# Stormwater Runoff from Bridges

# Final Report to Joint Legislation Transportation Oversight Committee

## In Fulfillment of Session Law 2008-107

Prepared by:
URS Corporation – North Carolina
1600 Perimeter Park Drive
Suite 400
Morrisville, NC 27560

Prepared for:
NC Department of Transportation
Hydraulics Unit
1590 Mail Service Center
Raleigh, NC 27699-1590
919.707.6700

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Cover Photos: *C. dubia* photo provided by Jack Kelly Clark, courtesy of University of California Statewide Integrated Pest Management Program. All other photos by authors.

# Revision History

| Date | Description |
|---|---|
| May 9, 2012 | Errors in the calculation of unit event loads, annual loading rates, and runoff volumes were corrected. The following updates associated with the corrections were incorporated:<br>• Pages 4-9 through 4-16 in section 4 were updated, including all text and tables:<br>o Table 4.2-2 on pages 4-10 through 4-13 was updated with corrected median unit event loads and average unit annual loading rates.<br>o Table 4.2-3 on page 4-14 was updated with corrected annual loading rate values.<br>o Table 4.2-4 on page 4-16 was updated with corrected annual loading rate values.<br>• All tables in Appendix 3-G (Tables 3-G.1 to 3-G.15) were updated with corrected runoff volume values. |

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# Appendices

*(Appendices are provided electronically with this submittal)*

## List of Acronyms and Abbreviations

| | |
|---|---|
| µL | Microliters |
| µm | Micrometers |
| A | Arterial |
| AADT | Average annual daily traffic |
| AADThi | Annual average daily traffic at location i of factor group h |
| AASHTO | American Association of State Highway and Transportation Officials |
| ADT | Average daily traffic |
| Ai | Axle-correction factor for location i |
| ANCOVA | Analysis of variance |
| ASTM | American Society for Testing and Materials |
| ATR | Automatic traffic recorder |
| ATU | Aquatic Toxicology Unit |
| BLM | Biotic Ligand Model |
| BMP | Best management practice |
| BMU | Bridge Management Unit |
| BR | Blue Ridge |
| BSCCA | Bridge storm control and conveyance assessment |
| BSP | Bridge Stormwater Project |
| Bus. | Business |
| C | Coastal |
| C | Collector |
| *C. dubia* | *Ceriodaphnia dubia* |
| CA | Critical area |
| CaCO3 | Calcium carbonate |
| Caltrans | California Department of Transportation |
| CASQA | California Stormwater Quality Association |
| CBI | Catch basin insert |
| CCC | Criterion continuous concentration |
| CDS | Closed drainage system |
| CF | Cubic feet |
| CFS | Cubic feet per second |
| CMC | Criterion maximum concentration |
| CO | Colorado |
| CO2 | Carbon dioxide |
| COD | Chemical oxygen demand |
| CTE | Center for Transportation and the Environment |

## List of Acronyms and Abbreviations (Continued)

| | |
|---|---|
| CTR | Center for Transportation Research |
| CWP | Center for Watershed Protection |
| CY | Cubic yard |
| D/U | Downstream/upstream |
| DA | Drainage area |
| DCM | Division of Coastal Management |
| DDDS | Direct discharge drainage system |
| DelDOT | Delaware Department of Transportation |
| Dh | Day-of-week factor for factor group h |
| DNREC | Delaware Department of Natural Resources and Environmental Control |
| DO | Dissolved oxygen |
| DOTD | Department of Transportation and Development |
| DWQ | North Carolina Department of Environment and Natural Resources Division of Water Quality |
| E | East |
| EBL | Eastbound lane |
| ECOTOX | Ecotoxicology Database |
| EMC | Event mean concentration |
| EPA | Environmental Protection Agency |
| EPT | Ephemeroptera, Plecoptera, and Trichoptera |
| EPT S | EPT metric value |
| ESD | Environmental site design |
| ETS | Environmental Testing Solutions, Inc. |
| EWI | Equal width-interval |
| FHWA | Federal Highway Administration |
| FM | Farm-to-market |
| ft3 | Cubic feet |
| g/L | Grams per liter |
| Gh | Growth factor for factor group h |
| GIS | Geographic information system |
| HQW | High quality water |
| hrs | Hours |
| HSP | Highway Stormwater Program |
| I | Interstate |
| IC25 | Inhibition concentration |
| Inspect. | Inspection |
| IRIS | Integrated Risk Information System |

## List of Acronyms and Abbreviations (Continued)

| | |
|---|---|
| L | Liter |
| L | Local |
| LA DOTD | Louisiana Department of Transportation and Development |
| lb/ac | Pound/acre |
| lb/acre-yr | Pound/acre-year |
| LOEC | Lowest observable effect concentration |
| LRL | Lab reporting level |
| Ma | Major |
| Maint. | Maintenance |
| MDDNR | Maryland Department of Natural Resources |
| MDE | Maryland Department of the Environment |
| MEP | Maximum extent practicable |
| mg/L | Milligrams per liter |
| Mh | Seasonal (monthly) factor for factor group h |
| Mi | Minor |
| mL(s) | Milliliter(s) |
| MLR | Multiple linear regression |
| MM | Mile marker |
| mm | Millimeters |
| MP | Mile post |
| MSCC | Maximum soil contaminant concentration |
| MSHA | Maryland State Highway Association |
| N | Nitrogen |
| N | North |
| NA | Not applicable |
| n.d. | No date |
| NC | North Carolina |
| NCAC | North Carolina Administrative Code |
| NCBI | North Carolina biotic index |
| NCDENR | North Carolina Department of Environment and Natural Resources |
| NCDOT | North Carolina Department of Transportation |
| NCGA | North Carolina General Assembly |
| NCHRP | National Cooperative Highway Research Program |
| NCMIN | North Carolina Multimodal Investment Network |
| NCSU | North Carolina State University |
| NCWSC | North Carolina Water Science Center |

## List of Acronyms and Abbreviations (Continued)

| | |
|---|---|
| NE | Northeast |
| NEPA | National Environmental Policy Act |
| NO2 | Nitrite |
| NO3 | Nitrate |
| NOAA | National Oceanic and Atmospheric Administration |
| NOEC | No observable effect concentration |
| NPDES | National Pollutant Discharge Elimination System |
| NRC | National Research Council |
| NSW | Nutrient sensitive waters |
| NURP | National Urban Runoff Program |
| NW | Northwest |
| NWIS | National Water Information System |
| NWQL | National Water Quality Laboratory |
| ORW | Outstanding resource water |
| P | Phosphorus |
| P | Piedmont |
| PA | Principal Arterial |
| PADEP | Pennsylvania Department of Environmental Protection |
| PAH | Polycyclic aromatic hydrocarbons |
| PCB | Polychlorinated biphenyls |
| PCSP | Post-construction Stormwater Program |
| PEC | Probable effect concentration |
| PFDS | Precipitation Frequency Data Server |
| PFSH | Preformed scour hole |
| pH | Potential of hydrogen |
| POC | Parameter-of-concern |
| PSD | Particle size distribution |
| QAQC | Quality assurance / quality control |
| R | Rural |
| RAIS | Risk Assessment Information System |
| Rd | Road |
| ROS | Regression order statistics |
| ROW | Right-of-way |
| RT | Regional Tier |
| S | South |
| S | Sulfur |

## List of Acronyms and Abbreviations (Continued)

| | |
|---|---|
| SBL | Southbound lane |
| SC | Specific conductivity |
| SCDOT | South Carolina Department of Transportation |
| SCM | Stormwater control measure |
| SE | Southeast |
| SEPA | State Environmental Policy Act |
| SOP | Standard operating procedures |
| SR | State Route |
| SRT | Subregional Tier |
| St | Street |
| s.u. | Standard units |
| SVOC | Semi-volatile organic compound |
| SW | Southwest |
| SWT | Statewide Tier |
| TAC | Texas Administrative Code |
| TEC | Threshold effect concentration |
| TC | Total carbon |
| TCEQ | Texas Commission on Environmental Quality |
| TCLP | Toxicity characteristic leaching procedure |
| Td | Average time of dry periods at the monitoring site |
| TDS | Total dissolved solids |
| TIP | Transportation Improvement Program |
| TKN | Total Kjeldahl nitrogen |
| TMDL | Total maximum daily load |
| TOC | Total organic carbon |
| Total S | Total taxa richness |
| Tp | Average time of precipitation at the monitoring site |
| TPH | Total petroleum hydrocarbons |
| Tr | Duration of wet-weather event (years) |
| Tr | Trout water |
| TRC | Total residual chlorine |
| TSG | Traffic Survey Group |
| TSS | Total suspended solids |
| TX | Texas |
| U | Urban |
| UNC | University of North Carolina |

## List of Acronyms and Abbreviations (Continued)

| | |
|---|---|
| US | United States |
| USACE | United States Army Corps of Engineers |
| USDOI | United States Department of the Interior |
| USEPA | United States Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Service |
| USGBC | United States Green Building Council |
| USGS | United States Geological Survey |
| UT | Unnamed tributary |
| VOlhi | 24-hour axle volume at location I of factor group h |
| vpd | Vehicles per day |
| Vr | Volume of runoff for wet-weather event |
| VSS | Volatile suspended solids |
| W | West |
| WBT | Westbound lane |
| WERF | Water Environment Research Foundation |
| WET | Whole effluent toxicity |
| WOE | Weight-of-evidence |
| WS | Water supply |
| WSDOT | Washington State Department of Transportation |
| YCT | Yeast-cerophyll® |

# Executive Summary

In July of 2008, Session Law 2008-107, House Bill 2436, was enacted by the North Carolina General Assembly (NCGA). Section 25.18 of this law, “Stormwater Runoff from Bridges,” required the North Carolina Department of Transportation (NCDOT) to study the effects of stormwater runoff from bridges over waterways and report to the Joint Legislative Transportation Oversight Committee by July 1, 2010 (NCGA, 2008). The following goals were established to meet the requirements of the law:

- Characterize bridge deck runoff pollutants (quality and quantity) using scientifically accepted methods and identify those of concern.
- Estimate the effect of bridge deck runoff on surface water bodies by evaluating water quality chemistry and effects on aquatic life.
- Conduct a pilot study of at least 50 sites to evaluate stormwater treatment controls for their ability to provide necessary hydrologic control and stormwater treatment for target pollutants in bridge deck runoff.
- Determine the cost of implementing effective treatments for existing and new bridges over waterways in North Carolina.

The Bridge Stormwater Project (BSP) was established in November 2008 and included a team of over 150 experts from NCDOT; URS Corporation; North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ); United States Geological Survey (USGS); North Carolina State University (NCSU); Withers and Ravenel; Kimley-Horn and Associates, Inc.; Lenat Consulting Services; Environmental Testing Solutions, Inc.; and the Center for Transportation and the Environment (CTE).

To assess the effect of bridge deck runoff on receiving streams, the BSP team relied on a weight-of-evidence (WOE) approach to integrate the diverse and complicated interactions associated with episodic stormwater events and receiving water quality. The lines of evidence or analyses performed included biological assessments, ambient water quality chemistry, aquatic toxicity, bridge deck runoff quantity and chemistry, and sediment quality. The analyses resulted in over one hundred thousand data points being collected and reviewed to support the WOE evaluation. While several parameters-of-concern from bridge deck runoff exceeded site-specific surface water quality thresholds, the analyses associated with aquatic toxicity, biological assessments, and sediment data did not indicate long-term adverse impacts from untreated bridge deck discharges. Therefore, the BSP team concluded that NCDOT’s current use of stormwater control measures (SCMs) for the mitigation of bridge deck runoff is protective of surface waters. Section 3, BSP Monitoring Program, provides detailed information about data collection for the BSP, and section 4, Effect of Stormwater Runoff from Bridges, presents the WOE evaluation.

The second major initiative that the BSP completed was conducting a pilot study of bridge SCMs at over 50 sites. The purpose of the pilot study was to represent SCMs that are implemented or could be implemented to control or treat bridge deck runoff and provide cost, constructability, and applicability information. For the purposes of the study, SCM types are organized into the following general categories: Level I treatment, Level II treatment, maintenance, and design-related SCMs. As indicated by the session law, SCM types considered included those “found effective by other states and new treatments identified through investigation and research” (NCGA, 2008). New SCMs considered as part of this study included the Bridge Conveyance and Collection System Assessment (BSCCA), bridge sweeping, off-site stormwater mitigation, and environmental site design (ESD). Table ES-1 provides a summary of the SCM types considered for the study. A detailed description of the pilot study sites and characteristics is provided in section 5 of the report.

**Table ES-1: Summary of Stormwater Control Measure Types by Category**

| Level I Treatment | Level II Treatment | Design-Related | Maintenance |
|---|---|---|---|
| Bioretention Basin | Conveyance Channel | Closed System | Bridge Stormwater Collection and Conveyance Assessment (BSCCA) |
| Catch Basin Insert (CBI) | Energy Dissipator | Deck Conveyance | Bridge Sweeping |
| Dry Detention Basin | Level Spreader | Dispersion | |
| Filter Strip | Preformed Scour Hole (PFSH) | Environmental Site Design (ESD) | |
| Filtration Basin | Stream Bank Drop Structure | Off-site Stormwater Mitigation | |
| Infiltration Basin | | | |
| Stormwater Wetland | | | |
| Swale | | | |

The final product the BSP team developed was a cost estimate for implementing effective stormwater controls on all new and existing bridges in the state.

To accomplish this task, the team identified the number of bridges and the types of treatments that would be required for new construction bridge projects. A list of planned bridge projects was developed representing bridges over waterways to be initiated between August 2009 and June 2014 using NCDOT’s 60-Month Let List. During this time, 389 projects were identified that will involve the construction of 451 bridges over waterways. Approximately 347 of the bridges will be replacements, while the remaining 104 bridges will be new locations associated with new roadway projects. Figure ES-1 shows the locations of bridge projects and roadway projects with bridges over waterways to be initiated during the 5-year period. Quantity estimates were derived using the list of future bridges and application of NCDOT’s current use of SCMs, with some simplifying assumptions and enhancements based on recommendations from the BSP team.

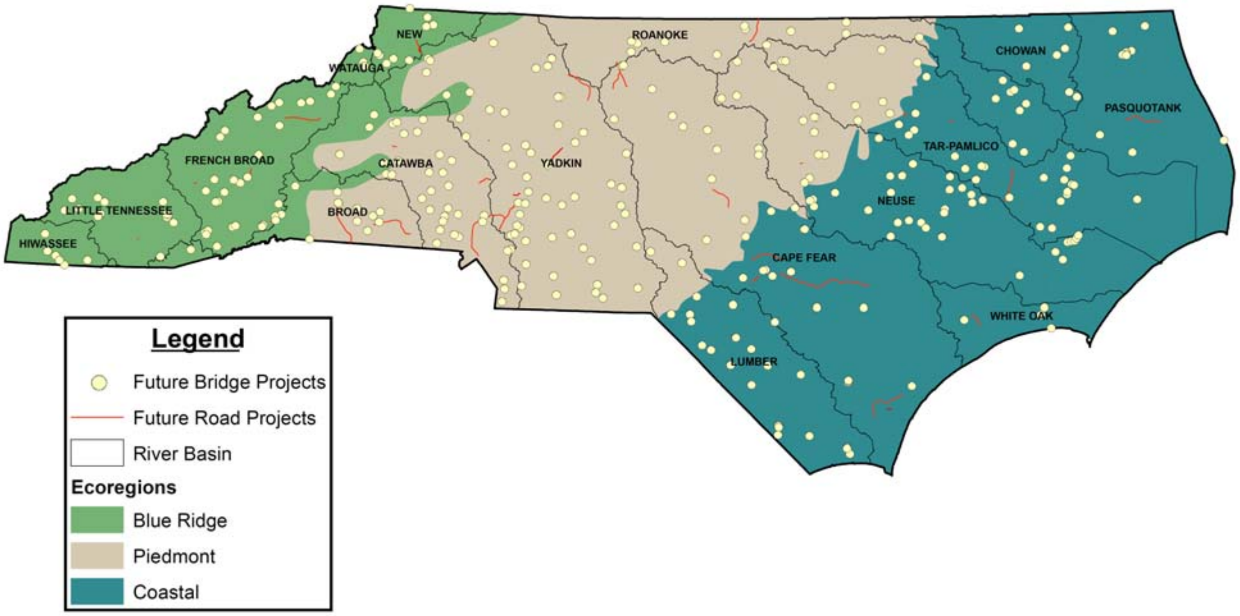


**Figure ES-1: Planned future bridge projects over waterways from NCDOT’s Work Program, 2009-2014.**

The BSP team used the WOE evaluation and field observations made during the study to determine effective SCMs for existing bridges. In addition to the continued implementation of SCMs currently in practice, the BSP team recommends the implementation of BSCCA, retrofits for sensitive waters, and bridge sweeping for existing bridges. The team recommends that NCDOT's Bridge Management Unit incorporate BSCCA into its biennial bridge inspections to assess and prioritize retrofit opportunities for sensitive waters. Retrofits would be constructed based upon priority need, as established by the NCDOT Hydraulics Unit. In addition, bridge sweeping operations would support water quality preservation and protection.

Section 6 of the report, Selecting Effective Bridge SCMs, documents the application of SCMs to bridges, the approach for selecting effective SCMs, and an estimate of the quantity of bridge SCMs for the 5-year cost analysis period.

Based upon the quantity estimates for new construction and the retrofit program for existing bridges, costs were developed for bridge SCM implementation. From the cost analysis, it was determined that a total of approximately $35 million would be required to implement the necessary controls over the next five years. Of the $35 million, $5 million would be required for design, $26 million for construction, and $4 million for operation. Table ES-2 summarizes these costs for new and existing bridges. Section 7 of the report, Cost of Effective Bridge SCMs, presents the bridge SCM cost analysis for the five-year period.

**Table ES-2: Statewide Cost Estimate of SCM Implementation for New and Existing Bridges Over Waterways – 5-year Time Period**

| Description | Design Cost | Construction Cost | Operating Cost[a] | Total Cost |
|---|---|---|---|---|
| New Bridges | $3,834,000 | $23,975,000 | $3,512,000 | $31,321,000 |
| Existing Bridges | $900,000 | $2,060,000 | $800,000 | $3,760,000 |
| Total 5-year Cost Estimate | $4,734,000 | $26,035,000 | $4,312,000 | $35,081,000 |

**Notes:**

[a] Operating cost includes inspection, routine maintenance, and infrequent maintenance costs.

The BSP team addressed the objectives of the session law as documented above; however, the team also acknowledges that further efforts are needed to facilitate an effective implementation of the recommended SCMs over the next five years. Following are key conclusions and recommendations of the study. Additional discussions are provided in section 8, Conclusions and Recommendations.

- The weight-of-evidence considered in this study indicates that bridge deck runoff does not have a widespread effect on receiving waters and that NCDOT's current use of stormwater control measures for mitigation of bridge deck runoff is protective of surface waters.
- Results of the Bridge Stormwater Project should be integrated into the Highway Stormwater Program (HSP) to facilitate continuous process improvement of NCDOT's mission, "Connecting people and places in North Carolina - safely and efficiently with accountability and environmental sensitivity." Since 1998, NCDOT has had a National Pollutant Discharge Elimination System (NPDES) stormwater permit issued by the NCDENR DWQ that allows NCDOT to discharge stormwater runoff per the requirements of the permit (NCDENR, 2005). To comply with the NPDES permit and mitigate for stormwater runoff, NCDOT has established the HSP. Through the HSP, NCDOT manages stormwater runoff through planning, design, and maintenance of site-specific projects, watershed programs, and education and training of NCDOT personnel and contractors.

- Results from this study should be used to update and advise the site-specific SCM selection process used during NCDOT project planning with environmental agencies.
- Additional investigation into the effectiveness of bridge sweeping as an SCM and potential improvements to existing sweeping practices to benefit stormwater quality is needed.
- The NCDOT *Stormwater Best Management Practices (BMP) Toolbox* should be updated based on information from the BSP.
- Verify that NCDOT deicing practices continue to incorporate national state-of-the-art practices for mitigation.
- Implement SCMs as necessary to address water quality concerns for existing bridges through the NCDOT Retrofit Program.
- Additional development is needed for the proposed Bridge Stormwater Collection and Conveyance Assessment SCM prior to implementation.
- Develop guidance and protocol for implementation of off-site mitigation practices for stormwater runoff.
- Provide systematic training for designers and engineers associated with selection and implementation of bridge SCMs.
- Complete investigation to assess the contribution of bacteria from bridge decks and to evaluate potential impacts to receiving waters.
- Complete study to assess when dispersion of bridge deck runoff through deck drains is an acceptable practice and to develop design criteria for application.
- Complete ongoing monitoring to evaluate pollutant removal performance of SCMs.

# 1.0 Introduction

The Bridge Stormwater Project (BSP) was initiated in November 2008 to comply with Session Law 2008-107, *The Current Operations and Capital Improvements Appropriations Act of 2008*, enacted by the North Carolina General Assembly (NCGA). Section 25.18, "Stormwater Runoff from Bridges," states the following:

> **STORMWATER RUNOFF FROM BRIDGES**
>
> **SECTION 25.18.(a)** Of funds available to the Department of Transportation, the Department, in cooperation with the Center for Transportation and the Environment at North Carolina State University, shall conduct a pilot study on 50 bridges, located throughout the State in various ecosystems, of the installation of various types of storm water detention, collection, and filtering systems during new bridge construction over waterways. The Department may also retrofit existing bridges as part of its pilot study. Treatments and methods used in the pilot study shall include but not be limited to those treatments found effective by other states and new treatments identified through investigation and research which may be effective. Construction or retrofitting shall be initiated on at least 25 of the 50 bridges by July 1, 2009. Construction or retrofitting shall be initiated on the remaining bridge projects by January 1, 2010.
>
> **SECTION 25.18.(b)** An interim report shall be made to the Joint Legislative Transportation Oversight Committee no later than July 1, 2009, that includes information which quantifies stormwater runoff at structures as well as the types of pollutants, the various treatments which will be constructed and evaluated to target these pollutant types, and a measurement and collection plan to determine effectiveness of the evaluated treatments.
>
> **SECTION 25.18.(c)** A final report shall be made to the Joint Legislative Transportation Oversight Committee no later than July 1, 2010. The final report shall include as a minimum, the effectiveness of the treatments included in the study, costs of each treatment, and the costs of implementing effective treatments on new bridge construction projects as well as existing bridge retrofit projects for all bridges over waterways in the State.

Following passage of Session Law 2008-107, the North Carolina Department of Transportation (NCDOT) and the Center for Transportation and the Environment (CTE) formed a collaborative association, referred to as the BSP team. The BSP team, led by the NCDOT Hydraulics Unit Highway Stormwater Program (HSP), facilitated the interaction of pertinent resource agencies and subject matter experts to develop a science-based approach to meet the requirements of Section 25.18 of the session law. The BSP team was comprised of the following organizations, in addition to NCDOT and CTE:

- **North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ)** is the primary state regulatory authority on stormwater quality. DWQ staff provided guidance for interpreting the results of stormwater quality monitoring and developing the protocol for biological monitoring performed as part of the BSP.
- **United States Geological Survey (USGS)** is a premier scientific organization that is widely known for extensive and long-term environmental data collection efforts. USGS assisted in the development of the BSP monitoring program and led the efforts to collect and analyze water and sediment chemistry samples.

- **North Carolina State University (NCSU)** conducts research on the implementation and performance of stormwater control measures (SCMs), also known as stormwater best management practices (BMPs). Such research has influenced stormwater policy in the state of North Carolina. NCSU staff provided insight and guidance for the design of selected stormwater SCMs.
- **Consultants** were employed to manage and facilitate the design of the BSP monitoring program, data control and evaluation, and design and implementation of selected stormwater controls. URS Corporation (Morrisville, NC) provided program management for the project. Withers and Ravenel and Kimley-Horn and Associates, Inc. assisted with stormwater control design and construction oversight. Lenat Consulting Services provided services for biosurveys and Environmental Testing Solutions, Inc. performed bioassay analyses.

The BSP team developed and implemented a successful approach to addressing the requirements in the session law. Regular communication and internal review by team members was performed to adjust the BSP monitoring program and study approach so that all team members were integrated into the decision-making and planning process. On January 6, 2010, the BSP team met to discuss intermediate results of the monitoring program, data analysis, and stormwater control measure (SCM) types included in the project. DWQ, USGS, NCSU, and NCDOT staff and consultants attended the meeting and expressed continued agreement on the project approach. Meeting participants also provided additional input and recommendations for the interpretation of stormwater monitoring results.

In accordance with Section 25.18(a) of the session law, construction or retrofitting of stormwater SCMs was initiated by July 1, 2009 for 25 of the bridges included in the pilot study and by January 1, 2010 for the remaining bridges. In addition, an interim report was prepared and submitted to the Joint Legislative Transportation Oversight Committee on July 1, 2009 as required by Section 25.18(b) of the session law. This report serves as the final report made to the Joint Legislative Transportation Oversite Committee, which represents fulfillment of Section 25.18(c) of the session law.

## 1.1 Project Objectives

The primary goal of the BSP was to develop and implement an approach to comply with Session Law 2008-107, Section 25.18 (a, b, and c), “Stormwater Runoff from Bridges.” To satisfy the intent of the session law, the following objectives were developed:

- Characterize bridge deck runoff pollutants (quality and quantity) using scientifically accepted methods and identify those of concern.
- Estimate the effect of bridge deck runoff on surface water bodies by evaluating water quality chemistry and effects on aquatic life.
- Conduct a pilot study of at least 50 sites to evaluate stormwater treatment controls for their ability to provide necessary hydrologic control and stormwater treatment for target pollutants in bridge deck runoff.
- Determine the cost of implementing effective treatments for existing and new bridges over waterways in North Carolina.

## 1.2 Final Report Layout

This final report for the BSP provides summary information on executed project tasks designed with input from North Carolina resource agencies to comply with the session law. In addition, as the spirit of the session law seeks to protect surface water quality, some project tasks were conceptualized to improve the general understanding of the relationship between bridge deck runoff and receiving streams. A summary of information provided in this report, by section, follows.

### Section 2 – Background and Project Approach

Section 2 provides background information on stormwater quality and quantity and the use of SCMs to control and treat bridge deck runoff. Previous research on characterizing and treating bridge deck runoff performed by the United States Environmental Protection Agency (USEPA), NCDOT, and other state departments of transportation is provided. This background information is used to support the project approach, provided at the end of section 2.

### Section 3 – BSP Monitoring Program

To investigate the potential relationship between bridge deck runoff and receiving streams, a monitoring and sample collection plan (herein referred to as the monitoring program) was developed to characterize bridge deck runoff and instream quantity and quality, characterize bridge deck solids and instream bed sediment chemistry near the bridge crossing, and assess the ecological effects of bridge deck runoff through various bioassessments. The monitoring program development, site selection and characteristics, field activities, and analytical procedures and methods are provided in section 3 of the report.

### Section 4 – Effect of Stormwater Runoff from Bridges

Section 4 discusses the effect of bridge deck runoff on receiving streams using a weight-of-evidence (WOE) approach. The results of the monitoring program described in section 3 are evaluated to estimate the physical, chemical, and biological cause and effect of bridge deck runoff. The results of each evaluation are considered collectively to determine if a clear causal relationship exists between bridge deck runoff and receiving stream impacts.

### Section 5 – Bridge SCM Pilot Study

Section 5 presents the bridge SCM pilot study conducted at over 50 sites throughout the state. The sites include a collection of newly constructed and retrofitted SCMs to both showcase the stormwater management options currently implemented by NCDOT and present innovative SCMs that could be integrated into NCDOT’s post-construction stormwater program (PSCP). Information and lessons learned from evaluating the pilot study sites were used to suggest areas of additional study and to support a cost estimate of SCM implementation on bridge decks statewide.

### Section 6 – Effective Bridge SCMs for Statewide Application

Based on the results of the WOE evaluation of bridge deck runoff effects on receiving streams in section 4 and the examples of SCMs presented in the bridge SCM pilot study sites in section 5, a basis of estimate for applying SCMs to bridge decks statewide is provided in section 6. The basis of estimate includes both a discussion of SCM effectiveness and applicability and a process for estimating SCM quantities for planned bridge projects statewide.

### Section 7 – Costs of Bridge SCMs

Using the basis of estimate developed in section 6, a cost estimate for SCMs applied to planned bridge projects is presented in section 7. A combination of cost data maintained by NCDOT on past projects and regionally and nationally based literature values is used to develop the cost estimate.

### Section 8 – Conclusions and Recommendations

Section 8 presents conclusions based on the BSP study and recommendations for additional SCM investigations and program initiatives.

# 2.0 Background and Project Approach

Stormwater runoff has been identified as one of the major concerns for impairment of surface waters (USEPA, 2009a). When causes of impairment are identified, it is sometimes assumed that transportation-related runoff plays a major role, despite the fact that highways often comprise a small portion of the overall watershed. Because bridge deck crossings put transportation runoff in close proximity to receiving streams, it is now common for regulatory agencies nationwide to require specific stormwater management approaches for bridge deck runoff. For example, it is commonly recommended that instead of directly discharging bridge deck runoff to receiving streams, it should be directed to the vegetated right-of-way (ROW) prior to discharge, with the assumption that such a configuration is better for surface water quality (Dupuis, 2002). While extensive information exists on roadway runoff as a whole, few studies have focused on bridge deck runoff (Dupuis, 2002). Given the costs, maintenance, and design efforts associated with bridge deck stormwater management approaches, a better understanding of the relationship between bridge runoff and receiving stream impacts and the appropriate application of treatment systems is needed.

This project provides a focused look at the impact of bridge deck runoff on receiving streams in North Carolina and provides information on the applicability of SCMs to treat runoff when necessary and feasible. In developing the project, NCDOT and its collaborators reviewed established research to understand the characteristics of bridge deck runoff and methods of treating it. This section provides background information, summarizing research performed by the US Environmental Protection Agency (USEPA), NCDOT, and other state departments of transportation on stormwater runoff impacts in general (due to the quantity and quality of the runoff), and introduces the processes by which SCMs function and provide treatment for bridge deck runoff. This historical information influenced the foundation of the BSP project approach, which is described at the end of this section.

## 2.1 Transportation-Related Runoff: Quality and Quantity

Roadway runoff (i.e., any runoff that is generated from within transportation rights-of-way) has been identified as one of several pollutant source categories that may contribute to surface water impairment (USEPA, 2009a). Because pollutant-producing processes in roadway runoff are unique to the transportation land use, roadway stormwater runoff data has been independently collected and studied by many sources (Gupta et al., 1981; FHWA, 1990; Sansalone and Buchberger, 1997; Barrett et al., 1998, Kayhanian et al., 2007). To date, however, there has been little evaluation of how bridge deck runoff characteristics compare to typical roadway runoff characteristics. Generally, roadway runoff water quality data is used as an approximation for the pollutant profile of bridge deck runoff (Dupuis, 2002).

Common components found in roadway stormwater runoff include metals, inorganic salts, aromatic hydrocarbons, suspended solids, and materials that are a result of wear and tear on a vehicle, such as oil, grease, rust, and rubber particles (Jongedyk, 1999; Dupuis, 2002). Each of these parameters is generally linked to automotive sources, roadway materials, and roadway maintenance activities. However, pollutant concentrations generated for any one outfall are a function of many factors other than traffic patterns and bridge characteristics, including antecedent dry periods, seasonal cumulative rainfall, rainfall intensity, and land use (Kayhanian et al., 2003). In addition, dry atmospheric deposition can be the major source of some parameters, such as trace metals, in urban watersheds (Sabin et al., 2005). Table 2.1-1 provides a list of common highway runoff pollutants and their primary sources.

### Table 2.1-1: Sources of Common Highway Runoff Parameters

| Parameter | Sources in the Highway Environment |
|---|---|
| Bromide | Exhaust |
| Cadmium | Tire wear, insecticides |
| Chloride | Deicing salts |
| Chromium | Metal plating, moving engine parts, brake lining wear |
| Copper | Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides |
| Cyanide | Anti-cake compound used to keep deicing salt granular |
| Fecal coliform,<br>E. coli (indicators) | Soil, litter, bird droppings, livestock and stockyard waste hauling |
| Iron | Rust (automobile body and bridge structure), moving engine parts |
| Lead | Bearing and tire wear, oil and grease |
| Manganese | Moving engine parts |
| Nickel | Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving |
| Nitrogen | Atmosphere, fertilizer application |
| Particulates | Pavement wear, vehicles, atmosphere, maintenance |
| Petroleum | Spills, motor lubricants, antifreeze and hydraulic fluids, leachate from asphalt surfaces |
| Phosphorus | Atmosphere, fertilizer application |
| Polychlorinated Biphenyls (PCBs), pesticides | Applying pesticides to highway rights-of-way, background atmospheric deposition, PCB catalyst in synthetic tires |
| Sodium, calcium | Deicing salts, grease |
| Sulfate | Roadway beds, fuel, deicing salts |
| Zinc | Tire wear, motor oil, grease |

**Source:** Table adapted from Dupuis, 2002.

Stormwater quantity can also negatively impact receiving streams. The construction of any new transportation facility, whether that facility includes a bridge deck or not, will increase impervious area in a watershed. Increasing impervious area increases both runoff volume and peak flow rates. These changes, if not properly mitigated, can negatively impact receiving streams by causing hydromodification, or the alteration of the hydrologic characteristics of a receiving stream that can negatively impact water quality (USEPA, 2007). Some characteristics of hydromodification include increased movement and deposition of stream sediment, channel modification as receiving streams attempt to accommodate larger flows, stream bank erosion, increased stream turbidity, and changes in flow patterns. Such changes to the receiving stream can degrade water quality below intended uses and negatively impact biological habitat (USEPA, 2007).

In addition to hydromodification, receiving streams can be impacted by an increase of sediment deposition from erosion as runoff flows overland from the bridge to the stream bank. Sedimentation in small streams may negatively impact biotic communities by increasing potential toxicity and reducing available sunlight, thereby reducing the diversity and reproduction of aquatic communities (Waters, 1995). For bridges that drain runoff via gutter flow and bridge end collectors or closed drainage systems (CDS), there is a possibility for erosion to occur between the pipe outlet (typically located on the bridge embankment or near a bent) and the receiving stream. For bridges that discharge runoff from the deck using deck drains, lack of energy dissipation at the point of physical impact between runoff and the land beneath the bridge deck may also cause erosion. The likelihood of localized erosion can be verified through the use of professional judgment (e.g., bridge deck height) or erosion prediction through calculation of flow velocities in conveyance and at points of discharge.

### 2.1.1 Bridge Runoff Characterization Studies from Other States

As previously mentioned, the characterization of bridge deck runoff from other types of transportation-related runoff has not been extensively studied. However, many assumptions about bridge deck runoff influence stormwater management decisions, such as the concept that pollutants are present in higher concentrations in bridge deck runoff than in other types of highway runoff or that pollutants in bridge deck runoff have the potential to negatively influence most receiving streams. Therefore, a literature review was conducted to evaluate the current body of knowledge regarding bridge deck runoff quality. The case studies reviewed focused all or in part on evaluating bridge deck runoff. Individual studies conducted in states other than North Carolina are provided below. Some general conclusions from these case studies include the following:

- Statistical analysis from one study (Malina et al., 2005) has shown that bridge deck runoff is generally not statistically different from highway runoff.
- Pollutant loadings from bridge decks to a receiving stream can be minimal when compared to pollutant loadings from other watershed sources.
- Specific instances of elevated parameters, particularly zinc, may be linked to galvanized bridge materials.
- While parameter concentrations in bridge deck runoff can exceed nationwide benchmarks, no widespread link between bridge deck runoff and negative impacts to receiving streams has been shown.
- Deicing activities and pollutant accumulation in sediment are potential sources of localized toxicity that require further study.

The observations listed above support the concept that surface water quality protection may be better served by managing stormwater runoff on a watershed scale as opposed to focusing management efforts specifically on bridges. In addition, there may be opportunities to improve water quality by identifying and controlling the source of pollutants (e.g., by replacing certain bridge materials).

### Characterization of Stormwater Runoff from a Bridge Deck and Approach Highway, Effects of Receiving Water Quality (2005)

**Investigators: Joseph F. Malina, Jr; Michael E. Barrett; Andrew Jackson; and Tim Kramer**

Malina et al. studied the characteristics of bridge deck stormwater runoff by monitoring three different bridge sites located in Texas: (1) a bridge that spans Barton Creek as part of Loop 360 in Austin, Texas, with an average daily traffic (ADT) of 58,000 vehicles per day (vpd); (2) a bridge that spans the North Fork of the Double Mountain Fork of the Brazos River as part of Loop 289 in Lubbock, Texas, with an ADT of approximately 10,000 vpd; and (3) a bridge that spans Clear Creek as part of FM 528 located in Friendswood, Texas, with an ADT of approximately 15,000 vpd. Volumetric flow rates and flow-weighted composite samples were collected from the approach highway and bridge deck for 15 rainfall events at the Austin site from June 2003 through February 2004, for 12 rainfall events at the Lubbock site from January 2004 through May 2004, and for 16 rainfall events at the Houston site from November 2003 through February 2005.

Malina et al. made the following conclusions:

- Statistical data comparing bridge deck runoff event mean concentrations (EMCs) to the approach highway EMCs revealed limited instances when parameters were significantly different from each other. Highway runoff data can be used as a conservative approximation of bridge deck runoff data.
- Pollutant concentrations in this study were of the same order of magnitude as or less than average historical highway runoff concentrations.
- Bridge deck loading of all measured water quality constituents into Barton Creek were minimal, while loadings from upstream sources were several orders of magnitude greater.
- No substantial adverse impact to the receiving streams was observed or indicated by bridge deck runoff from the three monitored sites.

### Assessing the Effects of Highway Bridge Deck Runoff on Nearby Receiving Waters in Coastal Margins Using Remote Monitoring Techniques (2004)

**Investigator: Oke Nwaneshiudu**

Nwaneshiudu conducted a study assessing the quantity and quality of stormwater runoff from a bridge that spans Clear Creek as a part of highway FM 528 near Houston, Texas. Stormwater was collected at the approach road near the outfall of the drainage culvert at the overpass of Clear Creek and from the bridge deck itself. Event mean concentrations were collected using a flow-paced monitoring scheme; aliquots for composite samples were collected in equally timed increments once the water level rose above a certain stage in the roadway approach culvert or in the flume used to estimate bridge deck runoff flow rates.

Water quality samples were also collected from Clear Creek, coinciding with samples collected at the culvert and bridge deck. Flow data for Clear Creek was collected from a monitoring station operated by the U.S. Geological Survey (USGS) located at the bridge.

Nwaneshiudu made the following conclusions:

- Zinc concentrations from bridge deck were consistently ten times higher than the culvert and creek samples and higher than the USEPA standard. These findings may be attributed to old galvanized metal bridge railing.
- Total copper and dissolved copper concentrations from bridge deck runoff were consistently higher than the USEPA standard.
- Total lead and dissolved lead concentrations from bridge deck runoff were orders of magnitude less than the USEPA standard.
- Chemical oxygen demand (COD) concentrations from bridge deck runoff were significantly less than values from a nationwide survey of highway runoff data (FHWA, 1990).
- Phosphate concentrations in the creek were on average much higher than concentrations from bridge deck runoff.
- Total nitrogen and total Kjeldahl nitrogen (TKN) concentrations showed no trend, but were sometimes above the USEPA standard.
- Total suspended solids (TSS) and volatile suspended solids (VSS) concentrations showed no consistency or noticeable trends and were relatively low.

### Effectiveness of a Stormwater Collection and Detention System for Reducing Constituent Loads from Bridge Runoff in Pinellas County, Florida (1996)

**Investigator: Yvonne Stoker**

A study was conducted by USGS in cooperation with Pinellas County, Florida to evaluate the quantity and quality of stormwater runoff generated from the Bayside Bridge located in west-central Florida, spanning 2.7 miles across part of the Old Tampa Bay. Monitoring of stormwater runoff from the bridge deck was conducted from May 1993 through September 1995. Water quality samples were collected using an automated sampler set to collect aliquots on a timed basis. Samples were analyzed individually throughout each storm event (i.e., they were not composited into one event mean concentration (EMC). Storm events collected during May and June of 1993 occurred before the Bayside Bridge was opened to traffic. The results summarized in this case study pertain to inflow water quality samples from the bridge deck. The study also evaluated a dry detention basin that received and treated stormwater runoff from the bridge deck. A case study for the performance of the dry detention basin is provided in Section 2.2.1.

Stoker made the following conclusions:

- Most constituents measured in stormwater runoff from the bridge were greatest at the beginning of the storm.
- Quality of stormwater runoff from the bridge varied with season, runoff volume, and the antecedent dry period.
- Maximum values of most measured constituents occurred in the spring of 1994 when rainfall was minimal.
- Maximum stormwater loads of nitrogen, iron, aluminum, nickel, and zinc occurred on August 22, 1995, also the date of maximum measured storm volume.

### National Cooperative Highway Research Program (NCHRP) Report 474: Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters, Volume 1 Final Report (2002)

**Investigator: Thomas V. Dupuis**

NCHRP Report 474 (Dupuis, 2002) provides a summary and critical review of an extensive set of scientific and technical literature addressing bridge deck runoff and highway runoff performed by Federal Highway Administration (FHWA), USGS, state departments of transportation, and universities. The report focuses on the identification and quantification of pollutants in bridge deck runoff and how to identify the impacts of bridge deck runoff pollutants to receiving waters using a weight-of-evidence approach.

Volume 1 of the final report includes a literature review of major studies focused on characterizing bridge deck runoff. The report also focuses on the investigation and development of several biological methods to help identify impacts. The following major conclusions from evaluating the results of the literature review as a whole are presented in the NCHRP report:

- The studies reviewed showed that direct discharge to some types of receiving streams, primarily small streams and lakes, can lead to localized increases in pollutant concentrations in sediment and, in some cases, aquatic biota. However, whether localized effects adversely affected biota was not investigated.
- Undiluted highway runoff can exceed federal and state ambient water quality criteria, but this alone does not automatically result in negative effects to receiving waters. The quality and use of receiving waters, as well as the flow path and possible reactions of runoff, must be considered independently of runoff loading.
- Lead concentrations in highway runoff have significantly decreased since the 1970s due to the phase-out of leaded gasoline.

- Comparison of historic metal toxicity research to present day data may prove difficult due to the measurement of metal toxicity shifting from total metals to dissolved metals.
- The ability of sediment to accumulate metals, polycyclic aromatic hydrocarbons (PAHs), nutrients, and other compounds warrants further research of sediment quality impacts and further development of standards and criteria.
- The results of bioassay testing using whole effluent toxicity from various studies have been mixed. For the studies that do show some level of toxicity, the runoff samples were high in salt content from deicing activities. The bioassay methods used by these studies may not be appropriate for evaluating stormwater runoff. Most bioassays expose the organism being testing continuously to runoff for long periods of time. However, stormwater runoff is delivered to receiving streams in short, intermittent time frames.
- Of the research reviewed, no clear link was been identified between bridge deck runoff and biological impairment.

### 2.1.2 Bridge Runoff Characterization Studies from North Carolina

NCDOT performs stormwater characterization studies as part the Highway Stormwater Program (HSP). Conducting research that “result(s) in independent quantitative assessment of pollutant loads…or measure(s) structural BMP effectiveness” is a requirement of NCDOT’s National Pollutant Discharge Elimination System (NPDES) permit (NCDENR, 2005). Previous HSP research projects that involved stormwater characterization have focused on runoff from roadways and non-linear facilities, as these types of transportation-related runoff reflect a larger portion of the overall NCDOT facility network. However, one completed research project performed by researchers at the University of North Carolina at Charlotte (UNC Charlotte) included a bridge deck in a statewide characterization effort. A case study on this project is provided in this section.

The researchers’ conclusions indicate that bridge deck runoff from one site in Charlotte had high EMCs as compared to the majority of other study sites, but bridge concentrations were similar to previously published urban runoff data for the Charlotte, NC area. In addition, the researchers theorized that the bridge deck curb wall might be responsible for accumulation of pollutants (Wu and Allan, 2001). While further research into the relationship between bridge design configurations and pollutant mobilization during storm events is necessary, this observation indicates that design-related stormwater management options may be used to improve runoff quality from bridge decks in urban areas.

**Sampling and Testing of Stormwater Runoff from North Carolina Highways (2001)**
**Investigators: Jy S. Wu and Craig J. Allen (UNC Charlotte)**

As part of NCDOT’s compliance with NPDES requirements, ten sites, distributed across North Carolina, were used to study the characteristics of highway stormwater runoff. One of the ten sites received drainage from a three lane concrete bridge in Charlotte, North Carolina with an ADT greater than 30,000 vpd. Runoff draining from the bridge deck is routed to a pipe located on the northeast corner of the bridge through a pipe under the bridge and is discharged into a vegetated area after passing through a sample collection trough with a 60 degree V-notch weir. Runoff monitoring data was collected at the weir from May 1999 through December 2000, with a minimum of 20 storm events being collected, distributed approximately evenly in each quarter of the calendar year, as suggested by NCDENR DWQ. Twenty-seven runoff events were used for the analysis of this site, with storm events ranging from 0.18 in to 1.70 in and an average storm event size of 0.67 in.

- Median EMCs for this bridge deck site were higher than EMCs for the other nine (non-bridge) sites studied for COD, nitrate, TKN, lead, and zinc. EMCs for TSS at the bridge location were identified as the second highest of the ten sites in the study.
- High levels of pollutant concentrations were attributed to high traffic congestion, no vegetation cover, and accumulation of pollutants on the bridge deck due to the curb wall.
- Site average EMC for all constituents at the bridge location resembled the water quality characteristics of previously published Charlotte, North Carolina urban runoff data.

## 2.2 Stormwater Control Measures

Due to the changes in stormwater quantity and quality that result from increased impervious area in a watershed, NCDOT regularly implements structural treatment options, source control, and design-related policies to protect surface waters. These surface water quality protection approaches are collectively referred to as stormwater control measures (SCMs). An SCM, often referred to as a best management practice or BMP, is any action or device that mitigates pollution from stormwater runoff. SCMs are primarily distinguished as being either structural or nonstructural (NCDOT, 2008a). Figure 2.2-1 provides a breakdown of the various types of SCMs typically used by NCDOT.

Some structural SCMs are used primarily to prevent erosion during the construction phase when vegetative cover has been removed or is not yet established on bare soil. These SCMs, collectively referred to as Erosion and Sediment Control, are implemented on a temporary basis and, therefore, do not pertain to surface water quality protection once a bridge or roadway is in service. Post-construction structural SCMs are permanent controls that treat stormwater runoff from stabilized drainage areas. Post- construction SCMs are either incorporated as part of the overall site drainage design or retrofitted in areas where surface water protection is necessary (NCDOT, 2008a). Some examples of structural post-construction SCMs include dry detention basins, bioretention basins, infiltration basins, and swales. Nonstructural SCMs are processes, policies, or practices implemented to influence behaviors, decisions, or actions that reduce the amount of pollution entering surface waters. Ultimately, nonstructural SCMs are designed to achieve source control (NCDOT, 2008a).

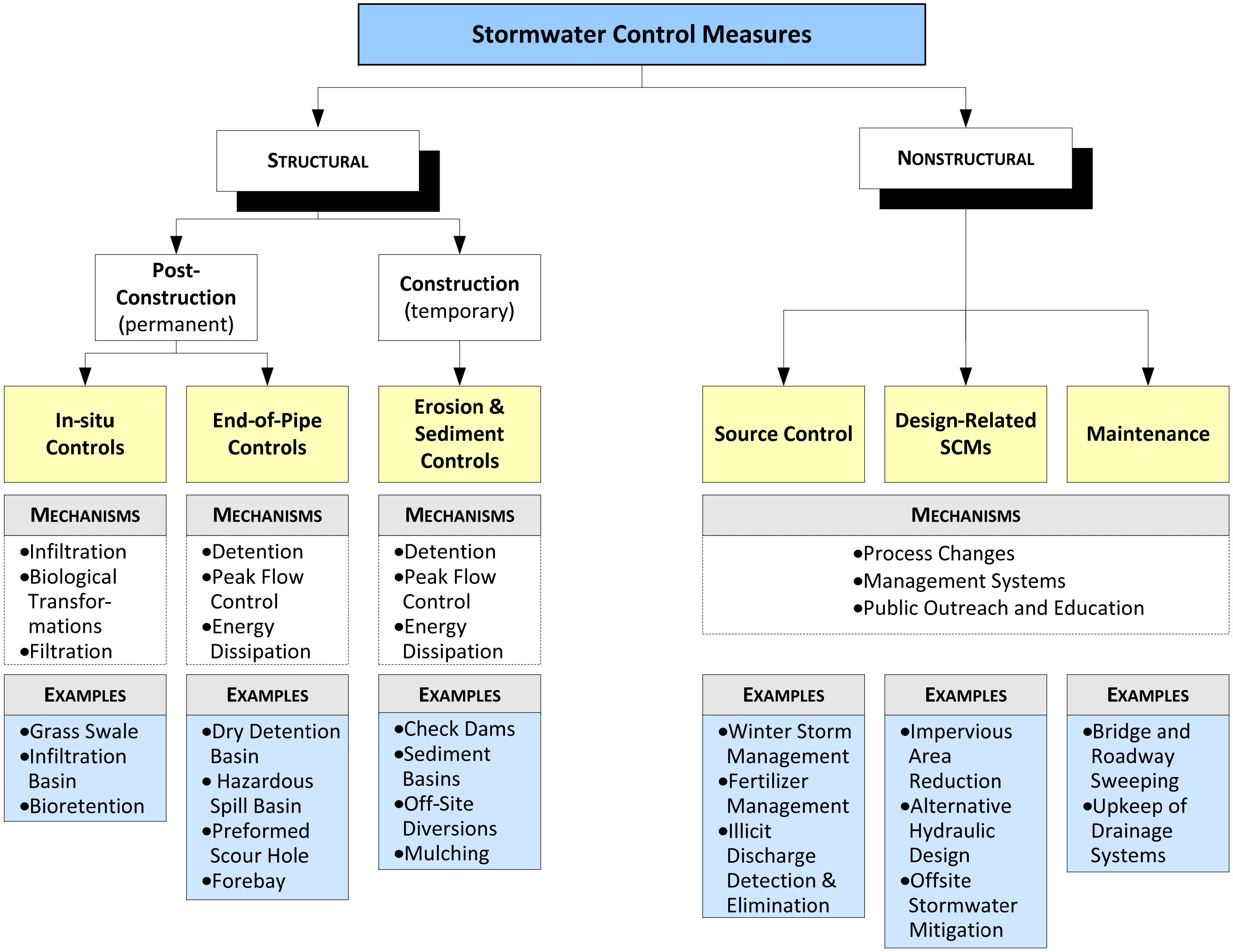


**Figure 2.2-1: SCM types. Modified from the NCDOT Stormwater Best Management Practices Toolbox (NCDOT, 2008a).**

SCMs of particular interest to NCDOT are design-related SCMs. Design-related SCMs for bridge decks would include creating guidance on bridge materials and hydraulic conveyances that can reduce the concentration or load of pollutants in runoff that enters receiving streams. One example of a design-related SCM is NCDOT's no-direct discharge policy, which advocates eliminating direct discharge of runoff from bridge decks to receiving streams under most conditions (Henderson, 2002).

Session Law 2008-107 requests information on the "effectiveness of [SCM] treatments" (NCGA, 2008). For an SCM to be effective in a specific application, particularly a structural SCM, the SCM must have the capability of reducing the concentration or load of any targeted parameters to a degree commensurate with receiving water quality goals. Stormwater SCMs function according to the same water treatment principles used in drinking water and wastewater treatment. SCMs can also be categorized according to their unit operations and processes, i.e., the physical, chemical, or biological processes that directly predominate to remove or contain a pollutant. For a thorough discussion of unit operations and processes common to stormwater SCMs, refer to NCHRP Report 565, *Evaluation of Best Management Practices for Highway Runoff Control* (2006). Some common pollutant removal mechanisms from that reference follow:

- **Sedimentation** – Runoff is detained in a basin so that suspended solids and particulate-bound pollutants settle as a function of particle density, particle size, and fluid viscosity (under quiescent conditions) to the bottom of the water column.
- **Filtration and Infiltration** – Runoff passes through an engineered media or existing soils where solids and particulate-bound pollutants are physically filtered by the media. If the media has adsorptive properties, dissolved pollutants may be entrained by the media as well. Treated runoff recharges groundwater supplies and reduces volumes delivered to receiving streams as surface flow.
- **Microbially Mediated Transformations** – Runoff is contained in a microbially diverse environment (e.g., a stormwater wetland, vegetated basin). Microbes decompose and mineralize organic pollutants and transform inorganic pollutants before runoff is released.
- **Sorption** – Runoff is contained in SCM systems (e.g., swales, filtration basins, stormwater wetlands) where substances of one state are incorporated into another substance (absorption) or molecules are bonded onto the surface of another molecule (adsorption).
- **Uptake and Storage** – Organic and inorganic constituents are removed from runoff by plants and microbes through nutrient uptake and bioaccumulation.

Many SCMs use a variety of unit operations and processes for pollutant removal. Only recently, however, has the practice of considering SCM unit operations (i.e., treatment mechanisms or processes) in the design and selection of structural SCMs and SCM treatment trains been advocated, such as in NCHRP Report 565 (2006). The use of physical processes, such as sedimentation and filtration, can be used to remove a significant portion of the pollutant load when a pollutant is predominately particulate bound. However, more complex chemical and biological unit operations may be required to treat pollutants that readily change form within the aqueous environment as a function of redox, pH, and available partitioning sites (i.e., solids load or media characteristics) (NCHRP, 2006).

The general practice for evaluating SCMs and comparing one SCM type to another in past studies has involved calculating pollutant removal efficiencies, or the ratio of effluent concentration to influent concentration expressed as a percentage (CWP, 2007). This narrow concept of "effectiveness" is not adequate for use in the current study for several reasons:

- Pollutant removal efficiencies for many SCMs that remove and sequester pollutants are largely a function of the influent stormwater pollutant profile (Wright Water Engineers and Geosyntec Consultants, 2007; CASQA, 2003; USEPA, 2009b). Since influent stormwater conditions can be site specific and are rarely verified by monitoring, using this criteria alone as an estimate of effectiveness may not be appropriate.

- Comparing pollutant removal of SCMs that use volume reduction as the primary unit operation (e.g., infiltration basins) to SCMs that promote sedimentation can be difficult. Since volume reduction SCMs remove a portion of the pollution load instead of targeting a particular pollutant, the treatment is based entirely on site-specific soil infiltration rates.
- SCMs that provide diffuse flow or otherwise prevent erosion have the potential to provide a widespread water quality benefit, but do not have comparable pollutant removal efficiencies to SCMs that actively remove pollutants already entrained in runoff. It can be complicated to quantitatively compare the theoretical load prevented (e.g., erosion prevented by riprap in the bridge overbank) to the theoretical load removed (e.g., solids removed in a dry detention basin).

If it can be reasonably assumed that bridge deck runoff does contribute a significant amount of a given parameter-of-concern to a receiving stream, then selecting an SCM based on pollutant removal efficiency alone may not guarantee adequate protection of the receiving stream. Since pollutant removal efficiencies are largely a function of influent parameter concentrations, they provide more information on influent water quality than SCM performance. In addition, methods for calculating percent removals can vary from study to study and agency to agency, making the use of existing literature problematic (CASQA, 2003). Some researchers now theorize that the effluent generated by some SCMs have an irreducible concentration, or an effluent concentration that represents the lowest concentration of which the SCM is capable. If the irreducible concentration of an SCM is greater than the influent pollutant profile for a parameter, the SCM would not be capable of any further reductions in concentration (Scheuler, 2000; NCHRP, 2006). These reasons, among others, have since prompted the International Stormwater BMP Database to stop providing pollutant removal efficiencies in their database and reports (Wright Water Engineers and Geosyntec Consultants, 2007). Developing procedures for selecting SCMs based on compiled irreducible concentrations and well-defined receiving stream goals (such as benthic macroinvertebrate health ratings) is the focus of current research (McNett et al., 2010). Until widely accepted procedures exist for identifying effective SCMs based on a distribution of effluent concentrations proven to protect receiving stream quality, many regulatory agencies, including NCDENR, require SCMs based on surrogate strategies. These surrogate strategies include mandating certain SCM types under certain circumstances, providing assumed pollutant removal credits for SCMs based on type, and assumed surface water quality protection for a suite of SCMs specific to certain receiving stream classifications or sensitive watersheds (NCDENR, 2009; NRC, 2008).

Once it is determined that an SCM is required for a project due to a regulatory requirement or that an SCM might be effective at treating bridge deck runoff at a particular site, the feasibility of SCM implementation must be considered. Like the urban grid system and other portions of the linear roadway system, successful installation of SCMs to treat bridge deck runoff is a function of structural, topographical, and regulatory considerations. A significant structural constraint to successful SCM application is the design and orientation of the bridge deck drainage system. The bridge deck drainage system is the structural conveyance system that removes runoff from the bridge deck before it encroaches onto the travel lanes. The drainage system is generally designed to accommodate an allowable spread during a specified design storm, or the horizontal distance available for runoff conveyance measured from the bridge deck gutter. Typical bridge deck drainage system components include the bridge deck itself, gutters, inlets, pipes, downspouts, deck drains, and bridge end collectors (FHWA, 1993).

Figure 2.2-2 shows a diagram of a typical bridge deck.

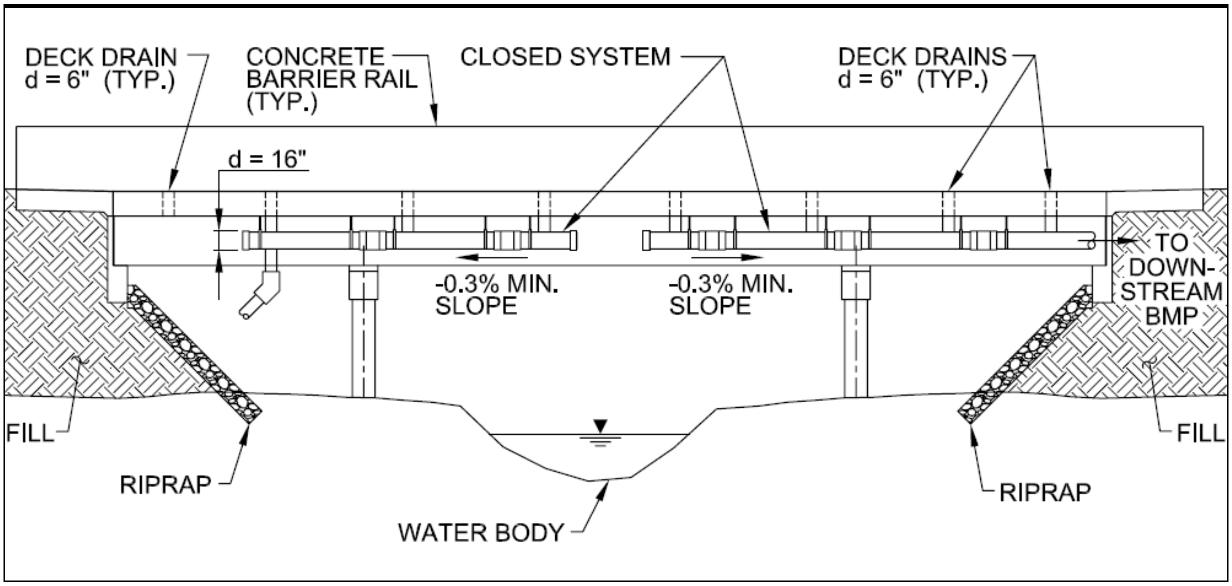


**Figure 2.2-2: Profile view of a bridge drainage system for a girder bridge (NCDOT, 2008a).**

Bridge deck drainage systems often use bridge end collectors to prevent upslope runoff from flowing onto the bridge deck and to collect runoff from the downslope end of the bridge deck. Bridge deck drainage systems also use various types of bridge deck inlets or deck drains to remove water from the bridge deck within the limits of allowable spread. Bridge deck end collectors and inlet systems can be used as stand alone drainage systems or in combination systems to properly drain runoff from a bridge deck (FHWA, 1993). A deck drain is an opening in the bridge deck that allows runoff to free fall onto the embankment or buffer or drain into a longitudinal pipe that routes collected runoff to a downstream collection system, SCM, or energy dissipation device (refer to figure 2.2-3).

Types of bridge deck drainage systems include, but are not limited to, the following:

- Gutter flow to a bridge end collector located on the downslope of the bridge.
- Deck drains that discharge freely across both the overbank and receiving stream.
- Deck drains that discharge only over the overbank (gutter flow is used to contain runoff in the portion of the bridge over receiving stream).
- Deck drains that discharge into a lateral trunk line across the entire bridge deck, discharging to some area downstream of the bridge.
- Combination system of deck drains that discharge freely over the overbank and deck drains that discharge into a trunk line over the receiving stream. In this scenario, the trunk line outlet is usually installed vertically down an end bent and discharges into the overbank.
- Deck drains that drain to a SCM directly under the bridge deck that discharges into the overbank or receiving stream.

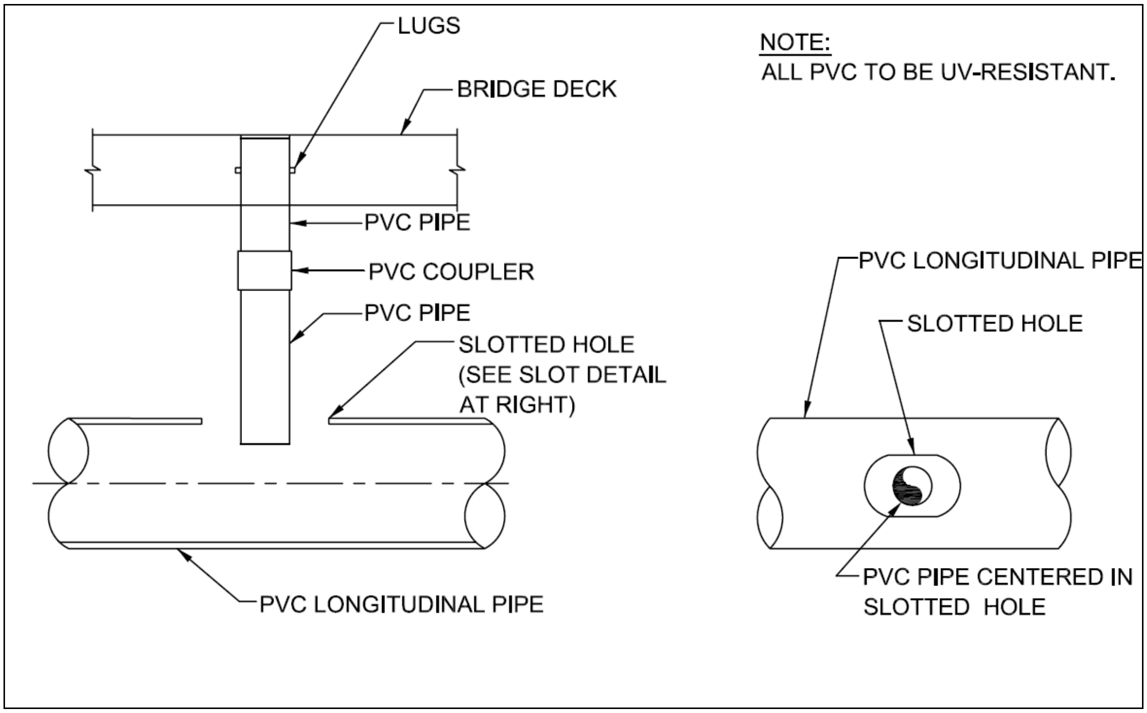


**Figure 2.2-3: Profile view (left) and plan view (right) of deck drain and longitudinal pipe connection (for a closed drainage system) (NCDOT, 2008a).**

Systems that disperse runoff across the bridge deck or overbank areas (i.e., deck drains without longitudinal trunk lines) require additional drainage design in the overbank or adjacent right-of-way to route runoff to an SCM. When runoff is discretely conveyed from the bridge deck, such as in a closed system or a bridge end collector that discharges into a single discharge point, the likelihood of feasible SCM implementation is improved. Provided there is available spread on the bridge deck, deck drains on an existing bridge may be blocked and runoff conveyed to a SCM via the bridge deck gutter. Blocking deck drains or similar modifications to the existing or designed bridge drainage system requires an evaluation of hydraulic capacity according to the appropriate design guidelines.

While closed drainage systems (i.e., inclusion of a longitudinal trunk line to direct runoff from the bridge deck) facilitate SCM implementation, several details must be considered during the initial bridge design. Some considerations include the following (Dupuis, 2002):

- The additional weight of piping systems needed for stormwater conveyance may create an additional load on the bridge.
- The spacing and sizing of deck drains and drop inlets used to drain bridge deck runoff for structural SCMs may conflict with structural members of the bridge.
- The piping system must be analyzed for structural integrity to ensure that piping can safely span between pipe supports.
- Piping typically used in stormwater conveyance systems will be difficult to access for debris removal and routine maintenance, which may be more pronounced depending on bridge type.
- Topography and approach slope of some bridges preclude design for gravity drainage back to land.

In addition to constraints inherent to the design of the drainage system, SCM installation near bridge decks is subject to the same geographic and topographic limitations as the rest of the linear roadway environment.

Limited area and steep slopes near the bridge deck can preclude orienting the SCMs to the contours of the site. Adequate area for an SCM may be available underneath the bridge deck in the overbank area, but there may be inadequate sunlight to support vegetated treatment. Finally, a high groundwater table and regulatory limitations in coastal areas and sensitive watersheds may prevent additional construction work near the receiving stream.

Off-site stormwater mitigation can be considered when treatment of bridge deck runoff is impracticable or when there is a larger environmental and economic benefit from implementing stormwater controls in other areas of the watershed. Stormwater mitigation generally refers to providing stormwater treatment elsewhere in the watershed to offset the amount of runoff and associated pollutants entering the receiving stream associated with the added bridge deck impervious area. Other states, including Delaware and Maryland, have stormwater mitigation programs that outline guidelines for mitigation and provide accounting systems for tracking mitigated areas. The Delaware Department of Transportation (DelDOT) and the Delaware Department of Natural Resources and Environmental Control (DNREC) have collectively developed a stormwater mitigation variance that can be implemented on state projects "when it has been demonstrated that exceptional circumstances exist at the project site which would cause undue hardship and not fulfill the intent of the State and Federal stormwater quality laws" (DelDOT and DNREC, 1996). Mitigation credit accounting is done by watershed, and the acreage of land provided with a stormwater quality control is considered a *credit* that is balanced against the acreage of land developed but untreated as a *debit* (DelDOT and DNREC, 1996). The accounting system used by the Maryland State Highway Association (MSHA) is similar to the program in Delaware, where accounting for stormwater mitigation is modeled after banking, considering impervious coverage as currency and watersheds as accounts where credits and debits are logged. Requests for stormwater mitigation go through a review and approval process that involves both the MSHA and the Maryland Department of the Environment (MDE, 2001; Sanghavi, 2004). Both programs allow for an accumulation of debits that must be resolved when a maximum limit is reached.

### 2.2.1 SCM Implementation Studies from Other States

To gather information about successful implementation of SCMs for bridge decks, a literature search was conducted to review both the various SCM treatment types typically used by other states to treat bridge deck runoff as well as any performance evaluations conducted on these SCMs. Presentation of these case studies are intended to support the Session Law 2008-107 requirement to "include…treatments [in the study] found effective by other states and new treatments identified through investigation and research" (NCGA, 2008). The following are some general conclusions from these case studies:

- Of the studies found in the literature, most evaluated the performance of dry detention basins with little investigation of other types of SCMs. Performance information was provided about the basins; however, no link between necessary protection of the receiving stream and effluent concentrations from the dry detention basins was established. While the studies show that dry detention basins are capable of reducing some parameters-of-concern, not enough information is provided to determine if the basins are effective at protecting receiving waters.
- One study researched an innovative stormwater drainage system that included pans on the Isle of Palms Connector bridge in South Carolina (Ross and Leitman, 1994). Results from this study do not necessarily provide enough information to make conclusions about the effectiveness of the pan system. In light of the maintenance burden associated with the pans, this treatment option does not appear feasible for widespread application.

### Granulometry, Chemistry and Physical Interactions of Non-Colloidal Particulate Matter Transported by Urban Storm Water (2003)

### Investigator: Hong Lin

A grit chamber and sedimentation basin were implemented to treat runoff from an 886-ft section of the Interstate I-10 City Park Lake overpass, located in Baton Rouge, Louisiana. Runoff was collected from the eastbound highway surface, routed through the collection trough, and transported by a collection pipe into the grit chamber where coarse sand was removed. Stormwater runoff was then routed into a settling basin where other solids, including silt and clay particles, slowly settled out (Lin, 2003). Both the grit chamber and settling basin were located underneath the bridge, as shown in figure 2.2-4.

Because the primary function of the grit chamber and sedimentation basin at the Baton Rouge site was to facilitate collection of stormwater and solids samples for detailed evaluation, not much information exists on performance efficiency of the sedimentation basin and grit chamber. However, monitoring results showed that the sedimentation basin was capable of removing particles in the fine sand range (2< D50 <3). The suspended fraction of solids that entered the sedimentation basin accounted for 6.6 to 36.8% of the total solid mass, measured across 12 storm events. Approximately 60% of sediment-sized solids (greater than 75-µm in diameter) remained in suspension after one hour of quiescent settling (Lin, 2003). This finding may impact the design retention time of gravitational settling tanks for bridge decks with characteristics similar to the I-10 overpass.

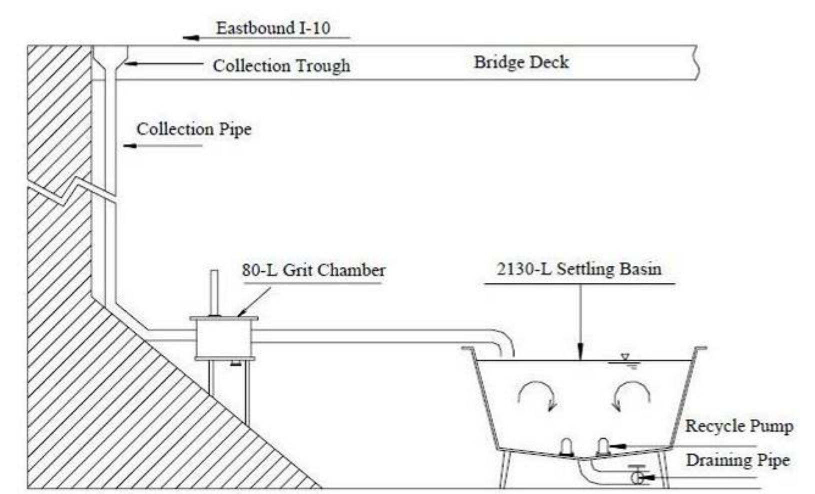


**Figure 2.2-4: Profile view of sampling system at the Baton Rouge experimental site (Lin, 2003).**

## Determination and Treatment of Substances in Runoff in a Controlled Highway System (Cross Lake) (2003)

### Investigator: D.M. Griffin, Rishi Raj Bhattarai, Mehran Esalmi, Sashi Shretha

Louisiana Tech University conducted a study to investigate the quality and quantity of stormwater runoff from the Cross Lake Bridge and to examine the effectiveness of a detention basin in removing contaminants from the runoff (2003). The Cross Lake Bridge, part of I-220, is located in Shreveport, Louisiana and spans approximately 10,000 feet over Cross Lake. The bridge deck area is approximately 880,000 sq ft. Cross Lake is a significant receiving stream because it serves as a potable water supply for the City of Shreveport. Due to concerns over the potential contamination of the water supply from a hazardous material spill from the bridge deck, a closed drainage system was implemented. The closed drainage system transports all runoff to a detention basin located at the east end of the Cross Lake Bridge. Stormwater runoff from the bridge deck was routed and stored in the detention basin until the Louisiana Department of Transportation and Development (LA DOTD) determines it should be emptied into nearby wetlands that drain into a bayou. Figure 2.2-5 shows the location of the detention basin and monitoring stations in relation to the Cross Lake Bridge.

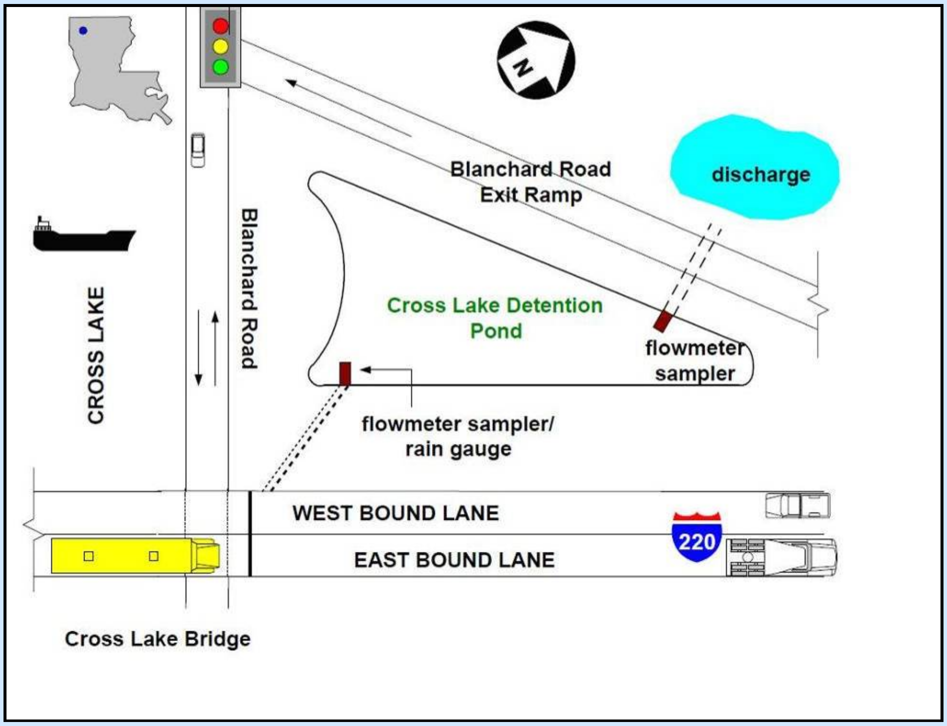


**Figure 2.2-5: Cross Lake Bridge with detention basin (Griffin et al., 2003).**

The detention basin is a concrete-lined holding basin whose water level was valve-controlled. The maximum depth of the detention basin varies from 6-8 feet, sloping in the direction of the outlet. The basin surface area is approximately 40,000 sq ft. Average detention time in the basin is between 5-10 days, but varies upon operation of the valve system. The detention basin is utilized in this application due to low maintenance and relatively low cost compared to other methods of reducing pollutants from non-point bridge deck stormwater runoff. Stormwater monitoring was conducted at the inlet and outlet of the detention basin, collecting over 33 drainage events (i.e., samples collected at the inflow and outflow of the basin that reflect the time interval between draining the pond) between June 1997 and March 1999.

Griffin et al. made the following conclusions:

- Approximately 50% of the rainfall that falls on the Cross Lake Bridge reaches the detention basin due to leaking and disconnections in the drainage system from the bridge to the detention basin.
- The detention basin was able to remove TSS, COD, total phosphorus, ammonia, nitrate, oil and grease, and total petroleum hydrocarbons by varying degrees as measured by pollutant removal efficiencies.
- Limited metals sampling was performed on solids and water samples from the pond between September 1999 and April 2000. Results show that the majority of the metals in the basin are particulate-bound, suggesting sedimentation may be adequate for removal of metals in the basin.

### Effectiveness of a Stormwater Collection and Detention System for Reducing Constituent Loads from Bridge Runoff in Pinellas County, Florida (1996)

**Investigator: Yvonne E. Stoker**

A study was conducted by the USGS in cooperation with Pinellas County, Florida to evaluate the quantity and quality of stormwater runoff generated from the Bayside Bridge and to determine the effectiveness of the stormwater collection and detention basin systems of the bridge in reducing constituent loads to Old Tampa Bay. The Bayside Bridge is located in west-central Florida and spans 2.7 miles across part of the Old Tampa Bay. The Bayside Bridge is a concrete bridge deck with an elevated center for marine vessel clearance (Stoker, 1996). Information on the results of stormwater characterization for this project is provided in section 2.1.1 of this report.

Stormwater runoff on the Bayside Bridge drains into iron grating and empties into longitudinal collection pipes located under the bridge. Runoff that exceeds the design capacity (1.5 inch storm event) discharges to Old Tampa Bay via overflow deck drains located adjacent to the grated inlets. Stormwater collected from the bridge drains via gravity to the north or south ends of the bridge. Stormwater draining to the northern part of the collection system (drainage area of 561,000 sq ft) is retained in a detention basin and overflow basin, located at the northern end of the bridge. The detention basin is shallow; the maximum depth of the basin is 1.5 ft deep. The combined surface area of the detention basin and the overflow basin is 82,800 sq ft. Excess water in the detention basin is routed into Old Tampa Bay through a bleed-down pipe and concrete weir that connects to a ditch along the east side of the basin. Figure 2.2-6 shows the bridge with detention basin location (Stoker, 1996). Stormwater monitoring was conducted for select storm events between May 1993 and September 1995 to characterize stormwater runoff and basin outflow using automated samplers. The automated samplers were programmed to collect aliquots on a timed basis once the basin elevation reached a specific level.

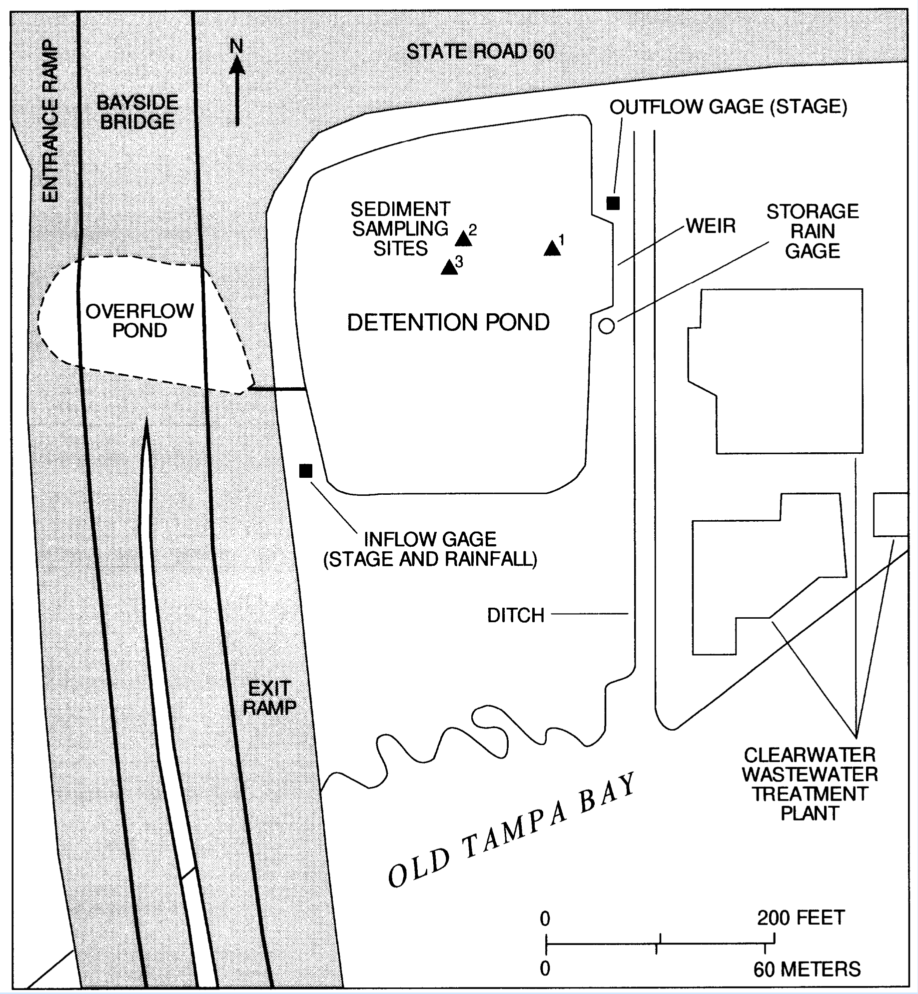


**Figure 2.2-6: Bayside Bridge location and detention basin system (Stoker, 1996).**

Stoker made the following conclusions:

- The pH in the outflow of the detention basin was relatively high during the summer months of 1993, 1994, and 1995, exceeding 9.0. High pH values are associated with low inorganic nitrogen concentrations, indicating a high level of photosynthesis by algae or aquatic plants in the basin.
- Settled solids were sampled in the dry detention basin before and after the bridge was open for traffic. Concentrations of VSS and nitrate+nitrite-nitrogen were higher in

basin solids before the bridge was open to traffic. Otherwise, TKN, phosphorus, and some metals were greater in basin solids after the bridge opened to traffic. However, the concentrations of aluminum, chromium, copper, lead, nickel, and zinc in the basin were within ranges measured in natural estuarine sediments.

- Using statistical analyses, it was determined that significant differences between inflow and outflow in the basin existed for all constituents but mercury. TSS, VSS, nutrients, and metals were generally greater in the inflow than outflow. The quality of outflow from the basin was influenced by inflow concentrations, biological activity, and the quality of direct precipitation onto the basin.
- When evaluating constituents as loads, the pond had a net export of ammonia, organic carbon, arsenic, and occasionally phosphorus. The source of arsenic in the basin is unknown. TSS loads were reduced approximately 30 to 45%, inorganic nitrogen loads were reduced by 60 to 90%, and most trace metal loads were reduced by 40 to 99%.

### 1994 Report of the Isle of Palms Connector for the Charleston Harbor Project (1994)

**Investigator: Philippe Ross and Paige Leitman**

The nearly two-mile long Isle of Palms Bridge crosses over marsh and creek habitat to connect the City of Mount Pleasant with the Isle of Palms in South Carolina. The bridge consists of a 1.24-mi causeway and a 0.62-mi span over the intracoastal waterway. To treat bridge deck runoff on the causeway, runoff was collected and transported to pans placed slightly beneath the bridge deck using a system of gutters and pipes (figure 2.2-7). In theory, the pans function to retain stormwater between storm events so that detained water would evaporate and any particulate-bound pollutants would be left in the pans as a solid residue. The South Carolina Department of Transportation (SCDOT) maintained the pan system by vacuuming water and solids from the bottom of the pans every thirty days. The runoff was stored in a holding tank and released to a pipe network to two spoil areas. These spoil areas were gravel coated, marsh-like areas where microbially mediated processes were expected to treat runoff (Ross and Leitman, 1994). Figure 2.2-8 shows the spoil areas of the stormwater drainage system off of the bridge span.

Several problems were documented with the pan system. The pans spilled over when a rainfall event greater than their designed storm (0.5 inches) occurred or when the pans iced over in the winter. Also, SCDOT did not consistently vacuum the pans every month and the pipes, pans, gutters and bridge leaked and spilled runoff directly into marsh areas not designated as spoil areas.

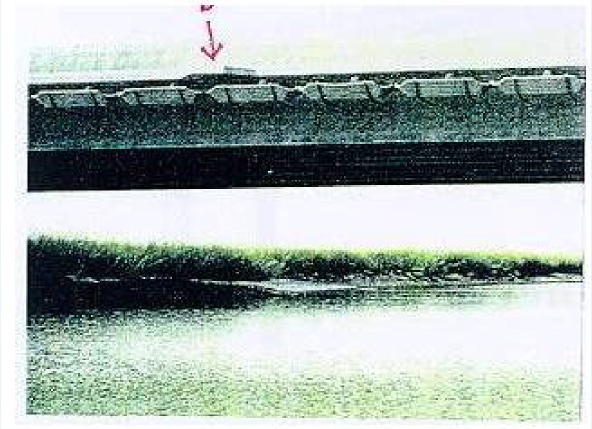


**Figure 2.2-7: Stormwater pan system on the Isle of Palms Connector in South Carolina (Ross and Leitman, 1994).**

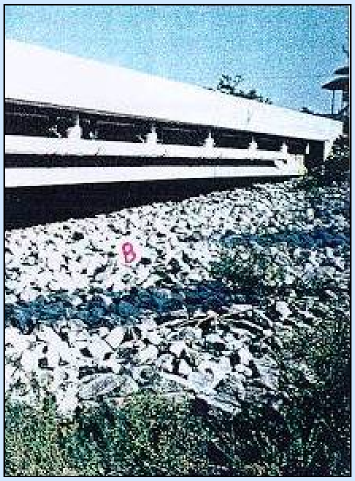


**Figure 2.2-8: Stormwater spoil area near the Isle of Palms Connector in South Carolina (Ross and Leitman, 1994).**

To evaluate the performance of the pan system in preventing stormwater runoff parameters-of-concern from entering Swinton Creek beneath the bridge, a quarterly sampling program was initiated. Aqueous runoff and solids samples were collected from the pans themselves and runoff was collected exiting the pans during a storm event. Bed sediment was collected in three locations: Swinton Creek in the vicinity of the causeway, the north Spoil area, and the south spoil area. Solids collected from the pans and sediment samples were used in an alternate assay test that measured the growth of a type of marine bacteria, a type of lettuce, and the Atlantic Littleneck Clam. Sediment was chosen as the best indicator of highway runoff effect for this study as the researcher contends that sediment is the primary sink for contaminants in highway runoff. In addition, due to tidal influences on the study site, surface water in vicinity of the study site is changed out with each high tide, reducing the significance of toxic impacts of aqueous phase samples.

In the first year of monitoring, no significant toxicity was observed from any of the bioassay tests. Unfortunately, runoff and sediment samples were not characterized for chemistry due to lack of funding. The authors of this study do not discuss if the lack of toxicity in sediment samples is due to an inherently small amount of toxic parameters in the bridge runoff or if the pan system is responsible for preventing toxic constituents from entering sediment. However, since no toxicity was observed in solids collected from the pan system, nor bed sediment, a preliminary conclusion would be that the particulate fraction of runoff from the bridge deck did not require treatment. The authors caution that, because this study only reported data for the first year of monitoring, all findings are preliminary and more monitoring is needed before significant data trends can be identified.

### 2.2.2 SCM Implementation Studies from North Carolina

NCDOT regularly monitors SCMs implemented to treat transportation-related runoff to meet NPDES permit requirements. Of the variety of SCM performance studies conducted, two have investigated SCMs that receive runoff from bridge decks. These two case studies are provided in this section. Both the Line (2006) and Wu and Allan (2006) studies investigated the same filter strip receiving runoff from an overpass in Johnston County. Line (2006) also investigated a coastal filtration basin receiving runoff from a concrete bridge deck. Overall conclusions from both case studies reveal the following:

- When possible, infiltration should be incorporated as a unit process for volume control and pollutant load reduction. However, it is critical to consider the elevation of nearby water bodies to prevent groundwater intrusion into the treatment system when infiltration and filtration are primary goals.
- The filter strip studied in both projects appeared to use both infiltration and physical filtration to reduce pollutant concentrations and loads. Provided effluent concentrations and loads adequately meet receiving water quality goals, this SCM design could be used at future sites.

**Evaluating BMPs for Treating Stormwater and Wastewater from NCDOT's Highways, Industrial Facilities, and Borrow Pits (2006)**
**Investigator: Dan Line**

In 2006, North Carolina State University embarked on a statewide project to provide pollutant removal efficiency data for NCDOT SCMs. This report summary focuses on the portion of the report that evaluated SCMs treating highway runoff. Of the SCMs studied, the drainage areas to two SCMs included bridge decks: a filter strip at I-40, NC 42 in Johnston County and a filtration basin near Hwy 70 in New Bern. While the filter strip in Johnston County receives runoff from an overpass bridge (i.e., the bridge does not span a waterway), results are included in this case study to provide information on SCM performance.

The area draining to the filter strip in Johnston County consisted of a two-lane road (NC42), a traffic light intersection between NC42 and the ramp to I-40, and a portion of the overpass over I-40. The SCMs consisted of an upstream forebay to remove large particulates, a level spreader downstream of the forebay to promote diffuse flow, and the filter strip itself. The 24 ft wide and 56 ft long filter strip was vegetated with Bermuda grass sod, resulting in a dense vegetative mat. Automated samplers were used to collect flow-proportionate composite samples from directly upstream of the forebay and level spreader and immediately downstream of the filter strip. Fourteen storm events were collected at the filter strip over the course of the study. A photo of the filter strip is provided as figure 2.2-9. General conclusions from the filter strip performance monitoring include the following:

- Runoff volume was nearly twice as high in the inflow as the outflow, indicating that notable infiltration of runoff was occurring in the filter strip even in the winter season. Infiltration is an important treatment mechanism as all potential parameters-of-concern are removed from outflow.
- Inflow and outflow composite runoff samples were analyzed for cadmium, chromium, copper, lead, nickel, and zinc in three storm events. Concentrations of cadmium, copper, and nickel were below detection in both inflow and outflow samples. Of the remaining metals, only zinc was above detection in outflow samples.
- Concentrations of nitrate+nitrite-nitrogen, dissolved phosphorus, and TSS in inflow were less than corresponding concentrations from nationwide highway data. Concentrations of these parameters were all reduced by the filter strip.
- The composite samples were analyzed for 67 semi-volatile compounds. Of these, only bis(2-ethylhexyl)phthalate was found at concentrations greater than the detection limit.
- Evaluation of pollutant removal efficiencies as concentrations and loads indicate that the filter strip may be more efficient at removing parameters-of-concern in the growing season.
- Statistical analysis of pollutant removal efficiencies showed TKN and total nitrogen had reductions consistent and great enough to be significant.
- Phosphorus concentration generally increased in the filter strip, possibly due to disturbances in the filter strip for experimental set up of a follow-on project.

**Figure 2.2-9: A filter strip that receives overpass runoff at Hwy 42 and I-40 in Johnston County, North Carolina (Wu and Allan, 2006).**

The filtration basin in New Bern was referred to in the report as an enhanced roadside swale.

