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Assessment of Impacts of Bridge Deck Runoff Contaminants on Receiving Waters

This NCHRP Digest describes the findings of Phase I of NCHRP Project 25-13, "Assessment of Impacts of Bridge Deck Runoff Contaminants on Receiving Waters," conducted by CH2M HILL, Inc. The digest was prepared by Thomas V. Dupuis, Principal Investigator, from the interim report.

SUMMARY OF FINDINGS

This digest summarizes the initial results of in-progress research associated with the assessment of bridge deck runoff impacts on receiving waters. It presents the findings of a critical review of scientific and technical literature on water-quality impacts and assessment methods for bridge deck runoff, maintenance practices, and spills. The digest also presents the results of a survey of state and provincial highway agencies addressing mitigation measures currently employed or being considered for bridge deck runoff, maintenance activities, and spills. This information will be especially timely for practitioners interested in current literature and practices associated with bridge runoff.

A considerable body of information is available on the chemical quality and loadings that can be expected from bridges. It includes data for totally impervious highway sources. However, this subset of highway runoff data generally is not readily available to bridge planners and designers. A more accessible database needs to be developed to assist in implementation of the final process. Special consideration should be given to metals data included in any database that is developed or used or to data used by practitioners on a case-by-case basis. Factors that suggest reevaluation of historical metals databases include reduced lead concentrations associated with phaseout of leaded gasoline, incidental contamination during sampling and analysis, and the need for dissolved metals data.

The literature review also revealed that several studies have directly assessed bridge runoff impacts, and only one of those studies included comprehensive field evaluation of aquatic biota. Other studies have included more comprehensive field evaluation of highway runoff impacts, but those studies did not isolate the effects of bridges from those of the larger highway areas that also contribute pollutants to the receiving waters. Such studies provide only qualitative insight into potential bridge effects. There have been several laboratory bioassay studies of highway and bridge runoff effects on biota, but these do not all reliably reflect organism responses to short-term, intermittent storm water discharges (i.e., do not account for timescale considerations). This lack of definitive knowledge of biological responses is perhaps the most significant data gap revealed by the literature review. Additional testing in Phase II could fill the data gap and also provide validation of laboratory and field test methodologies that can be implemented in the final process.

Both the literature review and the survey indicated that there have been few, if any, detailed field studies of water-quality impacts of bridge maintenance activities or spills from bridges to receiving waters. Several reports have described potential impacts, and there are a number of management practices and other measures that 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. Although no studies were found that directly assessed the impacts and risks of spills specifically for bridges, a body of information was identified concerning assessment of spills on highways. This information allowed the research team to

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include a preliminary spill assessment method for the process. One important data gap regarding spills is that current hazardous material databases generally do not identify specific chemical constituents carried by vehicles but instead use several broad categories. A method to fill this gap is presented in the *Suggested Research* section, but it is expected to be beyond the scope of current funding for NCHRP 25-13.

The survey revealed that the issue of storm water runoff, maintenance activities, and spills associated with bridges is rapidly becoming more prominent and difficult to address in many states. This is particularly true for the 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, protected aquatic species, etc.) 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. 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 the larger bridges. They also expressed a strong desire that, if mitigative measures are to be implemented, they should provide a real environmental benefit.

INTRODUCTION AND RESEARCH APPROACH

The object of NCHRP Project 25-13 is to develop a rational process for identifying, assessing, and managing bridge deck runoff that could adversely affect beneficial uses of receiving waters. The process is to address on-site and off-site mitigation options, including watershed-based considerations and pollution trading. It also must be applicable to inland and coastal settings and should address project-specific and cumulative impacts on receiving waters.

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

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

The U.S. Environmental Protection Agency (U.S. EPA) 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 such practices. Among the practices U.S. EPA recommends are that the designer:

- 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 ft (121.9 m) long 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 new 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 where avoiding direct discharge is impractical, excessively costly, or provides little actual environmental benefit. Consequently, there is a need for a reliable process that highway designers and planners can use in the very early stages of scoping new bridge projects and also to make sound, common-sense decisions about the need to retrofit existing bridges.

There is an extensive body of information regarding highway runoff quality, receiving water impacts, assessment methods, and mitigation measures, but 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 physical features at the receiving water crossing:

- There is no flexibility regarding the size of the footprint; i.e., lateral right-of-way (ROW) does not exist on which to build mitigation measures, storm water must drain by gravity back to land, or mitigation measures must be located on the bridge at substantial cost.
- The topography and approach slope at some bridge locations preclude design or retrofit for gravity drainage back to land.
- The length of some bridges precludes gravity drainage to land. Should costly storm water pumping systems be considered? If so, what should the design criteria be, and what should be done in cases where even pumping

is not practicable? What are the structural and safety considerations for such drainage systems?

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 part of the highway drainage area. Thus, highways often, although not always, contribute a small fraction of the overall pollutant load to a given receiving water body and bridges contribute even less. This 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 (e.g., off-site mitigation, or pollutant trading).

Although it is recognized that site-specific effects must be considered thoroughly in any watershed or trading concept, there are opportunities related to a variety of storm water pollutants—including nutrients, bacteria, sediments/solids, and even metals or organic compounds—if the problem is not localized near the bridge site (e.g., metals accumulations in sediments in a downstream reservoir that are subject to metals inputs from a variety of sources). The 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, 1996b). Highway agencies should logically be a part of that process. Our survey of state Departments of Transportation (DOTs) revealed that Washington State and Delaware DOTs have already established watershed-based programs for banking, off-site mitigation, and trading alternatives for storm water as well as other resources.

NCHRP Project 25-13 will focus on developing a process that state DOTs can use to make sound, scientifically defensible decisions on the need for, and the extent of, control of bridge deck runoff. Achieving the panel's specific project objectives will depend on addressing at least the following issues:

- There is a need to determine what the existing literature tells us about the effects of bridge deck storm water runoff on receiving waters. If it is determined that there are key data gaps, we must then determine how filling those gaps should be incorporated into the decision-making process.
- The process developed must be cost-effective and fully integrated with the current and future regulatory frame work, recognizing that there is a new regulatory focus; i.e., highways are or will soon be directly regulated by the National Pollutant Discharge Elimination System (NPDES), existing Phase I and upcoming Phase II, in addition to requirements pursuant to the National Environmental Policy Act, CZARA, and Clean Water Act Section 404 permits and Section 401 water-quality certification.
- There is a need to go beyond simple but potentially misleading analyses focused on chemical concentrations in the water column. This includes toxicological and aquatic biological assessments. Current risk assessment procedures also need to be evaluated.
- There is a need to bring in 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.
- There is a need to reevaluate the historical databases for some constituents, especially metals at trace-level concentrations.

This digest covers Tasks 1 and 2 of the Working Plan for NCHRP Project 25-13. A brief description of these tasks is provided below.

Task 1 (Review Literature on Impact Methods and Data) assembled and critically reviewed U.S. and international literature on water-quality impacts associated with bridge deck runoff, maintenance activities, and spills. It also 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 and assessments of the effects of highway and bridge deck runoff, maintenance, and spills on water quality.

Task 2 (Survey Practices and Costs) developed a survey questionnaire that was mailed to all U.S. state and Canadian highway agencies as well as key researchers in the field. The survey elicited information on mitigation measures being used or considered for bridge runoff and also solicited information on ongoing or recently completed studies of bridge runoff impacts and likely bridges/locations to serve as cases to test the process (Task 5). CH2M HILL sought follow-up information by making telephone calls to survey respondents as needed.

The information and background developed in Tasks 1 and 2 provided the basis for design of a preliminary process to evaluate and develop mitigative strategies, where necessary, for bridge deck storm water runoff. The process must be clearly described and readily understood by highway practitioners. The process uses conceptual flowcharts and reference tables to guide users through the process and identify analyses and related processes that need to considered. The process is being tested and refined in Phase II of the research and thus is not presented herein. Ultimately the process will be published in a practitioner's handbook.

