes that state coastal management programs need not require implementation of these practices. Among the practices U.S. EPA recommends are the following:

- Direct pollutant loadings away from bridge decks by diverting runoff waters to land for treatment.
- Restrict use of scupper drains on bridges less than 400 feet in length and on bridges crossing very sensitive ecosystems.
- Site and design new bridges to avoid sensitive ecosystems.
- On bridges with scupper drains, provide equivalent urban runoff treatment in terms of pollutant load reduction elsewhere on the project to compensate for the loading discharged off the bridge.

Apart from one's position on whether all, or even most, newly constructed bridges should be designed to preclude direct discharge, there remains the question of 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 use 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.

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 circumstance provides opportunities to consider and implement 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).

If a 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), enhancing pollutant control elsewhere in the watershed or implementing pollutant trading are potential solutions for a variety of storm water pollutants including nutrients, bacteria, sediments/solids, and even metals or organic compounds. Of course, site-specific effects must be thoroughly considered in any plan to enhance pollutant control elsewhere in the watershed or implement pollutant trading. U.S. EPA, most states, and even many local governments are moving rapidly toward watershed-scale planning for water quality protection and enhancement, including pollutant trading (U.S. EPA, 1996a; U.S. EPA, 1996b). Highway agencies should logically be a part of that process. CH2M HILL's survey of state departments of transportation (DOTs) has revealed that several DOTs have already established watershed-based programs for banking, off-site mitigation, and/or trading alternatives for storm water as well as other resources.

NCHRP Project 25-13 focused on developing a process that state DOTs can use to make sound, scientifically defensible decisions on the need for, and the extent of, bridge deck runoff control. It was decided that the process should

- Determine what the existing literature tells us about the effects of bridge deck storm water runoff on receiving waters, address key data gaps, and explain how filling those gaps should be incorporated into the decision-making process.
- Include full and cost-effective integration with the current and future regulatory framework. Highways are, or will soon be, directly regulated by the National Pollutant Discharge Elimination System (NPDES), Phase I and Phase II, in addition to requirements pursuant to the National Environmental Policy Act (NEPA), CZARA, Clean Water Act Section 404 permits, and Section 401 water quality certification.
- Go beyond simple but potentially misleading analyses focused on end-of-pipe and water column chemical concentrations. This would include toxicological and aquatic biological assessments. Current risk assessment procedures also require evaluation.
- Incorporate the latest research on impact assessment including consideration of new scientific data on pollutant bioavailability, speed of action, and the merit of site-specific analysis rather than generic approaches and default assumptions.
- Reevaluate the historical databases for some constituents, especially metals at trace-level concentrations.

RESEARCH PLAN

This report covers Tasks 1 through 8 of the research plan for NCHRP Project 25-13. A brief description of these tasks is provided below.

Phase I

Task 1 (Review Literature on Impact Methods and Data)

For this task U.S. and international literature on water quality impacts associated with bridge deck runoff, maintenance activities, and spills was assembled and critically reviewed. The review included compilation of assessment methods and mitigation measures related to bridge deck runoff. The search was supplemented by extending the survey under Task 2 to include inquiries on past and ongoing studies, as well as assessments of the impacts of highway and bridge deck runoff, maintenance, and spills on water quality.

Task 2 (Survey Practices and Costs)

This task consisted of developing a survey questionnaire that was mailed to all state and provincial highway agencies, as well as key researchers in the field. The survey elicited information on mitigation measures currently being used or considered for bridge runoff. The survey also solicited information on ongoing or recently completed studies of bridge runoff impacts and bridges/locations that might serve as cases for testing the process (see Task 5). CH2M HILL sought follow-up information via telephone calls to survey respondents as needed.

Task 3 (Design Preliminary Process)

The information and background developed in Tasks 1 and 2 provided the basis for designing the preliminary process to evaluate and develop mitigative strategies, when necessary, for bridge deck storm water runoff. The process makes use of conceptual flow charts and reference tables to guide the user and identifies analyses and related processes that need to be considered. The process is adaptable to different constraints and priorities in different states and even to variable constraints in different watersheds within states. Although the overall process is normalized so that it will be useful to all practitioners, it will also be necessary to address appropriate site-specific factors. For example, the process will direct the user to determine the individual state's promulgated water quality criteria for subsequent use in impact evaluation.

Task 4 (Interim Report)

Following completion of Tasks 1 through 3, the research team prepared an interim (Phase I) report that summarized the literature obtained and reviewed, the information obtained from the survey, and details of the preliminary process developed in Task 3.

Phase II

Task 5 (Apply the Process to Selected Sites)

The preliminary process developed in Tasks 1 through 4 was applied in Task 5. The research team prepared a list of candidate evaluation sites based on information collected from the Task 2 survey and with input from panel members. The objective of Task 5 was to determine whether the process developed led to outcomes that made sense and were acceptable to state DOTs, environmental resource agencies, and other stakeholders. Processes that could be validated with actual data from the selected sites were especially beneficial. Additional funding was requested by the panel and approved so that Task 5 could be expanded to include tests of several of the biological methods at two specific bridge sites. The field tests employed time-variable bioassays and in situ biomonitoring to evaluate the toxicity of bridge deck runoff at one freshwater site and one saltwater site.

Task 6 (Document Lessons Learned)

Task 6 was closely linked to the stakeholder feedback procedure above. Working with focus groups, the research team recorded key observations—especially observations offered by stakeholders who could "inherit" the recommended evaluation and implementation process. The panel's input on Task 6 was obtained in writing via comments on progress reports and associated attachments. The panel's input was reflected in Task 7.

Task 7 (Refine Process and Prepare Practitioner's Handbook)

The development of a high-quality *Practitioner's Handbook* was a central task of this project. The research team worked on certain details of the document to carefully establish format, outline, and user characteristics. The *Handbook* was organized so that readers could quickly find information. Through work with the focus groups (see Tasks 5 and 6), it was possible to develop a handbook that is concise, useful, amendable, and adaptable for state and regional uses. Our work with focus groups also allowed "field testing" with potential end-users to specifically explore desired handbook characteristics.

Task 8 (Prepare and Submit Final Report)

For Task 8, the results of Task 4 (Interim Report) and all the Phase II elements were synthesized.

CHAPTER 2

FINDINGS

LITERATURE REVIEW

The object of the literature review was to identify, collect, and critically review published papers, published reports, and information on ongoing studies regarding receiving water effects, impact-assessment methods, and mitigation practices for storm water runoff, spills, and maintenance activities associated with bridge decks. Although this project focuses on bridge deck studies and information, selected publications and information related to urban and highway runoff have been included to the extent that they provide relevant insights into general types of impacts, methods, and mitigation measures associated with bridge decks.

CH2M HILL interviewed selected researchers and experts by telephone to help focus the search. Those interviewed are listed below with their affiliations and areas of research:

- Roger Bannerman—Wisconsin Department of Natural Resources, research on urban runoff effects on freshwater systems.
- Chris Yoder—Ohio EPA, bioassessment expert.
- Frederick Weisner—Wisconsin Department of Transportation (WisDOT).
- Michael Barrett—University of Texas, characteristics and treatability of highway runoff.
- Brian Mar—University of Washington, urban and highway runoff issues.
- Harold Hunt—California Department of Transportation (Caltrans), California Aquatic Bioassessment Workgroup, highway runoff and aquatic studies.
- Robert Traver—Villanova University, highway runoff best management practice (BMP) research.
- John Sansalone—University of Cincinnati (at the time of the study), Louisiana State University (currently), research on highway runoff characteristics and BMPs.
- Heidi Bell—U.S. EPA, development of national sediment criteria.
- Ed Herricks—University of Illinois, timescale considerations for urban storm water toxicity.
- Greg Granato—Massachusetts-Rhode Island U.S. Geological Survey (USGS) District, research on deicing chemicals and highway runoff, compilation of a document database for highway runoff quality.
- Phillipe Ross—the Citadel, research on the aquatic impacts of bridge deck runoff on an estuarine system in South Carolina (i.e., Isle of Palms Connector).

In addition, several watershed management agencies in the San Francisco Bay area were contacted. These contacts led to information about ongoing research, published articles, and additional personal contacts that aided in this study.

The literature review also involved searching the following databases and library collections for information on water quality impacts and mitigation measures associated with bridge deck runoff, maintenance, and spills:

- Universities Water Information Network
- Sea Grant Program Libraries
- Biosis
- Enviroline
- Dialog
- Transportation Research Information Services
- University of California Institute of Transportation Studies Library
- Northwestern University Transportation Library
- U.S. EPA Office of Water website
- USGS highway runoff website

These information sources were selected because they cover the breadth of issues involved in this study.

Finally, CH2M HILL also included a request for data, studies, and other information related to impacts, methods, and mitigation in the survey that was sent to state DOTs, Canadian provincial highway agencies, and key researchers. The survey did not identify any additional completed or ongoing studies beyond those found through database searches and contacts with key researchers.

GENERAL CONCEPTS AND CONSIDERATIONS

In the late 1970s and early 1980s, the FHWA sponsored a comprehensive, nationwide program of research and assessment method development related to storm water runoff from operating highways. The first phase of the program characterized the quality and loadings of pollutants and developed a predictive procedure for estimating annual loads (Gupta et al., 1981). The second phase consisted of detailed field studies documenting the relative sources of these pollutants and their movement and migration within the highway ROW (Kobriger and Geinopolos, 1984). The third phase consisted of comprehensive field and laboratory bioassay studies of receiving water effects (Dupuis et al., 1985a). Subsequent efforts included assessment of the potential water quality effects of various highway maintenance practices (Dalton, Dalton, and Newport/URS, 1985) and development of management practices for mitigation of effects (Versar, 1985). The scope and some of the key findings of this program are listed in Table 1.

In 1990, FHWA published an updated and improved method of estimating pollutant loadings and impacts of highway runoff, with emphasis on chemical quality (Driscoll et al., 1990). In 1996, FHWA published two other documents related to highway runoff: (1) a compilation of previous highway runoff information and extensive documentation of relevant BMPs (Young et al., 1996); and (2) a detailed evaluation of retention, detention, and overland flow BMPs (Dorman et al., 1996). The scope and some of the key findings of these more recent FHWA efforts are also listed in Table 1.

USGS as well as a number of state DOTs, universities, and other entities also have conducted a wide variety of highway runoff studies over the last two decades—many in cooperation with FHWA. Table 2 lists references for relevant research.

USGS and FHWA have developed an online searchable database of references concerning highway runoff quality. The results are published in a number of reports (Bent et al., 2001; Breault and Granato, 2000; Bricker, 1999; Buckler and Granato, 1999; Church et al., 1999; Dionne et al., 1999; Granato et al., 1998; Jones, 1999; Lopes and Dionne, 1998; Tasker and Granato, 2000) that address runoff quality issues, including the following:

- Sediment and trace element monitoring,
- Geochemical effects of highway runoff,
- Assessments of biological effects of highway runoff,
- Storm water flow measurements,
- Methods for examining runoff quality data,
- Evaluation of quality-assurance and quality-control documentation,
- Semivolatile and volatile organic compounds, and
- Statistical evaluation of storm water data.

NCHRP has also sponsored, or is sponsoring, several research projects relevant to Project 25-13 and has also published documents related to this project. These include Projects 25-1, 25-9, and 25-12 (see Table 3) and several *Synthesis of Highway Practice* documents such as *NCHRP Synthesis of Highway Practice 67: Bridge Drainage Systems* (Copas and Pennock, 1979) and *NCHRP Synthesis of Highway Practice 176: Bridge Paint: Removal, Containment, and Disposal* (Appleman, 1992).

Table 4 lists references for additional research and documentation regarding highway runoff quality, environmental effects, and BMP strategies developed outside the United States.

The majority of this substantial body of research has been devoted to documenting highway runoff quality and loadings. These include various predictive methods; the sources of pollutants in highway runoff (e.g., atmospheric versus vehicular); the specific characteristics and forms that highway runoff pollutants take (e.g., dissolved versus particulate, particle size associations, etc.); and evaluation of structural and nonstructural BMPs for highway runoff.

Fewer studies have assessed actual receiving water effects. Of these studies, most measured highway pollutants in runoff and receiving waters or inferred effects or lack thereof based exclusively on runoff concentrations relative to ambient water quality criteria. Some also measured sediment accumulations and/or uptake into the tissue of biological organisms but were unable to relate such concentrations to adverse impacts on the biota or designated uses of the receiving water. Several studies have included laboratory bioassays using highway runoff, but none of these have accounted for the frequency/duration, timescale issues critical to storm water runoff assessment. A relatively small number of studies have included field assessment of biological communities, which is perhaps the best indicator of long-term effects on aquatic biota.

Of those studies that did directly evaluate receiving water effects, few attempted to study bridge runoff specifically, or isolate bridge effects from those of the larger highway ROWs, which generally also contributed pollutants to the studied receiving waters. Those that did isolate bridge runoff effects are described in detail later in this section of the report.

Despite this general lack of specificity with respect to bridge runoff effects, a number of observations were made, and lessons were learned from the urban and highway runoff literature and used to inform the process developed for NCHRP Project 25-13. These are described in the next several sections.

Sources and Types of Pollutants

Table 5 summarizes typical highway runoff constituents and sources. The constituents most frequently scrutinized for impact assessment are metals (e.g., acute and chronic toxicity to aquatic life); particulates (e.g., "carriers" of other constituents 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 (Boxall and Maltby, 1997; Dupuis et al., 1985b; Hewitt and Rashed, 1992; Hoffman et al., 1985; Ishimaru et al., 1990; Perry and McIntyre, 1987; Yamane et al., 1990).

TABLE 1 Summary of previous FHWA highway runoff program

FHWA Project	Description of Scope of Work	Key Findings
Phase I–Constituents of Highway Runoff (Gupta et al., 1981)	Identified and quantified constituents (including metals) in highway runoff from extensive sampling (159 events) at six sites, three in Milwaukee, and one each in Nashville, Denver, and Harrisburg. Sampling was conducted 1976–77; a statistical predictive procedure for annual pollutant loadings from highway runoff was developed.	Loadings of pollutants from highways are highly correlated to design features (flush shoulder, grassy ditch drainage vs. curb and gutter impervious drainage), number of dry days between events, and traffic volume. Analyses of total and dissolved fractions for lead and zinc revealed dissolved lead concentrations were not detectable (at detection limits of 0.05 to 0.10 mg/L). This was the case even when the total fraction for the same sample was as high as 160 mg/L. Dissolved zinc concentrations were also substantially lower than the total fraction, generally by at least a factor of 10.
Phase II–Sources and Migration of Highway Runoff Pollutants (Kobriger and Geinopolos, 1984)	Identified and quantified background pollutant loadings to the highway system (for example, atmospheric deposition), pollutants originating from the highway system (for example, vehicular sources, maintenance practices, pavement type, etc.), and the mechanisms of pollutant dispersal within and transfer out of the highway system to receiving waters. Extensive sampling at four sites, Sacramento, Milwaukee, Harrisburg, and North Carolina. Sampling was conducted from 1978 to 1982; migration paths evaluated for metals included wet and dry atmospheric deposition, dry weather accumulation on the pavement and in the right-of-way (ROW), washoff and transport during runoff events, atmospheric removal during dry periods, groundwater percolation, accumulation in soils throughout the ROW, and uptake in vegetation.	General sources of constituents found in highway runoff are still applicable (Table 3). Atmospheric deposition of metals from background sources to the ROW is substantially greater in urban areas compared to rural areas. Atmospheric deposition of metals to the ROW during dry periods is a more important source than precipitation. Highway design features, traffic volumes, and location (for example, rural vs. urban) strongly influence constituent concentrations and loadings. Major modes of particulate and soluble constituents (including metals) migration within the highway ROW and to receiving waters are still valid.
Phase III–Effects of Highway Runoff on Receiving Waters (Dupuis et al., 1985a)	Analyzed the effects of constituents in the receiving waters. Extensive physical, chemical, and biological sampling of runoff and receiving waters at three sites (one lake and two streams), two in Wisconsin and one in North Carolina. Sampling was conducted from 1980 to 1983. All three sites were in rural/suburban areas because of difficulty of finding urban sites where other sources of pollution would not confound study results.	Annual pollutant loads from highways were low relative to total watershed loads (that is, the ROW usually represents a small fraction of the total watershed area). There were no violations of existing state water quality standards or EPA acute criteria in receiving waters attributable to highway discharges. Metals from highways did not accumulate to substantially elevated concentrations in sediments at the two rural streams studied in Phase III. Adverse biological impacts from pollutants from highways were not identified for the three receiving waters studied in Phase III. Combined with laboratory bioassay results from this study and others, it was concluded that runoff from rural highways with average daily traffic (ADT) less than 30,000 vehicles per day (VPD) would not adversely affect aquatic biota.

TABLE 1 (Continued)

FHWA Project	Description of Scope of Work	Key Findings
Phase IV–Maintenance Impacts and Management Practices (Dalton, Dalton, Newport/URS, 1985; Versar, 1985)	Evaluated: a) effects of highway maintenance on water quality, and b) management practices for mitigation of highway stormwater runoff pollution.	Highway maintenance practices have a low potential for water quality impacts. Four management measures were considered effective for highway runoff pollutant removal: vegetative controls, wet detention, infiltration, and wetlands.
Pollutant Loadings and Impacts from Highway Stormwater Runoff (Driscoll et al., 1990)	Updated characteristics database to include 933 storms at 31 sites in 11 states; developed methods for estimating pollutant concentrations and stream and lake impacts.	Probabilistic methods allow estimation of frequency and magnitude of criteria excursions; incorporate use of dissolved metals form and more realistic exposure duration/speed-of-action concept.
Evaluation and Management of Highway Runoff Water Quality (Young et al., 1996)	Compilation of past documentation and research on highway runoff quality; impact assessment; and mitigation.	Extensive information provided on best management practices (BMPs).

The chemical characteristics of bridge deck runoff have not been extensively documented. Although only a small number of studies have focused specifically on bridge deck runoff (Dupuis et al., 1985a; Kszos et al., 1990; Yousef et al., 1984), others have documented the characteristics of highway runoff from impervious sites, which may be directly comparable to bridge deck runoff (Gupta et al., 1981; Kobriger and Geinopolos, 1984). Of the six field sites for a Michigan DOT study, bridge deck runoff was sampled at two, with runoff from one other impervious site also being sampled (CH2M HILL,1998).

Predictive procedures have been developed to estimate runoff quality based on site characteristics such as average daily traffic (ADT), vehicle traffic during storms, urban versus rural setting, and other variables (Balades et al., 1985; Barrett et al., 1995; Driscoll et al., 1990; Gupta et al., 1981; Kerri et al., 1985; Mar et al., 1982; Racin et al., 1982). The chemical quality of all urban and rural runoff can vary considerably from storm to storm and from location to location. However, the data from the cited studies are sufficiently robust to develop reasonable statistically based estimates of chemical quality for most constituents of concern for water quality impact assessment (note that special considerations for metals are discussed below).

The highway runoff studies cited above have generally shown that various constituents in undiluted highway runoff

TABLE 2 Relevant research conducted by state DOTs, the U.S. Geological Survey (USGS), universities, and other entities

State	Reference
Florida	Yousef et al., 1984; Yousef et al., 1990; Schiffer, 1988; 1989a; 1989b; and 1989c; Hampson, 1986; Wanielista et al., 1980; Irwin and Lasey, 1979; Birkett et al., 1979; McKinzie and Irwin, 1983; Evink, 1980
Washington	Farris et al., 1973; Portele et al., 1982; Mar et al., 1982; Horner and Mar, 1982; 1985; Newbry and Yonge, 1996; Chui et al., 1982
Michigan	CH2M HILL, 1998
Ohio	Sansalone et al., 1995; 1996
South Carolina	Ross, 1996
Texas	Barrett et al., 1995; 1998
Virginia	Van Hassel et al., 1980; Mudre, 1985
New York	Bucholz, 1986; Kszos et al., 1990
North Carolina	Wu et al., 1998
California	Winters and Gidley, 1980; Racin et al., 1982; Kerri et al., 1985

TABLE 3 Summary of other NCHRP highway runoff research projects

NCHRP Projects	Description of Scope of Work
NCHRP Project 25-1 Effects of Highway Runoff on Wetlands (Kobriger et al., 1983)	Many state and federal agencies value wetlands as a natural resource and have enacted considerable legislation to ensure preservation of their natural benefits such as providing wildlife habitats, recreational areas, flood storage, and nutrient sinks. Also, interest has been increasing on possibly creating and managing wetlands to enhance the environment. However, wetlands can be affected adversely by partial disturbance, changes in their characteristics and functions, and total elimination. An area of mounting concern is the effect of highway runoff. NCHRP Project 25-1 identified the interactions between wetland systems and highway runoff, the effect of highway runoff as it relates to wetlands, and developed guidelines for the practical management of highway runoff on wetlands. The project thoroughly reviewed a substantial amount of information on wetland ecology, the function of wetlands, highway runoff constituents, and other related subjects having either a direct or indirect, but transferable, relationship to the research objectives' requirements. Although no one situation is exactly like another, the results of this research provide excellent background for understanding the characteristics of wetlands, their functions, and the effects of highway runoff. Practical guidance for the management of runoff from highways in proximity to wetlands was developed and should be of considerable interest and use. The guidance includes the management of runoff from the highway to and in the wetlands. A possibility also addressed is the use or creation of wetlands to mitigate the effects of highway runoff.
NCHRP Project 25-9 Environmental Impact of Construction and Repair Materials on Surface and Ground Water (Nelson et al., 2001)	Construction and repair materials formerly were viewed as being innocuous and of no concern to environmental quality. The perception now is that some of these materials may pose an environmental concern. Furthermore, a variety of recycled and waste materials are being considered for use as construction and repair materials, thereby increasing the number of nontraditional materials in contact with surface water and groundwater. This research project concentrated on evaluating several construction and repair materials, identifying the mobility of leachates and their possible toxicity to aquatic organisms. Materials used in construction and repair that are likely to come into contact with the surface water and groundwater include: asphalt, concrete additives, metals, grouts, plastics/synthetics, shredded rubber tires, creosote and other timber preservatives, and others. Explicitly excluded from consideration were constituents originating from construction processes, vehicular operations, maintenance operations, and atmospheric deposition. The object of this research was to develop a validated methodology for assessing the environmental effects of highway construction and repair materials on surface water and groundwater, and to apply the methodology to a spectrum of materials in representative environments. Toxicity tests identified phosphogypsum, foundry sand, a plasticizer, crumb rubber, shingles, and municipal solid waste incinerator bottom ash as the most potentially toxic. Toxicity was reduced when these raw materials were incorporated into paving or fill. With the exception of municipal solid waste incinerator bottom ash and the plasticizer, toxicity was eliminated for all of these materials when considering the effect of soil sorption.
NCHRP Project 25-12 Wet Detention Pond Design for Highway Runoff Pollution Control	Many best management practices (BMPs) provide various degrees of contamination control and other environmental benefits in different highway settings. The control systems most often recommended are dry or wet detention ponds and vegetative strips. Vegetative strips have been somewhat effective in decreasing the pollutants in stormwater runoff, but existing land area and topography, particularly slope, do not always meet design requirements. Dry detention pond design has not proven satisfactory; ponds designed for large storms do not effectively treat runoff from small storms and those designed for small flows are subject to clogging. The use of wet detention ponds has proven effective to a limited degree. Wet detention ponds are one of the less documented pollutant control systems in highway settings. Although they have proven useful for reducing the amount and concentration of potential pollutants in some highway applications, they have exhibited widely varying degrees of efficiency.