However, because the SCM consisted of a depressed area with fine aggregate sand filter material, and was not designed primarily for conveyance or reduction of flow rates, the SCM is a filtration basin, not a swale, regardless of the orientation of the basin. The basin receives runoff from a concrete bridge deck over the Trent River near its confluence with the Neuse River, a small section of Highway 70, and a traffic light intersection. The amount of runoff from the bridge as compared to the intersection and highway was unknown as the drain from the bridge to the Trent River was partially plugged. The basin is 8 ft wide and 200 ft long. The filter media consists of washed ASTM C33 fine aggregate concrete sand overlain with Centipede grass sod. Flow-proportionate samples were collected using autosamplers at the inflow and outflow of the SCM for 14 storm events. A photo of the filtration basin is provided as figure 2.2-10. General conclusions about the filtration basin performance include the following:

- For 10 of the 14 events, outflow from the site was greater than inflow, indicating that groundwater intrusion into the SCM was occurring for storms with high rainfall accumulation or storms with antecedent wet soil conditions.
- Of the metals evaluated in the inflow and outflow, all were below detection except for zinc. Zinc concentrations were above detection in inflow samples only for two of three storm events monitored for metals.
- Chloride concentrations were higher in outflow than inflow, likely due to groundwater intrusion. However concentrations were below North Carolina surface water quality standards.
- TSS was reduced to below detection limits in outflow for 9 of the 14 storm events.
- Samples from three storm events were analyzed for 67 semi-volatile organic compounds. Only phenol was found at a concentration greater than the detection limit, in the inflow for one storm event only.
- Removal of nitrogen and phosphorus species was limited due to groundwater influx.

**Figure 2.2-10: A filtration basin treating runoff from a concrete bridge over the Trent River in New Bern, North Carolina (Line, 2006).**

**Evaluation and Implementation of BMPs for NCDOT's Highway and Industrial Facilities (2006)**

**Investigators: Jy Wu and Craig J. Allan**

Researchers at UNC-Charlotte also investigated the filter strip at I-40 and NC42, described above in the Line (2006) study. Automated samplers were used to collect flow-proportionate composite samples from the inflow and outflow of the filter strip for nine storm events.

General conclusions from this monitoring program included the following:

- Peak flow reductions from inflow to outflow were observed for all storm events monitored, ranging from a 15-90% reduction depending on the size of the storm event.
- Approximately 10-40% of inflow volume was removed by infiltration, as determined by calculating ratios of cumulative outflow-to-inflow volume.
- Outflow TSS concentrations from the filter strip averaged 5.4 (+/- 2.2) mg/L, which represents the irreducible concentration of TSS from the filter strip. Average inflow concentration was at 32 mg/L.
- Total nitrogen concentrations in the inflow and the outflow were similar (mean concentration of 1.51 mg/L in inflow compared to 1.37 mg/L in outflow), suggesting that concentrations were too low for the filter strip to provide any treatment, other than load reduction via infiltration.
- Orthophosphate concentrations were five times higher in the outflow than in the inflow, possibly due to the late spring / early summer sampling period.

## 2.3 NCDOT's Current Stormwater Management Practices for Bridge Deck Runoff

Evaluation, design, and implementation of SCMs to control stormwater runoff from roadways, bridges, and non-linear facilities is currently integrated into planning, design, and construction tasks associated with projects in new locations and retrofits. SCM implementation is a standard, existing practice captured in NCDOT's mission statement: "Connecting people and places in North Carolina – safely and efficiently, with accountability and environmental sensitivity." NCDOT's current process to implement SCMs is directed by numerous established practices, policies, and regulations, intended to avoid or mitigate for impacts from NCDOT's activities. Where avoidance and mitigation is not feasible, NCDOT implements treatment technologies to reduce effects on and to protect the environment. The following guidance and regulatory documents and policies influence NCDOT's management of stormwater runoff from bridges over waterways:

- **State Stormwater Regulations and NCDOT's NPDES Permit** – numerous regulations promulgated by NCDENR to be protective of selective sensitive watersheds. Often these regulations include design criteria, buffer requirements, and/or restrictions which NCDOT must implement to the maximum extent practicable. The state stormwater regulations are included in sections of 15A NCAC 02H, 15A NCAC 02B, and various session laws (NCDENR, n.d.). NCDOT implements the state stormwater regulations in part through their NPDES permit.

- **NCDOT's *Stormwater Best Management Practices Toolbox*** – written by NCDOT and URS Corporation and approved by NCDENR, the *Stormwater BMP Toolbox* includes guidance on the design and implementation of structural SCMs, including bridge conveyance systems and those providing stormwater treatment (NCDOT, 2008a).
- **NCDOT's No-Direct Discharge Policy** – established in 2002 and subsequently incorporated into the NCDOT *Stormwater BMP Toolbox*, this policy, outlined in a memo from the NCDOT State Hydraulics Engineer, presents bridge deck drain design practices to avoid discharging bridge deck runoff at most bridges over waterways (Henderson, 2002).
- **Endangered Species Act of 1973** – SCMs to mitigate effects on endangered species, including streams with endangered aquatic species, are evaluated and implemented as required under the Endangered Species Act of 1973 (Title 16 of the United States Code [USC] 1531-1544) and the NPDES permit (NCDENR, 2005).
- **Impaired Waters (Clean Water Act)** – SCMs are implemented to address parameters-of-concern as identified by NCDENR under Section 303(d) of the Clean Water Act (33 USC 1251 et seq.) and through total maximum daily loads (TMDLs) waste load allocations assigned to NCDOT.
- **Low Impact Bridge Replacement Policy** – established by NCDOT and NCDENR, the policy allows streamlining environmental permitting of replacement bridges that are not significantly different from the existing bridge.

Implementation of these regulations and policies is structured under the NCDOT's Post-Construction Stormwater Program (PCSP). As a requirement of NCDOT's NPDES permit for stormwater discharges statewide, NCDOT is working with NCDENR to develop the PCSP. The PCSP applies to 78,000 linear miles of roadway distributed through the 100 counties of the state. Including ferry routes and industrial facilities, NCDOT's linear and non-linear network is the second largest in the country (NCDOT, 2008b). NCDOT's linear network includes 1,455,647 total linear feet, or approximately 1,200 acres, of impervious bridge deck area. Figure 2.3-1 shows the distribution of bridge decks over waterways in the state. The geographic scope of NCDOT's bridge and roadway network requires NCDOT to develop a stormwater program that is protective of a wide variety of natural resources while being flexible enough to address site-specific concerns (NCDOT, 2008b).

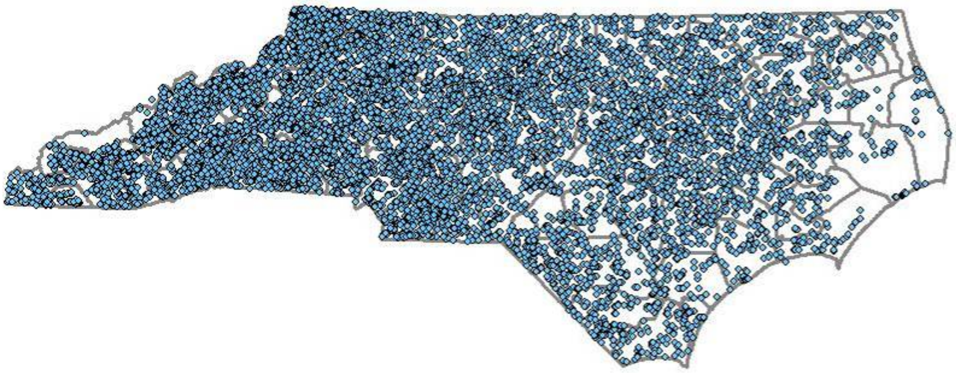


**Figure 2.3-1: Distribution of bridges over waterways in North Carolina.**

For construction projects at new locations, SCMs can also be identified and implemented under the Merger Process, a process whereby the appropriate agency representatives discuss and reach a consensus on how the aspects of a particular project will meet the regulatory requirements of Section 404 of the Clean Water Act during the National Environmental Policy Act (NEPA) / State Environmental Policy Act (SEPA) decision-making phase of transportation projects (NCDOT, n.d.). NCDOT participates in the Merger Process with the U.S. Army Corps of Engineers (USACE), NCDENR (DWQ and the Division of Coastal Management [DCM]), the Federal Highways Administration (FHWA), and other stakeholder agencies and local units of government. The Merger Process allows agency representatives to quickly and comprehensively evaluate and resolve regulatory issues by providing a common forum for them to discuss and reach a compromise-based decision and identify necessary SCMs. Additional discussion of NCDOT's current practices to manage bridge deck runoff is provided in section 6.

Of central importance to NCDOT's various stormwater management initiatives is the control of stormwater runoff from impervious surfaces. Where possible, NCDOT currently implements bridge stormwater controls to collect runoff and drain it back to the bridge approach, avoiding direct discharge to the receiving stream, especially in cases of sensitive streams. Conversely, runoff from many older or large bridges is directly discharged to receiving waters, with no water quality treatment before entering waterways. Currently, it is not fully understood if retrofitting existing bridges with conveyance systems that will prevent direct discharge of bridge deck stormwater runoff into receiving waters will provide significant environmental benefit to receiving streams (Dupuis, 2002).

## 2.4 Foundation of BSP Project

Based on the review of landmark bridge deck runoff studies and available research projects on bridge characterization and SCM implementation, it is evident that not much is known about the unique impacts of bridge deck runoff on receiving streams or whether existing SCMs are adequate for treating bridge deck runoff. With the exception of maintenance practices with known toxic inputs (such as deicing practices), preliminary studies that have investigated biological integrity near bridge crossings have not revealed a definitive link between bridge deck runoff and biological impairment. Further, examples of SCM implementation to treat bridge deck runoff are rare due to the limited feasibility of installing structural SCMs in the highly compacted, small land area typical of bridge crossings. Of SCM studies available, not enough information is provided to show that implementation of an SCM has added measurably to the protection of surface water quality nor that surface water quality goals have been met. Further investigation of both bridge deck runoff impacts to receiving streams and successful implementation of SCMs to mitigate known impacts is needed.

Session Law 2008-107 requires a study of "various types of storm water detention, collection, and filtering systems" for bridges over waterways. The study should include, "a pilot study on 50 bridges…includ[ing]…treatments found effective by other states and new treatments identified through investigation and research which may be effective" (NCGA, 2008). Ultimately, the Session Law requires a cost estimate for implementing treatments on newly constructed bridges and necessary bridge retrofit projects for all bridges over waterways in the state. While developing a project approach to satisfy the requirements of the session law, various fundamental questions were raised by the project team:

- Does bridge deck runoff in North Carolina generally contain toxic parameters or other parameters-of-concern typical to transportation runoff such that receiving streams are consistently negatively affected? What is the best way to identify a negative effect on receiving streams?
- How does the effect of bridge deck runoff on a receiving stream compare to upstream watershed sources of potential impact?

- If a relationship between receiving stream effects and elevated pollutant loads in bridge deck runoff is evident, are there certain bridge characteristics that might influence a negative receiving stream effect?
- Is water and particulate chemistry in bridge deck runoff considerably different than roadway runoff? If so, what aspects of the pollutant profile are unique? Is a tailored stormwater management approach to managing bridge deck runoff critical for protection of surface waters?
- What constitutes an effective SCM? What is the best way for effectiveness to be measured and evaluated? How do we know that implementation of SCMs is providing a net benefit to receiving stream quality?
- Is the existing NCDOT PCSP, which includes implementation of structural SCMs to treat bridge deck runoff when deemed appropriate by regulation or consultation with state environmental agencies, adequately protective of receiving streams with bridge crossings? If not, what additional SCMs or SCM-related programs, such as off-site mitigation, might be necessary?

Clearly, the requirements of the session law are focused on evaluating bridge deck runoff treatment options. Much current information exists in the literature and in North Carolina regulatory requirements about typical SCM function and performance ability for urban and transportation-related runoff. However, because much is unknown about bridge deck runoff as a unique subset of transportation runoff, a greater understanding of a cause and effect relationship between bridge deck runoff and receiving stream quality is a prerequisite for development of treatment programs. Therefore, a project approach was developed to address some of the fundamental questions presented above. The intention of the project approach is not only to provide a more accurate cost estimate of SCMs that reflects the protection of surface waters from bridge deck runoff, but also to advance the knowledge of bridge deck runoff as a potentially unique subset of stormwater runoff.

The first major effort of the project was to design a multi-faceted monitoring program to allow for a weight-of-evidence (WOE) evaluation of bridge deck runoff effect on receiving streams. Due to the inherent heterogeneity of the natural environment, there are limitations to the conclusions that can be drawn from any one environmental study. Therefore, the WOE technique uses several types of environmental data as lines of evidence to strengthen the acceptance of a particular hypothesis. The WOE approach is described by several fundamental references, including NCHRP Report 474 (Dupuis, 2002) and Burton and Pitt (2002). The WOE approach is also used by NCDENR to assess potential reasons for impairment in streams (NCDENR, 2003, 2004a, 2004b, 2004c). The BSP monitoring plan that supports the WOE evaluation for this project includes the following:

- Bridge deck runoff quality and quantity monitoring.
- Instream water quality and quantity monitoring upstream of bridge crossings.
- Instream biological surveys.
- Time-variable exposure bioassays.
- Instream bed sediment collection and characterization.
- Bridge deck solids collection and characterization from regional bridge decks.

In addition to collecting data from a variety of matrices (i.e., stormwater runoff, bed sediment, macroinvertebrates), the variability of the bridge deck system in North Carolina was considered. Thus, monitoring and sampling sites were selected to represent several bridge crossing attributes, such as pavement type, ecoregion, average daily traffic (ADT), bridge area, and receiving stream classification. In this report, results from the BSP monitoring program are used in the WOE evaluation to compare bridge deck runoff to other types of runoff and upstream instream conditions, provide insight into the potential hydrologic impacts of bridge crossings on receiving streams, assess what impact the bridge crossing has on bed sediment chemistry and macroinvertebrate health and diversity, and examine biological toxicity of runoff. The results of these evaluations, using best professional judgment, are collectively assessed to determine whether a conclusive causal relationship exists between bridge deck runoff and receiving stream impacts.

Based on the results of the WOE evaluation, an assessment of the adequacy of the current NCDOT PCSP is performed, based on the following assumptions. If no obvious causal relationship between bridge deck runoff and receiving stream effect is observed, it can be assumed that bridge deck runoff is not a primary source of receiving stream impact. In this scenario, the current PCSP would be conservatively protective of receiving stream quality. Conversely, were the lines of evidence from the monitoring program to reveal bridge deck runoff as a potential significant source of impact, a reevaluation of the PCSP would be necessary to include innovative treatment options, policies, and design-related SCMs. In this alternative scenario, recommendations for feasibility studies and program evaluations will be provided. In addition to evaluating the PCSP based on the outcome of the WOE evaluation, additional improvements to the current PCSP regarding bridge deck drainage systems and bridge deck runoff management are provided to support continual improvement of the NCDOT NPDES program.

Next, per session law requirements, a cost estimate is presented that determines the costs of SCM implementation for bridge decks statewide. The basis of the cost estimate is supported by the following:

- Development of a clear definition of SCM effectiveness and an evaluation of SCM applicability for treatment of bridge deck runoff, based on the principles of irreducible concentrations and monitoring data. Applicability is also qualitatively evaluated for source control SCMs.
- Evaluation of at least 50 bridge SCM pilot study sites, as required by the session law. These sites were selected to represent SCMs that are currently implemented or could be implemented to either treat or provide source control for bridge deck runoff as part of the NCDOT PSCP. Cost, constructability, and applicability of SCMs for bridge deck crossings were obtained from the pilot studies.
- Creation of a decision process, based on the current PCSP or a modified PCSP, to estimate the number of SCMs that may need to be applied to planned bridge construction and retrofit projects.
- Preparation of blended cost relationships for the various aspects of the life-cycle of SCM costs based on professional judgment and cost models available in the literature.

Beyond the cost estimate, the results of this study, considering its magnitude and the lack of previous information on bridge deck runoff in the literature, should facilitate process improvement for bridge deck runoff management in North Carolina and elsewhere. Therefore, a series of conclusions and recommendations are provided to facilitate implementation of lessons learned into existing processes between NCDOT and other environmental state agencies for improving stormwater management decisions that pertain to bridge deck runoff.

# 3.0 BSP Monitoring Program

Inherent in the session law requirements to investigate the costs for effective stormwater treatment of bridge deck runoff is the hypothesis that untreated bridge deck runoff significantly impacts receiving streams such that their designated use may be compromised. While some studies have indicated that bridge deck runoff might result in elevated constituent concentrations in sediment and biota in the immediate vicinity of bridges (Yousef et al., 1984; Mudre and Ney, 1986), there has been no evidence of toxicity of runoff or adverse effects on aquatic biota or water quality degradation over larger spatial scales (Dupuis, 2002; Mudre and Ney, 1986). Without verifying the assumption of impact or lack thereof, critical context is missing to properly evaluate the need for and the cost of statewide SCM implementation. Therefore, BSP partners and various monitoring experts collaborated on a multi-pronged monitoring program to support evaluation of bridge deck runoff effect. The goals of the monitoring program were to (1) characterize bridge deck runoff, (2) characterize streambed sediment at bridge crossings and bridge deck solids, and (3) assess toxicological effects and aquatic health at bridge crossings in North Carolina.

Sampling program development, site selection and characteristics, field activities, and analytical procedures and methods are provided in this section of the report. For data evaluation and a discussion of the overall effect of bridge deck runoff on receiving streams, as supported by the collected monitoring data, refer to section 4.

## 3.1 Monitoring Program Overview

### 3.1.1 Site Selection

Monitoring sites were selected to represent the various physiographic regions, land uses, bridge characteristics, and receiving streams typical of NCDOT bridge crossings statewide. The elements of the monitoring program are discussed in section 3.1.2. Monitoring sites for each element are discussed in the respective section for that program element.

Significant effort was made to distribute BSP monitoring sites across North Carolina in order to capture differences in environmental resources. Ecoregions, established by the USEPA, serve this purpose by identifying regions with different geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Griffith et al., 2002). For the purpose of the BSP, the ecoregion of a location is used as a convenient way to identify ecological diversity and location, and to evaluate general contributions of regional characteristics. North Carolina is divided into three major ecoregions for the BSP based upon the four USEPA Level III ecoregions established by Griffith et al. (2002). The BSP has followed the protocol of the USGS and other resource agencies in combining the Middle Atlantic Coastal Plain and the Southeastern Plains identified by Griffith into one Coastal ecoregion, which generally includes North Carolina’s Sand Hills region and the coastal counties. The Blue Ridge ecoregion incorporates the mountainous areas to the far western portion of the state, and the Piedmont ecoregion includes the area of broad plains and hills making up the central portion of the state. Figure 3.1-1 presents the three ecoregions used in this study and the location of sampling sites included in each of the monitoring regimes.

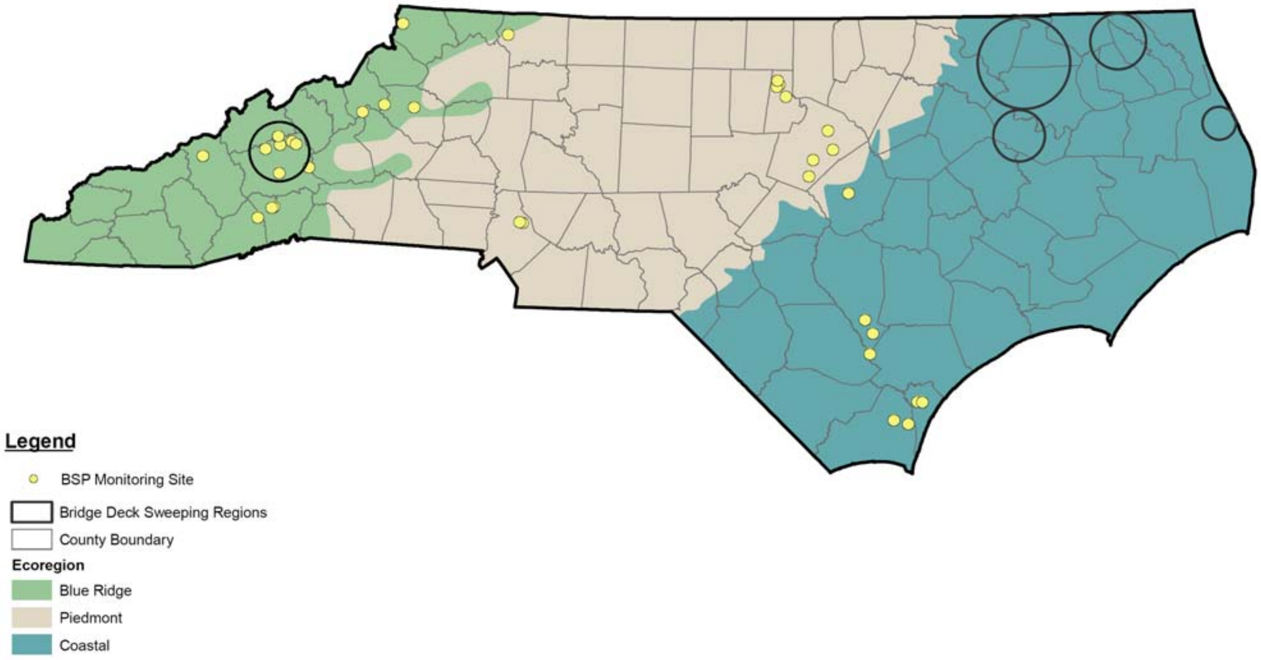


**Figure 3.1-1: BSP bridge monitoring program sites and study areas.**

Effort was also taken to monitor at sites featuring different stormwater management systems. A bridge deck with a *direct discharge drainage system (DDDS)* allows for the collection of runoff to discharge freely to the surface waters below the bridge through deck drains or scuppers. *No-direct discharge drainage systems (DDDS)*, in contrast, are systems where runoff is redirected through constructed infrastructure and includes both *closed* systems, where bridge deck runoff is piped to a central discharge location (usually to an SCM for water quality purposes), and systems where bridge gutters redirect runoff (typically for bridges with low runoff volume). Bridge drainage systems are discussed further in section 5. Additional information on bridge deck drainage systems can be found in the *NCDOT Stormwater BMP Toolbox* (NCDOT, 2008).

**Figure 3.1-2: Direct discharge (left) and no-direct discharge drainage systems (right).**

### 3.1.2 Program Regimes

Monitoring regimes were initiated to provide information on the physical, chemical and biological effects of bridge deck runoff. The major BSP monitoring regimes are listed below, along with the subsection in the report containing more detailed information about each element of the monitoring regime.

The **Water Quality and Quantity Monitoring Regime** allows for quantification of the volume and chemistry of runoff, and the resultant impacts on the receiving stream. Water column chemistry identifies the levels of constituents most aquatic biota are actually exposed to. The implementation of this regime included the collection of:

- Bridge deck runoff quality as event mean concentrations (EMCs) to identify specific water chemistry parameters that might impact the integrity of the receiving stream (section 3.2.1).
- Bridge deck runoff quantity hydrologic parameters to support assessment of receiving stream hydromodification risks and water chemistry mass load calculations (section 3.2.1).
- Instream water quality and quantity upstream of bridge crossings at select sites to identify existing conditions and impairments from collective watershed sources other than the bridge deck (section 3.2.2).

The **Sediment/Solids Chemistry Monitoring Regime** allows for the characterization of the sediment bed chemistry. Sediment layers are a major source/sink of pollutants in lotic ecosystems. Whereas water column chemistry responds to short-duration events, sediment chemistry provides information relevant over a longer timescale. The implementation of this regime included the collection of:

- Streambed sediment samples to identify changes in sediment quality downstream of the bridge deck compared with upstream, and downstream of direct discharge drainage systems compared with no-direct discharge drainage systems (section 3.3.1).
- Solid material from bridge deck surfaces through sweeping activities performed on a regional scale to determine parameter concentrations in solids present on decks that could potentially be conveyed to receiving streams during storm events (section 3.3.2).

The **Biological Monitoring Regime** involved the study of the toxicity of waters to test organisms and the lotic community structure to determine ecological impacts from bridge deck runoff. Whereas the study of the chemistry of the water column and the sediment layers allows for an understanding of the exposure of aquatic biota to potentially detrimental levels of chemical constituents, biological monitoring allows for understanding the resultant impacts (or lack thereof) of the exposure, related to the bioavailability of these constituents. The implementation of this regime included the performance of:

- Biological assays (bioassays) to assess the toxicity of bridge deck runoff by studying the survival and reproduction of test organisms exposed to both bridge deck runoff and instream samples (section 3.4.1).
- Biological surveys (biosurveys) to evaluate the integrity of macroinvertebrate habitats in the vicinity of bridges by comparing population structures spatially and temporally, and relative to a pristine reference site (section 3.4.2).

In addition to the above monitoring regimes, **traffic surveys** were conducted to determine current ADT at select monitoring sites to support full site characterization. Accurate traffic data is vital in characterizing vehicular impacts on receiving streams. The methods for traffic data collection are provided in section 3.5.

Table 3.1-1 includes a list of all monitoring sites included in this study and the corresponding monitoring regime performed at each site.

**PROVISIONAL DATA DISCLAIMER**

*Water and sediment quality sampling activities and associated laboratory analyses (for activities pertaining to data in sections 3.2, 3.3, and 3.4) were ongoing at the time of the development of this report, and the data used in the preparation of this report may be incomplete. For the water quality and quantity monitoring results, chemical analyte concentrations, stream stage and discharge values presented throughout this report are designated as 'provisional.'*

**Table 3.1-1: Monitoring Regime Matrix for Bridge Monitoring Sites**

| Ecoregion | Bridge Number | Stream Name | Bridge Deck Runoff Quality and Quantity (15 Sites) | Instream Quality and Quantity (4 Sites) | Streambed Sediment Quality (30 Sites) | Bioassay (13 Sites) | Biosurvey (15 Sites) | Traffic Survey (15 Sites) |
|---|---|---|---|---|---|---|---|---|
| Blue Ridge | NA | Cataloochee Creek | | | X | | X | |
| Blue Ridge | 040338 | Roaring Fork Creek | | | | | X | |
| Blue Ridge | 100124 | Flat Creek | | | X | | | |
| Blue Ridge | 100145 | Dillingham Creek | X | | X | | X | X |
| Blue Ridge | 100147 | Dillingham Creek | | | X | | | |
| Blue Ridge | 100250 | Flat Creek | X | | X | | X | X |
| Blue Ridge | 100494 | Swannanoa River | X | X | X | X | X | X |
| Blue Ridge | 100498 | Swannanoa River | | | X | | | |
| Blue Ridge | 100734 | Big Ivy Creek | X | | X | X | X | X |
| Blue Ridge | 130003 | Lost Cove Creek | | | | | X | |
| Blue Ridge | 130007 | Yadkin River | | | | | X | |
| Blue Ridge | 440007 | Boylston Creek | | | X | | | |
| Blue Ridge | 440008 | Boylston Creek | X | | X | X | X | X |
| Blue Ridge | 560522 | Little Ivy Creek | | | X | | | |
| Blue Ridge | 850037 | Mitchell River | | | | | X | |

## Table 3.1-1: Monitoring Regime Matrix for Bridge Monitoring Sites (continued)

| Ecoregion | Bridge Number | Stream Name | Bridge Deck Runoff Quality and Quantity (15 Sites) | Instream Quality and Quantity (4 Sites) | Streambed Sediment Quality (30 Sites) | Bioassay (13 Sites) | Biosurvey (15 Sites) | Traffic Survey (15 Sites) |
|---|---|---|---|---|---|---|---|---|
| Blue Ridge | 870106 | Boylston Creek | | | X | | | |
| Coastal | 080085 | Black River | | | X | | | |
| Coastal | 090061 | Town Creek | X | | X | X | | X |
| Coastal | 090074 | Town Creek | | | X | | | |
| Coastal | 640002 | Smith Creek | | | X | | | |
| Coastal | 640132 | Smith Creek | X | | X | X | | X |
| Coastal | 810014 | Black River | X | X | | X | | X |
| Coastal | 810058 | Black River | | | X | | | |
| Piedmont | 120008 | Clarke Creek | | | X | | | |
| Piedmont | 310005 | Mountain Creek | X | X | X | X | X | X |
| Piedmont | 310025 | Little River | | | X | | | |
| Piedmont | 310061 | Mountain Creek | | | X | | | |
| Piedmont | 310064 | Little River | X | X | X | X | X | X |
| Piedmont | 500050 | Middle Creek | | | X | | | |
| Piedmont | 590083 | Mallard Creek | | | X | | | |
| Piedmont | 590296 | Mallard Creek | X | | X | X | X | X |
| Piedmont | 910124 | Perry Creek | X | | X | X | X | X |
| Piedmont | 910255 | Swift Creek | X | | X | X | X | X |
| Piedmont | 910273 | Middle Creek | X | | X | X | | X |
| Piedmont | 911102 | Mango Creek | X | | X | X | | X |

**Note:** Bridge deck solids were collected through sweeping activities from over 100 bridges regionally clustered within Division 1 and Division 13, which are not presented in this table. Refer to section 3.3.2 for details of the bridge sweeping locations and related monitoring activities.

## 3.2 Water Quality and Quantity Monitoring

A number of studies have evaluated highway stormwater runoff quality, but only a few have concentrated on the effects the runoff has on receiving waters. Even fewer studies have concentrated on the effects of bridge runoff specifically (Dupuis, 2002, p. 7).

Water quality and quantity monitoring sites were selected from across North Carolina to help understand the impacts of bridge deck runoff on receiving stream water quality. The BSP water quality study included sampling and analysis of bridge deck runoff at 15 sites, and sampling and analysis of receiving waters at 4 of the 15 sites. The samples collected were characterized to evaluate concentrations of target parameters typically associated with stormwater runoff. The discharge point at which bridge deck samples were collected was also monitored continuously for flow during wet weather periods to quantify the bridge deck runoff volume and flow rate. Rainfall activity was also monitored at each site.

Surface water samples were taken from locations upstream of the bridge crossings during both wet and dry weather periods to evaluate stream variability not associated with bridge deck runoff effects, either naturally or from other anthropogenic sources. A chemical analysis of the instream samples was performed to evaluate constituent levels in the sample. Stream flow data was also monitored at each site.

All field monitoring activities were conducted by U.S. Geological Survey (USGS) North Carolina Water Science Center (NCWSC) staff. All chemical analyses for water samples were conducted by USGS Laboratories.

## 3.2.1 Bridge Deck Runoff Monitoring

Bridge deck runoff samples were collected at 15 bridge sites and analyzed to determine the presence and quantity of chemical constituents. Each site was retrofitted to allow for the monitoring of bridge deck runoff volumes and rainfall throughout the monitoring period, which spanned from March 2009 through February 2010.

### 3.2.1.1 Monitoring Sites

**Site Selection**

A variety of factors were used in selection of sites for runoff volume and chemistry monitoring, including site location, traffic and bridge characteristics, stormwater drainage systems, and suitability of the site for installation of monitoring equipment.

Due to the need to collect runoff in direct discharge bridges, only no-direct discharge bridges were selected for this study. Direct discharge bridges are analyzed and compared with no-direct discharge bridges based on differences in streambed sediment chemistry in section 3.3.

Other factors considered in site selection included the following:

- Distribution of sites among three ecoregions.
- Range of bridge characteristics, including bridge deck drainage area, wearing surface type, location, ADT volumes, and roadway functional class.
- Range of stream characteristics, including watershed drainage area, contributing watershed land use, and stream classification.
- Exclusion of sites with significant off-site runoff in the vicinity or upstream of the bridge.

After analysis of several candidate sites, a total of 15 monitoring sites were selected for continuous monitoring of runoff volume and runoff chemistry for up to 12 storm events. These sites are shown in figure 3.2-1. The characteristics associated with each site are included in table 3.2-1. Photographs of each bridge and receiving stream are provided in appendix 3-A. Individual monitoring site maps are provided in appendix 3-B.

### Site Retrofits

To facilitate the goals of the monitoring effort, portions of each bridge deck drainage system were modified to accommodate USGS monitoring equipment and to facilitate collection of stormwater samples. The outlet pipe at each site was altered based upon existing pipe material, pipe grade, and access constraints to the inside of the pipe. Site modifications involved installation of a monitoring box with an automated sampler for collection of stormwater samples and modification of the pipe discharge to allow for a 1–1.5 foot vertical freefall from the mouth of the pipe to the ground surface. Soil stabilization measures, including the use of riprap and filter fabric, were implemented as needed to prevent erosion of soil. Stream buffer zones were not disturbed as a result of these activities. All modifications were designed by Professional Engineers, and reviewed and approved through the appropriate DWQ Division Office.

Figure 3.2-2 shows two bridge sites that were modified to accommodate monitoring equipment and enable data collection. The location of the primary equipment at each site is illustrated in the monitoring site maps in appendix 3-B.

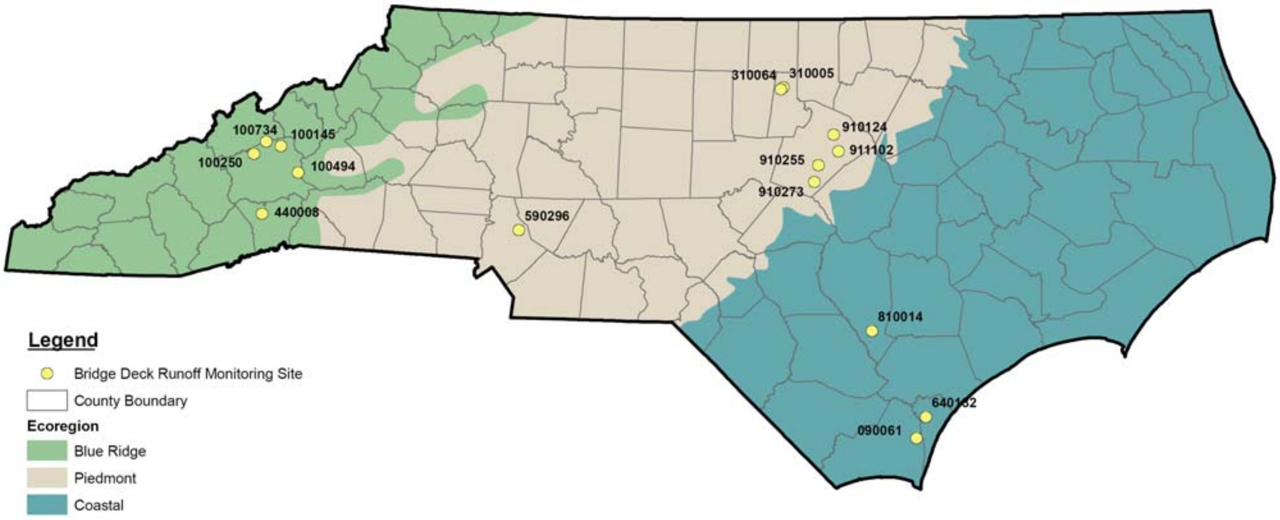


**Figure 3.2-1: Bridge deck monitoring sites.**

**Figure 3.2-2: USGS bridge deck runoff monitoring equipment: bridge deck runoff monitoring box and modified outlet pipe at Mountain Creek (left) and monitoring equipment, including a rain gage, at Black River (right).**

## Table 3.2-1: Bridge Deck Runoff Monitoring Sites and Characteristics

| Bridge Number | Stream Name | Drainage System[a] | Ecoregion[b] | County | NCMIN Tier[c] | Route[d] | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class[e] | AADT (vpd)[f] | River Basin | Stream Classification[g] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type[h] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100145 | Dillingham Creek | ND (2) | BR | Buncombe | SRT | SR 2173 | Dillingham Road | R | Mi-C | 1,800 | French Broad | WS-II; Tr, HQW | 24.6 | 0.12 | C |
| 100250 | Flat Creek | ND (2) | BR | Buncombe | SRT | SR 1742 | Lower Flat Creek Road | R | Mi-C | 400 | French Broad | C | 24.6 | 0.02 | B |
| 100494 | Swannanoa River | ND (1) | BR | Buncombe | SWT | I-40 | I-40 | U | PA-I | 25,500 | French Broad | C | 4.2 | 1.30 | C |
| 100734 | Big Ivy Creek | ND (2) | BR | Buncombe | SRT | SR 2207 | Stockton Road | R | Ma-C | 1,500 | French Broad | WS-II; HQW | 60.6 | 0.09 | C |
| 310005 | Mountain Creek | ND (2) | P | Durham | SRT | SR 1616 | Bahama Road | R | Mi-C | 2,800 | Neuse | WS-II; HQW; NSW, CA | 7.2 | 0.13 | B |
| 310064 | Little River | ND (2) | P | Durham | SRT | SR 1461 | Johnson Mill Road | R | L | 500 | Neuse | WS-II; HQW; NSW, CA | 78.2 | 0.12 | C |
| 440008 | Boylston Creek | ND (2) | BR | Henderson | SRT | SR 1314 | Ladson Road | R | L | 1,400 | French Broad | WS-IV | 15.4 | 0.09 | B |
| 590296 | Mallard Creek | ND (1) | P | Mecklenburg | SWT | I-85 | I-85 | U | PA-I | 112,000 | Yadkin | C | 19.6 | 0.79 | C |
| 910273 | Middle Creek | ND (2) | P | Wake | SRT | SR 1006 | Old Stage Road | R | Mi-C | 5,000 | Neuse | C; NSW | 57.5 | 0.13 | B |
| 911102 | Mango Creek | ND (1) | P | Wake | SWT | I-540 | I-540 | U | PA-I | 34,000 | Neuse | C; NSW | 2.4 | 1.80 | C |
| 910124 | Perry Creek | ND (2) | P | Wake | SRT | SR 2006 | Perry Creek Road | U | L | 13,000 | Neuse | C; NSW | 11.2 | 0.17 | C |

| Bridge Number | Stream Name | Drainage System [a] | Ecoregion [b] | County | NCMIN Tier [c] | Route [d] | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [e] | AADT (vpd) [f] | River Basin | Stream Classification [g] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [h] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 910255 | Swift Creek | ND (2) | P | Wake | SRT | SR 1006 | Old Stage Road | U | Mi-A | 11,500 | Neuse | WS-III; NSW | 1.7 | 0.04 | C |
| 810014 | Black River | ND (2) | C | Sampson | RT | NC 411 | Hitching Post Road | R | Ma-C | 750 | Cape Fear | C; Sw; ORW:+ | 676 | 0.18 | B |
| 640132 | Smith Creek | ND (1) | C | New Hanover | SWT | US 74 | US 74 | U | L | 26,000 | Cape Fear | C; Sw | 21.8 | 2.59 | C |
| 090061 | Town Creek | ND (2) | C | Brunswick | RT | NC 133 | NC 133 | R | Ma-C | 5,600 | Cape Fear | C; Sw | 115.1 | 0.25 | B |

**Notes:**

[a] ND (1) – No-direct discharge drainage system - bridge deck that conveys stormwater into a closed drainage system attached to the bridge superstructure; ND (2) – No-direct discharge drainage system - bridge deck lacking a closed system that conveys stormwater via gutter flow only

[b] BR – Blue Ridge; C – Coastal; P – Piedmont

[c] North Carolina Multimodal Investment Network (NCMIN) Tier: RT – Regional Tier; SRT – Subregional Tier; SWT – Statewide Tier. Data compiled from information provided by NCDOT Bridge Management Unit (BMU) staff and NCDOT (2009).

[d] I – Interstate; NC – North Carolina Highway; SR – State Road; US – United States Highway; SBL – Southbound lane; WBL – Westbound lane

[e] PA – Principal Arterial; I – Interstate; Ma – Major; Mi – Minor; C – Collector; L – Local; A – Arterial

[f] AADT – Average annual daily traffic volume; vpd – vehicles per day; see section 3.5.

[g] NCDENR Stream Classification: B – Primary Recreation, Fresh Water; C – Aquatic Life, Secondary Recreation, Fresh Water; CA – Critical Area; HQW – High Quality Water; NSW – Nutrient Sensitive Water; ORW – Outstanding Resource Water; SW – Swamp Water; TR – Trout Water; WS-II – Water Supply II, Underdeveloped; WS-IV – Water Supply IV, Highly Developed; + - Subject to the Outstanding Resource Waters rule (NCDENR, 2007).

[h] Data from NCDENR (2007). B – Bituminous; C – Concrete

### 3.2.1.2 Data Collection Methods and Techniques

Monitoring of bridge deck runoff required modifications to each site to accommodate the instrumentation and equipment necessary to facilitate sample and data collection. Sampling was performed by USGS in accordance with in-house protocols (USGS, 1997–, chap. A4). An overview of the methods and techniques is provided in this section.

### Sample Collection

A total of 178 bridge deck runoff samples were collected between March 2009 and February 2010. The breakdown of the total samples collected at each site is summarized in table 3.2-2.

**Table 3.2-2: Bridge Deck Runoff Sample Summary**

| Bridge # | Stream Name | # Samples Collected[a] |
|---|---|---|
| 090061 | Town Creek | 12 |
| 100145 | Dillingham Creek | 11 |
| 100250 | Flat Creek | 10 |
| 100494 | Swannanoa River | 14 |
| 100734 | Big Ivy Creek | 12 |
| 310005 | Mountain Creek | 13 |
| 310064 | Little River | 13 |
| 440008 | Boylston Creek | 10 |
| 590296 | Mallard Creek | 12 |
| 640132 | Smith Creek | 11 |
| 810014 | Black River | 12 |
| 910124 | Perry Creek | 13 |
| 910255 | Swift Creek | 12 |
| 910273 | Middle Creek | 11 |
| 911102 | Mango Creek | 12 |
| | **Total Samples Collected (March 2009-February 2010)** | **178** |

**Notes:**

[a] The number of samples presented in this table includes samples collected for which laboratory analysis was incomplete at the time of data analysis for this report.

Bridge deck runoff was sampled using ISCO® 6712 series automatic samplers with either a single 20-liter Teflon-lined bottle or four 5-liter glass bottles to collect a flow-weighted composite sample for each storm event. Each automated sampler was housed inside of a monitoring box anchored into a concrete pad near the outlet of each monitored pipe. An approximately 2-inch high backwater weir and diffuser plate was installed in the outlet of the collection pipe to increase the flow depth for acoustic velocity measurements and agitate the flow prior to sample intake. A Doppler velocity meter and a pressure transducer were installed in the pipe to measure the velocities and stage of the discharge. The sampler intake tube was placed just upstream of the diffuser plate. Each sampler was equipped with cell phone telemetry, which enabled remote programming and data retrieval.

The typical protocol for the collection of samples by the automated sampler is described as follows:

- The autosamplers were programmed remotely in advance of a forecasted storm event, based on the expected duration and total precipitation.
- The autosampler intake tube collected the first aliquot (sub-sample) when the stage of flow behind the weir reached 0.085 feet (1.02 inches).
- Remaining aliquots were collected after pre-defined volume intervals (i.e. flow-weighted). The size of the volume interval was based on the bridge deck drainage area of each site.
- The distribution of sub-samples over the hydrograph was based on the forecasted total precipitation and duration of the event. The goal of the autosampler program was to collect aliquots over the rising, peak and falling portions of the hydrograph, and to distribute aliquot collection over the entire hydrograph based on flow volume (i.e. the higher flow, the more frequent samples were collected).
- In the event that the duration or intensity of the storm event was larger than anticipated, sample collection ceased when the sample collection vessel become full.
- A minimum sample volume of 5 liters was required before the sample could be considered for water quality analysis.

All composite water samples collected in the field were processed through sample splitting (sub-sampling) devices, primarily by use of Teflon churn splitters, then filtered, preserved, and shipped to the National Water Quality Laboratory (NWQL) for chemical analysis. All sample preparation, collection, and processing was performed by USGS NCWSC staff following procedures in accordance with the USGS National Field Manual for the Collection of Water-Quality Data (USGS, 1997–, chap. A5).

A tipping bucket rain gage was installed in the vicinity of each bridge site to monitor rainfall activity and record the depth of precipitation (inches) at one-minute intervals during each corresponding sample event. The rain gages were placed to avoid and/or minimize interference from tree canopies and splash from the highway. When feasible, the rain gage at each site was connected to the automated sampler with a buried cable encased in a protective conduit sleeve. The microprocessor connected to the sampler was capable of storing data from the sampler, velocity meter, pressure transducer, and rain gage. The automated ISCO sampler processes the velocity and stage measurements to instantaneously calculate the discharge through the collection system pipe, based on the preset pipe diameter. Discharge data from the pipe outlet were routinely collected and stored at 1-minute intervals. Data was uploaded to the National Water Information System (NWIS) database daily, but only rainfall data was displayed on the web for public viewing.

Photos of the instrumentation and equipment described above are shown in figure 3.2-3.

**Figure 3.2-3: USGS bridge deck runoff monitoring equipment: (clockwise from top left) tipping bucket rain gage and autosampler monitoring box; autosampler intake tube, diffuser plate, velocity meter and pressure sensor inside discharge pipe; ISCO autosampler inside monitoring box; and monitoring box with autosampler intake tube and conduit connection to pipe outlet.**

### Laboratory Methods

The chemical analyses of bridge deck runoff samples collected by USGS were performed at NWQL in Denver, Colorado, with the exception of oil and grease, which was conducted at Test America Laboratories in Denver, Colorado, and suspended sediment concentrations, which were determined at the USGS Kentucky Sediment Laboratory in Louisville, Kentucky. A complete list of analytes, laboratory methods, and parameters determined by field measurements is presented in appendix 3-C.

Laboratory samples required to be filtered were processed by standard USGS protocols (USGS, 1997–, chap. A5). Samples measuring total levels, such as total nitrogen and total carbon, and volatile organic compounds were not filtered. Both total recoverable and dissolved fractions of trace metals were determined. The total recoverable concentration was determined by subjecting the sample to a mild acid to partition metals in the sample into solution. Dissolved fractions of metals, which are typically more bioavailable than the particulate-bound fraction, were determined by filtering runoff samples through a 0.45–µm pore-size disposable capsule filter prior to analysis (USGS, 1997–, chap. A5).

#### 3.2.1.3 Bridge Deck Runoff Monitoring Results

All 178 bridge deck runoff samples were analyzed by the NWQL to determine the concentrations of 125 target analytes. The results from the laboratory analyses for all samples are provided in appendix 3-D and summary statistics on the analytical data are provided in appendix 3-E. An explanation of USGS definitions of censored and uncertain data commonly associated with the laboratory analyses is provided in appendix 3-F. Further evaluations of the bridge deck runoff water quality data presented in this section are discussed in section 4.

A summary of the key hydrologic data collected for each wet-weather period associated with each bridge deck runoff sample is provided in appendix 3-G. The summary includes site specific variables including total precipitation, antecedent dry period, calculated runoff volume, and duration of runoff pertaining to each sample event.

### 3.2.2 Instream Monitoring

Instream water samples were collected from receiving streams at four bridge sites, a subset of the bridge deck runoff monitoring sites. Samples were collected upstream of each bridge during storm and base flow conditions and analyzed to determine chemical constituents and concentrations. Streamflow was also measured continuously throughout the monitoring period.

The instream monitoring sites, methods, and techniques for data collection, analytes and laboratory methods, and results of monitored activities are discussed in the following sections.

#### 3.2.2.1 Monitoring Sites

The four bridge sites selected for instream water quality monitoring were distributed across the three ecoregions as follows: Swannanoa River (Blue Ridge), Little River (Piedmont), Mountain Creek (Piedmont) and Black River (Coastal). In addition to the distribution of sites across varying ecoregions, the sites represent a variety of other characteristics such as contributing bridge deck drainage area, stream drainage area, stream class, and daily traffic counts. The four instream sites and characteristics are included in table 3.2-1, presented in section 3.2.1.1.

Three of the four sites (Little, Mountain, and Black) have been historically monitored and were equipped with stream gages and automated samplers prior to the start of the BSP study. For these sites, the existing stream gages were utilized and the automated sampling equipment was installed. The Swannanoa River site was not previously monitored and received a new, temporary streamflow gage and automated sampler for this study. The four instream monitoring site locations are illustrated on figure 3.2-4. Individual site maps of each site are presented in appendix 3-B.

#### 3.2.2.2 Data Collection Methods and Techniques

Water samples were collected from the receiving stream using both point sample and cross-sectionally integrated techniques, upstream of each bridge during storm flow and base flow conditions. An automated sampler and USGS streamflow gage were installed for sample collection and flow monitoring. Stream gages were located in the stream channel, just upstream of each bridge location, or sometimes attached to the bridge structure. The stream gage recorded stage at 15-minute intervals. The instream stage and stream flow data were collected, processed, and analyzed in accordance with the USGS standard procedures and Rantz et al. (1982). The location of the equipment at each site is illustrated in the monitoring site maps in appendix 3-B.

### Instream Sample Collection

Instream water samples were collected during wet- and dry-weather periods, with dry weather samples being collected monthly, and wet-weather samples collected, when possible, coincidentally with bridge sample events described previously. Samples were collected by methods that achieve a composite water sample with multiple sub-samples over the course of the sample period. The quantity of samples collected from each site for each instream condition is summarized in table 3.2-3.

**Table 3.2-3: Instream Water Quality Sample Summary**

| Stream Name | USGS Stream Gage Station ID | # Samples Instream Base Flow Conditions | # Samples Instream Storm Conditions |
|---|---|---|---|
| Swannanoa River | 3448800 | 11 | 8 |
| Mountain Creek | 208524088 | 10 | 8 |
| Little River | 208521324 | 12 | 9 |
| Black River | 2106500 | 8 | 4 |
| **All Sites, Total Samples per Condition** | | **41** | **29** |

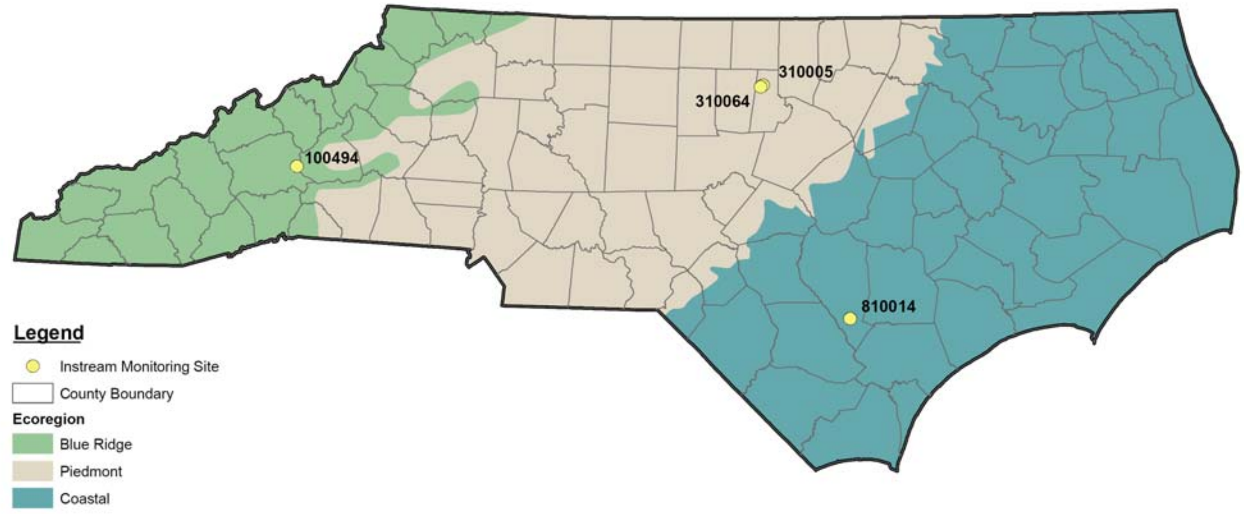


**Figure 3.2-4: Instream monitoring sites.**

The two primary methods used for instream sample collection consisted of either cross-sectionally integrated sampling or automated point sampling. The type of sampling method corresponding to each sample event is noted in appendix 3-H. Additionally, the sampling method can be *isokinetic* or *non-isokinetic*. Isokinetic samplers collect samples with no changes in stream velocity, and are preferred because they result in more representative samples. Surface water sampling equipment, including types of samplers, associated with sample activities are described in the USGS field manual (USGS, 1997–, chap. A2). The techniques associated with sampling methods are described in USGS (n.d., chap. A4).

**Cross-sectional sampling** involves the collection of multiple samples along the stream cross section. There are two types of cross-sectional sampling:

- **Equal Width-Interval (EWI)** depth integrated sample methods extract numerous sub-samples at equally spaced increments across the width of the stream at various depths in the water column, resulting in a composite sample representative of the stream quality as a whole. EWI methods were used to collect samples manually during normal flow conditions on a routine monthly basis. The samples were collected with Teflon bottles, sometimes attached with nozzles, using variable techniques that depended upon the stage and velocity of the stream at the time of sampling. EWI methods utilize both isokinetic samplers as well as non-isokinetic samplers as needed, depending on the stream conditions at the time of sampling (USGS, 1997–, chap. A2) The method corresponding to each sample are noted in the results presented in appendix 3-H. The method is labeled as EWI, which indicates stream conditions permitted an isokinetic sample to be collected, or otherwise noted as EWI (non-iso), which denotes that stream conditions dictated the collection of a non-isokinetic sample.
- **Grab sample methods** are used to manually collect instream samples at or near the stream surface during normal flow conditions during routine sampling. Grab methods were similar to EWI methods in that a composite sample across the cross section of the stream is collected; however, grab methods do not account for depth-integration into the water column. Grab methods were primarily used when EWI methods were determined unsuitable (i.e. not enough depth in stream channel to obtain depth-integrated sample.

**Automated sample methods** were used during storm flow conditions to collect samples which were temporally-composited from a single point at a fixed-depth in the stream. The automated sampler (ISCO$^{®}$ 6712 series) had a fixed-depth in-take tube through which water samples were pumped from the stream. The automated samplers were housed in monitoring boxes and anchored into a concrete pad mounted on the stream bank just upstream of the bridge crossing. The storm event samples that were collected were coincident with samples collected from the bridge deck.

Figure 3.2-5 illustrates two of the instream sampling methods.

**Figure 3.2-5: Instream sampling methods and techniques: EWI method (left) and automated samplers inside monitoring box (right).**

At the time of sampling, physical measurements including water temperature, pH, and specific conductance were determined. During routine sampling, measurements of dissolved oxygen and barometric pressure were also collected.

A minimum sample volume of 5 liters was required before the sample could be considered for water quality analysis. All composite water samples collected in the field were processed through sample splitting by use of a Teflon churn splitter. Filtered and non-filtered samples were preserved before shipped to NWQL for chemical analysis. Sample preparation, collection, processing, shipping, and equipment cleaning were performed by USGS NCWSC staff in accordance with established USGS procedures (USGS, 1997–, chap. A5).

#### 3.2.2.3 Instream Water Quality Methods

The parameters and laboratory methods pertaining to the chemical analysis of instream samples were identical to those described for bridge runoff in section 3.2.1 and appendix 3-C.

#### 3.2.2.4 Instream Monitoring Results

41 dry-weather and 29 storm instream water samples were analyzed by USGS laboratories to determine the concentrations for over 125 target analytes. Results of the chemical analyses summarized for each site, followed by summary statistics, are presented in appendix 3-H. Further evaluation of the instream water quality data presented in this section is provided in section 4 of this report.

Instream stage and flow values recorded during instream sampling were used for hydrological and loading comparisons, discussed in section 4.4. Due to the size of the data set, this information is not included in this report. Interested parties can obtain this information for the Swannanoa River, Little River, Mountain Creek, and Black River sites at http://waterdata.usgs.gov/nc/nwis.

## 3.3 Sediment/Solids Chemistry Monitoring

Streambed sediment provides habitat for aquatic organisms and an interface for groundwater and surface water interactions; thus, they are an important component of lotic ecosystems. Many constituents associated with roadway runoff, including several trace metals, nutrients, and persistent organic compounds such as polycyclic aromatic hydrocarbons (PAHs), preferentially adsorb to solids, and are transported by runoff to the bottom sediment layer in receiving waters. A substantial proportion of some constituents may be present in the sediment phase, and dissolved concentrations in the overlying water may not adequately reflect pollutant loadings to the receiving water (Yousef et al., 1984; Gjessing et al., 1984; Pitt et al., 1995). While water samples are influenced by precipitation and runoff events and can exhibit substantial temporal variability, the concentration of material attached to sediment particles may represent pollutant loading on a time scale from weeks to years (Mudre and Ney, 1986).

Various studies have noted increased concentrations of metals and PAHs in sediment downstream of highway runoff outlets (Dupuis, 2002; Gjessing et al., 1984; Maltby et al., 1995a, 1995b; Mudre and Ney, 1986; Van Hassel et al., 1980; Yousef et al., 1984), although other studies have not indicated significant impacts on instream concentrations (Dupuis et al., 1985, Farris et al., 1973). These increases are often localized, and research on highway runoff suggests that constituent concentrations several hundred feet downstream tend to be inline with levels upstream of the discharge (Lygren et al., 1984; Mudre and Ney, 1986).

Increased constituent concentrations in sediments due to stormwater runoff may have toxicity implications for aquatic biota (Masterson and Bannerman, 1994; Pitt, 1995; Pitt et al., 1995). Dupuis et al. (1985) found localized increases in metals and salt concentrations in sediments and plants near bridge deck scupper drains in Lower Nemahbin Lake, WI, but concurrent biological sampling did not indicate adverse effects on aquatic biota. Maltby et al. (1995a; 1995b) found increased concentrations of PAHs and several metals (cadmium, chromium, lead, and zinc) in downstream sediments in several small streams, resulting in a small reduction in survival of a test benthic amphipod. PAHs, copper and zinc were identified as potential toxicants. A review by Eisler (1987) indicates elevated incidence of tumors and hyperplastic diseases, and some circumstantial evidence about cancers, in fish in areas with high sediment Polycyclic Aromatic Hydrocarbon (PAH) levels. Arsenic, cadmium, chromium, lead, mercury, nickel, and zinc have been detected in streambed sediments and in the tissue of fish, indicating bioaccumulation of these metals in the environment (MacCoy and Black, 1998).Lead concentrations in benthic insects, and nickel and cadmium levels in certain fish were found to be related to traffic density and sediment levels of these constituents (Van Hassel, 1980).

In addition to studying sediment, it is important to study dust and particulates on bridge decks to correlate sediment quality degradation with roadway constituents. Bridge deck solids are often the principal sources of PAHs and heavy metals discharged to receiving waters, including lead from gasoline engine exhausts, cadmium and zinc from lubricating oil and tires, and PAHs from tires and asphalt (Brown and Peak, 2006; Mudre and Ney, 1986; Lygren et al., 1984).

Two studies were performed as part of the BSP to quantify the impacts of solids loading from bridge deck runoff on the water quality of receiving waters. The first study involved an investigation of the spatial change in sediment chemistry around the bridge. Streambed sediment samples were collected upstream and downstream of 30 bridge deck sites across North Carolina. Constituent levels were evaluated for evidence of adverse impacts on the receiving stream from bridge deck runoff.

A second study utilized street cleaning to focus on understanding the chemistry of solids that could be carried by runoff into receiving streams. This second study, a bridge deck sweeping study, was performed to obtain samples of solids on bridge decks collected during highway sweeping activities across North Carolina. The organic and inorganic constituents of the solids were then analyzed to assess potential impact to receiving waters. Street cleaning has been found to be an effective SCM in areas such as highways (Pitt et al., 2004), suggesting that sweeper solids are fairly representative of the constituents in bridge deck solids.

## 3.3.1 Streambed Sediment Chemistry Monitoring

Streambed sediment samples were collected upstream and downstream of 30 bridge deck sites across North Carolina between June and August 2009. Samples were analyzed to quantify streambed sediment pollutant concentration differences upstream and downstream of the roadway bridge. Concentration differences would then be evaluated to note correlations between streambed sediment quality and contributing bridge deck runoff. Greater detail of the monitoring efforts, sampling techniques, laboratory analytes and methods, and results are discussed in the following section.

### 3.3.1.1 Sediment Monitoring Sites

Thirty bridges crossing over surface waters across North Carolina were selected as streambed sediment monitoring sites. The 30 sites, listed in table 3.3-1, were divided into two main categories based on the existing bridge deck stormwater collection and conveyance system — sites with direct discharge drainage systems and sites with no-direct discharge drainage systems.

Figure 3.3-1 presents the locations of 16 direct discharge sites and 14 no-direct discharge drainage systems across North Carolina selected as streambed sediment monitoring sites. Direct discharge bridge sites were selected to represent a similar range of physiographic region, watershed size, land use, average annual daily traffic (AADT), pavement type, etc. as the no-direct discharge bridge sites.

One of the direct discharge bridge sites, Cataloochee Creek, was selected as a reference site. The purpose of the reference site is to establish a standard on which the biodiversity of target organisms are judged. This site was selected due to its relatively pristine condition, as measured by the bioclassification rating of the site, using DWQ standards (NCDENR, 2006). Bioclassifications and biological monitoring are discussed in section 3.4.

The 30 streambed sediment sample sites and site characteristics are listed in table 3.3-1.

## Table 3.3-1: Streambed Sediment Sample Sites and Characteristics

| Bridge Number | Stream Name | Drainage System [a] | Ecoregion [b] | County | NCMIN Tier [c] | Route [d] | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [e] | AADT (vpd) [f] | River Basin | Stream Classification [g] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [h] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NA | Cataloochee Creek | D | BR | Haywood | SRT | SR 1395 (FS Rd 284) | National Park Road (Old NC 284) | R | UNK | UNK | French Broad | C; Tr, ORW | 49.1 | UNK | T |
| 080085 | Black River | D | C | Bladen | SRT | SR 1550 | Beatty's Bridge Road | R | Mi-C | 690 | Cape Fear | C; Sw, ORW: + | 1.2 | 0.23 | C |
| 090061 | Town Creek | ND | C | Brunswick | RT | NC 133 | NC 133 | R | Ma-C | 5,600 | Cape Fear | C; Sw | 115.1 | 0.25 | B |
| 090074 | Town Creek | D | C | Brunswick | SWT | US 17 (SBL) | Ocean Highway (E.) | R | PA | 12,000 | Cape Fear | C; Sw | 47.4 | 0.14 | B |
| 100124 | Flat Creek | D | BR | Buncombe | SRT | SR 2137 | Upper Flat Creek Road | R | L | 930 | French Broad | C | 3.7 | 0.02 | B |
| 100145 | Dillingham Creek | ND | BR | Buncombe | SRT | SR 2173 | Dillingham Road | R | Mi-C | 1,800 | French Broad | WS-II; Tr, HQW | 24.6 | 0.12 | C |
| 100147 | Dillingham Creek | D | BR | Buncombe | SRT | SR 2173 | Dillingham Road | R | L | 300 | French Broad | WS-II; B; Tr, HQW | 9.1 | 0.02 | B |
| 100250 | Flat Creek | ND | BR | Buncombe | SRT | SR 1742 | Lower Flat Creek Road | R | Mi-C | 400 | French Broad | C | 24.6 | 0.02 | B |
| 100494 | Swannanoa River | ND | BR | Buncombe | SWT | I-40 | I-40 | U | PA-I | 25,500 | French Broad | C | 4.3 | 1.30 | C |
| 100498 | Swannanoa River | D | BR | Buncombe | SWT | I-240 (WBL) | I-240/ I-74 | U | PA-I | 29,000 | French Broad | C | 115.3 | 0.39 | C |
| 100734 | Big Ivy Creek | ND | BR | Buncombe | SRT | SR 2207 | Stockton Road | R | Ma-C | 1,500 | French Broad | WS-II; HQW | 60.6 | 0.09 | C |
| 120008 | Clarke Creek | D | P | Cabarrus | SRT | SR 1449 | Harris Road | R | Mi-C | 1,900 | Yadkin | C | 21.8 | 0.14 | C |

## Table 3.3-1: Streambed Sediment Sample Sites and Characteristics (continued)

| Bridge Number | Stream Name | Drainage System [a] | Ecoregion [b] | County | NCMIN Tier [c] | Route [d] | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [e] | AADT (vpd) [f] | River Basin | Stream Classification [g] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [h] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 310005 | Mountain Creek | ND | P | Durham | SRT | SR 1616 | Bahama Road | R | Mi-C | 2,800 | Neuse | WS-II; HQW, NSW,CA | 7.4 | 0.13 | B |
| 310025 | Little River | D | P | Durham | SRT | SR 1004 | Old Oxford Road | R | Ma-C | 5,300 | Neuse | WS-IV; NSW | 104.5 | 0.09 | B |
| 310061 | Mountain Creek | D | P | Durham | SRT | SR 1464 | South Lowell Road | R | L | 1,100 | Neuse | WS-II; HQW, NSW | 4.3 | 0.02 | B |
| 310064 | Little River | ND | P | Durham | SRT | SR 1461 | Johnson Mill Road | R | L | 500 | Neuse | WS-II; HQW, NSW,CA | 78.2 | 0.12 | C |
| 440007 | Boylston Creek | D | BR | Henderson | SRT | SR 1331 | Banner Farm Road | R | L | 2,200 | French Broad | WS-IV | 14.8 | 0.02 | B |
| 440008 | Boylston Creek | ND | BR | Henderson | SRT | SR 1314 | Ladson Road | R | L | 1,400 | French Broad | WS-IV | 15.4 | 0.09 | B |
| 500050 | Middle Creek | D | P | Johnston | RT | NC 210 | NC 210 | R | Ma-C | 4,700 | Neuse | C; NSW | 129.7 | 0.09 | B |
| 560522 | Little Ivy Creek | D | BR | Madison | SRT | SR 1609 | Forks of Ivy Road | R | Ma-C | 690 | French Broad | WS-II; HQW | 46.3 | 0.08 | C |
| 590083 | Mallard Creek | D | P | Mecklenburg | SRT | SR 2467 | Mallard Creek Road | R | Mi-A | 98,000 | Yadkin | C | 11.9 | 0.274 | C |
| 590296 | Mallard Creek | ND | P | Mecklenburg | SWT | I-85 | I-85 | U | PA-I | 112,000 | Yadkin | C | 19.6 | 0.79 | C |
| 640002 | Smith Creek | D | C | New Hanover | SRT | SR 1175 | North Kerr Avenue | U | Mi-A | 14,000 | Cape Fear | C; Sw | 12.6 | 0.12 | C |

## Table 3.3-1: Streambed Sediment Sample Sites and Characteristics (continued)

| Bridge Number | Stream Name | Drainage System [a] | Ecoregion [b] | County | NCMIN Tier [c] | Route [d] | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [e] | AADT (vpd) [f] | River Basin | Stream Classification [g] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [h] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 640132 | Smith Creek | ND | C | New Hanover | SWT | US 74 | US 74 | U | L | 26,000 | Cape Fear | C; Sw | 21.8 | 2.59 | C |
| 810058 | Black River | D | C | Sampson | SRT | SR 1007 | Wildcat Road | R | L | 580 | Cape Fear | C; Sw, ORW: + | 710.9 | 0.24 | B |
| 870106 | Boylston Creek | D | BR | Transylvania | SRT | SR 1502 | King Road | R | Mi-C | 680 | French Broad | C | 2.8 | 0.01 | B |
| 910124 | Perry Creek | ND | P | Wake | SRT | SR 2006 | Perry Creek Road | U | L | 13,000 | Neuse | C;NSW | 11.2 | 0.17 | C |
| 910255 | Swift Creek | ND | P | Wake | SRT | SR 1006 | Old Stage Road | U | Mi-A | 11,500 | Neuse | WS-III; NSW | 1.7 | 0.04 | C |
| 910273 | Middle Creek | ND | P | Wake | SRT | SR 1006 | Old Stage Road | R | Mi-C | 5,100 | Neuse | C; NSW | 57.5 | 0.13 | B |
| 911102 | Mango Creek | ND | P | Wake | SWT | I-540 | I-540 | U | PA-I | 34,000 | Neuse | C; NSW | 2.4 | 1.80 | C |

**Notes:** NA – Information not applicable; UNK - Unknown

[a] ND – No-direct discharge drainage system; D – Direct discharge drainage system

[b] BR – Blue Ridge; C – Coastal; P – Piedmont

[c] RT – Regional Tier; SRT – Subregional Tier; SWT – Statewide Tier. Data compiled from information received from NCDOT BMU staff and NCDOT (2009).

[d] I – Interstate; NC – North Carolina Highway; SR – State Road; US – United States Highway; SBL – Southbound lane; WBL – Westbound lane

[e] PA – Principal Arterial; I – Interstate; Ma – Major; Mi – Minor; C – Collector; L – Local; A – Arterial

[f] AADT – Average annual daily traffic volume; vpd – vehicles per day; see section 3.5.

[g] NCDENR Stream Classification: B – Primary Recreation, Fresh Water; C – Aquatic Life, Secondary Recreation, Fresh Water; CA – Critical Area; HQW – High Quality Water; NSW – Nutrient Sensitive Water; ORW – Outstanding Resource Water; SW – Swamp Water; TR – Trout Water; WS-II – Water Supply II, Underdeveloped; WS-IV – Water Supply IV, Highly Developed; + - Subject to the Outstanding Resource Waters rule. Data from NCDENR (2007).

[h] B – Bituminous; C – Concrete; T – Timber

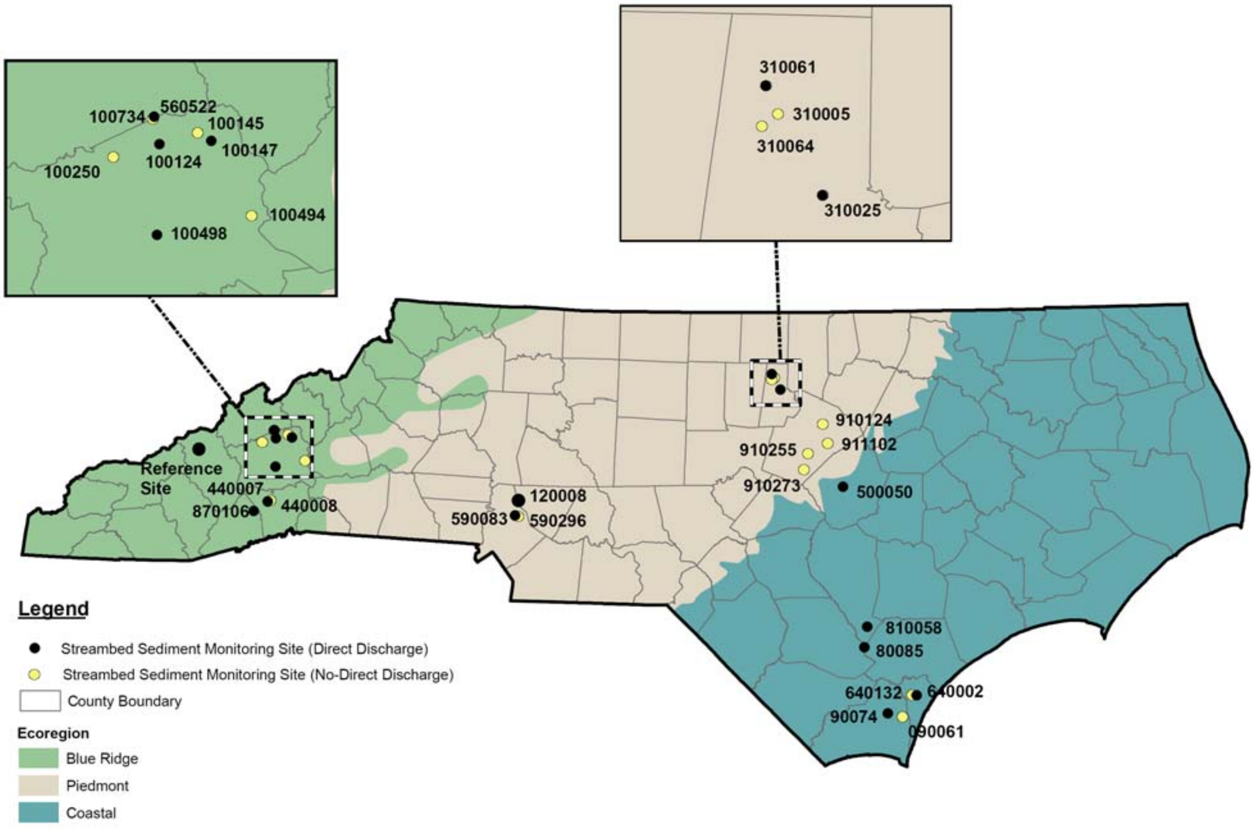


**Figure 3.3-1: Streambed sediment monitoring sites.**

### 3.3.1.2 Sediment Sampling and Data Collection

Streambed sediment samples were collected from all 30 sites between June and August 2009. The sampling period was limited to minimize seasonal variability and was also conducted during low flow conditions.

Samples were collected at a total of 60 locations, one each upstream and downstream from each of the 30 bridges. Additionally, nine samples (three samples per ecoregion) were collected for quality control purposes. Quality-control samples included field replicates and field split replicates for all constituents, and matrix spikes for semi-volatile organic compounds (SVOC).

For each streambed sediment sample site, 5–10 depositional zones, likely to contain fine-grained sediment (<63 µm), were identified on both the upstream and downstream side of the bridge. The number and location of depositional zones was dependent on the amount of available fines for each sample. Depositional zones varied from just below the bridge deck to up to 15 stream widths upstream or downstream from the bridge. The surficial 1–2 cm of streambed sediment within each depositional zone was sub-sampled and composited to produce a single sample from each location, one upstream and one downstream from the bridge. The collection of streambed sediment samples from different depositional zones are illustrated in figure 3.3-2. Sample collection and processing procedures followed protocols developed by USGS (USGS, 1997–, chap. A8) and guidelines by Shelton and Capel (1994). Pre-cleaned, non-contaminating sampling devices were selected and used based on target analytes and site conditions as recommended by USGS protocols. The streambed sediment sample zones for each of the 30 monitored bridge sites are presented in the Monitoring Site Maps in appendix 3-B.

It is important to note that the receiving streams receive runoff from the approach sections of the roadway and from ditches that are located adjacent to the roadway in addition to the bridge deck. Although sampling locations were selected to minimize the contribution of non-bridge runoff, this was not practical at all sites. Therefore, differences between upstream and downstream sediment chemistry may reflect sources other than bridge deck runoff.

**Figure 3.3-2: Instream (left) and bridge deck (right) streambed sediment sampling.**

### 3.3.1.3 Sediment Analysis Methods

Analysis of streambed sediment is an approach widely used to assess contaminant distributions in streams. Trace elements and hydrophobic organic constituents frequently have high sorption coefficients, and can accumulate in streambeds. Solids transported during precipitation events may settle, and analysis of the water phase alone may not adequately quantify trace element and organic loads to the receiving stream (Shelton and Capel, 1994).

Each streambed sediment sample collected was sieved though a 2-mm sieve, with the materials passing through referred to as the *bulk sediment sample.* This bulk sample was then sieved through a 63-µm sieve to yield a *fine-grained subsample*, which includes silt and clay. The *percentage fines*, defined as the ratio of the mass of the fine-grained solids to the total mass of the bulk sample, was determined. Particle size is relevant because adsorption of constituents in related to specific surface area (i.e., the smaller particles have more sorption sites for a given mass of soil), and particle chemistry (e.g., clays offer more favorable surface chemistry for hydrophobic organic compounds). All subsequent chemical analyses were performed on the fine-grained fraction in order to minimize variability associated with grain-size differences.

Samples were analyzed by either the USGS Water Quality Laboratory in Denver, Colorado or the USGS Sediment Chemistry Laboratory in Atlanta, Georgia. All sediment samples were dried at 105° C to constant weight, and analyzed for a suite of major and trace elements as well as phosphorus (P), total carbon (TC), total organic carbon (TOC), nitrogen (N), and sulfur (S). Sediment samples sent to the USGS Water Quality Laboratory (Denver, CO) were analyzed for 38 SVOCs including PAHs and phthalates. A complete list of parameters and corresponding laboratory methods are summarized in appendix 3-I.

### 3.3.1.4 Sediment Results

Each of the 69 streambed sediment samples collected from the 30 sites was analyzed for 73 different parameters. The results were grouped into inorganic parameters (trace metals, nutrients, and major and total elements) and organic parameters (38 SVOCs). The inorganic and organic results are summarized in tables 3-J.1 and 3-J.2 in appendix 3-J. The results are discussed in section 4.3.

## 3.3.2 Bridge Deck Sweeping

The objective for the bridge deck sweeping effort was to determine the concentration of various target organic and inorganic constituents in sediment that accumulate on bridge decks, and that could potentially run off into receiving streams during storm events. Solids from bridge deck sweeping equipment were collected during sweeping events of bridge decks across NC, and used to characterize bridge deck solids.

### 3.3.2.1 Bridge Deck Sweeping Sites

Sweeping events were conducted from July through December 2009. The events consisted of sweeping multiple bridges within NCDOT Divisions in order to collect sediment samples for evaluation. Divisions were selected based on statewide distribution and staff schedule availability. Division 1 represented the Coastal ecoregion and Division 13 represented the Blue Ridge ecoregion. Events were scheduled to occur once in each selected Division for each weather season (summer, fall, winter, spring). In total, seven sweeping events occurred, for the summer and fall seasons in both Divisions 1 and 13. A summary of sweeping events can be found in table 3.3-2 and seen in figure 3.3-3.

**Table 3.3-2: Bridge Deck Sweeping Events Summary**

| Sweep Event Date | Ecoregion | NCDOT Division | Season | Counties Swept | # Hoppers/ # Samples | Number of Bridges Swept | Total Bridge Deck Area Swept (acres) | Total Volume of Material Collected |
|---|---|---|---|---|---|---|---|---|
| 12/17/2009 | Coastal | 1 | Fall | Dare | (1)/(1) | 1 | 42.8 | 1 $yd^3$ |
| 11/18/2009 | Coastal | 1 | Fall | Martin | (2)/(9) | 30 | 3.0 | 4 $yd^3$ |
| 11/3/2009 | Blue Ridge | 13 | Fall | Buncombe | (3)/(9) | 38 | 24.5 | 8 $yd^3$ |
| 9/16/2009 | Blue Ridge | 13 | Summer | Buncombe and Madison | (3)/(9) | 19 | 9.3 | 9 $yd^3$ |
| 9/2/2009 | Coastal | 1 | Summer | Hertford and N. Hampton | (3)/(9) | 37 | 4.6 | 3 $yd^3$ |
| 8/25/2009 | Coastal | 1 | Summer | Pasquotank, Camden, and Perquimmons | (1)/(3) | 13 | 4.8 | 10 $ft^3$ |
| 7/14/2009 | Coastal | 1 | Summer | Dare | (2)/(10) | 1 | 42.8 | 3 $ft^3$ |

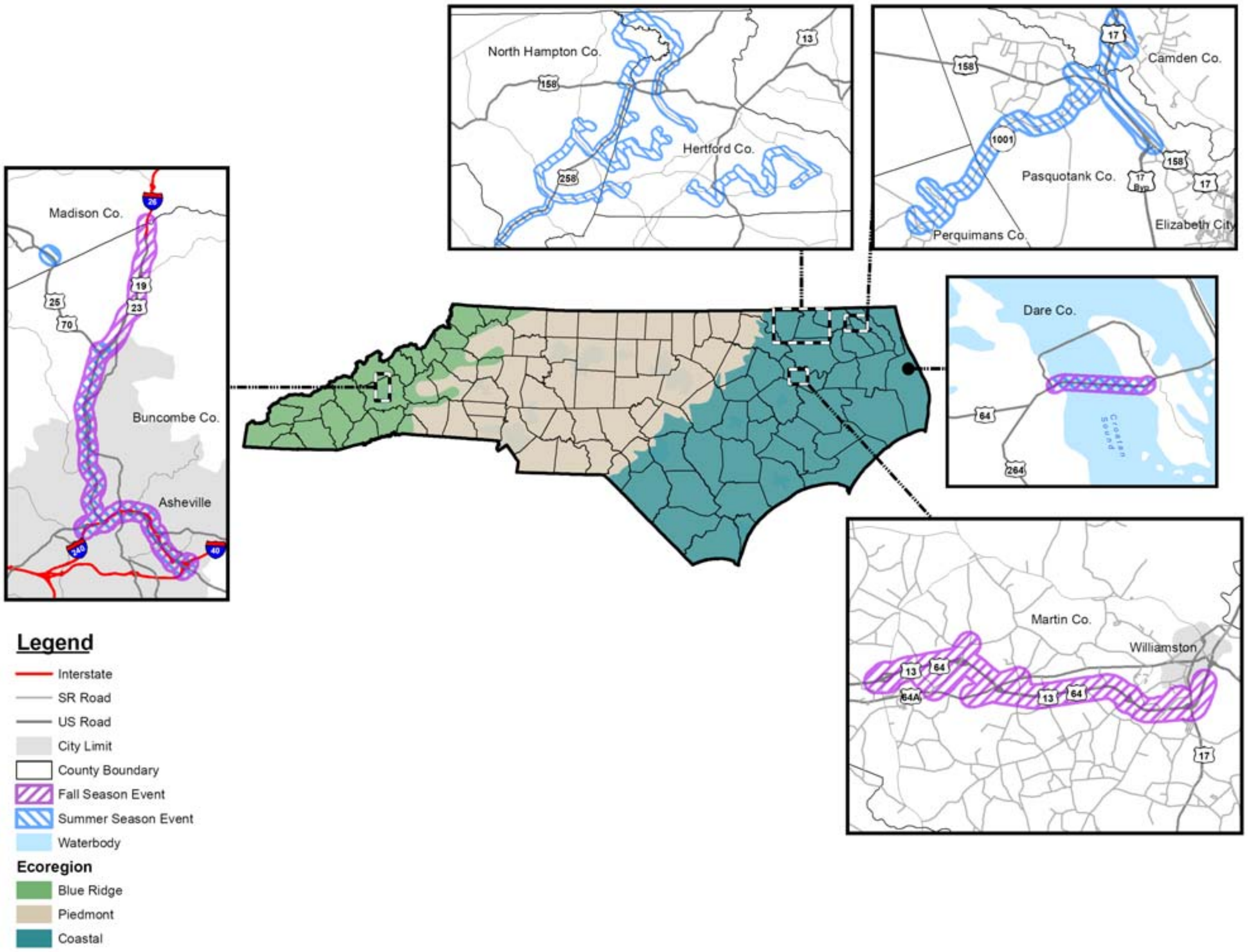


**Figure 3.3-3: Bridge deck sweeping events.**

### 3.3.2.2 Solids Sampling and Data Collection

Sweeping events were conducted for multiple State bridges within Divisions 1 and 13 utilizing an Allianz Johnston VT650 sweeper, with a dual sweep configuration, pure vacuum sweeper, shown in figure 3.3-4. With a stainless steel 8.5-cubic yard debris hopper and 343-gallon clean water tank, the VT650 combines gutter and widesweep brooms, water spray jets, a gearbox driven vacuum fan, and a recirculating water system, among other features, to provide a combination of sweeping and vacuum for the removal of roadway sediment.

Sweeper solids are used as a surrogate for the solids present in the bridge deck. Previous studies have reported vacuum sweepers demonstrate greater efficiencies in removing coarse and fine sediment from roadway surfaces, with efficiencies ranging from 60 to 92 percent (Pitt et al., 2004; Breault et al., 2005). Earlier studies of mechanical sweepers such as the NURP study (EPA, 1983) reported poor removal of silt and clay by sweepers. However, vacuum sweepers have been reported to exhibit removal efficiencies in excess of 80% of silt/clay in the absence of wind (Breault et al., 2005). Thus, while sweeper solids can be expected to slightly understate the proportion of silt and clay in bridge deck solids, the differences are not considered to be substantial to change the conclusions from such an analysis. The bridge deck conditions before and after one of the BSP sweeping events are illustrated in figure 3.3-5.

**Figure 3.3-4: Bridge sweeping equipment: Allianz Johnston VT650 sweeper.**

**Figure 3.3-5: Bridge deck before sweeping (left) and after sweeping (right).**

With input from USGS staff, a Standard Operating Procedure (SOP) was created for the BSP bridge deck sweeping study, and is attached as appendix 3-K. The SOP was created to serve as general guidance for procedures to be implemented during sweeping events. According to the SOP, the following standards were desired for all sweeping events:

- A 2–3 day dry period to precede sweeping events preferred
- Sweeper hopper to be cleaned before the start of each sweep event
- Prefer three full hoppers of sediment material for sampling for each event. Multiple bridges to be swept in order to collect three full hoppers of sediment material. Three samples of sediment to be collected from each hopper.
- Sediment samples representative of all sediment in the hopper to be collected by the “grab sample” method in 1-liter, wide-mouth, glass sample jars provided by USGS. Sample jars to be labeled and stored on ice until delivered to USGS.
- Upon delivery of samples to USGS, USGS to pack and ship samples for lab analysis.

Multiple bridges were swept by each sweeper. Solids samples were collected by hand from the sweeper hoppers at the NCDOT maintenance yards, and transferred into glass jars. Metal shovels were used to manipulate the dump pile so that sediment samples could be taken from various areas of the dump pile in order to collect a representative sample of the sediment collected.

#### 3.3.2.3 Solids Analysis Methods

Solids samples were delivered to the USGS office in Raleigh, North Carolina. USGS staff combined the solids samples collected from each sweeping event to create a composite sample. The composite sample was then sieved into two sub-samples, a bulk sample, consisting of solids with <2-mm diameter size, and a fine sample, consisting of solids with <63-µm diameter size. As with bed sediment samples, the percent fines in the samples were determined. All subsequent chemical analyses were performed on both the bulk sample and fine-grained fraction, in contrast with only the fine-grained fraction in the case of streambed sediment. Sample analysis was conducted as discussed in section 3.3.1.3. A complete list of parameters and corresponding laboratory methods are summarized in appendix 3-I.

#### 3.3.2.4 Solids Results

A summary of the results from the characterization of sediment samples for each sweeping event are summarized in tables 3-L.1 and 3-L.2 in appendix 3-L. A discussion of the results is included in Section 4.3.

## 3.4 Biological Monitoring

Biological monitoring provides environmental decision-makers with an important tool in measuring the impacts of a point source on the receiving stream. Chemical analysis of stream samples measures contaminant concentrations at a single point in time, and can fail to both adequately document pollutant loads spatially and temporally, as well as quantify the impact of these loads on the lotic ecosystem. A study of aquatic organisms allows stakeholders to understand stresses on aquatic biota which might be missed by chemical analysis (Allan et al., 2006; Pitt et al., 1995).

Biological monitoring supports determinations of water quality, vis-à-vis addressing questions about the suitability of the stream for the beneficial uses and sustenance of aquatic life, identifying the causes of water quality degradation, and provides a benchmark for tracking changes in water resource integrity (Barbour et al., 1999). Past studies indicate that constituents in highway runoff, such as metals, particulates, nutrients, salts and polycyclic aromatic hydrocarbons can bioaccumulate in aquatic biota, and result in acute and chronic toxic effects on aquatic life (Dupuis, 2002; Eisler 1987; Yousef et al., 1984).

The effects of stormwater runoff on aquatic biota need to be evaluated across different time scales, ranging from minutes and hours, to the long-term effects, ranging from days to months or years (Herricks et al., 1998). Over shorter time scales, dilution of runoff could be small at some sites, and impacts are dominated by the toxicity of stormwater runoff. Over longer time scales, sedimentation of pollutants could result in a significant source of toxicity (Pitt et al., 1995), although these effects may be ameliorated by mixing effects.

Different methods are required to study biotic impacts of stormwater runoff across different time scales. Two types of biological indicators available for measuring the impact of runoff from bridges are aquatic toxicity tests (also known as *bioassays*) of waters collected from bridge runoff, and biological surveys (or *biosurveys* for short) of the receiving stream.

Bioassays are generally laboratory experiments that measure effects on growth, survival, reproduction (or other applicable endpoints such as enzyme production, etc.) to aquatic organisms. Organisms are exposed to one or more concentrations of an aqueous sample, and observations are made over time to evaluate the effects associated with the exposure. Bioassays are appropriate indicators of biotic stress over shorter time periods of hours or days (Herricks et al., 1998). When combined with watershed-based metrics, bioassays can be a valuable tool in identifying sources of biological health impairment in receiving waters.

Aquatic toxicity tests are generally (but not always) performed in a laboratory. Biosurveys, on the other hand, are performed by collecting aquatic biota, often benthic macroinvertebrates, directly from a stream. These organisms, discussed in greater detail in Section 3.4.2, include a variety of crustaceans, mollusks, aquatic worms, and insects, lacking in a backbone (hence, invertebrates), and have been found to be useful biological indicators of the health of an aquatic system due to their sensitivity to pollution. Macroinvertebrates are useful biological monitors because they are found in all aquatic environments, are less mobile than many other groups of organisms, and are of a size that makes them easily collectable. Aquatic biota show responses to a wide array of potential pollutants, including those with synergistic or antagonistic effects. The sedentary nature of the benthos ensures that exposure to a pollutant or stress reliably denotes local conditions, and allows for comparison of sites that are in close proximity (Voshell et al., 1997). However, the effectiveness of measuring biological integrity varies with watershed geology, geomorphology, climate, microclimates, vegetation, location in the watershed, instream habitat and a host of other variables. Even in the same region, watershed or stream reach properties can be very inconsistent (Sovern and MacDonald, 1996). Nevertheless, biosurveys are useful indicators of biotic health over longer time scales, such as months or even years (Herricks et al., 1998).

Two studies were performed as part of the BSP effort to assess the impacts of bridge deck stormwater runoff on aquatic populations in the receiving stream. A bioassay using time-variable chronic bioassay procedures was performed with stormwater samples as a medium to cultivate the test organism, *Ceriodaphnia dubia* and observe the response while exposing them to stormwater for a duration equivalent to the sample collection time, and then to water known to be free from pollutants for the remaining duration of the test. Toxicity was then measured through evaluation of the survival and reproductive rates of the test organism.

A second study involved a biosurvey of benthic macroinvertebrates using established protocols. The biological richness of the population was quantified both in terms of the abundance of indicator organisms, as well in terms of a biotic index based on the relative predominance of pollution tolerant species.