FINDINGS

Literature Review

The object of the literature review was to identify, collect, and critically review published papers and reports, as well as 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 key 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 the following researchers and experts by telephone to help focus the search:

- Robert Pitt, of the University of Alabama, a national expert in the area of urban storm water runoff;
- Roger Bannerman, of the Wisconsin Department of Natural Resources, who has conducted extensive research on urban runoff effects on freshwater systems;
- Chris Yoder, a bioassessment expert from the Ohio EPA;
- Frederick Weisner, of the Wisconsin Department of Transportation;
- Michael Barrett, of the University of Texas, who has studied the characteristics and treatability of highway runoff;
- Brian Mar, of the University of Washington, who has been studying urban and highway runoff issues for many years;
- Harold Hunt, of Caltrans, an aquatic biologist who has done various highway runoff and aquatic studies and is a member of the California Aquatic Bioassessment Workgroup;
- Robert Traver, of Villanova University, who is doing highway runoff best management practice (BMP) research;
- John Sansalone, of the University of Cincinnati, who is doing research on highway runoff characteristics and BMPs;
- Heidi Bell, with U.S. EPA, in relation to development of national sediment criteria;
- Ed Herricks, of the University of Illinois, who is conducting a research project for the Water Environment Research Foundation regarding timescale considerations for urban storm water toxicity;
- Greg Grenato, with the Massachusetts-Rhode Island U.S. Geological Survey (USGS) District, who has conducted research on deicing chemicals and highway runoff and also is compiling a document database for highway runoff quality; and
- Phillipe Ross, of the Citadel, who is researching 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 will aid in this study.

The literature review involved searching the following databases 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, the University of California Institute of Transportation Studies Library, the Northwestern University Transportation Library, and the U.S. EPA Office of Water and USGS highway runoff web sites. These databases were selected because they cover the breadth of issues involved in our study.

Finally, we 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 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 to document the relative sources of the pollutants and their movement and migration within the highway ROW (Kobriger et al. 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 1985a) 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 evalu-

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, extensive sampling (159 events) at 6 sites, 3 in Milwaukee, plus Nashville, Denver, and Harrisburg; sampling was conducted in 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 et al. 1984)	Identified and quantified background pollutant loadings to the highway system (e.g., atmospheric deposition), pollutants originating from the highway system (e.g., 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 4 sites, Sacramento, Milwaukee, Harrisburg, and North Carolina. Sampling was conducted from 1978–82; migration paths evaluated for metals included wet and dry atmospheric deposition, dry weather accumulation on the pavement and in the 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 1-3). 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 (e.g., rural vs. urban) strongly influence constituent concentrations and loadings. Major modes of migration of particulate and soluble constituents (including metals) within the highway ROW and to receiving waters are still valid.
Phase III, Effects of Highway Runoff on Receiving Waters (Dupuis et al. 1985)	Analyzed the effects of constituents in the receiving waters. Extensive physical, chemical, and biological sampling of runoff and receiving waters at 3 sites (1 lake and 2 streams), 2 in Wisconsin and 1 in North Carolina. Sampling was conducted from 1980–83. 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 (i.e., 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 2 rural streams studied in Phase III. Adverse biological impacts from pollutants from highways were not identified for the

TABLE 1 (Continued) Summary of previous FHWA highway runoff program

FHWA Project	Description of Scope of Work	Key Findings
		3 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 ADT less than 30,000 vehicles per day (VPD) would not adversely affect aquatic biota.
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 storm water 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 BMPs.

ation of retention, detention, and overland flow BMPs (Dorman et al. 1996). The scope and some of the key findings of the more recent FHWA efforts are also listed in Table 1.

A number of state DOTs, USGS, universities, and other entities also have conducted a wide variety of highway runoff studies over the last two decades, many in cooperation with FHWA. In particular, relevant research has been conducted in Florida (Birkett et al. 1979; Evink 1980; Hampson 1986; Irwin and Lasey 1979; McKinzie and Irwin 1983; Schiffer 1988, 1989a, 1989b, 1989c; Wanielista et al. 1980; Yousef et al. 1984, 1990), Washington (Farris et al. 1973; Horner and Mar 1982; Mar et al. 1982; Newbry and Yonge 1996; Portele et al. 1982; Mar and Horner 1982; Chui 1982; Horner and Mar 1985; Horner 1985), Michigan (CH2M HILL 1998), Ohio (Sansalone et al. 1995; Sansalone et al. 1996), South Carolina (Ross 1996), Texas (Barrett et al. 1995), Virginia (Mudre 1985; Van Hassel et al. 1980), New York (Adams Kszos et al. 1990; Bucholz 1986), and California (Kerri et al. 1985; Racin et al. 1982; Winters and Gidley 1980).

The USGS is working with FHWA to catalogue references concerning highway runoff quality, although the study does not address impacts of highway runoff on receiving waters, nor will it provide a central repository for accessing highway runoff quality data (personal communication, Greg Granato, USGS, with Keith Pilgrim, CH2M HILL, December 1997). The USGS reference database will include documents from: (1) state DOT studies, (2) FHWA reports, (3) other sources such as academic papers, and (4) USGS reports.

NCHRP has also sponsored, or is sponsoring, several research projects and has published other documents relevant to Project 25-13. These include Projects 25-1, 25-9, and 25-12 (see Table 2) and several *Synthesis of Highway Practice* documents (Copas and Pennock 1979; Appleman 1992). Projects 25-9 and 25-12 are currently in progress.

Additional research and documentation regarding highway runoff quality, environmental effects, and BMP strategies have been developed in countries outside the United States, including Canada (Lorant 1992), England (Balades et al. 1985; Davis and George 1987; Dussart 1984; Hewitt and Rashed 1992; Maltby et al. 1995a, 1995b; Perry and McIntyre 1987; Shutes 1984), Norway (Baekken 1994; Gjessing et al. 1984a, 1984b), Germany (Dannecker and Stechmann 1990; Lange 1990; Stotz 1990), and Japan (Ishimaru et al. 1990; Yamane et al. 1990).

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

Relatively fewer studies have assessed actual receiving water effects. Of those, most measured highway pollutants in runoff and receiving waters or inferred effects or the lack

TABLE 2 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 in providing wildlife habits, 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 requirements of the research objectives. 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 near 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 Groundwaters	Construction and repair materials formerly were viewed as being innocuous and hence not of 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 identifying potentially mobile constituents from highway construction and repair materials and their possible impacts on surface water and groundwater. 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, Styrofoam, 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.

thereof based exclusively on runoff concentrations relative to ambient water-quality criteria. Some also measured sediment accumulations or uptake into the tissue of biological organisms but were unable to relate such concentrations to adverse impacts on the biota or beneficial uses of the receiving water. Several studies included laboratory bioassays with highway runoff, but none accounted for the frequency/duration, timescale issues that are critical to storm water runoff assessment. A relatively small number 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, fewer still attempted to study bridge runoff specifically or isolate bridge effects from those of the larger 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, there are a number of observations and lessons learned from the urban and highway runoff literature that can be used to inform the process being developed for NCHRP Project 25-13. These are summarized below.

Sources and Types of Pollutants. Table 3 summarizes typical highway 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, polynuclear aro-

TABLE 2 (Continued) Summary of other NCHRP highway runoff research projects

NCHRP Projects	Description of Scope of Work
NCHRP Project 25-12 Wet Detention Pond Design for Highway Runoff Pollution Control	There are many BMPs that 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 storm water 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. 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 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 will 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.

matic hydrocarbons (PAHs) have also been investigated from a toxicity perspective (Dupuis et al. 1985b; Hewitt and Rashed 1992; Hoffman et al. 1985; Ishimaru et al. 1990; Perry and McIntyre 1987; Yamane et al. 1990).

The chemical characteristics of bridge deck runoff have not been extensively documented. Although several studies have focused specifically on bridge deck runoff (Adams Kszos et al. 1990; Dupuis et al., 1985b; 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 et al. 1984). Of the six field sites for a Michigan DOT study, bridge deck runoff was sampled at two sites, and runoff from one other impervious site was also sampled (CH2M HILL 1998).