TABLE 3 (Continued)

NCHRP Projects	Description of Scope of Work
	Research is needed to quantify the effectiveness of wet detention ponds and to compare their performance to that of dry ponds; to update and verify design methodologies, especially in areas where right-of-way is limited; and to provide a reliable database for designing efficient, low-maintenance wet detention ponds in a highway environment. Wet ponds in this research project will be those having a permanent pool of water. The object of this research is to develop a methodology for designing efficient wet detention ponds in the highway environment. This methodology shall include performance characteristics, design guidelines, conditions, limitations, and applications for use. Wet and dry detention ponds will be compared to show the advantages and disadvantages of each system.

can at times exceed federal and state ambient water quality criteria. Of course, this does not mean that highway runoff necessarily causes excursions from promulgated numeric or narrative ambient criteria or impairment of designated uses for a given water body. Such effects will be dictated by fate and transport considerations in the receiving water including dispersion, dilution, bioaccumulation, and bioavailability, as well as the quality and use attainment status of the water body, irrespective of the highway runoff.

Lead concentrations in highway runoff have become substantially lower as FHWA's studies have progressed. Values in the early 1980s were much lower than they had been in the late 1970s, and more recent studies have shown continued reduction in lead concentrations. For example, the median lead concentration in 1993 NPDES storm water sampling in Grand Rapids, Michigan, was approximately 60 percent of the median event mean value recorded during U.S. EPA's Nationwide Urban Runoff Program (NURP) sampling in that same city (U.S. EPA, 1983; unpublished NPDES sampling data). Recent highway runoff sampling for Michigan DOT, including total and dissolved forms from totally and partially impervious urban and rural sites (a total of 18 events at 6 sites), also showed that lead concentrations were substantially lower than would be expected based on earlier FHWA studies (CH2M HILL, 1998). The *maximum* event mean concentration at all Michigan DOT sites was one-fourth the concentration of the *median* value for urban highways in FHWA's latest compilation (Driscoll et al., 1990). Thus, the FHWA database probably substantially overestimates lead concentrations and loadings from highways.

Because metals are ubiquitous in the environment, incidental and inadvertent contamination of water samples occurs with standard sampling and analytical methods, even when due diligence is exercised. U.S. EPA, USGS, and many states now recognize that such contamination is prevalent in historical metals databases (Telliard, 1995; USGS, 1994; Webb, n.d.; Windom et al., 1991). USGS currently uses clean techniques for its national ambient surface water–monitoring program. A comparison of data collected using clean techniques with data collected previously using traditional procedures reveals the differences between the two (see Table 6).

The significance of the recent insights into this incidental contamination is not only that the highway runoff database may need to be reevaluated for some metals. Most importantly, historical ambient background concentrations may be invalid, particularly if they were developed prior to the advent of clean procedures in the early to mid-1990s. The process developed under NCHRP Project 25-13 often requires background water quality data to make an evaluation; thus the issue of the validity of the historical metals database is important.

TABLE 4 Additional research and documentation regarding highway runoff quality, environmental effects, and best management practice (BMP) strategies developed outside the United States

Country	Reference
Canada	Lorant, 1992
Great Britain	McNeill and Olley, 1998; Boxall and Maltby, 1997; Maltby et al., 1995a; 1995b; Hewitt and Rashed, 1992; Perry and McIntyre, 1987; Balades et al., 1985; Dussart, 1984; Schutes, 1984; Davis and George, 1987
Norway	Gjessing et al., 1984a; 1984b; Baekken, 1994
Germany	Lange, 1990; Dannecker and Stechmann, 1990; Stotz, 1990
Japan	Yamane et al., 1990; Ishimaru et al., 1990

TABLE 5 Highway runoff constituents and their primary sources[a]

Constituent	Primary Source
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead[b]	Leaded gasoline (automobile exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Automobile body rust, steel highway structures (guard rails, etc.), moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Exhaust
Cyanide	Anti-cake compound (ferric ferrocyanide, Prussian blue or sodium ferrocyanide, yellow prussiate of soda) used to keep deicing salt granular
Sodium, calcium	Deicing salts, grease
Chloride	Deicing salts
Sulfate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
PCBs[c], pesticides	Spraying of highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, trucks hauling livestock and stockyard waste
Rubber	Tire wear

[a] Kobriger and Geinopolos, 1984.
[b] Significant reductions in lead were observed in the Milwaukee, Wisconsin, site from earlier studies. The reductions were directly related to reductions in the sale of leaded gasoline.
[c] Polychlorinated biphenyls.

Bioavailability of Metals

The total concentration of metals in the aquatic environment has been traditionally used to judge the potential toxicity of metals. Total metals may overestimate toxicity potential as the presence of water constituents such as calcium and dissolved organic matter can mitigate the potential for metals toxicity. According to the receptor-loading model, the toxic effect of a metal is elicited when the metal binds to a receptor, and in most cases the receptor is the gill of an aquatic organism (Bergman and Dorward-King, 1996). Recent study on metals toxicity has increased understanding on the specific mechanism of metals toxicity. Metals in bridge deck runoff, such as divalent cadmium and zinc, affect calcium uptake by gills, and divalent copper affects sodium uptake. Blockage of calcium and sodium uptake can lead to mortality by disrupting the osmoregulatory functions of the gills. Water constituents can mitigate toxicity either by competing for binding sites (e.g., calcium and hydrogen) or by binding metals that inhibit them from binding to gills (e.g., dissolved organic carbon ligands).

One approach to improving an estimate of the potential for metals toxicity is to measure the dissolved metal fraction, defined as metals that pass through a 0.45-μm membrane filter. Over the last several years, U.S. EPA and many states have reevaluated their approach to metals toxicity (Prothro, 1993). The key element of this reevaluation is that U.S. EPA now recognizes that the dissolved metal fraction should be used in establishing criteria. The Prothro memorandum states:

> It is now the policy of the Office of Water that the use of dissolved metal to set and measure compliance with water

TABLE 6 Comparison of results for traditional and clean methods for different locations

Location	Metal	Traditional Methods (μg/L)	Clean Methods (μg/L)	Data Source
Paper Mill Effluent, Wisconsin	Copper	11	2.38	CH2M HILL, unpublished
	Silver	1.1	0.004	
Paper Mill Upstream, Wisconsin	Copper	6.1	0.5	CH2M HILL, unpublished
	Silver	1.2	0.004	
Upper Mississippi River	Cadmium	3	0.016	Windom et al., 1991
	Chromium	1.1	0.073	
	Copper	5.6	1.5	
	Nickel	1.8	1.7	
	Zinc	6.7	0.29	
Power Plant, New Jersey	Mercury	< 0.200 to 0.320	0.000071 to 0.00937	CH2M HILL, unpublished
East Coast Rivers	Cadmium	0.33	0.011	Windom et al., 1991
	Copper	2.9	1	
	Lead	46	2.7	
	Zinc	0.72	0.007	
Chippewa River	Cadmium	0.36	0.0103	Webb, n.d.
	Copper	3.5	1.3	
	Zinc	8.2	1.1	
Wisconsin River	Copper	3.2	0.27	Webb, n.d.
	Zinc	3.8	0.42	
Mississippi River	Cadmium	2.5	0.033	Webb, n.d.
	Copper	12	1.9	
	Lead	22	0.84	
	Zinc	28	2.4	

> quality standards is the recommended approach, because dissolved metal more closely approximates the bioavailable fraction of metal in the water column than does total recoverable metal. This conclusion regarding metals bioavailability is supported by a majority of the scientific community within and outside the Agency. One reason is that a primary mechanism for water column toxicity is adsorption at the gill surface, which requires metals to be in the dissolved form.
>
> The position that the dissolved metals approach is more accurate has been questioned because it neglects the possible toxicity of particulate metal. It is true that some studies have indicated that particulate metals appear to contribute to the toxicity of metals, perhaps because of factors such as desorption of metals at the gill surface, but these same studies indicate the toxicity of particulate metal is substantially less than that of dissolved metal.
>
> Furthermore, any error incurred from excluding the contribution of particulate metal will generally be compensated by other factors, which make criteria conservative. For example, metals in toxicity tests are added as simple salts to relatively clean water. Because of the likely presence of a significant concentration of metals binding agents in many discharges and ambient waters, metals in toxicity tests would generally be expected to be more bioavailable than metals in discharges or in ambient waters.

This approach has since been codified in U.S. EPA's National Toxic Rule (NTR) (U.S. EPA, 1995). Use of dissolved criteria was incorporated into FHWA's latest assessment guidance (Driscoll et al., 1990), but the guidance requires updating to reflect the NTR or other, more relevant, site-specific values.

The dissolved fraction was selected because there is a standard analytical protocol for its determination (i.e., filtration through a 0.45-μm filter), and methods for the direct measurement of unbound metals are limited. Even the "dissolved" fraction, for most metals, 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. As shown in Table 1, dissolved metals concentrations in highway runoff, even those derived from conventional sampling and analysis (i.e., not using clean techniques), are substantially lower than total concentrations. 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 with current metals criteria difficult.

In addition to the use of dissolved metals, U.S. EPA and many states now explicitly recognize and provide regulatory support for the use of site-specific criteria and data. For example, U.S. EPA has developed guidance for the water effect ratio procedure, which is used to adjust national or statewide aquatic life–metals criteria to site-specific criteria on the basis of the relative bioavailability of the metal in site water compared with laboratory water (U.S. EPA, 1994b). In addition, the Great Lakes Water Quality Initiative provides for establishing site-specific wildlife and human health criteria based on actual field-measured bioaccumulation data.

Although these types of analyses may be complex, they should be included as options for consideration in any process developed, particularly in cases in which mitigation measures would be very costly and their real environmental benefit may be questionable.

Timescale and Probabilistic Considerations for Aquatic Toxicity

Much recent debate and litigation has occurred regarding historical assumptions about the appropriate duration and frequency of exposure for toxicity evaluations and the speed of action of toxicants in the receiving water. This issue is particularly relevant for the short-term exposure periods typical of storm water runoff. Because ambient criteria are based on fairly long exposure periods (i.e., at least 24 hours and usually much longer), there is a need to consider and develop wet weather criteria. The probabilistic nature of storm events, runoff quality, and receiving water effects also needs to be considered. FHWA's latest impact assessment methodology (Driscoll et al., 1990) addresses these considerations but may need to be updated to incorporate more recent evaluations (Abt Associates, 1995; Herricks et al., 1998; Novotny, 1996; Novotny et al., 1997; Society of Environmental Toxicology and Chemistry, 1997).

One of the more comprehensive assessments of timescale considerations for urban wet-weather discharges was recently completed for the Water Environment Research Foundation (WERF) (Herricks and Milne, 1998). The study included an extensive literature review; laboratory bioassay investigation of timescale toxicity effects of metals; and field evaluations of toxicity effects of combined sewer overflows and storm water discharges at sites in Illinois, Texas, and Ohio. The study also developed an ecosystem-based management context for wet weather discharges. Conclusions reached in that study that have relevance to the evaluation process developed in NCHRP Project 25-13 include the following:

- To evaluate the toxic effect of wet weather events, an appropriate toxicity-testing method should mimic the exposure of test organisms to pollutant; hence, consideration of the length, frequency, return period, and intensity of the wet weather event is needed.
- No single test system adequately meets all criteria for assessing aquatic life impacts, but modifications to standard test systems can provide the means to assess postexposure responses of test organisms.
- Toxicity tests on over 50 storm event samples consistently showed moderate to high in-pipe toxicity; however, in-pipe toxicity did not always result in receiving water impact as measured by in situ tests or biosurveys.
- No fundamental differences that could be attributable to regional characteristics existed in the characteristics of the toxic response to wet weather events.

The researchers also noted several key research needs, including the following: (1) monitoring fundamental organism processes and identifying specific mechanisms of effect; (2) evaluating pollutant accumulations and fate in sediment as related to wet weather discharges; (3) observing the effects of physical stress on organisms and the impact of unstable habitat on timescale toxicity; and (4) translating advances in scientific understanding to guide management and regulatory programs, including predictive tools and models (Herricks and Milne, 1998). Others have noted that a key research need for developing management and regulatory approaches is to increase understanding of how aquatic biota are affected by the specific mechanisms of metals (Society of Environmental Toxicology and Chemistry, 1997).

Pollutant Accumulation in Sediments

A number of researchers and reviewers have noted that, although wet weather discharges may not cause toxicity to aquatic life resulting from water column concentrations of pollutants, especially when dilution and timescale effects are considered, it is more likely that long-term effects on aquatic biota can be related to accumulations of toxicants in sediments. This has been suggested for urban storm water runoff (Masterson and Bannerman, 1994; Pitt, 1995; Pitt et al., 1995).

Accumulations of metals and PAHs in sediments downstream of highway runoff inputs have also been noted by some researchers (Dupuis et al., 1985a; Gjessing et al., 1984b; Maltby et al., 1995a; 1995b; Mudre and Ney, 1986; Van Hassel et al., 1980; Yousef et al., 1984), although other studies have not indicated such "enrichments" for some receiving waters (Dupuis et al., 1985a; Farris et al., 1973). These sediment concentrations have rarely been looked at from the perspective of attendant impacts on aquatic biota, nor have they been compared with sediment quality criteria. U.S. EPA is developing national guidance for sediment quality criteria for several organics, including PAHs and metals (U.S. EPA, 1993b; 1993c; 1994a; 1997) but has not implemented enforceable sediment quality standards. A few states, such as Washington, have adopted their own sediment quality standards.

Watershed Considerations

As noted in Chapter 1, U.S. EPA and most states have been moving quickly toward a broad focus on watersheds and ecosystems (U.S. EPA, 1996a; 1996b). This suggested that NCHRP Project 25-13 should include consideration of the relative sources of pollutants within a watershed (e.g., loading analyses) and opportunities, when appropriate, for pollutant trading, off-site mitigation, and banking.

FHWA and the Washington State DOT have provided information on how to estimate pollutant loads from highways relative to other sources (Dupuis et al., 1985c; Horner and Mar, 1982). The literature review for NCHRP Project 25-13 did not identify any studies specifically documenting relative loadings from bridge decks compared with other sources. FHWA's comprehensive study of receiving water effects showed that highway ROWs contributed small fractions of total pollutant loads to the three receiving waters studied (Dupuis et al., 1985a). This study directly measured loads from a variety of sources including atmospheric deposition and, most importantly, in-stream loadings from upstream sources. One of the three sites, the I-85/Sevenmile Creek site in North Carolina, consisted of a medium traffic highway—that is, an ADT of 25,500 vehicles per day (VPD)—discharging at several locations near the stream's headwaters.

One other research team has reported that pollutant loads (e.g., solids, PAHs, lead, and zinc) from all state and federal highways to the Pawtuxet River in Rhode Island could exceed 50 percent of the total annual loads (Hoffman et al., 1985). Because the authors did not describe how loads from sources other than the highways were quantified, the NCHRP Project 25-13 research team was not able to critically examine this result. Moreover, the research team has some reservations about the conclusion, given the relatively large degree of urbanization and significant upstream area that exist in the watershed.

Biological Impacts of Highway Storm Water Runoff

Although not dealing exclusively with bridge deck runoff impacts, a number of studies of highway runoff water quality have provided qualitative insight into the potential effects of bridge runoff. These studies have included field surveys (biosurveys) and laboratory bioassays. General methods and conclusions from these studies are presented in Table 7. Note that all the laboratory bioassay studies described in Table 7 used traditional long-term, continuous exposures and did not consider timescale effects associated with storm water discharges.

Receiving Water Impacts of Bridge Maintenance Activities and Spills

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

Bridge painting is probably the most common bridge-maintenance practice and potentially the one with the greatest adverse effects on a receiving water. Painting activities contribute blasting abrasives and paint chips (often leaded paint) into the receiving waters below a bridge. Surveys have indicated that up to 80 percent of the steel bridges repainted each year were previously painted with leaded paint and that 70 percent of used abrasives were lost to the environment (Young et al., 1996). Paint overspray and solvents also may be toxic to aquatic life if they reach the receiving water (Dalton, Dalton, and Newport/URS, 1985).

The NCHRP Project 25-13 survey revealed that metal bridge cleaning is a significant water quality issue in some states, particularly Washington, Tennessee, and Oregon (see discussion later in this chapter). According to the survey, the cleaning process produces a water solution that generally needs to be tested and/or treated before discharge to the receiving water, or it needs to be otherwise controlled and managed off site.

Another maintenance practice, road surface treatment (seal-coating), was investigated by FHWA (Dalton, Dalton, and Newport/ URS, 1985). Storm water runoff samples from a road surface that had been recently treated with an asphalt emulsion were analyzed by using 48-hour acute bioassays with *Daphnia magna.* In addition, the runoff water and asphalt emulsion were analyzed for PAHs. The authors concluded that the runoff was relatively nontoxic and PAHs were below detectable levels in all samples.

Overall, FHWA's study concluded that the impact on water quality of most highway maintenance practices could be minimized or reduced through readily available control practices or BMPs. *NCHRP Synthesis of Highway Practice 176* notes that fully enclosed containment structures are capable of recovering 85 to 90 percent of abrasives, paint particles, and dust for simple spans; however, this type of containment is not feasible for high trusses or other complex structures (Appleman, 1992).

As noted previously, NCHRP Project 25-9 evaluated the potential toxic effect of leachates from a large number of construction and repair materials on aquatic organisms in receiving waters. In general, most of the commonly used construction and repair materials such as asphalt cement, asphalt rubber binder, asphalt rubber hot mix, and loose hot mix asphalt, were not toxic. Asphalt cement and portland cement were moderately toxic, and toxicity was eliminated when the mitigating effect of soil sorption of leachates in the highway periphery was considered. The most potentially toxic materials were phosphogypsum, foundry sand, a plasticizer, crumb rubber, shingles, and municipal solid waste incinerator bottom ash. Because these materials are incorporated into asphalt or concrete before application, leaching tests were performed with these materials in asphalt or concrete. When these materials were incorporated into concrete, toxicity was reduced significantly, and, with the additional consideration of soil sorption, toxicity was eliminated for all these materials with the exception of municipal solid waste incinerator bottom ash. In NCHRP 25-9, a model is provided to predict the fate of

TABLE 7 Summary of biological data for highway runoff studies

Study	Biological Sampling Component	Relevant Results/Conclusions
Wisconsin Hwy. 15 (now I-43); Average Daily Traffic (ADT) = 7,400; snow melt runoff from grassy ditch drainage (Dupuis et al., 1985a)	Laboratory acute toxicity bioassays with undiluted runoff using five test species—*Pimephales promelas* (fathead minnow), *Gammarus pseudolimnaeus* (amphipod), *Asellus intermedius* (isopod), *Hexagenia* sp. (mayfly), and *Daphnia magna* (cladoceran).	Significant acute toxicity observed only for amphipod; results questionable for amphipod because of too high control mortality.
Wisconsin Hwy. 15 at Sugar Creek; mostly rural watershed; ADT = 7,400 (Dupuis et al., 1985a)	Field measurement of water chemistry, sediment quality, and benthic invertebrate communities upstream and downstream of highway runoff inputs.	Metals from highways did not accumulate to substantially elevated concentrations in sediments. Significant adverse biological impacts from pollutant loadings from highway were not identified.
I-85 at Sevenmile Creek in NC; ADT = 25,500 (Dupuis et al., 1985a)	Field measurement of water chemistry, sediment quality, and benthic invertebrate communities upstream and downstream of highway runoff inputs.	Metals from highways did not accumulate to substantially elevated concentrations in sediments. Significant adverse biological impacts from pollutant loadings from highway were not identified.
I-94 in Milwaukee; ADT = 120,000; early spring runoff from totally paved site (Dupuis et al., 1985a)	Laboratory acute toxicity bioassays with undiluted runoff using five test species—*Pimephales promelas* (fathead minnow), *Gammarus pseudolimnaeus* (amphipod), *Asellus intermedius* (isopod), *Hexagenia* sp. (mayfly), and *Daphnia magna* (cladoceran).	No significant acute toxicity observed for any species.
Caltrans algal assays ADT = 23,000, 66,000, and 185,000 (Winters and Gidley, 1980)	Laboratory bioassays using 5-day exposure with mixed algal populations from Lake Natomas; tested a range of runoff concentrations (that is, dilution factors) and considered filtered and unfiltered runoff effects.	Runoff from rural and suburban sites was generally stimulatory, with the high traffic site runoff causing inhibition of algal growth; filtration of the sample did not significantly alter bioassay response (suggesting dissolved or colloidal materials caused the observed effects).
Washington State DOT bioassays ADT = 7,700, 42,000 and 50,000 (Portele et al., 1982)	Laboratory bioassays using three species—*Selenastrum capricornutum* (green algae), *Daphnia magna*, and *Salmo gairderi* (rainbow trout); tested a range of runoff concentrations (that is, dilution factors); compared toxicity of direct roadway runoff to that allowed to run through 60-meter-long grassy ditch; and considered filtered and unfiltered runoff effects.	Filtered grassy ditch drainage samples exhibited lower toxicity than unfiltered and direct pavement samples for trout assays; algal assays showed no toxicity except for the 50,000 ADT site, with toxicity at that site attributed to soluble zinc and copper.
Newly constructed I-295 crossing six small streams north of Richmond, VA; ADT = 12,000 (Mudre, 1985)	2.5-year postconstruction field monitoring at 16 sites included metals concentrations in sediment, benthic invertebrates, fish whole bodies, and fish tissues (liver, kidney, and bone); also assessed biological integrity using benthic invertebrates and fish community structure.	Significant increases in metals concentrations occurred, with maxima reached after about 1 year for all but lead in fish whole bodies, although the increases varied in magnitude and were not always consistent. Three of seven biotic parameters showed difference between upstream and downstream sites: 1) percent of aquatic insects composed of chironomids increased with increasing sediment metals concentrations; 2) fish community species diversity increased at highway sites over time; and 3) similarity of fish community structure at study sites through time was greater for upstream sites compared to highway sites. According to author, results are indicative of low to moderate levels of pollution, with no fish kills or likely human health effects associated with consumption of fish caught along the highway. The NCHRP Project 25-13 research team notes that results were

TABLE 7 (Continued)

Study	Biological Sampling Component	Relevant Results/Conclusions
		mixed, with sufficient variability in data and habitat conditions to preclude definitive conclusions.
Highway E6 (Oslo) adjacent to Lake Padderudvann; ADT = 19,400 (Gjessing et al., 1984a)	Laboratory bioassays: 7-day tests with heterotrophic organisms (that is, bacteria, protozoa, and fungi from municipal wastewater plant), 4-day tests with two algal species (*Selenastrum capricornutum* and *Synedra acus*), tests with 1-year-old salmon, and a 53-day test with salmon eggs hatched on runoff particulate matter.	Assays showed no toxicity effects with runoff concentrations ranging from 10 to 100 percent; stimulatory effects were observed for heterotrophs and slight stimulatory effects for algae over the first 3 days.
Highway E18 (Oslo) adjacent to Lake Padderudvann (referred to as E6 in previous studies); ADT = 29,600 (Baekken, 1994)	Measured lake water chemistry, concentrations of polycyclic aromatic hydrocarbons (PAHs) and metals in a bivalve (*Adnodonta piscinalis*) and perch (*Perca fluviatilis*), and assessed benthic fauna communities in Lake Padderudvann and a nearby, but larger, control lake (Lake Semsvann).	Concentrations of cadmium and zinc were higher in bivalves in Lake Padderudvann, but no difference was observed for other pollutants; only lead in perch liver and PAH in perch flesh exceeded control or background levels; diversity and abundance of benthic communities were reduced on the highway side of the lake. The NCHRP Project 25-13 research team notes that the results of this study were mixed, and sufficient data detail was not provided in the paper to determine if noted differences were statistically significant.
M6 Motorway in northwest England; ADT not specified (Dussart, 1984)	Measured algae in seven small upland streams, upstream and downstream of the highway.	ANOVA showed significant increases in number of species, abundance, and diversity downstream of the highway.
M1 Motorway in England; ADT not specified, but assumed high because of route and location immediately northwest of London (Maltby et al., 1995a; 1995b)	Water quality, sediment quality, and biota of seven small streams receiving runoff assessed over 12-month period; downstream-of-highway stations all within 100 meters of stormwater outfalls, leading to "worst-case" analysis, as noted by authors; toxicity identification evaluation (TIE) also conducted using benthic amphipod (*Gammarus pulex*).	Increased concentrations of polycyclic aromatic hydrocarbons (PAHs) and several metals (cadmium, chromium, lead, and zinc) found in downstream sediments; differences in benthic macroinvertebrate diversity and composition detected at four of the streams, although no effect on epilithic algae was found. Diversity of hyphomycete (fungi) assemblage was affected only at one site with highest roadway area to stream size ratio. Effects on macroinvertebrates attributed to change from leaf litter processing and a benthic algae/coarse particulate organic matter base to one dependent on fine particulate organic matter. TIE indicated that water column concentrations of runoff were not toxic to *Gammarus*, but that sediment contamination resulted in slight reduction in survival over 14-day period. Sediment manipulations indicated PAHs, copper, and zinc as potential toxicants, with PAHs being responsible for most of the observed toxicity.
M1 Motorway and Pigeon Bridge Brook, Butterwaite Ditch, and Rockley Dike; ADT not specified, but assumed high because of route and location immediately northwest of London (Boxall and Maltby, 1997)	Extracts of PAHs from sediment from a brook, ditch, and a dike used in Phase III toxicity identification evaluation.	Phase III toxicity identification evaluation identified pyrene, fluoranthene, and phenanthene as the most toxic PAHs. Toxicity from highest to lowest was pyrene, fluoranthene, and phenanthene. PAH concentrations in sampled sediment from highest to lowest was benzo(b & k)fluoranthene, benzo(a)anthracene, fluoranthene, and pyrene.