## 3.4.1 Bioassay Monitoring

### 3.4.1.1 Introduction

Time-variable chronic bioassays were performed with bridge deck runoff and stream water collected from select bridge sites across NC. The objectives of this effort were to determine the toxicity of stormwater runoff from bridges and to evaluate the potential biological effects on receiving streams.

In NC, chronic effluent toxicity tests have been approved by the Director of DWQ as acceptable proof that an effluent is not presenting adverse impacts on aquatic life in the receiving streams due to toxic substances (NCDENR, 1998). These tests were generally associated with static or flow-through exposures of consistent exposure concentrations, and were not designed for the variable duration or frequency of exposures associated with stormwater. In an effort to address issues unique to evaluating aquatic toxicity in bridge runoff, time-variable bioassay guidance was developed by NCDENR for assessing bridge runoff and stormwater toxicity (NCDENR, 2009), based on a review of existing literature on the subject, including the recommendations of the NCHRP (Dupuis, 2002).

A traditional bioassay involves the collection of a 24-hour composite effluent sample and continuous exposure of test organisms to the effluent for a period of seven days. While appropriate for continuous point sources, this method overestimates the toxicity of intermittent stormwater runoff. The bioassay was modified to only expose test organisms for a period equal to the sample collection time over the course of the storm for which the composite sample was collected. Toxicity is measured by the response and reproduction rates of the organism to the time-variable exposure for each test condition. The test methods and procedures are discussed in Section 3.4.1.3 of this report.

The bioassay study was designed through collaboration with NCDOT, DWQ, USGS, Environmental Testing Solutions, Inc. (ETS) and URS Corporation. Sample collection was performed by the USGS and bioassay testing was conducted by ETS, a certified bioassay lab located in Asheville, NC.

### 3.4.1.2 Bioassay Monitoring Sites

Bioassays were conducted at 13 representative bridge sites in NC. A location map of all the bridge sites in the bioassay study is shown in figure 3.4-1. Site maps illustrating bioassay monitoring locations are provided in appendix 3-B.

Three sites are located in the Blue Ridge ecoregion, seven sites in the Piedmont ecoregion and three sites in the Coastal ecoregion. The distribution of sites across all three ecoregions was important to capture the variation in climate and rainfall in each of these areas since differences such as rainfall intensity and duration can have a significant effect on toxicity (Dupuis, 2002). Rainfall was monitored at all bridge sites, and a summary of the total depth of rainfall and duration of runoff for each storm event sampled for bioassay is provided in appendix 3-F. Characteristics of the bridge sites, such as bridge deck area, traffic volume, stream classification, and stream drainage areas varied among the sites. A list of the bioassay monitoring sites is presented along with their site-specific characteristics in table 3.4-1.

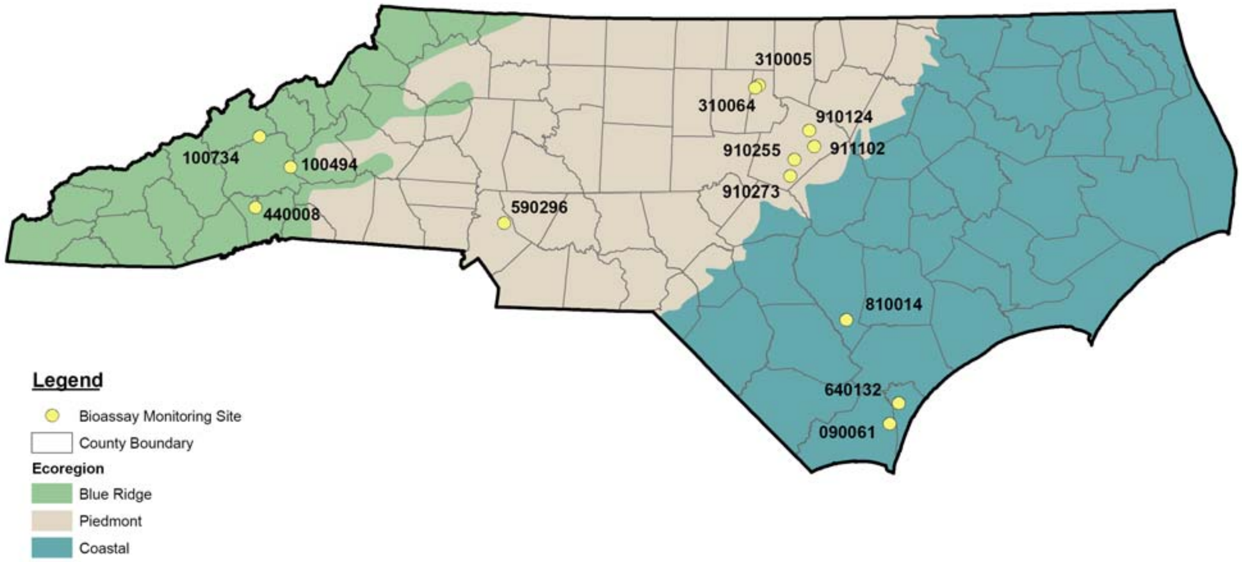


**Figure 3.4-1: Bioassay monitoring sites.**

## Table 3.4-1: Bioassay Monitoring Sites and Characteristics

| Bridge Number | Stream Name | Ecoregion[a] | County | NCMIN Tier[b] | Route | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class[c] | AADT (vpd)[d] | River Basin | Stream Classification[e] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 090061 | Town Creek | C | Brunswick | RT | NC 133 | NC 133 | R | Ma-C | 5,600 | Cape Fear | C; Sw | 115.1 | 0.25 | B |
| 100494 | Swannanoa River | BR | Buncombe | SWT | I-40 | I-40 | U | PA-I | 25,500 | French Broad | C | 4.2 | 1.30 | C |
| 100734 | Big Ivy Creek | BR | Buncombe | SRT | SR 2207 | Stockton Road | R | Ma-C | 1,500 | French Broad | WS-II; HQW | 60.6 | 0.09 | C |
| 310005 | Mountain Creek | P | Durham | SRT | SR 1616 | Bahama Road | R | Mi-C | 2,800 | Neuse | WS-II;HQW;NSW;CA | 7.2 | 0.13 | B |
| 310064 | Little River | P | Durham | SRT | SR 1461 | Johnson Mill Road | R | L | 500 | Neuse | WS-II;HQW;NSW;CA | 78.2 | 0.12 | C |
| 440008 | Boylston Creek | BR | Henderson | SRT | SR 1314 | Ladson Road | R | L | 1,400 | French Broad | WS-IV | 15.4 | 0.09 | B |
| 590296 | Mallard Creek | P | Mecklenburg | SWT | I-85 | I-85 | U | PA-I | 112,000 | Yadkin | C | 19.6 | 0.79 | C |
| 640132 | Smith Creek | C | New Hanover | SWT | US 74 | US 74 | U | L | 26,000 | Cape Fear | C; Sw | 21.8 | 2.59 | C |
| 810014 | Black River | C | Sampson | RT | NC 411 | Hitching Post Road | R | Ma-C | 750 | Cape Fear | C; Sw; ORW+ | 676 | 0.18 | B |
| 910124 | Perry Creek | P | Wake | SRT | SR 2006 | Perry Creek Road | U | L | 12,700 | Neuse | C;NSW | 11.2 | 0.17 | C |
| 910255 | Swift Creek | P | Wake | SRT | SR 1006 | Old Stage Road | U | Mi-A | 11,500 | Neuse | WS-III; NSW | 1.7 | 0.04 | C |
| 910273 | Middle Creek | P | Wake | SRT | SR 1006 | Old Stage Road | R | Mi-C | 5,000 | Neuse | C; NSW | 57.5 | 0.13 | B |
| 911102 | Mango Creek | P | Wake | SWT | I-540 | I-540 | U | PA-I | 34,000 | Neuse | C; NSW | 2.4 | 1.80 | C |

**Notes:**

[a] BR – Blue Ridge; P – Piedmont; C – Coastal

[b] RT – Regional Tier; SRT – Subregional Tier; SWT – Statewide Tier. Data from NCDOT (2009).

[c] PA – Principal arterial; I – Interstate; Ma – Major; Mi – Minor; C – Collector; L – Local; A – Arterial

[d] AADT – Average annual daily traffic volume; vpd – vehicles per day; see section 3.5.

[e] NCDENR Stream Classification: B – Primary Recreation, Fresh Water; C – Aquatic Life, Secondary Recreation, Fresh Water; CA – Critical Area; HQW – High Quality Water; NSW – Nutrient Sensitive Water; ORW – Outstanding Resource Water; SW – Swamp Water; TR – Trout Water; WS-II – Water Supply II, Underdeveloped; WS-IV – Water Supply IV, Highly Developed; + - Subject to the Outstanding Resource Waters rule. Data from NCDENR, 2007.

[f] B – Bituminous; C – Concrete; O – Other

### 3.4.1.3 Bioassay Survey Methods

Methods and procedures for the bioassay study are based on DWQ guidance (NCDENR, 2009), presented as appendix 3-M. An overview of the sample collection methods and bioassay test methods and procedures are provided in this section.

#### Sample Collection

The USGS sampling equipment and sample collection techniques for bioassay sample collection were the same as those for water chemistry monitoring for collection of bridge deck runoff and instream samples, discussed in section 3.2 of this report. In addition to samples collected for chemical analysis, USGS collected additional volume of samples for bioassay testing using *split sampling* techniques, defined as two or more samples derived from a single homogenized sample. For instream storm bioassays at the Little River and Swannanoa River sites, samples were collected temporally over the rising and peak portions of the hydrograph. Instream storm sampling at the Black River site utilized EWI methods rather than an automated point sampler because of the complexity of the hydrograph and the slow response of the stream. EWI sample collection time was coordinated to correspond with the peak of the hydrograph at Black River.

A total of 40 samples were collected for bioassay testing from 13 bridge sites between September 2009 and February 2010. Table 3.4-2 summarizes the number of bridge deck runoff and instream samples collected for each site.

#### Test Methods

Currently, there are no standardized aquatic toxicity testing procedures for assessing bridge deck runoff set forth by Environmental Protection Agency (EPA) or the State of NC. Therefore, procedures were developed for this project based on existing methods for traditional whole effluent toxicity (WET) testing, freshwater time-variable bioassays described in Dupuis (2002) and DWQ guidance on the subject (NCDENR, 2009), included as appendix 3-M.

Traditional WET bioassay procedures were designed to simulate continuous exposure of aquatic organisms to a point source effluent for a continuous seven days, and do not appropriately simulate biological exposure during storm runoff. The methodology for this study was a time-variable chronic bioassay, where the sample exposure time was modified to be equal to the collection time of the composite sample, reflecting the shorter durations of exposure during storm events. After the organism was exposed for the duration of the composite sample time, the organism was transferred to the control water for the remainder of the seven days. The modifications to traditional WET test methods developed for this study are summarized for each sample and test type in table 3.4-3.

## Table 3.4-2: Total Samples Collected for Bioassay Testing

| Bridge # | Stream Name | # Bridge Deck Runoff Samples | # Instream Base Flow Samples | # Instream Storm Samples | # Bioassay Samples Collected per Site |
|---|---|---|---|---|---|
| 090061 | Town Creek | *1* | - | - | 1 |
| 100494 | Swannanoa River | *3* | *3* | *3* | 9 |
| 100734 | Big Ivy Creek | *2* | - | - | 2 |
| 310005 | Mountain Creek | *1* | - | - | 1 |
| 310064 | Little River | *4* | *3* | *3* | 10 |
| 440008 | Boylston Creek | *1* | - | - | 1 |
| 590296 | Mallard Creek | *2* | - | - | 2 |
| 640132 | Smith Creek | *1* | - | - | 1 |
| 810014 | Black River | *3* | *2* | *3* | 8 |
| 910124 | Perry Creek | *1* | - | - | 1 |
| 910255 | Swift Creek | *1* | - | - | 1 |
| 910273 | Middle Creek | *1* | - | - | 1 |
| 911102 | Mango Creek | *2* | - | - | 2 |
| **Samples Collected per Condition** | | ***23*** | ***8*** | ***9*** | **40** |

## Table 3.4-3: Summary of Test Conditions and Modifications to Traditional Chronic WET Test Methods

| Sample Type | Test Type | Test Objective | Modification to Traditional Chronic WET Tests |
|---|---|---|---|
| **Bridge Deck Runoff** | Chronic Multi-Concentration using *C. dubia* | To determine if toxicity exists in the bridge runoff and the no observable effect concentration (NOEC), lowest observable effect concentration (LOEC), and the inhibition concentration (IC25). | Time variable modifications:<br>• Expose organisms to a flow-weighted composite of bridge deck runoff for a length of time equal to the sample collection time.<br>• For multi-concentration tests, the samples will be prepared at 5 different dilutions (5 treatments) |
| **Instream Storm Conditions**[b] | Chronic Pass/Fail using *Ceriodaphnia dubia* | To determine if toxicity exists in the stream [a] during storm flow conditions. | Time variable modifications:<br>• Expose organisms to a flow-weighted composite of instream stormwater for a length of time equal to the duration of the instream hydrograph influenced by the storm event, up to a maximum exposure time of 72 hours.<br>• For pass/fail test, the sample will be used at 100% concentration (1 treatment) |
| **Instream Normal-Flow Conditions**[c] | Chronic Pass/Fail using *Ceriodaphnia dubia* | To determine if toxicity exists in the stream [a] during normal flow conditions. | • Conducted as a standard chronic pass/fail test.<br>• For pass/fail test, the sample will be used at 100% concentration (1 treatment) |

**Source: (NCDENR, 2009)**

**Notes:**

[a] Tests conducted on samples collected upstream of the bridge.

[b] USGS staff assessed "normal-flow" conditions by comparing instream flow against the long-term median flow value obtained from the stream hydrograph.

Time variable chronic bioassays were performed on the bridge deck runoff samples using five treatments of runoff-control mixtures including full strength samples (100% runoff) and diluted samples (50%, 25%, 12.5%, and 6.25%). Control samples consisted of synthetic water and were used to dilute the bridge runoff and instream samples. The control water at test initiation and at renewals was tested to ensure a pH in the range of 6.5 and 8.5, and the total hardness in the range of 30-50 mg/L CaCO3. A summary of the dilution in each treatment are provided in table 3.4-4.

**Table 3.4-4: Summary of Bioassay Test Treatments**

| Test Treatments | Dilution of Bridge Deck Runoff Samples | | Dilution of Instream Samples | |
|---|---|---|---|---|
| | % Bridge Deck Runoff | % Laboratory Control Water | % Instream Water | % Laboratory Control Water |
| **Control** | 0 | 100 | 0 | 100 |
| **6.25%** | 6.25 | 93.75 | NA | NA |
| **12.5%** | 12.5 | 87.5 | NA | NA |
| **25%** | 25 | 75 | NA | NA |
| **50%** | 50 | 50 | NA | NA |
| **100%** | 100 | 0 | 100 | 0 |

Performing a test with five treatments helps to evaluate the test organism's response to a range of runoff toxicity levels. For example, if the 100% runoff mixture shows a toxic effect, but the 50% runoff mixture has no toxic effect, then the dilution of the receiving water will need to be at least 50% to eliminate toxicity (Dupuis, 2002). The time-variable chronic bioassays were performed on instream samples using full strength sample concentrations (100% solutions), and compared with control samples.

*Ceriodaphnia dubia* was the test organism selected for this study. *C. dubia* is a small aquatic invertebrate (cladoceran) common in lakes and larger rivers, and frequently used as an aquatic toxicity test organism. It has a rapid life cycle at 25°C, potentially producing offspring during a seven-day period (NCDENR, 1998). *C. dubia* used in chronic toxicity tests was less than 24 hours old, and within 8 hours of the same age, from the third or subsequent broods, and from broods in which the adult produced at least 8 neonates. Images of the aquatic invertebrate are presented in figure 3.4-2.

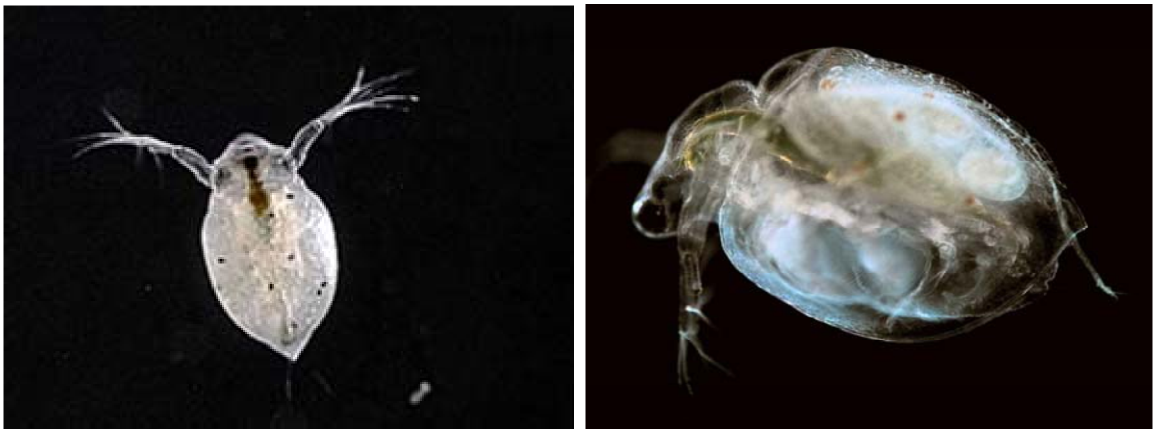


**Figure 3.4-2: Images of *C. dubia*. Sources: left photo – Jack Kelly Clark, courtesy of University of California Statewide Integrated Pest Management Program; right photo – NCDENR (2010).**

Over the course of each test, the percent of surviving organisms was documented daily to observe both acute and chronic toxicity. The number of young reproduced by each female was measured at the end of seven days, and is indicative of chronic toxicity. Reproduction rates for these organisms are a sensitive measure and indicator of the viability of the biological community.

Toxicity is typically quantified in terms of a no observable effect concentration (NOEC), the maximum concentration of runoff at which survival of test organisms in the test samples was statistically similar to survival in controls, or an inhibition concentration (IC25), the concentration of runoff that would cause a 25% reduction in reproduction or growth of the test organism (Dupuis, 2002). An alternate measure of toxicity is a simple pass/fail score; a sample fails when mortality of the test organisms in the test sample is significantly different than their survival in the control sample, or when the test organism in the test sample experiences 20% or greater reduction in reproduction or growth, which is statistically different from observed in the control sample (NCDENR, 1998). For the purposes of this study, the results from bridge deck runoff tests were expressed in terms of the IC25. For the instream tests, the toxicity was expressed in terms of pass/fail since the only treatment was the 100% solution.

A series of physical and chemical parameters were measured throughout each test, as outlined in table 3.4-5. Alkalinity, hardness, total residual chlorine (TRC), and turbidity were measured in the highest concentrations tested. Pre- and post-exposure solutions were typically analyzed during each renewal for pH, Dissolved Oxygen (DO), and temperature and analyzed daily for conductance. These measurements were documented in the toxicity test reports provided by ETS.

A summary of test requirements for instream and bridge runoff samples is provided in table 3.4-6. Known deviations from the test protocol were noted during the study and reported in toxicity test reports. In general, deviations from test protocol included:

Three bridge deck runoff samples were incorrectly processed by the laboratory as pass-fail tests with 1 treatment (100%) rather than multi-concentration tests using 5 treatments (100%, 50%, 25%, 12.5%, 6.25%). These cases are noted in table 3.4-6.

Sample holding times were exceeded on several occasions; however, DWQ guidance suggests that this does not necessarily invalidate the test unless the delay was excessive or unnecessarily long, as determined by the contract laboratory.

**Table 3.4-5: Summary of Bioassay Test Requirements**

| Test/Sample Type[a] | Minimum Quantity (mL) per Sample[b] | Feeding Rated[c] | Concentration of Treatments & Number of Replicates | Target Holding Time for Samples (hrs) | Measurements in Addition to Standard Temperature, DO, pH, Conductivity |
|---|---|---|---|---|---|
| **Chronic Multi-Concentration Test for Bridge Runoff (Storm)** | 600-1200 | 50 µL/day<br>Selenastrum and Yeast-cerophyll® (YCT) | 10 replicates per control &<br>5 treatments (100%, 50%, 25%, 12.5%, 6.25%) | 36 | For 100% Solution Only: Alkalinity, Hardness, TRC, Turbidity |
| **Chronic Pass/Fail Test for Instream (Storm)** | 600-1200 | 50 µL/day<br>Selenastrum and YCT | 12 replicates per control & 1 treatment (100%) | 36 | Alkalinity, Hardness, TRC, Turbidity |
| **Chronic Pass/Fail Test for Instream Background (Normal-Flow)** | 1200 | 50 µL/day<br>Selenastrum and YCT | 12 replicates per control & 1 treatment (100%) | 72 –toxicity testing<br>48 –turbidity | Alkalinity, Hardness, TRC, Turbidity |

**Source: NCDENR (2009)**
**Notes:**

[a] Control/Dilution water will be the standard control water used by the contract lab. Hardness must range from 30-50 mg/L CaCO3 and the pH must range from 6.5 to 8.5 s.u.

[b] If sample collection time exceeded 72 hours, a 1200 mL sample was required. The additional sample volume was used to review test solutions on day 2. Sample volumes allow 15 mL for DO, pH, conductivity measurements, and 50 mL for hardness. For instream samples, 200 mL was required for turbidity measurements. When sample volumes allowed, turbidity measurements were performed on the bridge runoff. Volumes may be adjusted by the contract lab.

[c] For stormwater tests in which stormwater exposure extends beyond the first day, organisms will be fed while in stormwater samples. Organisms will be fed such that they have access to food for at least 2 hours. Selenastrum (green unicellular algae) is to be prepared at a concentration of 1.71 x107 cells/mL. YCT is to have a dry weight of 1.7-1.9 g/L.

### 3.4.1.4 Bioassay Results

A summary of the toxicity tests results are provided in table 3.4-6. Of the 23 bridge deck runoff samples tested, three were identified as toxic due to significant reduction in the reproduction rates of the *Ceriodaphnia dubia*. The three sites for which the runoff was found to be toxic included Swannanoa River (100% and 50% concentrations from February 22, 2010 sample), Black River (100% concentration from November 10, 2009 sample), and Little River (100% concentration from September 17, 2009 sample). None of the eight instream normal flow samples or nine instream storm samples were found to be toxic. Test acceptance criteria and analysis methods were adopted from DWQ guidance on the subject (NCDENR, 2009), presented as appendix 3-M.

Appendix 3-N includes executive summaries of the toxicity test reports by ETS. Results for the bioassay tests are summarized in this section, while the conclusions from biological monitoring are discussed in section 4.5 of this report.

## Table 3.4-6: Bioassay Test Results for Bridge Deck and Instream Samples

| Bridge Monitoring Site | | | Sample and Test Type | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Bridge Deck Runoff: Chronic Multi-Concentration (100%, 50%, 25%, 12.5%, 6.25%) | | Instream Normal Flow Conditions: Chronic Pass/Fail (100%) | | Instream Storm Conditions: Chronic Pass/Fail (100%) | |
| ***Bridge Number*** | ***Stream Name*** | ***Sample Season*** | ***Sample Dates*** | ***Results*** | ***Sample Dates*** | ***Results*** | ***Sample Dates*** | ***Results*** |
| **100734** | **Big Ivy Creek** | Fall | 11/30/2009 | Pass, IC25 > 100% | | | | |
| | | Winter | 1/16/2010 | Pass, IC25 > 100% | | | | |
| **440008** | **Boylston Creek** | Fall | 12/2/2009 | Pass, IC25 > 100% | | | | |
| **810014** | **Black River** | Summer | 9/16/2009 | Pass (only 100% tested)[c] | 9/8/2009<br>9/11/2009 | Pass | | |
| | | Fall | 11/10/2009 | **Fail (IC25 = 81.5%)[a]** | | | 11/13/2009 | Pass |
| | | | | | | | 11/18/2009 | Pass (48 and 72 hours) |
| | | Winter | 1/17/2010 | Pass, IC25 > 100% | 1/12/2010<br>1/15/2010 | Pass | 1/27/2010 | Pass (48 and 120 hours) |
| **310064** | **Little River** | Summer | 9/17/2009 | **Fail[b] (only 100% tested)[c]** | 9/22/2009<br>9/25/2009 | Pass | | |
| | | Fall | 11/10/2009 | Pass, IC25 > 100% | 11/17/2009<br>11/20/2009 | Pass | 11/11/2009 | Pass |
| | | Winter | 1/17/2010 | Pass, IC25 > 100% | 1/5/2010 | Pass | 1/17/2010 | Pass |
| | | Winter | 2/5/2010 | Pass, IC25 > 100% | | | 2/5/2010<br>2/6/2010 | Pass |
| **590296** | **Mallard Creek** | Fall | 12/8/2009 | Pass, IC25 > 100% | | | | |
| | | Winter | 2/2/2010 | Pass, IC25 > 100% | | | | |
| **911102** | **Mango Creek** | Winter | 2/2/2010 | Pass, IC25 > 100% | | | | |
| | | Winter | 2/5/2010 | Pass, IC25 > 100% | | | | |
| **310005** | **Mountain Creek** | Winter | 2/5/2010 | Pass, IC25 > 100% | | | | |
| **910273** | **Middle Creek** | | 2/5/2010 | Pass, IC25 > 100% | | | | |
| **910124** | **Perry Creek** | | 2/2/2010 | Pass, IC25 > 100% | | | | |

## Table 3.4-6: Bioassay Test Results for Bridge Deck and Instream Samples (continued)

| Bridge Monitoring Site | | | Sample and Test Type | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Bridge Deck Runoff: Chronic Multi-Concentration (100%, 50%, 25%, 12.5%, 6.25%) | | Instream Normal Flow Conditions: Chronic Pass/Fail (100%) | | Instream Storm Conditions: Chronic Pass/Fail (100%) | |
| **640132** | **Smith Creek** | | 2/5/2010 | Pass, IC25 > 100% | | | | |
| **910255** | **Swift Creek** | | 2/5/2010 | Pass, IC25 > 100% | | | | |
| **100494** | **Swannanoa River** | Summer | 9/9/2009 | Pass (only 100% tested)[c] | 9/29/2009<br>10/2/2009 | Pass | 9/9/2009 | Pass |
| | | Fall | 11/10/2009 | Pass, IC25 > 100% | 11/17/2009<br>11/20/2009 | Pass | 11/10/2009 | Pass |
| | | Winter | 2/22/2010 | **Fail (IC25=38.4%)[d]** | 01/26/2010<br>1/29/2010 | Pass | 2/22/2010 | Pass |
| **090061** | **Town Creek** | | 2/5/2010 | Pass, IC25 > 100% | | | | |

**Notes:**

[a] The Black River bridge deck runoff sample collected November 10 - 11, 2009 significantly reduced *Ceriodaphnia dubia* reproduction in the full-strength sample. The IC25 was 81.5%.

[b] The Little River bridge deck runoff sample collected September 17, 2009 significantly reduced *Ceriodaphnia dubia* reproduction in the full-strength sample from short-term exposure (4-hours and 5-minutes). The IC25 was not evaluated due to incorrect test (See note c).

[c] Bridge deck runoff samples were incorrectly run using chronic pass/fail test procedures (used for instream samples) rather than chronic multi-concentration test procedures.

[d] The Swannanoa River bridge deck runoff sample collected February 22, 2010 significantly reduced *Ceriodaphnia dubia* reproduction rates in the 100% concentration and significantly reduced reproduction rates in the 50% concentration from short-term exposure (4 hours, 51 minutes). The IC25 was 38.4%.

## 3.4.2 Biological Survey Monitoring

### 3.4.2.1 Introduction

Biological surveys, also known as biosurveys, were conducted between April and October 2009 at select bridge sites across NC. Biosurveys were conducted by performing extensive field investigations and laboratory analyses to evaluate the surrounding biological integrity of aquatic habitats in the receiving stream.

The primary component of biosurveys is the comparison of populations of freshwater benthic macroinvertebrates (*benthos* for short), either spatially, i.e., from areas upstream and downstream of the bridge in question, or temporally, i.e., from before and after construction of the bridge. Benthos can be described as animals without backbones that are larger than a pencil dot (larger than ½ millimeter). Habitats for these animals include rocks, logs, sediment, debris, and aquatic plants. Benthos include crustaceans, mollusks, aquatic worms, and immature forms of aquatic insects such as stonefly and mayfly nymphs (MDDNR, 2003). Because benthos are sedentary, they are less able to escape the effects of pollutants; therefore, surveys of benthic populations indicate relatively localized information of contaminant exposure. Consequently, biosurveys are useful in comparing areas that are in close proximity to compare the effects of pollutant loads on benthic communities (NCDENR, 2006, p. 1).

An *in situ* measure of relative biotic integrity and habitat quality is especially useful in assessing environmental impacts of bridge deck runoff on receiving waters because benthic macroinvertebrates are extremely sensitive to disturbances within the habitat, and respond quickly to change both in species composition and abundance (Dupius, 2002, p. 35).

The BSP biosurvey study consisted of the following two primary evaluations:

- **Between-Site Comparisons:** Biosurveys were used to determine spatial variation of benthic communities. Benthos sampling and habitat assessments were conducted along the sampling points upstream and downstream of 12 bridge sites. A comparison of benthic communities at each site could indicate potential degradation of water quality due to bridge deck runoff. A single round of sampling was performed at each site between April and May 2009.
- **Between-Time Comparisons:** In addition to spatial mapping of benthic changes, temporal surveys were implemented to examine the changes in community structure in response to continued impacts from bridge deck runoff. Benthos sampling and habitat assessments were conducted once at the *downstream* location of three (3) sites in October 2009 to compare present biotic health with comparable measures determined during a previous post-construction evaluation, obtained from field log records. For temporal comparison with the samples collected in 2009, only the last pre-2009 sample was used at each site.

The biosurvey monitoring effort was conducted through collaboration with NCDOT, DWQ, and Lenat Consulting Services (Lenat). The field investigations were performed by DOT and DWQ staff, according to the standard protocol established by DWQ (NCDENR, 2006). The following sections include a brief discussion of the monitoring sites, an overview of the methods used in this study, and a summary of the results. Additional information can be found in the original reports prepared by Lenat, attached as appendix 3-O.

### 3.4.2.2 Biosurvey Monitoring Sites and Characteristics

Biosurveys were conducted at 15 bridge sites, shown in figure 3.4-3. The 12 sites selected for the between-site comparisons vary in hydraulic and hydrologic parameters such as bridge deck area, stream classification, stream drainage, land use qualities (i.e., regional tier designation, roadway functional class, ADT, rural vs.

urban, etc). Three sites with historical biosurvey data were selected for between-time analysis. Site maps that illustrate the geo-spatial limits of the surveys performed at each bridge location are provided in appendix 3-B.

For biosurvey studies, selection of appropriate sites and sampling locations at each site is critical to avoid influences from a variety of sources other than the impact being studied. For example, land use is a critical element in identifying sample locations as man-made activities can affect sedimentation, nutrients, and organic or inorganic compounds entering a segment of a river or stream (NCDENR, 2006, p. 2). In order to study the local effects caused by bridge deck runoff, sites were selected to minimize runoff from other point and non-point sources. The bridges were equipped with SCMs to re-route stormwater runoff from the bridge deck surface for water quality purposes, as discussed in Section 3.2. With the exception of one bridge (Cataloochee Creek), none of these bridges allowed direct discharge into the receiving stream.

The study sites selected were located within the Blue Ridge and Piedmont ecoregions. Sites located within the coastal ecoregion that were visited during the planning phase of the project, were not found to be suitable, according to guidelines established by NCDENR (NCDENR, 2006, pp. 2-3). These include restrictions on sampling sites to freshwater streams (non-estuarine or tidally-influenced) that are wadeable, and greater than 1 meter wide.

One of the 12 study sites in the between-site comparison study was included as a reference site to help evaluate the relative integrity of the remaining study sites. DWQ biologists have sampled this site multiple times, always producing an ‘Excellent’ bioclassification (discussed in Section 3.4.2.3) in both the upstream and downstream locations. The site is a bridge spanning Cataloochee Creek with a timber bridge superstructure, located in the Great Smoky Mountains National Park on National Park Road. Cataloochee Creek has a stream drainage area of 49.1 square miles completely located in a forested watershed and is known for its pristine water quality conditions. Although this bridge is not equipped with an SCM (allowing direct discharge), the bioclassification rating suggests there is no water quality impairment due to this bridge. Photos of the reference site are provided in figure 3.4-4.

A list of the biosurvey sites evaluated as part of this study is presented along with their site-specific characteristics in table 3.4-7. Monitoring site maps for all sites are included in appendix 3-B. Photos and descriptions of the between-site comparison locations are provided in appendix 3-O.

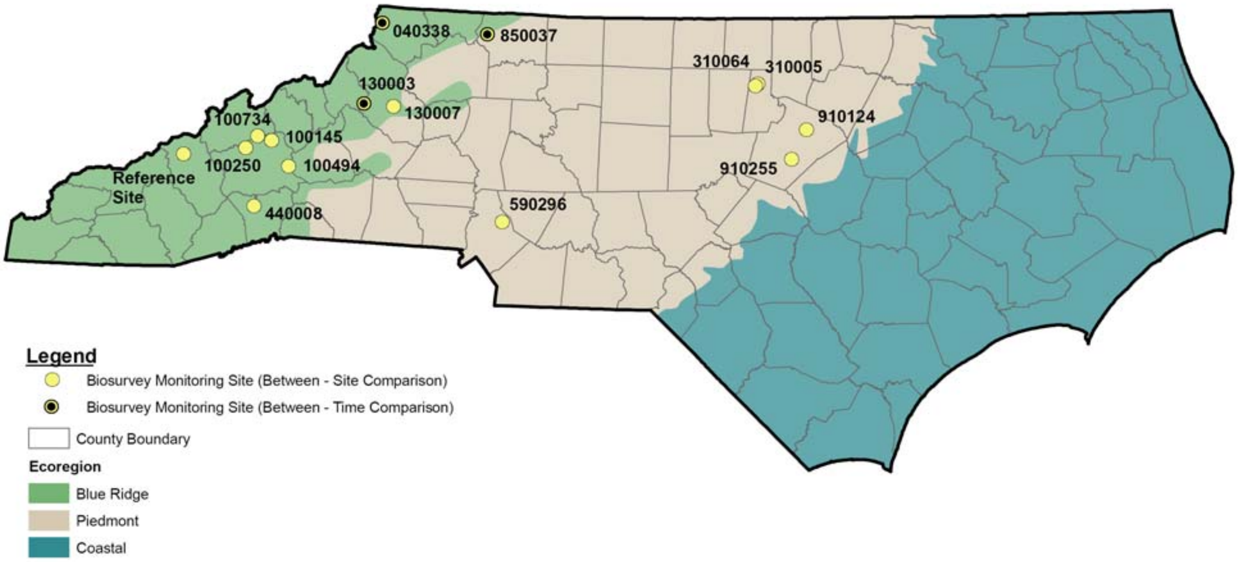


**Figure 3.4-3: Biosurvey monitoring sites.**

**Figure 3.4-4: Reference site – bridge over Cataloochee Creek. Upstream profile of bridge (left) and downstream view from bridge crossing (right).**

## Table 3.4-7: Biosurvey Monitoring Sites and Characteristics

| Bridge Number | Stream Name | Ecoregion [a] | County | NCMIN Tier [b] | Route | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [c] | AADT [d] | River Basin | Stream Classification [e] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Between-Site Comparison** | | | | | | | | | | | | | | |
| NA[h] | Cataloochee Creek | BR | Haywood | SRT | SR 1395 (FS Rd 284) | National Park Road (Old NC 284) | R | UNK | UNK | French Broad | C; Tr; ORW | 49.1 | UNK | O |
| 100145[g] | Dillingham Creek | BR | Buncombe | SRT | SR 2173 | Dillingham Rd | R | Mi-C | 1,800 | French Broad | WS-II; Tr, HQW | 24.6 | 0.12 | C |
| 100250[g] | Flat Creek | BR | Buncombe | SRT | SR 1742 | Lower Flat Creek Rd | R | Mi-C | 400 | French Broad | C | 24.6 | 0.02 | B |
| 100494[g] | Swannanoa River | BR | Buncombe | SWT | I-40 | I-40 | U | PA-I | 25,500 | French Broad | C | 4.2 | 1.30 | C |
| 100734[g] | Big Ivy Creek | BR | Buncombe | SRT | SR 2207 | Stockton Rd | R | Ma-C | 1,500 | French Broad | WS-II; HQW | 60.6 | 0.09 | C |
| 130007 | Yadkin River | BR | Caldwell | RT | NC 268 | NC 268 | R | Ma-C | 3,500 | Yadkin | C; Tr | 28.6 | 0.07 | B |
| 310005[g] | Mountain Creek | P | Durham | SRT | SR 1616 | Bahama Rd | R | Mi-C | 2,800 | Neuse | WS-II;HQW;NSW;CA | 7.2 | 0.13 | B |
| 310064[g] | Little River | P | Durham | SRT | SR 1461 | Johnson Mill Rd | R | L | 500 | Neuse | WS-II;HQW;NSW;CA | 78.2 | 0.12 | C |
| 440008[g] | Boylston Creek | BR | Henderson | SRT | SR 1314 | Ladson Rd | R | L | 1,400 | French Broad | WS-IV | 15.4 | 0.09 | B |
| 590296[g] | Mallard Creek | P | Mecklenburg | SWT | I-85 | I-85 | U | PA-I | 112,000 | Yadkin | C | 19.6 | 0.79 | C |
| 910124[g] | Perry Creek | P | Wake | SRT | SR 2006 | Perry Creek Rd | U | L | 13,000 | Neuse | C;NSW | 11.2 | 0.17 | C |
| 910255[g] | Swift Creek | P | Wake | SRT | SR 1006 | Old Stage Rd | U | Mi-A | 11,500 | Neuse | WS-III; NSW | 1.7 | 0.04 | C |

### Table 3.4-7: Biosurvey Monitoring Sites and Characteristics (Continued)

| Bridge Number | Stream Name | Ecoregion [a] | County | NCMIN Tier [b] | Route | Road Name | Rural (R) vs. Urban (U) | Roadway Functional Class [c] | AADT [d] | River Basin | Stream Classification [e] | Stream Drainage Area (sq mi) | Bridge Deck Surface Area (acre) | Wearing Surface Type [f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Between-Time Comparison** | | | | | | | | | | | | | | |
| 040338 | Roaring Fork Creek | BR | Ashe | SRT | SR 1320 | Roaring Fork Rd | R | L | 780 | French Broad | C; Tr | 5.0 | 0.06 | C |
| 130003 | Lost Cove Creek | BR | Caldwell | RT | NC 90 | Edgemont Rd | R | L | 140 | Catawba | C; Tr; ORW | 8.0 | 0.04 | C |
| 850037 | Mitchell River | BR | Surry | SRT | SR 1330 | Haystack Rd or River Rd | R | L | 300 | Yadkin | C; Tr; ORW | 11.8 | 0.02 | B |

**Notes:** UNK - Unknown

[a] BR – Blue Ridge; P – Piedmont

[b] RT – Regional Tier; SRT – Subregional Tier; SWT – Statewide Tier; NA – Not applicable

[c] PA – Principal arterial; A – Arterial; Ma – Major; Mi – Minor; C – Collector; L – Local.

[d] AADT – Average annual daily traffic volume; vpd – vehicles per day; see section 3.5.

[e] NCDENR Stream Classification: B – Primary Recreation, Fresh Water; C – Aquatic Life, Secondary Recreation, Fresh Water; CA – Critical Area; HQW – High Quality Water; NSW – Nutrient Sensitive Water; ORW – Outstanding Resource Water; SW – Swamp Water; TR – Trout Water; WS-II – Water Supply II, Underdeveloped; WS-IV – Water Supply IV, Highly Developed; + - Subject to the Outstanding Resource Waters rule. Data from NCDENR (2007).

[f] B – Bituminous; C – Concrete; O – Other

[g] Site was also monitored for water quality chemistry discussed in section 3.2.1 and for streambed sediment chemistry discussed in section 3.3.1.

[h] Reference Site: The bridge over Cataloochee Creek is located in the Great Smoky Mountain National Park and is owned by the National Park Service. This site has been monitored in the past by DWQ and has repeatedly been distinguished for its Excellent Bioclass Ratings, which indicates high quality water because of the abundance and quality of stream habitat identified at this site. For this reason, this site was selected as a Monitoring Reference Site. Streambed sediment sampling was also conducted here, which occurred at this site upstream and downstream of the bridge and is discussed in section 3.2.1.

### 3.4.2.3 Data Collection Methods and Techniques

Data collection methods and techniques were performed using *Standard Operating Procedures for Sampling of Benthic Macroinvertebrates* (NCDENR, 2006). For benthos sample collection the Standard Qualitative Method or Qual 5 Methods were used. An overview of these methods is provided below.

#### Benthic Sampling Standard Qualitative Method

The standard qualitative method data collection techniques consists of two kick net samples (kicks), three sweep-net samples (sweeps), one leaf-pack sample, two fine-mesh rock and/or log wash samples, one sand sample, and visual searches. Visual searches are performed to collect or observe organisms within the sampling area that were not already collected using the other four techniques. The benthic invertebrates are separated from the rest of the sample in the field ("*picked*") using forceps and white plastic trays, and preserved in glass vials containing 95% ethanol (NDENR, 2006, p. 5).

Since organisms cannot always be identified at the species level, a simpler approach is used by taking counts of the various stream organisms, which often include identification at higher levels (genus, family, etc.). Each different organism type in these situations is called a *taxon* (plural *taxa*). Thus *taxa richness* is a count of the number of different types of organisms (NDENR 2006).

Organisms were picked for taxonomic identification roughly in proportion to their abundance, but it was not necessary to collect all individual organisms. If a group of organisms were reliably identified as a single taxon in the field (an example would be *Isonychia*), then no more than 10 individuals were collected. Some organisms were not picked, even when found in the samples, either because abundance is difficult to quantify or because they are most often found on the water surface or on the banks and are not truly benthic (NDENR, 2006, p. 5).

#### Benthic Sampling Qual 5 Method

The Qual 5 method is an abbreviation of the standard qualitative method, primarily used in smaller streams. Five samples are collected using this method: one kick, one sweep, one leaf-pack, one fine mesh sample and "visuals". The sites sampled using the Qual 5 Method were Perry Creek, Swift Creek, Yadkin River, Lost Cove Creek, Mitchell River, and Roaring Fork River.

Figure 3.4-5 illustrates a few of the benthic sampling techniques conducted at each site. A summary of the various data collection techniques is provided in table 3.4-8.

**Figure 3.4-5: Benthic sampling techniques: sweep net (left) and kick net (right).**

### Table 3.4-8: Summary of Standard Qualitative and Qual 5 Collection Methods for Benthic Sampling

| Sampling Technique | Technique Description | Habitat Description for Sampling |
|---|---|---|
| **Kick Net**:<br>*Double layer of flexible nylon door or window screening (course mesh) held in place between two halves of a wooden pole using wood screws* | • Net is positioned upright on the stream bed, while the area upstream is physically disrupted using feet and/or hands<br>• Debris and organisms in kick net are then washed through a sieve bucket (0.6 mm opening) and larger leaves and debris are removed | • Substrates of streams in riffle areas with each sample location differing in current speed<br>• In very small streams or in sandy areas lacking riffles, kicks are taken from root masses, snags, or bank areas |
| **Sweep Net**:<br>*Long-handled triangular sweep net (course mesh)* | • Collection of samples by physically disrupting an area and then vigorously sweeping through the disturbed areas | • Bank areas and macrophyte beds<br>• Low current environments<br>• Gavel riffle areas (optional) |
| **Fine Mesh Sampler:**<br>*Fine nitex mesh (300 microns) placed between 4-inch PVC pipe fittings screwed together* | • Cylinder fits inside an slightly larger cylinder and often used to sieve material from rock or log washes to collect smaller invertebrates | • Rocks or logs in stream habitats<br>• Growths of periphyton, *Podostemum*, or moss |
| **Sand Sample:**<br>*Fine-mesh bag (300 microns) nitex netting; Used in conjunction with Fine Mesh Sampler* | • Collection of samples using dredge type technique along sand substrate to extract distinct fauna<br>• Requires a large bag that's held open near the substrate with one foot holding the bag on the sand. Sand is vigorously disturbed by the collector's hand or other foot | • Sandy substrates located in areas with the stream current |
| **Leaf-Pack Sample:**<br>*Sieve bucket with a U.S. Standard No. 30 sieve (0.600 mm ) openings* | • Collection of leaf-packs (decayed leaves), sticks and small logs that are washed into a sieve bucket and then discarded | • Rocks or snags in fast current areas |
| **Visual Search** | • 10 minutes of visual inspection which may involve lifting rocks or bark to observe the habitats beneath them, however does not require sample collection | • Tops, sides and crevices of rocks and logs in riffles and pools (large rocks and logs preferred)<br>• Under loose bark of logs<br>• Stream bottom |

**Source: (NCDENR, 2006)**

## Summary of Methods for Habitat Assessments

Habitat assessments are an important part of the field procedures for benthic sample collections. A habitat assessment is an instream survey that is performed to determine the extent of suitable habitat in the vicinity of a bridge crossing that can potentially affect the existence and/or abundance of benthic macroinvertebrates. The survey is performed by wading through 100–200 meters in either direction of the bridge and documenting observations that determine the availability and suitability of a habitat. The NCDENR Habitat Assessment Form was used, which provide definitions of various conditions to determine the associated score and reduce subjectivity of visual interpretations (NCDENR, 2006, pp. 33-42).

DWQ methodology as implemented in the NCDENR Habitat Assessment Form for evaluating instream aquatic habitat focuses on eight key components that affect the availability and suitability of a habitat. The components are rated individually and the summation of the scores ranges from 0 (lowest quality habitat) to 100 (highest quality habitat). The eight components (with their relative weight in parentheses) of the overall habitat score are:

- Channel modification (5)
- Instream habitat types (20)
- Bottom substrate (15)
- Pool variety (10)
- Riffle habitat (16)
- Bank stability and vegetation (14)
- Light penetration (10)
- Riparian vegetative zone width (10)

Select physical and chemical parameters were also measured in each stream, upstream and downstream of each bridge as part of the habitat assessment. These parameters include temperature, DO, conductivity, pH, stream width, and mean stream depth. Each site is also assessed for physical characterization such as land use, channel size and flow conditions, and turbidity.

## Summary of Methods for Determining Bioclassifications

The ultimate result of a standard qualitative benthos sample is the bioclassification, or bioclass rating (5=Excellent, 4=Good, 3=Good/Fair, 2=Fair, 1=Poor). The bioclass rating is used to evaluate the overall condition of benthic invertebrate populations and determined by the average of two metrics that provide a quantitative measure of the degree of pollutant-tolerant and/or pollutant-sensitive benthic species in a stream reach. These two metrics include the Ephemeroptera, Plecoptera, and Trichoptera metric value (EPT S) and the NC biotic index (NCBI). The metric values are converted to a scale of 1-5, then the average of the two is rounded to determine the final bioclassification. Correction factors and other criteria that affect the final bioclassification are discussed in greater detail in the SOP Manual (NCDENR, 2006, pp. 11-15).

EPT S is a surrogate for the total taxa richness at a site, and represents the taxa richness for pollution-sensitive aquatic insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). A high EPT value is indicative of a stream with higher water quality, while a low value is reflective of a stream where taxa richness has been compromised by physical and chemical stressors. Correction factors are sometimes required based on stream size, season, etc. before final bioclass ratings are determined so that scores are comparative statewide (NCDENR, 2006, pp. 11-12).

An alternative metric is the NCBI Metric Value, which represents an independent method of determining bioclassification to support water quality assessments. The NCBI metric was developed because EPT metrics must often be adjusted to account for collection method, stream size, seasonal changes and/or ecoregion, so an alternative measure of biological health was desirable (NCDENR, 2006, pp. 12-13). The common taxa, covering a large number of species and includes invertebrates from the orders Mollusca, Annelida, Arthropoda, and Insecta are assigned a tolerance value on a 1-10 scale. The NCBI is then computed as an abundance-weighted average tolerance value for the entire population of invertebrates. A higher NCBI indicates larger proportions of pollution-tolerant taxa, indicative of contaminant stresses.

Both the EPT S and NCBI values are then converted to scores on a 1-5 scale based on NCDENR guidelines, which were used to assign a bioclassification for the receiving stream (NDENR, 2006, pp. 5-6). The total taxa richness (Total S) was also determined, but was not scored or used to establish a bioclassification for the lotic system.

#### 3.4.2.4 Biosurvey Monitoring Results and Discussion

A summary of the biosurvey results from the between-site comparison study locations is provided in table 3.4-9. The table summarizes the bioclass rating, habitat scores, total taxa richness (Total S), EPT taxa richness (EPT S), NC Biotic Index (NCBI) determined upstream and downstream from each bridge site.

A summary of the biosurvey results from the between-time comparison study sites is provided in table 3.4-10. The table summarizes the bioclass rating, habitat scores, total taxa richness (Total S), EPT taxa richness (EPT S), NC Biotic Index (NCBI) determined downstream from each bridge site. The previous bioclass ratings are noted.

Discussion of the biosurvey results presented in this section is provided in section 4.5.2.

**Table 3.4-9: Biosurvey Results for Between-Site Comparison Study**

| Site Description | | 2009 BSP Biosurvey Results [a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stream Name | Bridge # | Bioclass Rating[c] | Habitat Evaluation | | Total S Metric Value | | EPT S Metric Value [Score] | | NCBI Metric Value [Score] | |
| | | (US/DS) | US | DS | US | DS | US | DS | US | DS |
| Dillingham Creek [b] | 100145 | Good | 75 | 69 | 72 | 81 | 38 [4.0] | 37 [4.0] | 4.1 [4.0] | 4.3 [4.0] |
| Swannanoa River | 100494 | Fair | 73 | 69 | 29 | 26 | 11 [1.6] | 9 [1.4] | 5.2 [3.0] | 6.1 [2.0] |
| Boylston Creek [b] | 440008 | Good-Fair | 70 | 64 | 52 | 71 | 22 [3.0] | 22 [3.0] | 6.3 [2.0] | 6.5 [2.0] |
| Flat Creek | 100250 | Fair | 77 | 77 | 63 | 82 | 20 [2.4] | 25 [3.0] | 6.2 [2.0] | 6.5 [2.0] |
| Big Ivy Creek | 100734 | Good | 83 | 75 | 64 | 75 | 34 [4.0] | 35 [4.0] | 4.8 [4.0] | 4.8 [4.0] |
| Mallard Creek | 590296 | Fair | 42 | 60 | 36 | 37 | 6 [1.4] | 5 [1.0] | 6.8 [2.0] | 6.8 [2.0] |
| Mountain Creek | 310005 | Good-Fair | 74 | 75 | 76 | 74 | 24 [3.6] | 23 [3.4] | 5.8 [3.4] | 5.9 [3.0] |
| Little River [b] | 310064 | Good | 83 | 83 | 91 | 79 | 30 [4.4] | 26 [4.0] | 5.5 [4.0] | 5.5 [4.0] |
| Perry Creek | 910124 | Poor | 45 | 48 | 38 | 34 | 5 [1.4] | 6 [1.4] | 7.5 [1.4] | 7.8 [1.0] |
| UT to Swift Creek | 910255 | Poor | 56 | 47 | 26 | 20 | 4 [1.0] | 2 [1.0] | 7.4 [2.0] | 7.6 [1.0] |
| Cataloochee Creek [b] | NA | Excellent | 89 | 89 | 86 | 90 | 44 [5.0] | 51 [5.0] | 3.0 [5.0] | 3.1 [5.0] |
| Yadkin River [b] | 130007 | Good-Fair | NA | 91 | 49 | 37 | 24 [3.0] | 21 [2.4] | 5.5 [3.0] | 5.3 [3.0] |

**Notes:**

[a] Results are reflective of the 2009 biosurveys conducted for the BSP. The Yadkin River biosurvey study was conducted in October 2009. The BSP biosurvey studies for all other sites were conducted between April and May 2009. US – Upstream; DS – Downstream; NA – Not Applicable. Values reported have been corrected for seasonal factors.

[b] Historically or previously monitored biosurvey site. For all four sites, there was no change in Bioclass Rating between the 2009 evaluation and the prior historical evaluation.

[c] A single value indicates that equal ratings were determined for the upstream (US) and downstream (DS) locations.

**Table 3.4-10: Biosurvey Results for the Between-Time Comparison Study**

| Site Description | | October 2009 BSP Biosurvey Results | | | | |
|---|---|---|---|---|---|---|
| **Stream Name** | **Bridge #** | **Bioclass Rating** | **Habitat Score** | **Total S Metric Value** | **EPT S Metric Value [Score]** | **NCBI Metric Value [Score]** |
| Roaring Fork Creek [a] | 040338 | Good | 83<br>83 | 44 | 28 [3.6]<br>28 [3.6] | 3.3 [5.0]<br>3.3 [5.0] |
| Mitchell River [b] | 850037 | Good-Fair | 92 | 55 | 23 [3.0]<br>23 [3.0] | 4.3 [4.0]<br>4.3 [4.0] |
| Lost Cove Creek [c] | 130003 | Good | 93 | 57 | 31 [4.0]<br>31 [4.0] | 3.6 [5.0]<br>3.6 [5.0] |

**Notes:**

[a] The last biosurvey conducted in 2008 at Roaring Fork Creek resulted in a Bioclass Rating of 'Good'. A comparison of the 2008 and 2009 downstream bioclass ratings reflected no change.

[b] The last biosurvey conducted in 2007 at Mitchell River resulted in a Bioclass Rating of 'Good'. DWQ ratings are based on 10-sample EPT abundance criteria. Use of a Qual 5 sample instead likely lowered EPT abundance, and consequently underpredicts Bioclass Rating. A comparison of the 2007 and 2009 downstream bioclass ratings does not reflect a material change in water quality.

[c] The previous biosurvey conducted in 2007 at Lost Cove Creek resulted in a Bioclass Rating of 'Good'. A comparison of the 2007 and 2009 downstream bioclass ratings reflected no change.

## 3.5 Traffic Surveys

The primary objective of the traffic survey study was to obtain up-to-date traffic volumes for the 15 sites that were studied in Section 3.2 for the chemical impacts of bridge deck runoff on the receiving streams. Traffic volumes are a useful parameter in analyzing the sources of chemical contaminants. Indeed, previous studies on highways have indicated high traffic routes have greater incidence of pollutants in runoff than low traffic routes (FHWA, 1990; Kayhanian et al., 2003; Van Hassel et al., 1980). This study attempts to test these relationships for bridge deck runoff.

Traffic data in the NCDOT Bridge Management Unit (BMU) database dated back to 2002. Since traffic data was to be used for statistical purposes, a field survey of current traffic volumes performed at each bridge site was initiated. Monitoring site maps are provided in appendix 3-B. The traffic survey study was conducted from May 2009 through March 2010 by the NCDOT Traffic Survey Group (TSG). Traffic surveys were generally conducted on a quarterly basis to capture seasonal differences in traffic patterns; however, due to site-specific constraints, this schedule was not met at all of the sites.

### 3.5.1 Survey Instrumentation, Methods, and Techniques

The TSG collects traffic data using Federal Highway Administration (FHWA) standards (FHWA, 2001). In order to collect traffic volume data for the BSP, each bridge site was equipped with portable (short-term), automated traffic counting devices using one of two data collection methods: radar devices or pneumatic road tubes.

Pneumatic road tube counts were collected using the Peek ADR-1000 counter/classifier. The ADR-1000 counter/classifiers were tested in the TSG shop facility using an ATSI ATRT-1700 Automated Traffic Recorder Tester before every deployment in the field. Additionally, TSG technicians field-verified the accuracy of the counters by comparing traffic volumes reported by the counters with manual counts by field personnel.

Radar counts were collected using the Wavetronix SmartSensor HD 125. These devices are serviced, calibrated, and bench tested by the vendor, and calibrated on-site at the time of installation. Manual validation counts are conducted at radar sites following installation and prior to removal for comparison to the radar device counts for quality assurance.

The type of equipment used at a particular site was governed by TSG safety policy. As part of the policy, pneumatic road tubes and other sensors are not installed in mainline travel lanes of an interstate or within work zones. For interstate and work zone sites, the portable radar devices were used and anchored to posts along the shoulders of the roadway. All other sites were equipped with pneumatic road tubes, temporarily adhered to the surface of the pavement. Figure 3.5-1 shows photographs of the two types of devices installed at each site.

**Figure 3.5-1: Traffic survey devices. Pneumatic road tubes installed on NC 411 near Bridge No. 810014 over Black River (left photo) and radar device installed on shoulder of I-540 near Bridge No. 911102 over Mango Creek (right photo).**

Traffic volumes at each site were collected on a continuous basis in hourly increments over a survey period, which spanned seven days. Most sites received four quarterly surveys, occurring approximately three months apart. Traffic volumes were recorded using one of three data collection techniques: volume by lane, volume by vehicle class, or total volume only, with volume by vehicle class being the preferred method when resources allowed. The FHWA *13-Category Classification System* (FHWA, 2001), presented as appendix 3-P, was used to identify vehicle classes at sites where volume by class was collected. The Peek ADR-1000 Type F default algorithm was used to convert axle-sensor information into vehicle counts by class. Table 3.5-1 summarizes the instrumentation and corresponding data collection method and technique associated with each site.

### 3.5.2 Results

The traffic volume data was used to calculate the Annual Average Daily Traffic volume (AADT) for each site as summarized in table 3.5-2. AADT describes the number of vehicles that traverse a road at a specific point on the road system, and is considered to be a traffic volume statistic of primary interest according to the FHWA standards (FHWA, 2001).

## Table 3.5-1: Traffic Survey Data Collection Methods and Techniques

| Site ID Information | | | | Portable Instrumentation Method | 7-Day Hourly Data Collection Technique [a] |
|---|---|---|---|---|---|
| Traffic Station ID | Bridge Number | Primary and/or Secondary Road Name(s) | Stream Name | | |
| 01 | 310064 | Johnson Mill Rd (SR 1461) | Little River | Pneumatic Tubes | Volume by Class |
| 02 | 910255 | Old Stage Rd (SR 1006) | Swift Creek | Pneumatic Tubes | Total Volume |
| 03 | 910273 | Old Stage Rd (SR 1006) | Middle Creek | Pneumatic Tubes | Total Volume |
| 04 | 640132 | US 74 | Smith Creek | Pneumatic Tubes | Volume by Lane |
| 05 | 090061 | NC 133 | Town Creek | Pneumatic Tubes | Total Volume |
| 06 | 810014 | NC 411 (Hitching Post Rd) | Black River | Pneumatic Tubes | Volume by Class |
| 07 | 100145 | Dillingham Rd (SR 2173) | Dillingham Creek | Pneumatic Tubes | Volume by Class |
| 08 | 100250 | Lower Flat Creek Rd (SR 1742) | Flat Creek | Pneumatic Tubes | Volume by Class |
| 09 | 100494 | I-40 | Swannanoa River | Radar | Volume by Lane |
| 10 | 440008 | Ladson Rd (SR 1314) | Boylston Creek | Pneumatic Tubes | Volume by Class |
| 11 | 100734 | Stockton Rd (SR 2207) | Big Ivy Creek | Pneumatic Tubes | Volume by Class |
| 12 | 310005 | Bahama Rd (SR 1616) | Mountain Creek | Pneumatic Tubes | Volume by Class |
| 13 | 910124 | Perry Creek Rd (SR 2006) | Perry Creek | Radar | Total Volume |
| 14 | 911102 | I-540 | Mango Creek | Radar | Volume by Lane |
| 15 | 590296 | I-85 | Mallard Creek | Radar | Volume by Lane |

**Notes:**

[a] Volume by Lane and Volume by Type (Class) breakdowns for the relative sites are summarized in appendix 3-Q. Annual average daily traffic volumes per site are in table 3.5-2.

Table 3.5-2: AADT Summary

| Traffic Station ID | Bridge Number | Stream Name | AADT [a] |
|---|---|---|---|
| 01 | 310064 | Little River | 500 |
| 02 | 910255 | Swift Creek | 11,500 |
| 03 | 910273 | Middle Creek | 5,000 |
| 04 | 640132 | Smith Creek | 26,000 |
| 05 | 090061 | Town Creek | 5,600 |
| 06 | 810014 | Black River | 750 |
| 07 | 100145 | Dillingham Creek | 1,800 |
| 08 | 100250 | Flat Creek | 400 |
| 09 | 100494 | Swannanoa River | 25,500 |
| 10 | 440008 | Boylston Creek | 1,400 |
| 11 | 100734 | Big Ivy Creek | 1,500 |
| 12 | 310005 | Mountain Creek | 2,800 |
| 13 | 910124 | Perry Creek | 13,000 |
| 14 | 911102 | Mango Creek | 34,000 |
| 15 | 590296 | Mallard Creek | 112,000 |

**Notes:**

[a] AADTs were rounded per the AASHTO guidelines on rounding (AASHTO, 2009).

At all sites, the available quarterly traffic volumes were averaged over the seven-day survey period to yield quarterly Average Daily Traffic (ADT) volumes. Although the three data collection techniques previously described were used to collect traffic volume data, only total volumes were used to calculate ADT. The quarterly ADT volumes and the average of all quarterly ADT volumes for each site are summarized in table 3.5-3. Traffic data summaries, including quarterly traffic volumes and breakdowns of each count sorted by travel lane and/or class, are summarized in appendix 3-Q.

The AADTs presented in table 3.5-2 were derived using two methods. The first method was used for sites at which all four quarterly ADTs were obtained. For these sites, the average of the quarterly ADTs were considered to be the AADT. The second method was used for sites at which all four quarterly counts were unavailable. For these sites, the quarterly ADTs were converted to AADT according the following formula (FHWA, 2001):

$$AADT_{hi} = VOL_{hi} M_h D_h A_i G_h \qquad \textbf{(3.4-1)}$$

where

$AADT_{hi}$ = the annual average daily traffic at location *i* of factor group *h*

$VOl_{hi}$ = the 24-hour axle volume at location *i* of factor group *h*

$M_h$ = the applicable seasonal (monthly) factor for factor group *h*

$D_h$ = the applicable day-of-week factor for factor group *h*

$A_i$ = the applicable axle-correction factor for location *i*

$G_h$ = the applicable growth factor for factor group *h*

Equation 3.4-1 was modified to account for the study's specific characteristics. Since the quarterly counts were taken over seven consecutive days, the $VOL_{hi}$ term was substituted with the quarterly ADT and the day-of-week factor $D_h$ was removed. Additionally, since the quarterly counts were current and the AADT was estimated for the present time, the growth factor $G_h$ was not needed. The TSG provided the applicable monthly factors $M_h$ and axle-correction factors $A_i$ generated from continuous volume monitoring stations located across the state based on the automatic traffic recorder (ATR) group associated with those stations. Stations are grouped based on similar seasonal patterns to provide a basis for generalized application of the factors at short-term count locations. The AADT calculations for sites at which all four quarterly counts were unavailable are summarized in table 3.5-4.

Overall, quarterly counts at all 15 sites indicate consistent traffic volumes over the monitoring period. It is important to note that quarterly traffic volumes may have been influenced by nearby construction detours, school traffic, or seasonal traffic patterns. For example, only two traffic counts were performed for the bridge over Flat Creek because this bridge was constructed in 2008–2009 and not opened to traffic until August 2009. The first traffic count was performed in October 2009, and traffic volumes recorded may not accurately reflect future traffic volume expected on this bridge. Also, this site had a fresh asphalt surface overlay and other construction operations in late summer 2009. Therefore, the pollutant profiles from the bridge deck runoff water quality samples may be impacted by concurrent construction activities, and may not necessarily be related to traffic volume. Known activities of this nature that may impact traffic volumes are noted in table 3.5-3.

## Table 3.5-3: Traffic Survey Results

| Site ID Information | | | Quarterly Report ADT[a] Volumes | | | | | | | | Average of Quarterly ADTs (vpd) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Traffic Station ID | Bridge Number | Stream Name | Q1 Apr–Jun 2009 | Q1 ADT (vpd) | Q2 Jul–Sep 2009 | Q2 ADT (vpd) | Q3 Oct–Dec 2009 | Q3 ADT (vpd) | Q4 Jan–Mar 2010 | Q4 ADT (vpd) | |
| 01 | 310064 | Little River | June 2-8 | 575 | Aug. 4-10 | 451 | Nov. 11-17 | 492 | Jan. 21-27 | 485 | 501 |
| 02 | 910255 | Swift Creek | June 1-7 | 11,713 | Aug. 4-10 | 11,566 | Nov. 4-10 | 11,303 | Jan. 20-26 | 10,729 | 11,328 |
| 03 | 910273 | Middle Creek | NA | NA | Sept. 23-29 | 5,199 | Nov. 4-10 | 5,190 | Jan. 20-26 | 4,806 | 5,065 |
| 04 | 640132 | Smith Creek | NA | NA | Aug. 4-10 | 26,502 | Nov. 4-10 | 27,083 | Jan. 21-27 | 25,984 | 26,523 |
| 05 | 090061 | Town Creek | NA | NA | Sept. 22-28 | 6,023 | Nov. 4-10 | 5,718 | Jan. 20-26 | 5,423 | 5,721 |
| 06 | 810014 | Black River | June 1-7 | 1,418 | Aug. 4-10 | 566 | Nov. 4-10 | 586 | Jan. 20-26 | 497 | 767 |
| 07 | 100145 | Dillingham Creek | June 2-8 | 1,863 | Aug. 4-10 | 1,879 | Oct. 23-29 | 1,796 | Mar. 12-18 | 1,596 | 1,784 |
| 08[b] | 100250 | Flat Creek | NA | NA | NA | NA | Oct. 24-30 | 398 | Feb. 23-Mar. 1 | 393 | 396 |
| 09 | 100494 | Swannanoa River | NA | NA | Aug. 4-10 | 27,574 | Dec. 1-7 | 23,359 | Feb. 18-24 | 28,180 | 26,371 |
| 10 | 440008 | Boylston Creek | June 2-8 | 1,668 | Aug. 4-10 | 1,333 | Oct. 23-29 | 1,321 | Feb. 19-25 | 1,327 | 1,412 |
| 11 | 100734 | Big Ivy Creek | June 2-8 | 1,527 | Aug. 4-10 | 1,492 | Oct. 23-29 | 1,493 | Feb. 23-Mar. 1 | 1,326 | 1,460 |
| 12 | 310005 | Mountain Creek | June 2-8 | 3,105 | Aug. 4-10 | 2,640 | Nov. 10-16 | 2,758 | Jan. 21-27 | 2,645 | 2,787 |
| 13[c] | 910124 | Perry Creek | June 5-11 | 12,912 | Aug. 4-10 | 11,760 | Oct. 2-8 | 13,487 | Mar. 19-25 | 14,606 | 13,191 |
| 14 | 911102 | Mango Creek | NA | NA | Sept. 17-23 | 34,320 | Dec. 9-15 | 35,071 | Jan. 21-27 | 32,378 | 33,923 |
| 15 | 590296 | Mallard Creek | NA | NA | Sept. 21-28 | 117,100 | Oct. 27-Nov. 2 | 117,580 | Feb. 9-15 | 114,549 | 116,410 |

**Notes:**

[a] Average Daily Traffic (ADT) volumes for each Quarter were averaged over a 7-day period.

[b] The construction of the bridge over Flat Creek was completed in August 2009. Traffic Surveys were delayed due to construction activity. This site received a fresh asphalt overlay in the summer months.

[c] The bridge over Perry Creek was along a route with construction activity and ADT volumes may have been impacted.

## Table 3.5-4: AADT Calculations for Sites with Less than Four Quarterly Measurements

| Traffic Station ID | ATR Group [a] | Q2 Jul–Sep 2009 | | | | Q3 Oct–Dec 2009 | | | | Q4 Jan–Mar 2010 | | | | Average of Quarterly AADTs (vpd) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ADT (vpd) | Seasonal Factor, $M_h$ | Axle Factor. $A_i$ | AADT (vpd) | ADT (vpd) | Seasonal Factor, $M_h$ | Axle Factor. $A_i$ | AADT (vpd) | ADT (vpd) | Seasonal Factor, $M_h$ | Axle Factor. $A_i$ | AADT (vpd) | |
| 03 | 1 | 5,199 | 0.95 | 0.99 | 4,890 | 5,190 | 0.98 | 0.99 | 5,035 | 4,806 | 1.09 | 0.99 | 5,186 | 5,037 |
| 04 | 1 | 26,502 | 0.93 | 0.98 | 24,154 | 27,083 | 0.98 | 0.98 | 26,011 | 25,984 | 1.09 | 0.98 | 27,756 | 25,974 |
| 05 | 1 | 6,023 | 0.95 | 0.98 | 5,607 | 5,718 | 0.98 | 0.98 | 5,492 | 5,423 | 1.09 | 0.98 | 5,793 | 5,631 |
| 08 [b] | 1 | NA | NA | NA | NA | 398 | 0.94 | NA | 374 | 393 | 1.03 | NA | 405 | 389 |
| 09 | 11 | 27,574 | 0.91 | 1.00 | 25,092 | 23,359 | 1.01 | 1.00 | 23,593 | 28,180 | 0.97 | 1.00 | 27,335 | 25,340 |
| 14 | 11 | 34,320 | 0.97 | 1.00 | 33,290 | 35,071 | 1.01 | 1.00 | 35,422 | 32,378 | 1.03 | 1.00 | 33,349 | 34,020 |
| 15 | 11 | 117,100 | 0.97 | 1.00 | 113,587 | 117,580 | 0.95 | 1.00 | 111,701 | 114,549 | 0.97 | 1.00 | 111,113 | 112,134 |

**Notes:**

[a] According to information received from NCDOT TSG staff, ATR Group 1, a non-interstate ATR group, is the most dominant group in the state. It is mostly rural in nature and is predominantly used for count locations on non-urban primary routes and all rural and most urban secondary roads. ATR Group 11, an interstate ATR group, applies to urban interstate and some rural locations strongly influenced by nearby large urban areas.

[b] Since classification counts were collected at Station 08, the Axle Factor was omitted.

# 4.0 Effect of Stormwater Runoff from Bridges

Session Law 2008-107 requires that the BSP investigate effective and implementable stormwater treatment options for bridge deck runoff in North Carolina (NCGA, 2008, Section 25.18.(c)). To implement SCMs to address water quality concerns, the relative impact of bridge deck runoff on receiving streams must be understood. Therefore, prior to developing a statewide SCM selection plan and cost estimate, it was first necessary to evaluate the effect of stormwater runoff from North Carolina bridges to the receiving streams.

As discussed in section 3 of this report, several monitoring regimes were implemented in the course of the BSP. The results of each monitoring program provide some insight into the relationship between bridge deck runoff and the health of receiving streams. Although there is significant knowledge and understanding within select branches of environmental assessment protocols (such as water chemistry, toxicology, biological assessments, etc.), uncertainty in the precision of results and their application to conclusively address environmental concerns exists within each branch (IM-NAS, 2009). For example, a whole effluent toxicity (WET) test performed in a laboratory may indicate the potential for toxicity of an effluent. However, the test does not precisely measure the interaction of other conditions in the stream which may contribute to or mitigate toxicity; it also does not measure the effect of these conditions on the actual animal population found at the location being studied. Therefore, the indication of toxicity exists, but the precise effect is uncertain.

Because no single environmental assessment can conclusively prove receiving stream impact, observations from the various monitoring regimes are considered as one body of evidence. This approach, referred to as the *weight-of-evidence* (WOE) approach, uses best professional judgment to determine if the collective results from multiple environmental monitoring regimes support or do not support a conclusion of effect. The WOE approach was used to evaluate the results of the BSP monitoring program to determine if, and under what conditions, bridge deck runoff may affect receiving stream quality.

## 4.1 The Weight-of-Evidence Concept

The concept of WOE in scientific study is a commonly used, but poorly defined, term drawing on the principles used to develop risk management decision processes. Results of environmental studies are understood to have uncertainty and variability due to the interacting effects of the species studied, numerous sources of pollutants within the environment, and individualized responses within a population to pollutants (IM-NAS, 2009; Burton and Pitt, 2002). The results of individual studies can provide insight to site-specific conditions that existed only at the time of the study, but may be limited in their application to long-term decision making for that site or others because of the limited temporal and spatial distribution evaluated. Additionally, site-specific results of a particular monitoring regime may indicate a “false-positive” impact from a source due to ambient instream conditions not associated with the source, and additional monitoring regimes can provide clarification. By using the WOE approach and multiple monitoring regimes or lines of evidence, reasonably defensible conclusions can be made regarding the effect of bridge deck runoff by assessing the cumulative results of the various studies. Such conclusions can then be used to develop a program to address bridge deck runoff to the maximum extent practicable.

Weight-of-evidence decisions are based upon the lines of evidence used and the standards of evidence applied (IM-NAS, 2009). The BSP study used multiple lines of evidence, namely, the chemical and physical analyses and biological assessments described in section 3 and discussed in this section. The standard of evidence concept relates to such issues as the consistency, strength, specificity, response of the association, and the plausibility shown by study data. The spatial distribution and repetition of analyses performed in the BSP research strengthens the standard of evidence. Therefore, the concurrence of elevated concentrations or indicated biological effect shown by the results of the different monitoring regimes performed increases the likelihood that the condition studied does impact the receiving stream quality. As stated by Burton and Pitt, "[a] multi-component assessment enables a more complete evaluation of causative factors and potential mitigation approaches" (2002).

### 4.1.1 Historical Use of WOE to Determine Environmental Impact

Although the BSP was not performed in response to environmental regulations, the monitoring regimes and the WOE approach adopted for the BSP from Dupuis (2002) are also used by USEPA and NCDENR to assess water quality and impaired waters (USEPA, 1998, 2000; NCDENR, 2003, 2007a, 2007b). Indeed, NCDENR considers the WOE approach, also known as strength of evidence, to "involv(e) a logical evaluation of multiple lines (types) of evidence to assess what information supports or does not support the likelihood that each candidate stressor is actually a contributor to impairment" (NCDENR, 2003).

Given the uncertainty and variation of each type of analysis, the use of multiple monitoring regimes (or lines of evidence) provides an integrated approach to assessing impacts based on biological, toxicological, and chemical-specific data, similar to the approach USEPA uses when implementing water quality standards (USEPA, 1996). A summary of the different lines of evidence used by USEPA and NCDENR and what they indicate about the water quality of the receiving stream is provided below.

**Biological Assessments (Biosurveys)**

- Macroinvertebrate monitoring is a reliable indicator of direct impacts to a receiving stream because the populations observed typically are immobile, are sensitive to small changes in their habitat, and respond to a wide range of potential pollutant mixtures (NCDENR, 2007a).
- Having short life cycles, macroinvertebrates are also sensitive to short-term pollution events (NCDENR, 2007a).
- Fish community assessments represent water quality conditions with a high degree of confidence (NCDENR, 2007b) and are considered one of the most meaningful indicators of stream health. Fish are directly and indirectly affected by chemical and physical changes in the environment (NCDENR, 2007a).
- Historical results of biosurveys from the same location can be compared over time to indicate long-term trends (USEPA, 1996).
- Biological assessments allow the evaluation of aggregate impacts, such as pollutants without water quality standards, and physical characteristics of the habitat, such as low flow, benthic substrate modification, and invasive species (USEPA, 2000). However, biological assessments do not identify specific causes of impacts.

**Ambient Water Quality Chemistry**

- Chemical analyses of instream water may indicate specific pollutants contributing to conditions causing stress, but are not direct indicators of biological integrity of the stream.
- The fate of most individual chemicals in water is understood and may be predictable when chemical-specific data is available. However, interaction of chemical mixtures is not apparent (USEPA, 1996).
- Chemistry data may not precisely describe the bioavailability of the pollutant, and direct impacts on biota are not measured (USEPA, 1996).

**Aquatic Toxicity Monitoring**

- Whole effluent toxicity (WET) testing can indicate toxicity caused by chemical interactions, including unknown or unregulated pollutants, although the specific chemical causing the toxicity is not identified (USEPA, 1996).

- Bioavailability and toxicity of pollutants are measured directly (USEPA, 1996).
- Relatively few species are used and may not reflect the ambient instream populations (USEPA, 1996).
- Tests do not indicate if the toxicants are persistent in the study site or available from sediment sources (USEPA, 1996).

**Bridge Deck Runoff Quantity**

- Excessive flow quantity can degrade benthic habitat and displace benthic populations (NCDENR, 2003).
- Stream bank erosion and destabilization can be caused by high velocity flows.

**Sediment Quality**

- Bioavailability of pollutants is not clearly related to sediment characteristics (Burton and Pitts, 2002).
- Bed sediments can represent a “long term record” of pollutants to which the stream has been exposed (NCDENR, 2004a).
- Macroinvertebrates may constantly be exposed to toxicants in sediment, as opposed to the intermittent and inconsistent exposure to pollutants in stormwater (NCDENR, 2004a).

When evaluating surface water quality, NCDENR uses the WOE approach to assess the ability of the stream to support its designated aquatic life use. Specifically, the lines of evidence NCDENR uses in aquatic life use assessments and watershed assessments include biological assessment, ambient water quality chemistry, aquatic toxicity monitoring, and sediment quality. It should be noted that NCDENR also assesses streams for their ability to meet uses associated with human health use categories (e.g., fish consumption, recreation, shellfish harvesting, and water supply) (NCDENR, 2006). However, these use categories are outside the scope of the BSP study.

As shown in several watershed assessment studies performed by NCDENR, results from line of evidence studies are assessed in concert to identify potential stressors (2003, 2004a, 2004b, and 2004c). The same approach has been taken in the BSP. The following sections provide a discussion of the implications of each BSP monitoring regime evaluated as part of the WOE approach for determining the effect of bridge deck runoff on receiving streams.

## 4.2 Bridge Deck Runoff – Water Chemistry

The first step to determining the effect of bridge deck runoff is to evaluate the water chemistry data collected from the 15 bridge deck runoff monitoring sites. For a full explanation of bridge deck runoff monitoring activities, refer to section 3.2 of this report. Bridge deck runoff water chemistry was evaluated using several approaches: (1) a comparison of BSP monitoring results to existing nationwide data, (2) an innovative approach that links bridge deck runoff to the receiving streams by developing stormwater thresholds and parameters-of-concern (POCs), and (3) an analysis of the relationship between bridge characteristics and the concentrations of parameters commonly associated with stormwater runoff

While water chemistry evaluations provide important context for a particular monitoring program against typical national values and some indication of important parameters to consider for further investigation, concrete proof of receiving stream impact can only be collected by evaluating water chemistry and bioassessment results in tandem. Therefore, the results and observations presented in this section identify parameters or sites that may require further investigation, but do not suggest definitive proof of receiving stream impact.

## 4.2.1 Comparison to Existing Stormwater Runoff Data

To determine if the BSP water chemistry monitoring results are typical when compared to other stormwater monitoring programs, the event mean concentrations (EMCs) and annual loading rates from the BSP data were compared to nationwide urban and highway runoff datasets. Although this type of evaluation does not directly assess the effect of stormwater runoff on a particular receiving stream, in the absence of numerical standards, such comparisons are the accepted method for assessing stormwater monitoring data. The following sections provide a discussion of the EMC and annual loading rate comparisons.

### 4.2.1.1 Event Mean Concentration Comparison

Over the course of a single storm event, a heterogeneous mix of solid material with adsorbed and dissolved nutrients, metals, and organic compounds is dynamically delivered in runoff. The complex mechanics of pollutant delivery during a particular storm event are a function of the hydrograph and variable rainfall intensity during the storm event (Sansalone et al., 2005). As a result, the concentration of a parameter at any particular instant in a storm event might vary by over an order of magnitude (Dean et al., 2005). To facilitate comparison of storm event data from one study to another and to account for the variability in parameter delivery, stormwater runoff water chemistry data is typically presented as a single index: the event mean concentration (EMC).

**Event Mean Concentration**

The EMC is a flow-weighted average concentration for a particular parameter as measured over the entire hydrograph of a storm event. The EMC is defined by equation 4.2-1 as the sum of the total parameter mass divided by the sum of the total runoff volume (NCHRP, 2006; Stenstrom and Kayhanian, 2005).

$$EMC = \frac{M}{V} = \frac{\int C(t)Q(t)dt}{\int Q(t)dt} \cong \frac{\sum_i c_i q_i}{\sum_i q_i} \qquad \textbf{(4.2-1)}$$

where

EMC = event mean concentration
M = total storm event parameter mass
V = total storm event runoff volume
C(t) = parameter concentration curve
Q(t) = stormwater flow rate curve
$c_i$ = parameter concentration in the $i^{th}$ interval
$q_i$ = flow rate in the $i^{th}$ interval

Functionally, to estimate the EMC, several discrete sub-samples of runoff are collected over the course of the hydrograph ($c_i$). Flow rate data is used to estimate the volume-delivery of stormwater runoff between sub-samples ($q_i$). Runoff samples for determining the EMC can be collected two ways: (1) through manual grab sampling conducted throughout the storm event, (2) by collecting aliquots during the storm event into several bottles on a timed or flow-proportionate basis, or (3) by combining aliquots collected during the storm event into one large, composite sampling vessel. Grab samples or aliquots can be analyzed individually, and an EMC subsequently calculated using equation 4.2-1. If a composite sample is analyzed in the lab, the concentration of any parameter of interest in the combined sample would be the parameter's EMC for the storm event (Geosyntec Consultants and Wright Water Engineers, Inc, 2009). For this study, EMCs were determined using automated samplers that collected aliquots on a flow-proportionate basis. Aliquots were combined into one 20-liter Teflon-lined bottle and analyzed as a composite sample in the lab. For more information on water chemistry monitoring, refer to section 3.2 of this report.

## Bridge vs. Roadway Runoff EMCs

Despite recent interest in the unique stormwater characteristics of transportation-related runoff, few published studies have specifically investigated stormwater runoff from bridge decks (Dupuis, 2002, vol. 1). Projects that have monitored bridge deck runoff have typically focused on a small number of isolated sites (Stoker, 1996; Wu and Allan, 2001; Malina et al., 2005a; Nwaneshiudu, 2004). Therefore, roadway runoff water quality data is used as an approximation for the pollutant profile of bridge deck runoff (Dupuis, 2002, vol. 1). However, bridge decks have inherent differences from other portions of the roadway corridor, including high imperviousness and isolated drainage systems, which may impact the degree of maintenance to the bridge or directly affect stormwater quality. From a policy perspective, if the pollutant profile of bridge deck runoff is significantly different from roadway runoff, a watershed-approach to stormwater management may require specifically targeting bridge decks for SCMs in sensitive watersheds.

Table 4.2-1 presents summary median EMCs for bridge deck runoff data from 15 bridge sites in North Carolina compared to other bridge deck runoff, highway runoff, and urban runoff studies. Five programs and studies are included in table 4.2-1: the California Department of Transportation (Caltrans) compilation (Kayhanian et al., 2007), a study performed for the Texas Department of Transportation (TxDOT) on a bridge and highway site, the National Urban Runoff Program (NURP) (USEPA, 1983), the FWHA stormwater monitoring project (FHWA, 1990), and the NCDOT Highway Stormwater Program (HSP). The Caltrans compilation represents 635 storm events collected from 34 highway sites distributed statewide. The USEPA-sponsored NURP was a nationwide monitoring program that compiled runoff information from 28 sites with a variety of non-transportation land uses. The FHWA sponsored a project in 1990 to perform stormwater monitoring from 31 highway sites in 11 states. Under its Highway Stormwater Program (HSP), NCDOT has sponsored a variety of stormwater characterization projects for roadway runoff. Median values were compiled for several projects to represent the typical roadway runoff pollutant profile for roadways in North Carolina. A summary of the compiled data from NCDOT research projects can be found as table 4-A.1 in appendix 4-A.

When the BSP median bridge runoff EMCs are evaluated against other existing data, the BSP median EMCs are generally comparable to or lower than EMCs from other types of stormwater runoff. Interestingly, nutrient EMCs from bridge runoff are lower than EMCs typical of urban runoff per the NURP data. Chloride concentrations are notably higher in the compiled data from the Caltrans highway runoff data, but this parameter was measured at select sites only (Kayhanian et al., 2007). The following parameters are higher in North Carolina bridge deck runoff (BSP data) than in North Carolina roadway runoff (NCDOT roadway EMCs):

- total recoverable zinc
- total suspended solids
- chloride
- orthophosphate
- total nitrogen

Of the parameters listed above, chloride, orthophosphate, and total nitrogen concentrations are similar enough that there may not be a statistically significant difference. In addition, total recoverable zinc and TSS concentrations in North Carolina bridge deck runoff and roadway runoff are lower than the other studies presented. This comparison provides no compelling evidence that bridge deck runoff in North Carolina is higher in parameters typically associated with stormwater runoff as compared to runoff from other roadways.

## Table 4.2-1: Typical Median EMCs from Bridge Deck, Highway, and Urban Runoff

| Parameter | | Units | BSP Bridge Deck Runoff | Malina et al., 2005a | Kayhanian et al., 2007 | FHWA, 1990 | Malina et al., 2005a | NCDOT Roadway EMCs[a] | USEPA, 1983 |
|---|---|---|---|---|---|---|---|---|---|
| | | | (Bridge Deck Runoff) | (TxDOT - Bridge Deck Runoff) | (Caltrans - Highway Runoff) | (FHWA - Highway Runoff) | (TxDOT - Highway Runoff) | (Highway Runoff) | (NURP - Urban Runoff) |
| **Number of Sites (n)** | | | **n = 15** | **n = 1** | **n = 34** | **n = 31** | **n = 1** | **n = 20** | **n = 28** |
| pH | | std. units | 6.8 | NA | 7 | NA | NA | 6.9 | NA |
| Solids | Total Dissolved Solids (TDS) | mg/L | 34 | NA | 60.3 | NA | NA | 65 | NA |
| | Total Suspended Solids (TSS) | mg/L | 39 | 91.0 | 59.1 | 93 | 123 | 18 | 100 |
| Water Quality Indicator Analyses, Nutrients, and Major Ions | Chloride | mg/L | 0.81 | NA | 620 | NA | NA | 0.79 | NA |
| | Specific Conductance | µmhos/cm | 51 | NA | 72.7 | NA | NA | NA | NA |
| | Total Phosphorus | mg/L-P | 0.169 | 0.090 | 0.18 | NA | 0.125 | 0.18 | 0.33 |
| | Orthophosphate | mg/L-P | 0.019 | NA | 0.06 | 0.293 | NA | 0.01 | NA |
| | Total Nitrogen | mg/L-N | 0.97 | NA | NA | 2.14[b] | NA | 0.81 | 2.18[b] |
| | Total Kjeldahl Nitrogen (TKN) | mg/L-N | 0.71 | 1.03 | 1.4 | 1.48 | 1.29 | 1.3 | 1.5 |
| | Ammonium/Ammonia | mg/L-N | 0.051 | NA | NA | NA | NA | 0.2 | NA |
| | Nitrate + Nitrite | mg/L-N | 0.21 | NA | NA | 0.66 | NA | 1.03 | 0.68 |
| Trace Metals | Total Recoverable Arsenic | µg/L | 0.97 | NA | 1.1 | NA | NA | NA | NA |
| | Dissolved Arsenic | µg/L | 0.62 | NA | 0.7 | NA | NA | NA | NA |
| | Total Recoverable Cadmium | µg/L | 0.10 | NA | 0.44 | NA | NA | ND | NA |
| | Dissolved Cadmium | µg/L | 0.03 | NA | 0.13 | NA | NA | NA | NA |
| | Total Recoverable Chromium | µg/L | 3.9 | NA | 5.8 | NA | NA | ND | NA |
| | Dissolved Chromium | µg/L | 0.62 | NA | 2.2 | NA | NA | NA | NA |
| | Total Recoverable Copper | µg/L | 9.6 | 12.9 | 21.1 | 39 | 21.9 | NA | 34 |
| | Dissolved Copper | µg/L | 2.7 | 3.60 | 10.2 | NA | 5.69 | NA | NA |
| | Total Recoverable Iron | µg/L | 1420 | NA | 12,600 | NA | NA | NA | NA |
| | Dissolved Iron | µg/L | 17 | NA | 150 | NA | NA | NA | NA |
| | Total Recoverable Nickel | µg/L | 2.3 | NA | 7.7 | NA | NA | ND | NA |

## Table 4.2-1: Typical Median EMCs from Bridge Deck, Highway, and Urban Runoff (continued)

| **Parameter** | | **Units** | **BSP Bridge Deck Runoff** | **Malina et al., 2005a** | **Kayhanian et al., 2007** | **FHWA, 1990** | **Malina et al., 2005a** | **NCDOT Roadway EMCs**[a] | **USEPA, 1983** |
|---|---|---|---|---|---|---|---|---|---|
| | | | (Bridge Deck Runoff) | (TxDOT - Bridge Deck Runoff) | (Caltrans - Highway Runoff) | (FHWA - Highway Runoff) | (TxDOT - Highway Runoff) | (Highway Runoff) | (NURP - Urban Runoff) |
| **Number of Sites (n)** | | | **n = 15** | **n = 1** | **n = 34** | **n = 31** | **n = 1** | **n = 20** | **n = 28** |
| | Dissolved Nickel | µg/L | 0.69 | NA | 3.4 | NA | NA | NA | NA |
| | Total Recoverable Lead | µg/L | 5.29 | 8.90 | 12.7 | 234 | 13.7 | ND | 144 |
| | Dissolved Lead | µg/L | 0.09 | ND | 1.2 | NA | ND | NA | NA |
| | Total Recoverable Zinc | µg/L | 65.9 | 168 | 111.2 | 217 | 130 | 30 | 160 |
| | Dissolved Zinc | µg/L | 16.8 | 28.0 | 40.4 | NA | 29.1 | NA | NA |
| Hydro-carbons | Oil and Grease | mg/L | 4.8 | 4.76 | 6 | NA | 5.64 | NA | NA |
| | Total Petroleum Hydrocarbons (TPH) | mg/L | 3.1 | NA | 1.4 | NA | NA | NA | NA |

**Notes:** NA = No Data available. ND = Indicates that there were insufficient detections of this constituent to allow for statistics to be calculated.