Predictive procedures have been developed to estimate the runoff quality based on site characteristics such as average daily traffic, 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). As with all urban and rural runoff, chemical quality can vary considerably from storm to storm and from location to location. However, the database generally is sufficiently robust to develop reasonable statistically based estimates of chemical quality for most constituents of concern for water-quality impact assessment (note: special considerations for metals are discussed later).

These studies have generally shown that various constituents in undiluted highway runoff can at times exceed federal and state ambient water-quality criteria. This of course 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 are 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 became substantially lower over time as FHWA's studies 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 about 60 percent of the median event mean value recorded during U.S. EPA's Nationwide Urban Runoff Program 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

TABLE 3 Highway runoff constituents and their primary sources (Kobriger et al. 1984)

Constituent	Primary Source
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead[a]	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Auto 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, pesticides	Spraying of highway ROWs, 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] Significant reductions in lead were observed at the Milwaukee, Wisconsin, site from earlier studies. The reductions were directly related to reductions in sales of leaded gasoline.

FHWA database probably substantially overestimates lead concentrations and loadings from highways and may need to be reevaluated for this NCHRP process.

Because metals are ubiquitous in the environment, incidental and inadvertent contamination of water samples occurs when standard sampling and analytical methods are used, even when due diligence is exercised. The U.S. EPA, USGS, and many states now recognize that such contamination is prevalent in the historical metals databases (Telliard 1995; USGS 1994; Webb 1992; Windom et al. 1991) and USGS recently began using only clean techniques for its national ambient surface water monitoring program. Table 4 summarizes the difference between data collected with clean techniques and data collected previously by traditional procedures.

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 but, most important, historical ambient background concentrations are probably invalid. Because one object of NCHRP Project 25-13 is to include background quality in the evaluation process, the issue of the validity of the historical database must be addressed.

Bioavailability of Metals. In the aquatic environment, the species and forms in which constituents exist determine toxic effects as illustrated for metals. Only the bioavailable species and forms are toxic to aquatic life. For copper, for example, it is the divalent free cation and possibly some inorganic complexes that have substantial toxicity, whereas particulate, dissolved organic, and most inorganic complexes are significantly less toxic.

Over the last several years, the U.S. EPA and many states have reevaluated their approach to metal toxicity

(Prothro 1993). The key element of this reevaluation is that the 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-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. Due to 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 further recognized by many in the scientific community (SETAC 1997) and codified in U.S. EPA's National Toxic Rule (NTR) (U.S. EPA 1995b). Use of dissolved criteria was incorporated into FHWA's latest assessment guidance (Driscoll et al. 1990), but the criteria need to be updated to reflect 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-mm filter). For most metals even the "dissolved" fraction may overestimate toxicity because some metal complexes smaller than 0.45 mm exert minimal toxicity. Many receiving waters contain naturally occurring substances that bind to metals and reduce their bioavailability. As shown in Table 1, concentrations of dissolved metals in highway runoff, even based on 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 it difficult to compare historical metals concentrations with current metals criteria.

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 recent guidance for the water effect ratio procedure, which is used to adjust national or statewide aquatic life metals criteria to site-specific criteria based on 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 makes a provision 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 where mitigation measures would be very costly and their real environmental benefit may be questionable.

Timescale and Probabilistic Considerations for Aquatic Toxicity. There has been much recent debate and litigation 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 is particularly relevant for the short-term exposure periods typical of storm water runoff. Because ambient criteria are based on fairly long exposure periods (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; SETAC 1997).

One of the more comprehensive assessments of timescale considerations for urban wet weather discharges was recently completed for the Water Environment Research Foundation (Herricks et al. 1998). The study included 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. Some of the conclusions reached that have relevance to the NCHRP Project 25-13 process include the following:

- It is important to have a measure of hydrograph response in parallel with toxicity assessment and to apply test systems appropriate to timescale of exposure.
- No single test system adequately meets all criteria for assessment of aquatic life impacts, but modifications to standard test systems can provide the means to assess postexposure responses of test organisms.
- Toxicity tests on more than 50 storm event samples consistently showed moderate to high in-pipe toxicity, but in-pipe toxicity did not always result in receiving water impact as measured by in situ tests or biosurveys.
- There were no fundamental differences in the characteristics of the toxic response to wet weather events that could be attributable to regional characteristics.

The researchers also noted the following key research needs: (1) monitoring fundamental organism processes and identifying specific mechanisms of effect; (2) pollutant accumulations and fate in sediment as related to wet weather discharges; (3) effects of physical stress on organisms and

TABLE 4 Comparison of results for traditional and clean methods for different locations

Location	Metal	Traditional Methods (mg/L)	Clean Methods (mg/L)	Data Source
Paper Mill Effluent, Wisconsin	Copper	11	2.38	CH2M HILL,
	Silver	1.1	0.004	unpublished
Paper Mill Upstream, Wisconsin	Copper	6.1	0.5	CH2M HILL,
	Silver	1.2	0.004	unpublished
Upper Mississippi River	Cadmium	3	0.016	Windom 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	0.000071 to	CH2M HILL,
		0.320	0.00937	unpublished
East Coast Rivers	Cadmium	0.33	0.011	Windom 1991
	Copper	2.9	1	
	Lead	46	2.7	
	Zinc	0.72	0.007	
Chippewa River	Cadmium	0.36	0.0103	Webb 1992
	Copper	3.5	1.3	
	Zinc	8.2	1.1	
Wisconsin River	Copper	3.2	0.27	Webb 1992
	Zinc	3.8	0.42	
Mississippi River	Cadmium	2.5	0.033	Webb 1992
	Copper	12	1.9	
	Lead	22	0.84	
	Zinc	28	2.4	

impact of unstable habitat on timescale toxicity; and (4) translation of advancement of scientific understanding to guide management and regulatory programs, including predictive tools and models (Herricks et al. 1998). Others have noted the lack of fundamental understanding of specific mechanisms of effect of metals on aquatic biota as a key research need to developing management and regulatory approaches (SETAC 1997).

Pollutant Accumulation in Sediments. Some researchers and reviewers have noted that although wet weather discharges may not cause toxicity to aquatic life due to 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 certainly was suggested for urban storm water runoff (Masterson and Bannerman 1994; 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 did not indicate such "enrichments" for some receiving waters (Dupuis et al. 1985a; Farris et al. 1973). These sediment concentrations have rarely been given the perspective of attendant impacts on aquatic biota or been compared with sediment quality criteria. Although U.S. EPA is developing national guidance for sediment quality criteria for several organics, including PAHs, and metals (U.S. EPA 1993a, 1993c, 1994a, 1997), few states to date have adopted enforceable sediment quality standards or specific implementing procedures.

Watershed Considerations. As noted in *Introduction and Research Approach*, U.S. EPA and most states are moving quickly toward a broad focus on watersheds and ecosystems (U.S. EPA 1996a, 1996b). This suggests that NCHRP Project 15-13 should include consideration of the relative sources of pollutants within a watershed (e.g., loading analyses) and opportunities, where appropriate, for pollutant trading, off-site mitigation, and banking.

FHWA and 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 [i.e., average daily traffic (ADT) = 25,500 vehicles per day (VPD)] discharging at several locations near the stream's headwaters.

One other research team has reported that pollutant loads (i.e., 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 critically to examine this result but, given the relatively large degree of urbanization and significant upstream area that exist in the watershed, has some reservation about the conclusion.

Biological Impacts of Highway Storm Water Runoff. Although not dealing exclusively with bridge deck runoff impacts, there have been a number of studies of highway runoff water quality that provide qualitative insight into the potential effects of bridge runoff. These include field studies (biosurveys) and laboratory bioassays. General methods and conclusions from these studies are presented in Table 5. Note that all the laboratory bioassay studies conducted to date and described in the table 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

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

Bridge painting is probably the most common bridge maintenance practice and the one with potentially the greatest adverse effects on the receiving water. Painting activities contribute blasting abrasives and paint chips (often leaded paint) into the receiving waters below the bridge. Surveys have indicated that as much as 80 percent of 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 it reaches the receiving water (Dalton, Dalton, Newport/URS 1985a).