(*continued on next page*)

TABLE 7 (Continued)

Study	Biological Sampling Component	Relevant Results/Conclusions
A74(M) motorway in southwest Scotland. ADT greater than 30,000 (McNeil and Olley, 1998).	Benthic invertebrates monitored at five river crossing locations along the A74(M).	Compared to upstream reference sites, invertebrates below motorway discharge outfalls were not affected at any sampling location. The concentration of metals in highway runoff ranged from 1 to 36 μg/L for dissolved copper and 29 to 132 μg/L for total zinc.

leachates from construction and repair materials in the highway environment and the effect of mitigating factors such as soil sorption.

The NCHRP Project 25-13 literature review did not identify any specific studies of the water quality impacts of spills from bridges. However, the review did lead to a number of more general studies of spills on highways, including risk assessment (Harwood et al., 1990) and mitigative/avoidance methods. The survey and follow-up calls revealed one highly relevant and comprehensive risk analysis by the Oregon DOT regarding potential spills from a highway to an adjacent drinking water supply lake (Kuehn and Fletcher, 1995). This report and other pertinent references are included with the spills assessment methodology outlined in the second volume of this report, the *Practitioner's Handbook.*

Studies Specifically Addressing Bridge Deck Storm Water Runoff Impacts

Lower Nemahbin Lake, Wisconsin

One of the sites in Phase III of FHWA's research program was the I-94/Lower Nemahbin Lake site west of Milwaukee in southeastern Wisconsin (Dupuis et al., 1985a). This site represents the single most comprehensive field study of bridge deck runoff effects on a receiving water found in the literature review. The site, including sampling stations, is shown in Figure 1. The ADT at the site during the 1-year period was 15,600 VPD. The site contained an elevated 1,400-foot-long, 1-acre curbed bridge deck for the eastbound lane containing regularly spaced open scupper drains discharging directly to the lake. The ADT on the eastbound bridge deck alone was 7,500 VPD. In addition to other sampling at the site, the bridge deck study components quantified the following:

- Bridge deck runoff quality (Station HR2 collected samples directly from a scupper drain);
- Concentrations of metals and salts in sediments and macrophytes in a littoral wetland adjoining the lake and receiving drainage from bridge scuppers on the east side of the bridge (Stations M3 through M8);
- Benthic macroinvertebrates and periphyton immediately adjacent to the Station HR2 scupper discharge point (Station BAS4), using qualitative and quantitative methods;
- Body burdens of metals in three species of aquatic organisms collected from the lake near the scupper drain (Station BAS4); and
- Results of microcosm experiments (i.e., in situ bioassays) using six different species of aquatic organisms (Station BAS4).

Although the study found localized increases in metals and salt concentrations in sediments and plants near the bridge deck scupper drains, it can be inferred from the concurrent biological sampling that the impact of these enrichments is minimal. Specific conclusions related to biological data from this study are presented in Table 8. The overall conclusion is that the highway storm water runoff, including that from the bridge deck, does not significantly affect water quality or aquatic biota in the lake.

Lake Ivanhoe and Lake Lucien, Florida

These studies evaluated bridge runoff effects on Lake Ivanhoe, a small lake just north of downtown Orlando, and Lake Lucien, a small lake north of the city (Wanielista et al., 1980; Yousef et al., 1984). These lakes receive bridge drainage directly from scuppers at some locations. At other locations, the lakes receive bridge drainage from scuppers after it has been discharged to grassy floodplains or detained in ponds prior to discharge. The ADT on I-4 was 110,000 VPD at Lake Ivanhoe and 42,000 VPD at Lake Lucien. An additional 23,000 VPD pass over Lake Lucien on Maitland Boulevard. Metals concentrations were measured in runoff, lake water, and bottom sediments, as well as in two plant and one algal species—*Hydrilla, Typha,* and *Spyrogyra,* respectively. Metal concentrations were also measured in benthic organisms (e.g., crustaceans, mollusks, and annelids).

The researchers concluded that plant species generally exhibited significantly higher metals concentrations when exposed to direct scupper inputs than when exposed to runoff that had first passed through grassy floodplains or ponds. Statistical comparisons were not made for benthic organisms because of insufficient sample size. Biosurveys were not included in the study, but the researchers concluded that direct

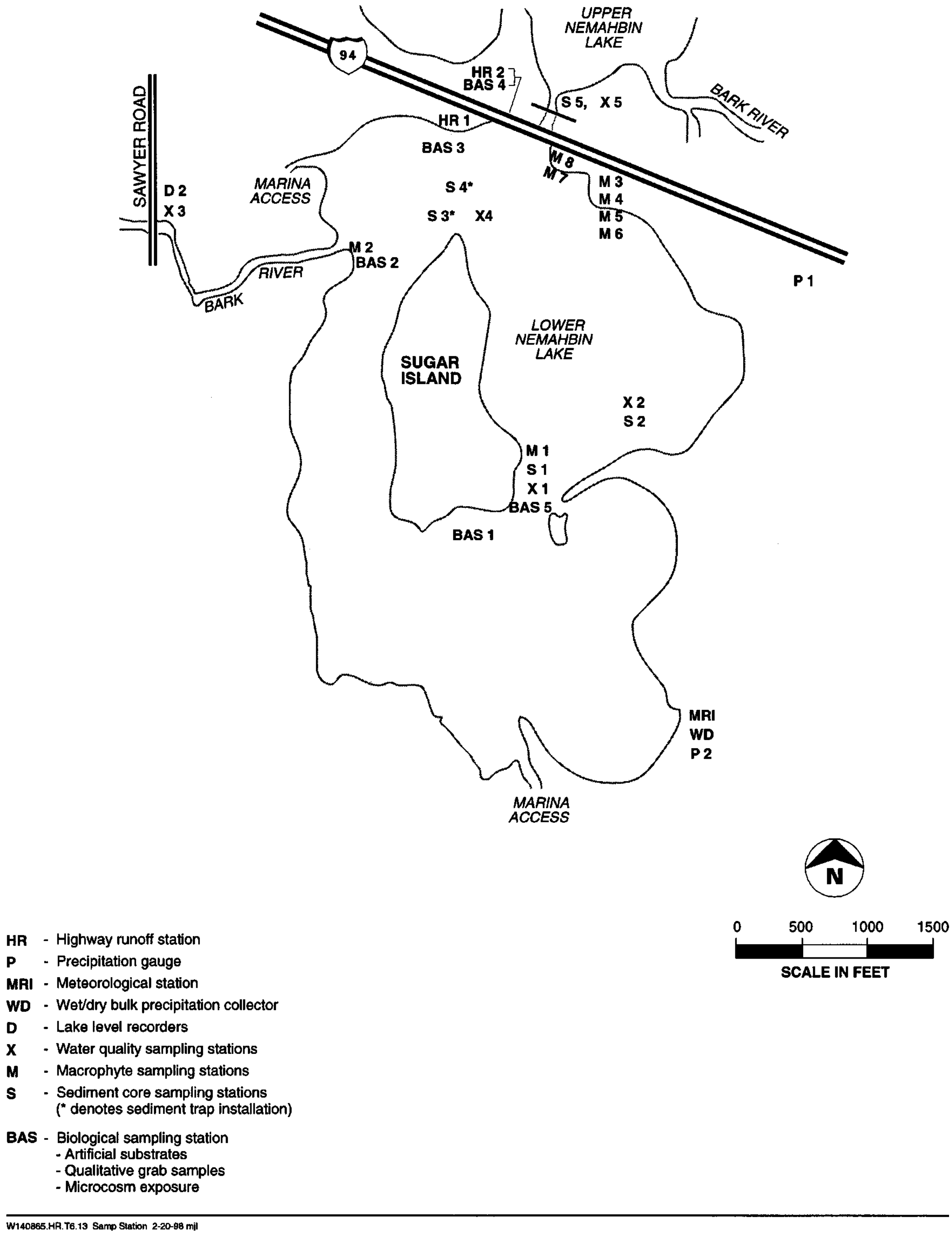

Figure 1. I-94/Lower Nemahbin Lake—sampling station locations.

TABLE 8 Summary of biological sampling at I-94/Lower Nemahbin Lake site (source: Dupuis et al., 1985a)

Biological Sampling Component	Relevant Results/Conclusions
Macrophytes (cattail)–metals and salts uptake, general condition.	Wetland vegetation effective at retaining metals, with background concentrations achieved within 20 meters (65 feet) of scupper inputs; elevated levels of salts and metals were observed in sediments and cattails near scuppers, but cattails appeared healthy and productive, with no visible signs of toxicity.
Benthic invertebrates (quantitative and qualitative).	Quantitative sampling showed that generally the abundance of invertebrates was not significantly different at runoff-influenced stations compared to controls; qualitative sampling also indicated little effect from runoff, with intolerant species found at both control and runoff-influenced stations.
Metals concentrations in three species of aquatic organisms—*Hyallela azteca* (amphipod), *Caenis* sp. (mayfly), *Enallagma* sp. (damselfly).	Although each species had higher concentrations of several metals at runoff-influenced stations compared to controls, there was no consistent pattern of enrichment evident between the species for any one metal; for all species certain metals were higher in the controls.
Field microcosms (in-lake flow-through cells containing test organisms) using five indigenous and one lab-raised species—*Daphnia* (zooplankton), *Caenis, Hyallela, Hydracarina* (aquatic mite), *Fredricella* (ectoproct), and *Enallagma*; organisms were exposed near runoff inputs and at controls for four 3-week periods.	No significant mortality resulting from runoff was observed compared to controls.

scupper discharges should be avoided at high traffic sites where the receiving water is small and landlocked.

Ochlockonee, Wakulla, and Braden Rivers, Florida

The focus of this study was to determine if bridge design features and construction methods had adversely impacted biota (Birkett et al., 1979). The study was not designed to specifically evaluate storm water runoff effects. The highway bridges studied included I-10 at the Ochlocknee River, an alluvial river with a broad floodplain; U.S. 98 at the Wakulla River, a clear spring-run with copious rooted macrophytes; and I-75 at the Braden River, a small tannic river lacking a floodplain. Benthic macroinvertebrates were sampled at each bridge including transects upstream, directly beneath each bridge, and downstream. Plants also were sampled at the Wakulla River site. The authors did not provide ADT data for these sites.

The authors concluded that there were no significant differences in invertebrate communities at the Ochlocknee River site. Significant impacts were found at the Wakulla River site but were attributed to dredging during construction and design criteria that promoted bottom scour. Data for the Braden River site were inconclusive—largely because of oil contamination of bottom sediments that occurred during construction.

Lake Chautauqua, New York

Laboratory bioassays were conducted using runoff from two bridges on the I-90 Throughway in western New York: one crossing Canadaway Creek and the other crossing Chautauqua Creek (Buchholz, 1986). Planktonic and attached filamentous algae assemblages collected from nearby Chautauqua Lake (which does not receive runoff from these bridges) were exposed to varying percentages of bridge runoff for periods varying from 4 to 12 days. Phytoplankton assays were conducted on a monthly basis from July 1982 to October 1983, and 12 assays with attached algae were conducted between December 1982 and November 1983. ADT information for I-90 was not provided.

Summer and fall runoff enhanced photosynthesis in phytoplankton and had no effect on attached algae. Spring and summer runoff containing road salts inhibited photosynthesis in both types of algae and altered the species composition of attached algae. The author also noted that *Selenastrum*, a common bioassay species, may be unsuitable as a test species for highway runoff because of its relative insensitivity to salt. The major drawback of this study from today's perspective is that the assays used long-term continuous exposure to runoff samples, without consideration of storm water timescale effects such as duration and frequency of exposure.

Biweekly lake water chemistry samples were also collected for a 2-year period (1982 to 1984) at nine stations near the Chautauqua Lake Bridge (Route 17), with seven other stations at more remote and background locations in the lake. Runoff from the bridge drains primarily through scuppers directly to the lake. This intensive sampling program focused on metals and salts. ADT information for Route 17 was not provided. No significant differences were found in soluble metals or salt concentrations between near-bridge stations and control stations, leading the author to conclude that the bridge is not having a detectable impact on water quality near the bridge.

Laboratory bioassays using runoff from the Lake Chautauqua Bridge and young-of-the-year sunfish (*Lepomis macrochirus*) were conducted in a later study (Kszos et al., 1990). Runoff was collected for four different periods, including several during the deicing season. The tests conducted were 12-day acute toxicity assays, with mortality monitored daily. Test concentrations ranged from 1 to 100 percent bridge runoff. Observed toxicity in bridge runoff was attributed primarily to salt concentrations, with zinc and cadmium concentrations being high enough to contribute to toxicity. The study indicated that, given the high degree of dilution that occurs in Lake Chautauqua, in-lake impacts are unlikely. As with all other historical lab bioassay tests with highway runoff, this study did not consider the timescale factors associated with storm water runoff.

Indian River, Florida

This study investigated the hydrodynamics, water quality, sediment quality, and aquatic biota (benthic macroinvertebrates and seagrass) in the vicinity of two causeways (SR-516 at Melbourne and SR-518 at Eau Gallie) crossing the Indian River, which is part of an important lagoonal system on Florida's east coast (Evink, 1980). Traffic volume for these bridges was not provided. Extensive data were collected upstream, downstream, and between the two bridges.

The authors concluded that the predominant water quality issue at the site is accelerated eutrophication (attributed to population growth in the area) leading to high nutrient loads from sewage and storm water. No adverse impacts on seagrasses were found other than those caused by physical damage (i.e., dredging). Similarly, the only significant difference found in macroinvertebrate communities was reduced diversity in summer at some downstream stations. The reduced diversity was attributable to factors other than the bridges, such as low dissolved oxygen. No significant differences existed in macroinvertebrate communities in the seagrasses at stations by the bridge. This was also the case in locations downstream and upstream of the bridge.

Isle of Palms Connector, South Carolina

The Isle of Palms Connector between Mt. Pleasant and two islands, Isle of Palms and Sullivan's Island, replaced an existing drawbridge damaged by Hurricane Hugo in 1989 (Ross, 1996). Because of concerns about the potential of runoff from the new bridge affecting water quality and therefore shellfish beds in the estuarine system the bridge would cross (Swinton Creek), an elaborate bridge drainage system, costing approximately $1.5 million, was incorporated into construction and operation (South Carolina DOT response to survey). The drainage system consists of (1) a series of trays or pans attached along each side of the low-level bridge structure to receive runoff that would otherwise be discharged directly to Swinton Creek, and (2) a closed-pipe collection system originally planned to convey runoff from a high-level span over the Intracoastal Waterway to an on-land gravel "spoil" area. The pans collect runoff and associated solids and oils for subsequent vacuum collection. Runoff volumes exceeding pan capacity overflow to Swinton Creek below. Because discharge to the spoil area could not be permitted, the plan now calls for the piping system to discharge to a wet detention basin near the disposal area.

Researchers at the Citadel began a toxicity monitoring program associated with the bridge in 1993 (Pilgrim, 1997). Dr. Phillipe Ross provided a preliminary, apparently unpublished, report of the first 2 years of testing to CH2M HILL. The initial 2-year program consisted of sediment bioassays with the Atlantic littleneck clam (*Mercenaria mercenaria*), black-seeded Simpson lettuce (*Latuca sativa*), and a bioluminescent marine bacterium (*Vibrio fisheri*). The clam assay measured growth, the lettuce assay measured root elongation, and the bacterium assay measured relative bioluminescence (an indicator of respiration). Sediment samples tested came from the scupper pans, the two spoil areas, Swinton Creek below the bridge, and a control area not subject to bridge runoff (Deewees Inlet). The bioluminescence test was used on various water samples including pan water, runoff water before it reached the pans, and pan overflow. According to the report, ADT increased from 7,000 VPD in the first year of the study to 13,500 VPD in 1995.

The overall results of the testing in the first two years of the study were mixed. Some tests showed significant differences in response, but most tests showed stimulatory effects or no significant differences when compared with controls for both sediment and water bioassays. At the time of the preliminary report, additional studies were ongoing. One concern of the NCHRP Project 25-13 research team is that the sediment bioassays, particularly those using pan and spoil area residues, do not provide a realistic assessment of the effects of the bridge on aquatic sediments or biota in the estuary. The quality and toxicity of these samples are not indicative of what the condition of the receiving waters would be if the bridge drainage system were not in place. Actual receiving water sediments would be substantially different than pan and spoil samples because the latter do not account for the dilution and dispersion of these solids, the dynamics of the estuarine system, or the attenuation effects associated with bioturbation and other processes. In addition, the water tests in this case do not address the timescale considerations of intermittent, short-duration discharges of storm water.

Overall Summary

Several studies have shown that direct scupper drainage to some types of receiving waters (e.g., small lakes) can lead to localized increases in certain pollutant concentrations—such as metals—in sediments and, in some cases, also in aquatic biota. Most of these studies did not consider whether such increases adversely affected the biota or other receiving water uses.

The only comprehensive study of bridge runoff, FHWA's I-94/Lower Nemahbin Lake site, found that, although direct scupper drainage increased metals concentrations in near-scupper surficial sediments, it did not have significantly adverse effects on aquatic biota near the scuppers. This conclusion was based on biosurveys and in situ bioassays. Traffic at this location was in the low range, and thus the results may not be representative of higher-traffic bridges.

With the possible exception of one study in Virginia (Mudre, 1985) and one in Norway (Baekken, 1994), studies of highway runoff impacts on aquatic biota tend to reinforce FHWA's earlier conclusion that low-traffic rural highways (i.e., less than 30,000 VPD) do not cause significant impacts (FHWA, 1987). FHWA's conclusion was based largely on results of its Phase III program (Dupuis et. al., 1985a), which included extensive bioassay testing and field study at three sites that had traffic volume less than 30,000 VPD. Note that Caltrans, based on analysis of its own data (Racin et al., 1982) and as yet unpublished FHWA data from its Phase II program, also determined in 1992 that fewer than 30,000 vehicles during a storm, equated to mean 30,000 ADT, would have ". . . little or no impact, because corresponding constituent masses were relatively small" (Racin, 1998). The NCHRP Project 25-13 research team notes that Mudre's results were mixed. Some, but not all, biotic parameters appeared to be sensitive to metals contamination; however, sufficient variability existed in the data and the habitat conditions to preclude definitive conclusions. Similarly, Baekken's results were mixed, and sufficient data detail was not provided in the paper for the NCHRP Project 25-13 research team to determine if differences were statistically significant.

Many studies completed since FHWA's Phase III program have indicated that relatively high-traffic highways can adversely affect aquatic biota in relatively small streams and lakes. These studies, as well as the Mudre (1985) and Baekken (1994) studies, involved drainage of substantial portions of the ROW to the receiving waters rather than drainage solely from the bridges. Therefore, they do not shed much light on the quantitative effects of bridges alone. These studies also generally show that the spatial extent of impact in the receiving water tends to be relatively localized.

Several studies have used laboratory bioassays to estimate highway runoff effects, including some with runoff from totally impervious sites that could be representative of bridge deck runoff quality. These studies have provided mixed signals regarding the aquatic toxicity of highway runoff. Some indicate no significant impacts, even at high-traffic locations, and others indicate some or substantial toxicity, particularly with undiluted runoff and runoff samples high in salt content because of deicing activity. All of the bioassay tests with bridge and highway runoff may be misleading, however, because they were conducted using the traditional approach of continuous exposure of organisms for relatively long periods of time. Short-term, intermittent exposure associated with storm water runoff may elicit a different result (i.e., timescale factors need to be considered).

Only two studies were found that addressed bridges or highways in coastal systems. The first was a study of two causeways in coastal Florida in a system stressed by other, much more significant, pollution sources (Evink, 1980). The Isle of Palms Connector studies were still in progress at the time of the literature review, and the one report reviewed did not provide meaningful results to the NCHRP Project 25-13 research team.

Few, if any, field studies detailing water quality impacts of bridges, or spills from bridges to receiving waters, have been conducted. Several reports have described potential or hypothetical impacts, and a number of management practices and other measures have been identified to reduce or minimize such impacts. A number of highway agencies are already implementing such measures for bridge cleaning and painting activities. Although no studies were found that directly assessed the impacts and risks of spills from bridges specifically, a body of information was identified concerning assessment of spills on highways.

SURVEY RESULTS

Surveys were sent to environmental managers and bridge design experts in 50 state transportation agencies, and 8 Canadian provinces, as well as to selected university and other researchers. The intent of the surveys was to identify past and ongoing studies of water quality impacts of bridge deck runoff. Panel member comments and the need of the research team to better understand the driving factors behind state DOT mitigation choices added to the survey's objective. Follow-up conversations with nearly 30 state transportation agencies added additional detail to the surveys. Table 9 provides a summary of the bridge deck mitigation measures used in each state and supporting details.