[a] Data was compiled from a variety of NCDOT research studies (Line, 2006; Skipper, 2008; Wu and Allan, 2001, 2006, 2009).

[b] Total Nitrogen was calculated by summing Total Kjeldahl Nitrogen (TKN) and Nitrate + Nitrite (NO3 + NO2).

#### 4.2.1.2 Annual Loading Rates Comparison

When characterizing stormwater in a given location, evaluating parameter delivery as a function of mass load can be as significant to developing a management strategy as comparing EMCs. While individual EMCs or site-median EMCs may provide insight into localized toxicity, the overall toxic impact of stormwater runoff to a waterbody is typically evaluated using mass loading rates. The primary stormwater pollutants are generally inorganic and, therefore, can persist in the environment and bioaccumulate in aquatic tissue (Burton and Pitt, 2002). In addition, EMCs may not facilitate evaluation of treatment technologies that rely on infiltration as a primary or secondary unit operation, such as infiltration basins, swales, and filter strips.

**Loading Rate**

Two mass loading indexes were calculated using bridge deck runoff water chemistry data: a unit load and an annual loading rate. The unit load, $L_u$, is the amount of parameter yield as mass delivered in a single storm event. The annual loading rate is an estimated mass load delivered from a watershed over the period of a year. Unit loads and annual loading rates were determined for 15 bridge deck runoff monitoring sites using a method presented by Wu and Allan (2001) (herein referred to as the Wu and Allen method). Unit loads were calculated using equation 4.2-2. For EMCs that were below detection limits (i.e., censored) and whose distributions per site followed normal, lognormal, or gamma distribution, a regression on order statistics (ROS) analysis was performed to estimate an EMC value. The ROS estimated values were used in the loading calculation. For more information on methods for handling censored and uncertain data, refer to Appendix 3-F.

$$L_u = \frac{(EMC \times V_r)}{DA} \tag{4.2-2}$$

where

$L_u$ = unit load per storm event (lb/acre)
EMC = event mean concentration (lb/L)
$V_r$ = volume of runoff for wet-weather event (L)
DA = contributing drainage area (acres)

Unit loads provide a single event parameter index, similar to EMCs, but from a mass perspective. To calculate a unit loading rate for each storm event, $L_{ur}$, the unit load is divided by the duration of the storm event converted to units of a fraction of a year, as in equation 4.2-3.

$$L_{ur} = \left( \frac{EMC \times V_r}{DA \times T_r} \right) \tag{4.2-3}$$

where

$L_{ur}$ = unit loading rate per storm event (lb/acre-year)
$T_r$ = duration of storm event (years)
All other variables as defined previously.

Finally, the $L_{ur}$ is averaged for every site and multiplied by the ratio of the average storm duration to the average time between storms over a long-term period at the site to calculate the annual loading rate, $L_{ar}$, presented in equation 4.2-4.

$$L_{ar} = L_{ur(ave)} \left( \frac{T_p}{T_d} \right) \tag{4.2-4}$$

where

$L_{ar}$ = annual loading rate (lb/acre-year)

$T_p$ = average time of precipitation (wet) at the monitoring site (years)
$T_d$ = average time of dry periods at the monitoring site (years)

The Wu and Allan method for calculating annual loading was selected for the project for several reasons:

- Data from the Wu and Allan (2001) report was used previously by NCDOT to establish nutrient area loading rates for nitrogen and phosphorus in runoff (NCDOT, 2009a). Using the same method allows for defensible comparisons of the BSP dataset against previously calculated values.
- The Wu and Allan method takes full advantage of the potential hydrologic data that could be available for each storm event. Wu and Allan compared results of their method to results from Scheuler's Simple Method, which relies on estimates of hydrologic data from precipitation and representative concentration values and concluded that estimates of total nitrogen export from runoff were overestimated by Scheuler's Simple Method (Wu and Allan, 2001). (Note: for the current study, Scheuler's Simple Method was used to calculate runoff volumes to facilitate application of the Wu and Allan method because discharge data were not available at the time of this analysis.)
- The Wu and Allan method incorporates a non-dimensional correction factor to account for the site-specific ratio of time of precipitation to time of dry weather (wet to dry ratio). This correction factor helps prevent overestimating or underestimating pollutant loads if the storm events collected do not necessarily represent the precipitation pattern implicitly assumed in a model.

### Bridge vs. Roadway Annual Pollutant Loading Rates

Median unit event loads and average unit annual loading rates for the 15 BSP bridge deck runoff monitoring sites are summarized in table 4.2-2. Table 4.2-3 provides a visual representation of the average unit annual loading rate at each site compared to the median value for all 15 sites. Based on visual inspection, annual loading rates for metals appear to be relatively higher at sites located in the Blue Ridge and Piedmont ecoregions as compared to sites located in the Coastal ecoregion. There was no discernible trend in annual loading rates for nutrients and solids for the different ecoregions. In general, annual loading rates at the Swannanoa River, Mallard Creek, and Swift Creek sites were relatively higher than the other sites; annual loading rates at the Dillingham Creek, Mango Creek, and Smith Creek sites were relatively lower than the other sites. It should be noted that the unit annual loading rates reported for each site in table 4.2-2 are based on an average of rates calculated for each event (rather than a median). The average value was considered to be a more appropriate comparison to the literature values, as many of these studies employed similar methods. However, it should be noted that a single high or low EMC value can bias the average annual value. For example, the higher annual loading rates calculated for bis-phthalate at Smith Creek and for orthophosphate at Flat Creek were each weighted by one relatively higher EMC value. Future evaluation of these data may identify these higher EMC values as outliers, and exclude them from the calculation of annual loading rates, provided some basis for their removal is established. However, for the current study, these relatively higher values were not excluded because no such basis was established.

A comparison of annual loading rates calculated for the 15 BSP bridge deck runoff monitoring sites to highway and bridge loading values reported in literature studies is provided in table 4.2-4. The median and range of loading values reported for the 15 sites were calculated using the following steps:

1. A unit event loading rate (lb/ac-yr) was calculated for each parameter, storm event, and site.
2. An average unit annual loading rate (lb/ac-yr) was calculated for each site and parameter as the average of the values from each storm event computed in Step 1, adjusted using the site-specific wet to dry ratio. A summary of these average unit annual loading rates is presented in table 4.2-2.
3. The median and range of annual loading rates reported in table 4.2-4 was determined using the 15 average annual loading rates computed in Step 2 for each parameter.

## Table 4.2-2: Median Unit Event Loads (lb/ac) and Average Unit Annual Loading Rates (lb/ac-yr) at the 15 BSP Monitoring Sites

| Stream Name, Bridge Number | | Flat Creek, 100250 | | Big Ivy Creek, 100734 | | Dillingham Creek, 100145 | | Swannanoa River, 100494 | |
|---|---|---|---|---|---|---|---|---|---|
| North Carolina Ecoregion | | Blue Ridge | | Blue Ridge | | Blue Ridge | | Blue Ridge | |
| Parameter | | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr |
| Solids | Total Dissolved Solids | 2.58E+00 | 5.13E+02 | 3.93E+00 | 3.84E+02 | 2.33E+00 | 1.93E+02 | 8.44E+00 | 8.55E+02 |
| | Total Suspended Solids | 1.63E+00 | 4.65E+02 | 1.26E+01 | 1.35E+03 | 2.86E+00 | 3.78E+02 | 1.32E+01 | 1.31E+03 |
| Nutrients | Total Phosphorus | 8.8E-03 | 3.9E+00 | 5.0E-02 | 1.2E+01 | 1.4E-02 | 1.3E+00 | 4.3E-02 | 4.8E+00 |
| | Orthophosphate | 4.3E-03 | 2.2E+00 | 2.5E-03 | 2.8E-01 | 1.5E-03 | 1.5E-01 | 3.4E-03 | 5.4E-01 |
| | Total Nitrogen | 4.3E-02 | 2.0E+01 | 1.1E-01 | 9.6E+00 | 6.4E-02 | 4.8E+00 | 1.5E-01 | 2.0E+01 |
| | Ammonia | 7.3E-03 | 6.2E+00 | 1.6E-03 | 2.9E-01 | 3.0E-03 | 2.3E-01 | 6.5E-03 | 1.4E+00 |
| | Total Kjeldahl Nitrogen | 3.7E-02 | 1.5E+01 | 8.8E-02 | 7.6E+00 | 4.0E-02 | 3.7E+00 | 1.1E-01 | 1.4E+01 |
| | Nitrate + Nitrite | 1.1E-02 | 3.6E+00 | 1.7E-02 | 2.0E+00 | 1.2E-02 | 1.1E+00 | 4.8E-02 | 6.1E+00 |
| Trace Metals | Total Recoverable Arsenic | 3.1E-05 | 8.7E-03 | 1.1E-04 | 1.1E-02 | 1.4E-04 | 1.3E-02 | 1.1E-04 | 1.2E-02 |
| | Total Recoverable Cadmium | 4.0E-06 | 9.1E-04 | 1.5E-05 | 1.4E-03 | 8.4E-06 | 5.0E-04 | 5.0E-05 | 6.0E-03 |
| | Dissolved Cadmium | 3.0E-06 | 6.5E-04 | 1.8E-06 | 1.9E-04 | 1.6E-06 | 1.7E-04 | 1.2E-05 | 1.8E-03 |
| | Total Recoverable Chromium | 1.3E-04 | 4.3E-02 | 1.5E-03 | 1.5E-01 | 4.5E-04 | 4.2E-02 | 1.8E-03 | 2.2E-01 |
| | Total Recoverable Copper | 2.60E-04 | 6.15E-02 | 1.76E-03 | 1.65E-01 | 5.15E-04 | 1.41E-01 | 4.18E-03 | 5.61E-01 |
| | Dissolved Copper | 1.3E-04 | 2.7E-02 | 2.2E-04 | 1.7E-02 | 1.4E-04 | 1.1E-02 | 1.2E-03 | 1.4E-01 |
| | Total Recoverable Iron | 4.96E-02 | 1.91E+01 | 7.46E-01 | 8.65E+01 | 1.95E-01 | 1.99E+01 | 4.99E-01 | 7.94E+01 |
| | Total Recoverable Nickel | 1.5E-04 | 4.4E-02 | 7.6E-04 | 8.1E-02 | 2.1E-04 | 2.1E-02 | 6.7E-04 | 8.8E-02 |
| | Total Recoverable Lead | 5.41E-05 | 1.69E-02 | 1.1E-03 | 1.27E-01 | 1.79E-04 | 1.90E-02 | 2.92E-03 | 3.24E-01 |
| | Dissolved Lead | 5.9E-06 | 2.0E-03 | 5.1E-06 | 4.6E-04 | 3.3E-06 | 3.0E-04 | 3.1E-05 | 3.8E-03 |
| | Total Recoverable Manganese | 1.64E-03 | 6.30E-01 | 1.24E-02 | 1.65E+00 | 3.80E-03 | 4.47E-01 | 9.88E-03 | 1.37E+00 |
| | Total Recoverable Zinc | 2.65E-03 | 7.78E-01 | 2.18E-02 | 2.32E+00 | 3.31E-03 | 3.82E-01 | 3.68E-02 | 4.59E+00 |
| | Dissolved Zinc | 1.93E-03 | 5.37E-01 | 1.47E-03 | 1.72E-01 | 5.61E-04 | 4.84E-02 | 4.04E-03 | 6.97E-01 |
| | Total Recoverable Aluminum | 2.78E-02 | 1.11E+01 | 4.35E-01 | 4.85E+01 | 1.16E-01 | 1.29E+01 | 2.69E-01 | 3.30E+01 |
| | Total Recoverable Mercury | 1.1E-06 | 1.1E-04 | 1.4E-06 | 1.6E-04 | 7.6E-07 | 7.4E-05 | 2.0E-06 | 2.0E-04 |
| Semi-volatiles | Bis(2-ethylhexyl)phthalate | 6.5E-05 | 1.7E-02 | 1.0E-04 | 1.2E-02 | 2.3E-05 | 2.8E-03 | 5.8E-04 | 5.3E-02 |
| Hydro-Carbons | Oil and Grease | 5.5E-01 | 2.1E+02 | 5.4E-01 | 7.5E+01 | 3.07E-01 | 2.3E+01 | 1.0E+00 | 1.6E+02 |

## Table 4.2-2: Median Unit Event Loads (lb/ac) and Average Unit Annual Loading Rates (lb/ac-yr) at the 15 BSP Monitoring Sites (continued)

| Stream Name, Bridge Number | | Boylston Creek, 440008 | | Mallard Creek, 590296 | | Mountain Creek, 310005 | | Little River, 310064 | |
|---|---|---|---|---|---|---|---|---|---|
| North Carolina Ecoregion | | Blue Ridge | | Piedmont | | Piedmont | | Piedmont | |
| Parameter | | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr |
| Solids | Total Dissolved Solids | 2.15E+00 | 5.70E+02 | 8.64E+00 | 3.36E+02 | 2.87E+00 | 2.52E+02 | 2.13E+00 | 4.02E+02 |
| | Total Suspended Solids | 7.63E+00 | 9.40E+02 | 1.58E+01 | 1.44E+03 | 1.99E+00 | 4.36E+02 | 2.17E+00 | 1.64E+03 |
| Nutrients | Total Phosphorus | 7.5E-02 | 4.5E+00 | 6.2E-02 | 5.8E+00 | 1.2E-02 | 3.8E+00 | 5.9E-03 | 3.8E+00 |
| | Orthophosphate | 5.6E-03 | 5.1E-01 | 1.6E-03 | 1.5E-01 | 4.1E-03 | 5.7E-01 | 5.8E-04 | 7.6E-02 |
| | Total Nitrogen | 2.3E-01 | 2.1E+01 | 2.3E-01 | 1.6E+01 | 1.2E-01 | 1.8E+01 | 6.0E-02 | 2.5E+01 |
| | Ammonia | 2.2E-02 | 4.1E+00 | 1.0E-02 | 5.7E-01 | 2.2E-02 | 3.2E+00 | 1.9E-03 | 3.6E+00 |
| | Total Kjeldahl Nitrogen | 2.1E-01 | 1.6E+01 | 1.5E-01 | 1.2E+01 | 9.4E-02 | 1.4E+01 | 4.4E-02 | 1.8E+01 |
| | Nitrate + Nitrite | 2.7E-02 | 5.2E+00 | 7.4E-02 | 3.9E+00 | 2.6E-02 | 3.4E+00 | 1.5E-02 | 7.1E+00 |
| Trace Metals | Total Recoverable Arsenic | 2.8E-04 | 2.5E-02 | 3.0E-04 | 2.3E-02 | 4.9E-05 | 8.4E-03 | 5.6E-05 | 1.6E-02 |
| | Total Recoverable Cadmium | 2.3E-05 | 2.1E-03 | 7.0E-05 | 6.0E-03 | 4.7E-06 | 7.4E-04 | 5.7E-06 | 2.0E-03 |
| | Dissolved Cadmium | 4.8E-06 | 7.2E-04 | 6.0E-06 | 7.2E-04 | 2.5E-06 | 3.4E-04 | 1.2E-06 | 3.1E-04 |
| | Total Recoverable Chromium | 5.1E-04 | 5.2E-02 | 3.5E-03 | 3.2E-01 | 1.6E-04 | 2.3E-02 | 1.3E-04 | 8.8E-02 |
| | Total Recoverable Copper | 1.54E-03 | 1.01E-01 | 1.02E-02 | 6.26E-01 | 6.24E-04 | 1.02E-01 | 3.69E-04 | 1.49E-01 |
| | Dissolved Copper | 2.8E-04 | 2.7E-02 | 1.2E-03 | 6.5E-02 | 4.4E-04 | 5.9E-02 | 1.6E-04 | 3.1E-02 |
| | Total Recoverable Iron | 5.51E-01 | 4.95E+01 | 6.53E-01 | 7.29E+01 | 5.54E-02 | 1.37E+01 | 4.84E-02 | 3.31E+01 |
| | Total Recoverable Nickel | 4.5E-04 | 4.0E-02 | 1.5E-03 | 1.1E-01 | 2.0E-04 | 4.6E-02 | 9.8E-05 | 4.6E-02 |
| | Total Recoverable Lead | 1.05E-03 | 8.27E-02 | 3.44E-03 | 7.57E-01 | 4.26E-04 | 5.09E-02 | 2.50E-04 | 2.28E-01 |
| | Dissolved Lead | 1.7E-05 | 2.3E-03 | 3.3E-05 | 3.6E-03 | 1.9E-05 | 2.7E-03 | 5.3E-06 | 1.2E-03 |
| | Total Recoverable Manganese | 1.67E-02 | 1.49E+00 | 2.10E-02 | 2.50E+00 | 6.10E-03 | 9.26E-01 | 2.39E-03 | 2.25E+00 |
| | Total Recoverable Zinc | 1.43E-02 | 1.34E+00 | 7.29E-02 | 6.42E+00 | 4.2E-03 | 7.31E-01 | 3.40E-03 | 1.37E+00 |
| | Dissolved Zinc | 4.16E-03 | 4.50E-01 | 8.83E-03 | 5.91E-01 | 3.30E-03 | 4.23E-01 | 1.18E-03 | 2.59E-01 |
| | Total Recoverable Aluminum | 4.91E-01 | 3.72E+01 | 3.26E-01 | 3.10E+01 | 4.41E-02 | 1.06E+01 | 4.57E-02 | 2.63E+01 |
| | Total Recoverable Mercury | 2.0E-06 | 4.0E-04 | 2.5E-06 | 1.8E-04 | 5.5E-07 | 1.1E-04 | 5.1E-07 | 3.0E-04 |
| Semi-volatiles | Bis(2-ethylhexyl)phthalate | 1.64E-04 | 2.5E-02 | 8.0E-04 | 7.3E-02 | 8.4E-05 | 1.0E-02 | 1.0E-04 | 3.9E-02 |
| Hydro-Carbons | Oil and Grease | 1.31E+00 | 1.2E+02 | 1.2E+00 | 1.5E+02 | 3.6E-01 | 4.9E+01 | 2.7E-01 | 7.7E+01 |

## Table 4.2-2: Median Unit Event Loads (lb/ac) and Average Unit Annual Loading Rates (lb/ac-yr) at the 15 BSP Monitoring Sites (continued)

| Stream Name, Bridge Number | | Perry Creek, 910124 | | Mango Creek, 911102 | | Swift Creek, 910255 | | Middle Creek, 910273 | |
|---|---|---|---|---|---|---|---|---|---|
| North Carolina Ecoregion | | Piedmont | | Piedmont | | Piedmont | | Piedmont | |
| Parameter | | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr |
| Solids | Total Dissolved Solids | 4.34E+00 | 3.48E+02 | 8.28E+00 | 1.35E+02 | 8.14E+00 | 8.01E+02 | 4.58E+00 | 2.34E+02 |
| | Total Suspended Solids | 4.78E+00 | 6.75E+02 | 6.07E+00 | 1.34E+02 | 1.50E+01 | 1.46E+03 | 3.99E+00 | 3.85E+02 |
| Nutrients | Total Phosphorus | 1.3E-02 | 2.5E+00 | 1.9E-02 | 2.8E-01 | 4.4E-02 | 5.2E+00 | 2.0E-02 | 2.0E+00 |
| | Orthophosphate | 9.2E-04 | 1.7E-01 | 4.1E-03 | 5.1E-02 | 5.0E-03 | 5.5E-01 | 3.7E-03 | 1.8E-01 |
| | Total Nitrogen | 9.8E-02 | 1.1E+01 | 1.5E-01 | 2.5E+00 | 2.6E-01 | 2.2E+01 | 1.8E-01 | 9.0E+00 |
| | Ammonia | 6.1E-03 | 1.4E+00 | 1.1E-02 | 1.6E-01 | 8.8E-03 | 2.0E+00 | 2.1E-02 | 1.2E+00 |
| | Total Kjeldahl Nitrogen | 7.2E-02 | 8.3E+00 | 8.6E-02 | 1.4E+00 | 2.7E-01 | 2.6E+01 | 1.4E-01 | 7.2E+00 |
| | Nitrate + Nitrite | 2.7E-02 | 2.9E+00 | 6.4E-02 | 1.0E+00 | 4.4E-02 | 3.8E+00 | 3.4E-02 | 1.8E+00 |
| Trace Metals | Total Recoverable Arsenic | 1.1E-04 | 1.1E-02 | 2.5E-04 | 3.6E-03 | 1.4E-04 | 1.7E-02 | 2.1E-04 | 1.3E-02 |
| | Total Recoverable Cadmium | 9.2E-06 | 1.6E-03 | 2.8E-05 | 3.3E-04 | 3.5E-05 | 3.1E-03 | 1.5E-05 | 8.9E-04 |
| | Dissolved Cadmium | 3.2E-06 | 3.5E-04 | 4.1E-06 | 1.3E-04 | 3.7E-06 | 3.0E-04 | 4.6E-06 | 2.4E-04 |
| | Total Recoverable Chromium | 5.7E-04 | 8.5E-02 | 8.4E-04 | 1.1E-02 | 2.6E-03 | 2.6E-01 | 1.0E-03 | 6.4E-02 |
| | Total Recoverable Copper | 2.19E-03 | 2.76E-01 | 4.05E-03 | 1.26E-01 | 4.74E-03 | 3.81E-01 | 1.99E-03 | 2.51E-01 |
| | Dissolved Copper | 4.8E-04 | 5.2E-02 | 5.8E-04 | 8.5E-03 | 8.6E-04 | 6.9E-02 | 8.0E-04 | 3.9E-02 |
| | Total Recoverable Iron | 1.44E-01 | 4.22E+01 | 3.41E-01 | 5.72E+00 | 6.11E-01 | 5.11E+01 | 1.87E-01 | 1.49E+01 |
| | Total Recoverable Nickel | 2.6E-04 | 4.7E-02 | 5.3E-04 | 6.7E-03 | 7.8E-04 | 8.0E-02 | 3.2E-04 | 2.0E-02 |
| | Total Recoverable Lead | 1.16E-03 | 1.55E-01 | 8.34E-04 | 1.68E-02 | 9.78E-03 | 8.63E-01 | 3.51E-03 | 2.34E-01 |
| | Dissolved Lead | 1.1E-05 | 1.0E-03 | 2.0E-05 | 2.3E-04 | 3.4E-05 | 4.2E-03 | 3.7E-05 | 2.2E-03 |
| | Total Recoverable Manganese | 4.41E-03 | 9.94E-01 | 9.01E-03 | 1.42E-01 | 2.64E-02 | 1.97E+00 | 6.61E-03 | 5.98E-01 |
| | Total Recoverable Zinc | 8.56E-03 | 9.91E-01 | 2.14E-02 | 2.52E-01 | 1.78E-02 | 2.31E+00 | 1.06E-02 | 6.18E-01 |
| | Dissolved Zinc | 1.61E-03 | 1.66E-01 | 1.70E-03 | 3.17E-02 | 3.74E-03 | 2.75E-01 | 2.83E-03 | 1.46E-01 |
| | Total Recoverable Aluminum | 9.60E-02 | 1.92E+01 | 2.83E-01 | 3.52E+00 | 3.28E-01 | 3.13E+01 | 1.02E-01 | 9.48E+00 |
| | Total Recoverable Mercury | 5.2E-07 | 8.5E-05 | 2.3E-06 | 3.7E-05 | 1.9E-06 | 2.5E-04 | 1.5E-06 | 1.0E-04 |
| Semi-volatiles | Bis(2-ethylhexyl)phthalate | 1.9E-04 | 2.8E-02 | 4.7E-04 | 1.8E-02 | 2.8E-04 | 5.2E-02 | 2.5E-04 | 2.3E-02 |
| Hydro-Carbons | Oil and Grease | 6.1E-01 | 5.9E+01 | 1.3E+00 | 1.9E+01 | 9.1E-01 | 1.2E+02 | 8.2E-01 | 5.2E+01 |

### Table 4.2-2: Median Unit Event Loads (lb/ac) and Average Unit Annual Loading Rates (lb/ac-yr) at the 15 BSP Monitoring Sites (continued)

| Stream Name, Bridge Number | | Black River, 810014 | | Smith Creek, 640132 | | Town Creek, 090061 | |
|---|---|---|---|---|---|---|---|
| North Carolina Ecoregion | | Coastal | | Coastal | | Coastal | |
| Parameter | | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr | lb/ac | lb/ac-yr |
| Solids | Total Dissolved Solids | 4.77E+00 | 2.69E+02 | 4.97E+00 | 1.99E+02 | 5.88E+00 | 7.01E+02 |
| | Total Suspended Solids | 6.21E+00 | 5.55E+02 | 3.93E+00 | 1.41E+02 | 7.20E-01 | 2.48E+02 |
| Nutrients | Total Phosphorus | 6.9E-02 | 4.1E+00 | 3.4E-02 | 2.5E+00 | 1.9E-02 | 2.5E+00 |
| | Orthophosphate | 1.9E-02 | 1.1E+00 | 2.2E-03 | 2.5E-01 | 3.4E-03 | 5.1E-01 |
| | Total Nitrogen | 2.8E-01 | 1.8E+01 | 6.7E-02 | 2.9E+00 | 1.1E-01 | 1.3E+01 |
| | Ammonia | 8.28E-02 | 4.0E+00 | 5.3E-03 | 2.0E-01 | 3.2E-03 | 4.2E-01 |
| | Total Kjeldahl Nitrogen | 2.7E-01 | 1.6E+01 | 4.7E-02 | 1.1E+00 | 8.7E-02 | 1.0E+01 |
| | Nitrate + Nitrite | 4.7E-02 | 2.2E+00 | 2.4E-02 | 1.1E+00 | 2.1E-02 | 2.3E+00 |
| Trace Metals | Total Recoverable Arsenic | 3.7E-04 | 2.5E-02 | 1.6E-04 | 7.8E-03 | 2.7E-04 | 3.2E-02 |
| | Total Recoverable Cadmium | 1.7E-05 | 1.5E-03 | 2.7E-05 | 8.6E-04 | 7.2E-06 | 9.0E-04 |
| | Dissolved Cadmium | 7.1E-06 | 5.4E-04 | 2.5E-06 | 1.4E-04 | 2.2E-06 | 2.7E-04 |
| | Total Recoverable Chromium | 4.1E-04 | 4.9E-02 | 9.6E-04 | 5.8E-02 | 2.0E-04 | 2.8E-02 |
| | Total Recoverable Copper | 1.11E-03 | 7.90E-02 | 1.62E-03 | 1.01E-01 | 8.18E-04 | 8.28E-02 |
| | Dissolved Copper | 5.5E-04 | 2.7E-02 | 2.3E-04 | 1.1E-02 | 3.0E-04 | 3.9E-02 |
| | Total Recoverable Iron | 8.73E-02 | 1.49E+01 | 2.21E-01 | 1.48E+01 | 5.37E-02 | 6.43E+00 |
| | Total Recoverable Nickel | 2.6E-04 | 2.8E-02 | 5.5E-04 | 2.9E-02 | 2.1E-04 | 2.4E-02 |
| | Total Recoverable Lead | 8.26E-04 | 7.63E-02 | 6.25E-04 | 2.59E-02 | 3.82E-04 | 5.47E-02 |
| | Dissolved Lead | 3.2E-05 | 2.3E-03 | 4.9E-06 | 2.7E-04 | 6.2E-06 | 1.0E-03 |
| | Total Recoverable Manganese | 7.08E-03 | 6.31E-01 | 6.82E-03 | 2.64E-01 | 2.03E-03 | 2.01E-01 |
| | Total Recoverable Zinc | 1.29E-02 | 1.01E+00 | 8.25E-03 | 3.79E-01 | 6.85E-03 | 6.25E-01 |
| | Dissolved Zinc | 6.07E-03 | 5.22E-01 | 9.81E-04 | 3.87E-02 | 2.07E-03 | 2.14E-01 |
| | Total Recoverable Aluminum | 9.76E-02 | 7.14E+00 | 1.10E-01 | 4.62E+00 | 3.78E-02 | 3.60E+00 |
| | Total Recoverable Mercury | 1.4E-06 | 8.4E-05 | 9.9E-07 | 6.1E-05 | 6.0E-07 | 1.0E-04 |
| Semi-volatiles | Bis(2-ethylhexyl)phthalate | 1.5E-04 | 1.4E-02 | 3.2E-04 | 1.2E-01 | 1.2E-04 | 1.7E-02 |
| Hydro-Carbons | Oil and Grease | 7.6E-01 | 5.4E+01 | 9.7E-01 | 4.7E+01 | 6.3E-01 | 7.4E+01 |

### Table 4.2-3: Visual Comparison of Unit Annual Loading Rates for BSP Monitoring Sites

| | | North Carolina Ecoregion and BSP Monitoring Site | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Blue Ridge | | | | | Piedmont | | | | | | | Coastal | | |
| | Parameter | Flat Creek | Big Ivy Creek | Dillingham Creek | Swannanoa River | Boylston Creek | Mallard Creek | Mountain Creek | Little River | Perry Creek | Mango Creek | Swift Creek | Middle Creek | Black River | Smith Creek | Town Creek |
| Solids | Total Dissolved Solids | ░ | ░ | □ | ▒ | ░ | □ | □ | ░ | ░ | □ | ▒ | □ | □ | □ | ▒ |
| | Total Suspended Solids | □ | ▒ | □ | ▒ | ░ | ▒ | □ | ▒ | ░ | □ | ▒ | □ | ░ | □ | □ |
| Nutrients | Total Phosphorus | ░ | ▒ | □ | ░ | ░ | ░ | ░ | □ | □ | □ | ░ | □ | ░ | □ | □ |
| | Orthophosphate | ▓ | ░ | □ | ░ | ░ | □ | ▒ | □ | □ | □ | ▒ | □ | ▒ | □ | ░ |
| | Total Nitrogen | ░ | □ | □ | ░ | ░ | ░ | ░ | ░ | □ | □ | ░ | □ | ░ | □ | □ |
| | Ammonia | ▒ | □ | □ | ░ | ▒ | □ | ▒ | ▒ | ░ | □ | ░ | □ | ▒ | □ | □ |
| | Total Kjeldahl Nitrogen | ░ | □ | □ | ░ | ░ | ░ | ░ | ░ | □ | □ | ▒ | □ | ░ | □ | □ |
| | Nitrate + Nitrite | ░ | □ | □ | ▒ | ░ | ░ | ░ | ▒ | ░ | □ | ░ | □ | □ | □ | □ |
| Trace Metals | Total Recoverable Arsenic | □ | □ | ░ | □ | ░ | ░ | □ | ░ | □ | □ | ░ | ░ | ░ | □ | ▒ |
| | Total Recoverable Cadmium | □ | ░ | □ | ▒ | ░ | ▒ | □ | ░ | ░ | □ | ▒ | □ | ░ | □ | □ |
| | Dissolved Cadmium | ▒ | □ | □ | ▓ | ▒ | ▒ | ░ | ░ | ░ | □ | □ | □ | ░ | □ | □ |
| | Total Recoverable Chromium | □ | ▒ | □ | ▒ | □ | ▓ | □ | ░ | ░ | □ | ▒ | ░ | □ | ░ | □ |
| | Total Recoverable Copper | □ | ░ | ░ | ▒ | □ | ▒ | □ | ░ | ░ | □ | ▒ | ░ | □ | □ | □ |
| | Dissolved Copper | □ | □ | □ | ▒ | □ | ▒ | ░ | ░ | ░ | □ | ▒ | ░ | □ | □ | ░ |
| | Total Recoverable Iron | □ | ▒ | ░ | ▒ | ▒ | ▒ | □ | ░ | ▒ | □ | ▒ | □ | □ | □ | □ |
| | Total Recoverable Nickel | ░ | ░ | □ | ▒ | □ | ▒ | ░ | ░ | ░ | □ | ░ | □ | □ | □ | □ |
| | Total Recoverable Lead | □ | ░ | □ | ▒ | ░ | ▓ | □ | ▒ | ░ | □ | ▓ | ▒ | □ | □ | □ |
| | Dissolved Lead | ░ | □ | □ | ░ | ░ | ░ | ░ | □ | □ | □ | ▒ | ░ | ░ | □ | □ |
| | Total Recoverable Manganese | □ | ░ | □ | ░ | ░ | ▒ | ░ | ▒ | ░ | □ | ▒ | □ | □ | □ | □ |
| | Total Recoverable Zinc | □ | ▒ | □ | ▒ | ░ | ▓ | □ | ░ | ░ | □ | ▒ | □ | ░ | □ | □ |
| | Dissolved Zinc | ▒ | □ | □ | ▒ | ░ | ▒ | ░ | ░ | □ | □ | ░ | □ | ▒ | □ | □ |
| | Total Recoverable Aluminum | □ | ▒ | ░ | ▒ | ▒ | ▒ | □ | ▒ | ░ | □ | ▒ | □ | □ | □ | □ |
| | Total Recoverable Mercury | ░ | ░ | □ | ░ | ▒ | ░ | ░ | ▒ | □ | □ | ▒ | □ | □ | □ | □ |
| Semi-Volatiles | Bis(2-ethylhexyl)phthalate | □ | □ | □ | ▒ | ░ | ▒ | □ | ░ | ░ | □ | ▒ | ░ | □ | ▓ | □ |
| Hydro-carbons | Oil and Grease | ▒ | ░ | □ | ▒ | ░ | ░ | □ | ░ | □ | □ | ░ | □ | □ | □ | ░ |

**Note:** Shades of cells represent the tendency of the site-specific average annual loading rate towards the following ranges:

| | |
|---|---|
| □ | Annual site loading rate is less than or equal to the median annual loading rate of all 15 BSP bridge sites. |
| ░ | Annual site loading rate is greater than the median value and less than twice the median value of all sites. |
| ▒ | Annual site loading rate is two times greater than the median value and less than five times the median of all sites. |
| ▓ | Annual site loading rate is five times greater than the median annual loading rate of all 15 BSP bridge sites. |

Literature values presented in table 4.2-4 are based on the work of several researchers who have reported on highway, secondary roadway, and bridge deck runoff characteristics throughout the United States. A compilation of median, minimum, and maximum values for these studies is provided in appendix 4-A.

Median annual loading rates for each parameter estimated as part of this study were compared to median values reported in three other bridge deck studies (table 4.2-4) to assess if the results of this study were generally inline with previous efforts. A summary of this comparison follows:

<u>Rates below or equal to other bridge deck values:</u>

- total dissolved solids
- total suspended solids
- dissolved orthophosphate
- ammonia
- total recoverable cadmium
- total recoverable chromium
- total recoverable copper
- dissolved copper
- total recoverable nickel
- total recoverable lead

<u>Rates above other bridge deck values</u>:

- total phosphorus
- total nitrogen
- total kjeldahl nitrogen
- dissolved zinc
- oil and grease

Likewise, following is a comparison of median annual loading rates calculated for the 15 BSP bridge deck runoff monitoring sites to median values reported in other highway studies for the applicable parameters:

<u>Rates below or equal to other highway values:</u>

- total dissolved solids
- dissolved orthophosphate
- nitrate + nitrite
- total recoverable cadmium
- total recoverable chromium
- total recoverable nickel
- total recoverable lead

<u>Rates above other highway values</u>:

- total suspended solids
- total phosphorus
- total nitrogen
- ammonia
- total kjeldahl nitrogen
- total recoverable copper
- total recoverable iron
- total recoverable zinc
- oil and grease

In general, BSP median loading rates for oil and grease and most nutrients appear to be higher than literature values, while rates for most metals and solids appear to be lower than literature values. While a comparison of the median rates is instructive, inspection of the range of loading rates provides additional insight into how the BSP unit annual loading rates compare to values from the other studies. As shown, ranges of BSP unit annual loading rates for most parameters are either within or below ranges reported in other highway studies; these parameters include total dissolved solids, total suspended solids, orthophosphate, ammonia, total kjeldahl nitrogen, total recoverable cadmium, total recoverable copper, total recoverable lead, total recoverable zinc, and oil and grease. For parameters where BSP maximum loading rates were higher than ranges reported in the other highway studies (including total phosphorus, total nitrogen, nitrate plus nitrite, total recoverable chromium, total recoverable iron, and total recoverable nickel), the BSP maximum values were generally comparable or within an order of magnitude of the maximum unit annual loading rate values reported by the other highways studies. It should also be noted that ranges for most literature values are very large (orders of magnitude for oil and grease and other parameters).

The comparison of unit annual loading rates provides no compelling evidence to suggest that bridge deck runoff loads in this study are consistently higher or lower than stormwater runoff loads from other studies.

## Table 4.2-4: Comparison of BSP Bridge Deck Runoff Annual Loading Rates to Literature Values

| Parameters | | Units | Literature Annual Loading Rates | | | | BSP Annual Loading Rates | |
|---|---|---|---|---|---|---|---|---|
| | | | Bridge Deck[a], n = 3 | | Highway[b], n > 29 | | Bridge Deck, n = 15 | |
| | | | Range | Median | Range | Median | Range | Median |
| Solids | Total Dissolved Solids | lb/ac-yr | 210 - 1,914 | 1,062 | 41 - 1,896 | 654 | 135 - 855 | 348 |
| | Total Suspended Solids | lb/ac-yr | 423 - 2,389 | 826 | 2 - 10,583 | 185 | 134 - 1643 | 555 |
| Nutrients | Total Phosphorus | lb/ac-yr | 0.8 - 0.83 | 0.82 | 0.01 - 8.9 | 0.91 | 0.28 - 12 | 3.8 |
| | Orthophosphate | lb/ac-yr | 0.31 - 1.1 | 0.71 | 0.01 - 3.7 | 0.55 | 0.051 - 2.0 | 0.28 |
| | Total Nitrogen | lb/ac-yr | 9.71 | 9.71 | 0.29 - 21.1 | 5.18 | 2.5 - 25 | 16 |
| | Ammonia | lb/ac-yr | 2.88 - 8.1 | 5.49 | 0.09 - 10.6 | 0.73 | 0.16 - 6.2 | 1.4 |
| | Total Kjeldahl Nitrogen | lb/ac-yr | 6.58 - 13.9 | 6.88 | 0.84 - 28.51 | 7.9 | 1.1 - 26 | 12 |
| | Nitrate + Nitrite | lb/ac-yr | ----- | ----- | 1.8 - 4.2 | 3.1 | 1.0 - 7.1 | 2.9 |
| Trace Metals | Total Recoverable Arsenic | lb/ac-yr | ----- | ----- | ----- | ----- | 0.0036 - 0.032 | 0.013 |
| | Total Recoverable Cadmium | lb/ac-yr | 0.03 | 0.03 | 0.006 - 0.05 | 0.03 | 0.00033 - 0.0060 | 0.0014 |
| | Dissolved Cadmium | lb/ac-yr | ----- | ----- | ----- | ----- | 0.0001 - 0.002 | 0.0003 |
| | Total Recoverable Chromium | lb/ac-yr | 0.08 | 0.08 | 0.01 - 0.09 | 0.06 | 0.011 - 0.32 | 0.058 |
| | Total Recoverable Copper | lb/ac-yr | 0.12 - 0.20 | 0.16 | 0.001 - 4.17 | 0.07 | 0.061 - 0.63 | 0.14 |
| | Dissolved Copper | lb/ac-yr | 0.03 | 0.03 | ----- | ----- | 0.0085 - 0.14 | 0.031 |
| | Total Recoverable Iron | lb/ac-yr | ----- | ----- | 0.047 - 25.70 | 2.23 | 5.72 - 86.5 | 19.9 |
| | Total Recoverable Nickel | lb/ac-yr | 0.08 | 0.08 | 0.02 - 0.06 | 0.04 | 0.0067 - 0.11 | 0.044 |
| | Total Recoverable Lead | lb/ac-yr | 0.07 - 0.18 | 0.125 | 0.001 - 18.9 | 0.40 | 0.0168 - 0.863 | 0.0827 |
| | Dissolved Lead | lb/ac-yr | ----- | ----- | ----- | ----- | 0.00023 - 0.0042 | 0.0020 |
| | Total Recoverable Manganese | lb/ac-yr | ----- | ----- | ----- | ----- | 0.142 - 2.50 | 0.926 |
| | Total Recoverable Zinc | lb/ac-yr | 1.23 | 1.23 | 0.002 - 9.28 | 0.28 | 0.252 - 6.42 | 0.991 |
| | Dissolved Zinc | lb/ac-yr | 0.21 | 0.21 | ----- | ----- | 0.0317 - 0.697 | 0.259 |
| | Total Recoverable Aluminum | lb/ac-yr | ----- | ----- | ----- | ----- | 3.52 - 48.5 | 12.9 |
| | Total Recoverable Mercury | lb/ac-yr | ----- | ----- | ----- | ----- | 0.000037 - 0.00040 | 0.00011 |
| Semi-volatiles | Bis(2-ethylhexyl)phthalate | lb/ac-yr | ----- | ----- | ----- | ----- | 0.003 - 0.1 | 0.02 |
| Hydro-carbons | Oil and Grease | lb/ac-yr | 19.5 - 58.3 | 31.16 | 0.05 - 684 | 14.1 | 19 - 211 | 74 |

**Notes:**

[a] Bridge deck literature values are from the following studies: Malina et al., 2005a; Wu and Allan, 2001; and Wu et al., 1998.

[b] Literature values for highway roads include freeways, highways, and secondary roads from the following studies: Wu and Allan, 2009; Skipper, 2008; Gilbert and Clausen, 2006; Burton and Pitt, 2002; Wu and Allan, 2001; Wu et al., 1998; Barrett et al., 1995a; Barrett et al., 1995b, and Horner, 1992.

## 4.2.2 Linking Bridge Deck Runoff to Receiving Streams

Despite a significant amount of stormwater characterization in the literature, no standard method exists for evaluating post-construction stormwater concentrations in an impairment context. In general, results from a particular stormwater monitoring project are compared to national compendiums of stormwater data or to previous locally collected stormwater monitoring programs. While such comparisons are convenient for assessing stormwater runoff concentrations in general, they do not provide insight into the impacts of stormwater runoff on a particular watershed. Logically, if a particular concentration is not contributing to impairment for a receiving stream with lower water quality standards, no significant stormwater treatment should be necessary. The same concentration profile might require sophisticated SCMs when paired with a high quality drinking water source. Therefore, efficient and cost-effective stormwater management, including SCM selection, becomes a function of evaluating stormwater characterization data against receiving stream surface water quality goals.

Linking stormwater runoff to overall degradation in receiving streams is an emerging area in stormwater management research. Fundamentally, it is understood that increased urbanization causes both hydrologic and water quality impairments to receiving streams (Burton and Pitt, 2002). However, the specific processes and chemical pathways for the impact of stormwater runoff from transportation facilities, particularly from bridge deck runoff, isolated from the impact of other nonpoint sources in the watershed are not currently well-understood (Dupuis, 2002). Stormwater research (past and current) has focused on tying the impacts of runoff to the degree of urbanization and alteration in the macroinvertebrate community (Klein, 1980; Dupuis, 2002; Yagow et al., 2006). It is anticipated that the understanding of the direct link between highway runoff and receiving stream impacts will continue to improve in the coming years.

Secondly, an innovative approach for evaluating stormwater runoff data was established, in which stormwater thresholds from a variety of surface water quality standards and criteria were compiled to develop a benchmark for bridge deck runoff receiving stream water quality goals. These thresholds were then used to determine the parameters-of-concern (POCs) for bridge deck runoff in North Carolina. Once established, the POCs were evaluated in an end-of-pipe direct comparison and instantaneous mixing scenario against site-specific water quality goals at three sites.

### 4.2.2.1 Stormwater Quality Thresholds

NCDENR has previously used USEPA's National Ambient Water Quality Criteria (NAWQC) for freshwaters to evaluate instream data during storm flows (NCDENR, 2003), but no standards or regulatory guidance exist in North Carolina for direct comparison of thresholds to stormwater EMCs. In the current absence of practitioner guidance, the BSP team elected to create a methodology for focusing attention on specific parameters and analyzing stormwater data in the context of North Carolina surface water quality conditions. Available surface water quality data from North Carolina, the USEPA, and other resources were used to create thresholds for comparison to stormwater runoff.

The use of surface water quality standards to assess stormwater chemistry is a suggested practice in the context of an integrated stormwater effect assessment (Dupuis, 2002). However, using surface water quality data in this context has limitations. Burton and Pitt (2002) outline a number of limitations to using thresholds for assessing stormwater impacts, including the following:

- Surface water standards and criteria based on biological effects may not be applicable to conditions at every site.
- Thresholds often do not account for antagonistic or synergistic effects that alter pollutant bioavailability.

- Many surface water quality criteria are designed for single acute and chronic average exposures that don't consider pulsed exposures for short time periods.
- Previous studies have shown instream degradation identified through biosurveys when measured water quality have met criteria.

Therefore, these thresholds are intended to help establish the absence of stormwater effect for stormwater runoff measured in the study from a weight-of-evidence perspective and to indentify parameters that might affect receiving stream quality. Conversely, the thresholds are not intended to unequivocally identify receiving stream impairments or confirm toxic impacts. The results of the water chemistry analyses presented in following subsections are only relevant when interpreted in conjunction with the biological assessments presented in section 4.5 of this report. The various resources used to compile surface water quality thresholds are provided in table 4.2-5. A full summary of all thresholds used in the BSP is provided as table 4-A.4 in appendix 4-A.

**Table 4.2-5: Water Quality Threshold References**

| Resource | Description |
|---|---|
| North Carolina Surface Water Quality Standards | These surface water standards apply to North Carolina surface waters and wetlands to maintain the surface water's use classification. Standards are provided in the North Carolina Administrative Code (NCAC) at 15A NCAC 02B. Standards are provided to protect freshwater and saltwater aquatic life from acute and chronic toxicity as well as human health from the consumption of water or fish tissue (15A NCAC 02B, 2007). |
| USEPA National Recommended Water Quality Criteria for Priority Toxic Pollutants and Non-Priority Pollutants | USEPA's compilation of recommended criteria for the protection of human health and aquatic life do not have specific jurisdiction of any surface waters, but are provided to states to facilitate development of state surface water quality standards (USEPA, 2009a). |
| DWQ's Compilation of NC Standards, USEPA Criteria, and Various Toxicological Databases | DWQ compiled chemical-specific toxicological data from available research stored in a variety of different databases supported by federal agencies in addition to existing North Carolina standards and USEPA recommended criteria. These databases include ECOTOX, the USEPA Integrated Risk Information System (IRIS), and the Risk Assessment Information System (RAIS) (NCDENR, 2010a). |
| Texas Commission on Environmental Quality (TCEQ) Criteria in Water for Specific Toxic Materials for Aquatic Life Protection | The Texas surface water criteria are outlined in the Texas Administrative Code (TAC) at 30 TAC 307.6(c)(1). Some metal criteria are provided in the dissolved form calculated using basin-specific hardness values. The Texas criteria were included due to the wide range of parameters for which criteria are provided (TCEQ, 2000). |

For metals in stormwater, the USEPA has developed hardness-dependant equations to calculate criteria for dissolved metals in an effort to control the more bioavailable, and therefore toxic, fraction of metals in stormwater. To establish general, conservative thresholds for the BSP, the 25th percentile hardness value (16 mg/L-$CaCO_3$) from all available instream data was used as an input to the USEPA hardness-dependant equations. Similarly, pH-dependant USEPA criteria (e.g., pentachlorophenol) were calculated using the 25th percentile instream pH value of 6.3. Currently, North Carolina standards control the total recoverable fraction of metals in surface waters. However, during the course of the BSP, NCDENR released proposed revisions to metals standards for several metals of interest to stormwater runoff. The proposed changes would eliminate standards for the total fraction and provide dissolved fraction standards for arsenic, cadmium, copper, lead, nickel, and zinc (among others). While the proposed standards have not yet been codified in North Carolina, these standards were included in the BSP at the suggestion of NCDENR staff to provide an up-to-date assessment of POCs. A table of the proposed North Carolina standards changes for metals can be found in appendix 4-A.

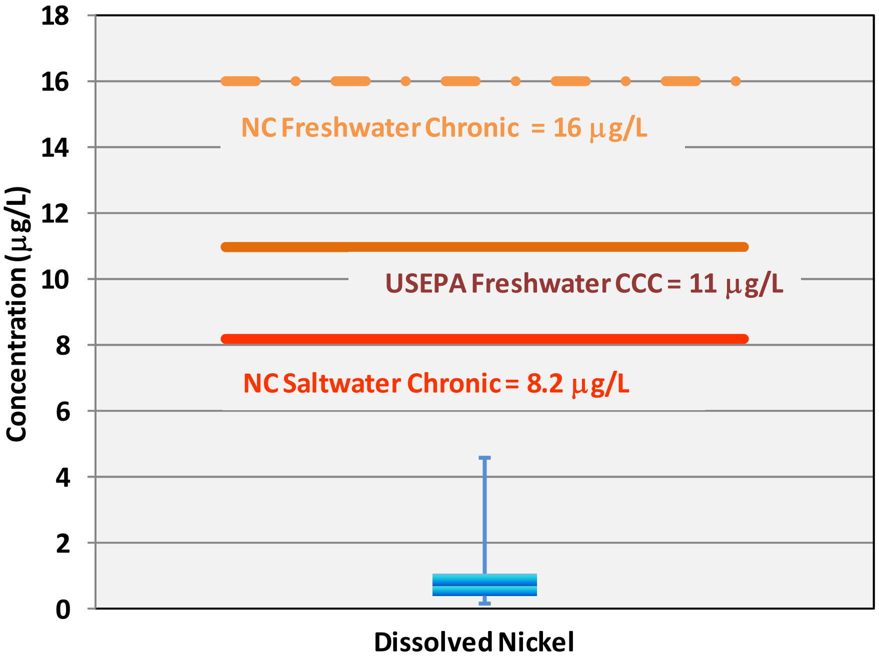
For the USEPA freshwater copper criterion continuous concentration (CCC) and criterion maximum concentration (CMC), the Biotic Ligand Model (BLM) was used to determine the dissolved copper threshold. The BLM considers metals speciation and the interactions of hardness, free ions, and inorganic and organic ligands to predict metal bioavailability (USEPA, 2007a). All available instream data as of January 2010 were used as inputs to the BLM. The model calculates an instantaneous CCC and CMC for set of instream water quality data. Per recommendations of USEPA's *Training Materials on Copper BLM: Data Requirements*, the geometric mean of instantaneous CCCs and CMCs was used as the freshwater dissolved copper thresholds (2007b). BLM output with the final thresholds is provided as table 4-A.6 in appendix 4-A.

#### 4.2.2.2 Determining Parameters-of-Concern

Solids, nutrients, major elements, trace metals, and organic compounds (including polycyclic aromatic hydrocarbons [PAHs], total petroleum hydrocarbons [TPH], and phthalates) were monitored in bridge deck runoff at 15 bridge sites throughout North Carolina as part of the BSP monitoring program. It was observed that some analytes, the semi-volatile organic compounds in particular, were largely below detection limits (i.e., censored), making it difficult to reliably confirm their existence in the stormwater runoff stream. Therefore, a method was developed to establish project-specific parameters-of-concern (POCs).

For the purposes of this project, POCs are defined as any monitored parameter whose maximum measured concentration exceeds the most stringent threshold from available local and nationally-recognized surface water quality criteria or environmental datasets. If the maximum measured EMC is lower than the most stringent threshold, regardless of stream classification or target receptor, that parameter would not be identified as a POC in a site-specific comparison of stormwater runoff and thresholds. The true benefit of the POC determination is to eliminate parameters that do not pose a significant risk of receiving stream impairment. An illustration of the POC methodology is provided in figure 4.2-1.

In figure 4.2-1, the maximum value for dissolved zinc, 108 μg/L, is higher than several surface water quality thresholds, qualifying the analyte as a POC. Conversely, dissolved nickel's maximum concentration of 4.6 μg/L is far below the least stringent surface water quality standard (North Carolina's saltwater chronic standard of 8.2 μg/L).



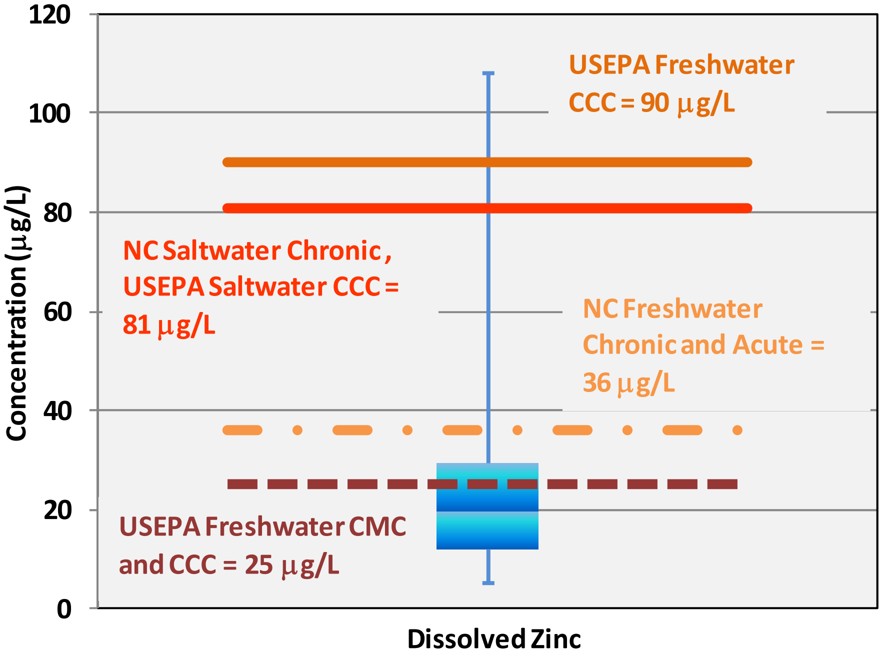


**Figure 4.2-1: Box plots of dissolved zinc and dissolved nickel bridge deck runoff as compared to surface water quality thresholds. North Carolina standards and USEPA criteria are shown; some standards with higher concentrations were excluded from the graphs to maintain a smaller scale for clarity. CMC = criterion maximum concentration, CCC = criterion continuous concentration**

For all parameters, the most stringent threshold was taken from the North Carolina Surface Water Quality Standards (15A NCAC, 2007) and the USEPA National Recommended Water Quality Criteria for Priority Toxic Pollutants and Non Priority Pollutants, when available. If criteria were not available for a particular parameter, available thresholds were obtained from USEPA databases (ECOTOX, IRIS, and RAIS) and from the Texas Commission on Environmental Quality (TCEQ) (NCDENR, 2010a; TCEQ, 2000). A full comparison of all bridge deck runoff EMCs to the most stringent threshold for solids, nutrients, trace metals, and volatile organics is provided as table 4-A.7 in appendix 4-A. The final BSP POCs are provided in table 4.2-6. It should be noted that these POCs are only applicable for the water column chemistry monitoring. Analytes present at trace levels in the water column can be present at higher levels in the sediment, so analytes not defined as POCs in this section were still included in section 4.3.

For many of the organic compounds, the laboratory reporting level was higher than the surface water quality threshold. In these cases, a single detectable concentration automatically labels such an organic compound as a POC. For the organic constituents listed as POCs, only bis(2-exylhexyl)phthalate meets project requirements for the calculation of summary statistics (refer to appendix 3-F for more information on censored datasets). The other organic compounds have greater than 70% nondetect values and less than 8 detected values for the storm events presented in this dataset. Therefore, due to the abundance of censored data for these parameters, no further evaluation will or can be performed. In addition, the high number of nondetect values suggests that despite being identified as a POC per project definitions, these parameters do not consistently pose a significant risk to surface water quality effect.

## 4.2.3 Site-Specific Water Chemistry Evaluation

### 4.2.3.1 Direct Comparison of Bridge Deck Runoff and Thresholds

To first assess bridge deck runoff data, bridge deck runoff data was directly compared to site-specific threshold values. This approach is highly conservative, as it does not take the impact of mixing of bridge deck runoff with the receiving stream into account. In addition to bridge deck runoff, upstream instream water chemistry was compared to surface water quality thresholds. Comparison of instream water chemistry to thresholds is critical, as preexisting exceedances in the receiving stream upstream of the bridge crossing indicate that other sources besides the bridge deck may be responsible for any impairment or that exceedances of thresholds reflect a natural background state for the receiving stream.

Instream water chemistry was monitored upstream of the bridge deck crossing at a subset of bridge deck runoff monitoring sites. Of these sites, Swannanoa River, Little River, and Black River were selected for further evaluation due to their variety in spatial distribution, bridge deck drainage areas, and ADT. Figure 4.2-2 provides a summary of the site locations with select site characteristics. The comparison of bridge deck runoff to surface water quality thresholds for the three sites is provided in tables 4.2-7 through 4.2-9. The evaluation of instream concentrations against surface water quality standards is provided as tables A-4.8 through A-4.10 in appendix 4-A.

## Table 4.2-6: Summary of BSP Bridge Deck Runoff Parameters-of-Concern

| Parameters-of-Concern | | Units | Max EMC[a] | Site of Max EMC[b] | Governing Threshold[c] | Threshold Reference[d] |
|---|---|---|---|---|---|---|
| pH (basic) | | std. units | 9.5 | Mango Creek | 9 | NCSWQS Freshwater Aquatic Life, USEPA Freshwater CCC, USEPA Human Health Water + Organism |
| pH (acidic) | | std. units | 3.5 | Black River | 5 | USEPA Human Health Water + Organism |
| Trace Metals | Total Recoverable Arsenic | µg/L | 4.6 | Town Creek | 0.018 | USEPA Human Health Water + Organism |
| | Dissolved Cadmium[e] | µg/L | 0.44 | Swannanoa River | 0.07 | USEPA Freshwater CCC |
| | Dissolved Copper[f] | µg/L | 20.7 | Perry Creek | 1.6 | USEPA Freshwater CCC |
| | Total Recoverable Iron | µg/L | 46900 | Swannanoa River | 300 | USEPA Human Health Water + Organism |
| | Dissolved Lead[e] | µg/L | 0.66 | Black River/Swift Creek | 0.33 | USEPA Freshwater CCC |
| | Total Recoverable Manganese | µg/L | 751 | Big Ivy Creek | 50 | USEPA Human Health Water + Organism |
| | Total Recoverable Nickel | µg/L | 31.2 | Swannanoa River | 25 | NCSWQS Water Supply |
| | Dissolved Zinc[e] | µg/L | 108 | Black River | 25 | USEPA Freshwater CMC, USEPA Freshwater CCC |
| | Total Recoverable Aluminum | µg/L | 19800 | Big Ivy Creek | 87 | USEPA Freshwater CCC |
| | Total Recoverable Mercury | µg/L | 0.039 | Mallard Creek | 0.012 | NCSWQS Freshwater Aquatic Life |
| Semi-volatiles | Benzo-[b]-fluoranthene | µg/L | 3 | Perry Creek | 0.0038 | USEPA Human Health Water + Organism |
| | Benzo-[a]-pyrene | µg/L | 2 | Mallard Creek | 0.0038 | USEPA Human Health Water + Organism |
| | Benzo-[k]-fluoranthene | µg/L | 1 | Mallard Creek/Perry Creek | 0.0038 | USEPA Human Health Water + Organism |
| | Bis(2-ethylhexyl)phthalate | µg/L | 26 | Smith Creek | 1.2 | USEPA Human Health Water + Organism |
| | Chrysene | µg/L | 2 | Perry Creek /Mallard Creek/Swift Creek | 0.0038 | USEPA Human Health Water + Organism |
| | Benzo-[a]-anthracene | µg/L | 1 | Perry Creek/Mallard Creek | 0.0038 | USEPA Human Health Water + Organism |
| | Indeno-[1,2,3-cd]-pyrene | µg/L | 1 | Perry Creek | 0.0038 | USEPA Human Health Water + Organism |
| Solids | Total Suspended Solids (TSS)[g] | mg/L | 688 | Big Ivy Creek | 10[g] | NCSWQS High Quality Waters/Trout Waters |
| Nutrients | Total Nitrogen[h] | mg/L | 4.3 | Flat Creek | NA[h] | NA[h] |
| | Total Phosphorus[h] | mg/L | 8.28 | Big Ivy Creek | NA[h] | NA[h] |

**Notes:**

[a] The max EMC refers to the maximum concentration measured for the parameter from all available EMCs collected through February 5, 2010 from the BSP bridge deck runoff monitoring sites.

[b] The site of max EMC denotes the bridge deck runoff monitoring location at which the maximum EMC was measured for a particular parameter.

[c] The governing threshold is the most stringent surface water quality standard or criteria from North Carolina and USEPA references, regardless of receptor or surface water quality classification. For example, in this broad evaluation to identify POCs, a freshwater criterion might be used on a saltwater stream if that criterion was more stringent than the saltwater criteria.

## Table 4.2-6: Summary of BSP Drain Deck Runoff Parameters-of-Concern (continued)

[d] NCSWQS refers to the North Carolina Surface Water Quality Standards as listed in 15A NCAC 2B for the protection of Freshwater Aquatic Life and Saltwater Aquatic Life (2007). USEPA refers to the United States Environmental Protection Agency National Recommended Water Quality Criteria (USEPA, 2009a). Recommended criteria are provided according to the following categories: Freshwater Criteria Maximum Concentration (CMC), Freshwater Criteria Continuous Concentration (CCC), Saltwater CMC, Saltwater CCC, Human Health for the Consumption of Water + Organisms, and Human Health for the Consumption of Organisms only.

[e] Dissolved criteria for cadmium, lead, and zinc were determined from the hardness-dependant equations provided by the USEPA. To be conservative, the 25th percentile instream hardness value from available instream data for BSP monitoring sites was used to calculate the thresholds. See USEPA (2009a) for more information.

[f] The dissolved copper freshwater threshold was developed using USEPA's Biotic Ligand Model, Version 2.2.1 (USEPA, 2007a).

[g] The only surface water quality standards that pertain to Total Suspended Solids are for NPDES wastewater discharges only. To evaluate TSS as a POC, the most stringent North Carolina scenario of a NPDES wastewater stream being discharged into a High Quality Water/Trout Water was adopted.  Refer to 15A NCAC 02B .0224.

[h] Numerical water quality standards for Total Nitrogen or Total Phosphorus are watershed specific. No thresholds are available to evaluate these parameters on a broader scale. However, nutrients are included in the list of Parameters of Concern due to their known contributions to algae booms and oxygen depletion.

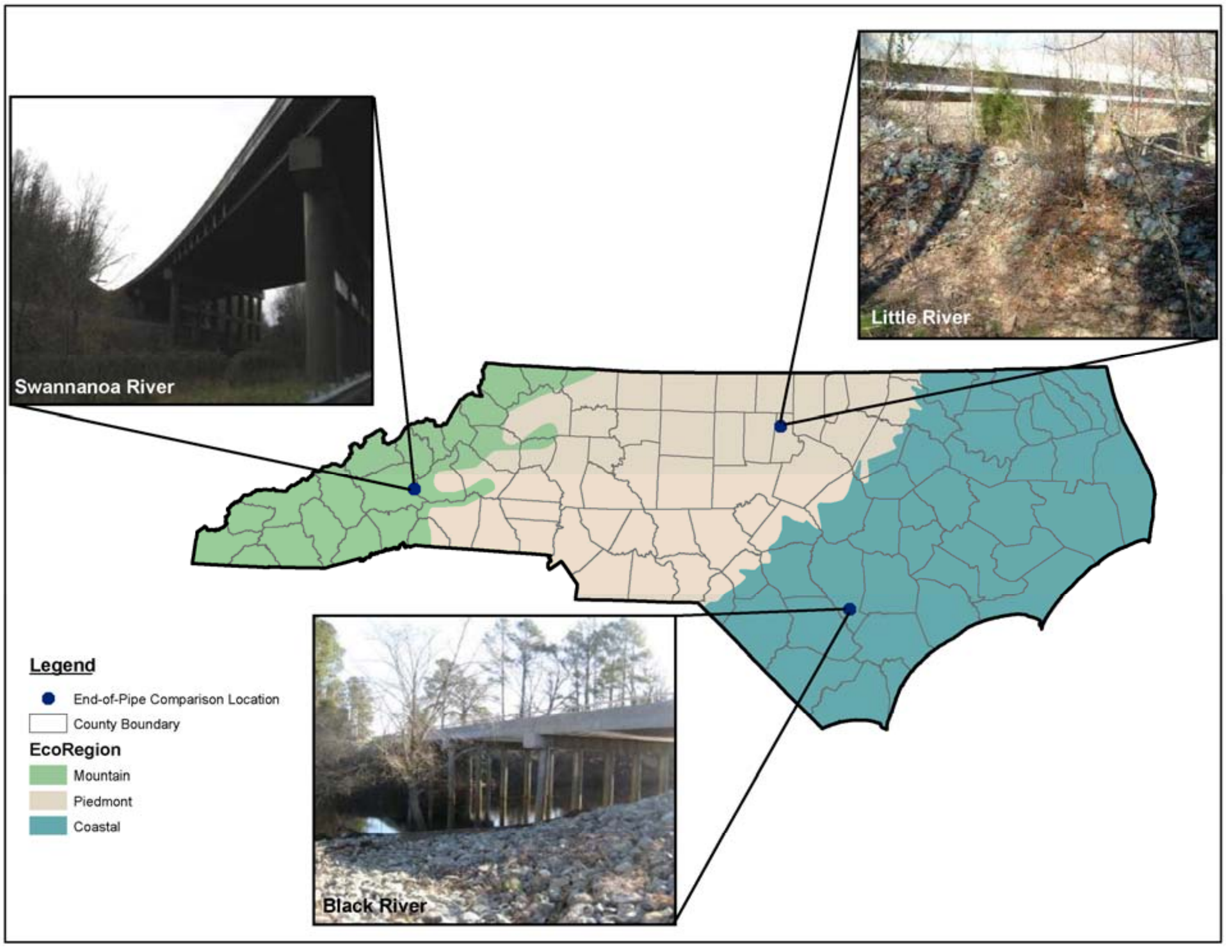


**Figure 4.2-2: Site location map and characteristics for Swannanoa River, Little River, and Black River.**

### Black River

For Black River, requirements for new and expanded NPDES permitted wastewater discharges in 15A NCAC 02B .0225 were applied to the surface water quality thresholds. Therefore, a threshold of 20 mg/L was observed for total suspended solids and a safety factor of one-half the normal standard was observed for other POCs. Direct comparison of bridge deck runoff EMCs to surface water quality thresholds shows exceedances for pH (acidic), dissolved cadmium, dissolved copper, total recoverable iron, dissolved lead, total recoverable manganese, dissolved zinc, total recoverable aluminum, total recoverable mercury, and total suspended solids. However, upstream of the bridge deck, Black River regularly exceeds surface water quality thresholds for total recoverable iron, total recoverable manganese, and total recoverable aluminum with similar concentrations as found in the bridge deck runoff (refer to table 4-A.8 in appendix 4-A). Black River instream samples also occasionally exceed thresholds for pH (acidic), dissolved copper, dissolved lead, and total recoverable mercury. Of these, pH, total recoverable mercury, and dissolved lead exceedances in instream and bridge deck runoff concentrations are generally similar. Dissolved copper and total suspended solids exceedances in bridge deck runoff are generally higher than concentrations that exceed thresholds instream. POCs that exceed thresholds in bridge deck runoff but that did not exceed thresholds upstream of the bridge crossing include dissolved cadmium and dissolved zinc.

## Table 4.2-7: Black River – Direct Comparison of Bridge Deck Runoff and Thresholds

| | Parameters-of-Concern[a] | Units | Threshold[b] | Bridge Runoff Water Quality Data: Event Mean Concentrations[c] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Apr 11, 2009 | Apr 14, 2009 | May 4, 2009 | June 4, 2009 | July 16, 2009 | July 27, 2009 | Sept 16, 2009 | Oct 12, 2009 | Nov 10, 2009 | Jan 17, 2010 |
| | pH (acidic and basic) | s.u. | 6 - 9 | **3.5** | 7.0 | 6.0 | **5.6** | 6.2 | 6.2 | **5.8** | 6.0 | 6.5 | **5.9** |
| Trace Metals | Total Recoverable Arsenic | μg/L | 5 | 3.1 | 1.3 | 3.7 | 3.1 | 1.2 | 2.1 | 0.85 | 0.91 | 3.0 | 2.3 |
| | Dissolved Cadmium | μg/L | 0.075 | 0.06 | 0.03 | 0.03 | 0.02 | **0.09** | 0.06 | **0.10** | **0.09** | 0.02 | 0.03 |
| | Dissolved Copper | μg/L | 1.35 | **4.6** | **3.2** | **3.0** | **2.2** | **2.9** | **1.9** | **3.3** | **4.3** | 0.87 | 1.0 |
| | Total Recoverable Iron | μg/L | 150 | **5250** | **466** | **429** | **2460** | **442** | **549** | 125 | **206** | **173** | **237** |
| | Dissolved Lead | μg/L | 0.27 | **0.66** | **0.34** | 0.18 | 0.11 | 0.21 | 0.10 | **0.28** | **0.31** | 0.04 | 0.04 |
| | Total Recoverable Manganese | μg/L | 25 | **119** | **27.1** | **30.5** | **124** | **54.8** | **34.8** | **26.9** | 20.4 | **54.8** | **25.5** |
| | Total Recoverable Nickel | μg/L | NA[d] | 5.7 | 1.4 | 1.2 | 7 | 2 | 1.1 | 1.3 | 2.0 | 1.1 | 0.53 |
| | Dissolved Zinc | μg/L | 18 | **108** | **32.4** | **48.1** | **47.4** | **79.2** | **37.6** | **44.0** | **38.8** | 7.5 | 12.0 |
| | Total Recoverable Aluminum | μg/L | 43.5 | **1380** | **521** | **445** | **1590** | **387** | **390** | **152** | **310** | **177** | **273** |
| | Total Recoverable Mercury | μg/L | 0.006 | **0.011** | **0.007** | **0.011** | **0.012** | **0.011** | < 0.010 | 0.005 | **0.016** | < 0.010 | ----- |
| Semi-volatiles | Benzo-[b]-fluoranthene[e] | μg/L | 0.0019 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.40 | < 0.30 | ----- | ----- |
| | Benzo-[a]-pyrene[e] | μg/L | 0.0019 | <0.33 | <0.33 | <0.33 | <0.33 | ----- | < 0.33 | ----- | < 0.33 | ----- | < 0.33 |
| | Benzo-[k]-fluoranthene[e] | μg/L | 0.0019 | < 0.4 | < 0.4 | < 0.4 | < 0.4 | < 0.4 | < 0.4 | < 0.4 | < 0.30 | ----- | < 0.30 |
| | Chrysene[e] | μg/L | 0.0019 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | ----- | < 0.33 |
| | Benzo-[a]-anthracene[e] | μg/L | 0.0019 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | ----- | < 0.26 |
| | Bis(2-ethylhexyl)phthalate[e] | μg/L | 0.6 | ----- | ----- | < 2 | < 2 | < 2 | < 2 | < 2 | < 2 | ----- | < 2 |
| | Indeno-[1,2,3-cd]-pyrene[e] | μg/L | 0.0019 | < 0.4 | < 0.4 | < 0.4 | < 0.4 | ----- | < 0.4 | < 0.4 | < 0.38 | ----- | ----- |
| Solids | Total Suspended Solids (TSS) | mg/L | 20 | **152** | < 27 | **54** | **48** | 15 | 15 | **23** | < 15 | **181** | **37** |
| Nutrients | Total Nitrogen | mg/L | NA[d] | 2.4 | 3.7 | 1.5 | 1.7 | 2.2 | 0.68 | 3.4 | 3.1 | 1.6 | 1.6 |
| | Total Phosphorus | mg/L | NA[d] | 0.58 | 0.275 | 0.345 | 0.652 | 0.248 | 0.157 | 0.219 | 0.200 | 0.760 | 0.970 |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources.

[b] These thresholds are specific to the site's surface water quality classification. Black River's North Carolina surface water quality classification is Class C, Swamp Water, and Outstanding Resource Water (ORW+).

[c] Bold and shaded values represent EMCs that exceed the surface water quality threshold value without considering mixing.

[d] NA = No thresholds apply to Black River for these parameters based on its surface water quality classification.

[e] It can not be determined if these POCs exceed the threshold as all measured EMCs are below detection and the detection limit is greater than the threshold.

## Table 4.2-8: Little River – Direct Comparison of Bridge Deck Runoff and Thresholds

| | Parameters-of-Concern[a] | Units | Threshold[b] | Bridge Runoff Water Quality Data: Event Mean Concentrations[c] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | June 15, 2009 | July 5, 2009 | July 17, 2009 | July 30, 2009 | Aug 5, 2009 | Sept 17, 2009 | Oct 12, 2009 | Oct 24, 2009 | Nov 10, 2009 | Jan 17, 2010 |
| pH (acidic and basic) | | s.u. | 6 - 9 | 6.1 | 6.8 | 6.7 | 6.8 | 6.6 | 7.0 | 7.1 | 7.0 | 7.0 | 6.8 |
| Trace Metals | Total Recoverable Arsenic | µg/L | 10 | 0.73 | 0.71 | 0.62 | 0.90 | 0.46 | 0.67 | 0.51 | 0.58 | 0.42 | ----- |
| | Dissolved Cadmium | µg/L | 0.15 | 0.01 | 0.02 | 0.01 | 0.03 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | ----- |
| | Dissolved Copper | µg/L | 2.7 | 0.57 | **3.8** | 1.7 | 2.2 | 1.8 | 1.6 | **2.8** | 1.8 | 1.5 | ----- |
| | Total Recoverable Iron | µg/L | 300 | **1930** | **1160** | **1030** | **1250** | 161 | 68 | **340** | 297 | 282 | ----- |
| | Dissolved Lead | µg/L | 0.54 | 0.04 | 0.08 | 0.03 | 0.07 | < 0.06 | 0.04 | 0.08 | 0.05 | 0.07 | ----- |
| | Total Recoverable Manganese | µg/L | 200 | 136 | 88.2 | 65.6 | 61.7 | 9.8 | 5.5 | 11.6 | 16.9 | 15.5 | ----- |
| | Total Recoverable Nickel | µg/L | 25 | 2.4 | 2.3 | 1.4 | 2.3 | 0.43 | 0.32 | 0.90 | 0.86 | 0.47 | ----- |
| | Dissolved Zinc | µg/L | 36 | 9.9 | 19.5 | 9.8 | 9.3 | 12.1 | 19.4 | 11.8 | 14.5 | 11.6 | ----- |
| | Total Recoverable Aluminum | µg/L | 87 | **1460** | **988** | **875** | **1180** | **205** | **109** | **326** | **302** | **295** | ----- |
| | Total Recoverable Mercury | µg/L | 0.012 | 0.009 | 0.010 | 0.012 | 0.011 | 0.009 | < 0.010 | 0.007 | < 0.010 | < 0.010 | ----- |
| Semi-volatiles | Benzo-[b]-fluoranthene[d] | µg/L | 0.0038 | < 0.40 | ----- | < 0.40 | ----- | < 0.40 | < 0.40 | < 0.30 | < 0.30 | ----- | ----- |
| | Benzo-[a]-pyrene[d] | µg/L | 0.0038 | < 0.33 | ----- | < 0.33 | ----- | < 0.33 | < 0.33 | < 0.33 | < 0.33 | ----- | < 0.33 |
| | Benzo-[k]-fluoranthene[d] | µg/L | 0.0038 | < 0.4 | ----- | < 0.4 | ----- | < 0.4 | < 0.4 | < 0.30 | < 0.30 | ----- | ----- |
| | Chrysene[d] | µg/L | 0.0038 | < 0.33 | ----- | < 0.33 | ----- | < 0.33 | < 0.33 | < 0.33 | < 0.33 | ----- | < 0.33 |
| | Benzo-[a]-anthracene[d] | µg/L | 0.0038 | < 0.26 | ----- | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | < 0.26 | ----- | < 0.26 |
| | Bis(2-ethylhexyl)phthalate | µg/L | 1.2 | < 2 | **7** | < 2 | < 2 | < 2 | < 2 | **2** | < 2 | ----- | < 2 |
| | Indeno-[1,2,3-cd]-pyrene[d] | µg/L | 0.0038 | ----- | ----- | < 0.4 | ----- | < 0.4 | < 0.4 | < 0.38 | < 0.38 | ----- | ----- |
| Solids | Total Suspended Solids (TSS) | mg/L | 20 | **98** | **59** | **46** | **56** | < 15 | < 15 | < 15 | < 15 | < 15 | ----- |
| Nutrients | Total Nitrogen | mg/L | NA[e] | 1.2 | 1.2 | 1.0 | 1.3 | 0.54 | 0.72 | 0.52 | 0.53 | 0.34 | 0.86 |
| | Total Phosphorus | mg/L | 2 | 0.125 | 0.115 | 0.558 | 0.123 | 0.030 | 0.025 | 0.057 | 0.052 | 0.045 | 0.110 |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources.

[b] These thresholds are specific to the site's surface water quality classification. Little River's North Carolina surface water quality classification is Water Supply II (WSII), High Quality Water (HQW), Nutrient Sensitive Water (NSW), Water Supply Critical Area (CA).

[c] Bold and shaded values represent EMCs that exceed the surface water quality threshold value without considering mixing.

[d] It can not be determined if these POCs exceed the threshold as all measured EMCs are below detection and the detection limit is greater than the threshold.

[e] NA = No thresholds apply to Little River for these parameters based on its surface water quality classification.

## Table 4.2-9: Swannanoa River – Direct Comparison of Bridge Deck Runoff and Thresholds

| Parameters-of-Concern[a] | | Units | Threshold[b] | Bridge Runoff Water Quality Data: Event Mean Concentrations[c] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mar 25, 2009 | Mar 27, 2009 | Mar 31, 2009 | Apr 10, 2009 | May 1, 2009 | June 10, 2009 | June 16, 2009 | July 28, 2009 | Aug 10, 2009 | Sept. 9, 2009 | Oct. 12, 2009 |
| pH (acidic and basic) | | s.u. | 6 - 9 | 8.2 | 8.7 | 6.7 | 6.2 | 6.4 | 6.9 | 7.0 | 6.8 | 6.5 | 6.6 | 6.6 |
| Trace Metals | Total Recoverable Arsenic | µg/L | 10 | 0.67 | 2.4 | 1.8 | 1.1 | 0.84 | 0.52 | 0.38 | 0.59 | 0.57 | 0.39 | 0.49 |
| | Dissolved Cadmium | µg/L | 0.15 | 0.08 | 0.09 | 0.06 | 0.05 | **0.44** | 0.07 | 0.08 | 0.10 | 0.05 | 0.04 | 0.05 |
| | Dissolved Copper | µg/L | 2.7 | **8.3** | **5.1** | **12.2** | **7.6** | **9.2** | **3.5** | **3.8** | **15.7** | **4.6** | **3.7** | **5.1** |
| | Total Recoverable Iron | µg/L | 300 | **4020** | **46900** | **25300** | **5890** | **2150** | **2390** | **2090** | **3860** | **2720** | **1330** | **1550** |
| | Dissolved Lead | µg/L | 0.54 | 0.36 | 0.29 | 0.20 | 0.39 | 0.34 | 0.21 | 0.17 | 0.15 | 0.09 | 0.18 | 0.14 |
| | Total Recoverable Manganese | µg/L | 50 | **70.0** | **720** | **444** | **102** | **57.4** | 36.6 | 35.2 | **71.2** | 47.5 | 24.9 | 27.0 |
| | Total Recoverable Nickel | µg/L | NA[d] | 4.9 | 31.2 | 15.8 | 7.3 | 4.6 | 2.7 | 3.2 | 5.2 | 3.1 | 1.7 | 2.0 |
| | Dissolved Zinc | µg/L | 36 | 33.0 | **45.2** | 27.0 | 16.7 | **52.4** | 14.1 | 20.8 | **79.1** | 28.1 | 26.3 | 17.2 |
| | Total Recoverable Aluminum | µg/L | 87 | **1760** | **9940** | **8060** | **3150** | **1570** | **1140** | **1040** | **1910** | **1290** | **716** | **765** |
| | Total Recoverable Mercury | µg/L | 0.012 | 0.009 | 0.009 | 0.007 | 0.010 | **0.017** | < 0.010 | 0.011 | < 0.010 | **0.015** | 0.005 | 0.006 |
| Semi-volatiles | Benzo-[b]-fluoranthene[e] | µg/L | 0.0038 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Benzo-[a]-pyrene[e] | µg/L | 0.0038 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | < 0.33 |
| | Benzo-[k]-fluoranthene[e] | µg/L | 0.0038 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Chrysene[e] | µg/L | 0.0038 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Benzo-[a]-anthracene[e] | µg/L | 0.0038 | ----- | < 0.26 | ----- | ----- | ----- | ----- | ----- | ----- | < 0.26 | ----- | < 0.26 |
| | Bis(2-ethylhexyl)phthalate | µg/L | 1.2 | **6** | **6** | **6** | **6** | **4** | < 2 | **2** | **4** | **2** | < 7 | **3** |
| | Indeno-[1,2,3-cd]-pyrene[e] | µg/L | 0.0038 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Solids | Total Suspended Solids (TSS) | mg/L | NA[d] | 69 | 71 | 66 | 136 | 103 | 39 | 27 | 103 | 69 | 53 | 37 |
| Nutrients | Total Nitrogen | mg/L | NA[d] | 1.5 | 0.54 | 0.99 | 1.5 | 1.5 | 1.2 | 0.83 | 1.4 | 0.80 | 0.75 | 0.55 |
| | Total Phosphorus | mg/L | NA[d] | 0.399 | 0.46 | 0.98 | 0.483 | 0.250 | 0.275 | 0.148 | 0.375 | 0.172 | 0.078 | 0.091 |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources.

[b] These thresholds are specific to the site's surface water quality classification. Swannanoa River's North Carolina surface water quality classification is Class C.

[c] Bolded and shaded values represent EMCs that exceed the surface water quality threshold value without considering mixing.

[d] NA = No thresholds apply to Swannanoa River for these parameters based on its surface water quality classification.

[e] It can not be determined if these POCs exceed the threshold as all measured EMCs are below detection and the detection limit is greater than the threshold. Blank cells indicate that data has not yet been provided by the USGS for these parameters and storm events.

### Little River

At Little River, requirements for new NPDES wastewater discharges in High Quality Waters (15A NCAC 02B .0224) were applied to TSS. Further, because Little River is in the Neuse River Basin, a phosphorus limit of 2 mg/L was used for the analysis, a requirement for certain NPDES wastewater discharges that existed prior to January 1, 2003. Direct comparison of bridge deck runoff to thresholds shows exceedances of dissolved copper, total recoverable iron, total recoverable aluminum, bis(2-ethylhexyl)phthalate, and total suspended solids.

TSS, total recoverable iron, and total recoverable aluminum exceed thresholds upstream of the bridge crossing at concentrations similar to those found in bridge deck runoff. Both dissolved copper and bis(2-ethylhexyl)phthalate exceeded their respective thresholds in bridge deck runoff on the same storm event dates: July 5, 2009 and October 12, 2009. These storm events had the two longest antecedent dry periods (17.5 days and 14.0 days, respectively) and relatively low event volumes (355 L and 343 L, respectively) as compared to other storm events collected at Little River. Dissolved copper is regularly associated with traffic-related stormwater runoff (NCHRP, 2006). Bis(2-ethylhexyl)phthalate is a volatile organic compound that mostly commonly enters urban runoff through its ubiquitous use in various products as a plasticizer (Burton and Pitt, 2002).

### Swannanoa River

At Swannanoa River, dissolved cadmium, dissolved copper, total recoverable iron, total recoverable manganese, dissolved zinc, total recoverable aluminum, total recoverable mercury, bis(2-ethylhexyl)phthalate exceed thresholds in bridge deck runoff. Of these, total recoverable mercury, total recoverable iron, total recoverable aluminum and total recoverable manganese also exceed thresholds in Swannanoa River upstream of the bridge crossing. Concentrations of exceeding parameters in both the instream water and runoff are generally similar. Total recoverable iron and total recoverable aluminum both had elevated concentrations in bridge runoff for two events (March 27, 2009 and March 31, 2009) above concentrations generally seen in the river upstream of the bridge. These storms were characterized by relatively long durations (18.4 and 15.2 hrs, respectively). TSS concentrations were not particularly elevated for these storm events, however. Dissolved cadmium, dissolved copper, dissolved zinc, and bis(2-ethylhexyl)phthalate were elevated in bridge deck runoff for at least one storm event, but not upstream river water. Dissolved copper was elevated above threshold values in bridge deck runoff for every storm event monitored between March 2009 and October 2009 at Swannanoa River.

In conclusion, direct end-of-pipe comparison of site-specific surface water quality thresholds revealed a number of water quality parameters that exceeded thresholds at Black River, Little River, and Swannanoa River. Of those parameters, dissolved copper, dissolved zinc, dissolved cadmium, and bis(2-ethylhexyl)phthalate were elevated above levels typically seen in the rivers upstream of the bridge crossing. TSS concentrations were elevated above the threshold of 20 mg/L at Black River and Little River.

### 4.2.3.2 Mixing Analysis

There has been extensive study and regulatory guidance on the use of mixing zones to evaluate industrial wastewater and other point-source discharges (USEPA, 2006). A mixing zone is defined by the USEPA as "an area where an effluent discharge undergoes initial dilution" (USEPA, 2006). For permitting purposes, mixing zones define an area at the point of initial contact between the point source discharge and the receiving stream where exceedances of the surface water quality criteria are allowed provided the criteria are met at the edge of the mixing zone (NCDENR, 1999). Each state has discretion to allow the use of mixing zones; however, the USEPA has the authority to review and approve any mixing use policy (USEPA, 1991). In North Carolina, per 15A NCAC 02B .0204, the use of mixing zones is applied on a case-by-case basis.

The BSP was unable to find any examples of state-developed guidance on the use of mixing zones to evaluate stormwater discharges (not associated with industrial activities) to receiving streams. However, NCHRP recommends the consideration of dilution and the degree to which stormwater EMCs exceed surface water quality standards after mixing (Dupuis, 2002, vol. 1). Further, it is reasonable to assume that, depending on the relative size and typical flow rates of the receiving stream as compared to stormwater flow rates and impervious drainage areas, the dilution effect might have an impact on fully mixed parameter concentrations.

A simple, instantaneous mixing model was applied to data from Swannanoa River, Little River, and Black River, to allow for comparison to the end-of-pipe comparison presented in section 4.2.3.2. The equation for mass balance assuming instantaneous mixing, provided as equation 4.2-5, is based on the approach typically used to develop permit limits for point-source toxicants (NCDENR, 1999).

$$C_a = \frac{(Q_{lf} + Q_{stw})(C_s) - (Q_{lf})(C_{rs})}{Q_{stw}} \qquad \textbf{(4.2-5)}$$

where

$C_a$ = allowable concentration (mg/L or µg/L)
$C_s$ = the North Carolina surface water quality standard or USEPA recommended surface water quality criteria (mg/L or µg/L)
$C_{rs}$ = the instream concentration, upstream of the bridge deck, for the corresponding $Q_{lf}$ event (mg/L or µg/L)
$Q_{lf}$ = the lowest instream flow rate measured during the project monitoring period for which a water quality sample was also collected (cfs)
$Q_{stw}$ = the maximum flow rate of bridge deck runoff over the monitoring period (cfs)

For this analysis, $Q_{lf}$ is defined as the lowest instream flow rate measured during the project monitoring period with corresponding water chemistry data. Although the 7Q10 flow rate (the lowest stream flow for 7 consecutive days that occurs on average once every 10 years [NCDENR, 1999]) is used as the $Q_{lf}$ when evaluating point source, continuous flow discharges; this approach is not necessarily applicable for an intermittent stormwater discharge.

The resulting mixing evaluation, therefore, represents a worst-case, theoretical scenario. The selected mixing inputs are not reflective of the flow and chemistry conditions of any one storm event, but reflect the most extreme observations from the monitoring period. Therefore, this analysis is a conservative method to identify impacts and confirm a lack of impact for parameters whose EMC value is below the allowable concentration, $C_a$. Results of the mixing analysis are provided in tables 4.2-10 through 4.2-12 for Black River, Little River, and Swannanoa River.

## Table 4.2-10: Black River – Mixing Analysis

| | Parameters-of-Concern[a] | Units | Max. Bridge Deck Runoff EMC[b] | Receiving Stream Concentration ($C_{rs}$)[c] | Surface Water Quality Threshold ($C_t$)[d] | $C_{rs} > C_t$? | Allowable Concentration ($C_a$)[e] | Max. Bridge EMC > $C_a$? |
|---|---|---|---|---|---|---|---|---|
| | pH (acidic, basic)[f] | s.u. | 3.5, 7.0 | 6.8, 6.8 | ----- | ----- | ----- | ----- |
| Trace Metals | Total Recoverable Arsenic | µg/L | 3.7 | 1.0 | 5 | No | 87 | No |
| | Dissolved Cadmium | µg/L | 0.10 | <0.02 | 0.075 | No | 1 | No |
| | **Dissolved Copper** | µg/L | 4.6 | 1.3 | 1.35 | No | 2 | **Yes** |
| | **Total Recoverable Iron** | µg/L | 5250 | 1540 | 150 | **Yes** | 150 | **Yes** |
| | Dissolved Lead | µg/L | 0.66 | 0.16 | 0.27 | No | 2.5 | No |
| | **Total Recoverable Manganese** | µg/L | 124 | 52.6 | 25 | **Yes** | 25 | **Yes** |
| | Total Recoverable Nickel[g] | µg/L | 7 | 1.3 | ----- | ----- | ----- | ----- |
| | Dissolved Zinc | µg/L | 108 | 1.9 | 18 | No | 348 | No |
| | **Total Recoverable Aluminum** | µg/L | 1590 | 373 | 43.5 | **Yes** | 43.5 | **Yes** |
| | **Total Recoverable Mercury** | µg/L | 0.016 | 0.007 | 0.006 | **Yes** | 0.006 | **Yes** |
| Semi-volatiles | Benzo-[b]-fluoranthene[h] | µg/L | <0.40 | <0.40 | 0.0019 | Unknown | 0.0019 | Unknown |
| | Benzo-[a]-pyrene[h] | µg/L | <0.33 | <0.33 | 0.0019 | Unknown | 0.0019 | Unknown |
| | Benzo-[k]-fluoranthene[h] | µg/L | < 0.4 | <0.4 | 0.0019 | Unknown | 0.0019 | Unknown |
| | Bis(2-ethylhexyl)phthalate[h] | µg/L | <2 | <2 | 0.6 | Unknown | 0.6 | Unknown |
| | Chrysene[h] | µg/L | <0.33 | <0.33 | 0.0019 | Unknown | 0.0019 | Unknown |
| | Indeno-[1,2,3-cd]-pyrene[h] | µg/L | <0.4 | <0.4 | 0.0019 | Unknown | 0.0019 | Unknown |
| | Benzo-[a]-anthracene[h] | µg/L | <0.26 | <0.26 | 0.0019 | Unknown | 0.0019 | Unknown |
| Solids | **Total Suspended Solids (TSS)** | mg/L | 181 | 36 | 20 | **Yes** | 20 | **Yes** |
| Nutrients | Total Nitrogen[g] | mg/L | 3.7 | 0.74 | ----- | ----- | ----- | ----- |
| | Total Phosphorus[g] | mg/L | 0.97 | 0.196 | ----- | ----- | ----- | ----- |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources.