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

Another maintenance practice, road surface treatment (seal-coating), was investigated by FHWA (Dalton, Dalton, Newport/URS 1985b). Storm water runoff samples from a road surface that recently had been treated with an asphalt emulsion were analyzed by 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 present at concentrations below detectable levels in all samples.

Overall, FHWA's study concluded that most highway maintenance practices that could affect water quality adversely can be minimized or reduced through readily available control practices or BMPs. An NCHRP report notes that fully enclosed containment structures are capable of recovering 85 to 90 percent of abrasives, paint particles, and dust for simple spans, but this type of containment is not feasible for high trusses or other complex structures (Appleman 1992). These issues are addressed in more detail in the preliminary process.

As noted above, NCHRP Project 25-9 is evaluating environmental effects of construction and repair materials on surface and groundwaters. The results of this study will be incorporated as appropriate into the NCHRP 25-13 process when they are available.

The literature review did not identify any specific studies of water-quality impacts caused by spills from bridges, but it did lead to several general studies of spills on highways, including risk assessment and mitigative/avoidance methods. The survey and follow-up calls revealed one highly relevant and comprehensive risk analysis by 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 preliminary process.

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 in southeastern Wisconsin west of Milwaukee (Dupuis et al. 1985a). This site represents the single most-comprehensive field study of bridge deck runoff effects on receiving water found in the literature. The site, including sampling stations, is shown in Figure 1. The

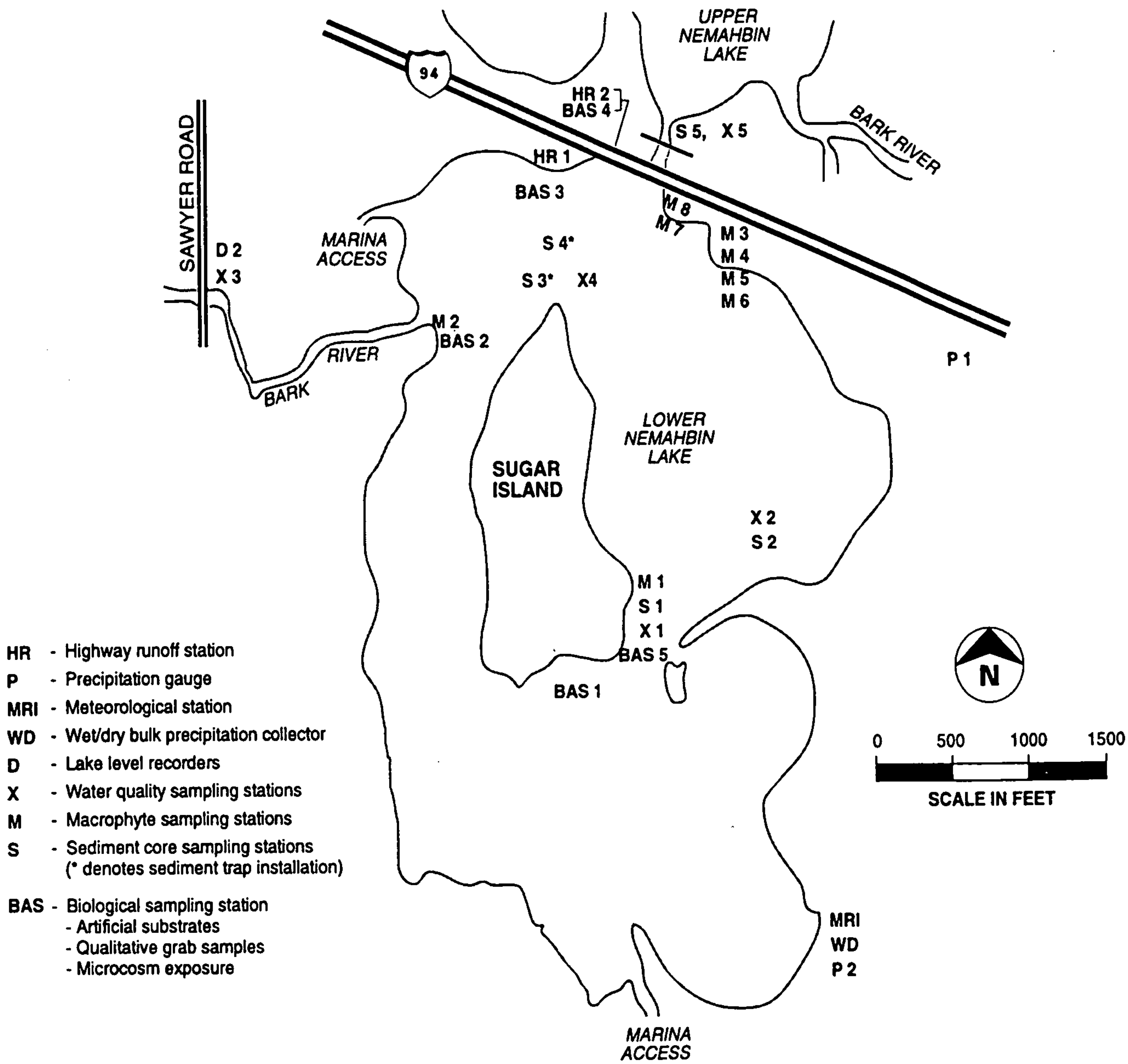

Figure 1. I-94/Lower Nemahbin Lake—sampling station locations.

ADT at the site during the 1-year period was 15,600 VPD. The site contained an elevated 1400-ft-long (426.7 m), 1-acre curbed bridge deck for the east-bound lane containing regularly spaced open scupper discharging directly to the lake. The ADT on the east-bound bridge deck alone was 7,500 VPD. In addition to other sampling at the site, the bridge deck study components quantified:

- 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 invertebrates and periphyton immediately adjacent to the station HR2 scupper discharge point (station BAS4) by 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) with six different species of aquatic organisms (station BAS4).

Although the study found that there were 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 im-

TABLE 5 Summary of biological data for highway runoff studies

Study	Biological Sampling Component	Relevant Results/Conclusions
Wisconsin Hwy. 15 (now I-43); ADT = 7,400; snow melt runoff from grassy ditch drainage; (Dupuis et al. 1985a)	Laboratory acute toxicity bioassays with undiluted runoff using 5 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 due to 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 5 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 (i.e., 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 & 50,000 (Portele et al. 1982)	Laboratory bioassays using 3 species—*Selenastrum capricornutum* (green algae), *Daphnia magna*, and rainbow trout; tested a range of runoff concentrations (i.e., dilution factors) and compared toxicity of direct roadway runoff to that allowed to run through a 60-meter 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.

pact of these enrichments is minimal. Specific conclusions related to biological data from this study are presented in Table 6. 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 (Yousef et al. 1984; Wanielista et al. 1980). These lakes receive bridge drainage directly from scuppers at some locations and after it is discharged to grassy floodplains or detained in ponds before discharge at other locations. The ADT on I-4 at Lake Ivanhoe was 110,000 VPD; at Lake Lucien it was 42,000 VPD. 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 (*Hydrilla* and *Typha*) and one algal (*Spyrogyra*) species and in benthic organisms (crustaceans, mollusks, and annelids).

The researchers concluded that plant species generally exhibited significantly higher metals concentrations when exposed to direct scupper inputs compared with locations where runoff has 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 scupper discharges should be avoided at high

TABLE 5 (Continued) Summary of biological data for highway runoff studies

Study	Biological Sampling Component	Relevant Results/Conclusions
Newly constructed I-295 crossing six small streams north of Richmond, VA; ADT = 12,000; (Mudre 1985)	2½-year post-construction 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. Only 3 of 7 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 these results were mixed, with sufficient variability in the data and the habitat conditions to preclude definitive conclusions.
Highway E6 (Oslo) adjacent to Lake Padderudvann; ADT = 19,400 (Gjessing et al. 1984a)	Lab bioassays: 7-day tests with heterotrophic organisms (i.e., 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 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.

traffic sites where the receiving water is small and landlocked.