Mitigation

Nearly all states surveyed were concerned with the potential need to mitigate storm water from new bridge decks. States often endorsed mitigation or the avoidance of direct storm water discharges from new small bridges. WisDOT noted that the vast majority of existing small bridges in Wisconsin have open-rail drainage. For new small bridges, it is typical for storm water to be conveyed over the surface to the

TABLE 9 Survey findings—mitigation measures

State or Province	Structural Mitigation System in Place or Proposed	Mitigation System Location	Reason for Mitigation	Cost of Treatment	Concerns with Structural Mitigation	Potential Test Site
Alabama	No	—	—	—	Cost, maintenance, necessity, effectiveness	None identified
Alaska	No response					
Arizona	No	—	—	—	—	None identified
Arkansas	Yes–proposed	U.S. 71 and Ouachita River	Endangered species, drinking water supply	Unknown	Cost, maintenance, structural impacts, corrosion, effectiveness, traffic safety	U.S. 71 and Ouachita River
California	Yes–existing and proposed	Proposed– San Francisco– Oakland Bay Bridge in San Francisco	NPDES[a] permit conditions	Drainage: $1.5 million; BMP[b]: $150,000	Maintenance budget, training of maintenance crew	San Francisco– Oakland Bay Bridge in Oakland
Colorado	No	—	—	—	Cost, effectiveness, maintenance	None identified
Connecticut	No response					
Delaware	No	—	—	—	Bridges in Delaware are often low sloped, a collection and mitigation system would be infeasible	Multiple sites available
Washington DC	No	—	—	—	—	None identified
Florida	Yes	Multiple sites	Bridge crossing an Outstanding National Resource Water	No response	Cost, maintenance, effectiveness	Multiple sites available
Georgia	Yes–under construction	Hwy. 41 and the Chattahoochee River, Kennedy Interchange (I-75 and I-285)	Bridge crossing waters in the Chattahoochee National Recreation Area	No response	Safety hazard (structural and drainage) caused by the mitigation system	Hwy. 41 and the Chattahoochee River
Hawaii	No response					
Idaho	No	—	—	—	—	None identified
Illinois	Yes	I-355 and the Des Planes River	Bridge crosses the Will County Forest Preserve	No response	Environmental benefit provided by the mitigation system	I-355 and the Des Planes River
Indiana	No	—	—	—	—	None identified
Iowa	No	—	—	—	Cost, maintenance (clogging), benefit to the environment	None identified
Kansas	No	—	—	—	Maintenance	None identified
Louisiana	Yes	Hwy. 220 and Cross Lake	Cross Lake is a drinking water reservoir for Shreveport, concern for hazardous material spills	$2.3 million	Expansion and contraction causing leaks, long term maintenance costs, structural complications	Hwy. 220 and Cross Lake
Maine	No	—	—	—	Cost	Multiple sites
Maryland	No	—	—	—	—	None identified
Massachusetts	No	—	—	—	Misappropriation of public dollars, low environmental benefit, public safety compromised	None identified
Michigan	No	—	—	—	—	Sand Creek and I-96

(*continued on next page*)

TABLE 9 (Continued)

State or Province	Structural Mitigation System in Place or Proposed	Mitigation System Location	Reason for Mitigation	Cost of Treatment	Concerns with Structural Mitigation	Potential Test Site
Minnesota	Yes	Multiple locations	401 water quality certification, concern for hazardous material spills, environmental group protest	$25,000–$50,000 for simple systems to $2 million if complex	Maintenance, clogging, freezing, adequate slope for drainage	Stillwater Bridge between Stillwater, MN and Wisconsin
Mississippi	No	—	—	—	—	U.S. 90 and the Pascagoula River (estuary)
Missouri	Yes–in construction	Route 364 and the Missouri River	Endangered species in the Missouri River, Pallid Sturgeon	$1 million	Clogging, freezing, excessive use of these mitigation systems	Route 364 and the Missouri River
Montana	No	—	—	—	Cost, maintenance	Multiple sites
Nebraska	No	—	—	—	Assessment of need for mitigation	None identified
Nevada	Yes	Multiple locations, mostly in the Truckee Valley	Pollution prevention plan agrees to no direct discharge	Not considered a major factor as most bridges are short	Maintenance	Multiple sites
New Hampshire	Yes	Proposed highway in Nashua, crosses Merrimack River and Pennichuck Brook	404 and 401 water quality certification, U.S. EPA, State Department of Environmental Protection (DEP), and citizen group action, primary concern is drinking water	$300,000 for additional stormwater piping and framing, labor and pond cost not included	Excessive cost	Multiple sites, 9 other bridge crossings planned
New Jersey	No	—	—	—	—	None identified
New Mexico	Yes	Location not identified	401 water quality certification, NPDES stormwater permit restricted direct discharges for new bridges as of 1993	—	—	None identified
New York	Yes	Route 200 and Bear Gutten Creek	Pollutant loading to a drinking water reservoir	Not known	—	None identified
North Carolina	No response					
North Dakota	No	—	—	—	—	None identified
Ohio	No response					
Oklahoma	No	—	—	—	Maintenance, cost, effectiveness	None identified
Oregon	No	Oregon DOT has agreed to avoid direct discharge for new bridges	Oregon Plan for the Coastal Salmon Recovery Initiative	Not known	Clogging of inlet drains and freezing	Multiple sites
Pennsylvania	No response					
Rhode Island	Yes–proposed	I-195 and the Providence River	401 water quality certification, and coastal zone management authority authorization	Not known	Cost, maintenance, and impact of mitigation systems on the construction of the bridge	I-195 and the Providence River
South Carolina	Yes	Isle of Palms Connector, near Charleston	Environmental group concern for pollutant loading from routine operation of bridge	$1.5 million	Cost, use of limited funds needed for bridge repair and replacement	Isle of Palms Connector

TABLE 9 (Continued)

State or Province	Structural Mitigation System in Place or Proposed	Mitigation System Location	Reason for Mitigation	Cost of Treatment	Concerns with Structural Mitigation	Potential Test Site
South Dakota	No response					
Tennessee	No	—	—	—	—	Multiple sites
Texas	No response					
Utah	No	—	—	—	—	None identified
Vermont	No response					
Virginia	No response					
Washington	Yes	Multiple locations	As part of Puget Sound Plan have agreed to mitigate new impervious surfaces	Not available	Cost, effectiveness, safety	Multiple sites
West Virginia	No	—	—	—	—	Multiple sites
Wisconsin	Yes	I-94 between Hudson, Wisconsin and Afton, Minnesota; others being considered on Chippewa River	Primary driver was hazardous material spills	$384,000	DOT staff has concerns about bridge drainage systems in general, including safety and maintenance associated with plugging and freezing, costs, effectiveness, structural integrity (for example, possibility of explosion of spill materials in enclosed drainage system)	Multiple sites; especially St. Croix and Chippewa rivers
Wyoming	No	—	—	—	—	None identified
British Columbia	No response					
Alberta	No	—	—	—	—	None identified
Saskatchewan	No	—	—	—	—	None identified
New Brunswick	No	—	—	—	—	None identified
Manitoba	No	—	—	—	—	None identified
Ontario	No response					
Nova Scotia	No	—	—	—	—	None identified
Newfoundland	No response					

NOTE: — indicates data not available or applicable.
[a]National Pollutant Discharge Elimination System.
[b]Best Management Practice.

end of the bridge deck and routed to a drain inlet that leads to a discharge via grassy ditch or some sort of BMP, such as a pond. States that explicitly noted that they follow this policy were Florida, Minnesota, Oregon, Washington, Massachusetts, Delaware, Nevada, Maine, New Jersey, Utah, New Mexico, and Idaho. Other states potentially follow this policy but did not explicitly mention it. Regardless, state DOTs have identified this practice as effective and economical.

Nearly all states disapprove of elaborate structural mitigation systems. The most commonly held concerns about the use of structural mitigation systems included maintenance difficulties (i.e., clogging, freezing), costs and/or less than optimal use of public dollars, weakening of the bridge's structural integrity, retention of storm water on the bridge deck as a safety hazard, feasibility, and questionable environmental benefit. Bridge scupper clogging was cited as a chronic problem that would only be accentuated with the use of pipe elbows to connect scuppers to below-deck piping.

States use a wide array of customized systems to collect storm water from bridge decks. The most commonly used systems involve scupper drains that are attached to below-deck horizontal piping via an elbow. The piping usually discharges to a pond or swale located below and to the side of the bridge deck. Multiple states have found these systems prone to clogging, leading not only to excessive maintenance burdens, but to systems that cannot be cleaned. Some innovative solutions include removable deck inlet inserts (Oregon) designed to collect debris and sediment, and trapezoidal trough systems (Minnesota) that are easier to clean. Nevada has selectively used a below-deck oil-water separator and sand filter for bridges with no slope. The South Carolina DOT believes that the bridge drainage pans and enclosed collection system for the Isle of Palms Connector, discussed in more detail in the literature review, were not needed in light of FHWA requirements and the amount of traffic involved. The NCHRP 25-13 research team has collected detailed descriptions or plans for some of these systems.

Mitigative Drivers

Permitting a new storm water discharge is often a major regulatory hurdle for state DOTs. Building a new bridge, or building a replacement bridge, often depends on the receipt of a federal 404 permit, a state 401 certification, or an NPDES storm water permit for the new point source discharge. Receipt of the permit, however, is dependent on a wide array of state- and site-specific circumstances. For example, permit receipt may depend on one or more of the following factors: protection of endangered species in a given river, protection of an Outstanding National Resource Water, protection of a drinking water source from normal storm water discharges or from hazardous material spills, reduction of dissolved solids loading to a reservoir, and protection of a wildlife preserve.

In the Puget Sound region of Washington State, the state DOT has agreed, as a permit condition, to mitigate for those impervious surfaces tributary to the Sound. In Illinois and Georgia, easements across forest preserves were not granted unless storm water from bridge decks was mitigated. The endangered pallid sturgeon of the Missouri River was the driving force behind the use of mitigation for the extension bridge at Page Avenue. Multiple bridge deck runoff mitigation systems have been implemented in Florida for those bridges crossing high-quality waters. In Minnesota and Wisconsin, the primary concerns are hazardous material spills and high-quality resource waters (e.g., wild and scenic rivers). Special concern for shellfish beds and pressure by environmental groups were the drivers for the Isle of Palms Connector mitigation system in South Carolina.

In almost all cases, regulatory decisions were not based on research or other supporting evidence. In most cases, mitigation systems were used because of a general feeling that bridge deck storm water could somehow impact the receiving water or could further degrade conditions of an urban water body. The wide range of reasons for using structural mitigation drove the NCHRP 25-13 research team to recognize that the process of evaluation must be flexible enough to take into account the multiple factors driving varying groups' concerns.

Additional Considerations and Solutions

The survey results reveal that each state is reacting differently to the need to address the potential impact of bridge runoff on receiving waters. Solutions also vary. Washington State has addressed many of the problems and solutions of bridge deck discharges. As an innovative approach, Washington has developed a watershed-based process for addressing storm water (and other resource impacts) that includes leveraging funds for higher-priority local storm water projects, water quality enhancement at an off-site wetland, and cost-sharing on regional treatment off site. Other states that mentioned they use compensating mitigation include Rhode Island, Maine, Massachusetts, and Delaware. According to a memorandum of understanding between the Delaware DOT and the state environmental agency, storm water banking is used by Delaware for nonbridge construction projects to reduce the inefficient use of small mitigation systems. For example, one large pond may be constructed to mitigate other storm water sources (highway or urban). The ultimate outcome of storm water banking and compensating mitigation is the overall reduction of pollutant loads to a watershed. Furthermore, the cost is lower, and the mitigation systems used are typically more effective.

Interviews with state DOT staff in Washington, Tennessee, and Oregon revealed concern about the impacts of steel bridge maintenance activities. When a bridge is washed in Tennessee, a 5-foot-long test section is washed and the resultant water collected. The water is tested using a toxic characteristic leaching procedure (TCLP) test. If it is considered hazardous, all the washwater is collected and disposed of as hazardous material. If it is not hazardous, it can either be collected or filtered (filtrate must meet state water quality criteria for lead, chromium, and solids) and then discharged to the receiving water. In Tennessee, the wastewater generated from grinding a concrete bridge deck must also be collected because the high pH of the wastewater slurry has been identified as toxic.

Source reduction is another method used to mitigate pollutant loading from a bridge deck. At the time of the survey, WisDOT, in cooperation with the Wisconsin Department of Natural Resources, planned to test new, highly efficient street-sweeping units on highways. Another source-reduction technique identified in the interviews is traffic routing for hazardous material or livestock carriers.

BIOLOGICAL RESEARCH FOR NCHRP PROJECT 25-13

The results of the literature review and survey, as well as discussions with focus groups, revealed a significant need to be able to characterize pollutants from highways and bridge decks and to identify the potential impacts of bridge deck runoff on the biotic integrity of receiving waters. To date, no clear link has been established between bridge deck runoff and biological impairment. A number of methodologies presented in the second volume of this report, the *Practitioner's Handbook,* are designed to assist the practitioner in determining the potential effects of bridge deck runoff. In addition, biological studies have been conducted under NCHRP Project 25-13 to test the use of biological methods to identify or predict the potential for impairment. The literature review, the methods in the *Practitioner's Handbook,* and the biological studies fit within the context of a rational process developed by U.S. EPA to identify the stressors responsible for biological impairment (U.S. EPA, 2000). This *Stressor Identification Guidance Document* (SIGD) and a related document by WERF (Novotny et al., 1997) are described in detail in the upcoming section "Discussion—Integrating Biological and Water Quality Data."

Bioassays

Site Description and Sampling

Time-variable and continuous bioassays were performed with bridge deck runoff collected at a freshwater site (I-85 and Mallard Creek near Charlotte, North Carolina) and a saltwater site (San Francisco-Oakland Bay Bridge, I-80, and the San Francisco Bay). The San Francisco-Oakland Bay Bridge (SFOBB) is characteristic of a large bridge with high traffic volume, whereas the I-85 Bridge, with moderately high traffic volume, is typical of many creek or small river crossings in urban/suburban areas of the United States (see Table 10).

The two sites also have distinctly different climates. Rainfall in the San Francisco Bay area has lower intensity and can last for several hours, whereas the duration of rainfall in North Carolina is generally shorter and has higher intensity (although there is considerable seasonal variation). These climatic differences can have a significant effect on toxicity. Greater rainfall intensity can increase pollutant washoff; however, because storm duration is shorter, the exposure period is also shorter. Lower rainfall intensity with long storm duration increases the exposure period (in the natural environment and in the bioassay); however, the low intensity may lead to lower pollutant concentrations.

Figure 2. I-85 and Mallard Creek, North Carolina.

Runoff was sampled during eight storm events, four at I-85 and Mallard Creek (see Figure 2) and four at the SFOBB (see Figure 3). The runoff events varied in intensity, duration, and rainfall depth (see Table 11). Multiple, discrete runoff samples were taken from storm drains at various time increments during each storm event. Samples were used for bioassays and for metals (EPA Method 6010B) and PAH analysis (EPA Method 8270). Other standard chemical measurements, such as pH and dissolved oxygen (DO), were made for the receiving water body and for the runoff. Rainfall collected during each event also was used in bioassay testing.

Bioassay Methodology

The purpose of the bioassay studies was to evaluate the practical use of the time-variable bioassay method as an indicator of the potential effect of bridge deck runoff on receiving

TABLE 10 Study site characteristics

	I-85 and Mallard Creek	SFOBB[a]
Average Daily Traffic (ADT)	74,000	274,000
Bridge deck area (acres)	1.8	48.1
Annual rainfall[b] (inches)	43	18
Average stream flow (cubic feet per second)	43	—

NOTE: — indicates data not available or applicable.
[a] San Francisco-Oakland Bay Bridge.
[b] Precipitation record from 1931 to 1980 at the Oakland airport, and 1948–1999 at the Charlotte airport.

Figure 3. Oakland side of the San Francisco-Oakland Bay Bridge.

water aquatic organisms. This technique addresses the primary shortcoming of traditional continuous whole effluent bioassays (referred to from now on as continuous bioassays) that were designed to simulate the continuous exposure of aquatic organisms to a point source effluent. Although appropriate for continuous point source discharges, exposure of aquatic organisms to storm water for 2 to 7 days will result in overestimation of the potential toxicity of storm water because the length of most storm events is far less than 2 days. The relationship between toxicant concentration and exposure time has been well-established (Bergman and Dorward-King, 1996; Herricks and Milne, 1998). With a fixed pollutant concentration, an increase in exposure time elicits a greater toxic response. Hence, to accurately measure potential toxicity, the duration of exposure used for bioassays should reflect the duration of exposure in the natural environment.

Bioassay testing for NCHRP Project 25-13 thus included the time-variable methodology, and, for comparative purposes, the traditional continuous methodology. Although the time-variable approach will most often best represent bridge runoff exposure conditions, the continuous method will be more applicable in some instances. One example would be a situation in which runoff discharges to a poorly flushed, and confined, receiving water with relatively low dilution. For such isolated cases, in which exposure may occur for prolonged periods, the traditional continuous bioassay may be more representative.

For the time-variable method, runoff samples are collected at discrete time intervals throughout a runoff event. Samples are returned to the laboratory (they are not composited), and the test species is placed in each discrete runoff sample (e.g., test organisms are placed in Sample 1 for 54 minutes, transferred to Sample 2 for 51 minutes, transferred to Sample 3 for 83 minutes, and so on) for a total length of time equal to the storm event length. The test organisms are then transferred to "clean" laboratory water for the remaining test time (for a total test time of 2 days for acute tests and 7 days for chronic tests). This procedure is followed to mimic the exposure of aquatic organisms to pollutants in the receiving water, starting with runoff and ending with clean laboratory water that mimics the exposure of aquatic organisms to low pollutant levels between storm events. If a toxic effect is initiated during exposure to runoff, the response can materialize during the clean water duration. The test method thus addresses the potential for this lagged response. This procedure also accounts for the "first flush" effect, in which pollutant concentrations are high at the start of a runoff event.

The transfer of the test organisms from one runoff sample to the next and finally to the clean laboratory water introduces the potential for added stress that is not experienced in traditional continuous bioassays. This potential added stress is addressed by transferring the control organisms between test chambers at the same time intervals as the test organisms that were placed in runoff are transferred. With the exception of the bioassay test on September 25, 2000, the time-variable

TABLE 11 Runoff event conditions

Site	Event Date	Rainfall Intensity (inches per hour)	Event Rainfall Depth[a] (inches)	Event Duration (minutes)	Antecedent Dry Period (hours)
Mallard Creek	09/25/00	1.62	2.03	90	55
Mallard Creek	11/07/00	0.03	0.02	45	45
Mallard Creek	11/09/00	0.04	0.05	90	37
Mallard Creek	04/03/01	0.55	0.69	90	>72
SFOBB[b]	04/16/00	0.02	0.11	382	56
SFOBB	05/07/00	0.05	0.29	340	>72
SFOBB	05/14/00	<0.01	0.02	93	>72
SFOBB	04/06/01	0.01	0.10	321	>72

[a] Total rainfall depth during sampling.
[b] San Francisco-Oakland Bay Bridge.

bioassay tests showed low mortality in the controls, demonstrating that the transfer of the test organisms during the tests did not introduce stress. Therefore, any toxicity measured in the time-variable bioassays can reasonably be attributed to exposure to storm water runoff.

The test design and conditions for the freshwater and saltwater bioassays are presented below in Tables 12 and 13. As noted above, test organisms used in the time-variable bioassays were exposed to runoff for a duration equal to the storm event duration (see Table 13) and then transferred to control water for the remainder of the test. Survival was measured after 2 days (acute toxicity), and survival and growth (organism weight) were measured at the end of 7 days (chronic toxicity) for both the time-variable and continuous bioassays.

Ceriodaphnia dubia and *Mysidopsis bahia* were the chosen test organisms for the freshwater and saltwater sites, respectively. *C. dubia* was chosen because it is a commonly accepted test organism and widely used in acute and chronic toxicity tests. Furthermore, *C. dubia* is sensitive to metals and a range of other toxicants. Similarly, the Mysid shrimp, *M. bahia*, was selected because of its widespread use as a test organism and its sensitivity to pollutants found in bridge deck runoff (e.g., metals). Other species can be used in time-variable bioassays. Herricks and Milne (1998) developed a weighting procedure to rank the relative

TABLE 12 Summary of test conditions for freshwater time-variable and continuous bioassays

Parameter	Condition
Test organism	*Ceridaphnia dubia*
Test type	Static renewal
Age of test organism	<24 hours, all released within 8-hour period
Test chamber size	30 milliliters
Test solution volume	15 milliliters
Renewal of test solutions [a]	Every 48 hours: days 2, 4, and 6
Number of replicate chambers per solution	10
Number of organisms per chamber	1
Primary control/ dilution water[b]	Reconstituted laboratory medium (hardness of 85 mg/L as $CaCO_3$)
Internal laboratory control water[b]	Moderately hard (100 mg/L as $CaCO_3$) reconstituted laboratory medium
Runoff sample concentrations	6.25%, 12.5%, 25%, 50%, and 100%[c]
Rainwater control concentration	100%
Temperature	25 ± 1 degree Centigrade
Feeding regime	0.1 milliliter each of YCT culture food and algae per test chamber daily
Aeration	None
Chronic test duration	7 days
Acute test duration	2 days
Time-variable test duration	See Table 11. Event duration = test duration in runoff; total test duration is 7 days.
Sampling scheme [a]	Six composite bridge deck runoff samples and one composite rainwater sample. Maximum holding time of 3 days (Event 1), 36 hours (Event 2), and 4 days (Event 3 and 4) between completion of collection and initial test use. Laboratory water was prepared as one batch.
Effects measured/endpoints	Survival and reproduction
Test acceptability	Laboratory water control with ≥80% mean survival, an average of ≥15 young per surviving female, and at least 60% producing three broods.

[a] Because this was a research evaluation, procedural modifications (e.g., sample holding times and test solution renewal frequency) were planned or intended.
[b] Consists of distilled water with $NaHCO_3$, $CaSO_4$, $MgSO_4$, and KCI.
[c] Dilutions were prepared only for the time-variable toxicity tests.

TABLE 13 Summary of test conditions for saltwater time-variable and continuous bioassay tests

Parameter	Condition
Test organism	*Mysidopsis bahia*
Test type	Static renewal
Age of test organism	7 days
Test chamber size	250 milliliters
Test solution volume	150 milliliters
Renewal of test solutions[a]	Every 48 hours: days 2, 4, and 6
Number of replicate chambers per solution	8
Number of organisms per chamber	5
Primary control/ dilution water	Deinonized laboratory water mixed with sea salts to salinity of 25 parts per thousand
Runoff sample concentrations	6.25%, 12.5%, 25%, 50%, and 100%[b]
Rainwater control concentration	100%
Temperature	26 ± 1 degree Centigrade
Feeding regime	0.15 milliliter of live brine shrimp nauplii per test chamber, twice daily
Aeration	None
Test duration	7 days
Sampling scheme[a]	Six composite bridge deck runoff samples and one composite rainwater sample. Maximum holding time of 38 hours (Events 1 and 2) and 66 hours (Event 3) between completion of collection and initial test use. Laboratory water used was prepared as one batch.
Effects measured/ endpoints	Survival and weight (biomass)/IC_{25}[c]
Test acceptability	Laboratory water control organism with ≥80% mean survival and average dry weight of ≥0.2 milligram.

[a] Because this was a research evaluation, procedural modifications (e.g., sample holding times and test solution renewal frequency) were planned or intended.
[b] Dilutions were prepared only for the time-variable toxicity tests.
[c] IC_{25} is defined as 25% inhibition concentration.

usefulness of a test organism for use in time-variable bioassays. This scoring technique considered criteria such as endpoint measurement time, response induction time, ecological relevance, sensitivity, contaminant specificity, availability of a standard testing method, and cost. The test organisms used for NCHRP Project 25-13 conform well with these guidelines.

Because *M. bahia* is a saltwater species, the salinity of the runoff was raised to 25 parts per thousand by adding Forty Fathoms brand artificial sea salt. For the first runoff event at I-85 and Mallard Creek, hardness in the runoff was adjusted to the hardness of Mallard Creek. Hardness can have a mitigating effect on toxicity, and a proper evaluation of the potential in-stream toxicity of runoff requires a hardness adjustment. Hardness in the runoff for the second through fourth events was greater than the hardness of Mallard Creek; therefore, no adjustment was made.

The time-variable bioassays were performed with a range of runoff-control water mixtures. Control water for the freshwater bioassays (Lewis et al., 1994) consisted of distilled water with added ions and cations (e.g., sodium, calcium, magnesium, potassium, and sulfate). The continuous bioassays were performed in 100 percent runoff. The time-variable bioassay mixtures ranged from 6.25 percent runoff (93.75 percent laboratory control water) to 100 percent runoff. Standard whole effluent toxicity testing procedures for permitting purposes typically involve the dilution of effluent with control water to check test organisms' response to increasing effluent doses. If an effluent is toxic, there should be a response to an increased effluent dose. This response is, in essence, a test of the bioassay procedure. Also, the dose-response relationship can be used to evaluate the potential toxicity of runoff once it is diluted in the receiving water. For example, if there is a toxic effect with 100 percent runoff, but no toxic effect with 50 percent runoff, dilution in the receiving water will need to be a minimum of 50 percent (i.e., one part runoff to one part receiving water) to eliminate toxicity.