[b] The maximum bridge deck runoff flow rate, Qstw, was 1.22 cfs for the bridge deck runoff monitoring period at Black River.

[c] If $C_{rs}$ is below detection, but  is clearly below Ct, Crs is assumed to be equal to the Lab Reporting Level (LRL) for the mixing calculation. Where the presence of the parameter has been confirmed instream, but not quantified, Crs is represented as being less than the LRL for simplicity. The minimum instream flow rate for the low flow receiving stream sampling event, $Q_{lf}$, is equal to 25 cfs.

[d] These thresholds are specific to the site's surface water quality classification. Black River's North Carolina surface water quality classification is Class C, Swamp Water, and Outstanding Resource Water (ORW+).

[e] If the receiving stream already exceeds its surface water quality threshold prior to stormwater runoff inputs, the allowable concentration is equal to the surface water quality threshold.

[f] Resultant pH values for natural streams are a function of $CO_2$-acidity, total inorganic matter, and alkalinity. The instantaneous mixing equation used to calculate the allowable concentration is not appropriate for the assessment of pH.

[g] Mixing analysis could not be performed because no thresholds apply to Black River for these parameters based on its surface water quality classification.

[h] The mixing analysis can not be performed for these parameters as both the bridge deck runoff and the instream concentrations were below detection, and the detection limits are higher than the surface water quality threshold.

## Table 4.2-11: Little River – Mixing Analysis

| | Parameters-of-Concern[a] | Units | Max. Bridge Deck Runoff EMC [b] | Receiving Stream Concentration ($C_{rs}$) [c] | Surface Water Quality Threshold ($C_t$) [d] | $C_{rs} > C_t$? | Allowable Concentration ($C_a$) [e] | Max. Bridge EMC > $C_a$? |
|---|---|---|---|---|---|---|---|---|
| pH (acidic, basic) [f] | | std. units | 6.1, 7.5 | 6.9, 6.9 | ----- | ----- | ----- | ----- |
| Trace Metals | Total Recoverable Arsenic | µg/L | 0.90 | 0.52 | 10 | No | 14 | No |
| | Dissolved Cadmium | µg/L | 0.03 | <0.02 | 0.15 | No | 0.20 | No |
| | **Dissolved Copper** | µg/L | 3.8 | 0.60 | 2.7 | No | 3.6 | **Yes** |
| | **Total Recoverable Iron** | µg/L | 1930 | 580 | 300 | Yes | 300 | **Yes** |
| | Dissolved Lead | µg/L | 0.08 | 0.06 | 0.54 | No | 0.7 | No |
| | Total Recoverable Manganese | µg/L | 136 | 114 | 200 | No | 236 | No |
| | Total Recoverable Nickel | µg/L | 2.4 | 0.26 | 25 | No | 35 | No |
| | Dissolved Zinc | µg/L | 19.5 | <2.8 | 36 | No | 51 | No |
| | **Total Recoverable Aluminum** | µg/L | 1460 | 97 | 87 | Yes | 87 | **Yes** |
| | Total Recoverable Mercury | µg/L | 0.012 | <0.010 | 0.012 | No | 0.013 | No |
| Semi-volatiles | Benzo-[b]-fluoranthene[g] | µg/L | <0.40 | <0.30 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[a]-pyrene[g] | µg/L | <0.33 | <0.33 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[k]-fluoranthene[g] | µg/L | <0.4 | <0.30 | 0.0038 | Unknown | 0.0038 | Unknown |
| | **Bis(2-ethylhexyl)phthalate** | µg/L | 7 | <2 | 1.2 | Unknown | 1.2 | **Yes** |
| | Chrysene[g] | µg/L | <0.33 | <0.33 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Indeno-[1,2,3-cd]-pyrene[g] | µg/L | <0.4 | <0.38 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[a]-anthracene[g] | µg/L | <0.26 | <0.26 | 0.0038 | Unknown | 0.0038 | Unknown |
| Solids | **Total Suspended Solids (TSS)** | mg/L | 98 | <15 | 20 | No | 22 | **Yes** |
| Nutrients | Total Nitrogen[h] | mg/L | 1.3 | 0.39 | ----- | ----- | ----- | ----- |
| | Total Phosphorus | mg/L | 0.558 | 0.030 | 2 | No | 3 | No |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources.

[b] The Maximum Bridge Deck Runoff Flow Rate, Qstw, was 2.23 cfs for the bridge deck runoff monitoring period at Little River.

[c] If Crs is below detection but is clearly below Ct, or the presence of the parameter was confirmed but not quantified, Crs is assumed to be equal to the Lab Reporting Level (LRL) for the mixing calculation. Where the presence of the parameter has been confirmed instream, but not quantified, Crs is represented as being less than the LRL for simplicity. The minimum instream flow rate for the low flow receiving stream sampling event, Qlf, is equal to 0.93 cfs.

[d] These thresholds are specific to the site's surface water quality classification. Little River's North Carolina surface water quality classification is Water Supply II (WSII), High Quality Water (HQW), Nutrient Sensitive Water (NSW), Water Supply Critical Area (CA).

[e] If the receiving stream already exceeds its surface water quality threshold prior to stormwater runoff inputs, the allowable concentration is equal to the surface water quality threshold.

[f] Resultant pH values for natural streams are a function of CO2-acidity, total inorganic matter, and alkalinity. The instantaneous mixing equation used to calculate the allowable concentration is not appropriate for the assessment of pH.

[g] The mixing analysis can not be performed for these parameters as both the bridge deck runoff and the instream concentrations were below detection, and the detection limits are higher than the surface water quality threshold.

[h] Mixing analysis could not be performed because no thresholds apply to Little River for these parameters based on its surface water quality classification.

## Table 4.2-12: Swannanoa River – Mixing Analysis

| | Parameters-of-Concern[a] | Units | Max. Bridge Deck Runoff EMC[b] | Receiving Stream Concentration ($C_{rs}$)[c] | Surface Water Quality Threshold ($C_t$)[d] | $C_{rs} > C_t$? | Allowable Concentration ($C_a$)[e] | Max. Bridge EMC > $C_a$? |
|---|---|---|---|---|---|---|---|---|
| pH (acidic and basic)[f] | | std. units | 6.2, 8.7 | 6.8, 6.8 | ----- | ----- | ----- | ----- |
| Trace Metals | Total Recoverable Arsenic | µg/L | 2.4 | 0.17 | 10 | No | 24 | No |
| | **Dissolved Cadmium** | µg/L | 0.44 | 0.02 | 0.15 | No | 0.3 | **Yes** |
| | **Dissolved Copper** | µg/L | 15.7 | <1.0 | 2.7 | No | 5.1 | **Yes** |
| | **Total Recoverable Iron** | µg/L | 46900 | 721 | 300 | **Yes** | 300 | **Yes** |
| | Dissolved Lead | µg/L | 0.39 | 0.05 | 0.54 | No | 1 | **No** |
| | **Total Recoverable Manganese** | µg/L | 720 | 100 | 50 | **Yes** | 50 | **Yes** |
| | Total Recoverable Nickel[g] | µg/L | 31.2 | 0.45 | ----- | ----- | ----- | ----- |
| | Dissolved Zinc | µg/L | 79.1 | 2.5 | 36 | No | 84 | No |
| | **Total Recoverable Aluminum** | µg/L | 9940 | 91 | 87 | **Yes** | 87 | **Yes** |
| | **Total Recoverable Mercury** | µg/L | 0.017 | <0.010 | 0.012 | No | 0.015 | **Yes** |
| Semi-volatiles | Benzo-[b]-fluoranthene[h] | µg/L | <0.40 | <0.40 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[a]-pyrene[h] | µg/L | <0.33 | <0.33 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[k]-fluoranthene[h] | µg/L | <0.4 | <0.4 | 0.0038 | Unknown | 0.0038 | Unknown |
| | **Bis(2-ethylhexyl)phthalate** | µg/L | 6 | <2 | 1.2 | Unknown | 1.2 | **Yes** |
| | Chrysene[h] | µg/L | <0.33 | <0.33 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Indeno-[1,2,3-cd}-pyrene[h] | µg/L | <0.4 | <0.4 | 0.0038 | Unknown | 0.0038 | Unknown |
| | Benzo-[a]-anthracene[h] | µg/L | <0.26 | <0.26 | 0.0038 | Unknown | 0.0038 | Unknown |
| Solids | Total Suspended Solids (TSS)[g] | mg/L | 136 | <15 | ----- | ----- | ----- | ----- |
| Nutrients | Total Nitrogen[g] | mg/L | 1.5 | 0.31 | ----- | ----- | ----- | ----- |
| | Total Phosphorus[g] | mg/L | 0.98 | 0.012 | ----- | ----- | ----- | ----- |

**Notes:**

[a] The BSP parameters-of-concern (POC) were determined by comparing the maximum EMC measured across all monitoring sites to the most stringent surface water quality criteria, standard, or toxicological data from various sources. Refer to table 4.2-6.

[b] The maximum bridge deck runoff flow rate, Qstw, was 1.82 cfs for the bridge deck runoff monitoring period at Swannanoa River.

[c] If Crs is below detection, but is clearly below Ct, Crs is assumed to be equal to the Lab Reporting Level (LRL) for the mixing calculation. Where the presence of the parameter has been confirmed instream, but not quantified, Crs is represented as being less than the LRL for simplicity. The minimum instream flow rate for the low flow receiving stream sampling event, Qlf, is equal to 2.6 cfs.

[d] These thresholds are specific to the site's surface water quality classification. Swannanoa River's North Carolina surface water quality classification is Class C.

[e] If the receiving stream already exceeds its surface water quality threshold prior to stormwater runoff inputs, the allowable concentration is equal to the surface water quality threshold.

[f] Resultant pH values for natural streams are a function of CO2-acidity, total inorganic matter, and alkalinity. The instantaneous mixing equation used to calculate the allowable concentration is not appropriate for the assessment of pH.

[g] Mixing analysis could not be performed because no thresholds apply to Swannanoa River for these parameters based on its surface water quality classification.

[h] The mixing analysis can not be performed for these parameters as both the bridge deck runoff and the instream concentrations were below detection, and the detection limits are higher than the surface water quality threshold.

Interestingly, performing the mixing analysis did not eliminate many parameters previously identified as exceeding the surface water quality threshold via direct comparison with end-of-pipe EMCs. In fact, no elevated POCs were eliminated in the mixing analysis at Little River. Because many of the parameters identified in the direct comparison analysis already exceeded thresholds upstream of the bridge deck crossing, the allowable concentration defaults to the threshold value. Therefore, observations of exceedances for total recoverable iron, total recoverable manganese, total recoverable aluminum, and total recoverable mercury are unchanged. However, dissolved zinc was below the allowable concentration at Black River and Swannanoa River, eliminating it as an elevated POC at these sites. A summary of results from both the direction comparison and mixing analysis are provided in table 4.2-13. Based on the results of the mixing analysis, it is reasonable to assume dissolved copper, TSS, and bis(2-ethylhexyl)phthalate as elevated POCs associated with bridge deck runoff given the variability of bridge and receiving stream characteristics at the three sites studied. In general, such a mixing analysis is beneficial for identifying situations where considering differences between stream flow rate and bridge deck runoff flow rate may help identify important POCs for stormwater treatment and mitigation purposes.

**Table 4.2-13: POCs Elevated above Thresholds for Direct Comparison and Mixing Analysis**

| Analysis | Black River | Little River | Swannanoa River |
|---|---|---|---|
| Direct Comparison of Bridge Deck Runoff and Thresholds | Dissolved Cd<br>Dissolved Cu<br>Dissolved Pb<br>Dissolved Zn<br>Total Recoverable Fe<br>Total Recoverable Mn<br>Total Recoverable Al<br>Total Recoverable Hg<br>TSS | Dissolved Cu<br>Total Recoverable Fe<br>Tot Recoverable Al<br>Bis(2-ethylhexyl) phthalate<br>TSS | Dissolved Cd<br>Dissolved Cu<br>Dissolved Zn<br>Total Recoverable Fe<br>Total Recoverable Mn<br>Total Recoverable Al<br>Total Recoverable Hg<br>Bis(2-ethylhexyl) phthalate |
| Parameters from Direct Comparison Not Also Elevated Upstream of Bridge Crossing | Dissolved Cd<br>Dissolved Cu<br>Dissolved Zn<br>TSS | Dissolved Cu<br>Bis(2-ethylhexyl) phthalate | Dissolved Cd<br>Dissolved Cu<br>Dissolved Zn<br>Total Recoverable Fe<br>Total Recoverable Al<br>Bis(2-ethylhexyl) phthalate |
| Comparison of Maximum Bridge Deck Runoff EMC to Allowable Concentration (Ca) – Mixing Analysis | Dissolved Cu<br>Total Recoverable Fe<br>Total Recoverable Mn<br>Total Recoverable Al<br>Total Recoverable Hg<br>TSS | Dissolved Cu<br>Total Recoverable Fe<br>Total Recoverable Al<br>Bis(2-ethylhexyl) phthalate<br>TSS | Dissolved Cd<br>Dissolved Cu<br>Total Recoverable Fe<br>Total Recoverable Mn<br>Total Recoverable Al<br>Total Recoverable Hg<br>Bis(2-ethylhexyl) phthalate |
| Parameters from Mixing Analysis Not Also Elevated Upstream of Bridge Crossing | Dissolved Cu<br>TSS | Dissolved Cu<br>Bis(2-ethylhexyl) phthalate | Dissolved Cd<br>Dissolved Cu<br>Bis(2-ethylhexyl) phthalate |

### 4.2.4 Bridge Characteristic Statistical Analysis

It is fairly well-established that precipitation-related factors such as antecedent dry period, seasonal cumulative rainfall, total precipitation for a wet-weather event, and rainfall intensity directly impact pollutant concentrations (Kayhanian et al., 2003; Li et al., 2008). However, because these indicator parameters can influence local regions and are highly variable, precipitation-based indicators of runoff quality are not particularly useful for determining which projects may require stormwater control measures (SCMs) due to higher pollutant loads during the project environmental planning stage of a bridge project. Therefore, previous researchers have attempted to define the relationship between site-specific characteristics and pollutant concentrations in an effort to best allocate stormwater management resources.

The first significant study that attempted to discern the potential relationships between roadway characteristics and pollutant concentrations was done by the FHWA (1990). Using data from 31 highway sites across 11 states, the FHWA separated sites into urban and rural highway sites based on an average daily traffic split of 30,000 vehicles per day and compared median EMC values for a variety of parameters between these two groups. While the urban roadway sites (> 30,000 ADT) show a significantly higher median EMC than the rural highway sites, linear correlation-regression analysis showed that as ADT increases, pollutant concentrations do not necessarily increase in a linear fashion. Therefore, the researchers concluded that ADT does not directly impact pollutant loads, but may be an indicator for atmospheric quality differences between urban and rural land uses (FHWA 1990).

Recently, Kayhanian et al. (2003) performed a statistical analysis on a comprehensive Caltrans highway runoff dataset of monitoring data from 83 highway sites over a 4-year period. Multiple linear regression (MLR) analysis and Analysis of Covariance (ANCOVA) were performed, among other statistical analyses. The MLR analysis revealed that ADT, event rainfall, cumulative seasonal precipitation, and antecedent dry period each had a similar effect on pollutant concentrations. While these four constituents have a statistically significant influence on pollutant concentrations, ADT is the only parameter that can be reasonably quantified by transportation agencies in advance of a project being built. In conclusion, ADT remains an important indicator of potentially high pollutant concentrations and can be useful for locating sites which would benefit from potential SCM retrofit installations. However, because ADT alone cannot accurately predict whether pollutant concentrations at a particular site will be higher than another, it should not be used as a sole indicator of impact.

The BSP investigated whether conclusions regarding the impact of ADT on roadway runoff also applied specifically to bridge deck runoff. Given the provisional nature of the dataset at the time of report preparation, simple hypothesis testing comparing stormwater EMC distributions from different groupings of bridge characteristics was performed, similar to the FHWA effort (FHWA, 1990). This analysis is a cursory investigation of the potential ability of bridge characteristics to predict elevated pollutant loads. Results should not be used to conclude that one bridge characteristic will result in elevated pollutant loads in all situations. Should a more in-depth evaluation of the impact of bridge characteristics as compared to hydrologic factors be desired, an MLR analysis should be performed on the fully approved dataset, in the fashion of Kayhanian et al. (2003).

Bridge deck runoff data from the 15 primary monitoring sites were grouped according to the site characteristics listed table 4.2-14.

**Table 4.2-14: Bridge Characteristics Evaluated For Relationship to Pollutant Load**

| Bridge Characteristic | Definition | Source of Information |
|---|---|---|
| Ecoregion | A site's location within one of the three physiographic regions in North Carolina. These regions include the Blue Ridge ecoregion, the Piedmont ecoregion, and the Coastal ecoregion. | Refer to Section 3.1 of this report for more information. |
| Average Daily Traffic | Average number of vehicles per day traveling past a specific point as measured during a given time period. ADT is analyzed in terms of high ADT (≥ 30,000 vpd) or low ADT (< 30,000 vpd). | Confirmed by traffic survey monitoring. Refer to Section 3.5 of this report for more information. |
| Bridge Deck Wearing Surface | The material that overlays the bridge deck and is primarily abraded through interaction with vehicle tires. Only the general material classifications concrete and bituminous (i.e., asphalt) are investigated in this analysis. | The NCDOT Bridge Database managed by the NCDOT Bridge Maintenance Unit. |
| Urban or Rural | Any roadway passing through an Urbanized Area or Urban Cluster within the state with a population greater than 5,000 people is defined as an urban facility. Roadways passing through Urban Clusters and all other areas with populations less than 5,000 are classified as rural facilities. | The NCDOT Bridge Database managed by the Bridge Maintenance Unit. NCDOT categorizes the roadway network per the FHWA Functional Classification Guidelines (FHWA, 1989). |
| North Carolina Multimodal Infrastructure Network (NCMIN) Tier | Roadways are classified in the NCMIN as Statewide, Regional, and Subregional according to the facility's general connectivity and usage. Statewide tiers connect regional centers and provide a mobility function. Regional tiers connect major population centers. Subregional tiers serve predominantly localized movements. | NCMIN Tiers are presented on county-specific maps on the NCDOT website (NCDOT, 2009b). |

Previous statistical analyses have used ADT to define urban and rural roadways (FHWA, 1990; Kayhanian et al., 2003). In this analysis, ADT was not used to define urban and rural areas, and the two characteristics were evaluated separately. The classification of urban and rural roadways according to surrounding area population is consistent with the functional roadway classification guidelines (FHWA, 1989). Further, given recent research that suggests atmospheric deposition of metals, which can account for a significant portion of metal inputs to runoff, is linked to proximity to urban areas, defining urban roadways by population is appropriate for this analysis (Sabin and Schiff, 2008).

Bridge deck runoff event mean concentrations, collected from March 2009 to March 2010, were combined into distributions based on the bridge characteristics listed in table 4.2-14. The distributions were subjected to a paired statistical analysis to determine if the populations were significantly different from each other. Decisions about significant difference for the BSP data were made by comparing the p-value from the appropriate statistical test to the standard significance level of 0.05 ($\alpha = 0.05$) (Freund and Wilson, 1997). The p-value reported by each analysis is an indicator of the weight-of-evidence against the null hypothesis (i.e., the assumption that two distributions are from the same population). Low p-values indicate that the results of the statistical tests are not probable if the null hypothesis (typically the status quo situation) is true. Therefore, the null hypothesis is rejected if the calculated p-value is less than 0.05.

Combined distributions that were fully detectable were tested first for normality or lognormality using the Shapiro-Wilk test. They were then tested for variance using the F-test, and depending on the underlying distribution, a two-way Student's t-test was performed, using equal or unequal variance as appropriate for each analyte. If the distribution was neither normal nor lognormal, significant difference between the datasets was determined using the Mann Whitney test. For any dataset that contained censored data, Gehan's test was performed in lieu of the Student's t-test; because Gehan's test is nonparametric, no test for normality was necessary. Gehan's test is a nonparametric analysis that tests for differences between the medians of two datasets that have multiple censoring points and detection limits. In the case of either the Student's t-test or Gehan's test, the goal of the analysis is to determine if EMCs from bridges with one characteristic are the same or different from EMCs with another characteristic, indicating that the characteristic may influence or predict pollutant loading.

Results of hypothesis testing are provided in table 4.2-15. Summary tables with detail results of each paired analysis are provided in appendix 4-A. The analysis focused on inorganic constituents, predominantly nutrients and metals that qualified as parameters-of-concern, due to the high number of nondetect values present for organic constituents. For the project-specific definition of parameters-of-concern (POC), refer to section 4.2.2 of this report.

Major observations from the bridge characteristic analysis include:

- Significant differences between total recoverable metals, particularly nickel, aluminum, manganese, iron, chromium, and lead, tend to track significant differences in total suspended solids. These metals tend to be predominantly particulate-bound, with the exception of manganese (Blazier, 2003). Therefore, these results may reflect a difference in solids generation by bridge characteristic.
- For characteristics in which total recoverable arsenic showed a significant difference (statewide vs. regional, regional vs. subregional, urban vs. rural, piedmont vs. coastal, and blue ridge vs. coastal), the higher arsenic mean and median was associated with the characteristic opposite to other total recoverable and dissolved metals and TSS. Because a major source of arsenic in stormwater runoff is air deposition from point sources (e.g., coal-fired power plants) (NCHRP, 2006), total recoverable arsenic loads in highway runoff may be related to atmospheric pathways. Higher total recoverable arsenic distributions were noted for coastal bridges primarily. Even though total recoverable arsenic was significantly higher in regional bridges as compared to statewide and subregional bridges, both regional bridge sites in this analysis (Town Creek and Black River) are also coastal sites.
- Similar to previous studies, ADT showed a small influence on pollutant distributions with only total recoverable zinc, copper, and cadmium significantly higher for high ADT bridges.
- Significantly higher nutrients were generally found in piedmont, regional, and subregional bridges and were associated with asphalt pavement. Surprisingly, only nitrate+nitrite and dissolved orthophosphate were significantly different between urban and rural sites. Further, the nitrate+nitrite distribution was higher in urban sites as opposed to rural sites.
- Dissolved metals, as a whole, did not exhibit any strong relationship with any one bridge characteristic. Dissolved zinc was only significantly different based on bridge surface material, with higher concentrations noted for asphalt bridges. The dissolved lead distribution was also higher in asphalt bridges. Dissolved copper and dissolved lead concentrations were significantly higher in piedmont and urban bridges. Dissolved cadmium concentrations were higher for statewide and regional bridges, but showed no significant difference between urban and rural bridges and high and low ADT bridges.
- Of all the characteristics investigated, the urban versus rural designation appears to have the most influence on pollutant loading. All solids parameters studied were higher in urban areas, as well as most total recoverable metals and dissolved copper and lead. Similar relationships were also noted for the concrete versus asphalt hypothesis testing, but most urban bridges were also concrete with the exception of Swift Creek.

### Table 4.2-15: Summary of Hypothesis Testing for Various Bridge Characteristics

| Parameter | | units | Ecoregion | | | | | | Concrete | Asphalt | High ADT | Low ADT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pied-mont | Coastal | Blue Ridge | Pied-mont | Blue Ridge | Coastal | | | | |
| Solids | Total Suspended Solids | mg/L | **43** | 36 | ----- | ----- | **50** | 36 | **49** | 28 | ----- | ----- |
| | Total Dissolved Solids | mg/L | ----- | ----- | ----- | ----- | ----- | ----- | **35** | 34 | ----- | ----- |
| | Suspended Sediment Conc. | mg/L | ----- | ----- | ----- | ----- | ----- | ----- | **961** | 417 | ----- | ----- |
| Nutrients | Total Nitrogen | mg/L | ----- | ----- | 1.0 | **1.2** | ----- | ----- | 1.0 | **1.3** | ----- | ----- |
| | Total Kjeldahl Nitrogen (TKN) | mg/L-N | ----- | ----- | ----- | ----- | ----- | ----- | 0.74 | **1.0** | ----- | ----- |
| | Nitrate+Nitrite | mg/L-N | **0.24** | 0.20 | 0.18 | **0.24** | ----- | ----- | ----- | ----- | ----- | ----- |
| | Ammonia | mg/L-N | ----- | ----- | 0.051 | **0.097** | ----- | ----- | 0.041 | **0.128** | ----- | ----- |
| | Total Phosphorus | mg/L-P | ----- | ----- | **0.481** | 0.228 | ----- | ----- | ----- | ----- | ----- | ----- |
| | Orthophosphate | mg/L-P | ----- | ----- | **0.020** | 0.017 | ----- | ----- | 0.011 | **0.023** | ----- | ----- |
| Trace Metals | Total Recoverable Arsenic | µg/L | 1.1 | **1.8** | ----- | ----- | 0.95 | **1.4** | ----- | ----- | ----- | ----- |
| | Dissolved Zinc | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | 13.5 | **19.8** | ----- | ----- |
| | Total Recoverable Zinc | µg/L | **118** | 59.9 | ----- | ----- | **120** | 59.9 | **143** | 68.5 | **212** | 94.2 |
| | Total Recoverable Nickel | µg/L | ----- | ----- | ----- | ----- | **4.7** | 3.0 | **5.1** | 2.6 | ----- | ----- |
| | Total Recoverable Aluminum | µg/L | **1385** | 467 | **2472** | 1385 | **2472** | 467 | **2160** | 954 | ----- | ----- |
| | Total Recoverable Manganese | µg/L | **88.4** | 35.0 | ----- | ----- | **101** | 35.0 | **101** | 61.9 | ----- | ----- |
| | Total Recoverable Iron | µg/L | **1320** | 429 | **5055** | 2541 | **2180** | 429 | **4680** | 1498 | ----- | ----- |
| | Dissolved Copper | µg/L | **4.7** | 2.3 | 2.1 | **4.7** | ----- | ----- | ----- | ----- | ----- | ----- |
| | Total Recoverable Copper | µg/L | ----- | ----- | 8.6 | **12.9** | ----- | ----- | **16.2** | 6.2 | **17.6** | 8.7 |
| | Total Recoverable Mercury | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Dissolved Cadmium | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Total Recoverable Cadmium | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | **0.12** | 0.08 | **0.15** | 0.10 |
| | Total Recoverable Chromium | µg/L | **4.3** | 1.6 | ----- | ----- | **5.3** | 1.6 | **10.9** | 5.6 | ----- | ----- |
| | Dissolved Lead | µg/L | **0.13** | 0.05 | 0.06 | **0.13** | ----- | ----- | 0.08 | **0.12** | ----- | ----- |
| | Total Recoverable Lead | µg/L | **8.75** | 2.35 | 8.87 | **26.1** | ----- | ----- | ----- | ----- | ----- | ----- |
| Hydro-carbon | Oil and Grease | mg/L | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |

**Notes:** Concentrations listed reflect either mean or median value for parameters that showed a statistically significant difference for a particular bridge characteristic. If concentrations are not listed for a particular parameter and bridge characteristic, no significant difference was found. Mean values are shown for parametric analyses (e.g., Student's t-test), and median values are shown for nonparametric tests (e.g., Mann Whitney test, Gehan's test). Bold values represent the higher mean or median value for a bridge characteristic and parameter within each comparison.

### Table 4.2-15: Summary of Hypothesis Testing for Various Bridge Characteristics (continued)

| | Parameter | units | North Carolina Multimodal Investment Network (NCMIN) | | | | | | Urban | Rural |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Statewide | Regional | Statewide | Subregional | Regional | Subregional | | |
| Solids | Total Suspended Solids | mg/L | **41** | 13 | ----- | ----- | 13 | **44** | **59** | 46 |
| | Total Dissolved Solids | mg/L | ----- | ----- | **35** | 32 | ----- | ----- | **37** | 32 |
| | Suspended Sediment Conc. | mg/L | ----- | ----- | ----- | ----- | ----- | ----- | **787** | 665 |
| Nutrients | Total Nitrogen | mg/L | 0.75 | **1.2** | 0.9 | **1.2** | ----- | ----- | ----- | ----- |
| | Total Kjeldahl Nitrogen (TKN) | mg/L-N | 0.60 | **1.2** | 0.49 | **0.83** | ----- | ----- | ----- | ----- |
| | Nitrate+Nitrite | mg/L-N | ----- | ----- | ----- | ----- | ----- | ----- | **0.25** | 0.18 |
| | Ammonia | mg/L-N | 0.041 | **0.138** | 0.041 | **0.065** | ----- | ----- | ----- | ----- |
| | Total Phosphorus | mg/L-P | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Orthophosphate | mg/L-P | 0.014 | **0.029** | ----- | ----- | **0.026** | 0.018 | 0.014 | **0.020** |
| Trace Metals | Total Recoverable Arsenic | µg/L | 1.1 | **2.1** | ----- | ----- | **1.8** | 0.94 | ----- | ----- |
| | Dissolved Zinc | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Total Recoverable Zinc | µg/L | **186** | 60.8 | **186** | 87.7 | ----- | ----- | **161** | 73 |
| | Total Recoverable Nickel | µg/L | **5.7** | 1.9 | ----- | ----- | 1.9 | **3.7** | **5.5** | 2.9 |
| | Total Recoverable Aluminum | µg/L | **1715** | 380 | ----- | ----- | 380 | **1814** | **1910** | 1380 |
| | Total Recoverable Manganese | µg/L | **102** | 31.6 | ----- | ----- | 31.6 | **86.6** | **110** | 65.1 |
| | Total Recoverable Iron | µg/L | **2120** | 326 | ----- | ----- | 326 | **1500** | **4607** | 2248 |
| | Dissolved Copper | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | **4.6** | 2.3 |
| | Total Recoverable Copper | µg/L | **18.5** | 5.2 | **18.5** | 8.7 | 5.2 | **8.7** | **19.5** | 5.6 |
| | Total Recoverable Mercury | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Dissolved Cadmium | µg/L | ----- | ----- | **0.03** | 0.02 | **0.03** | 0.02 | ----- | |
| | Total Recoverable Cadmium | µg/L | **0.16** | 0.08 | **0.16** | 0.08 | ----- | ----- | **0.16** | 0.08 |
| | Total Recoverable Chromium | µg/L | **6.0** | 1.2 | **13.8** | 7.5 | 1.2 | **4.3** | **14.3** | 4.6 |
| | Dissolved Lead | µg/L | ----- | ----- | ----- | ----- | ----- | ----- | **0.13** | 0.07 |
| | Total Recoverable Lead | µg/L | **6.4** | 2.1 | ----- | ----- | 2.1 | **6.3** | **30.0** | 6.9 |
| Hydro-carbons | Oil and Grease | mg/L | ----- | ----- | ----- | ----- | ----- | ----- | **5.3** | 4.3 |

**Notes:** Concentrations listed reflect either mean or median value for parameters that showed a statistically significant difference for a particular bridge characteristic. If concentrations are not listed for a particular parameter and bridge characteristic, no significant difference was found. Mean values are shown for parametric analyses (e.g., Student's t-test), and median values are shown for nonparametric tests (e.g., Mann Whitney test, Gehan's test). Bold values represent the higher mean or median value for a bridge characteristic and parameter within each comparison.

## 4.3 Solids and Instream Sediment

Streambed sediment samples were collected from 30 bridge sites across North Carolina to evaluate sediment chemistry bridge deck crossings and to determine if sediment chemistry varies based on the use of engineered drainage systems as compared to allowing direct discharge of bridge deck runoff to receiving streams. The scope of these investigations and the monitoring methods are discussed in section 3 of this report.

Bridge deck solids were also collected over a five month period to study the chemical constituents present in solids that could potentially enter receiving streams during storm events. The scope of these investigations and the monitoring methods are also discussed in section 3 of this report.

## 4.3.1 Streambed Sediment Quality

Streambed sediment samples were collected from 30 locations across North Carolina, including 16 from direct discharge sites and 14 from no-direct discharge study sites, between June 30 and August 7, 2009. A field replicate and two split samples were analyzed from a single study site in each geographic region for QA/QC purposes. Section 3.3 discusses the methods used in the collection and analysis of streambed sediments and includes results of the chemical analysis for a variety of organic and inorganic analytes. As indicated in section 3.3.1, all organic and inorganic constituent analyses were performed on the fine-grained subsample only.

Data evaluations were performed comparing analytes of potential environmental significance (a) downstream from direct discharge and no-direct discharge bridges; (b) upstream vs. downstream for all bridges; and (c) between ecoregions. Statistical analyses were conducted using the procedures outlined in section 4.2.4. For purposes of evaluation, data were averaged where multiple analyses were available for a single sample location (e.g., a primary sample, duplicates, and splits). For summary statistics, surrogate values were estimated for nondetect values using regression order statistics (ROS) if sufficient data were available (eight detections and a frequency of detection of 30%) and a discernible distribution could be derived based on the detected data  For more information on statistical procedures for censored and uncertain data, refer to appendix 3-F.

### 4.3.1.1 Direct versus No-Direct Discharge Bridges

Sediment bed data collected downstream from direct and no-direct discharge bridges were compared to assess the environmental impacts of each method. Summary statistics for organic and inorganic analytes are presented in tables 4-B.1 and 4-B.2 in appendix 4-B.  Similar to the statistical analyses presented in section 4.2, the null hypothesis, i.e., the assumption that the two populations being compared are the same, is rejected if the calculated p-value is less than 0.05.

**Inorganic Analytes**

In general, the majority of inorganic analytes were detected in samples downstream from both direct and no-direct discharge bridges. Thallium and uranium were not detected in any samples. Silver was detected only once among the 30 downstream sediment samples (downstream from a no-direct discharge bridge – Smith Creek [640132]). Molybdenum was detected downstream from 50% of the no-direct discharge bridges, and 44% of the direct discharge bridges. Cadmium was detected at every site except downstream of one direct discharge bridge.

The relative difference in the mean concentration at no-direct discharge bridges compared with direct discharge bridges did not show a discernable pattern. Excluding thallium, uranium, silver and molybdenum (due to the low frequency of detection), concentrations were higher downstream of no-direct discharge bridges on average for 47% of the constituents, and higher downstream of direct discharge bridges for 53% of the analytes. The relative difference in the mean concentration between no-direct and direct discharge bridges was generally within the range of ±40%. The single exception was mercury (-284%), which was associated with a single elevated concentration (3.8 mg/kg) observed downstream from a direct discharge bridge at Mallard Creek [590083]. This value was found to be a statistically significant outlier and not characteristic of bed sediments associated with any other bridges evaluated. This observation is believed to be an anomaly and not representative of bridge runoff characteristics.

Two-sample mean comparisons were conducted, with the null hypothesis that the mean concentrations downstream from no-direct discharge bridges were equal to the mean concentrations downstream from direct discharge bridges. No statistically significant differences were observed in inorganic concentrations downstream from direct and no-direct discharge bridges.

#### Organic Constituents

Unlike the inorganic data, the frequency of detection for organic constituents was relatively low. The following organic constituents were not detected downstream from any of the bridges evaluated – hexachlorobenzene, pentachloroanisole, 1,2,4-trichlorobenzene, 1,2-dimethylnaphthalene, 1,6-dimethylnaphthalene, 1-methyl-9H-fluorene, 1-methylpyrene, 2,3,6-trimethynaphthalene, 2-methylanthracene, acenaphthylene, dibenzo(a,h)anthracene, dibenzothiophene, diethyl phthalate, naphthalene, phenanthridine.

Relatively few organic constituents were detected at a frequency of greater than 50%. With the exception of pyrelene, the relative frequency of detection was similar to or slightly higher in no-direct discharge bridges as compared with direct discharge bridges. Organics detected at frequencies of greater than 50% include 9,10-anthraquinone, benzo(a)anthracene , benzo(b)fluoranthene, benzo(e)pyrene, bis(2-ethylhexyl)phthalate, fluoranthene, perylene, phenanthrene, and pyrene.

A statistical evaluation of organic analytes comparing no-direct and direct discharge bridges is presented in table 4-B.2 in appendix 4-B. Due to the low frequency of detection, statistical comparisons could only be made for perylene and pyrene. Concentrations of perylene and pyrene were not statistically different when comparing sediments downstream from no-direct and direct discharge bridges. To the extent that these two polycyclic aromatic hydrocarbons are indicative of organic constituents in general, there do not appear to be differences in impacts to bed sediments associated with direct and no-direct discharge bridges.

Combined with the inorganic data, the comparisons of direct and no-direct discharge drainage systems do not indicate that direct discharge bridges materially impact sediment quality downstream.

### 4.3.1.2 Sediments Upstream versus Downstream

In addition to the comparison of downstream sediment chemistry at direct and no-direct discharge bridge sites, sediment chemistry downstream and upstream of all 30 bridge sites were compared for evidence of impacts on bed sediment from bridge deck runoff.

#### Inorganic Constituents

A statistical evaluation of inorganic data comparing upstream versus downstream sediment is presented in table 4-B.3 in appendix 4-B.

Thallium and uranium were not detected either upstream or downstream. Molybdenum and silver were the only two other inorganic analytes that were detected at frequencies less than 50%: Molybdenum was detected at frequencies of 47% at both upstream and downstream locations, while silver was detected in 10% of the upstream samples and 3% of the downstream samples.

The relative mean difference was generally ±25% in comparing downstream with upstream concentrations. The only exception was mean mercury, which was 170% higher downstream. This was due to a single elevated downstream concentration (3.8 mg/kg) observed at Mallard Creek. As noted previously, this value was found to be a statistically significant outlier, and not characteristic of bed sediments associated with any other bridges evaluated. This observation is believed to be an anomaly, and not representative of bridge runoff characteristics. If the Mallard Creek datum is not included in the analysis, the relative percent difference in the mean mercury concentration is 0.6%.

Two-sample means comparisons indicated no statistically significant differences in constituent concentrations comparing sediments downstream with those upstream.

#### Organic Constituents

A statistical evaluation of organic data comparing upstream and downstream sediment samples is presented in table 4-B.4. As noted previously, the frequency of detection for organic constituents was relatively low. The following organic constituents were not detected downstream from any of the bridges evaluated – hexachlorobenzene, pentachloroanisole, 1,2,4-trichlorobenzene, 1,2-dimethylnaphthalene, 1,6-dimethylnaphthalene, 1-methyl-9H-fluorene, 1-methylpyrene, 2,3,6-trimethynaphthalane, 2-methylanthracene, acenaphthylene, dibenzo(a,h)anthracene, dibenzothiophene, diethyl phthalate, phenanthridine. Note that this list is the same as presented in the comparison of direct and no-direct discharge bridges, with the exception of naphthalene. Naphthalene was detected upstream at two locations (Black River [810058] and Swannanoa River [100494]), but was not detected at any downstream locations.

Relatively few organic constituents were detected at a frequency of greater than 50% in either downstream or upstream locations, including 9,10-anthraquinone, benzo(b)fluoranthene, chrysene, fluoranthene, perylene, phenanthrene, and pyrene.

The frequency of detection was about the same or slightly higher upstream as compared with downstream of the bridge deck sites. The relative percent difference in the mean concentration was within the range of about ±40%. The exception to comparable upstream and downstream concentrations was acenaphthene, for which the downstream concentration was 1310% higher downstream. This was based on a downstream detection of acenaphthene (860 µg/kg) at Black River (810058). This is the only location in which acenaphthene was detected downstream. Acenaphthene was detected at two upstream locations, both on the Black River (locations 810058 and 80085).

Statistical comparisons were limited to those constituents with at least a 30% frequency of detection among both upstream and downstream samples. This included 9,10-anthraquinone, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene, bis(2-ethylhexyl)phthalate, chrysene, fluoranthene, perylene, phenanthrene, and pyrene. No statistically significant differences were observed for any of these analytes when comparing downstream with upstream concentrations.

The lack of statistically significant differences in upstream and downstream concentrations at bridge sites indicates that bridge deck runoff does not materially impact sediment quality.

### 4.3.1.3 Sediment Quality by Ecoregion

Sediment samples were collected from the Blue Ridge, Piedmont and Coastal ecoregions of North Carolina. Summary statistics by ecoregion are presented for inorganic analytes in table 4-B.5, and for organic analytes in table 4-B.6. Data between ecoregions were compared by examining relative percent differences in the mean downstream analyte concentrations. However, interpretation must also be tempered by natural concentrations of inorganics that may naturally vary by ecoregion. Differences may also be associated with upstream anthropogenic concentrations of both inorganic and organic analytes. In an effort to distinguish naturally occurring variations and anthropogenic sources from the impacts of runoff from bridge decks, the ratios of constituents downstream relative to concentrations upstream was also considered. As an example, the relative difference in the mean manganese concentration when comparing Blue Ridge ecoregion sediments to Coastal ecoregion sediments was 65% (table 4-B.5), suggesting higher concentrations in sediments from the former ecoregion compared with the Coastal ecoregion. However, the downstream:upstream (D/U) ratio for manganese in both Blue Ridge and Coastal sediments is close to 1.0. Therefore, it is inferred that the differences in manganese concentrations are due to naturally occurring conditions characteristics of the geographic region or anthropogenic sources other than bridge runoff. The following discussion focuses on constituents in which the relative percent difference between ecoregions was greater than 50%.

### Inorganic Analytes

There was substantial ecoregional variability in the levels of inorganic constituents. However, in most cases, the D/U ratios suggested that these variations were associated with regional issues or anthropogenic causes rather than influenced by bridge deck runoff. For example, cadmium was highest in the Coastal ecoregion, slightly lower in the Blue Ridge ecoregion, and lowest in the Piedmont ecoregion. None of the variations appear to be associated with bridge runoff, as D/U ratios were all 1.0 or less (a ratio of less than one suggests a higher mean concentration upstream as compared with downstream of the bridge).

There were 2 of the 34 inorganic parameters for which D/U ratios were significantly greater than 1.0:

- Lead was more than twice as high in the Coastal ecoregion as compared with either the Blue Ridge or Piedmont regions. The D/U ratio in the Coastal ecoregion was 1.6, suggesting a higher concentration downstream. However, this was determined to be due to the average lead concentration in the Coastal ecoregion being elevated by a single monitoring site at Town Creek (90074). Excluding this location, the average of other downstream lead concentrations in the Coastal ecoregion (44 mg/kg) was still somewhat higher than observed in the Blue Ridge (38 mg/kg) and Piedmont (27 mg/kg) ecoregions, but D/U ratio was 1.1, suggesting bridge deck runoff was not responsible for elevated Coastal ecoregion lead levels. Town Creek (90074) appears to have some unique downstream lead characteristics not represented by other locations or regions.
- Mercury was much higher in the Piedmont as compared with the Coastal and Blue Ridge ecoregions. However, this was associated with a single location at Mallard Creek (590083). This appears to be an anomalous value not characteristic of other locations, and not associated with bridge runoff.

### Organic Analytes

Due to the low frequency of detection, it is difficult to develop comparisons among the organic analytes. Only 9,10-anthroquinone and perylene were detected at a frequency of greater than 50% in all geographic regions. For these two aromatic hydrocarbons, the highest concentrations were detected in the Coastal ecoregion. The highest concentration of 9,10-anthroquinone in the Coastal area was detected downstream of a bridge site (Smith Creek [640002]); however, the frequency of detection was higher upstream (100% vs. 60%). The D/U ratio for the Coastal region was 1.4; however, this ratio is unreliable because the estimate was based on a very small sample size (three and four non-censored values downstream and upstream, respectively). For perylene, the D/U ratio was 0.9–1.1 for the three ecoregions, suggesting little variation spatially across bridge sites.

There was no discernible pattern by region. Although the highest concentrations of most analytes occurred in the Coastal and Blue Ridge ecoregions, the highest frequency of detection for individual constituents was often associated with the Piedmont ecoregion (e.g., bis(2-ethylhexyl)phthalate, chrysene, fluoranthene, phenanthrene, pyrene). When adequate data was available to compute D/U ratios, these ratios were consistently close to 1.

Combined with the inorganic data, it appears that substantially all the ecoregional variability in constituent concentrations was due to factors other than bridge deck runoff.

### 4.3.1.4 Sediment Quality Benchmarks

Sediment quality benchmarks for the protection of benthic macroinvertebrates are available from a number of potential sources. MacDonald et al. (2000) developed consensus-based freshwater sediment screening concentrations based on information from a number of studies. *Threshold effect concentrations* (TECs) were developed as concentrations below which adverse effects are not expected to occur. *Probable effect concentrations* (PECs) were defined as levels above which effects are frequently expected to occur. TECs and PECs were used preferentially for comparison to bridge sweep data, but are available for a limited number of analytes. Other sources, in order of preference, were sediment screening values from the USEPA Region 4 Waste Management Division Sediment Screening Values for Hazardous Waste Sites (USEPA, 2001), and threshold and probable effect levels compiled from multiple sources within Buchman (2008).

Table 4.3-1 presents a comparison of mean concentrations of inorganic analytes upstream and downstream of bridge decks, and also mean concentrations downstream of bridge decks with direct and no-direct discharges, with sediment quality benchmarks. Mean concentrations in excess of the TEC were observed downstream of bridge deck sites for chromium, copper, lead, manganese, mercury, nickel and zinc. Mean concentrations of the PEC were observed downstream of bridge deck sites only for manganese. However, for all but lead and mercury, the levels identified upstream of bridge decks were in excess of these reference levels too, indicating influences other than bridge deck runoff were responsible for the elevated constituent levels. Similarly, except for lead and mercury, constituents with elevated levels downstream of direct discharge drainage bridges were also found to indicate elevated levels downstream of no-direct discharge drainage bridges. As discussed previously, the anomalies associated with lead and mercury were associated in each case with a single site, Mallard Creek for mercury and Town Creek for lead.

**Table 4.3-1: Comparison of Inorganic Sediment Analyte Levels with Sediment Quality Benchmarks**

| | Thresholds for Comparison | | Mean Concentration | | | |
|---|---|---|---|---|---|---|
| Analyte | TEC | PEC | All Bridges Upstream | All Bridges Downstream | Direct Downstream | No-Direct Downstream |
| Antimony | 12 | NA[a] | 0.45 | 0.50 | 0.51 | 0.48 |
| Arsenic | 9.79 | 33 | 4.92 | 4.93 | 4.88 | 4.98 |
| Cadmium | 0.99 | 4.98 | 0.30 | 0.27 | 0.31 | 0.23 |
| Chromium | 43.4 | 111 | **64.8** | **66.1** | **63.3** | **69.3** |
| Copper | 31.6 | 149 | **36.7** | **37.3** | **37.6** | **36.9** |
| Lead | 35.8 | 128 | 34.6 | **41.8** | **47.9** | 34.8 |
| Manganese | 630 | 1200 | **1,309** | **1,349** | **1,367** | **1,329** |
| Mercury | 0.18 | 1.06 | 0.073 | **0.196** | **0.300** | 0.078 |
| Nickel | 22.7 | 48.6 | **26.3** | **25.9** | **25.0** | **26.9** |
| Silver | 2 | NA[a] | NA | NA | NA | NA |
| Zinc | 121 | 459 | **152.0** | **150.9** | **151.1** | **150.8** |

**Note:** Values in bold exceed either the TEC or PEC levels for that constituent. NA – not applicable.

[a] No PEC benchmark exists for the analyte.

Table 4.3-2 presents a comparison of the levels of organic constituents in sediment relative to benchmarks. The majority of the samples featured constituent levels below laboratory reporting limits, and statistics were not able to be computed for the majority of analytes. Mean concentrations in excess of sediment quality benchmarks were only encountered for benzo[k]fluoranthene. The exceedance for benzo[k]fluoranthene was in an upstream sample, and consequently not related to bridge deck runoff.

**Table 4.3-2: Comparison of Organic Sediment Analyte Levels with Sediment Quality Benchmarks**

| | Thresholds for Comparison | | Mean Concentration | | | |
|---|---|---|---|---|---|---|
| Analyte | TEC | PEC | Upstream | Downstream | Direct | No-Direct |
| 1,2,4-Trichlorobenzene | 9,200 | NA[a] | NA[b] | NA[b] | NA[b] | NA[b] |
| 9H-Fluorene | 77.4 | 536.0 | NA[b] | NA[b] | NA[b] | NA[b] |
| Acenaphthene | 330 | NA[a] | NA[b] | NA[b] | NA[b] | NA[b] |
| Acenaphthylene | 330 | NA[a] | NA[b] | NA[b] | NA[b] | NA[b] |
| Anthracene | 57.2 | 845 | NA[b] | NA[b] | NA[b] | NA[b] |
| Benzo[a]anthracene | 108 | 1,050 | 40 | 32 | NA[b] | NA[b] |
| Benzo[a]pyrene | 150 | 1,450 | 56 | 61 | NA[b] | NA[b] |
| Benzo[ghi]perylene | 170 | 3,200 | NA[b] | NA[a] | NA[b] | NA[b] |
| Benzo[k]fluoranthene | 27.2 | 13,400 | **40** | NA[a] | NA[b] | NA[b] |
| Bis(2-ethylhexyl)phthalate | 182 | 750 | 98 | 105 | NA[b] | NA[b] |
| Chrysene | 166 | 1,290 | 50 | 51 | NA[b] | NA[b] |
| Dibenzo[a,h]anthracene | 33 | 135 | NA[b] | NA[a] | NA[b] | NA[b] |
| Diethyl phthalate | 630 | NA[a] | NA[b] | NA[a] | NA[b] | NA[b] |
| Fluoranthene | 423 | 2,230 | 105 | 87 | 82 | 133 |
| Indeno[1,2,3-cd]pyrene | 17.3 | 3,200 | NA[b] | NA[a] | NA[b] | NA[b] |
| Naphthalene | 176 | 561 | NA[b] | NA[a] | NA[b] | NA[b] |
| Phenanthrene | 204 | 1,170 | 54 | 52 | NA[b] | NA[b] |
| Pyrene | 195 | 1520 | 79 | 67 | 56 | 89 |
| Hexachlorobenzene | 20.0 | 100 | NA[b] | NA[b] | NA[b] | NA[b] |

**Notes:** Values in bold exceed either the TEC or PEC levels. NA – not applicable.

[a] No PEC benchmark exists for the analyte.

[b] No mean concentration was computed due to insufficient number or frequency of non-censored data values. For more information on censored data, see appendix 3-F.

### 4.3.1.5 Streambed Sediment Quality Conclusions

No statistically significant differences in sediment inorganic or organic concentrations were observed downstream from no-direct discharge bridges as compared with direct discharge bridges. No statistically significant differences in sediment inorganic or organic concentrations were observed downstream as compared with upstream locations. Some constituents were elevated at certain sites – specifically mercury downstream of the Mallard Creek bridge (590083) and lead downstream of the Town Creek site (90074). However, there was no general pattern of lead and mercury at other locations that would suggest the elevated concentrations at the Mallard and Town Creek sites were associated with bridge runoff. Ecoregional differences were observed for some analytes. However, these differences appear to be associated with naturally occurring conditions, or upstream anthropogenic influences. None of the differences appeared attributable to bridge runoff. Where sediment quality benchmarks were exceeded, except for lead and mercury, the exceedances were found to be independent of the discharge drainage design (i.e., direct versus indirect), and were also found to occur either upstream of the bridge deck, or at similar levels upstream and downstream, implicating sources other than bridge deck runoff. Overall, analysis of streambed sediment does not indicate any impacts of bridge deck runoff on sediment quality.

## 4.3.2 Bridge Deck Sweeping Solids Results

Bridge deck sweeping events were coordinated with NCDOT Divisions 1 and 13 to collect samples of deck solids from bridges across the Blue Ridge and Coastal ecoregions to understand the chemistry of bridge deck solids, and their potential impacts on the chemistry of bed sediments in the receiving streams. The methods for this study are discussed in section 3.3.

#### 4.3.2.1 Deck Sweeping Solids Quality

Bridge deck sweeping included the coordination and execution of sweeping events to collect solids samples from bridge decks across North Carolina. Laboratory analyses were performed to quantify the constituents present on bridge decks that could potentially be carried by stormwater runoff to receiving surface waters. The objective of the bridge deck sweeping effort was to evaluate the concentrations of target organic and inorganic constituents of potential environmental significance to solids that accumulate on bridge decks.

Sweeping events were planned for multiple bridges within each geographic region. Sweeping events were performed in the Coastal (Division 1) and Blue Ridge (Division 13) regions. Events were scheduled to occur once in each region for each season (summer, fall, winter, spring). In total, inorganic data were evaluated for 14 sweeping events for the summer and fall seasons in both the coastal and Blue Ridge regions. Organic data were evaluated for eight sweeping events for the summer season.

Discussions of bridge sweeping sites, data collection techniques, and laboratory methods and a summary of analytical results are presented in section 3.3. Results are evaluated in the context of multiple comparison benchmarks:

- Total Constituent Analysis Regulatory Levels
- North Carolina Maximum Soil Contaminant Concentrations (MSCC) and Remediation Goals
- Sediment quality benchmarks for the protection of benthic invertebrates

#### 4.3.2.2 Comparison with Total Constituent Analysis Regulatory Levels

The Toxicity Characteristic Leaching Procedure (TCLP) is designed to assess the mobility, by leaching, of specific organic and inorganic analytes present in wastes. If a solid waste fails the test for one or more of these compounds, the waste is considered to be a characteristic hazardous waste (unless there is an exemption that applies). Regulatory levels for TCLP analyses are codified in 40 CFR §261.24.

Waste characterization using TCLP was not performed as part of the bridge sweeping analytical suite. However, it is possible to use a rule of thumb (the *Rule of 20*) to estimate the toxicity of the bridge deck solids. If all the analyte of concern leached into the extraction fluid used in the TCLP test, the final liquid-phase concentrations (mg/L) would be 20 times smaller than the solid phase concentration (mg/kg), which can then be compared to the TCLP regulatory levels for the analyte in question. This then represents a conservative estimate of the toxicity of the sample. If the total analyte concentrations are below the TCLP thresholds, then the sample would not leach enough constituent under TCLP conditions to be considered hazardous. If the total concentration exceeds the TCLP threshold, it is not possible to rule out the possibility that the sample may be hazardous, and a formal TCLP analysis would be required (Davis, 2001).

Bridge sweep data are compared with TCLP threshold values in table 4.3.3. The table includes data for bulk samples, and fine-grained subsamples that represent solids passing through a 63-µm sieve. Mean and median solid-phase concentrations in bridge deck sweep samples were higher for the fine-grained subsamples than for the bulk samples for all analytes.

The levels of arsenic, barium, cadmium, mercury, selenium and silver were all below regulatory action levels for TCLP analysis. For lead and chromium, there were exceedances at the Virginia Dare bridge and Blue Ridge sites, but none at the multi-bridge coastal sites (0 of 6 samples). Lead concentrations based on the Rule of 20 were in excess of TCLP threshold levels for both the bulk sample and fine-grained subsample at 1 of the 2 Virginia Dare samples (2 of 4 samples), and in both fine-grained Blue Ridge samples (2 of 4 samples). For chromium, the TCLP levels were exceeded in both fine-grained Blue Ridge subsamples (2 of 4 samples), and a single fine-grained Virginia Dare sample (1 of 4 samples). Note that this is not an indication that the bridge deck sweep material is hazardous, but rather that a hazardous characterization cannot be ruled out, and a formal TCLP is necessary to draw any further conclusions.

TCLP regulatory levels are also available for a number of organics in 40 CFR §261.24. The only organic constituent analyzed in the bridge sweeping program that has a corresponding TCLP regulatory value is hexachlorobenzene, which was not detected in bridge deck solids.

#### 4.3.2.3 Comparison with North Carolina Maximum Soil Contaminant Concentrations (MSCCs) and Remediation Goals

Bridge sweep data was also compared with action levels developed by the State for chemical constituents in different contexts. It is important to note that these action levels are not applicable for stormwater applications; rather, these levels were used to provide benchmarks for elevated concentrations. Two metrics were used for comparison – MSCCs and soil remediation goals. The NCDENR Division of Waste Management has developed a list of MSCCs which consider leaching from soil to groundwater, as well as for residential and industrial cleanup levels to evaluate petroleum contamination in soil (15A NCAC 2L .0100; NCDENR, 2010b). Soil Remediation Goals are also published by the NCDENR Inactive Hazardous Sites Branch (NCDENR, 2010c), and were also used for comparison. The remediation goals are for remediation of non-petroleum sites and represent clean up/remediation levels used to justify whether an action may be warranted. MSCCs and soil remediation goals do not apply directly to bridge sweep solids, but provide a reference level for comparison purposes.

A comparison of the inorganic constituents of bridge sweep solids with MSCCs and soil remediation goals are presented as table 4.3-4. Organic bridge sweep solids constituent levels are compared with MSCCs and soil remediation goals in table 4.3-5. As noted previously, the mean and median solid-phase concentrations for all analytes were higher for the fine-grained subsample than the bulk sample. The following observations can be made from review of the data:

- Antimony exceeded the soil remediation goal in a single fall Blue Ridge multibridge sample, and a single summer Coastal sample from the Virginia Dare Bridge, both in the fine-grained subsample (total of 2 out of 14 subsamples).
- Arsenic exceeded the soil remediation goal in four fine-grained subsamples: summer and fall Coastal multibridge samples, and a summer and fall Virginia Dare Bridge sample (total of 4 out of 14 subsamples).
- Barium exceeded the MSCC soil-to-groundwater benchmark in all samples, with the exception of the fall and summer bulk Coastal samples from the Virginia Dare Bridge (total of 12 out of 14 subsamples).
- Beryllium, cadmium and copper levels were below regulatory action levels for the soil remediation goals.
- Chromium levels were orders of magnitude below regulatory levels for MSCCs and soil remediation goals.
- Lead exceeded both NC soil benchmarks in a single summer Coastal sample from the Virginia Dare Bridge for the bulk sample (1 out of 14 subsamples).
- Manganese exceeded the soil remediation goal in nearly all samples. Exceptions were one summer and one fall coastal multibridge sample, and one fall Virginia Dare Bridge sample, all bulk samples (total of 3 out of 14 subsamples).

- Mercury levels in all samples were orders of magnitude below soil remediation goal levels.
- Nickel levels in all samples were below soil remediation goals.
- Silver exceeded the MSCC soil-to-groundwater benchmark in a single Blue Ridge multi-bridge summer sample for the fine-grained fraction (1 out of 14 subsamples).
- Thallium was not detected at levels above the laboratory reporting levels. (For a discussion of laboratory reporting levels, see appendix 3-F).
- Vanadium exceeded the Soil Remediation Goal in all samples.
- Concentrations of 1,2,4-Trichlorobenzene, 9H-fluorene, acenaphthene, acenaphthylene, anthracene, benzo[ghi]perylene, benzo[k]fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, dibenzo[a,h]anthracene, diethyl phthalate, fluoranthene, indeno[1,2,3-cd]pyrene, phenanthrene, and pyrene were below MSCC and soil remediation goals, often by several orders of magnitude.
- Benzo(a)anthracene exceeded the MSCC soil-to-groundwater benchmark in a single summer Coastal multibridge fine-grained subsample (1 out of 14 subsamples).
- Benzo(a)pyrene exceeded each of the NC benchmarks (MSCC soil-to-groundwater and residential, as well as remediation goal) in one coastal Virginia dare bridge sample in the fine-grained subsample, one coastal multibridge sample in both the bulk sample and the fine-grained subsample, and one multibridge Blue Ridge sample in both the bulk sample and the fine-grained subsample (total of 5 out of 14 subsamples).
- Benzo(b)fluoranthene exceeded the MSCC residential soil benchmark and soil remediation goal in one Blue Ridge multibridge fine-grained subsample. All NC metrics were exceeded in one Coastal multibridge fine-grained subsample (total of 2 out of 14 subsamples).
- Naphthalene exceeded the MSCC soil-to-groundwater benchmark in one Coastal multibridge bulk sample (1 out of 14 subsamples).

## Table 4.3-3: Bridge Deck Solids – Comparison of Inorganic Constituents with TCLP Thresholds

| Ecoregion | Sampling Event Description | | | Trace Metals [a, b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sweep Event Description (# Bridges Swept) | Type [c] | Date | Arsenic (µg/g) | Barium (µg/g) | Cadmium (µg/g) | Chromium (µg/g) | Lead (µg/g) | Mercury (µg/g) | Selenium (µg/g) | Silver (µg/g) |
| | | | Thresholds for Comparison [d] | 100 | 2,000 | 20 | 100 | 100 | 4 | 20 | 100 |
| Blue Ridge | Multi-bridge (19 Bridges) | Bulk | 9/16/2009 | 1.7 | 640 | 0.3 | 100 | 49 | 0.01 | <0.1 | <0.5 |
| | Multi-bridge (19 Bridges) | Fine | 9/16/2009 | 4.3 | 1,100 | 1.3 | **160** | **150** | 0.03 | 0.5 | 0.5 |
| | Multi-bridge (38 Bridges) | Bulk | 11/1/2009 | 1.6 | 660 | 0.4 | 100 | 46 | 0.02 | 0.1 | <0.5 |
| | Multi-bridge (38 Bridges) | Fine | 11/1/2009 | 3.8 | 1,100 | 1.8 | **130** | **130** | 0.05 | 0.6 | <0.5 |
| Coastal | Virginia Dare Bridge (2 Bridges) | Bulk | 7/14/2009 | 3.1 | 220 | 0.1 | 85 | **450** | 0.03 | 0.1 | <0.5 |
| | Virginia Dare Bridge (2 Bridges) | Fine | 7/14/2009 | 8.7 | 620 | 1.5 | **160** | **140** | 0.07 | 0.5 | <0.5 |
| | Virginia Dare Bridge (2 Bridges) | Bulk | 12/17/2009 | 2.4 | 260 | 0.1 | 27 | 13 | 0.01 | <0.1 | <0.5 |
| | Virginia Dare Bridge (2 Bridges) | Fine | 12/17/2009 | 8.1 | 580 | 1.5 | 98 | 87 | 0.05 | 0.5 | <0.5 |
| | Multi-bridge (13 Bridges) | Bulk | 8/25/2009 | 1.2 | 360 | <0.1 | 64 | 24 | <0.01 | <0.1 | <0.5 |
| | Multi-bridge (13 Bridges) | Fine | 8/25/2009 | 2.9 | 520 | 0.7 | 57 | 63 | 0.01 | 0.2 | <0.5 |
| | Multi-bridge (37 Bridges) | Bulk | 9/2/2009 | 1.9 | 410 | 0.1 | 89 | 22 | <0.01 | <0.1 | <0.5 |
| | Multi-bridge (37 Bridges) | Fine | 9/2/2009 | 10 | 500 | 0.9 | 96 | 83 | 0.04 | 0.4 | <0.5 |
| | Multi-bridge (30 Bridges) | Bulk | 11/17/2009 | 1.5 | 350 | 0.2 | 18 | 22 | <0.01 | 0.1 | <0.5 |
| | Multi-bridge (30 Bridges) | Fine | 11/17/2009 | 14 | 530 | 0.9 | 80 | 91 | 0.04 | 0.5 | <0.5 |

**Notes:** Sweep Events: July 14 – December 17, 2009. TCLP = Toxicity Characteristic Leaching Procedure.

[a] Analytes not shown in this table indicate that there was no threshold for comparison. All sweeping sediment inorganic results can be found in table 3-L.1.

[b] Values in bold indicate exceedance of the TCLP threshold. Values preceded by a "<" sign indicate values below the method detection limit; see appendix 3-F for a discussion of reporting limits and censored data.

[c] Fine sample has been sieved to < 63 µm and Bulk sample has been sieved to < 2 mm.

[d] Based on EPA regulatory level multiplied by 20. Samples shown as bold exceed TCLP Threshold (Davis, 2001).

## Table 4.3-4: Bridge Deck Inorganic Sweep Results – Comparison with North Carolina MSCCs and Soil Remediation Goals

| Ecoregion | Sampling Event Description |  |  | Trace Metals [a,b] |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Sweep Event Description (# Bridges Swept) | Type [c] | Date | Antimony | Arsenic | Barium | Beryllium | Cadmium | Chromium | Copper | Lead | Manganese | Mercury | Nickel | Selenium | Silver | Thallium | Vanadium | Zinc |
|  |  |  |  | (µg/g) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Threshold for Comparison: MSCC – Soil-to-groundwater [d] |  |  |  |  |  | 290 |  |  | 4200 |  | 270 |  |  |  |  | 0.25 |  |  |  |
| Threshold for Comparison: MSCC – Residential [d] |  |  |  |  |  | 3,100 |  |  | 23460 |  | 400 |  |  |  |  | 78.2 |  |  |  |
| Threshold for Comparison: Soil Remediation Goals [e] |  |  |  | 6.2 | 4.4 |  | 30 | 7.4 | 24000 | 620 | 400 | 360 | 4.60 | 320 | 78.0 | 78 | 1.04 | 15.6 | 4,600 |
| Blue Ridge | Multi-bridge (19 Bridges) | Bulk | 9/16/2009 | 1.9 | 1.7 | **640** | 1.1 | 0.3 | 100 | 57 | 49 | **710** | 0.01 | 24 | <0.1 | <0.5 | <50 | **62** | 300 |
|  | Multi-bridge (19 Bridges) | Fine | 9/16/2009 | **13** | 4.3 | **1100** | 1.8 | 1.3 | 160 | 240 | 150 | **860** | 0.03 | 55 | 0.5 | **0.5** | <50 | **120** | 1500 |
|  | Multi-bridge (38 Bridges) | Bulk | 11/1/2009 | 2.7 | 1.6 | **660** | 1.3 | 0.4 | 100 | 62 | 46 | **720** | 0.02 | 28 | 0.1 | <0.5 | <50 | **80** | 300 |
|  | Multi-bridge (38 Bridges) | Fine | 11/1/2009 | 11 | 3.8 | **1,100** | 1.8 | 1.8 | 130 | 190 | 130 | **790** | 0.05 | 58 | 0.6 | <0.5 | <50 | **130** | 1,000 |
| Coastal | Virginia Dare Bridge (2 Bridges) | Bulk | 7/14/2009 | 5.9 | 3.1 | 220 | 0.6 | 0.1 | 85 | 180 | **450** | **550** | 0.03 | 14.0 | 0.1 | <0.5 | <50 | **35** | 280 |
|  | Virginia Dare Bridge (2 Bridges) | Fine | 7/14/2009 | 6.6 | **8.7** | **620** | 2.2 | 1.5 | 160 | 260 | 140 | **670** | 0.07 | 62 | 0.5 | <0.5 | <50 | **74** | 940 |
|  | Virginia Dare Bridge (2 Bridges) | Bulk | 12/17/2009 | 0.4 | 2.4 | 260 | 0.7 | 0.1 | 27 | 72 | 13 | 320 | 0.01 | 7.7 | <0.1 | <0.5 | <50 | **25** | 120 |
|  | Virginia Dare Bridge (2 Bridges) | Fine | 12/17/2009 | 6.0 | **8.1** | **580** | 2.0 | 1.5 | 98 | 200 | 87 | **480** | 0.05 | 44 | 0.5 | <0.5 | <50 | **65** | 640 |
|  | Multi-bridge (13 Bridges) | Bulk | 8/25/2009 | 0.4 | 1.2 | **360** | 1.1 | <0.1 | 64 | 16 | 24 | 350 | <0.01 | 10 | <0.1 | <0.5 | <50 | **35** | 64 |
|  | Multi-bridge (13 Bridges) | Fine | 8/25/2009 | 1.5 | 2.9 | **520** | 1.3 | 0.7 | 57 | 47 | 63 | **450** | 0.01 | 19 | 0.2 | <0.5 | <50 | **75** | 330 |
|  | Multi-bridge (37 Bridges) | Bulk | 9/2/2009 | 0.5 | 1.9 | **410** | 0.7 | 0.1 | 89 | 17 | 22 | **550** | <0.01 | 9 | <0.1 | <0.5 | <50 | **52** | 130 |
|  | Multi-bridge (37 Bridges) | Fine | 9/2/2009 | 1.7 | **10** | **500** | 1.3 | 0.9 | 96 | 79 | 83 | **680** | 0.04 | 22 | 0.4 | <0.5 | <50 | **94** | 400 |
|  | Multi-bridge (30 Bridges) | Bulk | 11/17/2009 | 0.4 | 1.5 | **350** | 1.0 | 0.2 | 18 | 15 | 22 | 230 | <0.01 | 7 | 0.1 | <0.5 | <50 | **30** | 140 |
|  | Multi-bridge (30 Bridges) | Fine | 11/17/2009 | 2.3 | **14** | **530** | 1.6 | 0.9 | 80 | 55 | 91 | **460** | 0.04 | 24 | 0.5 | <0.5 | <50 | **100** | 670 |

**Notes:** Sweep Events: July 14 – December 17, 2009.

[a] Analytes not shown in this table indicate that there was no threshold for comparison. All sweeping sediment inorganic results can be found in table 3-L.1.

[b] Values in bold indicate exceedance of either the Maximum Soil Contaminant Concentration or Soil Remediation threshold. Values preceded by a “<” sign indicate values below the method detection limit; see appendix 3-F for a discussion of reporting limits and censored data.

[c] Fine sample has been sieved to < 63 µm and Bulk sample has been sieved to < 2 mm.

[d] MSCC = Maximum Soil Contaminant Concentration Levels (NCDENR, 2010b).

[e] Soil Remediation Goals per (NCDENR, 2010c).

## Table 4.3-5: Bridge Deck Organic Sweep Results – Comparison with North Carolina MSCCs and Soil Remediation Goals

| Ecoregion | Sampling Event Description | | | Semi-volatiles [a,b] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sweep Event Description (# Bridges Swept) | Type [c] | Date | 1,2,4-Trichlorobenzene | 9H-Fluorene | Acenaphthene | Acenaphthylene | Anthracene | Benzo[a]anthracene | Benzo[a]pyrene | Benzo[b]fluoranthene | Benzo[ghi]perylene | Benzo[k]fluoranthene | Bis(2-ethylhexyl)phthalate | Chrysene | Dibenzo[a,h]anthracene | Diethyl phthalate | Fluoranthene | Indeno[1,2,3-cd]pyrene | Naphthalene | Phenanthrene | Pyrene |
| | | | | (µg/kg) | | | | | | | | | | | | | | | | | | |
| Threshold for Comparison: MSCC – Soil-to-groundwater [d] | | | | 2600 | 47,000 | 8,200 | 11,000 | 940,000 | 350 | 96 | 1,200 | 6,400,000 | 12,000 | 6,600 | 39,000 | 170 | | 290,000 | 3,400 | 160 | 56,000 | 270,000 |
| Threshold for Comparison: MSCC – Residential [d] | | | | 156,000 | 620,000 | 940,000 | 469,000 | 460,0000 | 880 | 88 | 880 | 469,000 | 9000 | 46,000 | 88,000 | 88 | | 620,000 | 880 | 313,000 | 469,000 | 469,000 |
| Threshold for Comparison: Soil Remediation Goals [e] | | | | 12,400 | 540,000 | 740,000 | | 440,0000 | 620 | 62 | 620 | | 6,200 | 35,000 | 62,000 | 62 | 9,800,000 | 460,000 | 620 | 11,200 | | 460,000 |
| Blue Ridge | Multi-bridge (19 Bridges) | Bulk | 9/16/2009 | <50 | E14 | M | M | E29 | 190 | **220** | E460 | E120 | E160 | E390 | 320 | <50 | <50 | 510 | E110 | E68 | 200 | 420 |
| | Multi-bridge (19 Bridges) | Fine | 9/16/2009 | <220 | <220 | <220 | E28 | E58 | E260 | **E350** | **900** | E280 | E320 | E1,900 | 550 | <220 | <220 | 770 | E240 | E100 | E280 | 650 |
| Coastal | Virginia Dare Bridge (2) | Bulk | 7/14/2009 | <20 | <20 | <20 | <20 | M | E20 | E24 | E39 | E14 | E21 | E68 | E31 | <20 | <20 | 71 | E18 | <20 | E29 | E41 |
| | Virginia Dare Bridge (2) | Fine | 7/14/2009 | <600 | <600 | <600 | <600 | <600 | E260 | **E340** | E600 | E230 | E340 | 2600 | E360 | <600 | <600 | E650 | E340 | <600 | E250 | E440 |
| | Multi-bridge (13 Bridges) | Bulk | 8/25/2009 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 |
| | Multi-bridge (13 Bridges) | Fine | 8/25/2009 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <1800 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 |
| | Multi-bridge (37 Bridges) | Bulk | 9/2/2009 | <50 | E110 | 210 | E28 | E69 | 210 | **280** | 550 | E120 | 220 | E170 | 400 | <50 | <50 | 1400 | E130 | **200** | 1,900 | 980 |
| | Multi-bridge (37 Bridges) | Fine | 9/2/2009 | <480 | <480 | E51 | E170 | E250 | **E510** | **E850** | **1900** | E440 | E720 | <910 | E730 | <480 | <480 | 1400 | E460 | <480 | E790 | 1,700 |

**Notes:** Sweeping Events: July 14 – September 16, 2009

[a] Analytes not shown in this table indicate that there was no threshold for comparison. All sweeping sediment organic results can be found in table 3-L.2.

[b] Values in bold indicate exceedance of either the Maximum Soil Contaminant Concentration or Soil Remediation threshold. Values preceded by a “<” sign or an “E” indicate values below the method detection limit; see appendix 3-F for a discussion of reporting limits and censored data.

[c] Fine sample has been sieved to < 63 µm and Bulk sample has been sieved to < 2 mm.

[d] MSCC = Maximum Soil Contaminant Concentration Levels (NCDENR, 2010b).

[e] Soil Remediation Goals per (NCDENR, 2010c).

#### 4.3.2.4 Sediment Quality Benchmarks

Bridge deck quality was also compared to the sediment quality benchmarks discussed in section 4.3.1.4. Inorganic bridge sweep data are compared with sediment quality benchmarks in table 4.3-6. Organic bridge sweep data are compared with sediment quality benchmarks in table 4.3-7. A summary of the number of exceedances by constituent and ecoregion is presented in table 4.3-8.

In general, except for mercury and silver, all inorganic analytes were detected at higher levels than threshold effect concentration (TEC) or probable effect concentration (PEC) levels. Among the organic analytes, the levels of 1,2,4-trichlorobenzene, acenapthene, acenaphthalene, dibenzo[a,h]anthracene, diethyl phthalate, and hexachlorobenzene were below these threshold levels, while 9H-florene, antracene, benzo[a]anthracene, benzo[a]pyrene, benzo[ghi]perylene, benzo[k]fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, fluoranthene, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, and pyrene were above one or both of these thresholds.

#### 4.3.2.5 Sediment Quality of Bridge Deck Sweeping Sample Conclusions

Total constituent analysis was performed by comparing the solid-phase concentrations with TCLP regulatory levels, using the Rule of 20, which overestimates partitioning of analytes into the liquid-phase. Levels below the thresholds multiplied are conclusively non-hazardous; however, levels above the thresholds are not necessarily hazardous, due to the conservative partitioning assumption. Arsenic, barium, cadmium, mercury, selenium and silver levels in bridge deck solids were found to be non-hazardous from the total constituent analysis. Lead and chromium levels were not above the TCLP threshold values in bridge sweeping samples from the Virginia Dare Bridge (Coastal ecoregion), and multibridge sweepings from the Blue Ridge ecoregion. This is not an indication that the bridge deck sweeping material is hazardous, but rather that the solids cannot be conclusively found to be non-hazardous without TCLP testing.

Several inorganic and organic constituents exceeded North Carolina MSCC soil-to-groundwater and residential benchmarks, as well as North Carolina soil remediation goals. These benchmarks may have limited relevance to the material as it exists on the bridges, but used as reference levels for characterization.

Both inorganic and organic constituents were found to exceed sediment quality benchmarks, including either one or both of TECs and PECs. However, caution must be observed in interpreting this data. These thresholds have been developed for streambed sediment and not for bridge deck solids. Mixing effects would be expected to reduce the impacts on the receiving stream, as discussed in section 4.2. It is also important to understand that many of the available sediment benchmarks were derived based on effects (or no effect) distributions from among multiple toxicity tests containing chemical mixtures. It is difficult to ascribe an effect or no effect concentration to a specific chemical when present in a mixture, and variations in chemical speciation, bioavailability, or the mixture of chemicals present can influence the efficiency of the derived values from these studies. It may be reasonable to conclude no or low potential for effects if such benchmarks are not exceeded. However, these values may be poor predictors of the probability or magnitude of effects when exceedances do occur.

It is also worth noting that bridge sweeping solids were not found to impact streambed sediment quality, as discussed in Section 4.3.1, as evidenced by the similarities in sediment chemistry upstream and downstream of bridges.

## Table 4.3-6: Bridge Deck Inorganic Sweep Results – Comparison with Sediment Quality Benchmarks

| Ecoregion | Sampling Event Description | | | Trace Metals [a,b] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sweep Event Description (# Bridges Swept) | Type [f] | Date | Antimony [c] | Arsenic [d] | Cadmium [d] | Chromium [d] | Copper [d] | Lead [d] | Manganese [e] | Mercury [d] | Nickel [d] | Silver [c] | Zinc [d] |
| | | | | (µg/g) | | | | | | | | | | |
| Threshold for Comparison: Sediment Ecological Screening Benchmark (TEC [g] or equivalent) | | | | 12 | 9.79 | 0.99 | 43.4 | 31.6 | 35.8 | 630 | 0.18 | 22.7 | 2 | 121 |
| Threshold for Comparison: Sediment Ecological Screening Benchmark (PEC [h] or equivalent) | | | | | 33 | 4.98 | 111 | 149 | 128 | 1200 | 1.06 | 48.6 | | 459 |
| Blue Ridge | Multi-bridge (19 Bridges) | Bulk | 9/16/2009 | 1.9 | 1.7 | 0.3 | **100** | **57** | **49** | **710** | 0.01 | **24** | <0.5 | **300** |
| | Multi-bridge (19 Bridges) | Fine | 9/16/2009 | 13 | 4.3 | **1.3** | ***160*** | ***240*** | ***150*** | **860** | 0.03 | ***55*** | 0.5 | ***1500*** |
| | Multi-bridge (38 Bridges) | Bulk | 11/1/2009 | 2.7 | 1.6 | 0.4 | **100** | **62** | **46** | **720** | 0.02 | **28** | <0.5 | **300** |
| | Multi-bridge (38 Bridges) | Fine | 11/1/2009 | 11 | 3.8 | **1.8** | ***130*** | ***190*** | ***130*** | **790** | 0.05 | ***58*** | <0.5 | ***1,000*** |
| Coastal | Virginia Dare Bridge (2 Bridges) | Bulk | 7/14/2009 | 5.9 | 3.1 | 0.1 | **85** | ***180*** | ***450*** | 550 | 0.03 | 14.0 | <0.5 | **280** |
| | Virginia Dare Bridge (2 Bridges) | Fine | 7/14/2009 | 6.6 | 8.7 | **1.5** | ***160*** | ***260*** | ***140*** | **670** | 0.07 | ***62*** | <0.5 | ***940*** |
| | Virginia Dare Bridge (2 Bridges) | Bulk | 12/17/2009 | 0.4 | 2.4 | 0.1 | 27 | **72** | 13 | 320 | 0.01 | 7.7 | <0.5 | 120 |
| | Virginia Dare Bridge (2 Bridges) | Fine | 12/17/2009 | 6.0 | 8.1 | **1.5** | **98** | ***200*** | **87** | 480 | 0.05 | **44** | <0.5 | ***640*** |
| | Multi-bridge (13 Bridges) | Bulk | 8/25/2009 | 0.4 | 1.2 | <0.1 | **64** | 16 | 24 | 350 | <0.01 | 10 | <0.5 | 64 |
| | Multi-bridge (13 Bridges) | Fine | 8/25/2009 | 1.5 | 2.9 | 0.7 | **57** | **47** | **63** | 450 | 0.01 | 19 | <0.5 | **330** |
| | Multi-bridge (37 Bridges) | Bulk | 9/2/2009 | 0.5 | 1.9 | 0.1 | **89** | 17 | 22 | 550 | <0.01 | 9 | <0.5 | **130** |
| | Multi-bridge (37 Bridges) | Fine | 9/2/2009 | 1.7 | **10.0** | 0.9 | **96** | **79** | **83** | **680** | 0.04 | 22 | <0.5 | **400** |
| | Multi-bridge (30 Bridges) | Bulk | 11/17/2009 | 0.4 | 1.5 | 0.2 | 18 | 15 | 22 | 230 | <0.01 | 7 | <0.5 | **140** |
| | Multi-bridge (30 Bridges) | Fine | 11/17/2009 | 2.3 | 14 | 0.9 | **80** | **55** | **91** | 460 | 0.04 | **24** | <0.5 | ***670*** |

**Notes:** Sweep Events: July 14 – December 17, 2009.

[a] Analytes not shown in this table indicate that there was no threshold for comparison. All sweeping sediment inorganic results can be found in table 3-L.1.

[b] Values in bold indicate exceedance of one comparison threshold. Values in bold and italics exceed two comparison thresholds. Values preceded by a "<" sign indicate values below the method detection limit; see appendix 3-F for a discussion of reporting limits and censored data.

[c] Threshold for Comparison reference: (USEPA, 2001).

[d] Threshold for Comparison reference: (MacDonald et al., 2000).

[e] Threshold for Comparison reference: (Ingersoll et al., 1996).

[f] Fine sample has been sieved to < 63 µm and Bulk sample has been sieved to < 2 mm.

[g] TEC = threshold effect concentration

[h] PEC = probable effect concentration

## Table 4.3-7: Bridge Deck Organic Sweep Results – Comparison with Sediment Quality Benchmarks

| Ecoregion | Sampling Event Description | | | Semi-volatiles [a,b] | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sweep Event Description (# Bridges Swept) | Type[f] | Date | 1,2,4-Trichlorobenzene[e] | 9H-Fluorene[d] | Acenaphthene[c] | Acenaphthylene[c] | Anthracene[d] | Benzo[a]anthracene[d] | Benzo[a]pyrene[d] | Benzo[ghi]perylene[e] | Benzo[k]fluoranthene[e] | Bis(2-ethylhexyl)phthalate | Chrysene[d] | Dibenzo[a,h]anthracene | Diethyl phthalate[e] | Fluoranthene[d] | Indeno[1,2,3-cd]pyrene[e] | Naphthalene[d] | Phenanthrene[d] | Pyrene[d] | Hexachlorobenzene[e] |
| | | | | (µg/kg) | | | | | | | | | | | | | | | | | | |
| | Threshold for Comparison: Sediment Ecological Screening Benchmark (TEC[g] or equivalent) | | | 9200 | 77.4 | 330 | 330 | 57.2 | 108 | 150 | 170 | 27.2 | 182[c] | 166 | 33[d] | 630 | 423 | 17.3 | 176 | 204 | 195 | 20.0 |
| | Threshold for Comparison: Sediment Ecological Screening Benchmark (PEC[h] or equivalent) | | | | 536.0 | | | 845 | 1050 | 1450 | 3200 | 13400 | 750[e] | 1290 | 135[e] | | 2230 | 3200 | 561 | 1170 | 1520 | 100 |
| Blue Ridge | Multi-bridge (19 Bridges) | Bulk | 9/16/2009 | <50 | E14 | M | M | E29 | **190** | **220** | E120 | **E160** | **E390** | **320** | <50 | <50 | **510** | **E110** | E68 | 200 | **420** | <50 |
| | Multi-bridge (19 Bridges) | Fine | 9/16/2009 | <220 | <220 | <220 | E28 | **E58** | **E260** | **E350** | **E280** | **E320** | ***E1900*** | **550** | <220 | <220 | **770** | **E240** | E100 | **E280** | **650** | <220 |
| Coastal | Virginia Dare Bridge (2 Bridges) | Bulk | 7/14/2009 | <20 | <20 | <20 | <20 | M | E20 | E24 | E14 | E21 | E68 | E31 | <20 | <20 | 71 | **E18** | <20 | E29 | E41 | <20 |
| | Virginia Dare Bridge (2 Bridges) | Fine | 7/14/2009 | <600 | <600 | <600 | <600 | <600 | **E260** | **E340** | **E230** | **E340** | ***2600*** | **E360** | <600 | <600 | **E650** | **E340** | <600 | **E250** | **E440** | <600 |
| | Multi-bridge (13 Bridges) | Bulk | 8/25/2009 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 | <55 |
| | Multi-bridge (13 Bridges) | Fine | 8/25/2009 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <1800 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 | <750 |
| | Multi-bridge (37 Bridges) | Bulk | 9/2/2009 | <50 | **E110** | 210 | E28 | **E69** | **210** | **280** | E120 | **220** | E170 | **400** | <50 | <50 | **1400** | **E130** | **200** | ***1900*** | **980** | <50 |
| | Multi-bridge (37 Bridges) | Fine | 9/2/2009 | <480 | <480 | E51 | E170 | **E250** | **E510** | **E850** | **E440** | **E720** | <910 | **E730** | <480 | <480 | **1400** | **E460** | <480 | **E790** | ***1700*** | <480 |

**Notes:** Sweep Events: July 14 – December 17, 2009

[a] Analytes not shown in this table indicate that there was no threshold for comparison. All sweeping sediment organic results can be found in table 3-L.2.

[b] Values in bold indicate exceedance of one comparison threshold. Values in bold and italics exceed two comparison thresholds. Values preceded by a "<" sign or an "E" indicate values below the method detection limit; see appendix 3-F for a discussion of reporting limits and censored data.

[c] Threshold for Comparison reference: (USEPA, 2001).

[d] Threshold for Comparison reference: (MacDonald et al., 2000).

[e] Threshold for Comparison reference: (Ingersoll et al., 1996).

[f] Fine sample has been sieved to < 63 µm and Bulk sample has been sieved to < 2 mm.

[g] TEC = threshold effect concentration

[h] PEC = probable effect concentration

**Table 4.3-8: Exceedances of Sediment Quality Benchmarks by Ecoregion**

| Constituent | Threshold Effect Concentration | | | Probable Effect Concentration | | |
|---|---|---|---|---|---|---|
| | Virginia Dare (Coastal) | Multibridge (Coastal) | Multibridge (Blue Ridge) | Virginia Dare (Coastal) | Multibridge (Coastal) | Multibridge (Blue Ridge) |
| Copper | 4 / 4 | 3 / 6 | 4 / 4 | 3 / 4 | 0 / 6 | 2 / 4 |
| Lead | 1 / 4 | 3 / 6 | 2 / 4 | 3 / 4 | 0 / 6 | 2 / 4 |
| Zinc | 1/ 4 | 4 / 6 | 2 / 4 | 2 / 4 | 1 / 6 | 2 / 4 |
| Cadmium | 2 / 4 | 0 / 6 | 2 / 4 | 0 / 4 | 0 / 6 | 0 / 4 |
| Chromium | 2 / 4 | 5 / 6 | 2 / 4 | 1 / 4 | 0 / 6 | 2 / 4 |
| Nickel | 1 / 4 | 1 / 6 | 2 / 4 | 1 / 4 | 0 / 6 | 2 / 4 |
| Arsenic | 0 / 4 | 1 / 6 | 0 / 4 | 0 / 4 | 0 / 6 | 0 / 4 |
| Manganese | 1 / 4 | 1 / 6 | 4 / 4 | 0 / 4 | 0 / 6 | 0 / 4 |
| 9H-Fluorene | 0 / 2 | 1 / 4 | 0 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Anthracene | 0 / 2 | 2 / 4 | 1 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Benzo(a)anthracene | 1 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Benzo(a)pyrene | 1 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Benzo(ghi)perylene | 1 / 2 | 1 / 4 | 1 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Benzo(k)fluoranthene | 1 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Bis(2-ethylhexyl)phthalate | 0 / 2 | 0 / 4 | 1 / 2 | 1 / 2 | 0 / 4 | 1 / 4 |
| Chrysene | 1 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Fluoranthene | 1 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Indeno(1,2,3-cd)pyrene | 2 / 2 | 2 / 4 | 2 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Naphthalene | 0 / 2 | 1 / 4 | 0 / 2 | 0 / 2 | 0 / 4 | 0 / 4 |
| Phenanthrene | 1 / 2 | 1 / 4 | 1 / 2 | 0 / 2 | 1 / 4 | 0 / 4 |
| Pyrene | 1 / 2 | 1 / 4 | 2 / 2 | 0 / 2 | 1 / 4 | 0 / 4 |

**Note:** The first numbers in each cell indicate the number of exceedances, and the second value indicates the total number of samples.