Ochlockonee, Wakulla, and Braden Rivers, Florida. The focus of this study was to determine whether bridge design features and construction methods had affected biota adversely (Birkett et al. 1979). The study was not designed specifically to 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 invertebrates were sampled at each bridge, including transects upstream, directly beneath

TABLE 5 (Continued) Summary of biological data for highway runoff studies

Study	Biological Sampling Component	Relevant Results/Conclusions
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; ADT not specified, but assumed high due to 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 storm water outfalls, leading to "worst-case" analysis, as noted by authors; toxicity identification evaluation (TIE) also conducted using benthic amphipod (*Gammarus pulex*).	Increased concentrations of PAHs and several metals (cadmium, chromium, lead and zinc) found in downstream sediments; differences in benthic macroinvertebrate diversity and composition detected at 4 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.

each bridge, and downstream. Plants also were sampled at the Wakulla River site. The authors did not provide ADT data for the 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. For this study, laboratory bioassays were conducted with 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 different percentages of bridge runoff for periods varying from 4 to 12 days. Phytoplankton assays were conducted monthly 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 species commonly used for bioassays, 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 (1982–1984) 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 in the largest inland lake in western New York. ADT information for Route 17 was not provided. There were no significant differences in soluble metals or salt concentrations between near-bridge and control stations, leading the author to conclude that the bridge is not having a detectable impact on water quality near the bridge.

TABLE 6 Summary of biological sampling at I-94/Lower Nemahbin Lake site (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 m (65 ft) 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 3 species of aquatic insects—*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 (inlake flow-through cells containing test organisms) using 5 indigenous and 1 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 due to runoff was observed compared to controls.

Laboratory bioassays with runoff from the Lake Chautauqua Bridge and young-of-the-year sunfish (*Lepomis macrochirus*) also were conducted in a later study (Adams 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. Given the high degree of dilution that occurs in Lake Chautauqua, the study indicated that in-lake impacts are unlikely. As with all other historical lab bioassay tests with highway runoff, this study did not consider the time-scale factors associated with storm water runoff.

Indian River, Florida. This study investigated the hydrodynamics, water quality, sediment quality, and aquatic biota (benthic macroinvertebrates and sea grass) near 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 the bridges was not provided. Extensive data were collected upstream, downstream, and between the 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 sea grasses were found other than those caused by physical damage (i.e., dredging). Similarly, the only significant difference in macroinvertebrate communities found was reduced diversity in summer at some downstream stations, which was attributable to factors other than the bridges, such as low content of dissolved oxygen. There were no significant differences in macroinvertebrate communities in the sea grasses at bridge stations or downstream compared with upstream locations.

Isle of Palms Connector, South Carolina. The Isle of Palms connector between Mt. Pleasant and the islands of Isle of Palms and Sullivan's Island was constructed to replace a drawbridge damaged by Hurricane Hugo in 1989 (Ross 1996). Because of concerns about potential water-quality impacts of runoff from the new bridge on shellfish beds in the estuarine system it would cross (Swinton Creek), an elaborate bridge drainage system that cost about $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, that receive runoff that would otherwise be discharged directly to Swinton Creek; and (2) a closed-pipe collection system that originally was 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 (personal communication, Phillipe Ross, of the Citadel, with Keith Pilgrim, CH2M HILL 1997). 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 also used to test 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 the first year to 13,500 VPD in 1995.

The overall results of the testing for both sediment and water bioassays thus far have been mixed, with some tests showing significant differences in response but most tests showing stimulatory effects or no significant differences compared with controls. Further studies are 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 effects of the bridge on aquatic sediments or biota in the estuary. The quality and toxicity of the samples are not indicative of what would occur in the receiving waters if the bridge drainage system were not in place. This is because 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 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 concentrations of certain pollutants, 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, indicated that direct scupper drainage, while increasing metals concentrations in near-scupper surficial sediments, did not have significant 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 (i.e., fewer than 30,000 VPD), rural highways do not cause significant impacts (FHWA 1987).[1] The research team notes that Mudre's results were mixed, with some biotic parameters appearing to be sensitive to metals contamination; but there was sufficient variability 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 whether differences were statistically significant.

Several studies completed since FHWA's Phase III have indicated that relatively high traffic highways can adversely affect aquatic biota in relatively small streams and lakes. All these studies, as well as Mudre's and Baekken's studies, involved drainage of substantial parts of the ROW other than just the bridges to the receiving waters and therefore do not shed much light on quantitative effects of bridges alone. These studies also generally show that the spatial extent of impact in the receiving water tends to be 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 provided mixed signals about the aquatic toxicity of highway runoff, with some indicating no significant impacts even at high traffic locations and others indicating some or substantial toxicity, particularly with undiluted runoff and when runoff samples had high salt content because of deicing activity. All the bioassay tests with bridge and highway runoff may be misleading, however, because they were conducted by 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

[1]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 fewer than 30,000 VPD. Note that Caltrans 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) based on analysis of Caltrans data (Racin et al. 1982) and as yet unpublished FHWA data from its Phase II program.

much more significant pollution sources (Evink 1980). The Isle of Palms connector studies are still in progress and the one report reviewed to date does not provide meaningful results to the NCHRP Project 25-13 research team.

There have been few, if any, detailed field studies of water-quality impacts of bridge maintenance activities or spills from bridges to receiving waters. Several reports have described potential or hypothetical impacts, and there are a number of management practices and other measures that 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 specifically for bridges, a body of information was identified concerning assessment of spills on highways.

Survey Results

Approach and General Results

Surveys were sent to environmental managers and bridge design experts in 50 state transportation agencies and 8 Canadian provinces and to other selected university researchers. The proposed 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 7 summarizes 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 avoidance of direct storm water discharges from new small bridges. Wisconsin DOT noted that nearly all small bridges in the state have open-rail drainage. For new small bridges, it is typical for storm water to be conveyed over the surface and to the end of the bridge deck to a drain inlet that leads to discharge by grassy ditch or some sort of BMP such as a pond. States that explicitly noted that they follow this policy include Florida, Minnesota, Oregon, Washington, Massachusetts, Delaware, Nevada, Maine, New Jersey, Utah, New Mexico, and Idaho.

Other states might follow this policy but did not explicitly mention it. Regardless, state DOTs have identified this practice as effective and of minimum cost.

Nearly all states expressed disapproval of the potential widespread use of elaborate structural mitigation systems. The most commonly held concern with the use of structural mitigation systems included maintenance difficulties (i.e., clogging, freezing), costs or less than optimal use of public dollars, weakening of the bridge's structural integrity, retention of storm water on the bridge deck causing a safety hazard, feasibility, and questionable environmental benefit. Bridge scupper clogging was cited as a chronic problem that would be exacerbated by 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 by an elbow. The piping usually exits 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 also to uncleanable systems. 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. South Carolina DOT indicated that it is their opinion that the bridge drainage pans and enclosed collection system for the Isle of Palms connector, discussed in more detail in the *Literature Review* section, were not needed in light of FHWA requirements and the amount of traffic involved. Detailed descriptions or plans for many of these systems have been collected by the NCHRP 25-13 research team.

Mitigative Drivers

Permitting a new storm water discharge is often a major regulatory hurdle for most state DOTs. Building a new or a replacement bridge often depends on receipt of a federal 404, state 401, or NPDES storm water permit for the new point source discharge. Receipt of the permit, however, depends on a wide array of state- and site-specific circumstances. For example, permit receipt may depend on 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, or 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 impervious surfaces tributary to the Sound. In Illinois and Georgia, easements across forest preserves were not granted unless storm water from the bridge deck was mitigated. The endangered Pallid Sturgeon of the Missouri River was the driving force behind the use of mitigation for the Page Avenue extension bridge. 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.