Bioassay Results

Time-Variable Bioassays. Tables 14 and 15 present the results of the time-variable bioassays with runoff and rainwater. Basic chemical characteristics (e.g., pH) of the water used in the time-variable and continuous bioassays and the chemical composition (e.g., metals) of runoff are presented in Tables 16 and 17. Table 14 (tests with water collected at the freshwater site on November 7, 2000; November 9, 2000; and April 3, 2001) demonstrates that the mean percent survival of *C. dubia* in acute (2-day) and chronic (7-day) tests did not decrease with an increasing concentration of runoff from 6.25 percent to 100 percent. Also, survival of *C. dubia* with 100 percent runoff was the same as or greater than survival for the control bioassays. Reproduction, measured as the mean number of offspring, was not affected by runoff. Reproduction is a sensitive measure that is an indicator of the potential long-term viability of a biological community

TABLE 14 Acute and chronic freshwater and saltwater time-variable bioassays with runoff

Freshwater (Mallard Creek & I-85)

	Event: September 25, 2000			Event: November 7, 2000			Event: November 9, 2000			Event: April 3, 2001		
	(2-day)	(7-day)		(2-day)	(7-day)		(2-day)	(7-day)		(2-day)	(7-day)	
Dilution (Percent runoff)	Mean Percent Survival	Mean Percent Survival	Mean Number of Offspring	Mean Percent Survival	Mean Percent Survival	Mean Number of Offspring	Mean Percent Survival	Mean Percent Survival	Mean Number of Offspring	Mean Percent Survival	Mean Percent Survival	Mean Number of Offspring
Control	[a]	[b]	[b]	100	100	23.6	100	90	23.5	100	100	32.25
6.25	[a]	[b]	[b]	100	100	23.9	100	100	27.2	100	100	33.4
12.5	[a]	[b]	[b]	100	100	22.4	100	100	28.6	100	100	30.8
25	[a]	[b]	[b]	100	90	19.0	100	100	28.9	100	100	32.8
50	[a]	[b]	[b]	100	90	19.2	100	100	31.6	100	100	31.9
100	[a]	[b]	[b]	100	100	21.1	100	100	31.5	100	100	35.1
IC_{25} (%)[d]			[b]			>100			>100			>100

Saltwater (San Francisco-Oakland Bay Bridge)

	Event: April 16, 2000			Event: May 7, 2000			Event: May 14, 2000			Event: April 6, 2001		
	(2-day)	(7-day)		(2-day)	(7-day)		(2-day)	(7-day)		(2-day)	(7-day)	
Dilution (Percent runoff)	Mean Percent Survival	Mean Percent Survival	Mean Weight[c] (mg)	Mean Percent Survival	Mean Percent Survival	Mean Weight (mg)	Mean Percent Survival	Mean Percent Survival	Mean Weight (mg)	Mean Percent Survival	Mean Percent Survival	Mean Weight (mg)
Control	100	95	0.304	97.5	87.5	0.315	95	90	0.339	100	97.5	0.29
6.25	97.5	92.5	0.343	97.5	97.5	0.321	10	97.5	0.350	97.5	92.5	0.276
12.5	97.5	87.5	0.321	97.5	92.5	0.383	95	90	0.319	97.5	92.5	0.249
25	97.5	92.5	0.318	90	90	0.325	93	92.5	0.316	95	92.5	0.278
50	97.5	90	0.376	95	90	0.339	95	92.5	0.362	100	92.5	0.294
100	95	77.5	0.245	80	75	0.318	100	100	0.421	100	92.5	0.291
IC_{25} (%)			97.2			>100			>100			>100

[a] Test results of questionable validity because control mortality and inconsistent dose-response results.
[b] Results of this test are invalid, control survival was below 80%.
[c] Mean weight is a measure of chronic toxicity and was measured at the end of 7 testing days.
[d] IC_{25} is defined as 25% inhibition concentration.

TABLE 15 Time-variable and continuous exposure bioassays with rainwater

Test Metric	Mean Percent Survival (Mean Number of Offspring)			
	September 25, 2000	**November 7, 2000**	**November 9, 2000**	**April 3, 2001**
Freshwater (Mallard Creek & I-85)				
Time-variable bioassay	[a]	[b]	[b]	[b]
Continuous exposure bioassays	100 (31.9)	[b]	100 (25.4)	80 (25.6)
	Mean Percent Survival (Mean Weight, mg)			
	April 16, 2000	**May 7, 2000**	**May 14, 2000**	**April 6, 2001**
Saltwater (San Francisco-Oakland Bay Bridge)				
Time-variable bioassay	95 (0.304)	95 (0.321)	90 (0.339)	[c]
Continuous exposure bioassay	92.5 (0.343)	90 (0.452)	87.5 (0.279)	100 (0.310)

[a] Results of this test are invalid, control survival was below 80%.
[b] Insufficient rainfall volume collected to perform bioassay.
[c] Rainwater bioassay not conducted because of laboratory error.

exposed to runoff. An IC_{25}, typically calculated using reproduction or growth data, is the concentration of runoff that will cause a 25 percent reduction in reproduction or growth. The IC_{25} was greater than 100 percent for all of the viable bioassays, providing evidence that runoff from I-85 will not affect the long-term integrity of the biological community below the I-85 Bridge.

Some toxicity to *M. bahia* with 100 percent runoff was observed for the SFOBB. Both 2-day acute toxicity and 7-day chronic toxicity was observed for the May 7, 2000 runoff event at a concentration of 100 percent. There was a general increase in 2-day and 7-day acute toxicity with an increasing concentration of runoff for this event. Some acute toxicity over 7 days was also evident for the April 16, 2000, event for 100 percent runoff. Chronic toxicity as measured by growth was observed only with runoff collected on April 16, 2000. Although some toxicity was observed, the IC_{25} (i.e., the concentration at which weight would be reduced by 25 percent) was 97.2 percent for the April 16, 2000, event (weight is a measure of growth and is another indicator of the potential long-term integrity of a biological community). The IC_{25} was greater than 100 percent for the other three runoff events. Weight was greater with 100 percent runoff than controls for the other three runoff events. Overall, these bioassay results provide evidence that runoff will not have a long-term adverse effect on biota in the region of the SFOBB.

Bioassays with rainwater from I-85 and Mallard Creek and the SFOBB did not show toxicity (see Table 15, compare to controls in Table 14). Thus, it is likely that any toxicity observed at I-85 and Mallard Creek and the SFOBB would

TABLE 16 Average chemical conditions of time-variable and continuous bioassays

	Mallard Creek & I-85				SFOBB[a]			
	9/25/00	**11/7/00**	**11/9/00**	**4/3/01**	**4/16/00**	**5/7/00**	**5/14/00**	**4/6/01**
PH	8.1	8.2	8.2	8.4	7.6	7.4	7.6	8.2
Conductivity (mmho)/Salinity (ppt)[b]	0.09	0.25	0.23	0.16	25	25	25	25
Dissolved Oxygen (mg/L)	8.3	8.0	8.2	8.3	7.1	8.3	8.1	7.6
Hardness (mg/L as $CaCO_3$)	45-50	220	90-95	35-115	[c]	[c]	[c]	[c]

[a] San Francisco-Oakland Bay Bridge.
[b] Conductivity measurement is for Mallard Creek and salinity (in parts per thousand) for SFOBB tests.
[c] Hardness was not measured for the saltwater bioassays.

TABLE 17 Total recoverable metals and polycyclic aromatic hydrocarbons (PAHs) in composite samples of bridge deck runoff collected for bioassays

	Chemical Concentration (µg/L)							
	I-85 & Mallard Creek				SFOBB[a]			
	9/25/00	11/7/00	11/9/00	4/3/01	4/16/00	5/7/00	5/14/00	4/6/01
Cadmium	<1.0	1.7	1.2	1.0	<2.0	1.4	1.3	2.8
Chromium	6.2	7.9	17	17	16	7.8	12	40
Copper	27	75	63	64	270	180	130	200
Lead	7.7	16	20	23	51	82	120	160
Nickel	<5.0	24	14	13	36	15	16	36
Zinc	73	570	210	260	760	460	360	640
Acenaphthene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
Acenaphthylene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
Anthracene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
Benzo(a)anthracene	<0.10	<0.05	0.069	0.14	<0.25	<0.05	<0.05	0.33
Benzo(a)pyrene	<0.10	0.089	0.10	0.14	<0.25	<0.05	<0.05	0.26
Benzo(b)fluoranthene	<0.10	0.087	0.13	0.35	<0.25	<0.05	<0.05	0.45
Benzo(g,h,l)perylene	<0.10	0.099	0.14	0.29	<0.25	<0.05	<0.05	0.70
Benzo(k)fluoranthene	<0.10	0.061	0.077	0.10	<0.25	<0.05	<0.05	<0.12
Indeno(1,2,3-cd)pyrene	<0.10	0.059	0.082	0.18	<0.25	<0.05	<0.05	0.25
Chrysene	<0.10	0.12	0.14	0.17	0.55	0.28	0.26	0.45
Dibenzo(a,h)anthracene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
Fluoranthene	<0.10	0.085	0.20	0.43	0.53	0.26	0.26	0.73
Fluorene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
2-Methylnaphthalene	<.10	<0.05	<0.05	0.095	<0.25	<0.05	<0.05	<0.12
1-Methylnaphthalene	<0.10	<0.05	<0.05	<0.05	<0.25	<0.05	<0.05	<0.12
Naphthalene	0.11	<0.05	0.057	0.10	<0.25	<0.05	<0.05	<0.12
Phenanthrene	0.12	0.085	0.23	0.35	0.27	0.16	0.30	0.36
Pyrene	0.10	0.18	0.26	0.30	0.57	0.30	0.39	0.85

[a] San Francisco-Oakland Bay Bridge.

be not from pollutants in rain but from pollutants in runoff from the bridge deck and vehicular activities.

Toxicity that was observed for the time-variable toxicity tests, although not significant, may be explained largely by the duration of exposure and metals concentrations. "Exposure time" in this discussion means the length of time that the test organisms are placed in bridge deck runoff. "Test duration" indicates the entire duration of the experiment, which includes exposure to control water. There was no acute or chronic toxicity for runoff collected at I-85 and Mallard Creek; however, runoff collected at the SFOBB on April 16, 2000, and May 7, 2000, exhibited some toxicity, and the metals concentrations in these samples were approximately 2 to 10 times greater than in the samples from Mallard Creek. No toxicity was observed for the May 14, 2000, event at the SFOBB most likely because of the combined effects of a significantly shorter exposure time and lower metals concentrations. Metals concentrations were lower for the May 14, 2000, event at the SFOBB, and toxicity was not observed. Although the concentrations of metals in runoff from the April 6, 2001, event at the SFOBB were equivalent to metals in runoff from April 16, 2000, and May 7, 2000, no toxicity was observed. This may be the result of a shorter rain event and hence a short exposure time. The time-variable bioassays at I-85 and Mallard Creek and at the SFOBB demonstrate that this type of bioassay method responds to both toxicant concentration and test duration.

The toxicity of the time-variable bioassays can be evaluated in a number of ways. Calculations can be carried out to determine the concentration of runoff that is lethal to 50 percent of the organisms (LC_{50}), or the concentration of runoff at which no toxicity occurs (i.e., no observed effect concentration or NOEC). The effect endpoint for chronic tests is typically the IC_{25}, or the concentration at which growth or the number of offspring is reduced by 25 percent when compared with controls. The NOEC level may be used to indicate the level of dilution required by the receiving stream to eliminate the toxicity of the runoff. Herricks and Milne (1998) have proposed the use of a simple rule for evaluating toxicity based on experience with the toxicity background level observed in studies with pre-storm and reference site samples. According to Herricks and Milne, a response of less than 20 percent (e.g., greater than 80 percent test organism survival) suggests no toxicity, 20 to 70 percent response indicates moderate toxicity, and greater than 70 percent response indicates high toxicity.

Continuous Bioassays. Continuous bioassays (7-day exposure with 100 percent runoff) were completed with the same runoff used in the time-variable bioassays (see Table 18). Exposure of *C. dubia* to 100 percent runoff collected at the I-85 site on September 25, 2000, and April 6, 2001, did not affect survival. Survival was reduced to zero percent and 52 percent with runoff collected on November 7, 2000, and November 9, 2000, respectively. A measure of potential long-term chronic effects, the number offspring from *C. dubia*, was reduced with the November 7, 2000, and November 9, 2000, runoff but was not significantly affected with the September 25, 2000, and April 6, 2001, runoff. These results are consistent with the chemical monitoring data. The runoff from November 7, 2000, had the highest toxicity and the highest concentration of copper and zinc. The September 25, 2000, bioassay had no toxicity and the lowest metals concentrations.

Runoff from the SFOBB was also toxic to *M. bahia* in continuous 7-day tests. No *M. bahia* survived in runoff from April 16, 2000, or May 7, 2000, whereas 9 percent and 20 percent survived in runoff from May 14, 2000, and April 3, 2001, respectively. Organism weight was reduced with runoff from all four events. Similar to reproduction for *C. dubia*, organism weight is a measure of the potential long-term survival of a species and the integrity of a biological community. The IC_{25} for all four tests ranged from 25 to 33 percent runoff. These results also demonstrate that the time-variable bioassays can produce toxicity data that are consistent with traditional continuous exposure bioassay methods. However, the time-variable bioassays more accurately reflect the magnitude of toxicity for most receiving waters, including the SFOBB case.

These continuous bioassay results need to be considered with the episodic nature of bridge deck runoff in mind. A proper evaluation of the potential of a bridge to cause biological impairment requires the bioassay to reflect the exposure condition of organisms in the receiving water. According to Herricks and Milne (1998), three timescales should be considered when evaluating the toxicity of wet weather discharges: intra-event, event, and long-term. In the bioassay testing for NCHRP Project 25-13, the intra-event timescale was addressed by the time-variable bioassays, in which organisms were sequentially placed in different runoff fractions. The time-variable bioassays also addressed the event timescale because the organisms were placed in runoff for a duration equal to the storm event duration. Only select conditions warrant the use of traditional continuous chronic bioassays (an example would be the previously described circumstance of a bridge crossing a small bay of a lake that does not readily exchange water with the main lake body or a small wetland). Herricks and Milne recommend the use of biosurveys to evaluate long-term toxic effects.

TABLE 18 Freshwater and saltwater 7-day continuous exposure chronic bioassays with runoff

	Mean Percent Survival (Mean Number of Offspring)			
Test Metric	**September 25, 2000**	**November 7, 2000**	**November 9, 2000**	**April 3, 2001**
Freshwater (I-85 & Mallard Creek)				
Control	100 (13.7)	100 (22.9)	100 (24.8)	100 (32.5)
100% Runoff	98 (15.6)	0 (0.2)	52 (0.6)	100 (21.9)
IC_{25} (%)	>100	25	26	77
	Mean Percent Survival (Average Weight)			
	April 16, 2000	**May 7, 2000**	**May 14, 2000**	**April 6, 2001**
Saltwater (San Francisco-Oakland Bay Bridge)				
Control	92.5 (0.342)	90 (0.458)	95 (0.328)	100 (0.286)
100% Runoff	0 (0)	0 (0)	9 (0.018)	20 (0.066)
IC_{25} (%)	25	25	26	33

Biosurveys

The literature review for this report revealed that only a limited number of studies (Baekken, 1994; Maltby et al., 1995a) have identified highway runoff as a potential source of impairment for benthic (i.e., bottom-dwelling) organisms. Because of this data gap, biosurveys were performed at the same freshwater (I-85 and Mallard Creek) and saltwater (SFOBB) sites as the time-variable bioassays. There was some toxicity for the SFOBB and no toxicity for the I-85 runoff in the time-variable bioassays. Using the strength of evidence concept presented in the SIGD (U.S. EPA, 2000), biosurveys of benthic organisms at these sites can be used to develop a more conclusive evaluation of impairment or the potential for long-term impairment. Hence, the biosurvey method both addresses the long-term timescale and supports the body of evidence needed to assess the potential adverse impacts of bridge deck runoff.

The examination of benthic invertebrate communities as a tool for evaluating environmental perturbations is well established. Bilyard (1987) and U.S. EPA (1992) cite the following reasons for using benthic macroinvertebrates to determine overall aquatic community health:

- Benthic macroinvertebrates are typically sedentary and are therefore most likely to respond to local environmental impacts, thus narrowing the list of possible causes of impairment.
- Benthic macroinvertebrates are also sensitive enough to disturbances of habitat that the communities respond fairly quickly with changes in species composition and abundance.
- Monitoring benthic macroinvertebrates provides an in situ measure of relative biotic integrity and habitat quality.
- Of the biota typically measured, the benthic invertebrate assemblage has the strongest supporting database. Thus, it has extensive historical and geographic application.

For the reasons listed above, the NCHRP 25-13 test program was designed to compare the benthic invertebrate community structure near the drain scuppers of a tested bridge with that of a reference condition to assess impact on the receiving water's aquatic life. The bridges and receiving waters chosen for this work were also important. The SFOBB has one of the highest ADT volumes in the country at 250,000 VPD. In addition, the benthic macroinvertebrate community structure in the San Francisco Bay area has been extensively studied, and a general consensus on what an impacted and nonimpacted (reference) community structure looks like has been formulated. The Mallard Creek site was also chosen because of a relatively high ADT (74,000 VPD), as well as for having a bridge deck area large enough to produce sufficient runoff volume, and an established reference site for comparison with the biosurvey results.

SFOBB

Site Description and Sampling. Samples were collected with a Ponar sampling device along five transects (three samples per transect) perpendicular to and below the bridge deck (see Figure 4 for sampling locations). Samples were sieved through a 0.5-mm-mesh screen to remove fine sands and consolidate the samples for processing. Organisms were generally identified to species and in some cases to family (e.g., Tubificidae). One sediment sample was also collected along each transect and evaluated for potential contaminants associated with bridge deck runoff. The sediment samples were

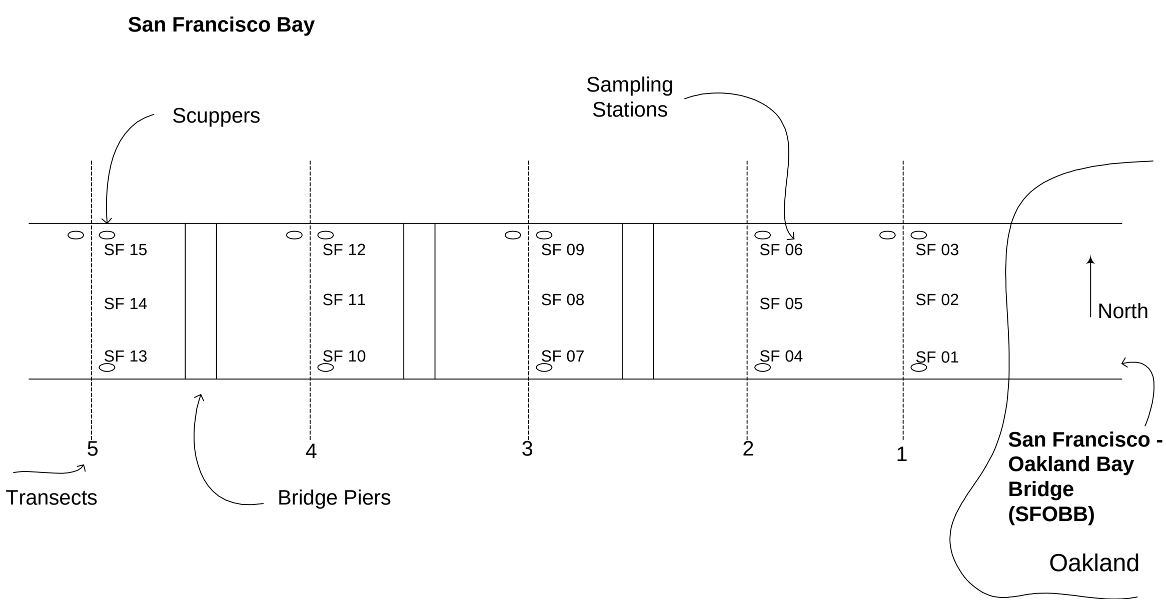

Figure 4. Schematic of San Francisco-Oakland Bay Bridge sampling stations.

analyzed for grain size, total organic carbon (TOC), and the following analytes: cadmium, chromium, copper, lead, nickel, zinc, and PAHs. Standard water quality characteristics such as DO, temperature, pH, conductivity, turbidity, total dissolved solids, and salinity were measured at representative points along each transect.

One of the primary challenges of biological surveys is the identification of an appropriate reference site with which to judge the results of a survey. The San Francisco Estuary Institute undertook a series of studies of benthic habitat and populations from 1994 to 1997 in the San Francisco Bay-Delta area (Thompson and Lowe, 2000) to devise a reference condition for benthic macroinvertebrates in the San Francisco Bay. Salinity gradients, sediment type, and other unidentified characteristics of the Bay were used to divide benthic assemblages of the Bay into three groups: marine-muddy, estuarine, and fresh-brackish. Development of the reference condition was based on a review of potential benthic indicators such as the number of taxa, total abundance, and indicator organisms that are either pollution tolerant or sensitive. A list of indicators was chosen according to the indicator response to a range of pollutant conditions in Bay sediments, previous usage according to the literature, general confirmation with expected benthic response, and professional judgment. The benthic indicators that were used to develop the reference condition included the number of taxa, total abundance, amphipod abundance, oligochaete abundance, and *Capitella capitata* abundance. Amphipods are pollutant sensitive, whereas the oligochaete and *Capitella capitata* are pollutant tolerant.

Results. The benthic macroinvertebrate community structure within the SFOBB study area was dominated by amphipods (34.3 percent of total abundance), tanaids (32.4 percent), mollusks (16.5 percent), and annelids (14.8 percent). A complete list of organisms identified in the study area is given in Appendix A-1. The dominant amphipods were *Ampelisca abita*, *Grandidierella japonica*, *Monocorophium acherusicum*, *Caprella* sp., and *Monocorophium* spp. The tanaids were represented by a single species, *Leptochelia dubia.* The dominant mollusk was *Gemma gemma.* Aquatic worms were represented by several dominant polychaetes including *Pseudopolydora kempi, Erogone lourei, Dorvillea rudolphi, Harmothoe imbricata, Neanthes succinea, Pseudopolydora paucilbranchia, Sabaco elongatus, Typosyllis* spp., *Tharyx parvus,* and the oligocheate family Tubificidae.

Many of these taxa inhabit both marine and estuarine environments, but several of the dominant organisms (e.g., the tanaid *Leptochelia dubia* and the amphipods *Ampelisca abita* and *Monocorophium acherusicum*) are almost exclusively found in the Central Bay muddy sediments (Thompson and Lowe, 2000). Based on the physical nature of the study area and the similarity of the community structure to Regional Monitoring Plan (RMP) site BC-11 and East Bay Municipal Utility District (EBMUD) sites 4, 5, and 6, near our study area, the reference condition selected for the study assemblage assessment was the marine-muddy assemblage (Thompson and Lowe, 2000).