## 4.4 Comparison of Bridge Deck Runoff Quantity and Pollutant Loads to Watershed Contributions

The hydrologic and water quality effects of increased stormwater runoff and pollutant loading on receiving waters have been well studied and documented, and these effects have been linked to land use change and urbanization (Burton and Pitt, 2001; Calder, 1993; Urbonas and Roesner, 1993). Effects of increased stormwater runoff include stream bank and channel erosion, worsened flooding, and an increased ability for runoff to detach sediment and transport pollutants downstream. Effects of increased pollutant loading include eutrophication of receiving waters and subsequent hypoxia due to excessive nutrients, toxicity of aquatic life or inedible fish caused by loading of metals and organics, and limited contact recreation and shellfish consumption due to bacteria. In an effort to better mitigate these effects, the National Research Council has recently recommended a shift in stormwater management and regulatory permitting to a more watershed based approach, where discharge permits are based on watershed boundaries rather than political boundaries (National Research Council, 2008).

While many studies have investigated the stormwater quality and pollutant loading from highways, few have focused specifically on the potential effects of bridge deck runoff on receiving waters (Dupuis, 2002, vol.1). Dupuis has proposed comparison of pollutant loading from bridge decks to other sources in the watershed as one piece of evidence considered in assessing the potential impact of bridge deck runoff on the receiving waters (Dupuis, 2002, vol.2). Malina et al. (2005a; 2005b) compared pollutant loads estimated for bridge decks in Texas to their receiving water loads and concluded that relative contributions from bridge decks were very small and did not result in adverse impact to receiving waters.

The purpose of the analysis presented here is to provide perspective on the relative contribution of runoff quantity and pollutant loads from bridge decks in North Carolina as compared to total watershed contributions; quantifying these relative contributions can provide further insight into the potential effects of bridge deck runoff on receiving waters. The approach adopted for this study involved characterizing runoff volume from all bridges over waterways in the state and comparing impervious area, runoff volume, peak flow rates, and pollutant loads estimated for selected bridge decks to those amounts estimated for their receiving waters. Three geographically distributed bridge sites with different watershed areas were selected for the site specific evaluations.

## 4.4.1 Bridge Deck Runoff Quantity

Bridge deck runoff quantity can be characterized by runoff volume and peak flow rate, which should both be considered when evaluating the potential hydrologic effect of bridge deck runoff on receiving streams.

In general, as rain falls on a bridge deck, it drains in the direction of roadway cross slope to the edge of the bridge deck. From there, runoff is conveyed by gutters and either exits through deck drains evenly spaced on the bridge deck or is conveyed off of the bridge deck into grated inlets or other collection system. For some bridge drainage systems, runoff will free fall from the deck drains onto the roadway embankment, the overbank, or in some cases, directly into a body of water. Deck drains discharging directly into a water body is common on long coastal bridges, where collection and conveyance of stormwater is not feasible due to the size and cost of systems required. For older bridges, gutters and deck drains were not provided and runoff generally would sheet flow directly off the bridge deck onto the overbank or into a waterway. In recent years, NCDOT has initiated a policy of no direct discharge to water bodies for bridge drainage systems; the NCDOT *Stormwater BMP Toolbox* outlines the adopted policy and design requirements for bridge drainage systems (2008). In accordance with the *Stormwater BMP Toolbox,* for more newly constructed bridges, deck runoff is conveyed away from the waterway via deck conveyance or hanging pipe systems and to overbank areas where runoff is dispersed through vegetated buffers before reaching waterways. More detailed discussion of bridge drainage and hydraulic design and controls are provided in FHWA's *Hydraulic Engineering Circular 21, Design of Bridge Deck Drainage* (1993).

### 4.4.1.1 Runoff Volume

The volume of stormwater runoff from bridges in North Carolina can be directly related to bridge deck area. The standard practice for design of stormwater treatments is to control and treat 90% of the average annual rainfall. For humid areas, like North Carolina, 90% of average annual rainfall is generally accepted by practical design methods to be the runoff from the 1-inch storm event (USGBC, 2007). DWQ provides design criteria that require stormwater treatments to control and treat the runoff from the 1 or 1.5-inch storm event, depending on location in the state (NCDENR, 2007c). Table 4.4-1 presents a summary of bridge deck area estimates and corresponding runoff volume representing 90% of the average annual rainfall (1-inch storm event) for existing bridges over waterways in North Carolina. Values for bridge deck area were derived from data compiled and maintained by NCDOT BMU staff for the approximately 10,481 existing bridges over waterways in North Carolina.

**Table 4.4-1: Bridge Deck Area and Runoff from 1-inch Storm Event for Bridges over Waterways**

| | Median Value | 25th Percentile | 75th Percentile | Total (Statewide Bridges) |
|---|---|---|---|---|
| Bridge Deck Area [a] | 1,935.9 $ft^2$ | 809.6 $ft^2$ | 4,320 $ft^2$ | 1,216 acres |
| Runoff from 1-inch Storm Event [b] | 153.3 $ft^3$ | 64.1 $ft^3$ | 342.0 $ft^3$ | 96.3 acre-ft |

**Notes**

[a] Deck areas for 10,841 existing bridges were estimated using existing bridge information compiled by NCDOT BMU staff.

[b] Runoff from bridge deck area calculated using the Simple Method and assuming a runoff coefficient of 0.95 and 1 inch of precipitation (Schueler, 1987). Runoff volumes were not calculated for 1.5 inches of precipitation.

Given that the trend of managing and regulating stormwater is moving in the direction of a more watershed-based approach (National Research Council, 2008), a watershed-based perspective of runoff volume would be useful in weighing the hydrologic effect of bridge deck runoff. To provide this perspective, runoff volume and impervious area attributed to bridge decks were compared to total watershed contributions for three sites: Black River, Little River, and Swannanoa River. As presented in section 4.2, these three sites were also evaluated through direct comparison of concentration thresholds to measured end of pipe values and through mixing analysis. The three sites are spatially distributed in each of the three ecoregions in North Carolina and represent various sized watershed areas (i.e., stream drainage areas at the point of bridge crossing).

Figures 4.4-1, 4.4-2 and 4.4-3 show locations of all bridges over waterways within each respective watershed area for the three bridge sites. Locations and deck areas for bridges over waterways in these watersheds were derived from information provided and maintained by NCDOT BMU staff. Table 4.4-2 presents a comparison of drainage areas (bridge deck and total watershed area) and associated average annual runoff estimates for each of the three bridge sites. As shown, deck area for all bridges in each watershed is a small fraction (below 0.05% in all cases) of the total watershed area. With the exception of the Swannanoa River site, the ratio of deck area for all bridges to total watershed areas is well below 1%. Overall, impervious area introduced by bridge decks in these watersheds is relatively small when compared to total imperious area and very small when compared to the total watershed area.

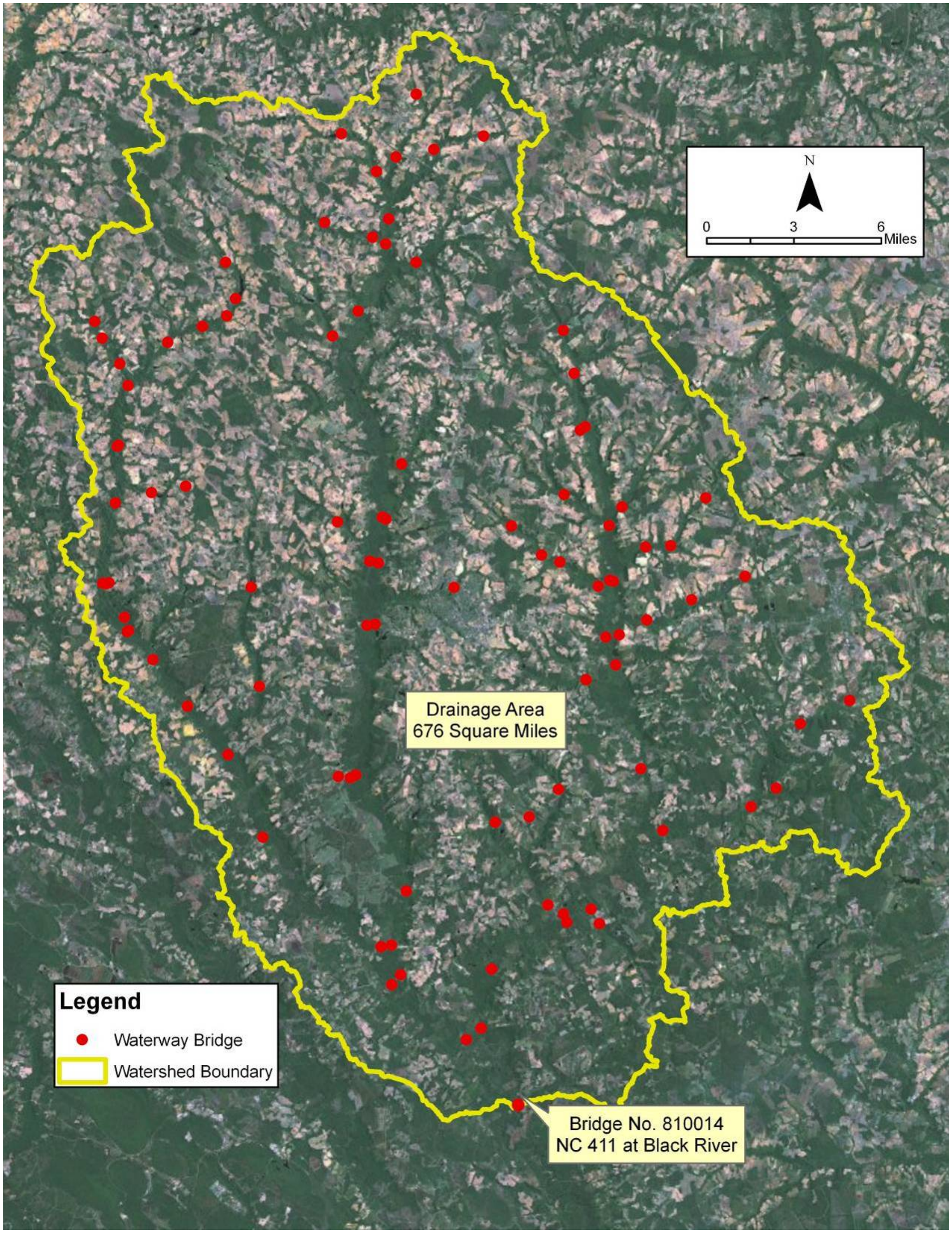


**Figure 4.4-1: Bridge locations within watershed for Black River at NC 41.**

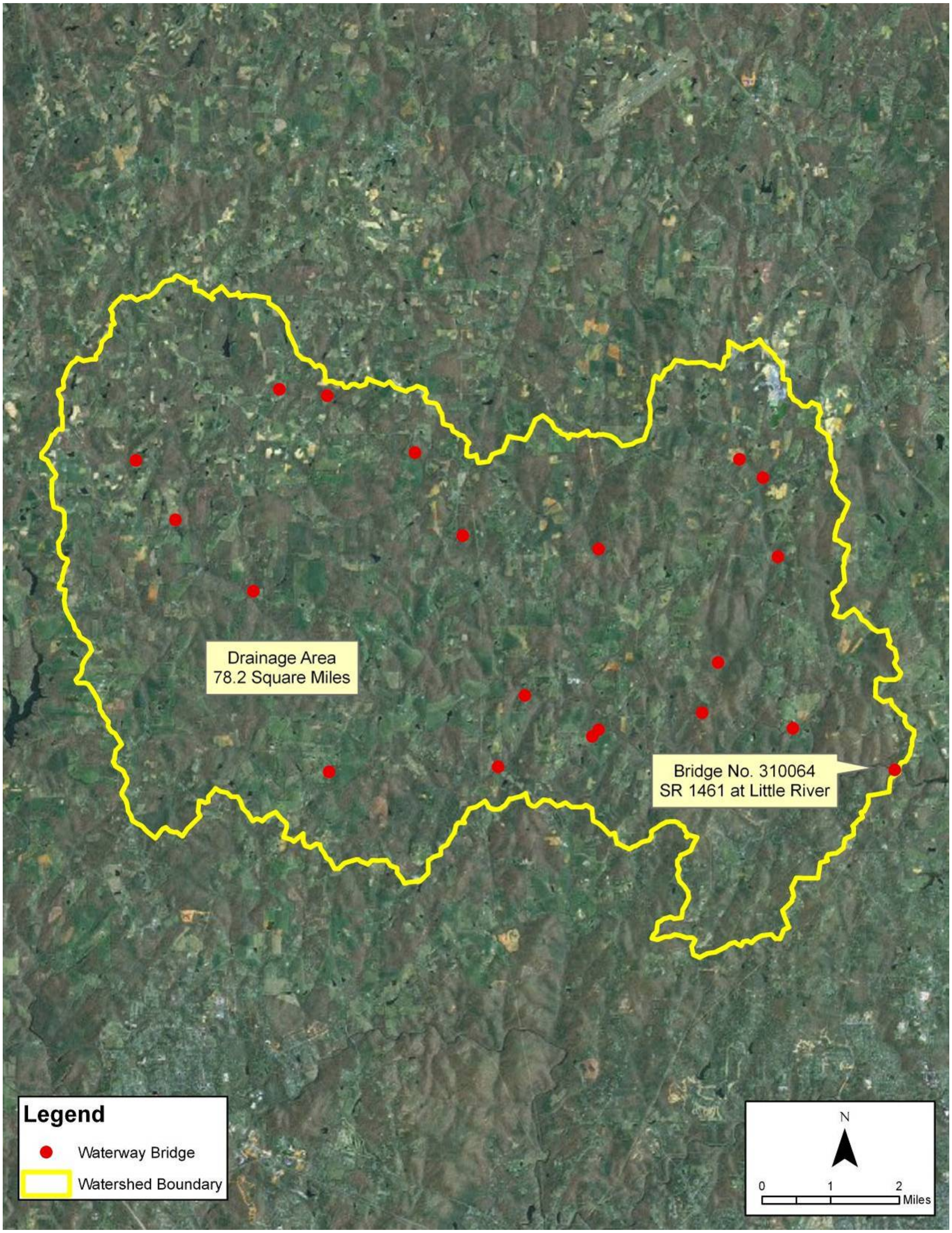


Figure 4.4-2: Bridge locations within watershed for Little River at SR 1461.

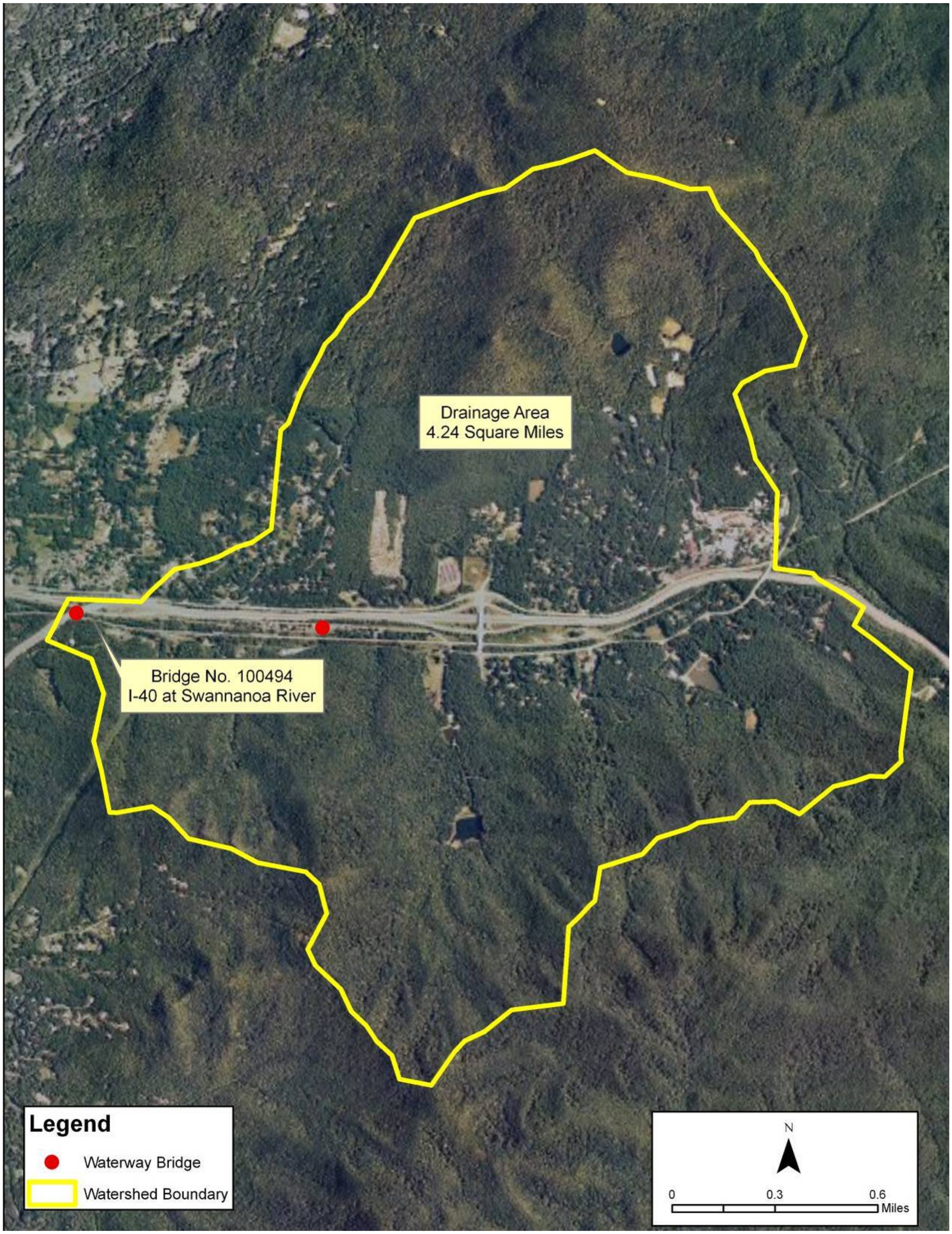


**Figure 4.4-3: Bridge locations within watershed for Swannanoa River at I-40.**

Average annual runoff was estimated for both the entire watershed area (stream drainage area at the point of bridge crossing) and for all bridge decks within the watershed area. Results and methods of estimation are summarized in table 4.4-2. As shown, average annual runoff estimated for all bridge decks are at most 1% of average annual runoff estimated for total watershed areas for all sites considered. The comparison indicates that runoff quantity attributed to bridge decks becomes less significant as the watershed area increases, which parallels the comparison of bridge deck area to total watershed area; while this observation may meet intuitive expectations, additional bridge sites with total watershed areas of varying size, land uses, and locations should be analyzed to confirm. Overall, average annual runoff volume estimates from bridge decks in these watersheds are small when compared to estimates from the total watershed areas.

#### 4.4.1.2 Peak Flow Rates

Similar to runoff volume, peak flow rate of runoff from bridges can be related to bridge deck area. To characterize and gain insight into peak flow rates from bridge decks, peak flow rates were estimated for various recurrence intervals from both bridge decks and receiving streams for the three watersheds previously evaluated. Peak flow rates were calculated using the estimated areas provided in table 4.4-2; results and calculation methods for the peak flow rate estimates are presented in table 4.4-3. As shown, the ratios of peak flow rate from all bridge decks in the watershed to peak flow rate in the receiving water (from entire watershed) were calculated for different recurrence intervals. In addition, the ratios of peak flow rate from the individual bridge deck (e.g., bridge crossing at Black River and NC 41) to peak flow rate in the receiving water were also estimated. When evaluating the comparison of peak flow rate estimates, it is important to note that peak flow rate at bridge decks will not typically occur simultaneously with the peak flow rate in the receiving water during a uniform precipitation event, especially for larger watersheds with slow drainage response times.

As shown in table 4.4-3, the ratios of peak flow rates from all bridge decks in the watershed to flow rates in the receiving streams were at or below 1% for all sites and storm events considered with the exception of the 2 and 5-year storms at Swannanoa, which were calculated to be 1.54% and 1.01%, respectively. The ratios of peak flow rates from individual bridge decks to the flows in the receiving waters were insignificant at Black and Little River sites (at or below 0.02%), while ratios calculated for the Swannanoa River site were small, but relatively higher by comparison, ranging from 0.59% to 1.52%. These results suggest that an individual bridge deck can have a much larger influence on peak flow rates in smaller watersheds, than in larger watersheds. In all cases, the ratios of peak flow rates from bridge decks to those of receiving streams decrease with increasing size storm event size, which meets expectations of the fundamental rainfall/infiltration/storage/runoff relationship. In general, the peak flow rate estimate comparisons indicate that peak flow rates from bridge decks are small when compared to peak flow rates in receiving streams for all storm events at the bridge sites considered.

While comparison of peak flow rates in table 4.4-3 indicates that regional effect may be minimal, local effects of concentrated flow from bridge decks are still a concern. High velocities of concentrated runoff discharged from bridge decks can cause erosion and scour and deliver sediments to receiving waters. The local effects of high flow rates are generally mitigated through implementation of practices that dissipate energy or promote diffuse flow. SCMs that perform these functions are discussed in section 5 of this report.

## Table 4.4-2: Drainage Area and Runoff Volume Estimate Comparisons at Three Bridge Sites

| Bridge Site | Black River at NC411 | Little River at SR 1461 | Swannanoa River at I-40 |
|---|---|---|---|
| Ecoregion [a] | Coastal | Piedmont | Blue Ridge |
| Watershed Area (stream drainage area at bridge crossing) (square miles) | 676[b] | 78.2[c] | 4.24[d] |
| Percent Impervious Area within Watershed Area | 1.4[e] | 0.6[e] | 3.1[f] |
| Estimated Impervious Area within Watershed Area (acres) | 6100 | 300 | 84 |
| Estimated Deck Area for Individual Bridge Deck (acres)[g] | 0.181 | 0.122 | 1.30 |
| Estimated Deck Area for all Bridges within Watershed Area (acres)[g] | 6.79 | 1.10 | 1.32 |
| Ratio of Deck Area for all Bridges to Impervious area within Watershed Area (expressed as %) | 0.11% | 0.4% | 1.6% |
| Ratio of Deck Area for all Bridges to Watershed Area (expressed as %) | 0.00157% | 0.00220% | 0.0486% |
| Average Annual Runoff for Watershed Area (acre-feet) | 569,000[b] | 51,100[c] | 5,980[h] |
| Normal Annual Precipitation (inches)[i] | 54.2 | 48.0 | 48.4 |
| Estimated Average Annual Runoff from Deck Area for all Bridges in Watershed Area (acre-feet)[j] | 350 | 50.2 | 60.7 |
| Ratio of Average Annual Runoff from Deck Area for all Bridges to Average Annual Runoff from Watershed Area (expressed as %) | 0.0614% | 0.0982% | 1.01% |

**Notes:**

[a] See section 3.1.

[b] Data from (USGS, 2009a).

[c] Data from (USGS, 2009b).

[d] Data from (USGS, 2009c).

[e] Percent impervious area for Black River and Little River watershed areas provided by USGS (Chad Wagner, e-mail message, February 23, 2010).

[f] Percent impervious area for Swannanoa River watershed area calculated using StreamStats, a web-based geographic information system maintained by USGS (USGS, n.d.[1]).

[g] Bridge deck areas were estimated using existing bridge information compiled and maintained by NCDOT BMU staff. See figures 4.3-1 through 4.3-3 for bridge deck locations in each drainage area.

[h] Period of record for streamflow at USGS station 03448800 Swannanoa River at Interstate 40 at Black Mountain, NC was not sufficient to calculate average annual runoff. Value provided was calculated by applying the average annual runoff in inches reported at station 03450000 Beetree Creek near Swannanoa, NC to the area reported at station 03448800. Both stations have drainage areas of similar size (5.46 square miles for 03450000) and area characteristics, and are approximately 6 miles apart (USGS, 2009d).

[i] Normal annual precipitation values were obtained from the 1971-2000 Climate Normals for NWS Cooperative Observer Stations published on the Web by the State Climate Office of North Carolina. The following climatic stations were utilized for each site: 319423 Willard 4 SW for Black River (USGS, n.d.[2]), Station 312515 Durham for Little River (USGS, n.d.[3]), and Station 310843 Black Mountain for Swannanoa River (USGS, n.d.[4]).

[j] Average annual runoff from deck area for all bridges in drainage area calculated using the Simple Method and assuming a runoff coefficient of 0.95 and the normal annual precipitation (Schueler, 1987).

### Table 4.4-3: Peak Flow Rate Estimate Comparisons at Three Bridge Sites

| Storm Event | 2-year | 5-year | 10-year | 50-year | 100-year |
|---|---|---|---|---|---|
| **Black River at NC 411** | | | | | |
| Peak Flow rate Estimate from Total Watershed Area (stream drainage area at bridge crossing) (cfs)[a] | 4,240 | 7,420 | 10,100 | 17,800 | 21,900 |
| Peak Flow Rate Estimate from all Bridge Decks (cfs)[b] | 33.7 | 39.4 | 43.8 | 53.3 | 57.3 |
| Ratio of Flow Rate from all Bridge Decks to Flow Rate from Total Watershed Area (expressed as %) | 0.79% | 0.53% | 0.43% | 0.30% | 0.26% |
| Peak Flow Rate Estimate from Individual Bridge Deck (cfs)[b] | 0.90 | 1.05 | 1.17 | 1.42 | 1.53 |
| Ratio of Flow Rate from Individual Bridge Deck to Flow Rate from Total Watershed Area (expressed as %) | 0.02% | 0.01% | 0.01% | 0.01% | 0.01% |
| **Little River at SR 1461** | | | | | |
| Peak Flow Rate Estimate from Total Watershed Area (stream drainage area at bridge crossing) (cfs)[a] | 3,450 | 5,810 | 7,480 | 11,300 | 13,000 |
| Peak Flow Rate Estimate from all Bridge Decks (cfs)[b] | 4.70 | 5.39 | 6.00 | 7.03 | 7.42 |
| Ratio of Flow Rate from all Bridge Decks to Flow Rate from Total Watershed Area (expressed as %) | 0.14% | 0.09% | 0.08% | 0.06% | 0.06% |
| Peak Flow Rate Estimate from Individual Bridge Deck cfs)[b] | 0.52 | 0.60 | 0.67 | 0.78 | 0.82 |
| Ratio of Flow Rate from Individual Bridge Deck to Flow Rate from Total Watershed Area (expressed as %) | 0.02% | 0.01% | 0.01% | 0.01% | 0.01% |
| **Swannanoa River at I-40** | | | | | |
| Peak Flow Rate Estimate from Total Watershed Area (stream drainage area at bridge crossing) (cfs)[c] | 339 | 617 | 834 | 1,351 | 1,611 |
| Peak Flow Rate Estimate from all Bridge Decks (cfs)[b] | 5.22 | 6.26 | 7.05 | 8.84 | 9.61 |
| Ratio of Flow Rate from all Bridge Decks to Flow Rate from Total Watershed Area (expressed as %) | 1.54% | 1.01% | 0.85% | 0.65% | 0.60% |
| Peak Flow Rate Estimate from Individual Bridge Deck (cfs)[b] | 5.14 | 6.16 | 6.94 | 8.71 | 9.46 |
| Ratio of Flow Rate from Individual Bridge Deck to Flow Rate from Total Watershed Area (expressed as %) | 1.52% | 1.00% | 0.83% | 0.64% | 0.59% |

**Notes:**

[a] Peak flow rates for total watershed area (stream drainage area at bridge crossing) for Black and Little Rivers were estimated by USGS using Bulletin 17B analysis (Weaver et al., 2009, pp. 76-77, 80-81).

[b] Peak flow rates for bridge deck areas were estimated using the rational method as presented in NCDOT's *Stormwater BMP Toolbox* (2008); runoff coefficient of 0.95 and 10-minute storm duration were assumed. Rainfall intensities utilized in the calculations for each storm event and site were estimated using NOAA's Precipitation Frequency Data Server (PFDS).

[c] Peak flow rates for total watershed area for Swannanoa River were calculated using regression equations developed by the USGS for rural, ungaged streams (Weaver et al., 2009, p. 21).

## 4.4.2 Bridge Deck Runoff Pollutant Loading vs. Watershed Loading

To provide further evidence to assess the potential effect of bridge deck runoff, an analysis was conducted to compare estimated pollutant loads in bridge deck runoff to pollutants loads in receiving streams during selected wet weather periods. The purpose of the analysis was to provide perspective on relative contribution of pollutants from bridge decks during wet weather conditions. The same bridge sites selected for the runoff comparison were also utilized for this analysis: Black River, Little River, and Swannanoa River.

Wet weather periods for the analysis at each site were selected based on the availability of data for both bridge deck runoff and instream flow. In addition, the general practice for the design of SCMs is to capture and treat stormwater runoff from 90% of the average annual rainfall. As previously discussed, in North Carolina, this storm event is generally accepted to be 1 to 1.5 inches, depending on location in the State (NCDENR, 2007c). As such, wet weather periods with total rainfall amounts near 1 to 1.5 inches were selected in an attempt to evaluate the wet weather event generally used for design of stormwater treatments.

Total loads were estimated for POCs as established in section 4.1 for each wet weather event and site considered. Loads in bridge deck runoff were calculated utilizing recorded discharge rates from the bridge deck drainage system and corresponding end-of-pipe event mean concentrations (EMCs). Total loads from the contributing watershed were calculated using surface water flow rates and instream concentrations measured upstream of the bridge. The load for both bridge deck runoff and instream flow was calculated as the runoff volume over a specified time period multiplied by the measured POC concentrations. The time period used to calculate runoff volume for both bridge deck and instream hydrographs was assumed to be from the start time of the automated sampler for the bridge deck to the end time of the automated sampler or sampling date for the receiving water during the selected wet weather period (for some instances, the receiving water was sampled manually rather than by automated sampler). Pollutant loads could not be calculated for all POCs during the selected wet weather events because in some cases, data were not available or values were below detection.

Using pollutant loads calculated for bridge decks and receiving waters, the relative contribution of pollutants from bridges were assessed. Because instream water quality was measured upstream of the bridge, percentage of bridge deck load to total watershed load was calculated as bridge deck load divided by the sum of bridge deck load and receiving water load. In addition, the load from all bridge decks in the contributing watershed area was grossly estimated by multiplying the load from the individual bridge deck by the ratio of total bridge deck area in the watershed to the individual bridge deck area at the stream crossing. The load from all bridge decks was also expressed as a percentage of total watershed load.

It should be noted that the pollutant loads and percentages calculated are approximations based on simplifying assumptions, including, 1) concentration data from a bridge deck discharge event can be applied to other discharge events during the selected wet weather period, 2) bridge deck discharge events during the selected wet weather period are associated with the hydrograph observed in the receiving water, and 3) unit loading rates calculated from an individual bridge deck can be applied to other bridge decks in the receiving water drainage area. Also, it is important to note that the BSP data used in the analysis are provisional and subject to revision. These assumptions and disclaimers should be taken into account when interpreting results of this analysis.

Results of the pollutant load comparison are provided in tables 4.4-4, 4.4-5, and 4.4-6, for bridge sites at Black River, Little River, and Swannanoa River, respectively. In addition, hydrographs for bridge deck discharge and receiving water flow, sample times for bridge deck runoff and receiving water, and the load comparison sample time period for each analysis are shown in figures 4.4-4, 4.4-5, and 4.4-6, for sites at Black River, Little River, and Swannanoa River, respectively. As shown in the tables, the load from all bridge decks as percentage of receiving water load do not exceed 0.25% for all sites and POCs considered. For the Black River and the Little River sites, the highest relative bridge deck loads were estimated for dissolved zinc, while at Swannanoa River, the highest relative bridge deck loads were estimated for nitrogen. Considering the simplifying assumptions previously discussed and that only one sampling event has been analyzed for each site, these observations should not be considered trends unless confirmed by additional data and analysis. In general, the relative contribution of pollutant loads from bridge decks to their receiving waters for the selected wet weather events and drainage areas considered is small.

Malina et al. (2005b) conducted similar comparisons of pollutant loads from bridge decks to those in receiving streams for three bridge sites in Texas. Malina et al. compared annual loads from bridge deck and receiving water, while the BSP study compared loads assessed during a single wet weather event. Nevertheless, a comparison of results can still shed light on relative significance of the current study. When comparing results from the two studies, it is important to consider that values from Malina et al. were intended to approximate average conditions, while values presented in this study for selected wet weather events could be higher or lower than average because they represent individual events. Annual load from bridge decks expressed as a percentage of annual load in the receiving stream as reported by Malina et al. for parameters common to the BSP study are reproduced in table 4.4-7. As shown, percentages for annual bridge loads shown in table 4.4-7 are slightly greater than percentage loads (single wet weather event) calculated for the individual bridge deck at Black River, very similar to those calculated for the individual bridge deck at Little River, and smaller than those calculated for the individual bridge deck at Swannanoa River. In general, bridge deck loads as a percentage of receiving water load for all bridge sites are similar and most within an order of magnitude of values presented by Malina et al. Based on the comparison of calculated annual pollutant loads from the individual bridge decks to those in the receiving streams, Malina et al. concluded that "mass loadings of constituents contributed by the runoff from bridge decks were minimal compared to the mass loads of constituents carried by the respective receiving stream". Malina et al. further concluded that runoff from the bridge decks under study "does not result in any substantial adverse impact to" their respective receiving streams.

While the analysis provided in this section and by other studies show that bridge deck pollutant loads are relatively small when compared to total watershed contributions (for the sites considered), this evaluation does not determine if the pollutant loads from bridge deck runoff presented are associated with having an effect on a receiving stream. In addition, loads should be evaluated for meeting specific stormwater management goals, such as goals associated with waste load allocations, pollutant trading, stormwater banking programs, or off-site mitigation, as required by a particular program or regulation.

## Table 4.4-4: Pollutant Load Comparison for Black River at NC 411 during Selected Wet Weather Period (July 27 to August 4, 2009)

| Parameters-of-concern [a] | | Bridge Deck EMC [b] 7/27/2009 | Load from Individual Bridge Deck (g) [c] | Receiving Water Conc. [b] 8/4/2009 | Receiving Water (Total Watershed) Load (g) [c] | Percent Individual Bridge Deck Load (of Total Watershed Load) [d] | Percent Total Bridge Deck Load in Watershed (of Total Watershed Load) [e] |
|---|---|---|---|---|---|---|---|
| pH (acidic and basic) | | 6.2 s.u. | NA | 6.3 s.u. | NA | NA | NA |
| Trace Metals | Total Recoverable Arsenic | 2.1 µg/L | 0.046 | 1.8 µg/L | 6,600 | 0.001% | 0.026% |
| | Dissolved Cadmium | 0.06 µg/L | 0.001 | 0.02 µg/L | 70 | 0.002% | 0.069% |
| | Dissolved Copper | 1.9 µg/L | 0.041 | 1.4 µg/L | 5,100 | 0.001% | 0.030% |
| | Total Recoverable Iron | 549 µg/L | 12.0 | 2,490 µg/L | 9,074,000 | <0.001% | 0.005% |
| | Dissolved Lead | 0.10 µg/L | 0.0022 | 0.32µg/L | 1,200 | <0.001% | 0.007% |
| | Total Recoverable Manganese | 34.8 µg/L | 0.758 | 59.1 µg/L | 215,000 | <0.001% | 0.013% |
| | Total Recoverable Nickel | 1.1 µg/L | 0.024 | 1.3 µg/L | 4,700 | 0.001% | 0.019% |
| | Dissolved Zinc | 37.6 µg/L | 0.819 | 3.9 µg/L | 14,000 | 0.006% | 0.219% |
| | Total Recoverable Aluminum | 390 µg/L | 8.49 | 289 µg/L | 1,050,000 | 0.001% | 0.030% |
| | Total Recoverable Mercury [f] | <0.010 µg/L | NA | 0.011 µg/L | NA | NA | NA |
| Semi-volatiles | Benzo-[b]-fluoranthene [f] | <0.40 µg/L | NA | <0.40 µg/L | NA | NA | NA |
| | Benzo-[a]-pyrene [f] | <0.33 µg/L | NA | <0.33 µg/L | NA | NA | NA |
| | Benzo-[k]-fluoranthene [f] | < 0.4 µg/L | NA | <0.4 µg/L | NA | NA | NA |
| | Chrysene [f] | <0.33 µg/L | NA | <0.33 µg/L | NA | NA | NA |
| | Benzo[a]anthracene [f] | <0.26 µg/L | NA | <0.26 µg/L | NA | NA | NA |
| | Bis(2-ethylhexyl)phthalate [f] | <2 µg/L | NA | <2 µg/L | NA | NA | NA |
| | Indeno[1,2,3-cd]pyrene [f] | <0.4 µg/L | NA | <0.4 µg/L | NA | NA | NA |
| Solids | Total Suspended Solids (TSS) [f] | 15 mg/L | 330 | <30 mg/L | NA | NA | NA |
| Nutrients | Total Nitrogen | 0.68 mg/L | 15 | 1.6 mg/L | 5,800,000 | <0.001% | 0.010% |
| | Total Phosphorus | 0.157 mg/L | 3.42 | 0.332 mg/L | 1,210,000 | <0.001% | 0.011% |

**Notes:**

[a] See section 4.2 for discussion and establishment of parameters-of-concern (POCs).

[b] Measured concentration values taken from table 4.2-7 in section 4.2. Shaded values indicate measured concentrations were greater than established thresholds. Data shown are provisional.

[c] Pollutant loads from both the individual bridge deck and the receiving water were calculated by multiplying runoff volume by the EMC measured for each POC. Runoff volume for both bridge deck and receiving water hydrographs were calculated using time period from start for the bridge deck to end of autosampling or sampling date for the receiving water. Discharge data used for the calculation were provided by USGS.

[d] Because receiving water concentration was measured upstream of the bridge, percent individual bridge deck load of total watershed load was calculated as bridge deck load divided by sum of bridge deck load and receiving water load.

[e] Total bridge deck load was estimated by calculating a unit loading based on the individual bridge deck at the stream crossing and applying to total bridge deck area within the watershed for the receiving water. See table 4.3-2 for bridge deck area for the individual bridge and for all bridges within the drainage area for the stream crossing.

[f] Pollutant load comparison could not be performed because no data were available or values were below detection.

## Table 4.4-5: Pollutant Load Comparison for Little River at SR 1461 during Selected Wet Weather Period (July 17 to 19, 2009)

| Parameters-of-concern [a] | | Bridge Deck EMC [b] 7/17/2009 | Load from Individual Bridge Deck (g) [c] | Receiving Water Conc. [b] 7/18/2009 | Receiving Water (Total Watershed) Load (g) [c] | Percent Individual Bridge Deck Load (of Total Watershed Load) [d] | Percent Total Bridge Deck Load in Watershed (of Total Watershed Load) [e] |
|---|---|---|---|---|---|---|---|
| pH (acidic and basic) | | 6.7 s.u. | NA | 6.7 s.u. | NA | NA | NA |
| Trace Metals | Total Recoverable Arsenic | 0.62 µg/L | 0.0094 | 1.1 µg/L | 320 | 0.003% | 0.027% |
| | Dissolved Cadmium | 0.01 µg/L | 0.0002 | 0.03 µg/L | 9 | 0.002% | 0.020% |
| | Dissolved Copper | 1.7 µg/L | 0.026 | 1.5 µg/L | 440 | 0.006% | 0.054% |
| | Total Recoverable Iron | 1,030 µg/L | 15.55 | 2,030 µg/L | 596,800 | 0.003% | 0.024% |
| | Dissolved Lead | 0.03 µg/L | 0.0005 | 0.22 µg/L | 65 | 0.001% | 0.007% |
| | Total Recoverable Manganese | 65.6 µg/L | 0.991 | 232 µg/L | 68,200 | 0.001% | 0.013% |
| | Total Recoverable Nickel | 1.4 µg/L | 0.021 | 0.94 µg/L | 280 | 0.007% | 0.068% |
| | Dissolved Zinc | 9.8 µg/L | 0.15 | 1.9 µg/L | 560 | 0.027% | 0.244% |
| | Total Recoverable Aluminum | 875 µg/L | 13.2 | 1,220 µg/L | 358,700 | 0.004% | 0.033% |
| | Total Recoverable Mercury | 0.012 µg/L | 0.00018 | 0.003 µg/L | 0.9 | 0.020% | 0.182% |
| Semi-volatiles | Benzo-[b]-fluoranthene [f] | <0.40 µg/L | NA | no data | NA | NA | NA |
| | Benzo-[a]-pyrene [f] | <0.33 µg/L | NA | <0.33 µg/L | NA | NA | NA |
| | Benzo-[k]-fluoranthene [f] | < 0.4 µg/L | NA | no data | NA | NA | NA |
| | Chrysene [f] | <0.33 µg/L | NA | no data | NA | NA | NA |
| | Benzo[a]anthracene [f] | <0.26 µg/L | NA | <0.26 µg/L | NA | NA | NA |
| | Bis(2-ethylhexyl)phthalate [f] | <2 µg/L | NA | <2 µg/L | NA | NA | NA |
| | Indeno[1,2,3-cd]pyrene [f] | <0.4 µg/L | NA | no data | NA | NA | NA |
| Solids | Total Suspended Solids (TSS) | 46 mg/L | 690 | 99 mg/L | 29,000,000 | 0.002% | 0.022% |
| Nutrients | Total Nitrogen | 1.0 mg/L | 15 | 1.0 mg/L | 290,000 | 0.005% | 0.047% |
| | Total Phosphorus | 0.558 mg/L | 8.43 | 0.185 mg/L | 54,400 | 0.015% | 0.141% |

**Notes:**

[a] See section 4.1 for discussion and establishment of parameters-of-concern (POCs).

[b] Measured concentration values taken from table 4.2-8 in section 4.1. Shaded values indicate measured concentrations were greater than established thresholds. Data shown are provisional.

[c] Pollutant loads from both the individual bridge deck and the receiving water were calculated by multiplying runoff volume by the EMC measured for each POC. Runoff volume for both bridge deck and receiving water hydrographs were calculated using time period from for the bridge deck to end of autosampling or sampling date for the receiving water. Discharge data used for the calculation were provided by USGS (Chad Wagner, e-mail messages, December 21, 2009; December 22, 2009; February 2, 2010; March 24, 2010).

[d] Because receiving water concentration was measured upstream of the bridge, percent individual bridge deck load of total watershed load was calculated as bridge deck load divided by sum of bridge deck load and receiving water load.

[e] Total bridge deck load was estimated by calculating a unit loading based on the individual bridge deck at the stream crossing and applying to total bridge deck area within the watershed for the receiving water. See table 4.3-2 for bridge deck area for the individual bridge and for all bridges within the drainage area for the stream crossing.

[f] Pollutant load comparison could not be performed because no data were available or values were below detection.

## Table 4.4-6: Pollutant Load Comparison for Swannanoa River at I-40 during Selected Wet Weather Period (June 16 to 18, 2009)

| | Parameters-of-concern [a] | Bridge Deck EMC [b] 6/16/2009 | Load from Individual Bridge Deck (g) [c] | Receiving Water Conc. [b] 6/15/2009 | Receiving Water (Total Watershed) Load (g) [c] | Percent Individual Bridge Deck Load (of Total Watershed Load) [d] | Percent Total Bridge Deck Load in Watershed (of Total Watershed Load) [e] |
|---|---|---|---|---|---|---|---|
| | pH (acidic and basic) | 7.0 s.u. | NA | 6.6 s.u. | NA | NA | NA |
| Trace Metals | Total Recoverable Arsenic | 0.38 µg/L | 0.024 | 0.47 µg/L | 22 | 0.111% | 0.113% |
| | Dissolved Cadmium | 0.08 µg/L | 0.005 | 0.02 µg/L | 9 | 0.054% | 0.055% |
| | Dissolved Copper | 3.8 µg/L | 0.24 | 0.82 µg/L | 380 | 0.063% | 0.064% |
| | Total Recoverable Iron | 2,090 µg/L | 132 | 3,700 µg/L | 1,703,000 | 0.008% | 0.008% |
| | Dissolved Lead | 0.17 µg/L | 0.011 | 0.09 µg/L | 41 | 0.027% | 0.027% |
| | Total Recoverable Manganese | 35.2 µg/L | 2.22 | 182 µg/L | 83,800 | 0.003% | 0.003% |
| | Total Recoverable Nickel | 3.2 µg/L | 0.20 | 2.3 µg/L | 1,100 | 0.018% | 0.019% |
| | Dissolved Zinc | 20.8 µg/L | 1.31 | 4.5 µg/L | 2,100 | 0.062% | 0.063% |
| | Total Recoverable Aluminum | 1,040 µg/L | 65.6 | 1,700 µg/L | 782,300 | 0.008% | 0.009% |
| | Total Recoverable Mercury | 0.011 µg/L | 0.0010 | 0.01 µg/L | 5 | 0.022% | 0.022% |
| Semi-volatiles | Benzo-[b]-fluoranthene [f] | no data | NA | no data | NA | NA | NA |
| | Benzo-[a]-pyrene [f] | no data | NA | no data | NA | NA | NA |
| | Benzo-[k]-fluoranthene [f] | no data | NA | no data | NA | NA | NA |
| | Chrysene [f] | no data | NA | no data | NA | NA | NA |
| | Benzo[a]anthracene [f] | no data | NA | no data | NA | NA | NA |
| | Bis(2-ethylhexyl)phthalate [f] | 2 µg/L | 0.1 | <2 µg/L | NA | NA | NA |
| | Indeno[1,2,3-cd]pyrene [f] | no data | NA | no data | NA | NA | NA |
| Solids | Total Suspended Solids (TSS) | 27 mg/L | 1,700 | 48 mg/L | 2,200,000 | 0.077% | 0.079% |
| Nutrients | Total Nitrogen | 0.83 mg/L | 52 | 0.72 mg/L | 33,000 | 0.159% | 0.161% |
| | Total Phosphorus | 0.148 mg/L | 9.34 | 0.133 mg/L | 6,120 | 0.152% | 0.155% |

**Notes:**

[a] See section 4.1 for discussion and establishment of parameters-of-concern (POCs).

[b] Measured concentration values taken from table 4.2-9 in section 4.1. Shaded values indicate measured concentrations were greater than established thresholds. Data shown are provisional.

[c] Pollutant loads from both the individual bridge deck and the receiving water were calculated by multiplying runoff volume by the EMC measured for each POC. Runoff volume for both bridge deck and receiving water hydrographs were calculated using time period from start of autosampling for the bridge deck to end of autosampling or sampling date for the receiving water. Discharge data used for the calculation were provided by USGS (Chad Wagner, e-mail messages, December 21, 2009; December 22, 2009; February 2, 2010; March 24, 2010).

[d] Because receiving water concentration was measured upstream of the bridge, percent individual bridge deck load of total watershed load was calculated as bridge deck load divided by sum of bridge deck load and receiving water load.

[e] Total bridge deck load was estimated by calculating a unit loading based on the individual bridge deck at the stream crossing and applying to total bridge deck area within the watershed for the receiving water. See table 4.3-2 for bridge deck area for the individual bridge and for all bridges within the drainage area for the stream crossing.

[f] Pollutant load comparison could not be performed because no data were available or values were below detection.

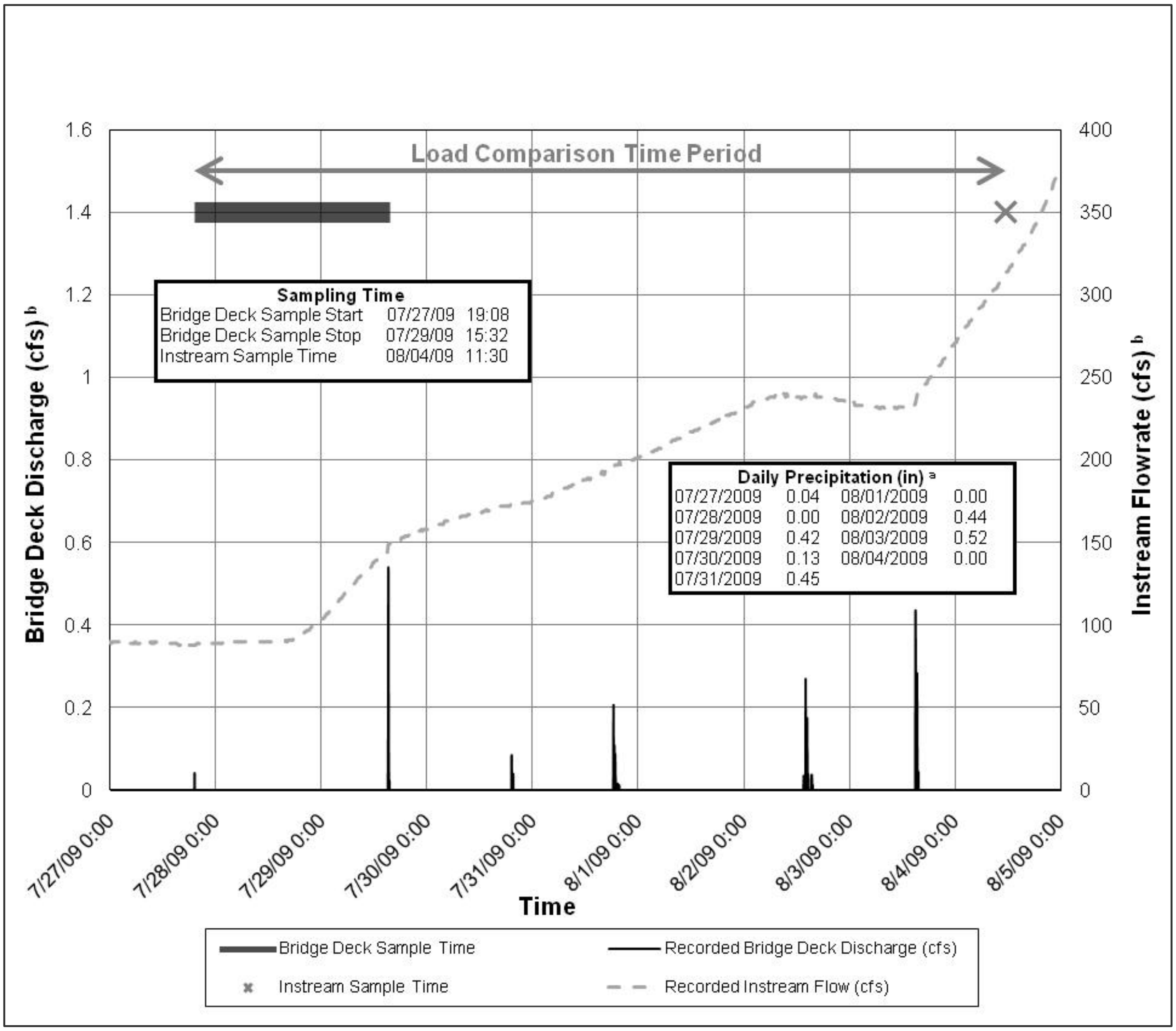


**Figure 4.4-4: Pollutant load comparison for Black River at NC 411 during selected wet weather period (July 27 to August 4, 2009). Notes: a Precipitation data obtained from the USGS National Water Information System Web Interface for Rain gage 344516078172145. Data were provisional at time of access. b Discharge data were provided by USGS.**

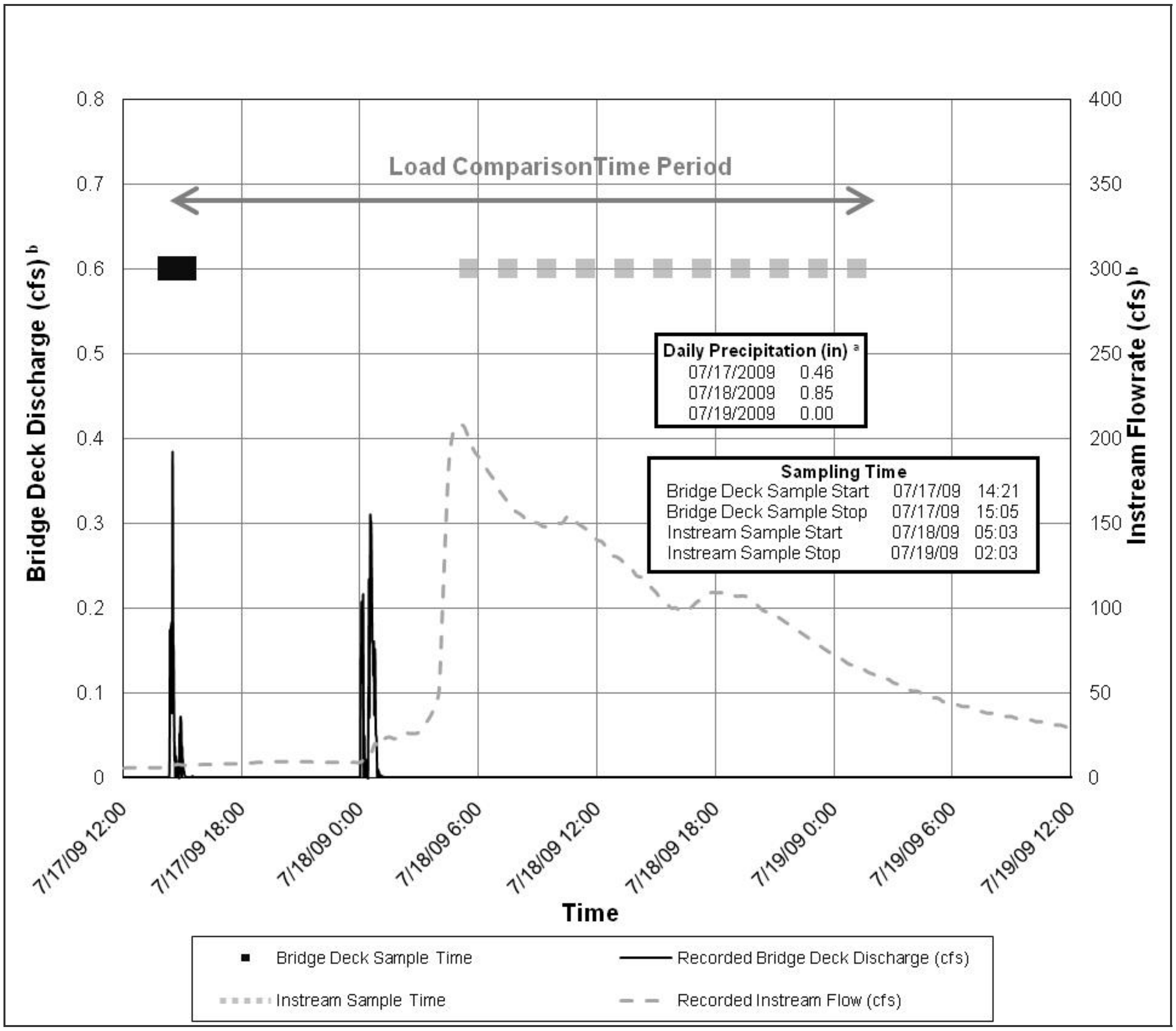
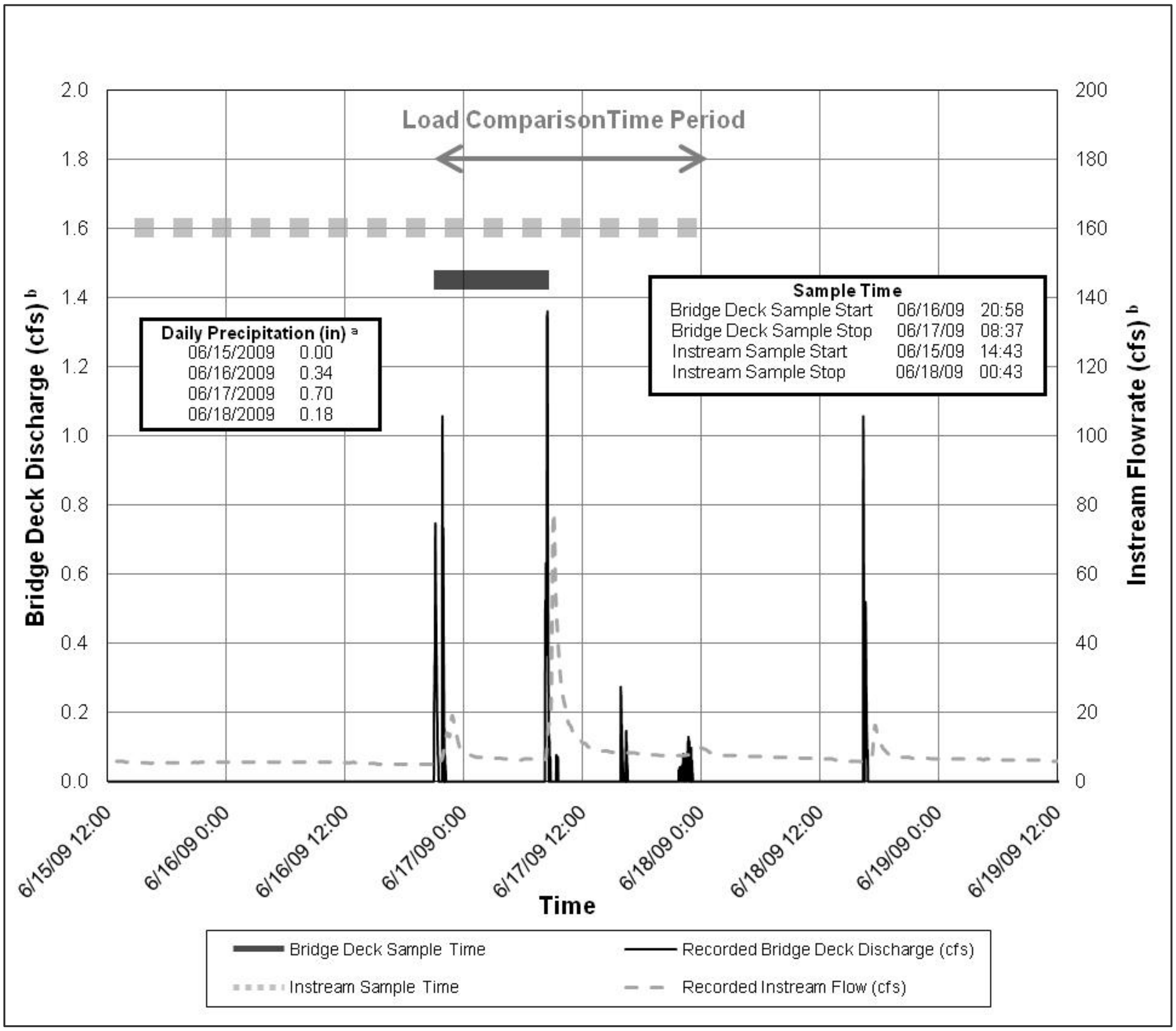


**Figure 4.4-5: Pollutant load comparison for Little River at SR 1461 during selected wet weather period (July 17 to 19, 2009). Notes: Precipitation data obtained from the USGS National Water Information System Web Interface for Rain gage 360829078550945. Data were provisional at time of access. Discharge data were provided by USGS.**



| Daily Precipitation (in) [a] | |
|---|---|
| 06/15/2009 | 0.00 |
| 06/16/2009 | 0.34 |
| 06/17/2009 | 0.70 |
| 06/18/2009 | 0.18 |

| Sample Time | | |
|---|---|---|
| Bridge Deck Sample Start | 06/16/09 | 20:58 |
| Bridge Deck Sample Stop | 06/17/09 | 08:37 |
| Instream Sample Start | 06/15/09 | 14:43 |
| Instream Sample Stop | 06/18/09 | 00:43 |

**Figure 4.4-6: Pollutant load comparison for Swannanoa River at I-40 during selected wet weather period (June 16 to 18, 2009). Notes: Precipitation data obtained from the USGS National Water Information System Web Interface for Rain gage 353708082182145. Data were provisional at time of access. Discharge data were provided by USGS**.

**Table 4.4-7: Annual Constituent Loads from Bridge Decks as Percentage of Annual Constituent Loads in Receiving Streams for Three Bridge Sites in Texas**

| Constituent | | Bridge Runoff Load as % of Load in Barton Creek, Austin, TX | Bridge Runoff Load as % of Load in Stream, Lubbock, TX | Bridge Runoff Load as % of Load in Clear Creek, Austin, TX |
|---|---|---|---|---|
| Trace Metals | Dissolved Copper | not calculated | 0.007% | 0.008% |
| | Dissolved Lead | not calculated | 0.007% | 0.020% |
| | Dissolved Zinc | not calculated | 0.014% | 0.011% |
| Solids | Total Suspended Solids (TSS) | 0.004% | 0.002% | 0.0005% |
| Nutrients | Total Nitrogen | 0.006% | not calculated | not calculated |
| | Total Phosphorus | 0.004% | 0.010 | 0.0003% |

**Notes:** All percentages in table reproduced from Malina et al. (2005b). Only constituents considered in both the Malina et al. study and the BSP study are represented in the table.

## 4.5 Biological Assessments

Biological monitoring activities were performed to determine the toxicity of bridge deck runoff and the biological health of the receiving waters. Two independent tests were used for this purpose. Biological assays involve collection of bridge deck runoff and instream samples, and measure the survival and reproduction of test organisms exposed to these samples in the laboratory. The scope and methods of these assays is discussed in section 3.4.1. Biological surveys involve sampling and classification of benthic macroinvertebrates, and analysis of their population structures to detect population changes due to chemical stresses. The scope and methods of these assays is discussed in section 3.4.2.

### 4.5.1 Biological Assay Results

#### 4.5.1.1 Discussion

A discussion of biological assay monitoring, including a description of the sites monitored, methods, and results was presented in section 3.4.1. The USGS collected a total of 40 samples for bioassay testing from 13 bridge sites between September 2009 and February 2010. A total of 23 samples were collected from the end-of-pipe during storm events to capture runoff from the bridge decks. Samples were also collected from the receiving stream, just upstream of the bridge during normal flow conditions (eight samples), as well as during storm conditions (nine samples). A summary of results are presented in table 3.4-6.

None of the 17 upstream toxicity tests performed during either normal or storm conditions exhibited chronic toxicity. Of the 23 bridge deck runoff samples tested, three (13%) exhibited toxicity to *C. dubia*. The three sites for which the runoff was found to be toxic included the following:

- Swannanoa River – February 22, 2010: IC25 = 38.4%
- Black River – November 10, 2009: IC25 = 81.5%

- Little River – September 17, 2009: Fail; reproduction significantly reduced in 100% bridge deck runoff sample . (This sample was accidentally processed for a pass/fail analysis, as discussed in Section 3.4.1)

For the Swannanoa River, an instream sample was collected concurrently with the failing bridge deck runoff sample, and no chronic toxicity was indicated. An examination of the toxicity test for the bridge deck runoff sample indicated elevated conductivity in bridge runoff. Conductivity can be used as an indication of the total dissolved solids (TDS) content. Although the relationship varies depending upon the types of dissolved solids present, a common relationship used is of the form (USDOI, 1998):

$$TDS = 0.67(SC) \tag{4.5-1}$$

where

TDS = Total dissolved solids (mg/L)
SC = Specific conductivity (µmhos/cm)

In the 100% bridge deck runoff sample, the conductivity was 4,110 µmhos/cm, suggesting a TDS concentration of about 2,750 mg/L. This conductivity was an order of magnitude higher than concurrent instream levels measured upstream of the bridge (418 µmhos/cm). The laboratory quality assurance program includes routine reference tests of the *Ceriodaphnia dubia* test organisms with sodium chloride as the reference toxicant, typically reported as an IC25 toxicity level. The reference toxicity test reported with the Swannanoa River bridge deck runoff test was an IC25 for sodium chloride of 1,070 mg/L. Toxicity results using sodium chloride provide an approximation of the toxicity associated with TDS, though toxicity can vary greatly depending upon the ionic makeup of TDS in the water sample. The sodium chloride reference test IC25 (1,070 mg/L) is about 38.9% of the estimated TDS concentration in the 100% bridge runoff sample, and is remarkably close to the IC25 of 38.4% reported for the bridge runoff toxicity test. This suggests that the toxicity observed in the February 2010 Swannanoa River sample is likely the result of TDS in the bridge deck runoff.

Other samples collected did not reveal high conductivity levels, including the instream storm condition sample (418 µmhos/cm), and two other bridge runoff samples at this site from September 2009 (30 µmhos/cm) and November 2009 (39 µmhos/cm). Toxicity testing of these samples did not indicate adverse effects on *C. dubia* survival, consistent with lower TDS levels in these samples.

Both bridge deck runoff samples and instream storm samples were collected from the Black River in November 2009. No toxicity was observed in the instream samples, but an IC25 of 81.5% was measured in bridge deck runoff. An examination of the toxicity test data suggests that unusually low hardness and pH were present in the bridge deck runoff sample. The reported hardness at the beginning of the bridge deck runoff test was 6 mg/L CaCO3, and the pH was 5.64. Low hardness and low pH are not uncharacteristic of rainwater, and are not related to bridge characteristics. However, the low hardness and low pH could explain the lower reproduction observed in organisms exposed to 100% bridge deck runoff. These water quality parameters are well below the ranges generally used for cultivating *C. dubia* in controls (NCDENR, 1998; NCDENR, 2009), and recommended by DWQ for renewal water for bridge runoff samples (NCDENR, 2009), which restrict hardness to 30- 50 mg/L CaCO3, and pH from 6.5-8.5). These water quality characteristics alone may account for the reduced reproduction in the Black River bridge deck runoff sample. However, it is also plausible that the toxicity of contaminants, if present, was exacerbated by the low hardness and pH. Hardness (primarily calcium and magnesium ions) acts to mitigate the toxicity of some contaminants. For example, the toxicity of many metals decreases with an increase in water hardness. Conversely, as hardness decreases, toxicity may increase. Lower pH may also act to increase the bioavailability of some constituents, thus increasing the potential for effects. A review of chemical analytical data (inorganics, nutrients, and SVOCs) showed no readily apparent potential contributors to toxicity.

In the Little River bridge deck runoff sample collected in September 2009, reproduction was reduced 47% (in 100% sample concentration) as compared with the control. The runoff sample exhibited hardness below the ideal range for test organisms (22 mg/L $CaCO_3$), but the sample pH was within acceptable limits (7.3) at test initiation. A number of other bridge deck runoff toxicity tests from Little River (as well as other locations) with similar hardness and pH characteristics did not demonstrate toxicity. Thus, there is the potential that other factors may have contributed to the observed toxicity. An IC25 could not be determined, as this sample was processed as a pass/fail test. A review of chemical analytical data (inorganics, nutrients, and SVOCs) showed no readily apparent potential contributors to toxicity. It is plausible that the low hardness could have stressed individuals sufficiently to reduce reproduction due to the lack of calcium to support proper growth. In addition, calcium and magnesium ions that contribute to water hardness generally lower metals toxicity by competing with metal ions for binding sites on the organism (NCDENR, 2010d). Thus, it is also possible that under conditions of very low hardness, even low levels of contaminants could contribute to the observed effects.

#### 4.5.1.2 Bioassay Conclusions

No instream background toxicity was indicated during either normal flow or storm events at any of 17 locations evaluated. However, toxicity was indicated in bridge deck runoff at three of 23 locations, as indicated by reduced reproduction in *C. dubia*. Toxicity at one of these locations (Swannanoa River) appears associated with elevated TDS in the bridge deck runoff. Toxicity at a second location (Black River) may be simply associated with low hardness and pH of the runoff that is below the physiochemical requirements of the organism. However, low hardness and pH also may exacerbate the toxicity of some contaminants (particularly metals), if present, although none were readily apparent. Toxicity was also observed in a summer bridge runoff sample from the Little River. Hardness was low (22 mg/L $CaCO_3$), but pH was normal (7.3). No readily apparent causal factors were identified in examination of chemical analytical data.

Toxicity in the Swannanoa River was the highest among all sites, and appears clearly associated with dissolved solids. Toxicity in bridge deck samples from Black River (IC25 = 81.5%) and Little River (reproduction reduce by 47% in 100% sample), was relatively low. For Black River and Littler River, toxicity was nominal, and any attenuation within the receiving stream is likely to reduce the concentration of bridge runoff to concentrations below which effects are likely to be expressed.

### 4.5.2 Biological Survey Results

#### 4.5.2.1 Between-Site Studies

Biosurveys were performed at 12 sites along reaches upstream and downstream from bridge crossings to evaluate localized effects from bridge deck runoff. Biosurvey results were presented in table 3.4-9 and summarized in Section 3.4.2.3. The ultimate result of benthos sampling is the identification of a bioclassification of Excellent, Good, Good/Fair, Fair or Poor for standard qualitative samples, based on EPT taxa richness and NCBI values. As discussed in Section 3.4.2.3, none of the bridge studies at the 12 between-site locations showed a change in bioclassification between the upstream and downstream areas. One study site (Swannanoa River) had a change in biotic index metric values large enough (+0.9 – a higher index indicates lower quality) to suggest a decline in water quality downstream of the bridge. Biotic index values at the other 11 sites showed a variation from -0.2 to 0.3, but changes less than 0.5 are not considered significant. Incidentally, the Swannanoa River bridge site is also the location where bioassay samples collected in February 2010 indicated chronic toxicity due to dissolved solids. Review of chemical analytical data associated with bridge deck runoff or upstream/downstream bed sediment data did not indicate any constituents that might be contributing to the apparent increase in the biotic index (i.e., decline in benthic quality).

Downstream sites often had slower current speeds and more pool/run habitat downstream of the bridge, which can increase habitat diversity. This produced increases in total taxa richness at four Blue Ridge sites: Dillingham Creek, Boylston Creek, Big Ivy Creek and Flat Creek. Note, however, that total taxa richness can be quite variable and is not used to establish bioclassifications (NCDENR, 2006).

Overall, results of the between-site studies suggest that bridge runoff did not substantially impact downstream benthic communities from bridges included in this study.

#### 4.5.2.2 Between-Time Studies

Benthic surveys were also conducted for between-time evaluations downstream of three bridge sites located in the Blue Ridge ecoregion. Results were presented in table 3.4-10. Of the three sites, Mitchell River is the only one that showed a change in bioclassification between the surveys conducted in 2007 (‘Good’) and 2009 (‘Good-Fair’). However, DWQ ratings are based on 10-sample EPT abundance criteria. The use of a Qual 5 sample in 2009 likely lowered EPT abundance, and consequently underpredicts the bioclassification rating. A comparison of the 2007 and 2009 downstream bioclass ratings does not reflect a material change in water quality.

## 4.6 Conclusions of Effect and Sources of Impairment

To confirm any source as the cause of effect on receiving streams, a study must establish a relationship between the source and the effect on the stream. This section will discuss the conclusions from the lines of evidence studies and their relevance to bridge deck runoff. The following list reproduces USEPA definition of the criteria for causality (USEPA, 1998):

- Criteria strongly affirming causality:
    - Strength of association
    - Predictive performance
    - Demonstration of a stressor-response relationship
    - Consistency of association
- Criteria providing a basis for rejecting causality:
    - Inconsistency in association
    - Temporal incompatibility
    - Factual implausibility
- Other relevant criteria:
    - Specificity of association
    - Theoretical and biological plausibility

Following NCDENR (2003), the BSP study assessed the candidate stressors listed below. An assessment of hydromodification due to dams was not performed, as it is outside the scope of the BSP.

- Habitat degradation--sedimentation
- Habitat degradation--lack of microhabitat
- Hydromodification

- Toxicity
- Organic and nutrient enrichment

### 4.6.1 Habitat Degradation

Results from the biosurveys were used to evaluate habitat degradation, including benthic macroinvertebrate community data and habitat evaluations. In general, the biosurveys indicate that bridge deck runoff does not substantially affect downstream benthic communities (see section 4.5). Site specific observations indicate that sites downstream of the bridge often had better benthic habitats and diversity than upstream of the bridge.

### 4.6.2 Hydromodification

The results of the biosurveys indicate that upstream and downstream benthic communities are statistically similar. Therefore, long-term effects from bridge deck runoff quantity on benthic communities are not apparent and the assessment performed in section 4.4 demonstrates regional effects may be minimal. However, it is possible that local concentrated flow conditions may periodically affect benthic communities and stream quality.

### 4.6.3 Toxicity Due to Bridge Deck Runoff

Lines of evidence used to evaluate toxicity include: water chemistry data, instream bioassay data, sediment chemistry data, watershed characteristics, and benthic community data.

The identification of several pollutants (dissolved and total copper, zinc, cadmium, lead, iron, manganese, aluminum, and mercury; total suspended solids; bis(2-ethylhexyl) phthalate; and nutrients) with concentrations above thresholds established from human health and aquatic criteria indicate a potential for toxic effects from bridge deck runoff (see section 4.2). However, biosurvey studies of benthic communities do not indicate changes upstream and downstream of the bridges.

Out of 23 samples collected, three bioassay samples from bridge deck runoff expressed toxicity. For two of these events (Black River – November 10, 2009 and Little River – September 17, 2009), low hardness and low pH (for Black River) commonly found in ambient rainwater characteristics may have caused or contributed to the toxicity. Two additional bioassay sampling events at Black River and one additional event at Little River showed no evidence of toxicity. Corresponding water chemistry data for the two toxic events were often within range of water chemistry data collected at their respective sites, and were lower than water chemistry data collected concurrent to bioassay events that did not show toxicity. For example, water chemistry results for total recoverable aluminum for the November 10, 2009 sample collected at Black River (concurrent to the bioassay test that failed) was 177 μg/l. Total recoverable aluminum results collected September 16, 2009 and January 17, 2010 were 152 and 273 μg/l respectively. Bioassay samples collected on these dates did not express toxicity although they had a higher number of individual parameters which exceeded the thresholds (refer to table 4.2-7). Therefore, the exceedance of water quality thresholds does not consistently correlate with the expression of toxicity in samples.

Where bioassay results do not provide evidence of toxicity but water chemistry results exceed thresholds, it is believed the instream concentration of the pollutants is not likely to be harmful to aquatic life during these events. Similar conclusions were drawn in NCDENR’s study of Corpening Creek (NCDENR, 2004a) where aluminum concentrations were greater than the chronic aquatic water quality criteria but bioassays did not indicate toxicity.

Unfortunately, water chemistry data corresponding to the February 22, 2010 bioassay from the Swannanoa River which expressed toxicity was not available at the time of report writing. The high conductivity and total dissolved solids found in this sample may indicate anti-icing or de-icing materials might have been applied to the bridge and contributed to the toxic results. See section 8 for more discussion on this topic. Additionally, bioassays were not conducted concurrent to water chemistry sampling events which resulted in the highest concentrations of the pollutants of concern.

A significant difference in sediment chemistry was not seen when comparing upstream and downstream results (see section 4.3.1) with the exception of outlier events for lead at Town Creek and mercury at Mallard Creek. Without these two outliers, downstream and upstream comparisons of all constituents were generally within 10 percent.

Quantifying causal effects of toxicity is difficult. The bioassay, biosurvey water chemistry and sediment chemistry data provide lines of evidence that the specific cause of toxicity from bridge deck runoff is inconclusive. However the same data indicates toxicity is occurring at least periodically and may be due to ambient rainwater characteristics, the periodic application of anti-icing or de-icing materials for safety concerns, or other unmeasured toxicants.

### 4.6.4 Organic and Nutrient Enrichment

Benthic community data and water quality data were evaluated to assess organic and nutrient enrichment.

Several streams showed signs of nutrient enrichment at upstream locations, presumably from upstream sources, as indicated by abundant periphyton (a mixture of algae, cyanobacteria, heterotropic microbes and detritus) growth. There was no indication during the biosurvey assessments of organic enrichment when comparing downstream locations to upstream locations. No organic contribution from bridge deck runoff would be expected since bridges do not generate organic materials and accumulation of organic material is minor.

Dissolved oxygen levels collected during habitat assessment range from 8 to 10 mg/L, exceeding North Carolina’s water quality standard of 5 to 6 mg/L, and do not indicate an effect from nutrients (see appendix 3-O for data).

Nutrients are generally considered parameters-of-concern for stormwater runoff (USEPA, 2009b). For the BSP study, thresholds for the comparison of water chemistry data were only available for receiving streams that had water quality standards established for NPDES permitted wastewater discharges, such as Little River’s total phosphorous standard of 2 mg/l. Median event mean concentrations for nutrients in bridge deck runoff collected during the BSP were below median event mean concentrations seen for urban runoff data (see table 4.2-1).

Data collected under the BSP do not indicate that bridge deck runoff contributes to stresses from organics or nutrient enrichment.

### 4.6.5 Conclusions of Effect and Sources of Impairment

As the previous discussion indicates, it is often difficult to assess specific causes of impacts to receiving streams, both at specific locations, and broadly to apply to discharges of bridge deck runoff statewide. However, regulatory agencies consider biological impacts to be a reliable indicator of the effect of a discharge on the receiving stream and the environment. Impacts to benthic communities were rarely identified, and toxicity to study populations was seen in few sampling events collected during the extensive BSP monitoring program. While the data presented does not conclusively provide a strong causality relationship to implicate bridge deck runoff as a primary source of impact, there is indication that periodic toxicity and hydromodification may be stressors related to bridge deck runoff.

Runoff from bridge decks can carry toxics from vehicles, road surface wear, and atmospheric deposition (see section 2 for extensive discussion). NCDENR has identified some vehicle components (i.e., brake pads) as potential sources, and acknowledges that little may be done for source control until changes in brake technology is available (NCDENR, 2003). Regardless, to address the general potential for pollutants and hydromodification from bridge deck runoff, NCDOT currently implements a programmatic approach stormwater management under its NPDES permit. Section 6 outlines the portions of the NCDOT stormwater management approach that specifically apply to bridges.

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# 5.0 Bridge SCM Pilot Study

A pilot study of bridge SCM implementation at 52 sites was conducted as part of the BSP as stipulated by Session Law 2008-107, Section 25.18(a), which requires that NCDOT "conduct a pilot study on 50 bridges, located throughout the State in various ecosystems, of the installation of various types of stormwater detention, collection, and filtering systems during new bridge construction over waterways." The session law also stipulates that the "treatments and methods used in the pilot study shall include but not be limited to those treatments found effective by other states and new treatments identified through investigation and research which may be effective" and allows NCDOT to "retrofit existing bridges as part of its pilot study" (NCGA, 2008). Initiation of construction or retrofitting was required for 25 of the 50 sites by July 1, 2009, and for the remaining sites by January 1, 2010.

The purpose of the pilot study was to represent SCMs that are implemented or could be implemented to control or treat bridge deck runoff and provide cost, constructability, and applicability information. The scope of the pilot study included selection, installation, evaluation, and documentation of SCMs at bridge sites. Sites were selected to reflect variability of ecosystems and bridge systems throughout the state and to demonstrate SCMs that are currently being implemented by NCDOT or that could be implemented to control and treat bridge deck runoff in North Carolina. Summaries of each SCM type considered in the study are provided in appendix 5-A. Significant cost, constructability, and other information was gathered as part of the pilot study, which can be utilized to evaluate SCM applicability and to estimate costs for SCM implementation. Reports summarizing information gathered for each pilot study site are included in appendix 5-B.

## 5.1 Bridge SCM Type Evaluation

### 5.1.1 SCM Categories

The SCM types included in this study were divided into four main categories: Level I treatment, Level II treatment, design-related, and maintenance. Level I treatment SCMs target and remove pollutants in stormwater runoff from the bridge deck. In general, Level I treatment SCMs remove pollutants by sedimentation and physical filtration of stormwater solids that carry particulate-bound pollutants. Level II treatment SCMs primarily prevent erosion by stabilizing soil in the vicinity of the bridge or by dissipating energy and promoting diffuse flow of bridge runoff. There are important distinctions between Level I and Level II treatment SCMs. Level I treatment SCMs remove pollutants that enter stormwater runoff based on processes that occur as runoff travels over the bridge deck (i.e., pavement abrasion, atmospheric deposition, leaching of metals from vehicles), whereas Level II treatment SCMs reduce the eroded solids that enter the runoff as it travels from the bridge deck collection system to the receiving stream. Design-related SCMs are measures that are evaluated in the design process and utilized as part of comprehensive project stormwater management. In general, these SCMs include bridge deck hydraulic management practices to avoid direct discharge of stormwater and practices that support overall stormwater management. For example, if it is determined during the design process that Level I treatment SCMs are not practicable, environmental site design (ESD) or off-site stormwater mitigation may be considered as the most feasible approach to stormwater management for the project, used in combination with a design-related SCM (deck conveyance, closed systems, or dispersion) to comply with policy or permit requirements. Finally, maintenance SCMs include activities performed as part of NCDOT asset management that either potentially reduce pollutant inputs into stormwater (e.g., bridge sweeping) or identify conditions that may be contributing to receiving stream pollution (e.g., bridge stormwater conveyance and collection system assessment [BSCCA]). A summary of the SCM types represented in the pilot study is provided in table 5.1-1.

**Table 5.1-1: Summary of SCM Types by Category**

| Level I Treatment | Level II Treatment | Design-Related | Maintenance |
|---|---|---|---|
| Bioretention Basin | Conveyance Channel | Closed System | Bridge Stormwater Collection and Conveyance Assessment (BSCCA) |
| Catch Basin Insert (CBI) | Energy Dissipator | Deck Conveyance | Bridge Sweeping |
| Dry Detention Basin | Level Spreader | Dispersion | |
| Filter Strip | Preformed Scour Hole (PFSH) | Environmental Site Design (ESD) | |
| Filtration Basin | Stream Bank Drop Structure | Off-Site Stormwater Mitigation | |
| Infiltration Basin | | | |
| Stormwater Wetland | | | |
| Swale | | | |

## 5.1.2 SCM Summaries

Summaries providing brief overviews and descriptions for each SCM type are located in appendix 5-A. The intent of each summary is to provide key information that may be used to evaluate each SCM. Each summary contains the following information:

> **SCM At-a-Glance**. A table was included in each summary to give a snapshot look at the SCM. In addition to indicating the SCM category, each table rates certain characteristics based on available literature, general knowledge, and best engineering judgment. Table 5.1-2 summarizes the characteristics considered and the general criteria with which the characteristics were rated. Ratings from sources such as the Pennsylvania *Stormwater Best Management Practices Manual* (PADEP, 2006) and the NCDENR *Stormwater Best Management Practices Manual* (2007) were strongly considered in determination of rating, while considering unique NCDOT design requirements (NCDOT, 2008) and the anticipated bridge application. Where a direct comparison was not feasible, engineering judgment was utilized. Judgment rationale included consideration of an SCM's specific bridge application, experience with a particular SCM, understanding of unit processes, and general knowledge of relative costs of SCMs in the state. The ratings were intended to provide a general review of commonly considered criteria when evaluating SCMs. A ranking guide is provided in appendix 5-B.

**Table 5.1-2: SCM Rating Criteria**

| SCM Consideration | Criteria for Rating |
|---|---|
| Water Quality | In general, how effective is the SCM at reducing pollutant loads? |
| Volume Reduction | How well does the SCM reduce the inflow hydrograph volume? |
| Peak Rate Attenuation | How well does the SCM reduce the peak flow rate? |
| Groundwater Recharge | How well does the SCM replenish groundwater? |
| Cost | What are the construction costs relative to other SCMs? |
| Land Requirement | How large is the SCM footprint relative to other SCMs and what is the probability of right-of-way acquisition? |
| Possible Site Constraints | What is the relative probability of encountering issues with placement of the SCM at a bridge site based on the physical characteristics of the SCM? |
| Maintenance Burden | What is the relative level of effort, considering frequency, cost, and scope of maintenance activities required to keep the SCM functioning as intended? |

**Description**. A brief overview of the SCM, including a description of the basic design concept and functionality.

**Bridge Implementation**. A description of how and where the SCM is typically put into practice at bridge sites.

**Key Considerations**. A summary of important information related to the design, construction, and maintenance of the SCM that should be considered in the SCM selection process.

**Costs**. Basic cost information and the location in the report where detailed cost information and analysis is provided.

### 5.1.3 Pilot Study Sites and Documentation

Pilot study sites were identified and selected using input from NCDOT division staff across the state, desktop evaluation of existing bridge information, and Graphic Information System (GIS) analysis. Potential sites were confirmed through site visits prior to implementation. Sites were selected to be spatially representative of the various ecoregions, NCDOT divisions, counties, and major watersheds in the state. Sites were also selected to represent the SCM types considered as part of this study. A list of the pilot study sites along with descriptive information is provided in table 5.1-3. The distribution of sites across the state, ecoregions, and river basins is depicted in figure 5.1-1.

**Table 5.1-3: Pilot Study Sites**

| Count | Bridge Number | SCM Type | Stream Name | Route | Road Name | County | Ecoregion |
|---|---|---|---|---|---|---|---|
| 1 | NA[a] | Infiltration Basin | Intracoastal Waterway | SR 1190 | New Location | Brunswick | Coastal |
| 2 | 090072 | Infiltration Basin | Jinnys Branch | NC 179 | SW Brick Landing Rd. | Brunswick | Coastal |
| 3 | 090198 | Swale | Intracoastal Waterway | SR 1172 | S. Sunset Blvd. | Brunswick | Coastal |
| 4 | 090198 | Infiltration Basin | Intracoastal Waterway | SR 1172 | S. Sunset Blvd. | Brunswick | Coastal |
| 5 | 090206 | Infiltration Basin | Montgomery Slough | SR 1105 | Middleton Ave. | Brunswick | Coastal |
| 6 | 100145 | ESD and Deck Conveyance | Dillingham Creek | SR 2173 | Dillingham Rd. | Buncombe | Blue Ridge |
| 7 | 100494 | Bioretention Basin | Swannanoa River | I-40 | I-40 | Buncombe | Blue Ridge |
| 8 | 130007 | Preformed Scour Hole (PFSH) | Yadkin River | NC 268 | NC 268 | Caldwell | Blue Ridge |
| 9 | 150049 | Energy Dissipator | White Oak River | SR 1101/<br>SR 1442 | Wetherington Landing Rd. / Stella Rd. | Carteret | Coastal |
| 10 | 170017 | Stream Bank Drop Structure | Cline Creek North | SR 1486 | Lee Cline Rd. | Catawba | Piedmont |
| 11 | 240237 | Filtration Basin | Neuse River | NC 55 | NC 55, Ramp 825 | Craven | Coastal |
| 12 | 270054 | Bridge Sweeping | Croatan Sound | US 64/US 264 | Virginia Dare Memorial Bridge | Dare | Coastal |

### Table 5.1-3: Pilot Study Sites (continued)

| Count | Bridge Number | SCM Type | Stream Name | Route | Road Name | County | Ecoregion |
|---|---|---|---|---|---|---|---|
| 13 | 270054 | Dry Detention Basin | Croatan Sound | US 64/US 264 | Virginia Dare Memorial Bridge | Dare | Coastal |
| 14 | 280416 | ESD | Beaverdam Creek | SR 2550 | Badin Lake Rd. | Davidson | Piedmont |
| 15 | 300065 | Infiltration Basins | Northeast Cape Fear River | NC 41 | S NC 41 Hwy. | Duplin | Coastal |
| 16 | 300309 | Energy Dissipator | Nahunga Creek | SR 1301 | Bowden Rd. | Duplin | Coastal |
| 17 | 400024 | Level Spreader | Deep River | NC 62 | NC Hwy 62 W | Guilford | Piedmont |
| 18 | 400033 | Level Spreader | Randleman Lake | SR 1138 | Tom Ball Rd. | Guilford | Piedmont |
| 19 | 400049 | Level Spreader | Randleman Lake | NC 62 | NC 62 | Guilford | Piedmont |
| 20 | 400763 | Filtration Basin | Oak Hollow Reservoir | SR 1979/ US 311 | US 311 Bypass | Guilford | Piedmont |
| 21 | 400764 | ESD | Oak Hollow Reservoir | SR 1979/ US 311 | US 311 | Guilford | Piedmont |
| 22 | 440008 | Swale | Boylston Creek | SR 1314 | Ladson Rd. | Henderson | Blue Ridge |
| 23 | 440108 / 440112 | Dispersion | Green River | I-26, US 74 | I-26 | Henderson | Blue Ridge |
| 24 | 440375 | BSCCA | Green River | US 176 | Spartanburg Hwy | Henderson | Blue Ridge |
| 25 | 500188 | Catch Basin Insert (CBI) | Beddingfield Creek | SR 1553 | Shotwell Rd. | Johnston | Piedmont |
| 26 | 500188 | PFSH | Beddingfield Creek | SR 1553 | Shotwell Rd. | Johnston | Piedmont |
| 27 | 50____a | Dry Detention Basin | Poplar Creek | SR 1923 Ext. | Booker Dairy Rd. | Johnston | Piedmont |
| 28 | 50____a | Dry Detention Basin | Neuse River | SR 1923 Ext. | Booker Dairy Rd. | Johnston | Piedmont |
| 29 | 590296 | Stormwater Wetland | Mallard Creek | I-85 | I-85 Northbound (NB) | Mecklenburg | Piedmont |
| 30 | 640132 | BSCCA | Smith Creek | US 74 EB | Martin Luther King Jr. Pkwy. | New Hanover | Coastal |
| 31 | 660024 | Bioretention Basin | New River | US 17 | Marine Blvd. | Onslow | Coastal |
| 32 | 790008 | Dry Detention Basin | Yadkin River | NC 49 / NC 8 | NC Hwy. 49 S | Rowan | Piedmont |
| 33 | 810012 | ESD | Black River | NC 41 | Tomahawk Hwy. | Sampson | Coastal |
| 34 | 810282 | Energy Dissipator | Beaverdam Swamp | SR 1002 | Spring Branch Rd. | Sampson | Coastal |
| 35 | 840060 | Dry Detention Basin | Dan River | NC 8 / NC 89 | NC 8/NC 89 | Stokes | Blue Ridge |
| 36 | 850056 | Filtration Basin | Fisher River | SR 1345 | Prison Camp Rd. | Surry | Piedmont |
| 37 | 910102 | PFSH | Lower Barton's Creek | SR 1844 | Mount Vernon Church Rd. | Wake | Piedmont |
| 38 | 910124 | PFSH | Perry Creek | SR 2006 | Perry Creek Rd. | Wake | Piedmont |
| 39 | 910229 | PFSH | Poplar Creek | SR 1007 | Poole Rd. | Wake | Piedmont |

| Count | Bridge Number | SCM Type | Stream Name | Route | Road Name | County | Ecoregion |
|---|---|---|---|---|---|---|---|
| 41 | 910471 | CBI | Swift Creek | SR 1375 | Lake Wheeler Rd. | Wake | Piedmont |
| 42 | 911101 | Swale and Closed System | Mango Creek | I-540 | I-540 | Wake | Piedmont |
| 43 | 911102 | ESD | Mango Creek | I-540 | I-540 | Wake | Piedmont |
| 44 | 911102 | Filtration Basin | Mango Creek | I-540 | I-540 | Wake | Piedmont |
| 45 | 920042 | ESD | Shocco Creek | SR 1613 | Shocco Springs Rd. | Warren | Piedmont |
| 46 | 980030 | Filter Strip | South Deep Creek | US 601 | Hwy 601 | Yadkin | Piedmont |
| 47 | NA[a] | Filtration Basin | Hiwassee River | US 64 | US 64 | Cherokee | Blue Ridge |
| 48 | NA[a] | Filtration Basin | Hiwassee River | US 64 | US 64 | Cherokee | Blue Ridge |
| 49 | Multiple | Stormwater Mitigation | Ross Creek | I-240 | I-240 | Buncombe | Blue Ridge |
| 50 | Multiple | Stormwater Mitigation | Lake Norman | I-77 | I-77 | Catawba | Piedmont |
| 51[b] | Division 1 | Bridge Sweeping | Various | Various | Various | Various | Coastal |
| 52[b] | Division 13 | Bridge Sweeping | Various | Various | Various | Various | Blue Ridge |

**Source:** Information provided in this table was obtained from information compiled and maintained by NCDOT BMU staff.

**Notes:**

[a] Bridge is under construction or bridge number has not been assigned. NA = not applicable.