TABLE 7 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–Bay Bridge in San Francisco	NPDES permit conditions	Drainage: $1.5 million, BMP: $150,000	maintenance budget, training of maintenance crew	Bay Bridge in Oakland
Colorado	No	—	—	—	cost, effectiveness, maintenance	none identified
Connecticut	Response Pending					
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	response pending	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 Rec. Area	data requested	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	data requested	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
Minnesota	Yes	multiple locations	401 water quality certification, concern for hazardous material spills, environmental group protest	$25,000 to $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	—	—	—	—	US 90 and the Pascagoula River (estuary)

TABLE 7 (Continued) 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
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, EPA, State DEP, and citizen group action, primary concern is drinking water	$300,000 for additional storm water piping and framing, labor and pond cost not included	excessive cost	multiples site, 9 other bridge crossings planned
New Jersey	No	—	—	—	—	none identified
New Mexico	Yes	location not identified	401 water quality certification, NPDES storm water 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	ODOT 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
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

TABLE 7 (Continued) 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
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 (e.g., possibility of explosion of spill materials in enclosed drainage system)	multiple sites; esp. 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					

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 belief that bridge deck storm water could somehow impact the receiving water or that it added to the degraded conditions of an urban water body. The wide range of reasons behind structural mitigation drove the research team to recognize that the process design must be flexible to account for the multiple driving factors behind the concerns of many groups.

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 to off-site wetland, and cost share on regional treatment off-site. Other states that mentioned use of compensating mitigation include Rhode Island, Maine, Massachusetts, and Delaware. Storm water banking is also used by Delaware (memorandum of understanding between Delaware DOT and state environmental agency) for non-bridge construction projects to reduce the inefficient use of many 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. However, the cost is lower and the mitigation systems used are typically more effective.

Interviews with Washington State, Tennessee, and Oregon revealed concern for impacts of steel bridge maintenance activities. If a bridge is washed in Tennessee, a 5-ft-long (1.52 m) test section is washed and the resultant water is collected. The water is tested (toxicity characterization leachate procedure [TCLP test]), and if it is considered hazardous all the wash water is collected and disposed of as hazardous material. If it is not hazardous, it can be either collected or filtered (filtrate must meet state water-quality criteria for lead, chromium, and solids) and then discharged to the receiving water. Tennessee also collects the wastewater from grinding a concrete bridge deck, because the high pH of the wastewater slurry has been identified as toxic.

Source reduction is another way to mitigate pollutant loading from a bridge deck. Wisconsin DOT, in cooperation with the Wisconsin Department of Natural Resources, was to begin testing new highly efficient street-sweeping units on highways in the spring of 1998. Another source reduction technique identified in the interviews is traffic routing (for hazardous material or livestock carriers).

CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

A considerable body of information is available on the chemical quality and loadings that can be expected from bridges. It includes data for totally impervious highway sources. However, this subset of highway runoff data generally is not readily available to bridge planners and designers. A more accessible database needs to be developed to assist in implementation of the final process. Special consideration should be given to metals data included in any database that is developed or used or to data used by practitioners on a case-by-case basis. Factors that suggest reevaluation of historical metals databases include reduced lead concentrations associated with phaseout of leaded gasoline, incidental contamination during sampling and analysis, and the need for dissolved metals data.

The literature review also revealed that several 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 did not isolate the effects of bridges from those of the larger highway areas that also contribute pollutants to the receiving waters. Such studies provide only qualitative insight into potential bridge effects. There have been several laboratory bioassay studies of highway and bridge runoff effects on biota, but they do not all reliably reflect organism responses to short-term, intermittent storm water discharges (i.e., do not account for timescale considerations). This lack of definitive knowledge of biological responses is perhaps the most significant data gap revealed by the literature review. Additional testing in Phase II could fill the data gap and also provide validation of laboratory and field test methodologies that can be implemented in the final process.

Both the literature review and the survey indicated that there have been few, if any, detailed field studies of water-quality impacts of bridge maintenance activities or spills from bridges to receiving waters. Several reports have described potential impacts, and there are a number of management practices and other measures that 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. Although no studies were found that directly assessed the impacts and risks of spills specifically for bridges, a body of information was identified concerning assessment of spills on highways. This information allowed the research team to include a preliminary spill assessment method for the process. One important 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. A method to fill this gap is presented in the *Suggested Research* section below, but it is expected to be beyond the scope of current funding for NCHRP 25-13.

The survey revealed that the issue of storm water runoff, maintenance activities, and spills associated with bridges is rapidly becoming more prominent and difficult to address in many states. This is particularly true for the larger bridges that require some form of active drainage. State and federal environmental authorities are raising these issues more frequently and often advocating for 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, protected aquatic species, etc.) 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. 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 the larger bridges. They also expressed a strong desire that, if mitigative measures are to be implemented, they should provide a real environmental benefit.

Although there are several data gaps that should be addressed before the NCHRP Project 25-13 process is finalized, the research team designed a preliminary process that includes a combination of flowcharts, tables, and specific assessment methods that can be used to address as many of the water-quality concerns about bridges as could be identified through the literature review and survey. This preliminary process will be refined through Phase II activities, including obtaining stakeholder feedback from several focus groups.

Suggested Research

Results of the literature review, survey, and process design tasks suggest a number of topics for which additional research would be useful for development and long-term ease of implementation of the NCHRP 25-13 process. Some may be accomplished within the current scope and budget for the project, whereas others may have to be addressed with as-yet-unidentified funds or developed on a case-by-case basis by practitioners of the process. Suggested research topics are listed below.

- Water-quality effects of maintenance practices generally have not been examined with field studies. FHWA and others, however, have addressed most of the potential impacts and recommend management measures that, for the most part, can be readily implemented. In addition, NCHRP Project 25-9 is investigating environmental effects of construction and repair materials. Consequently, the research team does not recommend a major effort under NCHRP Project 25-13, although maintenance practices could be considered at one or more of the Phase II test sites.

- The survey revealed that construction of bridges over high-quality or sensitive receiving waters, such as Outstanding National Resource Waters, can be highly controversial and difficult. An evaluation at such a site would be useful to address many of the concerns often raised. The research team suggests that at least one of the test sites for the process be one of these types of waters.
- Many of the methods included in the preliminary process require an estimation of bridge deck storm water runoff quality for multiple constituents. For a variety of reasons discussed in the *Literature Review* section, including reduced lead concentrations associated with phaseout of leaded gasoline, incidental contamination that may have affected metals data sets, 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. The scope and budget of Project 25-13 do not provide for database development, but the team's recommended approach to obtaining relevant data is included in the preliminary process.
- There is a paucity of reliable information available on impacts of bridge runoff on aquatic biota. The research team's recommended approach to address this data gap is to apply laboratory bioassays appropriate for storm water discharges and field biosurveys. Phase II funds are earmarked for this purpose.
- The research team is aware of only one study, by Oregon DOT, that examined the potential impact of a hazardous material spill in 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 traffic volume of the highway was low enough that, with highway improvements, the probability of a spill was small enough to conclude the drinking water supply was not at risk. However, this study was unable to identify and quantify all 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 risk from specific constituents in a hazardous material spill to a drinking water supply. A method to fill this gap has been developed by the research team, but it is beyond the scope of funding for NCHRP 25-13. It is described in the preliminary for practitioners' consideration where appropriate.
- The object of the survey was primarily to identify mitigation practices being used or considered for bridge runoff. The research team anticipates that a number of these applications will be further examined as part of Phase II of this project. The survey identified an upcoming evaluation of new street sweeping technologies that will be undertaken by Wisconsin DOT and 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. The research team proposes to continue to track such studies over the course of Project 25-13.

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REFERENCES

Abt Associates, "Speed of Action of Metals' Acute Toxicity to Aquatic Life." Prepared for U.S. EPA (Dec. 14, 1995).

Adams Kszos, L., et al., "Toxicity of Chautauqua Lake Bridge Runoff to Young-of-the-Year Sunfish (*Lepomis macrochirus*)." *Bulletin of Environmental Contamination and Toxicology,* Vol. 45, No. 6 (Dec. 1990) pp. 923–30.