The reference condition for the marine-muddy benthic assemblage is presented in Table 19. To determine the condition of the samples taken below the SFOBB, each sample was compared with the five metrics in Table 19 (also see Table 20). For example, the sample SF 01 had 18 taxa. As this number of taxa lies within the reference site range of 14 to 66, for this metric a score of zero is applied. If the number of taxa for SF 01 were outside this range, a score of 1 would have been applied. This is performed for each metric, and the scores are added to determine an overall score. If the overall score lies between 0 and 1, the sampling site is not impacted. A score of 2 signifies a slight impact, 3 signifies a moderate impact, and 4 to 5 signifies severe impact. With the exception of SF 02, which had a score of 1, all of the samples had a score of 0. Hence, the community structure within the SFOBB study area indicates no impact to benthic marine organisms.

Water quality and physical measurements were also taken along the transects on September 6, 2000 (see Appendix A-2). Sediment characteristics and analyte concentrations are listed in Appendix A-3. U.S. EPA has not promulgated sediment quality criteria; however, sediment quality guidelines have been developed and published by the National Oceanic and Atmospheric Administration (NOAA), the Ontario Ministry

TABLE 19 Reference condition for the marine-muddy benthic macroinvertebrate sub-assemblage[a]

Metrics	Marine-Muddy Sub-Assemblage Ranges		
	Minimum	Maximum	Mean
Number of taxa	14	66	35
Total abundance	77	4022	940
Amphipod abundance	2	3693	604
Oligochaete abundance	0	259	16
Capitella capitata abundance	0	7	1

[a] Developed by Thompson and Lowe (2000).

TABLE 20 Comparison of benthic infauna below the San Francisco-Oakland Bay Bridge (SFOBB) to the reference condition

Site	Number of Taxa	Total Abundance	Amphipod Abundance	Oligochaete Abundance	*C. capitata* Abundance	Number Outside 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.

of the Environment and Energy, and others (see Appendix A-3). Although a number of metals and PAH concentrations exceeded the sediment quality guidelines, in general, metals concentrations in sediments below the SFOBB were not greater than metals concentrations in sediments from other locations in the Bay (see Table 21). Hence, the biosurvey and sediment quality data are consistent and show that there are no effects of SFOBB runoff in the vicinity of the bridge.

I-85 and Mallard Creek

Site Description and Sampling. Mallard Creek is located in the Piedmont region of North Carolina, just north of Charlotte. It is a small- to medium-sized stream with a 34-square-mile watershed upstream of the I-85 Bridge. The average annual flow was approximately 40 cubic feet per second from 1997 to 1999 (USGS gage #0212414900), but stream flow

TABLE 21 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

	Sediment Source		
Pollutant (mg/kg)	Sediments Below SFOBB[a]	Solids on SFOBB Bridge Deck[b]	Regional Sediment 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: California Department of Transportation, 1998.
[c] Source: San Francisco Estuary Institute, 1996.

can vary significantly. For example, from 1997 to 1999 the maximum average daily flow was 2,350 cubic feet per second, and the minimum flow was 1.6 cubic feet per second.

Rapid Bioassessment Protocols (RBPs) were used in this study to identify the integrity of in-stream aquatic biota in the region of the I-85 Bridge. Benthic macroinvertebrates were sampled upstream of I-85 and at two locations downstream of I-85 in March 2000 and December 2000. One of the downstream sampling points was located directly below the bridge and was a measure of the potential effects of direct runoff on benthic macroinvertebrates. The other site, approximately 300 feet further downstream, represented completely mixed storm water/receiving water conditions. A multihabitat approach was used to evaluate the benthic invertebrate communities upstream and downstream of the I-85 Bridge. To enumerate all possible benthic invertebrate species in a stream reach, multiple habitats were sampled. Habitats sampled included the following: cobble in riffles and runs, woody debris, vegetated banks and undercut banks with emergent plants, submerged macrophytes, and sandy stream bottoms. A D-frame net was primarily used to sample the different habitats. Organisms were identified to the lowest possible taxa (e.g., species).

Habitat quality can have a significant influence on species type and abundance of benthic macroinvertebrates in a stream reach. Hence, habitat evaluation (which includes measurements of stream substrate and in-stream cover, channel morphology, and riparian and bank structure) is a critical part of RBPs and strengthens the biological comparison of reference areas (in this case upstream of the I-85 Bridge) with potentially impacted areas. Sediment was sampled at the reference and downstream sites and analyzed for metals, PAHs, TOC, and grain size. Basic water quality characteristics such as DO, temperature, pH, conductivity, and turbidity were also measured at the time of sampling.

A quantitative measure of the degree of pollutant-tolerant or pollutant-sensitive benthic species in a stream reach can be determined using a number of available metrics. These metrics are often developed by state agencies for the evaluation of biological integrity. The North Carolina Department of Environmental Health and Natural Resources (NCDEHNR) has developed several metrics, which were used by the NCHRP Project 25-13 research team to evaluate the overall condition of the benthic invertebrate populations in Mallard Creek upstream and downstream of the I-85 bridge. The NCDEHNR metrics include:

- *The EPT Biotic Index (EPTBI).* The EPTBI includes the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (EPT). These are pollutant-sensitive aquatic insects. A high EPTBI is indicative of a high-quality stream. Each EPT species is assigned a tolerance value according to its sensitivity to physical and chemical stressors. The tolerance values are used to calculate the EPTBI according to the following formula:

$$EPTBI = \frac{\left[\sum (TV_i \times N_i)\right]}{N}$$

where

TV_i = tolerance value for a given EPT species (for North Carolina),
N_i = the number of individual organisms counted for a particular ETP species, and
N = total number of individual organisms counted for all EPT species.

- *Total and EPT Taxa Richness.* The total number of taxa and EPT taxa collected.
- *The North Carolina Biotic Index (NCBI).* This index is based on tolerance values for a large number of species. A high tolerance value indicates greater tolerance to pollution. This index includes invertebrates from the orders Mollusca, Annelida, Arthropoda, and Insecta. Species in these orders were assigned tolerance values (0 to 10) by NCDEHNR, and an average tolerance value is developed for an entire population of invertebrates with the following formula:

$$NCBI = \frac{\left[\sum (TV_i \times N_i)\right]}{N}$$

where

TV_i = tolerance value for a given invertebrate species (for North Carolina),
N_i = the number of individual organisms counted for a particular invertebrate species, and
N = total number of invertebrates counted for all species.

- *Overall Bioclassification.* The overall bioclassification is developed as an average of the EPT taxa richness and the NCBI score. Appendix B-2 provides a complete description of how the overall bioclassification is determined.

Results. Data from the surveys of species type and abundance were organized by summing the number of species, applying tolerance values, classifying species into functional feeding groups, and calculating indices to evaluate the community structure and condition of benthic macroinvertebrates at Mallard Creek.

The benthic macroinvertebrate community structure within the Mallard Creek study area was dominated by oligochaetes (aquatic worms) and chironomids (true flies) in March and bivalves (clams and mussels), oligochaetes, trichopterans (caddisflies), and dipterans in December. A complete list of organisms identified in the study area is listed in Appendixes A-4 and A-5. The dominant oligochaetes were from the families Naididae and Tubificidae. Chironomids were generally the dominant dipterans, particularly *Cricotopus* sp. and *Poly-*

pedilum halterale. Cheumatopsyche sp. was the dominant trichopteran and *Corbicula fluminea* the dominant bivalve.

There were some small differences in the EPTBI and the NCBI between upstream and downstream sites. According to the EPTBI the biotic condition of the stream was “poor,” and according to the NCBI it was “fair.” Overall, the stream was classified as fair upstream and poor downstream of the bridge in March 2000 (see Table 22). A similar pattern was determined for the December 2000 survey (see Table 23) except all three sites were rated fair for the overall bioclassification.

The results of the habitat evaluation are presented in Tables 24 and 25, and a complete description of each habitat metric used in the evaluation is in Appendix B-1. Other habitat conditions such as basic water quality (e.g., pH and DO) and physical conditions (stream velocity) were evaluated for Mallard Creek and were considered in the overall habitat evaluation (see Appendixes A-6 and A-7). The fair to poor benthic invertebrate condition of the study sites was likely a function of the physical habitat of Mallard Creek (see Tables 24 and 25). Poor epifaunal substrate, riffle quality, embeddedness, and channel alteration were the primary factors responsible for a degraded stream habitat overall. The riparian zone was also of poor quality, and there was low vegetative protection, low bank stability, and a narrow vegetative zone.

To determine the relative integrity of a study site, researchers often compare it to a reference site, which is assumed to be in ideal or pristine condition. The reference site for this study, located in Mallard Creek upstream of the I-85 Bridge, was not in pristine condition. However, the aim of this study was to determine whether the bridge had had any effects on benthic invertebrate communities that were additional to other effects, not related to the bridge. For this reason, the habitat assessment for this study was designed to determine whether or not the study sites were comparable to the reference site. In March 2000, the habitat of the reference site was in better condition than both downstream sites, but all the sites were comparable in December 2000.

The concentration of metals and PAHs in sediment upstream and downstream of I-85 was low (see Appendixes A-8 and A-9). Sediment taken in March 2000 upstream of the I-85 Bridge showed higher concentrations of all metals and PAHs analyzed than sediment taken downstream, and metals and PAHs were generally higher upstream of I-85 in December.

TABLE 22 Bioassessment scores for Mallard Creek, March 2000

	Metric Value [Score]		
Metrics	**Upstream (Reference)**	**Directly Downstream of Bridge**	**300 Feet Downstream of Bridge**
Total Taxa Richness	31	26	23
EPT[a] Taxa Richness	2 [1]	2 [1]	2 [1]
NCBI[b]	6.6 [2]	7.32 [2]	7.41 [2]
EPTBI[c]	6.07	5.94	6.22
Overall Bioclassification[d]	[2]	[1]	[1]
Biological Condition			
EPT Taxa Richness	Poor	Poor	Poor
NCBI	Fair	Fair	Fair
Overall Bioclassification	Fair	Poor	Poor
Benthos Classification Criteria			
Condition	**EPTBI**	**NCBI**	**Overall Bioclassification**
Excellent	> 31	< 5.19	5
Good	24-31	5.19-5.78	4
Good-Fair	16-23	5.79-6.48	3
Fair	8-15	6.49-7.48	2
Poor	0-7	> 7.48	1

[a] Ephemeroptera, Plecoptera, and Trichoptera.
[b] North Carolina Biotic Index.
[c] EPT Biotic Index.
[d] The overall bioclassification is the average of the EPT Taxa Richness and NCBI scores with rounding based on EPT Abundance (see Appendix B-2).

TABLE 23 Bioassessment scores for Mallard Creek, December 2000

Metrics	Metric Value [Score]		
	Upstream (Reference)	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Total Taxa Richness	37	28	25
EPT[a] Taxa Richness	4 [1]	3 [1]	3 [1]
NCBI[b]	5.88 [3]	7.01 [2]	6.41 [3]
EPTBI[c]	6.44	6.20	5.93
Overall Bioclassification[d]	[2]	[2]	[2]
Biological Condition			
EPT Taxa Richness	Poor	Poor	Poor
NCBI	Good-Fair	Fair	Good-Fair
Overall Bioclassification	Fair	Fair	Fair
Benthos Classification Criteria			
Condition	**EPTBI**	**NCBI**	**Overall Bioclassification**
Excellent	>31	< 5.19	5
Good	24-31	5.19-5.78	4
Good-Fair	16-23	5.79-6.48	3
Fair	8-15	6.49-7.48	2
Poor	0-7	>7.48	1

[a] Ephemeroptera, Plecoptera, and Trichoptera.
[b] North Carolina Biotic Index.
[c] EPT Biotic Index.
[d] The overall bioclassification is the average of the EPT Taxa Richness and NCBI scores with rounding based on EPT Abundance (see Appendix B-2).

Discussion—Integrating Biological and Water Quality Data

The capacity of a water body to maintain a balanced biological community is often evaluated by (1) measurement of chemical characteristics and comparison against water quality criteria, (2) direct measurement of aquatic biota, and (3) evaluation of habitat. If the chemical, biological, and physical (habitat) integrity of a water body is maintained, then it is in "attainment" of its designated use. Attainment means that a water body capable of supporting a particular biological community is in fact supporting that designated biological community (e.g., trout in a cold water trout stream). When the indicators (chemical, biological, and physical) of attainment are considered individually, however, they may not always suggest the same conclusion. For example, biological impairment may be evident, but the impairment is due to habitat disturbance rather than chemical toxicants. A "weight of evidence" approach may be used to integrate and evaluate these metrics and determine whether a water body is in attainment or nonattainment of a designated use.

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:

1. All three groups of indices (i.e., physical, chemical-toxicological, and biological) indicate attainment;
2. Only statistics of the chemical group of indices (i.e., 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
3. Only biological indices indicate nonattainment, but impairment is caused by 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:

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

TABLE 24 Habitat assessment for Mallard Creek, March 2000

Habitat Category	Upstream (Reference)	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Substrate and Instream Cover (0-20)			
Epifaunal Substrate/Available Cover	15	11	10
Riffle Quality	14	12	11
Embeddedness	16	13	11
Channel Morphology (0-20)			
Channel Alteration	13	11	10
Sediment Deposition	11	12	11
Frequency of Riffles/Velocity-Depth Combinations	15	12	11
Channel Flow Status	15	14	11
Riparian and Bank Structure (0-10)			
Bank Vegetative Protection			
Left Bank	8	5	5
Right Bank	8	6	5
Bank Stability			
Left Bank	6	6	5
Right Bank	7	6	6
Riparian Vegetative Zone Width			
Left Bank	8	7	7
Right Bank	9	5	7
Total Score	145	120	110
Percent of Reference	100	83	76

If it has been established that a water body with a bridge crossing is not in attainment, further evaluation is required to determine if the bridge is responsible for the observed impairment. A commonsense approach to evaluating the source of impairment is presented in U.S. EPA's SIGD (U.S. EPA, 2000). This approach could be used to link together the use of chemical data, other relevant data, water quality criteria, continuous bioassays, and biosurveys. 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 presented in the SIGD is "strength of evidence" analysis. Because a bridge's region of influence is small compared with other watershed influences, it is important to determine whether there is enough evidence to identify a bridge as the cause of 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 the bridge in a watershed to localized effects near the bridge. Determining consistency of association involves considering whether the level of pollutants discharged from the bridge is consistent with the level of effects noted near the bridge. The causal considerations of consistency and coherence of evidence address whether or not the use of methods such as time-variable bioassays, continuous exposure chronic bioassays, and biosurveys consistently point 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, a toxicity determination from one time-variable bioassay alone should not lead to the conclusion of impairment. The evidence needed

TABLE 25 Habitat assessment for Mallard Creek, December 2000

Habitat Category	(Upstream) Reference	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Substrate and Instream Cover			
Epifaunal Substrate/Available Cover	11	9	6
Riffle Quality	13	13	11
Embeddedness	10	10	11
Channel Morphology			
Channel Alteration	11	12	7
Sediment Deposition	8	9	9
Frequency of Riffles/Velocity-Depth Combinations	12	10	10
Channel Flow Status	12	14	11
Riparian and Bank Structure			
Bank Vegetative Protection			
Left Bank	4	7	5
Right Bank	7	6	6
Bank Stability			
Left Bank	5	6	5
Right Bank	5	7	6
Riparian Vegetative Zone Width			
Left Bank	5	8	7
Right Bank	6	9	7
Total Score	114	120	101
Percent of Reference	100	105	89

to identify impairment could be improved by performing additional bioassays during several seasons and/or by performing an additional analysis such as a biosurvey. If localized effects are identified by a biosurvey, 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., exceedances of water quality criteria and enrichment of metals in sediment and biota) should be evaluated from a "strength of evidence" viewpoint.

Using a Weight of Evidence and Strength of Evidence Analysis Approach for the San Francisco-Oakland Bay Bridge and I-85 and Mallard Creek

Weight of Evidence

In this approach, physical, chemical, toxicological, and biosurvey data are used as indicators to determine whether a water body is achieving attainment. Runoff monitoring chemical data (i.e., chemical-toxicological indicators) are initially (and very conservatively) evaluated by comparing them to water quality criteria (see Table 26). For this type of evaluation, the average value in runoff can be compared with the 4-day and chronic criteria, and the maximum value in the range for runoff can be compared with the 1-hour and acute criteria. The concentration of lead, copper, and zinc in SFOBB runoff consistently exceeded water quality criteria for the San Francisco Bay (criteria for chromium, cadmium, and nickel were not consistently exceeded). These exceedances of criteria at the "end-of-pipe" (without dilution or fate and transport considerations) provide only the suggestion (but not evidence) of potentially adverse effects from runoff. Whole effluent toxicity testing is also included as a "chemical-toxicological indicator" according to WERF. At the SFOBB, growth and/or survival of *M. bahia* were reduced in time-variable bioassays with 100 percent runoff from two of the four storm events. For all four runoff events, however, growth and survival of *M. bahia* were not reduced with 50 percent runoff. It is expected that the free fall of runoff discharging through scupper

TABLE 26 Comparison of runoff pollutants and aquatic life water quality criteria, San Francisco-Oakland Bay Bridge (SFOBB), and I-85 and Mallard Creek (I-85)

Pollutant	SFOBB Runoff (μg/L) Range	SFOBB Runoff (μg/L) Average	Aquatic Life Water Quality Criteria (μg/L)-San Francisco Bay-(1-hour max/4-day)	I-85 Runoff (μg/L) Range	I-85 Runoff (μg/L) Average	Aquatic Life Water Quality Criteria (μg/L)-North Carolina
Cadmium	1.3-2.8	1.9	43/9.3	<1.0-1.7	1.2	2.0
Chromium	7.8-40	19	1,100/50	6.2-17	12	50
Copper	130-270	195	4.9/-	27-75	57	13 (acute)/ 9.0 (chronic)[a]
Nickel	15-36	26	140(max[b])/7.1(24 hour)	<5.0-24	57	88
Lead	51-160	103	140/5.6	7.7-23	17	25
Zinc	360-760	555	170(max[b])/58(24 hour)	73-570	278	120 (acute)/ 120 (chronic)[a]
PAHs[c]:			**(LC_{50})[d]**			**(LC_{50})[d]**
Phenanthrene	0.16-0.36	0.26	300.9	0.085-0.35	0.20	300.9
Pyrene	0.30-0.85	0.52	27.1	0.10-0.30	0.21	27.1
Fluoranthene	0.26-0.73	0.45	95.8	0.085-0.43	0.20	95.8

[a] National U.S. EPA criteria at 100 mg/L hardness (as $CaCO_3$).
[b] Instantaneous maximum.
[c] Polycyclic aromatic hydrocarbons.
[d] LC_{50}s for 14-day chronic toxicity tests using a freshwater amphipod, from Boxall and Maltby (1997).

drains and subsequent tidal dispersion and flushing would lead to dilution of the runoff to lower than 50 percent and thus eliminate toxicity. In addition, metals and PAH concentrations in sediment were not elevated near the bridge, and the biosurvey performed below the bridge did not show evidence of impairment when compared with a reference condition in the San Francisco Bay. Probably because of substantial dilution in this system, localized effects were not found. The chemical-toxicological indicators (i.e., bioassays, runoff pollutants, sediment metals, and PAHs), when considering dilution, did not consistently exceed criteria. Evidence of attainment is further supported by the biosurvey results.

The situation at the SFOBB with regard to attainment is in direct contrast to the situation at I-85 and Mallard Creek. The biosurvey results there show that Mallard Creek is impaired, and this alone provides evidence of nonattainment. In this case, the chemical-toxicological indicators such as runoff pollutants, bioassays, and sediment data can be used in a strength of evidence analysis to make a reasonable determination of whether the I-85 Bridge deck is the source of impairment in Mallard Creek.

Strength of Evidence

The biosurvey at the SFOBB showed no impairment of the biological community; thus, a strength of evidence analysis is not necessary. For the I-85 site, the concentration of copper and zinc in runoff generally exceeded criteria during runoff events, whereas the concentrations of cadmium, chromium, nickel, and lead did not exceed aquatic life water quality criteria. Again, exceedances of criteria in "end-of-pipe" runoff samples (without considering dilution in the stream) provide only the suggestion (but not evidence) of potential adverse effects. The survival and reproduction of *C. dubia* in 100 percent bridge runoff was not reduced in time-variable bioassays compared with controls with runoff from four events (see Table 14). This lack of toxicity demonstrates the importance of considering dilution and the importance of considering the degree to which pollutants exceed criteria in-stream, after mixing, when analyzing runoff quality data. It is important as well to consider how often criteria are exceeded and how many criteria are exceeded. For I-85, the pollutant concentrations are not expected to be greater than criteria after dilution is considered, and a very low toxicity risk was confirmed by the time-variable bioassays. Also, metals and PAH concentrations in sediment were greater at the reference site than at the two downstream sites. The habitat assessment (an integral part of a biosurvey) of the Mallard Creek site revealed that both the upstream and the downstream study areas provided poor habitat quality. This assessment, together with the other data gathered at the site, suggests that the I-85 Bridge is not the cause of biological impairment in Mallard Creek.

CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATION

INTRODUCTION

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 Project NCHRP 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 second volume of this report, the *Practitioner's Handbook.*

The process that the research team developed is fully described in the *Practitioner's Handbook.* Therefore, this chapter of the *Final Report* provides a brief overview of how the process was developed, including how stakeholder input was obtained and incorporated.

DEVELOPMENT OF THE *PRACTITIONER'S HANDBOOK*

The aim of the NCHRP Project 25-13 research team was to develop a handbook that met the needs of those practitioners looking for guidance in addressing questions on storm water runoff from bridges. As part of developing the *Practitioner's Handbook*, input was solicited from stakeholders from around the country. Another vital step toward creating the *Handbook* was the participation and review of NCHRP Project 25-13 panel members.

As described in Chapter 2, the process of getting input from stakeholders began with a survey of the appropriate transportation agency for each state in the United States and each province in Canada. The survey asked questions about the management techniques of states and provinces, and their issues regarding bridge deck runoff. The survey also identified key personnel associated with the topic (see "Survey Results" in Chapter 2). The project team followed up by contacting key personnel who had either identified a potential test site or expressed a willingness to participate in the making of a bridge deck runoff *Practitioner's Handbook.*

Most states do not anticipate construction of 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 need to be replaced, or significantly modified, 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.

One case where bridge deck runoff became a concern was the reconstruction of the Interstate 94 Hudson Bridge, between Wisconsin and Minnesota. WisDOT identified the Hudson Bridge as a potential case study for the development of the *Practitioner's Handbook.* As described previously in this report, the project team developed a preliminary process for evaluation of bridge deck runoff problems. WisDOT then applied the process and the appropriate methods from the preliminary draft of the *Handbook* to the case of the Hudson Bridge. Results from that first application of the *Handbook* can be found within the final *Practitioner's Handbook.*

Individuals, as well as several state DOTs, participated in a focus group for ongoing discussions about bridge deck runoff as it applied to NCHRP Project 25-13 and the *Handbook.* Participants included WisDOT, Minnesota DOT, New Hampshire DOT, Caltrans (Dragomir Bogdanic), and Dr. Dixie Griffin of Louisiana Tech University (on behalf of Louisiana DOT).

A second draft of the *Practitioner's Handbook*, one that incorporated comments from NCHRP Project 25-13 panel members and "lessons learned" from the Wisconsin case study, was developed. Each member of all the focus groups and the NCHRP Project 25-13 panel received a copy of the second draft for their review. After a review period, a meeting of all the focus groups, as one large focus group, was convened via conference call.

The conference call provided a means for practitioners to provide input on the *Handbook*, as well as to brainstorm new ideas for potential additional improvements. Focus group members also committed to contributing new information to the project team as it became available to ensure the most recent issues would be addressed. Comments from the large focus group and the NCHRP Project 25-13 panel were then incorporated into the final *Practitioner's Handbook.*

CHAPTER **4**

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Although the *Practitioner's Handbook* is designed to enable the practitioner to perform a site-specific assessment of bridge deck runoff, a number of important findings of this study are summarized in this chapter.