[b] These are "regional" sites that were included in the pilot study sites in order to provide characterization of bridge sweeping in each of these Divisions.

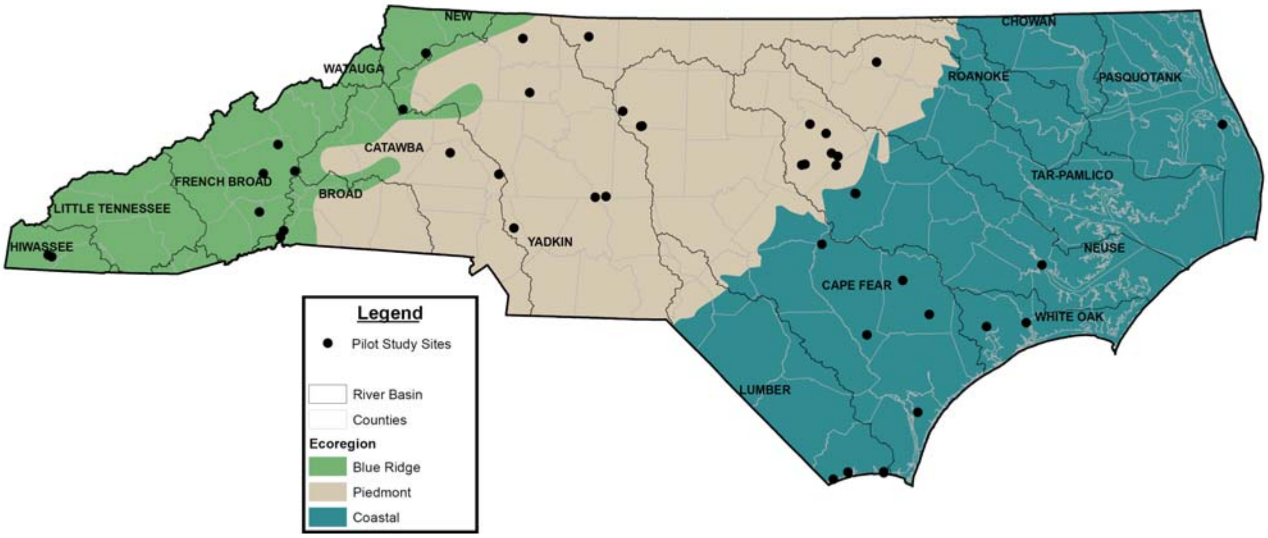


**Figure 5.1-1: Location map for the pilot study sites. Two sites contain multiple SCMs.**

Table 5.1-4 lists the number of each SCM type per ecoregion as well as the total number of each SCM represented in the pilot study sites. Two 'regional" bridge sweeping sites (associated with Division 1 and Division 13) are not associated with a specific bridge because bridge sweeping is conducted for multiple bridges within a division instead of for an individual bridge.

**Table 5.1-4: Distribution of Pilot Study Site SCM Types per Ecoregion**

| SCM Type | Blue Ridge | Piedmont | Coastal | Total |
|---|---|---|---|---|
| Bioretention Basin | 1 | - | 1 | 2 |
| Bridge Sweeping | 1 | - | 2 | 3 |
| BSCCA | 1 | - | 1 | 2 |
| Catch Basin Insert | - | 2 | - | 2 |
| Closed System | - | 1 | - | 1 |
| Deck Conveyance | 1 | - | - | 1 |
| Dispersion | 1 | - | - | 1 |
| Dry Detention Basin | 1 | 3 | 1 | 5 |
| Energy Dissipator | - | - | 3 | 3 |
| Filter Strip | - | 1 | - | 1 |
| Filtration Basin | 2 | 3 | 1 | 6 |
| Infiltration Basin | - | - | 5 | 5 |
| Level Spreader | - | 4 | - | 4 |
| Environmental Site Design | 1 | 4 | 1 | 6 |
| Preformed Scour Hole | 1 | 4 | - | 5 |
| Stormwater Mitigation | 1 | 1 | - | 2 |
| Stormwater Wetland | - | 1 | - | 1 |
| Stream Bank Drop Structure | - | 1 | - | 1 |
| Swale | 1 | 1 | 1 | 3 |
| **Total** | **12** | **26** | **16** | **54** |

**Note:** The total refers to the total number of SCMs included in the pilot study. There are two sites, numbers 6 and 42 in table 5.1-3, with two SCMs; therefore, the total number of sites is 52 and the total number of SCMs is 54.

The distribution of SCM types per ecoregion is shown in figure 5.1-2. Approximately half of the SCM types are located in the Piedmont region. The Blue Ridge and Coastal regions each contain approximately one-fourth of the total SCMs.

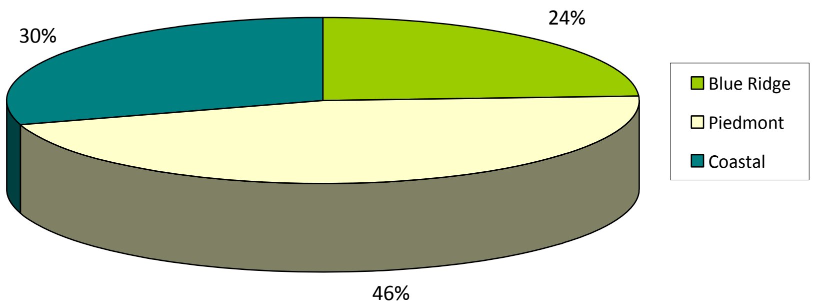


Figure 5.1-2: Distribution of pilot study SCM types by ecoregion.

The distribution of SCMs included in the pilot study sites per SCM category is shown in figure 5.1-3. The majority of the SCMs are Level I treatment SCMs (47%), followed by Level II treatment (24%), design-related (20%), and maintenance (9%).

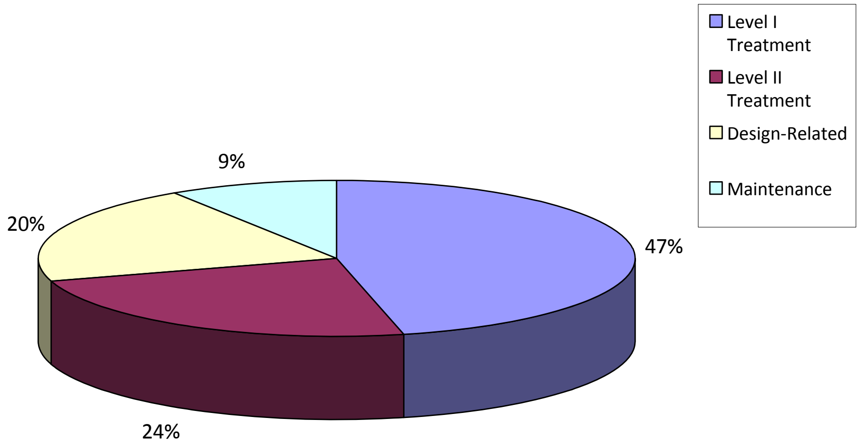


Figure 5.1-3: Distribution of pilot study SCM types by SCM category.

Reports were created for each of the pilot study sites to provide detailed information on the site and the SCM located at the site. Each report provides site summary information; SCM information; observations of SCM performance; a cost analysis summary; photographs; roadway and bridge plans, if available; location map; and SCM drainage map. Table 5.1-5 provides definitions for site characteristics tabulated in the reports. These attributes are provided to facilitate characterization of each site.

### Table 5.1-5: Definitions of Site Characteristics Provided in Pilot Study Site Reports

| Site Characteristic | Description |
|---|---|
| Bridge Number | NCDOT assigned bridge number designation |
| Road Name | Interstate, State, or North Carolina road number designation |
| County | Location of bridge by county |
| NCDOT Division | Location of bridge by NCDOT Division |
| Ecoregion | Location of bridge by physiographic region |
| Associated Waterway | Waterway related to bridge |
| Basin | River basin location of associated waterway |
| Waterway Classification | NC DENR Division of Water Quality Classification |
| Waterway Drainage Area | Drainage area of waterway at the bridge location |
| Average Daily Traffic | Average daily traffic as reported by NCDOT |
| SCM Drainage Area | Drainage area of SCM or SCMs associated with the bridge site |
| Percent Impervious | Impervious fraction of SCM drainage area, reported as a percentage |
| Bridge Deck Area | Area of bridge deck |
| Wearing Surface | Bridge wearing surface |
| NCMIN Tier | North Carolina Multimodal Investment Network Tier |
| Urban or Rural | NCDOT Functional Classification of Inventory Route |

The cost analysis summary provides a breakdown of capital cost, operating cost, and a 10-year total cost. The capital cost includes construction and design costs. The operating costs include annual costs as well as infrequent maintenance costs. The total 10-year cost includes the capital cost and the annualized operating costs for the first 10 years of an SCM’s life. Refer to section 7.0 of this report for a more detailed explanation of cost estimating. Pilot study site reports are located in appendix 5-B.

# 6.0 Effective Bridge SCMs for Statewide Application

Section 25.18(c) of Session Law 2008-107 requires that NCDOT report on the "the effectiveness of the treatments in the study" and estimate the "costs for implementing effective treatments on new bridge construction projects as well as existing bridge retrofit projects for all bridges over waterways in the State" (NCGA, 2008). The stormwater effect analysis for bridge deck runoff in section 4 revealed that localized or otherwise site-specific impacts to receiving streams from bridge deck runoff are possible and should continue to be proactively identified and addressed. However, other than a potential relationship between toxicity and deicing operations, there is currently no compelling evidence that pervasive, statewide impacts from bridge deck runoff are occurring in surface waters or that bridge deck runoff should be considered a higher priority for statewide treatment than other types of stormwater runoff. Because NCDOT currently implements post-construction SCMs for discharges from bridge decks, the results of the stormwater effect analysis indicate that the current SCM program is protective of surface waters. In addition, recommendations pertaining to Levels I and II treatment SCM implementation provided in several NCDENR watershed assessments are already included in NCDOT current practices, suggesting current practices are appropriate for mitigating impacts from bridge deck runoff (NCDENR, 2004a; NCDENR, 2004b; NCDENR, 2003).

To support preparation of the statewide SCM cost estimate for new bridge construction and bridge retrofit projects in the state, the determination of effective SCMs and an appropriate SCM implementation process is necessary. This section discusses how SCMs are considered to be effective and their applicability to bridges, then outlines NCDOT's current practices to meet with current water quality goals. Additionally, a process is presented for the application of bridge SCMs statewide, which becomes the basis of the statewide SCM cost estimate. Simplifying assumptions were adopted as necessary to prepare a quantity estimate of SCMs necessary to adequately address bridge deck runoff statewide. Many aspects of the implementation process will require further development prior to implementation based on recommendations and continued input from resource agencies, as summarized in section 8 of this report. The statewide cost estimate for SCM implementation is presented in section 7.

## 6.1 Defining SCM Effectiveness

To confidently assess whether an SCM is needed and what SCM can best perform stormwater treatment at a particular site, planners, designers and regulators must have knowledge of (1) SCMs that are capable of source control or treatment of stormwater runoff from a particular land use and (2) site-specific water quality goals. These two components create the concept of SCM effectiveness. For the purposes of the BSP, SCM effectiveness can be defined as follows:

> An SCM is considered effective if it can be reasonably deduced from available evidence that an SCM's capability for treatment or pollution prevention can provide cost-effective and sustainable mitigation for the effect of stormwater to meet receiving stream or water quality objectives.

In practice, however, the process of determining an SCM's effectiveness for a particular bridge or roadway project is not straightforward, for several reasons:

- It is generally not possible to identify site-specific pollutants-of-concern (POCs) at each bridge or roadway project. Because many of the storm event characteristics that influence pollutant load are related to variable and unpredictable precipitation attributes (intensity, duration, antecedent dry periods), properly characterizing stormwater runoff at a site requires a monitoring program that captures a number of storm events. This sort of monitoring is time and cost intensive and is not feasible at every project site.

- Even when monitoring data is available, it can be difficult to understand the significance of the magnitude of POC concentrations. The relationship between end-of-pipe concentrations of typical POCs and the degree of resulting impact on a receiving stream is poorly known (Burton and Pitt, 2002). For example, as discussed in section 4, many of the identified POCs in this study had concentrations elevated above surface water quality thresholds, but no expression of toxicity was identified for concurrent bioassays. Exceedances of thresholds do not necessarily signify that SCMs are needed to protect water quality.
- SCMs are not typically selected based on accurately identified POCs (see first bullet) and are still widely evaluated based on pollutant removal efficiency and not the irreducible concentration, as is recommended in the International Stormwater BMP Database (Wright Water Engineers and Geosyntec Consultants, 2007). As previously discussed, pollutant removal efficiency is largely a function of influent concentration. Because site-specific POCs are generally not identified, nor their typical concentrations known, pollutant removal efficiencies do not provide useful information for determining concentrations reduced or mass load removed for a particular POC. Further, discussions of SCM pollutant removal efficiency or effectiveness without understanding project-specific water quality goals does not provide useful information on SCM performance.
- For impaired receiving streams that have been subject to a TMDL where a particular load reduction target has been provided to various significant contributors, the load reductions are provided in terms of an annual mass load reduction. However, because it is generally difficult to predict the annual mass load removed from an SCM without knowing (1) the influent pollutant profile, (2) typical effluent concentrations from the SCM, and (3) hydrologic characteristics that determine flow rates and volume in advance, it is difficult to accurately select SCMs that can effectively meet TMDL requirements.

Many of the issues listed above, particularly irreducible concentrations of SCMs, prediction of pollutant profiles for sites, and linking end-of-pipe concentrations to receiving stream impacts, are the focus of current research and study. It is anticipated that as more is known about the relationship between pollutant generation, SCM function, and receiving stream effects, stormwater management programs can be developed that select SCMs based on more definitive effectiveness criteria. Using the best available information collected at this time, quantitatively determining the ability of an SCM included in this study to meet receiving stream or water quality objectives, and thus determine its effectiveness, is not feasible. Since determination of site-specific water quality goals is also not feasible without extensive studies, the BSP relied upon existing water quality regulations established by NCDENR to define sensitive receiving waters. Thus, the assumption of effectiveness for an SCM type is determined by its ability to be applied (termed *applicability*) to a specific location discharging to a sensitive stream as defined by NCDENR's water quality regulations.

Therefore, due to the lack of evidence for widespread bridge deck runoff effects on receiving streams in North Carolina and NCDOT's ongoing implementation of SCMs in compliance with water quality regulations, a default assumption of overall effectiveness is applied to SCMs currently implemented by NCDOT. Future efforts should continue to focus on developing an approach that links stormwater discharges to receiving water effects and that bases SCM selection and implementation on this interaction (see recommendations in section 8).

## 6.2 Applicability of SCMs

For new construction projects, NCDOT determines the need for SCMs on a project-by-project basis with NCDENR and other regulatory agencies as part of the project planning phase and Merger Process. Additionally, retrofit SCMs are selected and designed through NCDOT's Highway Stormwater Retrofit Program to meet site-specific water quality goals (NCDOT, 2008b). To support development of the bridge

SCM selection approach, SCMs typically used by NCDOT for maintenance, for pollution prevention, and to facilitate treatment of bridge deck runoff (as presented in section 5) were evaluated for their applicability to bridges. In addition, some improvements to existing SCMs are offered and evaluated for applicability.

Applicability refers to whether the SCM is capable of mitigating for the effects of stormwater by either removing pollutants from bridge deck runoff or preventing pollutants from entering runoff in a cost-effective and sustainable manner. Thus, applicability is one part of determining whether an SCM is effective. If an SCM is capable of addressing a problem and fits the specific needs of a site or receiving stream, it is assumed to be an effective SCM. The applicability discussion for Level I treatment SCMs focuses on their potential ability to remove pollutants found in bridge deck runoff, as characterized by this study. The general applicability of Level II treatment, maintenance, and designed-related SCMs and how these SCMs might be incorporated as a part of the statewide SCM selection and implementation approach is also discussed.

### 6.2.1 Level I Treatment SCMs

Level I treatment SCMs are those SCMs that actively target and remove pollutants generated in stormwater via a unit operation or process (i.e., sedimentation, sorption, filtration). In each case, the pollutants are chemically or physically sequestered by the SCM such that either the concentration or mass load leaving the SCM is reduced from influent runoff. For more information on treatment processes for SCMs, refer to section 2 of this report.

Recently, the concept of irreducible concentrations in stormwater treatment, or the observation that many SCMs cannot reduce pollutant concentrations below certain levels regardless of influent stormwater quality, has been presented in the literature (Scheuler, 2000; NCHRP, 2006). If the influent concentration for a particular pollutant is not significantly different from the irreducible concentration for a particular SCM type, then that SCM will not be capable of reducing pollutants at that site. Similarly, if the irreducible concentration of an SCM is greater than the surface water quality standard for a receiving stream, then implementation of that SCM may not provide adequate protection for that receiving stream. Because Level I treatment SCMs only provide a water quality benefit if they can reduce the concentration or load of a particular POC in stormwater runoff entering the SCM (unless flow or volume control is primarily desired), an investigation was performed to identify which Level I treatment SCMs are capable of treating bridge deck runoff.

Assessing the treatment capability of an SCM required first estimating an irreducible concentration for applicable POCs. For this analysis, the median effluent event mean concentration (EMC) obtained from published SCM performance data was used as a surrogate for the theoretical irreducible concentration for a particular parameter and SCM. These median effluent EMCs were then compared to the data complied from the 15 BSP brige deck runoff monitoring sites, as shown in the box plots provided at the end of this section for the Level I treatment SCMs investigated. For this evaluation, an SCM is considered to be an applicable treatment option for a particular POC if the median effluent EMC, serving as the estimate of the irreducible concentration, is generally equivalent to or lower than the median bridge deck runoff EMC.

The SCM performance data used to obtain median effluent EMCs was obtained from a number of resources, including the International Stormwater BMP Database and several research projects conducted on the performance of SCMs in North Carolina. Information about the resources used is provided in table 6.2-1. A summary of effluent EMCs obtained from these resources is provided in appendix 6-A as table 6-A.1. The largest source of information on SCM performance is the International Stormwater BMP Database. In 2008, the International Stormwater BMP Database released an overview-level summary of influent and effluent parameter concentrations by general SCM treatment type based on available monitoring data in the database at that time. The SCM treatment type categories were broadly grouped and not extensively considered for differences in design or other subcategories. Because the International Stormwater BMP Database compilation is the best available resource for SCM performance data, these broad SCM groups were maintained for this analysis. Based on the available performance data, capability evaluations were only performed on dry detention basins, filtration and bioretention basins combined, stormwater wetlands, and filter strips. Data available for these treatment types were also compiled from available NCDOT-sponsored research. A capability evaluation was not performed for infiltration basins. Infiltration basins function to remove pollutant load by infiltrating stormwater runoff before it can exit the basin. Therefore, a comparison of median effluent EMCs to bridge deck runoff water chemistry data is not an appropriate method to evaluate the capability of an infiltration basin for treatment. Instead, because infiltration basins do not target any specific POCs, they are capable of treating any constituent provided the infiltration rate of in situ material is high enough and no potential impacts to groundwater from stormwater runoff are anticipated. For more information on infiltration basins, refer to the NCDOT *Stormwater BMP Toolbox* (2008a).

The parameters included in this investigation are the POCs identified for this project and nutrient species that have historically been identified as stormwater pollutants due to their known contribution to algal blooms and oxygen depletion. For more information on the process used to select bridge deck runoff POCs, refer to section 4.2 of this report. As NCDENR is currently proposing to change total recoverable metals standards to dissolved metals standards, only dissolved fractions of cadmium, copper, lead, and zinc were identified as bridge deck runoff POCs (refer to appendix 6-A). However, SCM effluent data was not available for every metal in the dissolved phase; where necessary, total metal data was used to compare SCM effluent concentrations to bridge deck runoff.

**Table 6.2-1: Sources of SCM Effluent Performance Data**

| Reference | Description |
|---|---|
| Geosyntec Consultants and Wright Water Engineers, Inc. 2008. Overview of Performance by BMP Category and Common Pollutant Type. | This compilation of influent and effluent concentration statistics for various SCMs types was prepared for the International Stormwater BMP Database project. Median and 5th and 95th percentile concentrations are provided for constituents and general SCM types for over 200 SCM performance studies.<br>The International Stormwater BMP Database compiles and reports on SCM performance studies conducted globally and is available online at www.bmpdatabase.org. |
| Line, 2006. Evaluating BMPs for Treating Stormwater and Wastewater from NCDOT's Highways, Industrial Facilities, and Borrow Pits. NCDOT Research Project 2001-07. | This study was sponsored by NCDOT and conducted by staff at North Carolina State University (NCSU). Influent and effluent concentrations were monitored at a variety of SCMs located throughout North Carolina. SCMs included in this analysis include a bioretention basin, a filtration basin, a dry detention basin, a stormwater wetland, and a filter strip. |
| Johnson, 2006. Evaluation of Stormwater Wetland and Wet Pond Forebay Design and Stormwater Wetland Pollutant Removal Efficiency. | This study, conducted to meet the requirements of an M.S. at NCSU, investigated the performance of two stormwater wetlands treating parking lot runoff in Charlotte and Smithfield, NC. |
| Lenhart, 2008. A North Carolina Field Study to Evaluate the Effect of a Coastal Plan Stormwater Wetland on Water Quality and Quantity and Nitrogen Accumulation in Five Wetland Plant Species in Two Constructed Stormwater Wetlands. | This study, conducted to meet the requirements of an M.S. at NCSU, investigated the water quality performance of a stormwater wetland in River Bend, NC. |

**Table 6.2-1: Sources of SCM Effluent Performance Data (continued)**

| Reference | Description |
|---|---|
| Wu and Allan, 2006. Evaluation and Implementation of BMPs for NCDOT's Highway and Industrial Facilities. NCDOT Research Project 2003-19. | This research project, conducted at the University of North Carolina at Charlotte (UNC-Charlotte), was sponsored by NCDOT. Researchers investigated the performance of two transects of the roadway slope at NC 29 and Harris Blvd. in Charlotte, NC to evaluate their potential to function as filter strips. In addition, researchers evaluated the performance of the same filter strip featured in the Line (2006) study. |
| Passeport, 2007. Asphalt Parking Lot Runoff Nutrient Quality: Characterization and Pollutant Removal by Bioretention Cells. | This study, conducted to meet the requirements of an M.S. at Universite Pierre and Marie Curie, investigated the water quality performance of two bioretention basins in Alamance County, NC. |
| Sharkey, 2006. The Performance of Bioretention Areas in North Carolina: A Study of Water Quality, Water Quantity, and Soil Media. | This study, conducted to meet the requirements of an M.S. at NCSU, investigated the water quality performance of two bioretention basins, one in Greensboro, NC, another in Louisburg, NC. |

#### 6.2.1.1 Dry Detention Basin

The dry detention basin applicability evaluation is presented in figure 6.2-1 (located at the end of section 6.2.1). Dry detention basins function by using two main mechanisms: sedimentation and hydrologic control. Because they temporarily hold and slow down the release rate of runoff, dry detention basins are frequently implemented in areas where there are concerns about downstream erosion or stream modification. To remove POCs already entrained in stormwater runoff, dry detention basins allow for settling of solids and particulate-bound pollutants; removal is dependant on the characteristics of the particle size distribution (PSD) (Tchobanoglous and Burton, 1991). Therefore, the applicability of a dry detention basin for treating stormwater runoff relies on a POC being adequately particulate-bound to large enough solids to be removed by sedimentation. NCDENR assigns dry detention basins a pollutant removal credit of 50% for TSS, 10% for total nitrogen, and 10% for total phosphorus (NCDENR, 2009c). The relatively low regulatory credit assigned to dry detention basins for total nitrogen and total phosphorus as compared to other SCMs further indicates that this SCM is applicable for the removal of suspended solids and particulate-bound pollutants only.

In figure 6.2-1, both the median EMC value for the International Stormwater BMP Database (2008) and the study performed by Line (2006) are near to or above the 75th percentile for nitrogen species, indicating that dry detention basins studied are generally not capable of a notable reduction of nitrogen for at least half of the observed effluent EMCs. Both the International Stormwater BMP Database and Line (2006) median effluent EMCs closely tracked median total phosphorus concentrations from runoff, indicating dry detention basins may be applicable for treatment of total phosphorus, a predominantly particulate-bound parameter (NCHRP, 2006, appendix A of the Guidelines Manual).

For total suspended solids, the Line (2006) median EMC falls above the 75th percentile concentration. However, the International Stormwater BMP Database EMC is below the median bridge deck runoff concentration, indicating a good applicability for treatment. Given the number of dry detention basins used to compile the International Stormwater BMP Database median effluent EMC (n = 25), it is reasonable to conclude that this effluent EMC provides a more accurate picture of dry detention basin applicability for the treatment of TSS. As for metals, it is not surprising, given the dissolved nature of the POCs, that dry detention basins are generally not applicable for treatment.

### 6.2.1.2 Stormwater Wetland

The stormwater wetland applicability evaluation is provided as figure 6.2-2 (located at the end of section 6.2.1). Stormwater wetlands are afforded high pollutant removal credits for TSS (85%), total nitrogen (40%), and total phosphorus (40%) by NCDENR, indicating this SCM is considered generally applicable for these POCs (NCDENR 2009a). Stormwater wetlands remove pollutants through microbially mediated transformations typical of natural wetlands (NCHRP, 2006). Inorganic POCs, such as metals and some nitrogen species, can be treated through microbial respiration and the nitrogen cycle (converting nitrogen species to nitrogen gas that is released to the atmosphere) (NCHRP, 2006).

Median effluent EMCs from the Line (2006) and Johnson (2006) studies fall near or below the median bridge deck runoff EMC for total nitrogen. All reported median effluent EMCs fall near or below the median bridge deck runoff EMC for nitrate+nitrite. These trends indicate a good to high applicability for treatment for both total nitrogen and nitrate+nitrite. Median effluent EMCs fell generally higher on the box plot for ammonia and total Kjeldahl nitrogen (TKN), indicating that stormwater wetlands presented would be applicable only for bridge deck runoff sites with higher ammonia and TKN EMCs. While available median effluent EMCs show good applicability for treatment of total phosphorus, effluent EMCs do not indicate a good applicability for orthophosphate.

It is evident from the median effluent EMCs for TSS that stormwater wetlands are highly applicable for the reduction of solids in bridge deck runoff. The median effluent EMC from the International Stormwater BMP database is generally equivalent to the 25th percentile TSS value in bridge deck runoff. It is likely that the good applicability also shown for total recoverable copper and total recoverable zinc (dissolved copper and zinc effluent data was not available) reflect the high potential for TSS reduction. Stormwater wetlands are generally not applicable for the treatment of total recoverable cadmium (and hence dissolved cadmium), nor dissolved lead.

### 6.2.1.3 Bioretention/Filtration Basins

Both bioretention basins and filtration basins detain runoff in a shallow depression and allow for physical filtration through an engineered media. A filtration basin is a depressed area that includes any type of filter media, including sand filters. Bioretention basins are generally characterized by a more specific engineered media design that supports landscaped vegetation, making it a subtype of filtration basin. Similar to stormwater wetlands, NCDENR assigns high pollutant removal credits to bioretention basins for total suspended solids (85%), total nitrogen (35%), and total phosphorus (45%) (NCDENR, 2009b). The International Stormwater BMP Database provides summary effluent EMC data for these two SCM types combined (referred to as a *media filter*). Therefore, effluent EMC data from North Carolina filtration and bioretention basins were similarly combined to calculate median effluent EMCs. The results of the bioretention basin / filtration basin applicability evaluation are provided in figure 6.2-3 (located at the end of section 6.2.1).

The applicability evaluation for nitrogen showed mixed results. The International Stormwater BMP Database effluent median EMCs were higher than the 75th percentile for TKN and nitrate+nitrite, but were generally equivalent to the 25th percentile for total nitrogen (no data was available for ammonia). The Passeport (2007) project generally showed high applicability for total nitrogen, ammonia, and TKN. Results for nitrate+nitrite, however, indicate that the bioretention basins monitored in the Passeport (2007) study are only capable of treating nitrate+nitrite concentrations on the higher end of observed bridge deck runoff concentrations. The Sharkey (2006) and Line (2006) bioretention and filtration basin are generally not highly applicable for treatment of nitrogen species in bridge deck runoff, with one exception. The bioretention basins in the Sharkey (2006) study showed the best removal potential for nitrate+nitrite. With the exception of the Sharkey (2006) results, median effluent EMCs indicates that bioretention basins and filtration basins are highly applicable for the treatment of total phosphorus and orthophosphate. These results indicate that variation in design for filtration and bioretention basins may impact applicability for treatment of nutrients in bridge deck runoff.

Similar to other SCMs, International Stormwater BMP Database and Line (2006) median effluent EMCs show filtration basins and bioretention basins are highly applicable for treatment of TSS in bridge deck runoff. However, results from the 38 bioretention and filtration basins used to create the International Stormwater BMP Database median effluent EMC indicate that these SCMs are not capable of reducing dissolved metals concentrations in bridge deck runoff.

#### 6.2.1.4 Filter Strips

Filter strips are long, rectangular sections of land that are either grassed or forested to intercept stormwater runoff to physically filter pollutants and infiltrate stormwater. However, the infiltration capacity of in situ soils is not generally a design requirement of filter strips (unlike infiltration basins), so the degree to which infiltration impacts pollutant removal is variable from SCM to SCM. Filter strips are generally paired with some type of hydraulic structure to create diffuse flow, such as a level spreader or other type of weir. NCDENR allocates filter strips a 40% removal credit for TSS, a 30% removal credit for total nitrogen, and a 35% removal credit for total phosphorus (NCDENR, 2010a). The applicability evaluation for filter strips is shown as figure 6.2-4 (located at the end of section 6.2.1). For this applicability evaluation, monitoring data from two separate studies were combined into one median effluent EMC. Both of the research projects by Line (2006) and Wu and Allan (2006) monitored the same SCM: the level spreader and filter strip located at the intersection of NC 42 and I-40 in Clayton, NC. The Wu and Allan (2006) study also evaluated two vegetated roadway slopes along NC 29; a median effluent EMC from these two filter strips was separately calculated and presented in the figure.

For nutrients, the filter strip median effluent EMC from the International Stormwater BMP Database showed a high applicability for the treatment of total nitrogen, but not nitrate+nitrite (no data was available for ammonia or TKN). Both the Line (2006) and Wu and Allan (2006) level spreader and filter strip showed limited applicability for treatment of nitrogen species. The roadside slopes in Wu and Allan (2006) showed limited applicability for all nitrogen species except nitrate+nitrite. Only the Line (2006) and Wu and Allan (2006) data for the filter strip at NC 42 and I-40 showed filter strips to be applicable for the treatment of total phosphorus. Orthophosphate EMCs in bridge deck runoff were lower than median effluent EMC values.

Both the International Stormwater BMP Database and the Line (2006) and Wu and Allan (2006) combined median effluent EMC values show high applicability for the treatment of TSS. Conversely, the Wu and Allan (2006) roadside slopes median effluent EMC was higher than the 75th percentile bridge deck runoff EMC for TSS, indicating roadside slopes do not function to remove solids as well as other types of filter strips. The only SCM effluent data available for dissolved metals was from the International Stormwater BMP Database. The only POC for which the median effluent EMC was less than the 75th percentile bridge deck runoff EMC was dissolved zinc, indicating that filter strips may be capable of reducing dissolved zinc EMCs from bridge deck runoff only when EMCs on the higher end of the distribution are observed. Therefore, the applicability for the treatment of dissolved metals by filter strips is limited.

#### 6.2.1.5 Summary of Level I Treatment SCM Applicability Evaluation

Table 6.2-2 provides a summary of the SCM applicability evaluation. If at least one research summary showed the median effluent EMC value for an SCM was near or below the median bridge deck runoff EMC for a particular POC, it was listed as an applicable SCM. SCMs in bold type reflect instances when the International Stormwater BMP Database median effluent EMC value was near or below the median bridge deck runoff EMC for a particular POC. Because the International Stormwater BMP Database summary statistics are based on a much larger dataset than other studies included in this evaluation, these results should be given more weight.

Without identifying the site-specific POCs for each receiving stream in the state, the results of this Level I treatment SCM applicability evaluation are unable to support estimation of SCMs in specific locations for the required statewide SCM cost estimate. However, the evaluation does indicate that for all parameters with available effluent data, the most commonly applied Level I treatment SCMs are applicable for treating bridge deck runoff with the exception of dissolved metals. In the future, the results of this evaluation can be used to improve SCM selection for bridge deck runoff during the planning phase of projects with unique water quality goals, such as areas with known impairments and threatened and endangered species.

**Table 6.2-2: Summary of SCM Applicability Evaluation and Various Bridge Deck Runoff Parameters**

| Parameter | Applicable SCMs[a, b] |
|---|---|
| Total Nitrogen | **bioretention basin / filtration basin**, stormwater wetland, **filter strip** |
| Ammonia | bioretention basin / filtration basin, stormwater wetland |
| Nitrate+Nitrite | bioretention basin / filtration basin, **stormwater wetland**, filter strip |
| Total Kjeldahl Nitrogen | bioretention basin / filtration basin, stormwater wetland |
| Total Phosphorus | **dry detention basin, bioretention basin / filtration basin**, **stormwater wetland**, filter strip |
| Orthophosphate | bioretention basin / filtration basin |
| Total Suspended Solids[c] | **dry detention basin, bioretention basin / filtration basin**, **stormwater wetland**, **filter strip** |
| Dissolved Cadmium[d] | None |
| Dissolved Copper[d] | None |
| Dissolved Lead[d] | None |
| Dissolved Zinc[d] | None |

**Notes:**

[a] SCMs in bold type represent instances when median effluent EMC values from the International Stormwater BMP Database were near or below the median bridge deck runoff EMC. The International Stormwater BMP Database summary statistics were developed from a larger number of SCMs, so they best reflect true irreducible concentrations.

[b] Infiltration basins, though not listed in this table, are applicable for the treatment of all parameters, provided in situ soils support adequate infiltration rates.

[c] The removal of total suspended solids is also considered to reflect removal of particulate-bound metals, resulting in a reduction in total recoverable metals.

[d] No data were available from the sources examined on the removal of dissolved metals from stormwater wetlands.

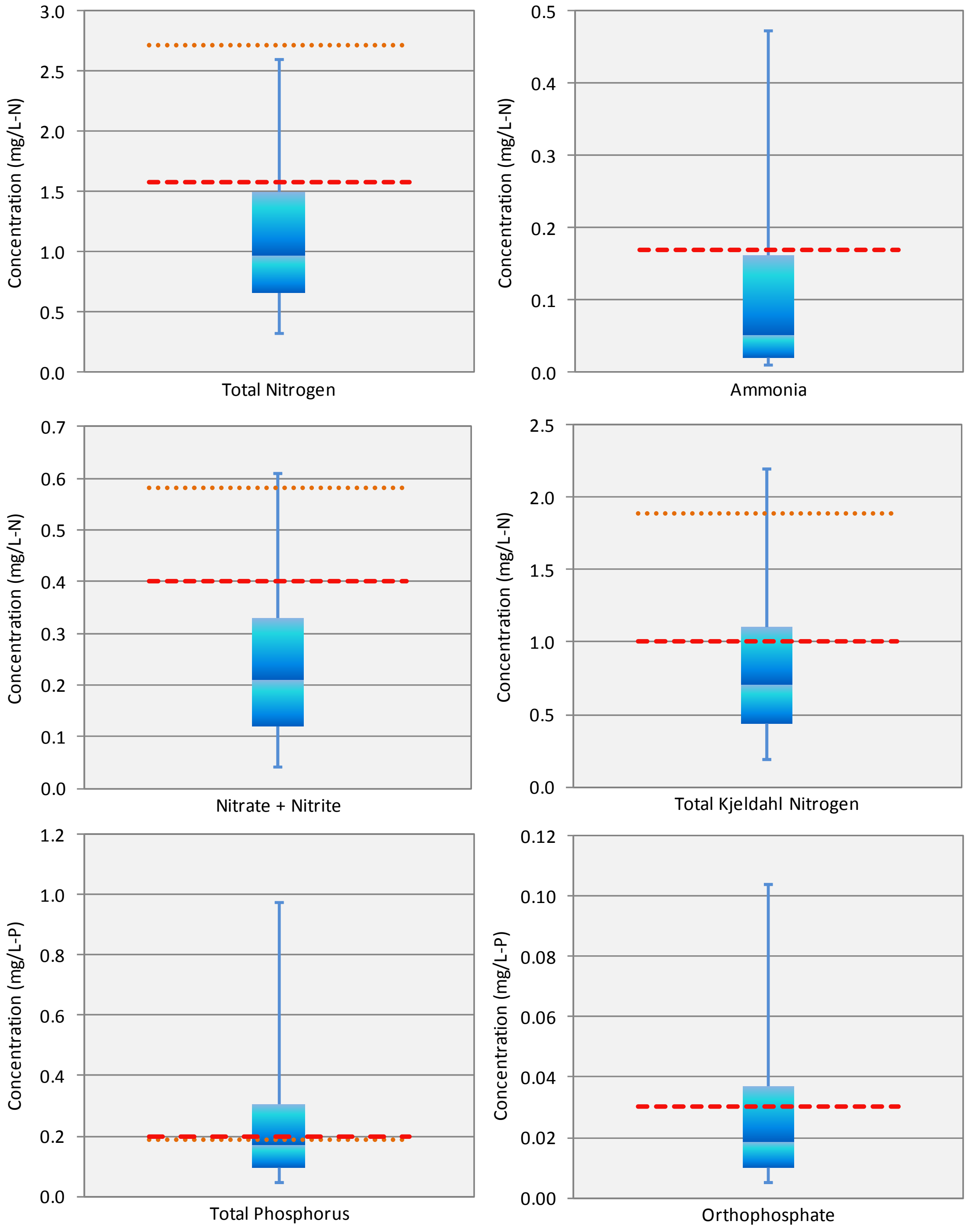


**Figure 6.2-1: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from dry detention basin studies.**

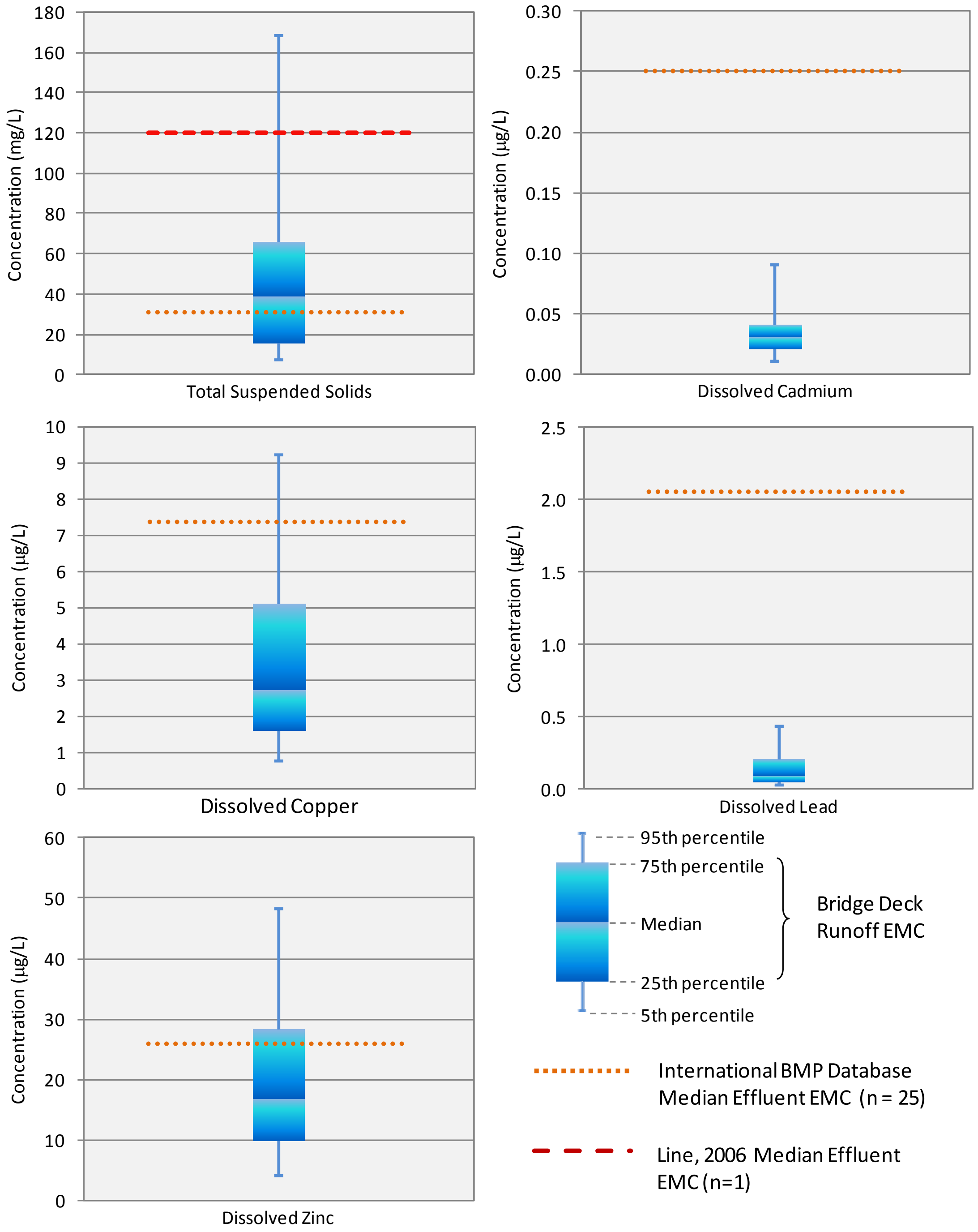


**Figure 6.2-1: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from dry detention basin studies (continued).**

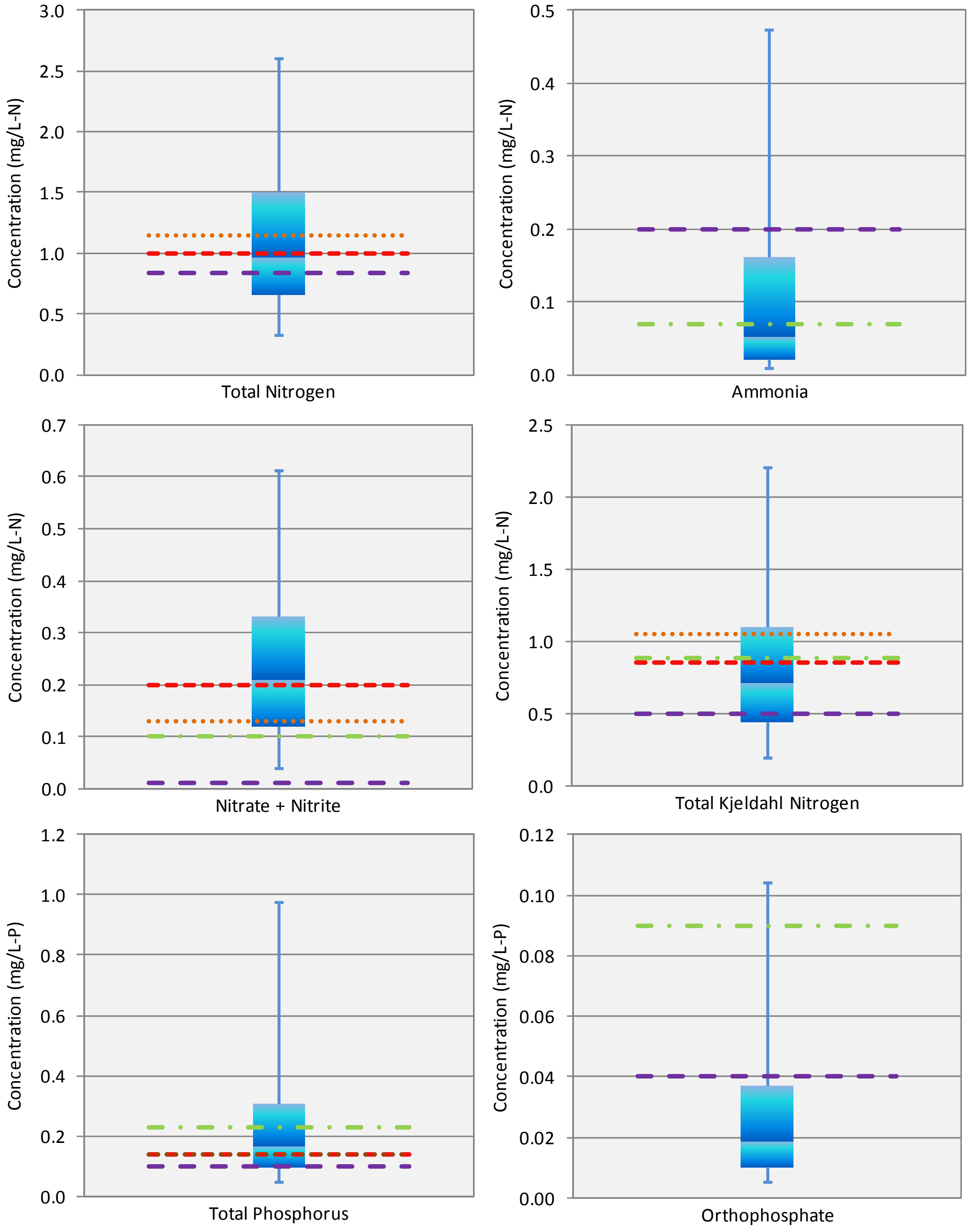


**Figure 6.2-2: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from stormwater wetland studies.**

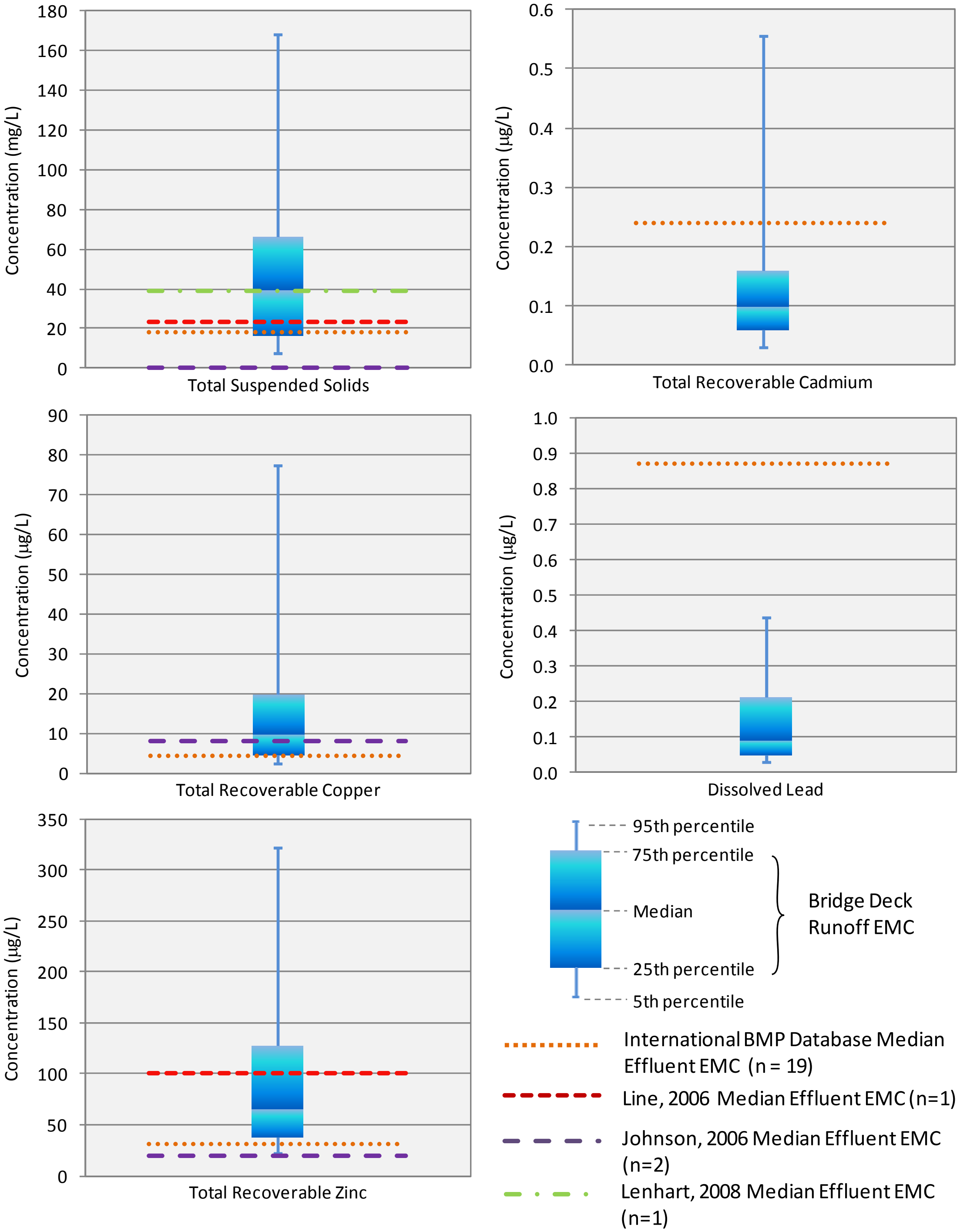


**Figure 6.2-2: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from stormwater wetland studies (continued).**

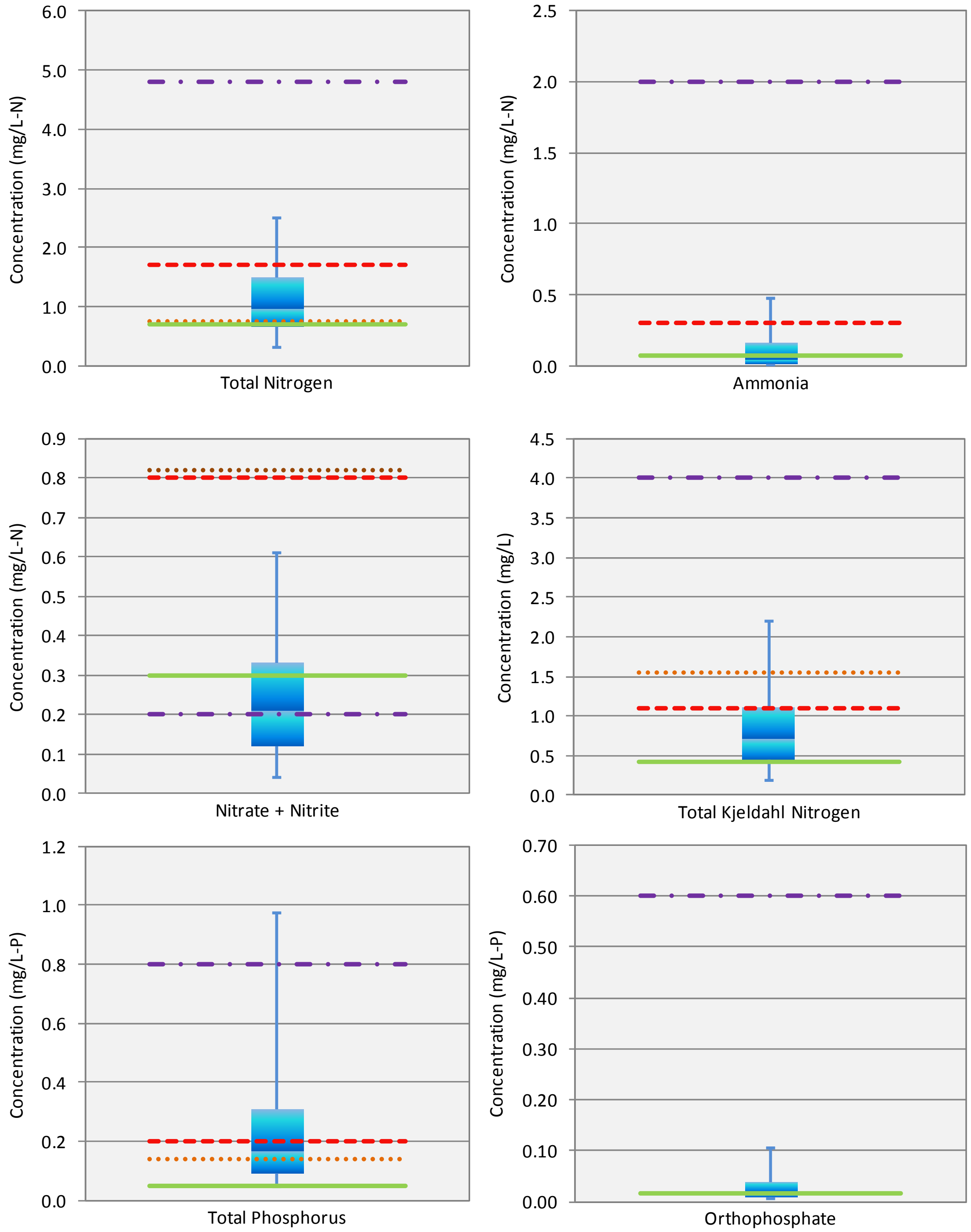


**Figure 6.2-3: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from bioretention basin and filtration basin studies.**

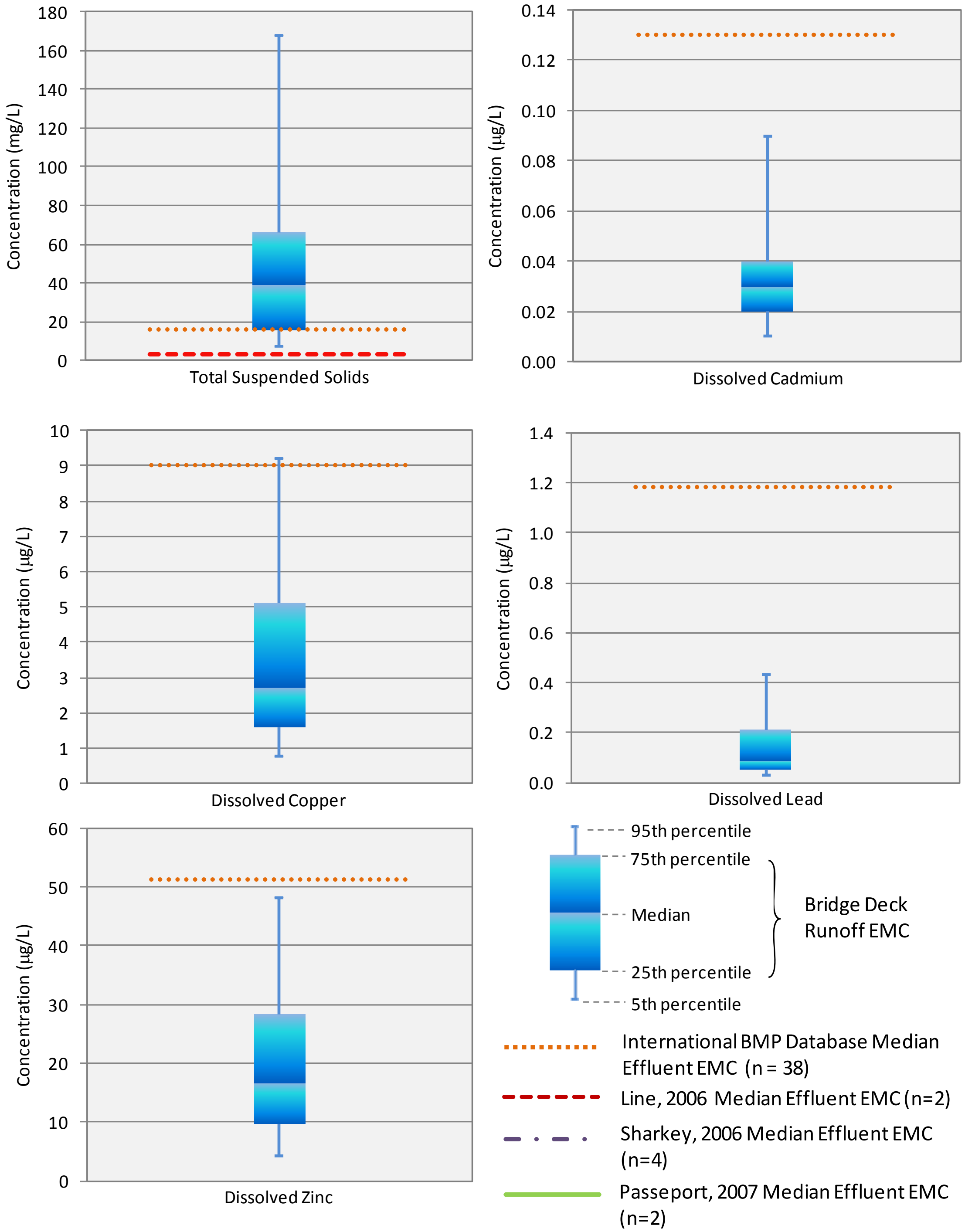


**Figure 6.2-3: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from bioretention basin and filtration basin studies (continued).**

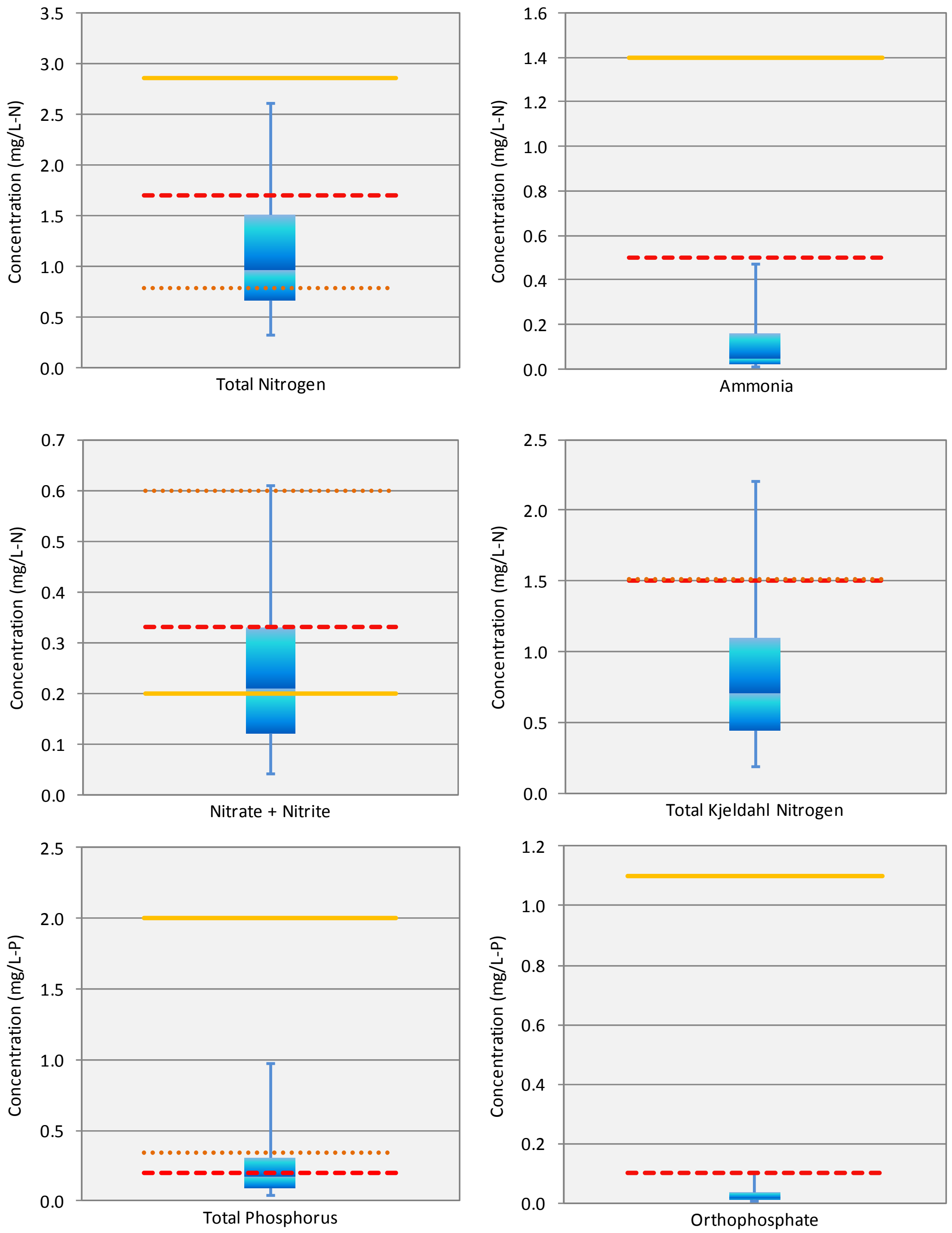


**Figure 6.2-4: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from filter strip studies.**

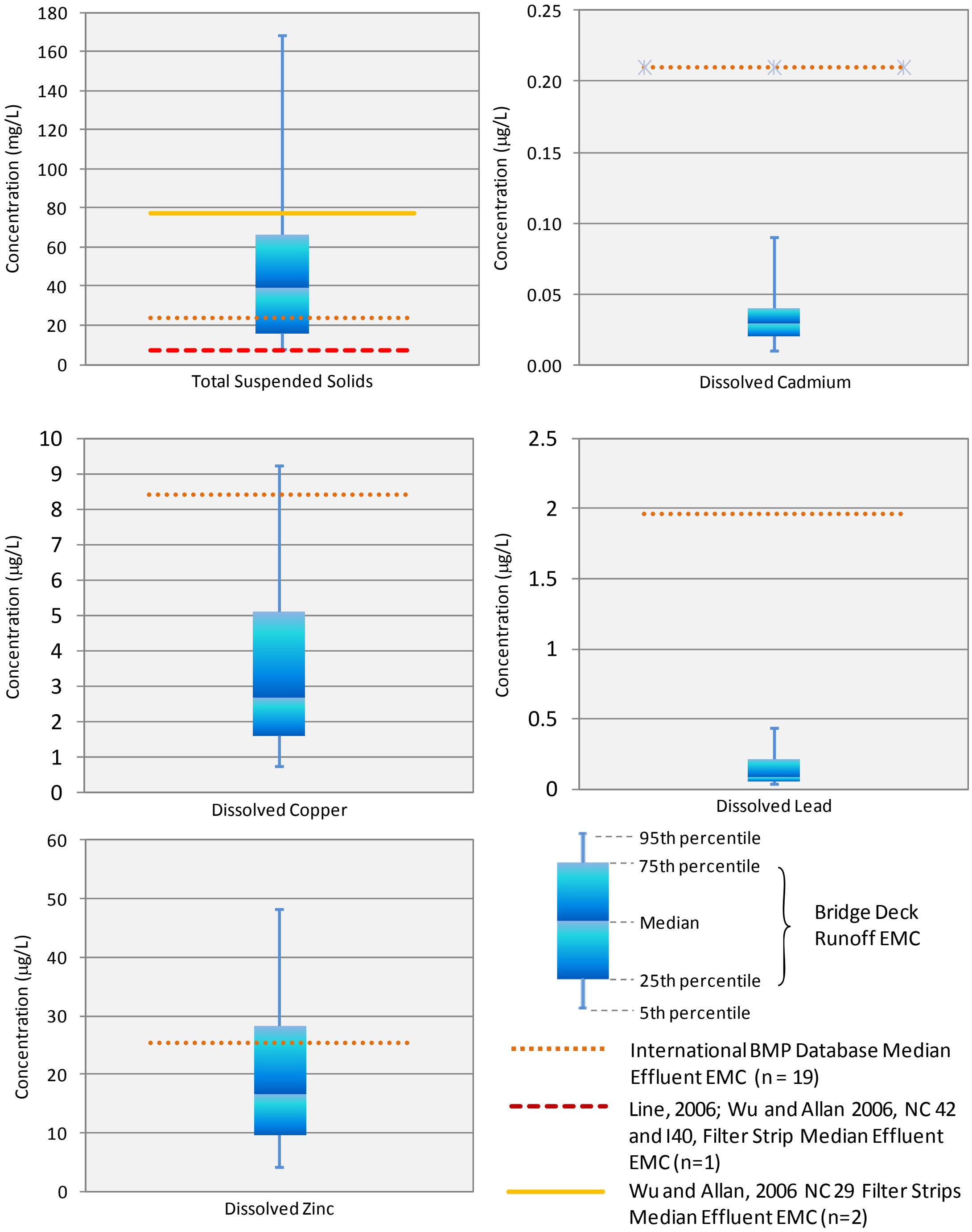


**Figure 6.2-4: Box plots of combined bridge deck runoff water chemistry data for select nutrients and POCs as compared to median effluent EMCs from filter strip studies (continued)**

## 6.2.2 Level II Treatment SCMs

The Level II treatment SCMs presented in section 5 are practices that primarily prevent erosion by stabilizing soil in the vicinity of the bridge or by dissipating energy from high velocity discharges and promoting diffuse flow. Preventing and reducing the amount of sediment entering waterways has long been recognized as very important in the protection and preservation of water quality and habitat. According to the NC Sedimentation Pollution Control Act of 1973, “sedimentation of streams, lakes and other waters of the State constitutes a major pollution problem” (NCDENR, 2010b). In the 2004 USEPA National Water Quality Inventory Report to Congress, sediment was listed as one of the top 10 impairments in assessed rivers and streams (USEPA, 2004). Burton and Pitt (2002) also show that sediment is the largest pollutant of waters resources by weight in the United States. It should be noted that the source of erosion and sediment loss in urban areas has largely been attributed to temporary construction activities (Burton and Pitt, 2002). However, based on the numerous field investigations performed as part of this study and as evidenced by results of the pilot study, significant opportunity still exists to prevent post-construction erosion due to concentrated flows of bridge deck runoff through the installation and routine maintenance of Level II treatment SCMs. As such, Level II treatment SCMs should be applicable for continued implementation on all new location and replacement bridges as appropriate to mitigate for erosive velocities of concentrated bridge deck runoff.

## 6.2.3 Maintenance SCMs

Maintenance SCMs under consideration as part of the study include BSCCA and bridge sweeping. Following is a discussion of the applicability of each of these SCMs for bridges over waterways.

### 6.2.3.1 Bridge Stormwater Conveyance and Collection System Assessment

The Bridge Stormwater Conveyance and Collection System Assessment, or BSCCA, is a concept that was borne from the extensive and numerous bridge site investigations performed to support this study. During these field investigations, many opportunities were observed where the conveyance and collection of stormwater from and around bridges could be improved to further minimize or avoid erosion. After preliminary examination of the existing procedures for routine bridge maintenance inspections, it was estimated that recognition and documentation of the potential need for these improvements could be incorporated into the existing inspection process with an acceptable level of effort. Following the inspection and documentation process, the potential needs for improvement could be forwarded to appropriate staff in NCDOT’s Hydraulics Unit for subsequent prioritization, design, and implementation of a solution. In addition to identifying and addressing potential erosion problems in the field, this process could also identify projects to support the NCDOT’ Retrofit Program under the Highway Stormwater Program, especially for Level II treatment SCM retrofits.

To implement BSCCA statewide, it is anticipated that training of inspection staff to recognize the need for improvements and additional inspection time for investigation and documentation will be required. While BSCCA needs further development before implementation (see recommendations in section 8), if incorporated successfully into the existing the bridge maintenance inspection practices, BSCCA should be applicable to all existing, new location, and replacement bridges over waterways in the state.

### 6.2.3.2 Bridge Sweeping

Because there are many benefits of bridge sweeping associated with maintenance of the bridge and safety of the motoring public, NCDOT currently conducts sweeping practices for many existing bridges throughout the state. While research has shown that routine sweeping can remove large amounts of sediment and floatables from roads, the direct benefit to stormwater quality or effect on receiving waters has not been conclusively defined (Schilling, 2005). Nevertheless, bridge sweeping should continue to be considered as a potential SCM for bridge decks, especially when other methods of treatment are not feasible or are cost prohibitive, which may be the case for long coastal bridges. In addition, existing sweeping practices in the state can possibly be improved through upgrade of equipment and new training for proper disposal of captured solids. While bridge sweeping may remove significant amounts of sediment, trash, and other debris (Dupuis, 2002), additional study will be necessary to further evaluate sweeping as an SCM, to shape sweeping practices for maximizing benefit to stormwater quality, and to define the applicability of sweeping for waterway bridges (see recommendations in section 8).

## 6.2.4 Design-Related SCMs

Design-related SCMs under consideration as part of this study include deck conveyance, closed systems, dispersion, environmental site design, and off-site stormwater mitigation. Evaluation of design-related SCMs is a management measure required under Part II, Section B.3.b of NCDOT's current NPDES permit (NCDENR, 2005). Following is discussion of the specific applicability of each of these SCMs for bridges over waterways.

### 6.2.4.1 SCMs to Support No-Direct Discharge

As discussed in section 5, deck conveyance and closed system SCMs are typically implemented to support NCDOT's no-direct discharge policy (Henderson, 2002) for bridges (discussed in section 6.3). These devices are also utilized to safely and effectively convey bridge deck runoff to another SCM for stormwater treatment. While these devices do not perform the actual function of pollution prevention or treatment, deck conveyance and closed systems can be an important part of comprehensive stormwater management for a bridge. In addition, deck conveyance (through bridge widening) and closed systems represent a need and, subsequently, a cost of stormwater management for bridges. These SCMs will continue to be applicable for collection and conveyance of stormwater runoff from new location and replacement bridges over waterways as needed to meet the site-specific stormwater management goals.

### 6.2.4.2 Dispersion

As described in section 5, the dispersion SCM involves promoting diffuse flow through even distribution of bridge deck runoff via deck drains over a vegetated overbank area or over open water. The intention of dispersion is to minimize the potential for concentrated flow and subsequent erosion in the overbank areas and to minimize the acute effect of a point source discharge on receiving waters. Design criteria for bridge deck drains for dispersion of runoff onto overbank areas in a safe and non-erosive manner have not been well defined. FHWA's *Hydraulic Engineering Circular 21, Design of Bridge Deck Drainage* recommends bridge deck drain heights above 25 feet to sufficiently disperse runoff to avoid erosion under the bridge (1993). Based on limited observations as part of this study, bridge deck drains over wetlands and overbank areas at even lesser heights may not result in a significant erosive impact. In addition, the effects of direct discharge of bridge deck runoff to large water bodies is still not certain; for bridges where water quality of bridge deck runoff may not be a concern, use of bridge deck drains to disperse runoff over a large area could be a significant cost savings when compared to implementation of deck conveyance or collection systems, especially for long coastal bridges. In any case, additional investigation into the potential effects of dispersion of bridge deck runoff over vegetated areas and open water and the development of associated design criteria is needed to determine the applicability of dispersion as part of comprehensive stormwater management for bridges over waterways (see section 8 for recommendations).

### 6.2.4.3 Environmental Site Design

Environmental site design (ESD) involves identifying opportunities to maximize the use of existing site features to achieve stormwater management goals, thereby reducing costs and, in some cases, preserving habitat areas. As evidenced by pilot study sites at Dillingham Creek, Beaver Dam Creek, Oak Hollow Reservoir, Black River, Mango Creek, and Shocco Creek, opportunities do exist to implement ESD, especially for retrofit applications. Future applications of the ESD concepts could increase as designers continue to understand unit processes of stormwater treatment and are encouraged to practice value engineering. While potential application of environmental site design SCMs seems promising, designers should also consider the intended purpose of existing features and be careful not to compromise these purposes or jeopardize safety of the transportation facility. Given proper design for stormwater treatment and consideration for safety and function of existing features, environmental site design SCMs should be applicable for existing, new location, and replacement bridges over waterways.

#### 6.2.4.4 Off-site Stormwater Mitigation

There are instances where implementing an SCM at a bridge crossing will not achieve load reduction of the parameters-of-concern. Alternatively, it may be determined that SCMs are able to achieve load reduction at a bridge crossing, but implementation of the SCM is not practicable. For these situations, off-site management or treatment of stormwater at a different location could be a viable alternative to mitigate for potential impacts of bridge deck runoff. These types of stormwater mitigation practices have been implemented by other states and organizations (see background information in section 2). Where implementation of SCMs at bridge sites are very costly, off-site stormwater mitigation can also provide an opportunity for NCDOT to maximize the amount of stormwater management or treatment for dollars spent. While off-site stormwater mitigation seems promising as a viable alternative and NCDENR has shown significant interest in the concept, further development of guidelines and acceptable practices will be necessary to determine its applicability to bridges over waterways (see section 8 for recommendations). It is anticipated that off-site stormwater mitigation will be applicable to existing, new location, or replacement bridges where stormwater management is needed. In addition, off-site mitigation could facilitate watershed mitigation for multiple bridges while providing habitat and public resources.

### 6.2.5 Long Coastal Bridges

Long coastal bridges present a challenging and unique situation for stormwater management. SCMs that may be applicable for much shorter bridge crossings may not be feasible for long coastal bridges. The collection systems needed to convey stormwater runoff from a long bridge deck to a land based facility could be prohibitively expensive to construct and maintain and may create unsafe conditions for maintenance personnel. Treatment facilities proposed to be located on the bridge structure, such as proprietary filtration systems, could add more structural complexity, could be very expensive to construct and maintain, and may not always perform as anticipated. As with collection systems, maintenance of Level I treatment SCMs located on the bridge introduce potentially prohibitive safety issues for NCDOT staff. These difficulties of providing effective stormwater treatment facilities for long coastal bridges have been faced by other states, including Caltrans during the San Francisco Oakland Bay Bridge East Span Seismic Retrofit Project (Caltrans, 2010). In addition to the difficulties of implementing SCMs, the question of SCM effectiveness for bridges crossing large water bodies is still uncertain and should continue to be evaluated on a site-specific basis. The protection and preservation of coastal water resources is of utmost importance in North Carolina, and the challenge of mitigating for the potential impact of long coastal bridges should continue to be investigated and solutions should continue to be developed (see section 8 for recommendations). Some options that are under consideration and show promise for application to long coastal bridges include off-site stormwater mitigation and bridge sweeping.

## 6.3 NCDOT's Current Practices and Applicable Requirements

As noted above, an SCM's effectiveness is represented by its applicability to a specific site when implemented on discharges draining to sensitive streams. It is generally accepted that applicability, compatibility, and cost are crucial parts of developing an effective stormwater management program that meets water quality goals (National Research Council, 2008). Therefore, NCDOT has implemented a stormwater management program that complies with the regulations, and incorporates other practices and polices regarding mitigation for the effects of stormwater runoff. Because the weight-of-evidence evaluation presented in Section 4 did not reveal pervasive, statewide receiving stream effects from bridge deck runoff, it is assumed that NCDOT's current approach to meeting water quality regulations is conservatively protective of surface waters in North Carolina. Therefore, NCDOT's current surface water quality programs and practices are the foundation for determining a number of SCMs that might be applied to bridge deck crossings over waterways in the state.

NCDOT has worked with NCDENR to develop a Post-Construction Stormwater Program (PCSP) to control runoff from NCDOT transportation projects and highway facilities (including bridges). NCDOT has been working closely with NCDENR to develop stormwater requirements for the PCSP, and stormwater control for bridges that will comply with these requirements as part of the HSP under NCDOT's NPDES permit. Additionally, NCDOT is required to implement post construction stormwater control measures for discharges to sensitive waters in accordance with its NPDES permit under Part II, Section B.5. While the NDPES permit requires implementation of post construction stormwater measures and the PCSP will ultimately provide a more prescriptive approach, there are other programs, rules, and policies that influence the implementation of SCMs for bridges. Following is a summary of some of these major influences on current practices.

### 6.3.1 State Stormwater Programs

The state of North Carolina has put into effect many rules and laws that implement and regulate post-construction stormwater management for development activities in the state. These rules and laws include, but are not limited to, the following (NCDENR, n.d.):

- General State Stormwater Requirements and Outstanding Resource Waters and High Quality Water Rules (15A NCAC 02H .1000)
- 20 Coastal Counties Stormwater Law (Session Law 2008-211)
- Phase II Post-Construction Law (Session Law 2006-246)
- Goose Creek Rules (15A NCAC 02B .0600)
- Jordan Lake Rules (15A NCAC 02B .0200)
- Nutrient Sensitive Water Rules (15A NCAC 02B .0200)
- Water Supply Watershed Rules (15A NCAC 02B .0200)
- Riparian Buffer Rules (15A NCAC 02B .0200)

Any water body identified as a sensitive water, per NCDOT's NPDES permit, must meet the permit requirements for post-construction stormwater management (NCDENR, 2005). These rules, laws, and the NPDES permit identify water quality sensitive areas and require that post-construction stormwater control measures be implemented to mitigate impact to water quality in accordance with the stated provisions. For new bridge construction, NCDOT currently implements SCMs to protect and preserve water quality in these sensitive areas. Depending on the provisions of applicable rule or law, SCMs are typically implemented to control and treat runoff generated from the 1.5 inch storm event in coastal areas and the 1-inch storm event elsewhere in the state or to provide diffuse flow into stream buffers.

### 6.3.2 NCDOT Best Management Practice Toolbox

Chapter 9 of the NCDOT *Stormwater BMP Toolbox* identifies the requirements for bridge runoff at stream crossings (2008a) and reiterates the practices put forth by NCDOT's no-direct discharge policy (Henderson, 2002). Following is a summary of the primary requirements outlined in the *Stormwater BMP Toolbox* and the policy:

- Bridges crossing streams within river basins with buffer rules shall not have deck drains that discharge directly into the water body or buffer zones; deck drains may discharge into the buffer zone if 12 feet above natural ground.
- Bridges over sounds or water bodies of the Intracoastal Waterway may be allowed to discharge directly into receiving waters because the volume of stormwater runoff from deck drains is small relative to the volume of the water bodies and sites for effective treatment are scarce, unless advised otherwise by the regulatory agencies. As most of these bridges facilitate boat passage, the bridge height and winds help disperse stormwater from the bridges.
- For bridges over other waters (perennial or tidal streams), direct discharge into the water body should be avoided to the maximum extent practicable (MEP). In addition, discharge from deck drains in over bank areas similar to stream buffer areas should be avoided.
- Where closed systems are utilized to achieve no-direct discharge, the discharge point shall be as far away from the surface water body as practical. Preformed scour holes or other devices were recommended to promote diffuse flow.

NCDOT has been implementing these policies for new location bridges as well as replacement bridges throughout the state since 2002. No-direct discharge is typically achieved through widening of the bridge to accommodate stormwater flow (deck conveyance) or through the use of closed systems.

### 6.3.3 Endangered Species

The NCDOT NPDES permit defines waters that are inhabited by threatened or endangered species as sensitive waters. Therefore, as required by the NPDES permit, NCDOT implements structural and nonstructural SCMs to protect habitats of endangered and threatened species (NCDENR, 2005). Impacts to threatened or endangered species are considered during planning of new location and replacement bridges. If the proposed bridge is located in an endangered species area, a Section 7 consultation (Endangered Species Act of 1973) is conducted and a biological opinion is rendered by the U.S. Fish and Wildlife Service (USFWS). NCDOT will implement post-construction SCMs as necessary to mitigate potential impacts from bridge deck runoff to threatened or endangered species. In addition, the project will adhere to the requirements of 15A NCAC 04B .0124 Design Standards in Sensitive Watersheds.

### 6.3.4 Impaired Waters (303(d) and TMDL)

As required by Section 303(d) of the Clean Water Act of 1972, North Carolina maintains a list (303(d) list) of waters impaired for one or more designated uses in the state that require a total maximum daily load (TMDL) (NCDENR, 2007d). Impaired water bodies on the 303(d) list are considered to be sensitive waters. As such, NCDOT implements post-construction SCMs for new location and replacement bridges that cross 303(d) listed water bodies, as determined by requirements of NCDOT’s NPDES permit (NCDENR, 2005, Part II, Section B.5). For bridges that discharge to 303(d) listed impaired waters where NCDOT has been assigned a Waste Load Allocation, stormwater treatments are implemented per requirements established through the assessment and monitoring plan, which is required by Part III.C of NCDOT’s NPDES permit (NCDENR, 2005).

### 6.3.5 Low Impact Bridge Replacements

In an effort to address the growing need for bridge replacements in the State of North Carolina, NCDOT developed a process to streamline environmental permitting and design for the replacement of low impact bridges. The process is intended to be both a cost and time saving measure. Low impact bridge replacements are characterized by those that do not include additional travel lanes, are on the existing horizontal alignment, require minimal environmental permitting, and meet other characteristics as outlined in Attachment B of the Low Impact Bridge Replacement Manual provided on the NCDOT website (NCDOT, 2010). More information and guidelines for implementation of the Division Managed Low-Impact Bridge Replacement Process are also provided in the Low Impact Bridge Replacement Manual. In general, NCDOT does not typically implement Level I treatment SCMs for low impact bridge replacements. However, Level II treatment SCMs and design-related SCMs to support the no-direct discharge policy may be implemented for low impact bridge replacements.

## 6.4 Statewide SCM Implementation Process

As part of this study, a process was developed to estimate the number of effective bridge SCMs for statewide implementation to support preparation of a statewide cost estimate. The process was shaped by current NCDOT stormwater practices and the PCSP. Some additional simplifications and improvements were added to the current PCSP based on information collected for this report, including Level I treatment SCM requirements for bridges having average daily traffic (ADT) over 30,000 vehicles per day (see additional discussion below) and implementation of BSCCAs (see section 8 for recommendations).

An approach was developed for both 1) new location and replacement bridges and 2) existing bridges. To facilitate approximation of the number of SCMs to be implemented and preparation of the statewide cost estimate, two central simplifying assumptions were adopted as part of the approach: 1) SCMs can be implemented and assessed by SCM category (i.e., Level I treatment or Level II treatment), 2) an SCM exists or will exist within the applied SCM category that is effective in meeting the applicable stormwater management goals. The approaches for both new and existing bridges and other specific assumptions are described below.

### 6.4.1 SCMs for New Location and Replacement Bridges

The process for estimating the number of SCMs to be implemented for new location and replacement bridges is summarized on the flow diagram in figure 6.4-1. Key assumptions used to prepare the flow diagram include the following:

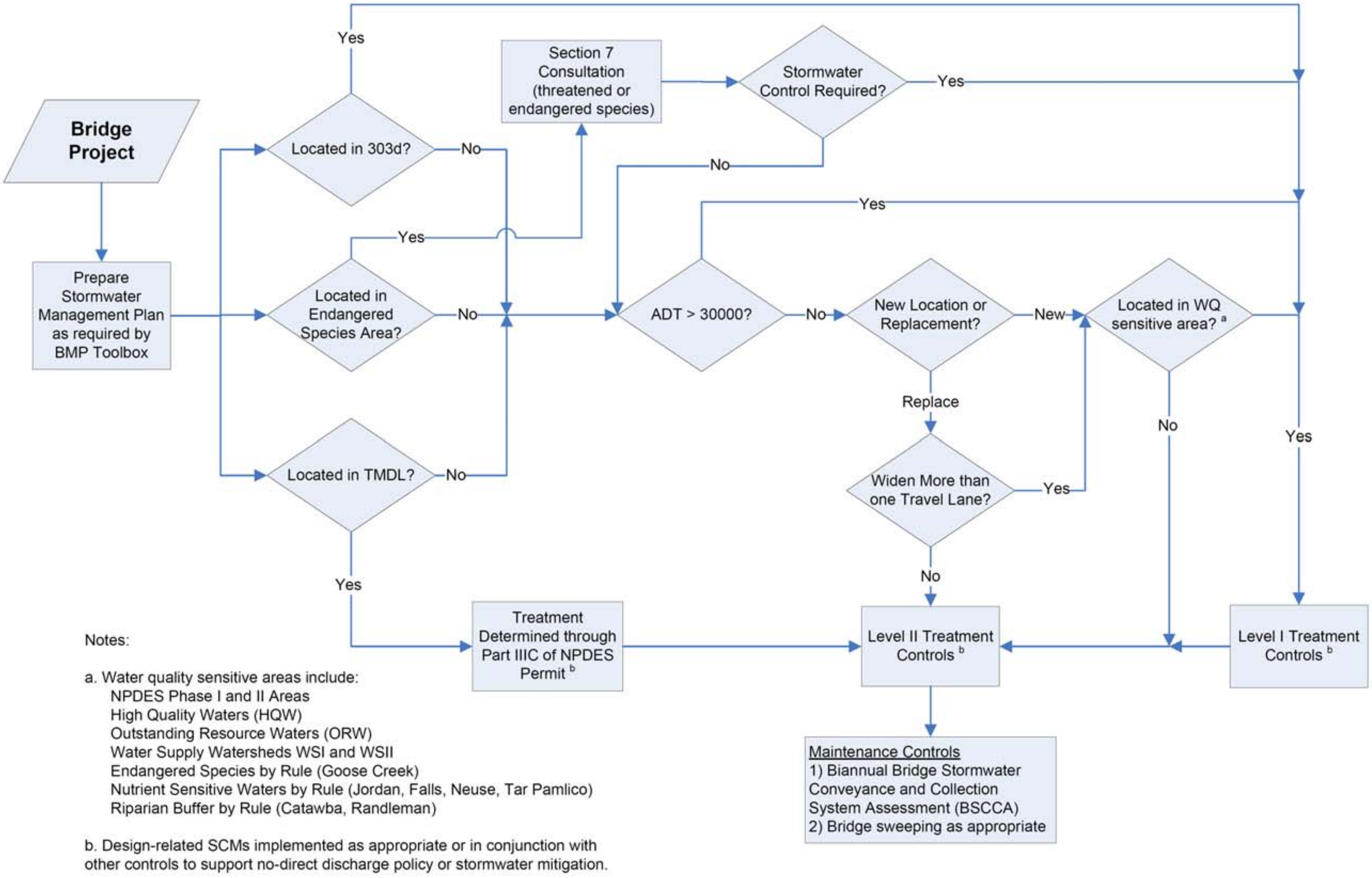
- Stormwater Management Plans will be required for all bridge projects.
- Level I treatment SCMs will be implemented on projects under certain conditions (discussed later).
- Level II treatment SCMs will be implemented on all projects.
- BSSCA program (Maintenance SCM) will be implemented for all projects following construction and concurrent with routine bridge maintenance activities.
- Bridge sweeping (Maintenance SCM) will continue to be implemented as appropriate (further investigations on implementation for water quality preservation and protection are needed).
- Design-related SCMs will be implemented as appropriate to support the no-direct discharge policy or stormwater mitigation.

As depicted in the flow diagram, while all new projects will include Level II treatment SCMs and BSCCA program implementation, Level I treatment SCMs will be applied under the following conditions:

- The bridge project crosses a waterbody on the 303(d) list as maintained by NCDENR.
- The bridge project is located in a TMDL area; treatment requirements will be determined in accordance with Part III, Section C of NCDOT’s NDPES permit (see discussion in section 6.3).

- The bridge project is located in an endangered species area and through biological assessments, the US Fish and Wildlife Service (USFWS) has rendered a biological opinion that a Level I treatment SCM is required to mitigate potential impacts (see discussion in section 6.3).
- The bridge project is located as part of a roadway with anticipated average daily traffic greater than 30,000 vehicles per day.
- The bridge project is a new location bridge and located in a water quality sensitive area (areas listed on figure 6.4-1)
- The bridge project is a replacement bridge that is widened more than one travel lane and located in a water quality sensitive area.

Requiring SCMs on projects that an anticipated average daily traffic of 30,000 vehicles per day or higher is not currently included as part of NCDOT's PCSP. However, NCDOT does currently focus retrofit implementation in areas where facilities cross sensitive streams with high ADT loads (NCDOT, 2008b). This ADT split of 30,000 vehicles per day originates from an FHWA study that showed roadways sites with ADTs higher than this benchmark had higher stormwater pollutant loads than lower ADT sites (FHWA, 1990). The researchers theorized that ADT did not directly impact pollutant loads, but might be an indicator of atmospheric quality differences between urban and rural land uses. In addition, ADT is currently used to determine SCM treatment requirements for other departments of transportation (WSDOT, 2008). As discussed in section 4, the use of ADT as an indicator of pollutant load is still being evaluated in the literature, and statistical analysis of provisional BSP bridge runoff data suggests that a roadways site's urban or rural classification per the FHWA Functional Classification Guidelines may be a more appropriate indicator of pollutant load. For the purposes of developing a statewide SCM cost-estimate, the use of ADT to determine SCM needs is an appropriate estimating tool. However, the use of ADT as a trigger for SCM treatment on a project-by-project basis should be investigated further before being incorporated into the PCSP for all types of transportation runoff. Refer to section 8 for recommendations.