Appleman, B. R., "Bridge Paint: Removal, Containment, and Disposal." *NCHRP Synthesis of Practice No. 176*, Transportation Research Board, National Research Council, Washington, DC (Feb. 1992).

Balades, J. D., et al., "Chronic Pollution of Intercity Motorway Runoff Waters." *Water Science Technology*, Vol. 17, No. 6/7 (1985) pp. 1165–1174.

Barrett, M. E., et al., "Water Quality and Quantity Impacts of Highway Construction and Operation: Summary and Conclusions." Technical Report CRWR 266, University of Texas at Austin (Nov. 1995).

Birkett, B. F., et al., "Effects of Bridging on Biological Productivity and Diversity." Report No. FL-ER-9-79. Prepared for Florida DOT (Oct. 1979).

Bucholz, R. W., "The Chemical Composition of Road-Runoff and Its Effect on Phytoplankton, Attached Algae, and Water Quality in Chautauqua Lake, N.Y." M.S. Thesis, State University College, New York (May 1986).

Chui, T. W., et al., "Pollutant Loading Model for Highway Runoff." *Journal of the Environmental Engineering Division, Proceedings of ASCE*, Vol. 108, No. EE6 (Dec. 1982).

CH2M HILL, "Highway Stormwater Runoff Sampling and Analysis." Final draft prepared for Michigan DOT (Feb. 1998).

Copas, T. L. and Pennock, H. A., "Bridge Drainage Systems." *NCHRP Synthesis of Practice No. 67*, Transportation Research Board, National Research Council, Washington, DC (1979).

Dalton, Dalton, and Newport/URS, "Highway Maintenance Impacts to Water Quality—Executive Summary, Volume I." Report No. FHWA/RD-85/057 (March 1985a).

Dalton, Dalton, and Newport/URS, "Investigations of Impacts of Selected Highway Maintenance Practices on Water Quality—Volume II." Report No. FHWA/RD-85/058 (March 1985b).

Dannecker, W., and Stechmann, H., "Substance Load in Rainwater Runoff from Different Streets in Hamburg." *Science of the Total Environment*, Vol. 93 (April 1990) pp. 385–392.

Davis, J. B., and George, J. J. , "Benthic Invertebrates as Indicators of Urban and Motorway Discharges." *Science of the Total Environment*, Vol. 59 (1987) pp. 291–302.

Dorman, M.E. et al. "Retention, Detention, and Overland Flow While Pollutant Removal from Highway Stormwater Runoff, Volume I: Research Report." Report No. FHWA-RD-96-095 (Nov. 1996).

Driscoll, E. G., et al., "Pollutant Loadings and Impacts from Highway Stormwater Runoff, Volume I: Design Procedure." Report No. FHWA-RD-88-006 (April 1990).

Dupuis, T. V., et al., "Effects of Highway Runoff on Receiving Waters, Volume II: Research Report." Report No. FHWA/RD-84/063 (Aug. 1985a).

Dupuis, T. V., et al., "Effects of Highway Runoff on Receiving Waters, Volume III: Resource Document for Environmental Assessments." Report No. FHWA/RD-84/064 (March 1985b).

Dupuis, T. V., et al., "Effects of Highway Runoff on Receiving Waters, Volume IV: Procedural Guidelines for Environmental Assessments." Report No. FHWA/RD-84/065 (July 1985c).

Dussart, G., "Effects of Motorway Run-off on the Ecology of Stream Algae." *Water Pollution Control*, Vol. 83, No. 3 (March 1984) pp. 409–415.

Evink, G. L., "Studies of Causeways in the Indian River, Florida." Report No. FL-ER-7-80, Florida DOT (1980).

Farris, G., et al., "Freeway Runoff from the I-90 Corridor." Department of Highways, Washington Highway Commission (May 1973).

Federal Highway Administration. "Technical Summary—Effects of Highway Runoff on Receiving Waters." Report No. FHWA/RD-84/062-066 (June 1987).

Gjessing, E., et al., "Acute Toxicity and Chemical Characteristics of Moderately Polluted Runoff from Highways." *Science of the Total Environment*, Vol. 33 (Feb. 15, 1984a) pp. 225–232.

Gjessing, E., et al., "Effect of Highway Runoff on Lake Water Quality." *Science of the Total Environment*, Vol. 33 (Feb. 15, 1984b) pp. 245–257.

Gupta, M. K., et al., "Constituents of Highway Runoff, Volume IV: Characteristics of Runoff from Operating Highways—Research Report." Report No. FHWA/RD-81/045 (Feb. 1981).

Hampson, P. S., "Effects of Detention on Water Quality of Two Stormwater Detention Ponds Receiving Highway Surface Runoff in Jacksonville, Florida." USGS Water Resources Investigations Report No. 86-4151 (1986).

Herricks, E., et al., "Time-Scale Toxicity in Aquatic Ecosystems." Prepared for Water Environment Research Foundation, Project No. 92-BAR-1 (Jan. 1998).

Hewitt, C. N., and Rashed, M. B., "Removal Rates of Selected Pollutants in the Runoff Waters from a Major Rural Highway." *Water Research,* Vol. 26, No. 3 (March 1992) pp. 311–319.

Hoffman, E. J., et al., "Stormwater Runoff from Highways." *Water, Air, and Soil Pollution*, Vol. 25 (1985) pp. 349–364.

Horner, R. R., "Highway Runoff Water Quality Research Implementation Manual." Prepared for Washington State DOT (Aug. 1985).

Horner, R. R., and Mar, B. W., "Guide for Water Quality Impact Assessment of Highway Operations and Maintenance." Prepared for Washington State DOT (Sept. 1982).

Horner, R. R., and Mar, B. W., "Assessing the Impacts of Operating Highways on Aquatic Ecosystems." *Transportation Research Record 1017*, National Research Council, Washington, DC (1985) pp. 47-55.

Irwin, G. A., and Lasey, G. I., "Water-Quality of Runoff from a Rural Highway Bridge Near Tallahassee, Florida." Report No. FL-ER-4-79, prepared for Florida DOT (1979).

Ishimaru, T., et al., "Risk Assessment of Drinking Water in a Reservoir Contaminated by PAHs Originated from Road Traffic." *Science of the Total Environment,* Vol. 93 (April 1990) pp. 125–130.

Kerri, K. D., et al., "Forecasting Pollutant Loads from Highway Runoff." *Transportation Research Record 1017*, National Research Council, Washington, DC (1985) pp. 39-46.

Kobriger, N. P., et al., "Guidelines for the Management of Highway Runoff on Wetlands." *NCHRP Report 264*, Transportation Research Board, National Research Council, Washington, DC (Nov. 1983).

Kobriger, N. P., et al., "Sources and Migration of Highway Runoff Pollutants—Volume III: Research Report." Report No. FHWA/RD-84/059 (1984).

Kuehn, E., and Fletcher, W., "Risk Analysis: Potential for Hazardous Materials Spills to Clear Lake." Oregon DOT (Nov. 1995).

Lange, G., "Design and Construction of Treatment Processes for Highway Runoff in the FRG." *Science of the Total Environment*, Vol. 93 (April 1990) pp. 499–506.

Lorant, F. I., "Highway Runoff Water Quality Literature Review." Report No. MAT-92-13, prepared for Ontario Ministry of Transportation (April 1992).

Maltby, L., et al., "The Effects of Motorway Runoff on Freshwater Ecosystems: 1. Field Study." *Environmental Toxicology and Chemistry*, Vol. 14, No. 6 (1995a) pp. 1079–1092.

Maltby, L., et al., "The Effects of Motorway Runoff on Freshwater Ecosystems: 2. Identifying Major Toxicants." *Environmental Toxicology and Chemistry*, Vol. 14, No. 6 (1995b) pp. 1093–1101.

Mar, B. W., et al., "Summary—Washington State Highway Runoff Water Quality Study, 1977–1982." Prepared for Washington State DOT (Sept. 1982).

Mar, B. W., and Horner, R. R., "A Predictive Model for Highway Runoff Pollutant Concentrations and Loadings." Proceedings of Stormwater and Water Quality Management Modeling Users Group Meeting, EPA-600/9-8, Washington, DC (March 25–26, 1982).