1. The literature review revealed a considerable body of information available on the chemical quality and loadings that can be expected from bridge runoff. This includes data for totally impervious highway sources. Unfortunately, this subset of highway runoff data generally is not readily available to bridge planners and designers. Development of a more accessible database would benefit practitioners as they implement the final process in the *Practitioner's Handbook.* Special consideration should be given to metals data included in any database that is developed or used, or to data used on a case-by-case basis by practitioners. Factors that suggest reevaluation of historical metals databases include reduced lead concentrations associated with phase-out of leaded gasoline, incidental contamination during sampling and analysis, and the need for dissolved metals data.
2. The literature review also revealed that only a small number of studies have directly assessed bridge runoff impacts, and only one of those included comprehensive field evaluation of aquatic biota. Other studies have included more comprehensive field evaluation of highway runoff impacts, but those studies generally did not isolate the effects of bridges from those of the larger highway areas that also contributed pollutants to the receiving waters. Such studies provide only qualitative insight into potential bridge effects.
3. The study survey established that the issues of storm water runoff, maintenance activities, and spills associated with bridges are rapidly becoming more prominent and difficult to address in many states. This is particularly true for larger bridges that require some form of active drainage. State and federal environmental authorities are raising these issues more frequently and often advocating drainage and containment systems that avoid direct discharge and provide for further treatment or control on land. The drivers for bridge mitigation systems are variable but often include concerns about high-quality or special resource waters (e.g., wild and scenic rivers and protected aquatic species) and the potential for hazardous material spills. Several drainage/containment systems have been built in recent years or are actively being designed or considered in a number of states, often at high cost. In the survey, state highway agencies expressed strong reservations about life-cycle costs, maintenance problems (e.g, clogging and freezing), and public safety aspects of drainage systems, especially for larger bridges. They also wanted to be sure that if mitigative measures were implemented, they would provide a real environmental benefit.
4. Bioassays to evaluate the potential toxic effect of bridge deck runoff must be modified to account for the episodic nature of runoff; hence, test organisms for bioassays should be exposed to bridge deck runoff for a length of time equal to the storm event length. These "time-variable" bioassays were performed in this study for runoff from two distinct bridges. The I-85 Bridge in North Carolina, which crosses a small stream, had, at the time of the study, a medium level of average daily traffic (ADT) at 74,000. The San Francisco-Oakland Bay Bridge (SFOBB), which crosses the San Francisco Bay, had, at the time of the study, a high ADT of 274,000. No toxicity was found in time-variable bioassays for I-85 runoff, and some toxicity was found in traditional chronic 7-day bioassays with 100 percent runoff (did not reflect runoff event duration). This demonstrates the importance of using the time-variable technique (described in this report) to accurately assess potential toxicity. There was some toxicity with 100 percent runoff from the SFOBB using the time-variable technique. There was significant toxicity with 100 percent runoff using the traditional 7-day chronic test (did not reflect runoff event length).
5. The impact of bridge deck runoff on aquatic organisms will be significantly affected by the dilution of runoff with receiving water. For example, with 50 percent SFOBB runoff and 50 percent laboratory water, no toxicity was observed for the time-variable bioassays. The free-fall energy of runoff from bridge scupper to a receiving water will promote mixing, leading to

the dilution of runoff in a receiving water. A dilution of greater than 50 percent is clearly expected at the SFOBB, thus eliminating toxicity. The effect of bridge deck runoff on aquatic organisms will likely be limited to poorly flushed systems in which dilution is low, and the exposure time is high. Dilution is also critical when assessing the effect of spills, maintenance activities, and chemical constituents of runoff.

6. An evaluation of metals data and water quality criteria for the I-85 Bridge and the SFOBB showed that copper and zinc in runoff were the metals that consistently exceeded criteria when dilution was not considered. The concentrations of copper and zinc were higher at the SFOBB than at the I-85 Bridge by a factor of 3 and 2, respectively.
7. The biosurvey results for I-85 at the Mallard Creek site demonstrate the importance of considering the effect of the upstream watershed on the physical condition (habitat) of the receiving water below the bridge deck.
8. Evaluation of chemical, bioassay, biosurvey, and habitat data should follow the “weight of evidence” and “strength of evidence” approaches. The weight of evidence approach uses the chemical, bioassay, biosurvey, and habitat data to determine if the receiving water body is impaired. If it is impaired, the strength of evidence approach can be used to determine if the bridge deck is responsible for the level of impairment observed.
9. Rainfall intensity can have an effect on the concentration of pollutants in runoff; hence, the use of the “simple method” and national monitoring data to estimate loading from bridge decks may overestimate or underestimate loads because of regional differences in precipitation intensity. The effect of rainfall intensity on pollutant loading can be evaluated with the intensity-correlation method presented in Method 11 of the *Practitioner’s Handbook.* The limitation of this method is the need for extensive monitoring data.
10. Structural problems with designing or retrofitting conveyance systems for bridges may make storm water conveyance impractical in some cases. Structural considerations include the effect of additional piping on overall bridge load, piping conflicts with structural members, and the need for expansion joints in piping. Drainage may be hindered for low-slope bridges, and assisted drainage by mechanical pumping may be infeasible in some cases.
11. When the conveyance of storm water from a bridge to an off-site best management practice (BMP) is hindered by structural problems or has been deemed impractical, a number of nonstructural BMPs may be implemented. Examples of nonstructural BMPs include inlet cleaning, street sweeping, and deicing control. New high-efficiency street-sweeping devices are now available that can remove a significant fraction of pollutants associated with small and large particles. Sweeping may be a practical alternative to structural, off-site BMPs.
12. The risk of a spill occurring on a bridge can be determined using traffic volume data (ADT), national estimates of truck accident rates (per million vehicle miles), data on the fraction of trucks that carry hazardous materials involved in accidents, and data on the fraction of hazardous material accidents that involve a spill (see Method 16, *Practitioner’s Handbook*). Local data can be used to improve the accuracy of risk estimates. The acceptable level of risk will depend on receiving water uses, stakeholder opinions, and other intangibles. One data gap regarding spills is that current hazardous materials databases generally do not identify specific chemical constituents carried by vehicles, but instead use several broad categories.
13. Because constructing storm water containment systems can be complicated and in many cases impractical, it is worthwhile to evaluate the influence of bridge deck runoff on the overall water quality of a receiving water from a watershed perspective. Hence, when appropriate, consideration should be given to methods such as mitigation banking and pollutant trading to protect the quality of a receiving water.
14. Both the literature review and the survey indicated that little, if any, field study has been focused on describing the water quality impacts of bridge maintenance activities or spills from bridges to receiving waters. Several reports have described potential impacts, and a number of management practices and other measures have been identified to reduce or minimize such impacts. A number of highway agencies, for example, are already implementing such measures for bridge cleaning and painting activities.

SUGGESTED RESEARCH

Results of the literature review, survey, and process design tasks suggested a number of areas in which additional research would make implementation of the NCHRP Project 25-13 process easier in the long term. Practitioners of the process may develop these on a case-by-case basis. Suggested research topics are listed below:

- FHWA and others have addressed most of the potential impacts of maintenance practices on water quality and recommended management measures that can usually be readily implemented. In addition, NCHRP Project 25-9 has investigated the environmental effects of construction and repair materials. However, water quality effects of maintenance practices generally have not been examined or verified with field studies.

- Many of the methods included in the process require an estimation of bridge deck storm water runoff quality for multiple constituents. As discussed in the literature review, accessing accurate information can be difficult for a number of reasons including reduced lead concentrations associated with the phase-out of leaded gasoline, incidental contamination that may have affected metals datasets, the need for dissolved metals data, and the need to focus on bridge deck (or impervious surface) runoff quality for this process. The research team recommends development of a bridge deck runoff quality constituent database that will be readily accessible by practitioners.
- Little reliable information is available on bridge runoff impacts to aquatic biota. The research team's recommendation for addressing this data gap is to apply laboratory bioassays appropriate for storm water discharges and field biosurveys. Thus, this project also included development and testing of a time-variable bioassay methodology along with use of field monitoring of the benthic macroinvertebrate community. These biological methods, along with chemical analyses of runoff and sediments, were employed at two bridge sites (I-85/ Mallard Creek in North Carolina and the SFOBB). Additional application of these methods by practitioners using the Project 25-13 *Handbook* will further increase the highway community's knowledge and interpretation of the potential effects of bridge deck runoff on aquatic biota and the potential need for mitigative strategies.
- The research team is currently aware of only one study, performed by Oregon DOT, that examined the potential impact of a hazardous material spill on a drinking water supply (Kuehn and Fletcher, 1995). This study evaluated the probability of a hazardous material spill from an adjacent highway into Clear Lake, Oregon. The study concluded that because the traffic volume of the highway was relatively low, highway improvements could make the probability of a spill low enough that the drinking water supply was not at risk. However, this study was unable to identify and quantify all of the potential human health toxicants that could be introduced into Clear Lake given a hazardous material spill event. This shortfall is primarily the result of current national hazardous material transport monitoring methods, which classify hazardous materials into a few basic categories. These categories are adequate for comparing relative risk when choosing between alternative highway routes but are less than ideal when trying to calculate the risk from specific constituents in a hazardous material spill to a receiving water.
- The primary objective of the survey was to identify mitigation practices that are being used or considered for bridge runoff. For example, the survey identified an upcoming evaluation of new street-sweeping technologies that will be undertaken by the Wisconsin DOT and the Wisconsin Department of Natural Resources. In addition, NCHRP Project 25-12 is further evaluating wet pond technology for highway applications. Such studies could lead to a reevaluation of costs and effectiveness of BMPs.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ADT: average daily traffic
BMP: best management practice
Caltrans: California Department of Transportation
CZARA: Coastal Zone Act Reauthorization Amendments of 1990
DO: dissolved oxygen
DOTs: departments of transportation
EBMUD: East Bay Municipal Utility District
EPT: Ephemeroptera, Plecoptera, and Trichoptera
EPTBI: EPT Biotic Index
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
NCBI: North Carolina Biotic Index
NCDEHNR: North Carolina Department of Environmental Health and Natural Resources
NEPA: National Environmental Policy Act
NOAA: National Oceanic and Atmospheric Administration
NOEC: no observed effect concentration (the concentration of runoff at which no toxicity occurs)
NPDES: National Pollutant Discharge Elimination System
NTR: National Toxic Rule
NURP: Nationwide Urban Runoff Program
PAH: polycyclic aromatic hydrocarbon
RBP: Rapid Bioassessment Protocol
RMP: Regional Monitoring Plan
ROW: right-of-way
SFOBB: San Francisco-Oakland Bay Bridge
SIGD: Stressor Identification Guidance Document
TCLP: toxic characteristic leaching procedure
TOC: total organic carbon
U.S. EPA: U.S. Environmental Protection Agency
USGS: U.S. Geological Survey
VPD: vehicles per day
WERF: Water Environment Research Foundation
WisDOT: Wisconsin DOT

APPENDIX A

DATA FROM THE BIOLOGICAL STUDIES

APPENDIX A-1 Benthic macroinvertebrates at the San Francisco-Oakland Bay Bridge study area

Organisms	Sta. SF 01	Sta. SF 02	Sta. SF 03	Sta. SF 04	Sta. SF 05	Sta. SF 06	Sta. SF 07	Sta. SF 08	Sta. SF 09	Sta. SF 10	Sta. SF 11	Sta. SF 12	Sta. SF 13	Sta. SF 14	Sta. SF 15
Porifera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poecilosclerida	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Platyhelminthes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Platyhelminthes	2	0	0	0	1	0	0	0	0	0	0	0	3	0	0
Cnidaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zooantharia	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Actiniaria	0	0	0	0	1	0	0	4	2	0	0	0	2	1	1
Nemertea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertea	0	0	0	0	0	0	0	3	0	0	1	0	0	1	0
Cerebratulus californiensis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Emplectonema gracile	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
Heteronemertea	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lineidae	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Annelida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Armandia brevis	0	0	1	0	0	0	0	0	0	1	0	0	1	1	0
Acrocirrus sp.	0	0	0	0	0	0	0	0	0	0	3	1	1	1	3
Capitelliadae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Capitella capitata	0	0	2	0	0	0	0	2	3	1	0	0	0	0	4
Chone sp.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
Cirraformia spirabrancha	0	0	0	0	0	0	0	3	0	0	0	0	0	1	2
Cirratulidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Dipolydora cornuta	0	0	0	0	0	0	1	3	0	0	0	0	1	0	0
Dorvillea rudolphi	0	0	0	0	0	0	2	3	1	6	5	9	5	5	44
Exogone lourei	2	1	0	2	0	0	2	9	1	6	6	7	9	19	28
Glycinde polygnatha	2	1	1	2	2	1	4	4	2	1	2	1	3	1	6
Glycinde sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Harmothoe imbricata	0	0	0	0	4	2	0	1	2	0	1	2	6	2	5
Hesionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Heteromastus sp.	1	0	0	2	2	4	0	2	1	0	0	0	0	0	0
Heteromastus filliformis	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
Leitoscoloplos pugettensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Mediomastus californiensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Mediomastus sp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Neanthus sp.	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Neanthus succinea	0	2	0	0	4	4	4	4	5	0	2	2	0	0	1
Nephtys caecoides	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Nereididae	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Orbiniidae spp.	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Phyllodoce williamsi	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Pseudopolydora paucibranchiata	0	0	0	0	0	1	2	1	2	1	8	3	12	3	5
Pseudopolydora kempi	1	37	98	0	0	0	0	0	0	0	0	0	0	0	0
Pygospio elegans	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Sabaco elongatus	0	0	0	2	0	3	8	2	7	0	0	0	0	0	1
Sphaerosyllis californiensis	0	0	0	0	0	0	1	0	0	0	0	2	0	0	2
Sphaerosyllis sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spio sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Streblospio benedicti	8	2	6	1	0	0	0	0	0	0	0	0	0	0	0
Typosyllis spp.	0	0	0	1	3	1	2	8	5	0	0	1	0	1	2
Tharyx parvus	4	2	21	0	0	0	0	0	0	0	0	0	0	0	0
Tubificidae A	0	0	0	1	1	0	1	4	1	2	0	5	1	0	3
Tubificidae B	1	1	5	0	1	6	0	12	2	1	0	2	2	2	0
Bryozoa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bowerbankia gracilis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Canopeum reticullum	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Caulibugula californica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Cryptosula pallasiana	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Ctenostomata	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Electa crustulena	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0
Electra crustulenta arctica	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hippothoa spp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Smittoidea prolifera	0	0	0	0	0	0	0	0	0	0	0	10	0	0	3
Mollusca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nudibranchia	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Bivalva	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Musculista senhousia	0	0	0	0	0	0	0	9	0	0	4	0	0	1	0
Gemma gemma	336	177	181	0	1	0	0	0	0	0	0	0	0	0	0
Venerupis philipinarum	0	0	1	0	0	0	2	3	0	0	2	0	2	3	2
Mytilus sp.	0	0	0	0	0	0	0	2	0	0	2	0	1	0	1

APPENDIX A-1 (Continued)

Organisms	Sta. SF 01	Sta. SF 02	Sta. SF 03	Sta. SF 04	Sta. SF 05	Sta. SF 06	Sta. SF 07	Sta. SF 08	Sta. SF 09	Sta. SF 10	Sta. SF 11	Sta. SF 12	Sta. SF 13	Sta. SF 14	Sta. SF 15
Arthropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Balanus crenatus	0	0	0	0	0	0	0	2	0	0	0	1	3	0	0
Tanaidacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptocheilia dubia	2	0	0	110	84	56	102	145	78	82	222	47	196	123	193
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gnorimosphaeroma oregonensis	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Synidotea laticauda	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Caprella sp.	8	7	0	7	8	3	4	6	2	6	70	1	3	3	6
Caprella natalensis	1	5	0	2	1	0	1	2	6	1	10	0	1	1	0
Caprella laeviuscula	0	0	0	10	11	0	0	0	5	1	1	0	0	0	0
Caprella equilibria	0	0	0	0	0	0	1	0	0	0	9	0	0	0	0
Ampelisca abdita	30	0	1	118	67	70	59	15	15	22	44	0	6	0	0
Amphithoe plumulosa	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0
Amphithoe sp.	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
Grandidierella japonica	56	61	166	11	1	6	33	32	6	6	29	0	0	0	1
Crassicorophium sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Monocorophium insidiosum	6	0	0	12	4	9	3	5	1	0	0	0	0	0	0
Monocorophium spp.	30	0	1	4	13	18	12	9	15	2	0	2	3	1	23
Monocorophium acherusicum	18	0	1	32	23	50	42	20	17	5	24	18	5	21	5
Decapoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cancer jordani	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3
Cancer productus	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Hemigrapsus oregonensis	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ascidacea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mogula spp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ascidacea	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
No. of Taxa	20	12	17	17	21	16	24	34	27	18	22	21	27	23	29
Total No. Individuals	511	297	491	318	235	235	290	321	191	147	449	131	274	195	354
Revised Taxa Richness	18	11	16	16	19	16	23	33	25	17	21	20	25	21	29
Total Polychetes	20	45	135	11	16	16	27	45	31	18	28	30	38	34	109
Percent of Total Abundance	3.9139	15.152	27.495	3.4591	6.8085	6.8085	9.3103	14.019	16.23	12.245	6.2361	22.901	13.869	17.436	30.791
Leptocheilia dubia															
Percent of Total Abundance	0.3914	0	0	34.591	35.745	23.83	35.172	45.171	40.838	55.782	49.443	35.878	71.533	63.077	54.52
Total Amphipods	149	73	169	196	130	157	156	89	74	43	187	21	18	26	35
Percent of Total Abundance	29.159	24.579	34.42	61.635	55.319	66.809	53.793	27.726	38.743	29.252	41.648	16.031	6.5693	13.333	9.887
Total Oligochaete	1	1	5	1	2	6	1	16	3	3	0	7	3	2	3
Percent of Total Abundance	0.1957	0.3367	1.0183	0.3145	0.8511	2.5532	0.3448	4.9844	1.5707	2.0408	0	5.3435	1.0949	1.0256	0.8475
Total Mollusca	336	177	182	0	1	0	2	14	0	0	8	0	4	5	3
Percent of Total Abundance	65.753	59.596	37.067	0	0.4255	0	0.6897	4.3614	0	0	1.7817	0	1.4599	2.5641	0.8475
Percent Dominant Taxon	65.753	59.596	36.864	37.107	35.745	29.787	35.172	45.171	40.838	55.782	49.443	35.878	71.533	63.077	54.52
Gemma gemma	X	X	X												
Ampelisca abdita				X		X									
Leptocheilia dubia					X		X	X	X	X	X	X	X	X	X

APPENDIX A-2 Basic water quality and physical characteristics for the San Francisco-Oakland Bay Bridge study area, September 6, 2000

Parameter	Units	Station SF01	Station SF02	Station SF03	Station SF04	Station SF05	Station SF06	Station SF07	Station SF08
Dissolved Oxygen	mg/L (ppm)	7.7		8.1	8.2		8.1	8.4	
Temperature	°C	17.98		18.03	18.21		18.21	18.23	
pH	units	8		8.1	8.12		8.11	8.13	
Conductivity	S/m	4.3		4.4	4.4		4.4	4.4	
Turbidity	NTU	9.9		9.9	9.4		18.2	9.1	
Salinity	%	2.8		2.8	2.8		2.8	2.9	
Total Dissolved Solids	g/L	27		27	27		27	27	
Depth to Bottom	ft	5.2	5.5	5.5	7.6	7.06	7.7	11	11.6
Percent Grain Size Distribution									
Gravel -Fine									
Sand -Coarse									
Sand- Medium		1.5							
Sand -Fine		84.8							
Silt		6.7							
Clay		7							

Parameter	Units	Station SF09	Station SF10	Station SF11	Station SF12	Station SF13	Station SF14	Station SF15
Dissolved Oxygen	mg/L (ppm)	8.6	8.5		8.7	8.7		8.4
Temperature	°C	18.39	18.4		18.45	18.15		18.25
pH	units	8.14	8.09		8.1	8.1		8.02
Conductivity	S/m	4.4	4.4		4.4	4.5		4.4
Turbidity	NTU	73	9.9		11.7	9.3		4.7
Salinity	%	2.9	2.9		2.9	2.9		2.9
Total Dissolved Solids	g/L	27	27		27	27		27
Depth to Bottom	ft	11	11.9	11	13.4	12.5	14.2	19
Percent Grain Size Distribution								
Gravel -Fine						10.6		
Sand -Coarse						18.7		
Sand- Medium						39.5		
Sand -Fine						16.2		
Silt						4.5		
Clay						10.5		

NOTE: °C = Degrees Celsius. g/L = grams per liter. ft = feet. mg/L = milligrams per liter (parts per million). NTU = Nephlometric turbidity units. S/m = Siemens per meter.

APPENDIX A-3 Metals and polycyclic aromatic hydrocarbons (PAHs) in sediment in the San Francisco-Oakland Bay Bridge study area

		Stations										Sediment Quality Guidelines			
		SF01		SF06		SF07		SF12		SF13					
Analyte	**Units**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**LEL[b]**	**ER-L[c]**	**NOAA[d]**	**ER-L[d]**
Metals															
Cadmium	mg/kg	< 0.14	0.14	< 0.22	0.22	< 0.22	0.22	< 0.18	0.18	< 0.17	0.17	0.6	1.2	0.676	1.2
Chromium	mg/kg	37[e]	0.42	83[e]	0.67	71[e]	0.65	25	0.53	160[e]	0.52	26	81	52.3	81
Copper	mg/kg	7.2	2.8	68[e]	4.5	120[e]	4.3	14	3.6	19[e]	3.5	16	34	18.7	34
Lead	mg/kg	21	0.7	36[e]	1.1	44[e]	1.1	14	0.89	42[e]	0.87	31	46.7	30.2	46.7
Nickel	mg/kg	32[e]	1.4	74[e]	2.2	66[e]	2.2	23[e]	1.8	20[e]	1.7	16	20.9	15.9	20.9
Zinc	mg/kg	50	14	150[e]	22	120	22	38	18	34	17	120	150	124	150
PAH Semivolatiles															
Acenaphthene	µg/kg	<35	35	<56	56	<54	54	< 44	44	140[e]	44		150	6.71	16
Acenaphthylene	µg/kg	<35	35	<56	56	<54	54	< 44	44	< 44	44				
Anthracene	µg/kg	<35	35	<56	56	<54	54	< 44	44	98[e]	44	220	85	46.85	85.3
Benzo(a)anthracene	µg/kg	<35	35	<56	56	<54	54	< 44	44	120[e]	44	320	230	74.83	261
Benzo(a)pyrene	µg/kg	<35	35	<56	56	<54	54	< 44	44	80	44	370	400	88.81	430
Benzo(b)fluoranthene	µg/kg	<35	35	<56	56	<54	54	< 44	44	69	44				
Benzo(g,h,I)perylene	µg/kg	<35	35	<56	56	<54	54	< 44	44	< 44	44				
Benzo(k)fluoranthene	µg/kg	<35	35	<56	56	<54	54	< 44	44	84	44	240			
Chrysene	µg/kg	<35	35	<56	56	<54	54	< 44	44	150[e]	44	340	400	107.8	384
Dibenzo(a,h)anthracene	µg/kg	<35	35	<56	56	<54	54	< 44	44	< 44	44				
Fluoranthene	µg/kg	35	35	<56	56	<54	54	< 44	44	430[e]	44	750	600	112.8	600
Fluorene	µg/kg	<35	35	<56	56	<54	54	< 44	44	140[e]	44	190	35	21.2	19
Indeno(1,2,3-cd)pyrene	µg/kg	<35	35	<56	56	<54	54	< 44	44	< 44	44				
1-Methylnaphthalene	µg/kg	<35	35	<56	56	<54	54	< 44	44	130	44				
2-Methylnaphthalene	µg/kg	<35	35	<56	56	<54	54	< 44	44	190[e]	44		65	20.2	70
Naphthalene	µg/kg	<35	35	<56	56	<54	54	< 44	44	140[e]	44		340	34.6	160
Phenanthrene	µg/kg	49	35	<56	56	<54	54	< 44	44	600[e]	44	560	225	86.7	240
Pyrene	µg/kg	<35	35	<56	56	<54	54	< 44	44	350[e]	44	490	350	152.7	665
Solids	%	71.4		44.6		46.5		56.3		57.1					
TOC[f] as NPOC[g]	mg/kg	2,300	500	11,000	1,000	13,000	1,000	63,000	1,000	65,000	5,000				

[a]EQL - Estimated Quantification Limit.
[b]LEL - Lowest Effect Level. Persaud, D., R. Jaagumagi, and A. Hayton. 1993. *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario,* Ontario Ministry of the Environment and Energy.
[c]ER-L - Effects Range-Low. Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. "Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments." *Environmental Management,* Vol. 19, No. 1, pp. 81–97.
[d]NOAA - National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Table. *HAZMAT Report 97-2.*
[e]Value is above lowest available guideline.
[f]TOC - Total Organic Carbon.
[g]NPOC - Nonpurgable Organic Carbon.