Notes:

a. Water quality sensitive areas include:
NPDES Phase I and II Areas
High Quality Waters (HQW)
Outstanding Resource Waters (ORW)
Water Supply Watersheds WSI and WSII
Endangered Species by Rule (Goose Creek)
Nutrient Sensitive Waters by Rule (Jordan, Falls, Neuse, Tar Pamlico)
Riparian Buffer by Rule (Catawba, Randleman)

b. Design-related SCMs implemented as appropriate or in conjunction with other controls to support no-direct discharge policy or stormwater mitigation.

**Figure 6.4-1: Process for estimating the number of SCMs implemented at new location and replacement bridges over waterways.**

### 6.4.2 SCMs for Existing Bridges

SCM implementation for existing bridges involves the installation of SCM retrofits and implementation of the proposed BSCCA SCM. Key assumptions for estimating the number of SCMs for existing bridges includes the following:

- Bridge SCMs will be implemented for existing bridges through NCDOT's Retrofit Program (Part II, Section B.1 of NPDES permit)
- Bridge SCM retrofits implemented could be Level I treatment, Level II treatment, maintenance, or design-related SCMs.
- The large amount of data gathered as part of this study will be utilized to optimize and prioritize both site and SCM selection for bridge retrofits (see recommendations in Section 8).
- BSCCA (Maintenance SCM) will be implemented as part of routine bridge maintenance inspections for all existing bridges. SCM opportunities identified as a result of BSCCAs can be implemented through NCDOT's Retrofit Program.
- Bridge sweeping (Maintenance SCM) will continue to be implemented as appropriate (further investigations on implementation for water quality preservation and protection are needed).

## 6.5 Statewide SCMs Quantity Estimate

Using the SCM implementation process as outlined in section 6.5, SCMs for bridges over waterways were estimated from NCDOT's 60-Month Let List to support preparation of a statewide cost estimate as presented in section 7. The NCDOT 60-Month Let List provided the necessary location and structure information to facilitate a reliable cost estimate. Following is an assessment of SCMs for both new and existing bridges for the Five-Year Work Program.

### 6.5.1 SCMs for New Location and Replacement Bridges

Using information compiled and maintained by NCDOT staff, a list of planned bridge projects was developed representing waterway bridges to be initiated between August 2009 and June 2014 (approximately 5 years). During this time period, 389 projects were identified that will involve the construction of 451 bridges over waterways; approximately 347 of the bridges will be replacements, while the remaining 104 bridges will be new locations associated with new roadway projects. Figure 6.5-1 shows the locations of bridge projects and roadway projects with bridges over waterways to be initiated during the approximate 5 year time period. As shown, the planned bridge projects are well distributed throughout the state and ecoregions.

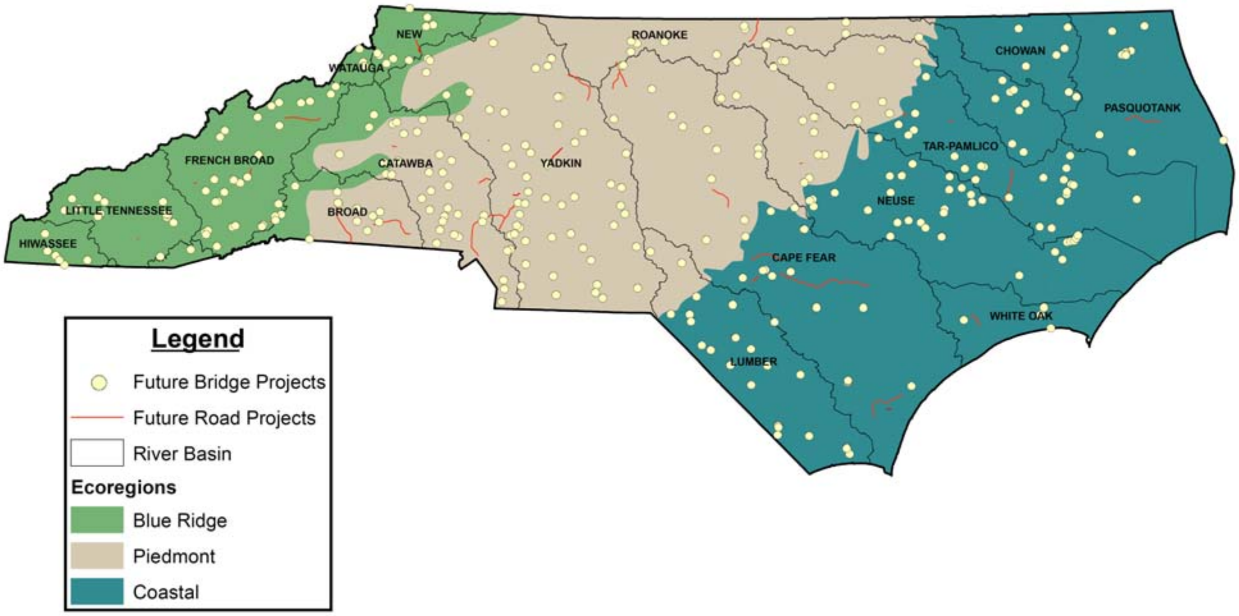


**Figure 6.5-1: Planned bridge projects from NCDOT's Five-Year Work Program, 2009-2014.**

For application of the SCM implementation process described in section 6.4 and to prepare a quantity estimate of SCMs needs for future bridge projects, the following assumptions were adopted based on information, knowledge, and experience of NCDOT staff:

- All new location and replacement bridge projects will require Level II SCMs.
- All new location bridges associated with new roadway projects are expected to have average daily traffic greater than 30,000 and will subsequently require Level I treatment SCMs.
- Of all bridge replacement projects, 3% are expected be widened more than one travel lane and will subsequently require Level I treatment SCMs.
- Of all bridge projects (new location and replacement), 4% are expected to be located in endangered species areas where USFWS may render an opinion that Level I treatment SCMs are required to mitigate impact.
- Of all bridge projects (new location and replacement), 4% will require collection systems (closed systems) to be installed to accommodate stormwater conveyance to satisfy the no-direct discharge policy of NCDOT.
- Of all bridge projects (new location and replacement), 16.5% will require that bridge decks be widened to accommodate stormwater conveyance (deck conveyance) to satisfy the no-direct discharge policy of NCDOT.
- The BSCCA SCM will be implemented for all new location and replacement bridge projects following construction and during routine bridge maintenance activities.

While NCDOT currently conducts bridge sweeping throughout the state, the practice will not be assessed as an SCM need because sweeping is currently performed primarily for maintenance and safety reasons and has not been fully developed for the preservation and protection of water quality (see section 8 for recommendations concerning sweeping practices).

It is important to note that the assumptions listed above were used purely to support the cost-estimate in section 7 and are a projection of future SCM needs. SCMs that are actually applied statewide in the next 5-year period will be determined by a project-by-project determination with environmental agencies, planners and designers. The SCMs for new location and replacement bridge projects were estimated for five years using the stated assumptions and are summarized in table 6.5-1.

**Table 6.5-1: Quantity Estimate of SCMs for New Bridge Projects – 5-Year Time Period**

| Description | Estimate |
|---|---|
| Bridges with Level II SCMs | 451 structures |
| Bridges with Level I treatment SCMs | 132 structures |
| Bridges with closed systems for stormwater conveyance | 18 structures |
| Bridges widened for stormwater conveyance (deck conveyance) | 74 structures |
| Bridges for BSCCA SCM implementation | 451 structures |

## 6.5.2 SCMs for Existing Bridges

For application of the SCM implementation process described in section 6.4 and to estimate the number of SCMs for existing bridge projects, the following assumptions were adopted based on information, knowledge, and experience of NCDOT staff:

- As part of the current Retrofit Program, it is estimated that four retrofit SCMs will be implemented every year for bridges.
- For purposes of this study and to support the statewide cost estimate, the retrofits implemented are assumed to be Level I treatment SCMs. Level II treatment, maintenance, or design-related SCMs could also potentially be implemented as retrofits.
- BSCCA will be implemented as part of routine bridge maintenance inspections for all existing bridges. Based on information compiled and maintained by NCDOT staff, there are approximately 10,481 existing bridges currently maintained and operated by NCDOT (as of August 2008).

Similar to the SCMs for new locations and replacement bridges, sweeping will not be assessed as an SCM need because sweeping is currently performed primarily for maintenance and safety reasons and has not been fully developed for the preservation and protection of water quality (see section 8 for recommendations concerning sweeping practices).

SCMs for existing bridges were estimated for five years using the stated assumptions and are summarized in table 6.5-2.

**Table 6.5-2: Quantity Estimate of SCMs for Existing Bridges – 5-Year Time Period**

| Description | Estimate |
|---|---|
| Bridges with Level I Treatment SCMs (retrofits) | 20 structures |
| Bridges for BSCCA SCM implementation | 10,481 structures |

**Note:** Existing bridges that are scheduled for replacement, as discussed in section 6.6.1, should be subtracted from this estimate for BSCCA when combining the SCM needs for both new bridges and existing bridges for the planned 5–year time period.

# 7.0 Costs of Bridge SCMs

Section 25.18 (c) of Session Law 2008-107 requires NCDOT to determine the "costs of each treatment [investigated in the BSP], and the costs of implementing effective treatments on new bridge construction projects as well as existing bridge retrofit projects for all bridges over waterways in the state" (NCGA, 2008). Quantifying capital outlays and annual expenditures associated with various SCMs is vital in supporting informed choices by environmental stakeholders during the planning process. This section describes activities performed under this project to develop such costs associated with the implementation of SCMs to manage bridge deck runoff, consistent with the requirements of the session law.

Developing generic costs for the implementation of SCMs is challenging due to variability introduced by several factors. There has been limited guidance on costing, with several studies only focusing on specific SCMs, and in some cases, providing conflicting evidence on unit costs and scale effects (NRC, 2008). Costs for SCMs have been shown to vary widely due to the influence of climate; site conditions; regulatory requirements, such as environmental and labor issues; aesthetic expectations; public versus private funding; and other influences (Lambe et al., 2005).

Many studies have focused on establishing construction costs for specific SCM types, based on analysis of historical construction costs of similar projects, or by the development of a bottom-up cost estimate (Wossink and Hunt, 2003; Caltrans, 2004; Narayana and Pitt, 2006). In general, economies of scale have been recognized in observed construction costs for SCMs (Lambe et al., 2005), which could be correlated to a unit size, such as a drainage area (Wossink and Hunt, 2003). Cost estimates are generally more reliable when based on local cost information; a common approach is to use engineering estimates to develop an understanding of material and labor requirements and to use local sources for unit cost data (Lambe et al., 2005). It should be noted in the planning process that retrofitting an SCM into an existing site can also involve substantially larger capital outlays than at a new construction site (NRC, 2008).

While capital costs are very significant, operating costs (inspection and maintenance) can represent a substantial outlay that must be considered while assessing the cost of SCM implementation. There have been relatively few studies into these recurring costs, and relatively little cost information is currently available (NRC, 2008; Lambe et al., 2005; Wossink and Hunt, 2003).

A comprehensive study by Lambe et al. (2005) evaluated the performance and cost of SCMs, and developed procedures to estimate whole-life costs for SCMs. The methodology included consideration of capital, operating, monitoring, environmental, disruption, disposal, risk, and residual costs. While development of these specific costs was outside the scope and purpose of this project, the information and concepts developed by Lambe were very useful in supplementing costs that could not be derived from data collected by NCDOT, especially for operating costs.

The BSP team developed order of magnitude costs for each SCM type and for the bridge SCM pilot study sites as discussed in section 5. To prepare the statewide cost estimate for implementation of SCMs for new and existing bridges over waterways, the BSP team developed blended unit costs for bridge SCMs and applied those unit costs to SCM quantity estimates for planned bridge projects that are part of NCDOT's 60-Month Let List as discussed in section 6. This section presents the BSP cost estimating approach for typical SCM, pilot study site, and statewide SCM implementation costs and subsequent results of application.

Assumptions used in the development of SCM costs are included in the respective sections. In addition, the following general assumptions were adopted in the development of cost estimates:

- Only capital costs (including design and construction costs) and operating costs (including inspection, routine maintenance, and infrequent maintenance costs) were developed as part of this project. Other costs discussed in literature including environmental costs, risk costs, disruption costs, and others were not evaluated due to the subjective nature of these costs.
- The sources used for cost data included, in order of preference, actual historical costs for SCMs incurred by NCDOT, engineering estimates prepared for NCDOT, published regional or national cost data, and engineering judgment. This approach acknowledges the superiority of historical cost data and emphasizes local information.
- Discounting of future costs to account for the time value of money was not included in the cost estimates due to the subjectivity required in estimating discount rates and timing of future costs.
- Typical costs for SCMs were estimated for a 10-year time period. This time period was selected to capture representative infrequent maintenance costs, which could be significant depending on the SCM type.
- Blended costs for SCMs used to develop the statewide cost estimate were adjusted to reflect a 5-year time period, to be consistent with the NCDOT Five-Year Work Program.

Other specific methodology and assumptions for estimating costs of SCM implementation and subsequent results of the study are provided in this section.

## 7.1 Typical SCM Costs

Order of magnitude SCM costs were developed for the BSP to satisfy the requirements of the session law and to provide a basis for evaluating applicable bridge SCMs. The following sections present the cost estimating methodology and resulting typical SCM costs developed for the BSP.

## 7.1.1 Methodology

Order of magnitude SCM costs are presented herein as 10-year total costs that include the *capital cost*, a one-time expense for designing and constructing an SCM, and associated *operating costs*, recurring costs for inspection and maintenance of the SCM, over a 10-year period. The 10-year costs are unadjusted totals; discount factors and inflation rates were not incorporated because these can change over time and are dependent on economic conditions. The methodology used to determine capital costs and operating costs for individual SCM types is provided below.

### 7.1.1.1 Capital Costs

Typical SCM capital costs were developed using available construction cost data and estimated design costs from NCDOT SCM projects. The following sections provide the methodology for determining construction costs and design costs.

**Construction Costs**

Typical construction costs for the SCM type cost estimates were based on actual costs from previously constructed NCDOT SCM projects or preliminary construction estimates for planned and ongoing projects. Preliminary construction estimates are cost estimates produced by the design engineer for designed but not yet constructed projects. For most of the typical SCM cost estimates, the construction cost was obtained by averaging the construction costs from applicable NCDOT SCM projects. The construction cost data used to develop the typical SCM costs are summarized in table 7.1-1.

### Table 7.1-1: SCM Construction Cost Data

| County | Route | Location | Impervious Area (Acres) | Total Construction Cost |
|---|---|---|---|---|
| **Level I Treatment SCMs** | | | | |
| **Bioretention Basins** | | | | |
| Hertford | US 258 | US 258 and US 158B in Murfreesboro | 0.15 | $42,208 |
| Carteret | SR 1347 | Smyrna Elementary School | 0.73 | $71,735 |
| Craven | US 70 | NE of intersection of US 70 & US 17 Bus. | 0.89 | $71,485 |
| Duplin | I-40 | I-40 south of the rest area at NC 24 | 0.67 | $64,269 |
| Forsyth | I-40 | Winston-Salem I-40 & US 52 interchange | 1.42 | $87,549 |
| Surry | I-77 | Rest Area on I-77 SB at MM 105 | 1.27 | $96,997 |
| Catawba | I-40 | I-40 Rest Area EBL, MP 138 | 0.49 | $90,499 |
| Gaston | US 321 | NW of interchange of US 321 & NC 279 | 0.64 | $44,148 |
| Buncombe | I-40 | I-40 & US 70 Interchange near MM 65 | 2.75 | $121,840 |
| | | | **Average Bioretention Basin Cost** | **$76,748** |
| **Dry Detention Basins** | | | | |
| Wake | Wade Avenue | UT to House Creek | 3.41 | $60,000 |
| Montgomery | US 220 | NC 211 & US 220 interchange | 0.50 | $55,006 |
| Stokes | NC 8/NC 89 | Dan River | 0.34 | $21,600 |
| Mecklenburg | NC 73 | I-77 & US 73 interchange | 3.33 | $21,845 |
| Jackson | US 74 | US 441 & US 74 interchange | 1.57 | $49,254 |
| | | | **Average Dry Detention Basin Cost** | **$41,541** |
| **Filtration Basins** | | | | |
| Craven | US 70 | US 70 and US 17 Bus. in New Bern | 0.95 | $109,090 |
| Guilford | SR 1979/US 311 | Oak Hollow Reservoir | 2.39 | $51,350 |
| Guilford | Camp Burton Rd | NCDOT E. Maintenance Yard | 4.50 | $178,775 |
| Guilford | Sandy Camp Rd | NCDOT W. Maintenance Yard | 3.40 | $193,267 |
| Montgomery | NC 24 | SW of interchange of NC 24/27 & NC 109 | 1.09 | $35,949 |
| Wake | I-540 | Mango Creek | 1.29 | $141,496 |
| Surry | SR 1345 | Fisher River | 0.28 | $43,622 |
| | | | **Average Filtration Basin Cost** | **$107,650** |
| **Stormwater Wetlands** | | | | |
| Iredell | I-77 | Lake Norman | 4.98 | $105,190 |
| Mecklenburg | I-77 | Sugar Creek | 3.64 | $104,453 |
| Mecklenburg | I-85 | Mallard Creek | 1.23 | $16,579 |
| | | | **Average Stormwater Wetlands Cost** | **$75,407** |
| **Swales** | | | | |
| Currituck | NC 168 | Intersection NC 34 and NC 168 | 0.98 | $7,053 |
| Cumberland | I-95 | NE of I-95 N Rest Area & S of NC 53 Exit | 1.36 | $17,914 |
| | | | **Average Swales Cost** | **$12,483** |

Table 7.1-1: SCM Construction Cost Data (continued)

| County | Route | Location | Impervious Area (Acres) | Total Construction Cost |
|---|---|---|---|---|
| **Level II Treatment SCMs** | | | | |
| **Level Spreaders** | | | | |
| Alexander | SR 1446 | Rocky Creek | 0.16 | $9,980 |
| Yadkin | US 601 | South Deep Creek | 0.70 | $23,640 |
| | | | **Average Level Spreader Cost** | **$16,810** |
| **Preformed Scour Holes** | | | | |
| Ashe | NC 163 | South Fork New River | N/A | $3,800.00 |
| Caldwell | NC 268 | Yadkin River | N/A | $822.00 |
| Wake | SR 1844 | Lower Barton's Creek | N/A | $3,700.00 |
| Wake | SR 2006 | Perry Creek | N/A | $2,400.00 |
| | | | **Average Preformed Scour Hole Cost** | **$2,681** |
| **Design-Related SCMs** | | | | |
| **ESD – Dry Detention** | | | | |
| New Hanover | I-40 | SE of interchange I-40 & SR 1002 | 0.85 | $3,659 |
| Wake | I-40 | NW of interchange of I-440/40 & S. Saunders St | 2.66 | $23,525 |
| Cumberland | I-95 | I-95 & NC 87 Interchange | 0.23 | $512 |
| Buncombe | I-40 | I-40 and NC 9 | 1.68 | $16,966 |
| Davidson | SR 2550 | Beaverdam Creek | 0.29 | $2,910 |
| | | | **Average ESD-Dry Detention Cost** | **$9,514** |
| **ESD – Swale** | | | | |
| Buncombe | I-40 | Interior loop of NE ramp at intersection of I-40 & I-240/US 74A | 1.01 | $15,391 |
| Henderson | SR 1314 | Boylston Creek | 0.74 | $8,650 |
| | | | **Average ESD-Swales Cost** | **$12,020** |
| **Closed Systems** | | | | |
| **County** | **TIP Number** | | | **Total Construction Cost** |
| Mitchell | B-2848 | | | $45,000 |
| Pender | B-4223 | | | $185,000 |
| Catawba | U-2306A | | | $125,000 |
| Brunswick | B-0682 | | | $275,000 |
| Stokes | B-4281 | | | $62,845 |
| Cumberland | U-4756 | | | $40,000 |
| Richmond | R-2502A | | | $30,000 |
| Pitt | B-3684 | | | $75,241 |
| Johnston | U-3334A | | | $208,300 |
| Harnett | B-4137 | | | $18,500 |
| Edgecombe | U-3826 | | | $266,000 |
| Ashe | B-1037 | | | $204,171 |
| Rutherford | R-2233AA | | | $63,000 |
| | | | **Average Closed System Cost** | **$122,927** |

## Design Costs

Design costs for the typical SCM cost estimates were estimated based on an analysis of 10 NCDOT retrofit SCM projects. Details about these projects are provided in table 7.1-2. Retrofits refer to SCMs that were not included in the original design of a project, but were implemented to address stormwater issues after the project was completed. Therefore, retrofits are designed and constructed as separate, individual projects, rather than being included in a larger project, such as the construction of a bridge or roadway. As such, these SCMs are expected to have higher design costs than SCMs designed as part of a larger, new construction project. Design costs specific to retrofit projects might include site visits, additional surveying, utilities investigations, and bid administration. Itemized costs were examined within the budgets for the 10 retrofit projects under consideration, and it was concluded that design costs for SCMs associated with new construction projects were approximately 40% of the design costs for SCM retrofit projects. Based on this assumption, the design budgets were adjusted to yield a new construction or non-retrofit SCM design cost. The adjusted budgeted design costs were compared to preliminary construction cost estimates for these projects to assess the relationship between design and construction cost. Based on the analysis, a regression equation was generated to estimate design cost percentages based on construction cost, as shown in figure 7.1-1. The equation was used to estimate the design cost percentage for each typical SCM cost estimate.

**Table 7.1-2: Design Cost Analysis Data**

| SCM Type | County | Route | Across | Preliminary Construction Estimate | Adjusted Budgeted Design Cost [a] | Design Cost % |
|---|---|---|---|---|---|---|
| Bioretention basin | Buncombe | I-240 | Ross Creek | $246,780 | $17,239 | 7% |
| Dry detention basin | Stokes | NC 8 / NC 89 | Dan River | $29,000 | $15,381 | 53% |
| Filtration basin | Wake | I-540 | Mango Creek | $156,772 | $13,820 | 9% |
| Filtration basin | Guilford | SR 1979 / US 311 | Oak Hollow Reservoir | $66,650 | $14,805 | 22% |
| Filtration basin | Surry | SR 1345 | Fisher River | $49,590 | $14,256 | 29% |
| Level spreader/filter strip | Yadkin | US 601 | South Deep Creek | $27,340 | $15,484 | 57% |
| ESD – natural system | Wake | I-540 | Mango Creek | $31,912 | $4,145 | 13% |
| Stormwater wetland | Mecklenburg | I-85 | Mallard Creek | $24,079 | $14,256 | 59% |
| Stormwater wetland | Iredell | I-77 | Lake Norman | $114,290 | $15,646 | 14% |
| Swale | Wake | I-540 | Mango Creek | $53,435 | $13,217 | 25% |

**Note:**

[a] Actual design costs for retrofit projects were adjusted to be representative of new construction or non-retrofit projects.

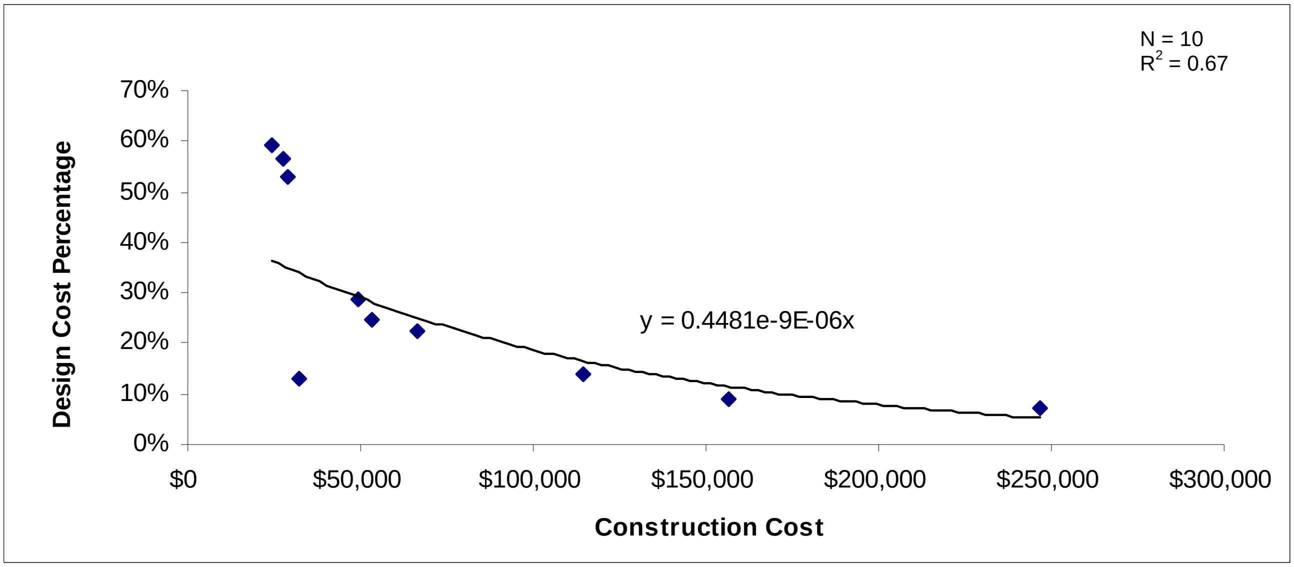


**Figure 7.1-1: Comparison of design cost percentage to construction cost.**

### 7.1.1.2 Operating Costs

Operating costs represent the costs necessary to inspect, operate, and maintain an SCM. Typical operating cost estimates were derived from the following sources (in order of preference): local data and information, regional or national estimates or models, and best engineering judgment where other data was not available.

For each SCM type, operating costs reported include the cost of an annual inspection, the costs of routine maintenance, and the costs of infrequent maintenance. A cost of $100 per annual inspection was assumed based on the inspection requirements of the NCDOT *Stormwater Control Inspection and Maintenance Manual* (2009) and estimates from NCDOT SCM inspection units for the cost of time, materials, and equipment required for inspection and reporting. Routine maintenance costs were based on procedures expected to be performed on a regular basis to maintain the proper working order of an SCM, such as vegetation management, trash and debris removal, and minimal grading and repairs. Infrequent maintenance costs were based on maintenance tasks anticipated to be performed periodically but less frequently than routine maintenance. Examples of infrequent maintenance include accumulated sediment removal; soil media, mulch, and riprap replacement; and larger scale grading and repairs.

## 7.1.2 Typical SCM Cost Estimates

To characterize potential SCM costs, 10-year cost estimates, which incorporate capital costs and operating costs over the first 10 years of an SCM's life, were developed for each type of SCM included in the BSP. The resulting typical SCM cost estimates are provided in the following sections.

### 7.1.2.1 Levels I and II Treatment SCMs

Typical cost estimates for Levels I and II treatment SCMs are provided in table 7.1-3. Typical cost estimates for stream bank drop structures and conveyance channels were not developed because of a lack of available construction cost data.

## Table 7.1-3: Typical Costs for Levels I and II Treatment SCMs

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

**Notes:**

[a] Construction costs for most SCMs were obtained from averaging construction costs from applicable completed, ongoing, and/or planned NCDOT projects. These projects are presented in table 7.1-1. Other construction costs were obtained as noted.

[b] Design costs were obtained by applying the estimated construction cost to the appropriate regression equation, as described in section 7.1.1., except for preformed scour holes, which is assumed to be negligible due to the simplicity of the design and the low construction cost.

[c] Annual inspection costs were assumed to be $100 per inspection as discussed in section 7.1.1.

[d] Routine maintenance costs were based on best estimates provided by NCDOT SCM maintenance units.

[e] Infrequent maintenance costs were estimated as follows:

- Bioretention basin: obtained from Water Environment Research Foundation (WERF) Curb Contained Bioretention Basin model (Lambe et al., 2005) for a medium level of maintenance.
- Catch basin insert: based on best engineering judgment that the insert will need to be replaced every five years.
- Dry detention basin: obtained from WERF Extended Detention Basin model (Lambe et al., 2005) for a medium level of maintenance.
- Filtration basin: based on best engineering judgment that sod and soil media will be replaced every five years.
- Infiltration basin: assumed to be the same as that of a dry detention basin.
- Stormwater wetland: obtained from the WERF Retention Ponds model (Lambe et al., 2005) for a medium level of maintenance. This model was chosen because of the similarity of stormwater wetlands to retention ponds and the lack of available data for stormwater wetland infrequent maintenance.
- Swale: obtained from the WERF Swales model for medium level of maintenance, which is described as “vegetation management and seasonal maintenance” (Lambe et al., 2005).
- Preformed scour holes: based on best engineering judgment that accumulated sediment will be removed and riprap will be replaced every five years.
- Level spreader and filter strip: based on best engineering judgment that grading, seeding, and repair will be necessary every two years.

[f] Construction cost for a typical catch basin insert assumes the cost of one insert and one filter per location. Insert and filter costs were based on NCDOT internal data.

[g] No annual inspection cost is included in the estimated catch basin insert operating cost because the filters are replaced three times per year and, therefore, will not require a separate inspection.

[h] Routine maintenance costs for catch basin insert were based on the assumption that the filter will be replaced three times per year.

### Table 7.1-3: Typical Costs for Levels I and II Treatment SCMs (continued)

[i] The 10-year total cost for a level spreader includes a filter strip. A separate estimate for a filter strip was not developed. These SCMs are often installed concurrently, and the cost of a filter strip is relatively low compared to that of a level spreader.

[j] Construction cost for a typical infiltration basin is assumed to be equal to that of a dry detention basin plus the cost for a geotechnical investigation to determine the adequacy of in situ soils for infiltration. A geotechnical investigation was estimated to cost $10,000 per site.

[k] The 10-year total cost estimate for a typical preformed scour hole is assumed to be representative of costs for both energy dissipators and preformed scour holes.

[l] Design cost was assumed to be negligible for preformed scour holes due to the simplicity of the design and the low construction cost.

### 7.1.2.2 Maintenance SCMs

**Bridge Sweeping**

In NCDOT divisions across the state in which sweeping was performed, annual sweeping costs range from $20,000 to $850,000. Where reported, sweeping costs per linear foot of bridge deck ranged from $0.80 to $1.23 per Division swept.

**BSCCA**

Costs for Bridge Stormwater Collection and Conveyance Assessment (BSCCA) are anticipated to be related to additional training of inspectors and additional effort during the inspection process for recognition and documentation of potential conveyance and collection issues. Refer to section 7.1.3.5 for assumptions used in the statewide cost estimate for the BSCCA SCM.

### 7.1.2.3 Design-related SCMs

Typical cost estimates for Levels I and II treatment SCMs are provided in table 7.1-4. A typical cost estimate for dispersion was not developed because dispersion uses the existing bridge scupper system as the SCM and, therefore, does not generate additional costs. A typical cost estimate for off-site stormwater mitigation was not developed because off-site stormwater mitigation is a design-related SCM that describes a system of providing off-site treatment to compensate for sites where treatment is not effective. The off-site treatment includes the use of SCMs for which cost estimates were developed.

## Table 7.1-4: Typical Costs for Design-related SCMs

| | Capital Cost | | | Operating Cost | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SCM Type** | **Construction Cost[a]** | **Design Cost[b]** | **Total Capital Cost** | **Annual Inspect. Cost[c]** | **Routine Maint. Cost[d]** | **Annualized Infrequent Maint. Cost[e]** | **Total Annualized Operating Cost** | **Total 10-year Operating Cost** | **10-year Total Cost** |
| Closed system | $123,000 | $15,000[f] | **$138,000** | $0 | $1,000 | $6,150 | $7,150 | **$71,500** | **$209,500** |
| Deck conveyance | $43,000[g] | N/A[g] | **$43,000** | $0 | $0 | $0 | $0 | **$0** | **$43,000** |
| ESD – dry detention | $10,000 | $4,000 | **$14,000** | $100 | $500 | $1400 | $2,000 | **$20,000** | **$34,000** |
| ESD – natural system | $3,000[h] | $1,000 | **$4,000** | $100 | $500 | $1400 | $2,000 | **$20,000** | **$24,000** |
| ESD – swale | $12,000 | $5,000 | **$17,000** | $100 | $200 | $400 | $700 | **$7,000** | **$24,000** |

**Notes:**

[a] Construction costs for most SCMs were obtained from averaging construction costs from applicable completed, ongoing, and/or planned NCDOT projects. These projects are presented in table 7.1-1. Other construction costs were obtained as noted.

[b] Design costs were obtained by applying the estimated construction cost to the appropriate regression equation, as described in section 7.1.1, except where otherwise noted.

[c] Annual inspection costs were assumed to be $100 per inspection as discussed in section 7.1.1, except where assumed to be included in regular bridge maintenance.

[d] Routine maintenance costs were based on best estimates provided by NCDOT SCM maintenance units. Routine maintenance costs for closed systems include costs associated with sweeping and scupper cleaning. Routine maintenance costs for ESD types were assumed to be same as that of a dry detention basin for ESD–detention basin and ESD-natural system, and the same as that of swale for ESD-swale (see table 7.1-3). Routine maintenance costs for deck conveyance were assumed to be included in regular bridge maintenance.

[e] Infrequent maintenance costs were estimated as follows:

- Closed system: based on best engineering judgment that closed systems will require replacement every 20 years.
- Deck conveyance: assumed to be included in regular bridge maintenance.
- ESD-dry detention and ESD–natural swale assumed to be the same as that of a dry detention basin, because sediment and debris removal are the primary concern. ESD–swale assumed to be the same as that for a swale (see table 7.1-3).

[f] Design cost for closed system was assumed to be less than that of other SCM types and, therefore, was not obtained as described in section 7.1.1. Closed systems design cost is assumed to be $15,000 based on the design cost of a representative NCDOT closed system project.

[g] Construction cost for deck conveyance, or bridge widening, was based on data provided by NCDOT staff and does not include cost for design. Design efforts for deck conveyance are assumed to be minimal and design costs for deck conveyance are assumed to be negligible. The weighted cost to widen a bridge is assumed to be $98 per square foot, the average length of widening is assumed to be 147 feet, and the assumed width of widening is 3 feet. This results in a total estimated cost of $43,000 per bridge for widening to avoid direct discharge.

[h] Construction cost for a natural ESD was assumed to be that of a preformed scour hole based on the assumption that a preformed scour hole, or similar device, will be required to diffuse flow into the natural feature. See table 7.1-3 for preformed scour hole cost estimate.

## 7.2 Pilot Study Cost Estimates

Cost estimates were developed for each of the 50 pilot study sites to characterize costs for the particular SCMs at each site and to provide an additional means of identifying costs for bridge SCMs. The following sections present the cost estimating methodology and resulting costs for the 50 pilot study site SCMs.

## 7.2.1 Methodology

For preparation of a cost estimate for an SCM within a 50 pilot study site, any known actual costs, known preliminary construction cost estimates, and known design budgets were used. When actual construction costs or preliminary construction estimates were unavailable, some known data, typically impervious drainage area, were used to estimate construction costs. When actual design costs or design budgets were unavailable, design costs were estimated based on the method described in section 7.1.1. Operating costs for SCMs within the 50 pilot study sites were estimated using the inspection and routine and infrequent maintenance cost information presented in table 7.1-3. Using the estimated capital and operating costs, a 10-year cost estimate was developed for each study site SCM.

Several costs items were inherently the same for most of the 50 pilot study site cost estimates, such as additional cost due to retrofitting, design cost relative to construction cost, and SCM inspection cost. If the 50 pilot study site SCM was a retrofit project and actual costs or preliminary construction estimates were unavailable, additional cost was added to the construction cost estimate based on analysis of NCDOT retrofit projects as presented in section 7.2.1.3.

### 7.2.1.1 Construction Cost Estimates Based on Impervious Area

The construction cost data presented in table 7.1-1 were analyzed for the most appropriate relationships on which to develop regression equations for the purposes of estimating construction costs. Methods used in other studies were considered as well, including the relationship of construction cost versus water quality volume, which was used in the Caltrans BMP Retrofit Pilot Program (Caltrans, 2004), and the relationship of construction cost versus total drainage area, which was typically used in the Water Environment Research Foundation (WERF) models (Lambe et al., 2005). These various relationships were evaluated, and the most appropriate relationship was determined to be that of construction cost versus water quality volume because SCMs, particularly Level I treatment SCMs, are typically sized based on the water quality volume. According to the NCDOT *Stormwater BMP Toolbox*, “water quality volume is directly related to the amount of impervious cover” (NCDOT, 2008), so the relationship of construction cost versus water quality volume was simplified to be that of construction cost versus impervious drainage area.

Regression equations for construction cost versus impervious drainage were developed for bioretention basins, dry detention basins, filtration basins, stormwater wetlands, level spreaders, and ESD-dry detention basins for use in estimating construction costs when actual costs and preliminary construction costs were not available for a particular study site. Figures 7.2-1 through 7.2-6 depict the regression equations for these SCMs, respectively.

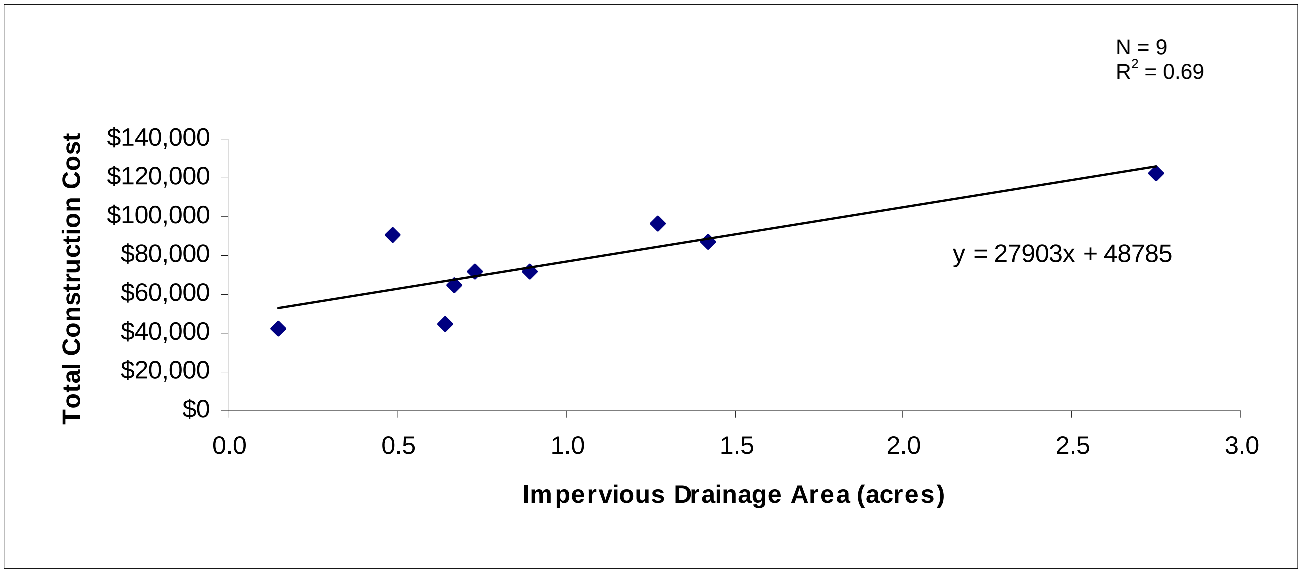


Figure 7.2-1: Comparison of bioretention basin construction cost to impervious drainage area.

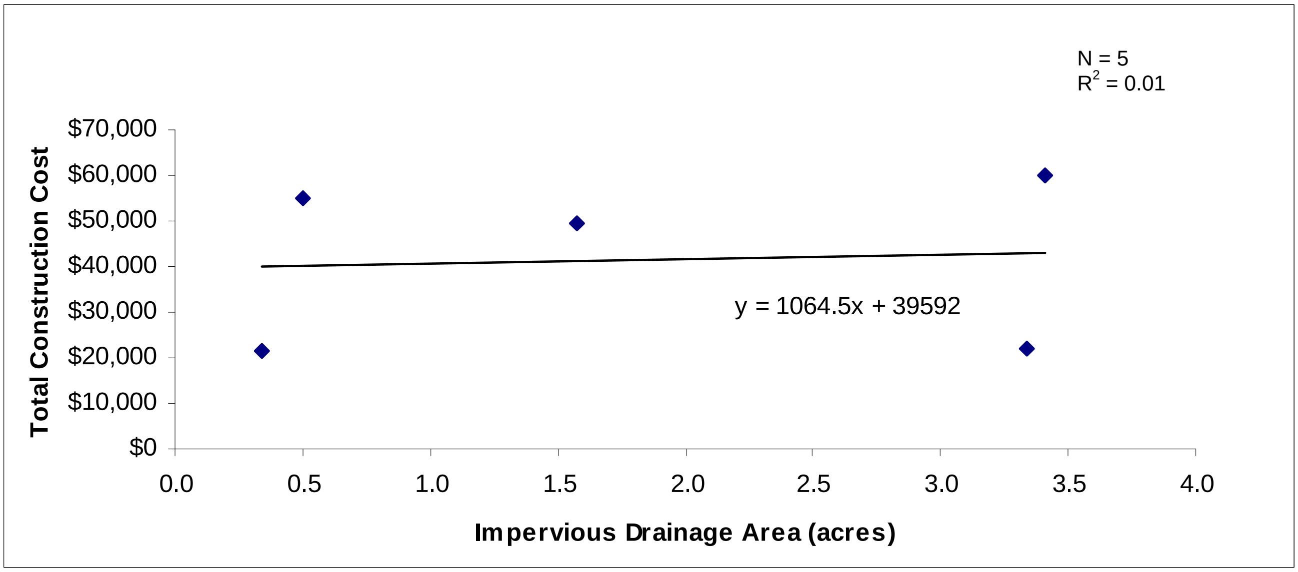


Figure 7.2-2: Comparison of dry detention basin construction cost to impervious drainage area.

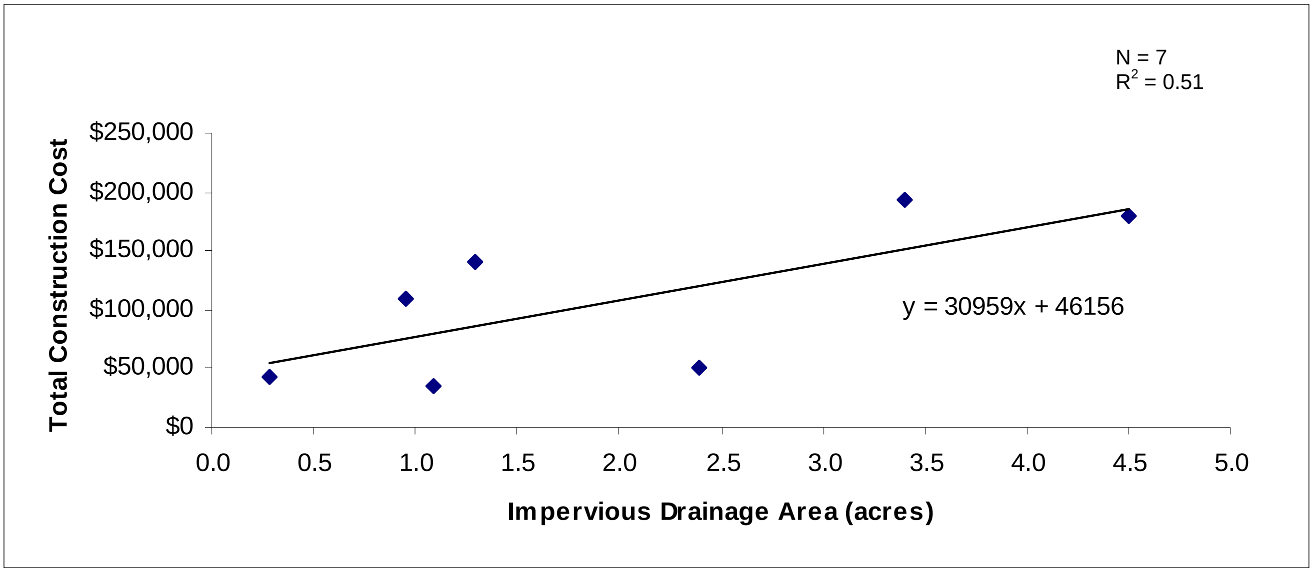


**Figure 7.2-3: Comparison of filtration basin construction cost to impervious drainage area.**

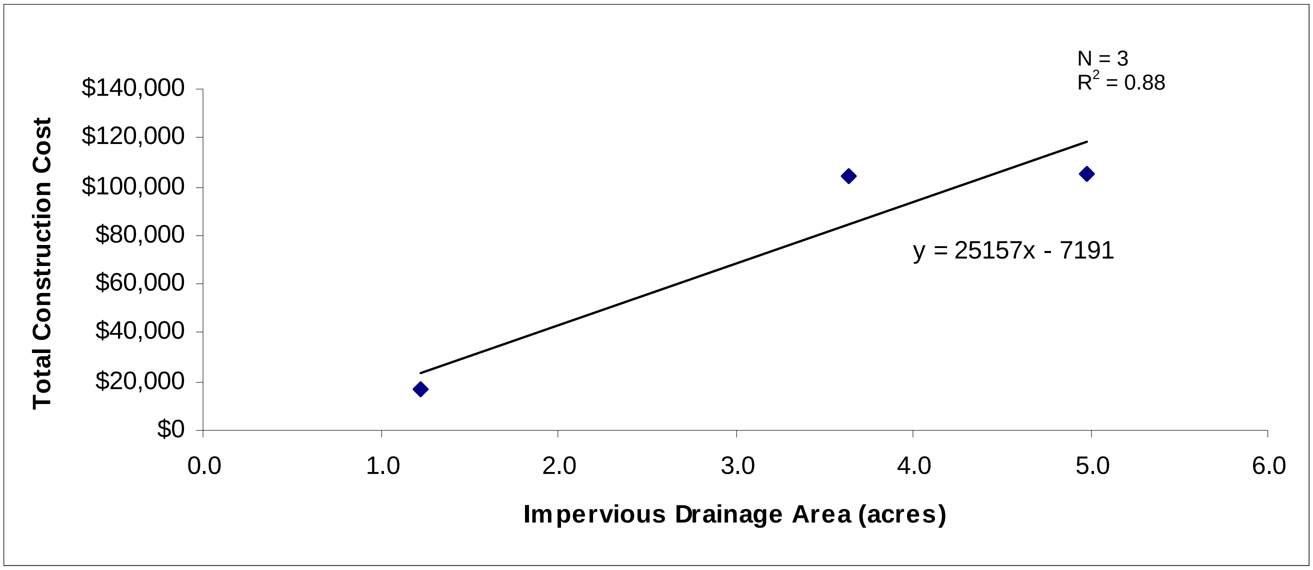


**Figure 7.2-4: Comparison of stormwater wetland construction cost to impervious drainage area.**

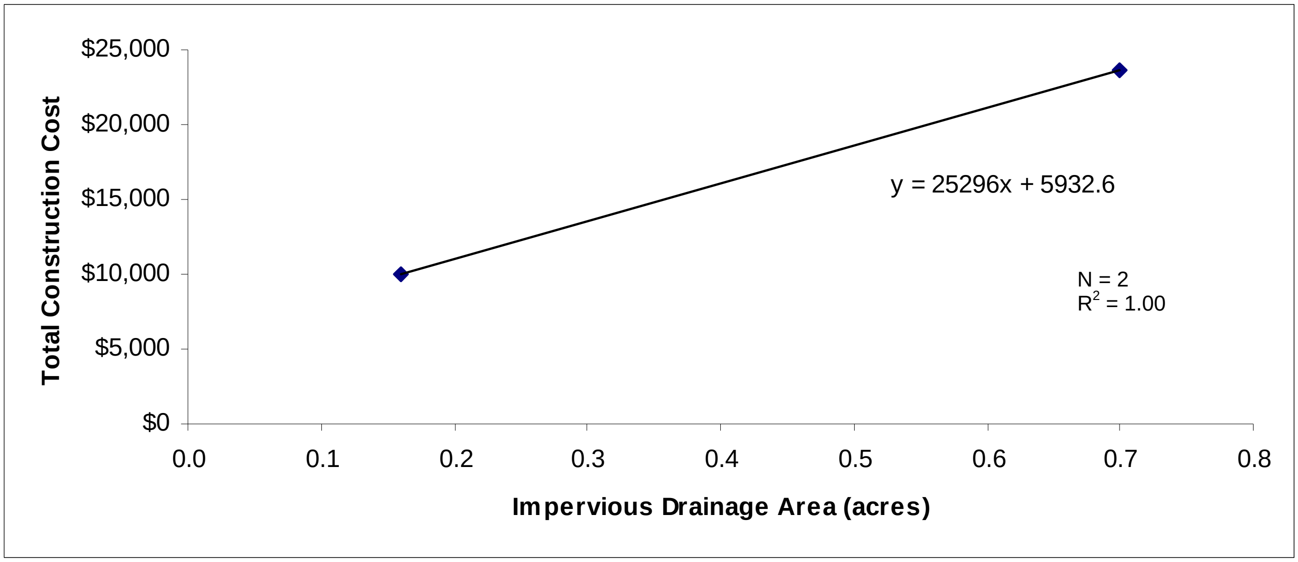


**Figure 7.2-5: Comparison of level spreader construction cost to impervious drainage area.**

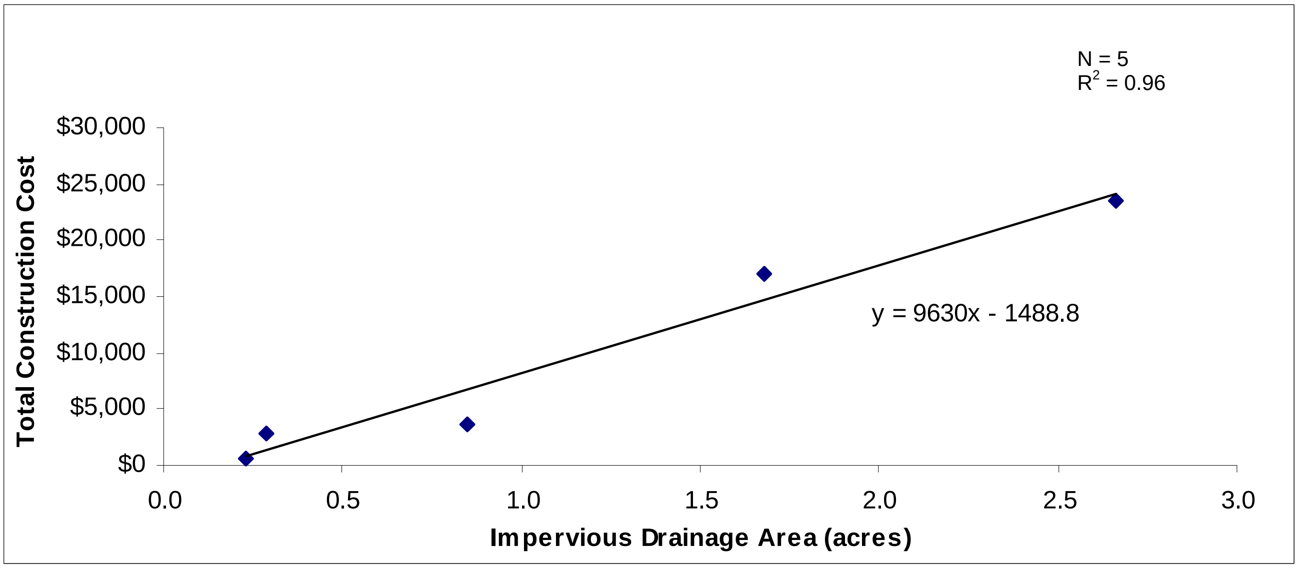


**Figure 7.2-6: Comparison of dry detention ESD construction cost to impervious drainage area.**

### 7.2.1.2 Construction Cost Estimates for Other SCMs

Construction costs for swales and preformed scour holes within the 50 pilot study sites were not estimated based on the relationship of construction cost versus impervious drainage area because costs of these SCM types are not expected to vary significantly from one installation to another. For swales within the 50 pilot study sites for which actual costs and preliminary engineer's estimates were not available, the average construction cost per acre of impervious drainage area from the available NCDOT data was used to estimate the construction cost. For preformed scour holes within the 50 pilot study sites for which actual costs and preliminary engineer's estimates were not available, the average construction cost of $3,000, as presented in table 7.1-3, was used as the construction cost estimate.

### 7.2.1.3 Retrofit Project Cost Adjustment

As described above, retrofits refer to SCMs that were not included in the original design of a project, but were implemented to address stormwater issues after the project was completed. Therefore, retrofits are designed and constructed as separate, individual projects, rather than being included in a larger project, such as the construction of a bridge or roadway. Based on analysis of the preliminary construction estimates for 16 NCDOT retrofit projects, provided in table 7.2-1, retrofits were found to add approximately 17% to the construction cost of an SCM. Several costs within these estimates, such as mobilization, surveying, and traffic control, were considered to be retrofit-specific because they would typically be absorbed into the total costs of a larger, new construction project. To convert these retrofit project costs to costs for non-retrofit projects, the retrofit-specific costs were deducted from the total estimate. The percent differences between the retrofit cost and the non-retrofit cost for each project were averaged, which yielded the 17% additional cost due to retrofitting. The range of percent difference for the projects was 8 to 33%.

Although retrofit-specific costs were deducted from the total construction cost to estimate the additional cost of an SCM due to retrofitting, there are other factors that could make a retrofit SCM project more expensive than a non-retrofit SCM project. Since retrofit projects are typically much smaller than new-construction projects, unit costs for materials are expected to be higher. It is assumed that as the size of the project and quantities increase, the unit prices decrease, which makes the cost to construct an SCM as part of new-construction less expensive than the same SCM were it to be a retrofit project. Similarly, other design and construction costs may be higher for retrofits because the costs are not distributed over a larger project. In addition, other unforeseen costs could be associated with retrofit projects, including costs attributed to difficult site drainage characteristics where gravity collection and conveyance is not feasible. These additional costs are difficult to quantify but could reveal that the percent difference for retrofit projects is higher than the 17% as assessed through the analysis described above. However, based on the data available, 17% was applied to construction cost estimates for 50 pilot study sites SCMs to account for additional cost due to retrofitting.

Similarly, design cost estimates were adjusted for retrofits within the 50 pilot study sites. As reported in Section 7.1.1.1, non-retrofit project SCM design costs were found to be 40% of retrofit SCM design costs. Inversely, retrofit SCM design costs are two and a half times those of non-retrofit SCM design costs, which is equivalent to an additional 150% of the design cost. Therefore, an additional 150% was applied to estimated design costs for retrofit SCMs within the 50 pilot study sites.

**Table 7.2-1: Additional Cost due to Retrofitting Analysis Data**

| SCM Type | County | Route | Waterway Crossed | Preliminary Construction Estimate (Retrofit Cost) | Non-retrofit Construction Cost | Percentage Difference |
|---|---|---|---|---|---|---|
| Bioretention basin | Mecklenburg | NC 218 / US 601 | Goose Creek | $100,462 | $78,020 | 22% |
| Dry detention basin | Stokes | NC 8 / NC 89 | Dan River | $29,000 | $21,600 | 26% |
| Energy dissipator | Catawba | SR 1486 | Cline Creek North | $11,050 | $10,050 | 9% |
| Filtration basin | Wake | I-540 | Mango Creek | $156,772 | $141,496 | 10% |
| Filtration basin | Guilford | SR 1979 / US 311 | Oak Hollow Reservoir | $66,650 | $51,350 | 23% |
| Filtration basin | Surry | SR 1345 | Fisher River | $49,590 | $43,622 | 12% |
| Filtration basins | Buncombe | I-240 | Ross Creek | $246,780 | $223,080 | 10% |
| Level spreader / filter strip | Yadkin | US 601 | South Deep Creek | $27,340 | $23,640 | 14% |
| Level spreader | Alexander | SR 1446 | Rocky Creek | $12,802 | $9,980 | 22% |
| ESD – natural system | Wake | I-540 | Mango Creek | $31,912 | $28,857 | 10% |
| PFSH | Alexander | SR 1446 | Rocky Creek | $7,336 | $4,884 | 33% |
| Stormwater wetland | Mecklenburg | I-85 | Mallard Creek | $24,079 | $16,579 | 31% |
| Stormwater wetland | Iredell | I-77 | Lake Norman | $114,290 | $105,190 | 8% |
| Stormwater wetland | Mecklenburg | I-77 | Sugar Creek | $123,609 | $104,453 | 15% |
| Stormwater wetland | Mecklenburg | NC 51 / I-485 | Clear Creek | $139,214 | $111,402 | 20% |
| Swale | Wake | I-540 | Mango Creek | $53,435 | $48,264 | 10% |
| | | | | | **Average Percent Difference** | **17%** |

**Note:** Non-retrofit construction costs do not include mobilization/demobilization or surveys.

## 7.2.2 Pilot Study Costs

The cost estimates for the 50 pilot study sites were prepared similarly to the typical SCM type cost estimates. Capital, operating, and 10-year cost estimates were developed for each SCM within the 50 pilot study sites. Cost summaries for the 50 pilot study sites can be found within the individual pilot study site reports in appendix 5-B. A summary of the 50 pilot study sites cost estimates is presented in table 7.2-2.

## Table 7.2-2: Pilot Study Sites Cost Estimate Summary

| Bridge No. | SCM Type | County | Capital Costs | | | Operating Costs | | | | 10-year Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Design | Construction | Total | Inspect. | Routine Maint. | Infrequent Maint. | Total | |
| NA[b] | Infiltration basin | Brunswick | $13,000 | $40,000 | **$53,000** | $100 | $200 | $1,400 | **$1,700** | **$70,000** |
| 090072 | Infiltration basin | Brunswick | $6,000 | $14,000 | **$20,000** | $100 | $200 | $1,400 | **$1,700** | **$37,000** |
| 090198 | Infiltration basin | Brunswick | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| 090198 | Swale | Brunswick | $4,000 | $9,000 | **$13,000** | $100 | $200 | $400 | **$700** | **$19,000** |
| 090206 | Infiltration basin | Brunswick | $14,000 | $50,000 | **$64,000** | $100 | $200 | $1,400 | **$1,700** | **$81,000** |
| 100145 | ESD – natural system (and deck conveyance) | Buncombe | $7,000 | $7,000 | **$14,000** | $100 | $500 | $400 | **$1,000** | **$24,000** |
| 100494 | Bioretention basin | Buncombe | $44,000 | $147,000 | **$191,000** | $100 | $600 | $1,200 | **$1,900** | **$210,000** |
| 130007 | PFSH | Caldwell | $0 | $1,000 | **$1,000** | $100 | $200 | $100 | **$400** | **$5,000** |
| 150049 | Energy dissipator | Carteret | $0 | $3,000 | **$3,000** | $100 | $200 | $100 | **$400** | **$7,000** |
| 170017 | Stream bank drop structure | Catawba | $36,000 | $10,000 | **$46,000** | $100 | $200 | $400 | **$700** | **$52,000** |
| 240237 | Filtration basin | Craven | $17,000 | $76,000 | **$93,000** | $100 | $200 | $600 | **$900** | **$102,000** |
| 270054 | Bridge sweeping | Dare | NA | NA | **$6,000** | NA | NA | NA | **NA** | **$60,000** |
| 270054 | Dry detention basin | Dare | $7,000 | $20,000 | **$27,000** | $100 | $500 | $1,400 | **$2,000** | **$47,000** |
| 280416 | ESD – natural system | Davidson | $38,000 | $3,000 | **$41,000** | $100 | $500 | $400 | **$1,000** | **$51,000** |
| 300065 | Infiltration basin | Duplin | $6,000 | $15,000 | **$21,000** | $100 | $200 | $1,400 | **$1,700** | **$38,000** |
| 300309 | Energy dissipator | Duplin | $0 | $3,000 | **$3,000** | $100 | $200 | $100 | **$400** | **$7,000** |
| 400024 | Level spreader | Guilford | $36,000 | $59,000 | **$95,000** | $100 | $700 | $800 | **$1,600** | **$111,000** |
| 400033 | Level spreader | Guilford | $36,000 | $37,000 | **$73,000** | $100 | $700 | $800 | **$1,600** | **$89,000** |
| 400049 | Level spreader | Guilford | $36,000 | $32,000 | **$68,000** | $100 | $700 | $800 | **$1,600** | **$84,000** |
| 400763 | Filtration basin | Guilford | $28,000 | $50,000 | **$78,000** | $100 | $200 | $600 | **$900** | **$87,000** |
| 400764 | ESD – dry detention | Guilford | $9,000 | $17,000 | **$26,000** | $100 | $500 | $400 | **$1,000** | **$36,000** |
| 440008 | Swale | Henderson | $24,000 | $12,000 | **$36,000** | $100 | $200 | $400 | **$700** | **$42,000** |

## Table 7.2-2: Pilot Study Sites Cost Estimate Summary

| Bridge No. | SCM Type | County | Capital Costs | | | Operating Costs | | | | 10-year Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Design | Construction | Total | Inspect. | Routine Maint. | Infrequent Maint. | Total | |
| 440108 / 440112 | Dispersion | Henderson | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| 440375 | BSCCA | Henderson | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| NA[a] | Dry detention basin | Johnston | $5,000 | $13,000 | **$18,000** | $100 | $500 | $1,400 | **$2,000** | **$38,000** |
| NA[a] | Dry detention basin | Johnston | $5,000 | $13,000 | **$18,000** | $100 | $500 | $1,400 | **$2,000** | **$38,000** |
| 500188 | CBI | Johnston | $0 | $1,000 | **$1,000** | $0 | $1,900 | $300 | **$2,200** | **$23,000** |
| 500188 | PFSH | Johnston | $0 | $3,000 | **$3,000** | $100 | $200 | $100 | **$400** | **$7,000** |
| 590296 | Stormwater wetland | Mecklenburg | $22,000 | $24,000 | **$46,000** | $100 | $500 | $3,100 | **$3,700** | **$83,000** |
| 640132 | BSCCA | New Hanover | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| 660024 | Bioretention basin | Onslow | $15,000 | $55,000 | **$70,000** | $100 | $600 | $1,200 | **$1,900** | **$89,000** |
| 790008 | Dry detention basin | Rowan | $13,000 | $40,000 | **$53,000** | $100 | $500 | $1,400 | **$2,000** | **$73,000** |
| 810012 | ESD – natural system | Sampson | $3,000 | $6,000 | **$9,000** | $100 | $500 | $400 | **$1,000** | **$19,000** |
| 810282 | Energy dissipator | Sampson | $0 | $3,000 | **$3,000** | $100 | $200 | $100 | **$400** | **$7,000** |
| 840060 | Dry detention basin | Stokes | $38,000 | $29,000 | **$67,000** | $100 | $500 | $1,400 | **$2,000** | **$87,000** |
| 850056 | Filtration basin | Surry | $36,000 | $50,000 | **$86,000** | $100 | $200 | $600 | **$900** | **$95,000** |
| 910102 | PFSH | Wake | $0 | $4,000 | **$4,000** | $100 | $200 | $100 | **$400** | **$8,000** |
| 910124 | PFSH | Wake | $0 | $2,000 | **$2,000** | $100 | $200 | $100 | **$400** | **$6,000** |
| 910229 | PFSH | Wake | $0 | $3,000 | **$3,000** | $100 | $200 | $100 | **$400** | **$7,000** |
| 910311 | Level spreader | Wake | $6,000 | $14,000 | **$20,000** | $100 | $700 | $800 | **$1,600** | **$36,000** |
| 910471 | CBI | Wake | $0 | $1,000 | **$1,000** | $0 | $1,900 | $300 | **$2,200** | **$23,000** |
| 911101 | Swale and closed system | Wake | $33,000 | $53,000 | **$86,000** | $100 | $200 | $400 | **$700** | **$92,000** |
| 911102 | ESD – natural system | Wake | $10,000 | $32,000 | **$42,000** | $100 | $500 | $400 | **$1,000** | **$52,000** |
| 911102 | Filtration basin | Wake | $35,000 | $157,000 | **$192,000** | $100 | $200 | $600 | **$900** | **$201,000** |
| 920042 | ESD – natural system | Warren | $7,000 | $7,000 | **$14,000** | $100 | $500 | $400 | **$1,000** | **$24,000** |
| 980030 | Filter strip | Yadkin | $39,000 | $27,000 | **$66,000** | $100 | $700 | $800 | **$1,600** | **$82,000** |

**Table 7.2-2: Pilot Study Sites Cost Estimate Summary**

| Bridge No. | SCM Type | County | Capital Costs |  |  | Operating Costs |  |  |  | 10-year Cost |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Design | Construction | Total | Inspect. | Routine Maint. | Infrequent Maint. | Total |  |
| NA[a] | Bridge sweeping | Coastal | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| NA[a] | Bridge sweeping | Blue Ridge | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| Mult. | Stormwater mitigation | Iredell | $39,000 | $114,000 | **$153,000** | $100 | $500 | $3,100 | **$3,700** | **$190,000** |
| Mult. | Stormwater mitigation | Buncombe | $43,000 | $247,000 | **$290,000** | $100 | $200 | $600 | **$900** | **$299,000** |
| NA[a] | Filtration basin | Cherokee | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |
| NA[a] | Filtration basin | Cherokee | NA | NA | **NA** | NA | NA | NA | **NA** | **NA** |

**Notes:**

[a] Bridge is under construction or bridge number has not been assigned.

[b] These are “regional” sites that were included in the 50 pilot study sites in order to provide characterization of bridge sweeping in each of these Divisions.

## 7.3 Statewide SCM Implementation Cost Estimate

Session Law 2008-107 requires that NCDOT determine the cost of implementing SCMs for all bridges over waterways in the state. To satisfy this requirement, five-year costs have been developed for new location, replacement, and existing bridges statewide. The statewide cost estimate was developed using the SCM quantity estimates as reported in section 6 for new and existing bridges over a five-year time period and blended costs for SCMs as presented in the following section.

## 7.3.1 Methodology

A five-year time period was chosen for estimating the cost of statewide bridge SCM implementation as discussed in section 6. Blended cost estimates were developed for Levels I and II treatment and design-related SCMs and applied to the SCM quantity estimates as reported in section 6, to arrive at a total five-year cost for new and existing bridges. In addition, five-year costs were estimated for implementation of maintenance SCMs (the BSCCA program) for both new and existing bridges. The following sections present the blended costs developed for each SCM category.

### 7.3.1.1 Blended Cost for Level I Treatment SCMs

To determine the five-year cost estimate for application of Level I treatment SCMs per bridge, construction cost data from 25 NCDOT Level I treatment SCM projects were analyzed. The projects used are summarized in table 7.3-1.

## Table 7.3-1: Level I Treatment SCM Construction Cost Data

| SCM Type | County | Route | Location | Total Construction Cost |
|---|---|---|---|---|
| Bioretention basin | Carteret | SR 1347 | Smyrna Elementary School | $71,735 |
| Bioretention basin | Craven | US 70 | NE of US 70 & US 17 Bus intersection | $71,485 |
| Bioretention basin | Duplin | I-40 | I-40 south of the rest area at NC 24 | $64,269 |
| Bioretention basin | Forsyth | I-40 | I-40 & US 52 interchange | $87,549 |
| Bioretention basin | Surry | I-77 | Rest Area on I-77 SB at MM 105 | $96,997 |
| Bioretention basin | Catawba | I-40 | I-40 Rest Area EBL, MP 138 | $90,499 |
| Bioretention basin | Gaston | US 321 | NW of interchange of US 321 & NC 279 | $44,148 |
| Bioretention basin | Mecklenburg | NC 218 / US 601 | Goose Creek | $78,020 |
| Bioretention basin | Cabarrus | NC 73 | NW of intersection of NC 73 & I-85 | $122,336 |
| Bioretention basin | Buncombe | I-40 | I-40 & US 70 interchange | $121,840 |
| Dry detention basin | Wake | Wade Avenue | UT to House Creek | $60,000 |
| Dry detention basin | Montgomery | US 220 | NC 211 & US 220 interchange | $55,006 |
| Dry detention basin | Stokes | NC 8 / NC 89 | Dan River | $21,600 |
| Dry detention basin | Mecklenburg | NC 73 | I-77 & US 73 interchange | $21,845 |
| Dry detention basin | Jackson | US 74 | US 441 & US 74 interchange | $49,254 |
| Filtration basin | Craven | US 70 | US 70 and US 17 Bus. In New Bern | $109,090 |
| Filtration basin | Guilford | SR 1979 / US 311 | Oak Hollow Reservoir | $51,350 |
| Filtration basin | Guilford | Camp Burton Rd | NCDOT E. Maint. Yard | $178,775 |
| Filtration basin | Guilford | Sandy Camp Rd | NCDOT W. Maint. Yard | $193,267 |
| Filtration basin | Montgomery | NC 24 | SW of NC 24/27 & NC 109 interchange | $35,949 |
| Filtration basin | Wake | I-540 | Mango Creek | $141,496 |
| Filtration basin | Surry | SR 1345 | Fisher River | $43,622 |
| Filtration basins | Buncombe | I-240 | Ross Creek | $223,080 |
| Stormwater wetland | Mecklenburg | I-77 Welcome Ctr | UT to Sugar Creek | $104,453 |
| Stormwater wetland | Iredell | I-77 | I-77 SBL Rest Area | $105,190 |
| Stormwater wetland | Mecklenburg | I-85 | Mallard Creek | $16,579 |
| | | | **Average Level I Treatment SCM Construction Cost** | **$86,901** |

The average total construction cost was assumed to represent a blended construction cost estimate for a Level I treatment SCM. The design cost was estimated using the average construction cost of $88,000 and the method described in section 7.1.1. The total annualized operating costs for Level I treatment SCMs were averaged to yield a blended Level I treatment SCM total averaged annualized operating cost, as summarized in table 7.3-2. The costs were applied over the five-year letting period for a five-year blended cost estimate for a Level I treatment SCM. Since some bridges may require one Level I treatment SCM and others may require two Level I treatment SCMs, one and one-half SCMs were assumed per bridge structure to yield the five-year total blended cost estimate of Level I treatment SCMs per bridge. The five-year total blended cost estimate for Level I treatment SCMs per bridge structure is presented in table 7.3-3.

**Table 7.3-2: Level I Treatment SCM Total Annualized Operating Cost**

| SCM Type | Total Annualized Operating Cost |
|---|---|
| Bioretention Basin | $1,900 |
| Dry Detention Basin | $2,000 |
| Filtration Basin | $900 |
| Infiltration Basin | $1,700 |
| Stormwater Wetland | $3,700 |
| **Average Annualized Operating Cost** | **$2,040** |

### 7.3.1.2 Blended Cost for Level II Treatment SCMs

Preformed scour holes are the most widely used Level II treatment SCM; therefore, the typical cost estimate for preformed scour holes presented in section 7.1.2 was assumed to be representative of the blended cost estimate for Level II treatment SCMs. The capital and annualized operating costs were totaled over five years to yield the five-year total blended cost estimate for Level II treatment SCMs per bridge structure as presented in table 7.3-3.

### 7.3.1.3 Blended Cost for Design-related SCMs for No-direct Discharge

As discussed in section 6, closed systems and bridge deck widening (or deck conveyance) are design-related SCMs that are implemented to support the no-direct discharge policy of NCDOT. Their estimated costs will be used as the blended cost per structure for closed systems and deck conveyance as described below.

#### Closed Systems

The typical cost estimate for closed systems as presented in section 7.1 was used to develop the five-year cost estimate for closed systems. The capital and annualized operating costs were totaled over five years to yield the five-year total cost estimate for closed systems per bridge structure as presented in table 7.3-3.

#### Deck Conveyance

As previously described in section 7.1, the estimated cost to widen one bridge is $43,000.

### 7.3.1.4 Blended Cost for Retrofit SCMs for Existing Bridges

As presented in section 7.2.1.3, retrofits were found to add 17% to the construction cost of an SCM and 150% to the design cost of an SCM. For purposes of this study, the retrofits implemented are assumed to be Level I treatment SCMs. In order to determine the five-year total cost estimate for retrofit projects, the blended Level I treatment SCM construction cost was increased by 17% and the blended Level I treatment SCM design cost was increased by 150%. The adjusted capital costs and annualized operating costs were totaled over five years to yield the five-year total blended cost estimate for retrofit SCMs as presented in table 7.3-3.

#### 7.3.1.5 Cost of Maintenance SCMs

As discussed in section 6.4, implementation of the Bridge Collection and Conveyance Assessment (BSCCA) program is included as part of the approach for SCM implementation for both new and existing bridges. As reported in section 7.1.2, the Costs for Bridge Stormwater Collection and Conveyance Assessment (BSCCA) are anticipated to be related to training and implementation statewide. While the quantity estimate for BSCCA was provided in section 6 as number of structures, the cost was estimated based on the potential need for initial training, incorporation into existing inspection practices, and additional time required for field operations. The estimated initial training and implementation costs are $100,000, and it is expected that there will be an annual additional field operations cost of $100,000; for the five year time period, the total cost for BSCCA program implementation statewide was estimated to be $600,000.

### 7.3.2 Statewide Cost Estimate Summary

The five-year cost estimates for SCMs as part of the statewide implementation are summarized in table 7.3-3. The total five-year costs of SCM implementation statewide for the 451 waterway bridges scheduled to be let from August 2009 to June 2014 are $35 million as summarized in table 7.3-4.

**Table 7.3-3: 5-Year Cost Estimates for Statewide SCM Implementation for New and Existing Bridges**

| Description | Capital Costs |  |  | Total Annualized Operating Costs | Total 5-year Cost per Structure |
|---|---|---|---|---|---|
|  | Design | Construction | Total Capital |  |  |
| **New Bridges** |  |  |  |  |  |
| Level II Treatment SCMs | $0 | $3,000 | **$3,000** | **$400** | **$5,000** |
| Level I Treatment SCMs | $18,000 | $87,000 | **$105,000** | **$2,000** | **$172,500** [a] |
| Design-related SCMs (Closed Systems) | $15,000 | $123,000 | **$138,000** | **$7,000** | **$173,000** |
| Design-related SCMs (Deck Conveyance) | $0 | $43,000 | **$43,000** | **$0** | **$43,000** |
| **Existing Bridges** |  |  |  |  |  |
| Retrofit SCMs | $45,000 [c] | $103,000 [c] | **$148,000** | **$2,000** | **$158,000** |
| Maintenance SCMs (BSCCA Implementation) | NA | NA | **$100,000** | **$100,000** | **$600,000** [b] |

**Notes:**

[a] Level I treatment SCM total 5-year cost per structure assumes 1.5 SCMs per structure.

[b] The BSCCA Implementation total 5-year cost is a statewide implementation cost and not a cost per structure.

[c] The Level I treatment SCM costs w ere adjusted to yield a Retrofit SCM cost based on the additional costs associated with retrofit projects as discussed above.

## Table 7.3-4: Statewide Cost Estimate of SCM Implementation for New and Existing Bridges – 5-Year Time Period

| Description | Quantity Estimate | Unit Cost | Estimated Cost |
|---|---|---|---|
| **New Bridges** | | | |
| Level II Treatment SCMs | 451 structures | $5,000/structure | $2,255,000 |
| Level I Treatment SCMs | 132 structures | $172,500/structure | $22,770,000 |
| Design-related SCMs (Closed Systems) | 18 structures | $173,000/structure | $3,114,000 |
| Design-related SCMs (Deck Conveyance) | 74 structures | $43,000/structure | $3,182,000 |
| **Existing Bridges** | | | |
| Retrofit SCMs | 20 structures | $158,000/structure | $3,160,000 |
| Maintenance SCMs (BSCCA implementation) | 5 years | NA | $600,000 |
| | | **Total 5-Year Cost Estimate** | **$35,081,000** |

**Note:** The estimated cost is the 5-year total cost that includes capital costs (design and construction costs) and operating costs (inspection, routine maintenance, and infrequent maintenance costs).

# 8.0 Conclusions and Recommendations

The North Carolina Department of Transportation (NCDOT) Bridge Stormwater Project (BSP) was initiated in November 2008 to comply with Session Law 2008-107, Section 25.18, “Stormwater Runoff from Bridges” (NCGA, 2008). The law required NCDOT to provide a final report to the Joint Legislative Transportation Oversight Committee by July 1, 2010. The BSP team identified the following goals to comply with the legislation:

- Characterize bridge deck runoff pollutants (quality and quantity) using scientifically accepted methods and identify those of concern.
- Estimate the effect of bridge deck runoff on surface water bodies by evaluating water quality chemistry and effects on aquatic life.
- Conduct a pilot study of at least 50 sites to evaluate stormwater treatment controls for their ability to provide necessary hydrologic control and stormwater treatment for target pollutants in bridge deck runoff.
- Determine the cost of implementing effective treatments for existing and new bridges over waterways in North Carolina.

This report summarized the efforts of the two-year project that addressed the stated objectives of the law and resulted in a five-year cost estimate for implementing stormwater controls for all waterway bridges in North Carolina. The results of the BSP have led to the following conclusions and recommendations:

**The weight-of-evidence considered in this study indicates that bridge deck runoff does not have a widespread effect on receiving waters and that NCDOT’s current use of stormwater control measures for the mitigation of bridge deck runoff is protective of surface waters.** Results of the bridge deck runoff effect analysis and subsequent weight-of-evidence (WOE) evaluation indicate the following: quality and pollutant loading in bridge deck runoff is similar to roadway and urban runoff; bioassessments made upstream and downstream of bridges provided similar results; periodic toxicity of bridge deck runoff is possible, but not common (periodic toxicity observed may be linked to roadway deicers; see other recommendation); bridge deck runoff did not contribute to stresses from organics or nutrient enrichment; and localized hydromodification and potential erosion due to concentrated flow from bridge decks could impact receiving waters. NCDOT currently implements structural stormwater control measures (SCMs) to treat discharges to sensitive waters and SCMs to reduce potential erosion and hydromodification. Consequently, results of the study indicate that NCDOT’s current approach to SCM implementation is protective of state surface waters. As such, the current NCDOT stormwater practices, with some simplifying assumptions and enhancements, were the primary basis for assessing the statewide SCM quantity estimates and developing a statewide cost estimate for SCM implementation. Some of the enhancements that were incorporated into the basis of estimate have also resulted in recommendations of this report.

**Results of the Bridge Stormwater Project should be integrated into the Highway Stormwater Program (HSP) to facilitate continuous process improvement of NCDOT’s mission, *“Connecting people and places in North Carolina - safely and efficiently with accountability and environmental sensitivity.”*** Since 1998, NCDOT has had a National Pollutant Discharge Elimination System (NPDES) Stormwater Permit issued by the North Carolina Department of Environment and Natural Resources (NCDENR) Division of Water Quality (DWQ) that allows NCDOT to discharge stormwater runoff per the requirements of the permit (NCDENR, 2005). NCDOT has established the HSP to comply with the NPDES permit and mitigate the effects of stormwater runoff. Through the HSP, NCDOT manages stormwater runoff through planning, design, and maintenance of site-specific projects, watershed programs, and education and training of NCDOT personnel and contractors. Specific examples are given in recommendations that follow.

**Results from the BSP should be used to update and advise the site-specific SCM selection process used during NCDOT project planning with environmental agencies for sensitive areas.** NCDOT developed the Merger Process with the US Army Corps of Engineers (USACE), NCDENR, the Federal Highway Administration (FHWA), and other stakeholder agencies to streamline project development and environmental permitting. The Merger Process provides a forum for representatives of each agency to assess site-specific environmental conditions during the planning and early design phases for the construction of new roadways and bridges (NCDOT, n.d.[1]). The Merger Process already allows for a site-specific SCM selection process to address the environmental concerns of the various agencies. As discussed in section 6, site-specific goals for SCMs should be based on regional water resource management strategies and should be linked to the designated uses and water quality standards of receiving waters (National Research Council, 2008). However, as evidenced by this report and other studies, linking stormwater discharges from bridges to receiving water effects can be difficult. Future efforts should continue to develop a process that more closely links stormwater discharges from bridges to receiving water effects and bases SCM selection on their effectiveness. As technology progresses and assessment techniques become more efficient and less expensive, the statewide bridge SCM selection and implementation process should be reevaluated and updated as deemed appropriate by DWQ and the HSP. Findings of the BSP should be considered during future Merger projects to optimize selection of appropriate SCM types to effectively address stormwater management goals for the project.

**Additional investigation is needed to establish the effectiveness of bridge sweeping as an SCM and to provide potential improvements to existing sweeping practices to benefit stormwater quality.** NCDOT conducts sweeping practices for many existing bridges throughout the state because of the associated maintenance and safety benefits. However, NCDOT does not currently conduct bridge sweeping to specifically address stormwater quality concerns. While research has shown that routine sweeping can remove large amounts of sediment from roads, the direct benefit to stormwater quality or effect on receiving waters has not been conclusively defined (Schilling, 2005). Nevertheless, because of the potential to remove large amounts of sediment, bridge sweeping should continue to be considered as a potential water quality Level II treatment SCM for bridge decks. Bridge sweeping may be a viable alternative for stormwater mitigation, especially when other methods of treatment are not feasible or are cost-prohibitive, which may be the case for long coastal bridges. In addition, potential improvements to existing sweeping practices should be considered, including equipment upgrades and new training for proper disposal of captured solids. Additional study is recommended to further evaluate sweeping as an SCM and to shape sweeping practices (including frequency, type of equipment, and disposal practices) to maximize the benefit for stormwater quality.

**The NCDOT *Stormwater Best Management Practices (BMP) Toolbox* should be updated based on information from this study.** The *Stormwater BMP Toolbox* is NCDOT's guidance manual for the design and application of post-construction SCMs for the management of stormwater from transportation facilities (NCDOT, 2008); preparation of the manual is a management measure of NCDOT's NPDES permit under Part II, Section B.3 (NCDENR, 2005). Additional information should be added to the *Stormwater BMP Toolbox* based on data collected and analysis performed as part of this study. Potential additions that should be considered for higher priority include information for off-site stormwater mitigation and filtration SCMs. However, prioritization of subject matter should be directed by the HSP in conjunction with input from appropriate resource agencies. In addition, the chapter on bridge controls (chapter 9) in the *Stormwater BMP Toolbox* should be updated based on findings of this study (or based on additional investigations) as deemed appropriate by the HSP.

**Verify that NCDOT deicing practices continue to incorporate national state-of-the-art practices for mitigation.** As discussed in section 4, a bridge deck stormwater sample collected at the Swannanoa River site on February 22, 2010 was found to be toxic during biological assay testing. Based on preliminary data, the toxicity was attributed to high total dissolved solids, which could be due to the dissolution and subsequent transport in stormwater of deicers that were applied to the roadway during the winter months. However, given that receiving stream flow was much greater than peak discharge from the bridge deck during the storm event (peak discharge from the bridge deck was approximately 3% of minimum flow recorded in the stream on February 22, 2010), substantial mixing and dilution of bridge deck runoff with the receiving stream could occur, reducing instream concentrations of total dissolved solids below levels of concern for aquatic life. In support of this scenario, other bioassay testing of the receiving water on the same date indicated no significant toxicity and other bioassay testing using dilutions of the bridge deck runoff collected on the same date (25% dilution and less) yielded no toxicity. In addition, this site had SCMs installed that would have further reduced the impacts of any discharges from this bridge. While this site had SCMs in place, other existing bridges discharge directly to receiving streams and the importance of NCDOT's snow and ice removal policies should continue to be evaluated. NCDOT's current Snow Clearing Policy requires NCDOT staff to apply the minimal amount of ice control materials appropriate for the road use and weather conditions, in consideration of the effect that materials may have on the environment (NCDOT, n.d.[2]). Where necessary, NCDOT utilizes other controls, such as traction materials (e.g., sand) in lieu of deicers; however, the contribution to TSS and effect of sediment on receiving waters must also be considered. Additionally, NCDOT is in the process of developing its *BMPs for Industrial and Road Maintenance Activities* manual, which is proposed to include a chapter on chemical deicer use.

It should also be noted that there are limited effective substitutes for salt and brine as deicers, and the tradeoff of jeopardizing the safety of the motoring public by not applying deicers to roadways is not acceptable. In addition, there are no effective methods for removing salt from stormwater, which points toward source control as the only viable alternative for mitigation (Talend, 2009). Given these considerations, it is recommended that NCDOT continue to investigate alternative snow and ice control methodologies in consideration of stormwater quality and aquatic life of receiving waters.

**Implement SCMs for existing bridges through the NCDOT Retrofits Program**. Under Part II, Section B.2 of the current NPDES permit, NCDOT is required to construct 14 retrofits per year (NCDENR, 2005). It is proposed that retrofit sites identified annually include SCMs associated with managing stormwater from existing bridges. To maximize the benefit to water quality and aquatic habitats of receiving waters, the data collected and analysis performed as part of the BSP should be used to optimize site and SCM type selection for retrofits.

**Additional development is needed for the proposed Bridge Stormwater Conveyance and Collection Assessment (BSCCA) SCM prior to implementation.** As discussed in section 6, the concept for BSCCA was born from the extensive and numerous bridge site investigations performed to support the BSP. During these field investigations, it was observed that the conveyance and collection of stormwater from and around bridges could be improved to further minimize or avoid erosion. Preliminary discussions with NCDOT Bridge Maintenance Unit (BMU) staff and examination of the current bridge maintenance inspection process indicated that recognition and documentation of potential conveyance and collection problems could be incorporated into the existing biennial bridge maintenance inspections already performed by NCDOT. In addition, discussions with resource agencies about implementation of BSCCA have been positive. As such, the protocol for the BSCCA stormwater control measure should continue to be developed with input from NCDOT BMU staff and DWQ. Currently, it is anticipated that implementation will require additional training of inspectors and may require additional effort during the inspection process for recognition and documentation of potential conveyance and collection problems.

**Develop plan for off-site stormwater mitigation practices for bridges and provide DWQ.** Following the January 6, 2010 meeting with the BSP team, DWQ requested that a proposal for off-site mitigation be developed. Off-site mitigation offers solutions for effective watershed stormwater mitigation where implementing SCMs for bridges is problematic or not practicable, where more stormwater mitigation could be gained for dollar spent, and where retrofit projects are to be constructed. Off-site stormwater mitigation and treatment practices are currently implemented in other states, such as California (Scott McGowen, Caltrans, e-mail message, July 21, 2009), Delaware (DelDOT and DNREC, 1996), and Maryland (MDE, 2001). It is recommended that NCDOT work with DWQ to develop guidelines and protocol for the implementation of off-site stormwater mitigation practices. The effort should include researching practices found to be successful by other states, the United States Environmental Protection Agency (USEPA), and other organizations.

**Provide systematic training for designers and engineers associated with selection and implementation of bridge SCMs.** In accordance with NCDOT's NPDES permit Part II, Section B.5, training for staff and others is provided through the Post-Construction Stormwater Program (PCSP), including training on implementation of the *Stormwater BMP Toolbox* and incorporation of watershed quality strategies (NCDENR, 2005). Additional training for designers and engineers should also include optimal selection and implementation of bridge SCMs. Such training should include information incorporated into the *Stormwater BMP Toolbox* and *BMPs for Industrial and Road Maintenance Activities* (under development) associated with bridge SCMs as discussed in previous recommendations. The additional training associated with bridge SCMs should both promote understanding of unit processes for stormwater treatment and encourage value engineering. Measures that promote the most water quality benefit for dollar spent should be emphasized as part of training for designers and engineers, including implementation of environmental site design concepts, design aspects that facilitate construction and maintenance, and others, as deemed appropriate by the HSP and DWQ.

**Complete investigation to assess the contribution of bacteria from bridge decks and to evaluate potential impacts to receiving waters.** Monitoring for bacteria in bridge deck runoff was not included in the original BSP monitoring plan because of the logistics required for the short holding times and available certified labs. The difficulty in transporting a bridge deck runoff sample to the laboratory within the holding times required for fecal coliform and enterococci bacteria were the same as experienced by Malina et al. (2005) during sampling and analysis of stormwater from bridges in Texas; most of the samples collected were not analyzed for fecal coliform because of the lag time between sample collection and receipt by the lab. Nevertheless, bacteria in stormwater runoff are certainly a concern in North Carolina because of the potential for shellfish contamination and for the limitation of contact recreation. Currently, NCDOT is conducting source assessment and performing monitoring to determine levels of bacteria from the Virginia Dare Bridge. The majority of this work is expected to be completed in early summer of 2010.

**Complete study to assess when dispersion of bridge deck runoff through deck drains is an acceptable practice and to develop bridge criteria for application.** As discussed in sections 5 and 6, the dispersion SCM involves even distribution of bridge deck runoff via deck drains over a vegetated overbank area or over open water. The intention of dispersion is to minimize the potential for concentrated flow and subsequent erosion in the overbank areas and to minimize the acute effect of a point source discharge on receiving waters. Based on observations of this study, deck drains at certain heights over wetlands and vegetated overbank areas with certain slopes may not result in any adverse erosive impact. For bridges where water quality of bridge deck runoff may not be a concern, use of scupper drains to disperse runoff over a large area could be a significant cost savings when compared to implementation of deck conveyance or collection systems (installed to support NCDOT's no-direct discharge policy); these savings could be significant for long coastal bridges and, if combined with off-site stormwater mitigation, could result in a more effective water quality benefit. NCDOT should complete investigations into the applicability of dispersion of bridge deck runoff, including developing with DWQ a specific bridge criteria where dispersion of bridge deck runoff is an acceptable practice and assessing the effects on overbank areas, wetlands, and receiving waters.

**Complete ongoing monitoring to evaluate pollutant removal performance of Level I treatment SCMs.** Given the timeframe requirements of this study, extensive monitoring to support evaluation of the pollutant removal performance of all SCM types presented in the study was not feasible. As discussed in section 6, however, the pollutant removal performance of some Level I treatment SCM types has been assessed and reported by many other studies and provided valuable information for this report. In addition, NCDOT has ongoing research on the performance of bioretention cells, grassed swales, and environmental site design as a part of this study and as a compliance requirement of the NPDES Stormwater Permit, Part II Section G (NCDENR, 2005). This research will evaluate irreducible concentrations and removal of dissolved metals and other parameters-of-concern identified in this study.

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