Masterson, J. P., and Bannerman, R. T., "Impacts of Stormwater Runoff on Urban Streams in Milwaukee County, Wisconsin." Proceedings of the American Water Resources Association, National Symposium on Water Quality (Nov. 1994).

McKinzie, D. J., and Irwin, G. A., "Water-Quality Assessment of Stormwater Runoff from a Heavily Used Urban Highway Bridge in Miami, Florida." Report No. FL-ER-25-84, prepared for Florida DOT (Dec. 1983).

Mudre, J. M., "An Analysis of the Contamination by and Effects of Highway-Generated Heavy Metals on Roadside Stream Ecosystems." Doctoral Dissertation, Virginia Polytechnic Institute and State University (June 6, 1985).

Mudre, J. M., and Ney, J. J., "Patterns of Accumulation of Heavy Metals in the Sediment of Roadside Streams." *Archives of Environmental Contamination and Toxicology*, Vol. 15 (1986) pp. 489–493.

Newbry, G. P., and Yonge, D. R., "The Retardation of Heavy Metals in Stormwater Runoff by Highway Grass Strips." Report No. WA-RD-404.1, conducted for Washington State DOT (May 1996).

Novotny, V., "Methodology for Ascertaining Aquatic Risks by Stormwater Discharges." RIVERTECH96, 1st Int. Conf. on New Emerging Concepts for Rivers, Chicago, IL, Proc. (Sept. 22–26, 1996) pp. 348–355.

Perry, R., and McIntyre, A. E., "Oil and Polynuclear Aromatic Hydrocarbon Contamination of Road Runoff—A Comparison of Treatment Procedures." *Oil in Freshwater: Chemistry, Biology, Countermeasure Technology*, Pergamon Press, New York (1987).

Pitt, R. E., *Biological Effects of Urban Runoff Discharges*. CRC Press, Boca Raton, FL (1995) chap. 9.

Pitt, R. E., et al., "Urban Stormwater Toxic Pollutants: Assessment, Sources, and Treatability." *Water Environment Research*, Vol. 67, No. 3 (May/June 1995) pp. 260–275.

Portele, G. J., et al., "Effects of Seattle Area Highway Stormwater Runoff on Aquatic Biota." Prepared for Washington State DOT (Jan. 1982).

Prothro, M., "Office of Water Policy and Technical Guidance on Interpretation and Implementation of Aquatic Life Metals Criteria." U.S. EPA Memorandum (Oct. 1, 1993).

Racin, J. A., "Additional Open Comment on Interim Report for NCHRP Project 25-13." Unpublished material. (April 6, 1998).

Racin, J. A., et al., "Estimating Highway Runoff Quality." Report No. FHWA/CA/TL-82/11 (1982).

Ross, P., "Second Yearly Report on Isle of Palms Connector." Unpublished report.

Sansalone, J. J., et al., "Correlation Between Heavy Metals and Suspended Solids in Highway Runoff—Implications for Control Strategies." Prepared for Transportation Research Board, National Research Council, Washington, DC (April 1995).

Sansalone J. J. et al., "Relationship Between Particle Size Distribution and Specific Surface Area of Urban Roadway Stormwater Solids." Prepared for Transportation Research Board, National Research Council (July 1996).

Schiffer, D. M., "Effects of Pretreatment of Highway Runoff on Quality of Wetland Bed Sediments." AWRA Coastal Water Resources Symposium, Wilmington, NC, Proc. (1988).

Schiffer, D. M., "Effects of Highway Runoff on Water Quality of Two Wetlands in Central Florida." USGS Water Resources Investigations Report No. 88-4200 (1989a).

Schiffer, D. M., "Water-Quality Variability in a Central Florida Wetland Receiving Highway Runoff." *Water Laws and Management*, AWRA (1989b).

Schiffer, D. M., "Effects of Three Highway-Runoff Detention Methods on Water Quality of the Surficial Aquifer System in Central Florida." USGS Water Resources Investigations Report No. 88-4170 (1989c).

Schutes, R. B. E., "Influence of Surface Runoff on the Macroinvertebrate Fauna of an Urban Stream." *Science of the Total Environment,* Vol. 33 (1984) pp. 271-282.

Society of Environmental Toxicology and Chemistry (SETAC), "Reassessment of Metals Criteria for Aquatic Life Protection." February 1996 Pellston Workshop, Pensacola, FL, Proc. (1997).

Stotz, G., "Decontamination of Highway Surface Runoff in the FRG." *Science of the Total Environment*, Vol. 93 (April 1990) pp. 507–524.

Telliard, W. A., "Monitoring Trace Metals at Ambient Water Quality Criteria Levels: Briefing Book." U.S. EPA (Jan. 1995).

U.S. EPA, "Results of the Nationwide Urban Runoff Program, Executive Summary." (Dec. 1983)

U.S. EPA, "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters." Report 840-B-92-002 (Jan. 1993a).

U.S. EPA, "Technical Basis for Deriving Sediment Quality Criteria for Nonionic Organic Contaminants for the Protection of Benthic Organisms by Using Equilibrium Partitioning." EPA-822-R-93-011 (Sept. 1993b).

U.S. EPA, "Notice of Availability, Sediment Criteria Documents." *Federal Register,* Vol. 59 (Jan. 18, 1994a) p. 2652.

U.S. EPA, "Interim Guidance on Determination and Use of Water-Effect Ratios for Metals." (Feb. 1994b).

U.S. EPA, "Revision of Metals Criteria." *Federal Register,* Vol. 60 (May 4, 1995) p. 22228.

U.S. EPA, "Draft Framework for Watershed-Based Trading." Report No. EPA 800-R-96-001 (May 1996a).

U.S. EPA, "Watershed Approach Framework." Report No. EPA 840-S-96-001 (June 1996b).

U.S. EPA, "Assessing the Toxicity and Bioavailability of PAH Mixtures in Sediments." Report No. EPA-822-RP-97-001 (May 1997).

USGS, "Revision of New Division Protocol for Collecting and Processing Surface-Water Samples for Low-Level Inorganic Analyses." OWRQ TM 94.09 (Jan. 1994).

Van Hassel, J. H., et al., "Heavy Metals in a Stream Ecosystem at Sites Near Highways." *Transactions of the American Fisheries Society*, Vol. 109 (1980) pp. 636–643.

Versar, Inc., "Management Practices for Mitigation of Highway Stormwater Runoff Pollution—Volume IV: Executive Summary." Report No. FHWA/RD-85/004 (1985).

Wanielista, M. P., et al., "Management of Runoff from Highway Bridges." Report No. FL-ER-10-80, prepared for Florida DOT (1980).

Webb, D. A., "Background Metal Concentrations in Wisconsin Surface Waters." Wisconsin Department of Natural Resources (n.d., ca. 1992).

Windom, H. L., et al., "Inadequacy of NASQAN Data for Assessing Metal Trends in the Nation's Rivers." *Environmental Science and Technology,* Vol. 25, No. 6 (June 1991) pp. 1137–1142.

Winters, G. R., and Gidley, J. L., "Effects of Roadway Runoff on Algae." Report No. FHWA/CA/TL-80/24 (1980).

Yamane, A., et al., "Storm Water Runoff of Hydrocarbons in the Tama River Basin in Tokyo (Japan) and Their Fate in the River." *Water Science and Technology,* Vol. 22 (1990) pp. 119–126.

Young, G. K., et al., "Evaluation and Management of Highway Runoff Water Quality." Publication No. FHWA-PD-96-032 (June 1996).

Yousef, Y. A., et al., "Fate of Heavy Metals in Stormwater Runoff from Highway Bridges." *Science of the Total Environment,* Vol. 33 (Feb. 1984) pp. 233–244.

Yousef, Y. A., et al., "Heavy Metal Accumulation and Transport Through Detention Ponds Receiving Highway Runoff." *Science of the Total Environment,* Vol. 93 (April 1990) pp. 433-440.

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