APPENDIX A-4 Benthic macroinvertebrates in Mallard Creek, North Carolina, March 2000

SPECIES	Tolerance Value[a]	Functional Feeding Groups[b]	Stations		
			Reference	Directly Downstream of Bridge	300 Feet Downstream of Bridge
MOLLUSCA					
Bivalvia					
Corbiculidae					
Corbicula fluminea	6.12	FC	23	11	
ANNELIDA					
Oligochaeta					
Haplotaxida					
Enchytraeidae	9.84	CG	10		
Lumbricidae		CG	20		
Naididae	8[c]	CG			
Nais sp.	8.88	CG	30	303	960
Tubificidae w.o.h.c.	7.11	CG	251	16	120
Limnodrilus hoffmeisteri	9.47	CG	20		120
Lumbriculida					
Lumbriculidae	7.03	CG	20		
ARTHROPODA					
Crustacea					
Decapoda					
Cambaridae					
Cambarus sp.	7.62	CG	4	3	3
Insecta					
Ephemeroptera					
Heptageniidae					
Stenonema modestum	5.5	SC		1	
Odonata					
Gomphidae					
Gomphus sp.	5.8	P	1	1	
Macromiidae					
Macromia sp.	6.16	P	1		
Megaloptera					
Corydalidae					
Corydalus cornutus	5.16	P	10		
Trichoptera					
Hydropsychidae					1
Cheumatopsyche sp.	6.22	FC	50	2	10
Hydropsyche betteni sp.	7.78	FC	1		
Coleoptera					
Dryopidae					
Helichus basalis	4.63	SC		10	
Diptera					
Ceratopogonidae					
Bezzia/Palpomyia	6.86	P	10		
Chironomidae			10	10	3
Ablabesmyia mallochi	7.19	P	29		
Chironomus sp.	9.63	CG		10	
Corynoneura sp.	6.01	CG	14		
Cricotopus sp.	7[c]	CG	334	180	297
Cricotopus/Orthocladius			102	70	380
Cricotopus tremulus	7[c]	CG			16
Cryptochironomus fulvus	6.38	P	102		
Dicrotendipes sp.	8.1	CG		10	
Eukiefferiella claripennis	5.58	CG	58	150	528
Microtendipes sp.	5.53	CG	72		
Nanocladius sp.	7.07	CG			16
Paratendipes sp.	5.11	CG	44		16
Paralauterborniella nigrohalteralis	4.77	CG		10	
Parametriocnemus lundbecki	3.65	CG	14	10	
Phaenopsectra sp.	6.5	SC		20	
Polypedilum convictum	4.93	SH	116	10	50
Polypedilum fallax	6.39	SH		10	
Polypedilum halterale	7.31	SH	131	10	66

APPENDIX A-4 (Continued)

SPECIES	Tolerance Value[a]	Functional Feeding Groups[b]	Stations: Reference	Stations: Directly Downstream of Bridge	Stations: 300 Feet Downstream of Bridge
Polypedilum illinoense	9	SH		10	16
Potthastia sp.	6.4	CG	14		16
Pseudochironomus sp.	5.36	CG	14		
Rheotanytarsus sp.	5.89	FC		10	50
Saetheria tylus	7.07	CG			148
Tanytarsus sp.	6.76	FC	276	20	33
Thienemanniella xena	5.86	CG			16
Thienemannimyia sp.	8.42	P		10	
Tribelos sp.	6.31	CG	131		
Culicidae					
Hemerodromia sp.	7.57	P		10	
Simuliidae					
Simulium sp.	4	FC	10	10	50
Tipulidae					
Tipula sp.	7.33	SH			1
Total Number of Organisms			1,922	917	2,916
Total Number of Species			31	26	23
Total Number of EPT[d] Organisms			51	3	11
NCBI[e]			6.60	7.32	7.41
EPTBI[f]			6.07	5.94	6.22

[a]North Carolina’s Tolerance Values range from 0 (for organisms very intolerant of organic wastes) to 10 (for organisms very tolerant of organic wastes).
[b]Functional Feeding Groups: SH = Shredder, CG = Collector/Gatherer, FC = Filtering Collector, SC = Scraper, and P = Predator.
[c]Hilsenhoff Tolerance Values used when North Carolina’s values were not available.
[d]Ephemeroptera, Plecoptera, and Trichoptera.
[e]North Carolina Biotic Index.
[f]EPT Biotic Index.

APPENDIX A-5 Benthic macroinvertebrates in Mallard Creek, North Carolina, December 2000

Species	Tolerance Value[a]	Functional Feeding Groups[b]	Stations: Reference	Stations: Directly Downstream of Bridge	Stations: 300 Feet Downstream of Bridge
MOLLUSCA					
Bivalvia					
Veneroida					
Corbiculidae					
Corbicula fluminea	6.12	FC			47
Gastropoda					
Basommatophora					
Ancylidae					
Ferrissia rivularis	6.55	SC			7
Planorbidae	6[c]	SC			
Menetus dilatatus	8.23	SC	10		
ANNELIDA					
Oligochaeta		CG			
Haplotaxida					
Naididae	8[c]	CG		226	
Nais communis	8.81	CG	8	791	10
Tubificidae w.o.h.c.	7.11	CG	5	113	57
Limnodrilus hoffmeisteri	9.47	CG	2		3
Lumbriculida					
Lumbriculidae	7.03	CG			3
ARTHROPODA					
Arachnoidea					
Acariformes					3
Crustacea					
Decapoda					
Cambaridae			3	2	
Insecta					
Ephemeroptera					
Heptageniidae	4[c]	SC			
Stenonema sp.	4[c]	SC		10	
Stenonema modestum	5.5	SC	1		12
Tricorythidae	4[c]	CG			
Tricorythodes sp.	5.06	CG	10		
Odonata					
Coenagrionidae	9[c]	P	1		
Argia sp.	8.17	P	10		
Gomphidae	1[c]	P			
Ophiogomphus sp.	5.54	P			3
Trichoptera					
Hydropsychidae	4[c]	FC			
Cheumatopsyche sp.	6.22	FC	535	338	41
Hydropsyche sp.	5[c]	FC			7
Hydropsyche betteni sp.	7.78	FC	100	10	
Coleoptera					
Elmidae	5[c]	CG			
Macronychus glabratus	4.58	SH	10		
Optioservus sp.	2.36	SC	10		
Stenelmis sp.	5.1	SC	20		
Diptera					
Chironomidae			90	70	20
Ablabesmyia mallochi	7.19	P	19	29	
Brillia flavifrons	5.18	SH		15	3
Corynoneura sp.	6.01	CG	115	44	
Cricotopus sp.	7[c]	CG	306	482	183
Cryptochironomus fulvus	6.38	P	19		
Dicrotendipes sp.	8.1	CG		15	
Diplocladius cultriger	7.41	CG	172	15	
Eukiefferiella claripennis	5.58	CG	19		
Microtendipes sp.	5.53	CG	19	44	7
Orthocladius sp.	5.34	CG	76	15	7
Pagastia sp.	1.77	CG		29	

APPENDIX A-5 (Continued)

Species	Tolerance Value[a]	Functional Feeding Groups[b]	Stations: Reference	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Parametriocnemus lundbecki	3.65	CG	458	277	27
Phaenopsectra sp.	6.5	SC		15	13
Polypedilum convictum	4.93	SH	134	58	30
Polypedilum fallax	6.39	SH	38		
Polypedilum halterale	7.31	SH	57		37
Polypedilum illinoense	9	SH		102	
Pseudochironomus sp.	5.36	CG	19		
Rheocricotopus robacki	7.28	CG	96	117	
Rheotanytarsus sp.	5.89	FC	96	102	7
Tanytarsus sp.	6.76	FC	153	73	7
Thienemanniella xena	5.86	CG	19		
Thienemannimyia sp.	8.42	P	76	15	
Tribelos sp.	6.31	CG	19	15	
Simuliidae	6[c]	FC			
Simulium sp.	4	FC	200	50	13
Tipulidae	3[c]	SH			
Antocha sp.	4.25	CG	20		3
Tipula sp.	7.33	SH	3	30	2
Total Number of Organisms			2948	3102	552
Total Number of Species			37	28	25
Total Number of EPT[d] Organisms			646	358	60
NCBI[e]			5.88	7.01	6.41
EPTBI[f]			6.44	6.20	5.93

[a]North Carolina's Tolerance Values range from 0 (for organisms very intolerant of organic wastes) to 10 (for organisms very tolerant of organic wastes).
[b]Functional Feeding Groups: SH = Shredder, CG = Collector/Gatherer, FC = Filtering Collector, SC = Scraper, and P = Predator.
[c]Hilsenhoff Tolerance Values used when North Carolina's values were not available.
[d]Ephemeroptera, Plecoptera, and Trichoptera.
[e]North Carolina Biotic Index.
[f]EPT Biotic Index.

APPENDIX A-6 Basic water quality and physical characteristics for Mallard Creek, March 2000

Parameter	Units	Stations Reference	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Dissolved Oxygen	mg/L	12.03	12.2	11.1
Temperature	^{o}C	10.4	12.4	11.7
pH		7.2	7.6	7.3
Conductivity	µmhos/cm	108	161	165
Turbidity	NTU	62	2.8	0.3
Stream Classification		Perennial	Perennial	Perennial
Stream Type		Warmwater	Warmwater	Warmwater
Canopy Cover		Partly shaded	Partly shaded	Partly shaded
Local Erosion		Moderate/Heavy	Moderate/Heavy	Moderate/Heavy
Velocity (cross section average)	feet/second	1.29	1.37	0.85
Predominant Land Use		Commercial/Medium Residential	Commercial/Medium Residential	Commercial/Medium Residential
High Water Mark	feet	9	9	9
Percentage of Inorganic Substrate				
Boulder		5	5	5
Cobble		10	10	5
Gravel		25	20	20
Sand		50	50	60
Silt		5	5	5
Clay		5	10	5
Percentage of Organic Substrate				
Detritus		98	100	100
Muck-mud		0	0	0
Marl		2	0	0

APPENDIX A-7 Basic water quality and physical characteristics for Mallard Creek, December 2000

Parameter	Units	Stations Reference	Directly Downstream of Bridge	300 Feet Downstream of Bridge
Dissolved Oxygen	mg/L (ppm)	15.11	14.72	15.89
Temperature	^{o}C	3.98	2.84	3.56
pH		7.6	7.57	7.59
Conductivity	µmhos/cm	169	166	172
Turbidity	NTU	NC	NC	NC
Stream Classification		Perennial	Perennial	Perennial
Stream Type		Warmwater	Warmwater	Warmwater
Canopy Cover		Partly shaded	Partly shaded	Partly shaded
Local Erosion		Moderate/Heavy	Moderate/Heavy	Moderate/Heavy
Velocity (cross section average)	feet/second	0.37	0.68	0.7
Predominant Land Use		Commercial/Medium Residential	Commercial/Medium Residential	Commercial/Medium Residential
High Water Mark	feet	9	9	9
Percentage of Inorganic Substrate				
Boulder		5	5	5
Cobble		10	10	5
Gravel		25	20	20
Sand		50	50	60
Silt		5	5	5
Clay		5	10	5
Percentage of Organic Substrate				
Detritus		100	100	100
Muck-mud		0	0	0
Marl		0	0	0

APPENDIX A-8 Metals and polycyclic aromatic hydrocarbons (PAHs) in Mallard Creek sediment taken above and below I-85, March 2000

		Stations									
		Reference		Directly Downstream of Bridge		300 Feet Downstream of Bridge					
Analyte	**Units**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**LEL[b]**	**ER-L[c]**	**NOAA[d]**	**TEC[e]**
Metals											
Cadmium	mg/kg	0.17	0.14	0.23	0.13	0.16	0.12	0.6	1.2	0.583	0.592
Chromium	mg/kg	36	0.41	23	0.4	24	0.37	26	81	36.3	56
Copper	mg/kg	7	2.7	9.5	2.7	4.3	2.5	16	34	28	28
Lead	mg/kg	2.6	0.68	2.5	0.67	1.8	0.61	31	46.7	34.2	34.2
Nickel	mg/kg	4.2	0.68	2.9	0.67	2.3	0.61	16	20.9	19.5	39.6
Zinc	mg/kg	18	2.7	17	2.7	12	2.5	120	150	94.2	159
PAH Semivolatiles											
Acenaphthene											
Acenaphthylene	μg/kg	<34	34	<34	34	<31	31				
Anthracene	μg/kg	<34	34	<34	34	<31	31				
Benzo(a)anthracene	μg/kg	<34	34	<34	34	<31	31				
Benzo(a)pyrene	μg/kg	<34	34	<34	34	<31	31				
Benzo(b)fluoranthene	μg/kg	<34	34	<34	34	<31	31				
Benzo(g,h,I)perylene	μg/kg	<34	34	<34	34	<31	31				
Benzo(k)fluoranthene	μg/kg	<34	34	<34	34	<31	31				
Chrysene	μg/kg	<34	34	<34	34	<31	31				
Dibenzo(a,h)anthracene	μg/kg	<34	34	<34	34	<31	31				
Fluoranthene	μg/kg	<34	34	<34	34	<31	31				
Fluorene	μg/kg	60	34	<34	34	<31	31	750	600	31.46	64.23
Indeno(1,2,3-cd)pyrene	μg/kg	<34	34	<34	34	<31	31				
1-Methylnaphthalene	μg/kg	<34	34	<34	34	<31	31				
2-Methylnaphthalene	μg/kg	<34	34	<34	34	<31	31				
Naphthalene	μg/kg	<34	34	<34	34	<31	31				
Phenanthrene	μg/kg	<34	34	<34	34	<31	31				
Pyrene	μg/kg	39	34	<34	34	<31	31	560	240	41.9	
	μg/kg	39	34	<34	34	<31	31	490	665	53	570
Solids	%	73.7		74.5		81.6					
TOC[f] as NPOC[g]	mg/kg	910	500	2000	500						

[a]EQL - Estimated Quantification Limit.
[b]LEL - Lowest Effect Level. Persaud, D., R. Jaagumagi, and A. Hayton. 1993. *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario,* Ontario Ministry of the Environment and Energy.
[c]ER-L - Effects Range-Low. Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. “Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments.” *Environmental Management,* Vol. 19, No. 1, pp. 81–97.
[d]NOAA - National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Table. *HAZMAT Report 97-2.*
[e]TEC - Threshold Effect Concentration. In Jones, D. S., G. W. Suter II, and R. N. Hull. 1997. “Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment—Associated Biota: 1997 Revision.” *ES/ER/TM-95/R4,* Oak Ridge National Laboratory, Oak Ridge, TN.
[f]TOC - Total Organic Carbon.
[g]NPOC - Nonpurgable Organic Carbon.

APPENDIX A-9 Metals and polycyclic aromatic hydrocarbons (PAHs) in Mallard Creek sediment taken above and below I-85, December 2000

		Stations									
		Reference		Directly Downstream		300 Feet Downstream					
Analyte	**Units**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**Results**	**EQL[a]**	**LEL[b]**	**ER-L[c]**	**NOAA[d]**	**TEC[e]**
Metals											
Cadmium	mg/kg	<0.12	0.12	<0.13	0.13	<0.13	0.13	0.6	1.2	0.583	0.592
Chromium	mg/kg	27	0.36	31	0.4	21	0.4	26	81	36.3	56
Copper	mg/kg	7.6	2.4	9.8	2.7	6.3	2.7	16	34	28	28
Lead	mg/kg	5.3	0.6	2.5	0.66	2.4	0.67	31	46.7	34.2	34.2
Nickel	mg/kg	7	1.2	4.4	1.3	3.4	1.3	16	20.9	19.5	39.6
Zinc	mg/kg	16	12	21	13	18	13	120	150	94.2	159
PAH Semivolatiles											
Acenaphthene	µg/kg	<30	30	<33	33	<34	34				
Acenaphthylene	µg/kg	<30	30	<33	33	<34	34				
Anthracene	µg/kg	<30	30	<33	33	<34	34				
Benzo(a)anthracene	µg/kg	40	30	<33	33	<34	34				
Benzo(a)pyrene	µg/kg	34	30	<33	33	<34	34				
Benzo(b)fluoranthene	µg/kg	49	30	<33	33	<34	34				
Benzo(g,h,I)perylene	µg/kg	<30	30	<33	33	<34	34				
Benzo(k)fluoranthene	µg/kg	41	30	<33	33	<34	34				
Chrysene	µg/kg	46	30	<33	33	<34	34				
Dibenzo(a,h)anthracene	µg/kg	<30	30	<33	33	<34	34				
Fluoranthene	µg/kg	69	30	<33	33	<34	34	750	600	31.46	64.23
Fluorene	µg/kg	<30	30	<33	33	<34	34				
Indeno(1,2,3-cd)pyrene	µg/kg	<30	30	<33	33	<34	34				
1-Methylnaphthalene	µg/kg	<30	30	<33	33	<34	34				
2-Methylnaphthalene	µg/kg	<30	30	<33	33	<34	34				
Naphthalene	µg/kg	<30	30	<33	33	<34	34				
Phenanthrene	µg/kg	<30	30	<33	33	<34	34	560	240	41.9	
Pyrene	µg/kg	76	30	<33	33	<34	34	490	665	53	570
Solids	%	83.2		75.5		74.5					
TOC[f] as NPOC[g]	mg/kg	870	500	920	500	780	500				

[a]EQL - Estimated Quantification Limit.
[b]LEL - Lowest Effect Level. Persaud, D., R. Jaagumagi, and A. Hayton. 1993. *Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario,* Ontario Ministry of the Environment and Energy.
[c]ER-L - Effects Range-Low. Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. “Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments.” *Environmental Management*, Vol. 19, No. 1, pp. 81–97.
[d]NOAA - National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Table. *HAZMAT Report 97-2.*
[e]TEC - Threshold Effect Concentration. In Jones, D. S., G. W. Suter II, and R. N. Hull. 1997. “Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment—Associated Biota: 1997 Revision.” *ES/ER/TM-95/R4*, Oak Ridge National Laboratory, Oak Ridge, TN.
[f]TOC - Total Organic Carbon.
[g]NPOC - Nonpurgable Organic Carbon.

APPENDIX B

BIOLOGICAL METRICS FOR MALLARD CREEK STUDY SITE

APPENDIX B-1

DEFINITION OF METRICS USED IN THE I-85 AND MALLARD CREEK HABITAT ASSESSMENT

Substrate and Instream Cover — Measure of the Quantity and Quality of Habitat for Benthic Invertebrates

Scoring

	Optimal	Suboptimal	Marginal	Poor
	(16-20)	(11-15)	(6-10)	(0-5)

Metrics

Epifaunal Sustrate/Available Cover	Measure of natural structures such as cobbles, fallen trees, branches, and sites for spawning
Riffle Quality	Refers to the type of substrate in riffles
Embeddedness	The extent to which rocks are covered/embedded by sediment

Channel Morphology — A Description of the Physical and Hydraulic Condition of a Stream

Scoring

	Optimal	Suboptimal	Marginal	Poor
	(16-20)	(11-15)	(6-10)	(0-5)

Metrics

Channel Alteration	Physical changes in the shape (e.g., straightening) of a stream channel
Sediment Deposition	Accumulation of solids in the stream bottom
Frequency of Riffles/Velocity-Depth Combinations	Streams with multiple combinations of riffles with different velocity and depth provide habitat diversity, streams with a high number of velocity-depth regimes are given high scores
Channel Flow Status	A measure of how filled a stream is with water, streams with more bank exposure are given a lower score

Riparian and Bank Structure — A Measure of the Integrity of the Stream Bank and Riparian Zone

Scoring

	Optimal	Suboptimal	Marginal	Poor
	(9-10)	(6-8)	(3-5)	(0-2)

Metrics

Bank Vegetative Protection	A measure of the vegetation in the near-stream riparian zone
Bank Stability	Evaluation of the degree of stream bank erosion
Riparian Vegetative Zone Width	Width of vegetation from the stream bank edge through the riparian zone

APPENDIX B-2

METHOD FOR DETERMINING THE OVERALL BIOCLASSIFICATION DESIGNATION OF NORTH CAROLINA STREAMS

For Piedmont streams, the overall bioclassification of a stream is developed from the North Carolina Biotic Index (NCBI) and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness (total number of different species that are in the orders Ephemeroptera, Plecoptera, and Trichoptera). Equal weight is given to both the NCBI value and EPT taxa richness value when assigning the overall bioclassifications. A score of zero to five is applied to the NCBI and the EPT taxa richness in Table B2-1. A simple average of the NCBI score (zero to five) and the EPT taxa richness score (zero to five) provides the overall bioclassification score. The overall bioclassification score (zero to five) is used to determine an overall bioclassification ranging from "poor" to "excellent" as shown in Table B2-2.

In some cases, an average of the NCBI and the taxa richness score will be exactly halfway between two classifications (e.g., 1.5, 2.5, 3.5). In this case, it is necessary to round the score up or down to develop an overall bioclassification. This rounding problem is addressed by using EPT abundance values (i.e., total number of organisms counted that are in the orders Ephemeroptera, Plecoptera, and Trichoptera) that were determined for the field samples. For each score, round down if the EPT abundance determined for the field samples is less than the EPT abundance value shown in Table B2-3, and round up if it is equal to or above the value.

TABLE B2-1 Overall bioclassification score for North Carolina Biotic Index (NCBI) values and Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness values

Overall Bioclassification Score	NCBI Value	EPTBI[a] Value
5 (Excellent)	<5.14	>33
4.6	5.14-5.18	32-33
4.4	5.19-5.23	30-31
4 (Good)	5.24-5.73	26-29
3.6	5.74-5.78	24-25
3.4	5.79-5.83	22-23
3 (Good-Fair)	5.84-6.43	18-21
2.6	6.44-6.48	16-17
2.4	6.49-6.53	14-15
2 (Fair)	6.54-7.43	10-13
1.6	7.44-7.48	8-9
1.4	7.49-7.53	6-7
1 (Poor)	>7.53	0-5

[a] EPT Biotic Index

TABLE B2-2 Overall bioclassification

Overall Bioclassification Score	Condition
5	Excellent
4	Good
3	Good-Fair
2	Fair
1	Poor

TABLE B2-3 Rounding bioclassification of overall score based on Ephemeroptera, Plecoptera, and Trichoptera (EPT) abundance

Overall Bioclassification Score	EPT Abundance Value
4.5	135
3.5	103
2.5	71
1.5	38

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