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National Management Measures to Control Nonpoint Source Pollution from Urban Areas

Management Measure 7: Bridges and Highways

November 2005

MANAGEMENT MEASURE 7 BRIDGES AND HIGHWAYS

7.1 Management Measure

Plan, design, operate, and maintain highways and bridges to:

- Protect sensitive ecosystems, including wetlands and estuaries, by minimizing road- and bridge-related impacts and water crossings, and by establishing protective measures including setbacks during construction;
- Reduce the runoff of pollutants through the use and proper maintenance of structural controls;
- Reduce the generation of pollutants from maintenance operations by minimizing the use of pesticides, herbicides, fertilizers, and deicing salts and chemicals; and
- Reduce the generation and runoff of pollutants during highway and bridge repair operations by decreasing the use of hazardous materials and incorporating practices to prevent spillage into sensitive areas.

7.2 Management Measure Description and Selection

7.2.1 Description

Motor vehicles generate runoff pollutants through emission and deposition of automobile exhaust and through discharges of both fluids and solid particles while traveling and braking. In a study of traffic-generated particulates in Cincinnati (where the average daily traffic load is 150,000 vehicles), Sansalone and Buchberger (1997) found that of the 13,500 mg of particulates per square meter of road surface generated per day, 44 to 49 percent originated from pavement wear, 28 to 31 percent from tire wear, and 15 percent from engine and brake pad wear. The study also found that 6 percent of particulates were deposited from settleable exhaust and 3 percent from atmospheric deposition.

A study by Shepp (1996) examined generation of petroleum hydrocarbons in urban runoff from four land uses: all-day parking lots, streets, gas stations, and convenience stores. Shepp found that convenience stores had the highest hydrocarbon concentration (see Figure 7.1). Evaluation of the land uses and their respective catchment areas suggested that the degree of automotive exposure (a combination of duration of exposure to vehicles with engines running and volume of traffic) is the primary factor in the generation of petroleum hydrocarbons in runoff from automotive-intensive land uses.

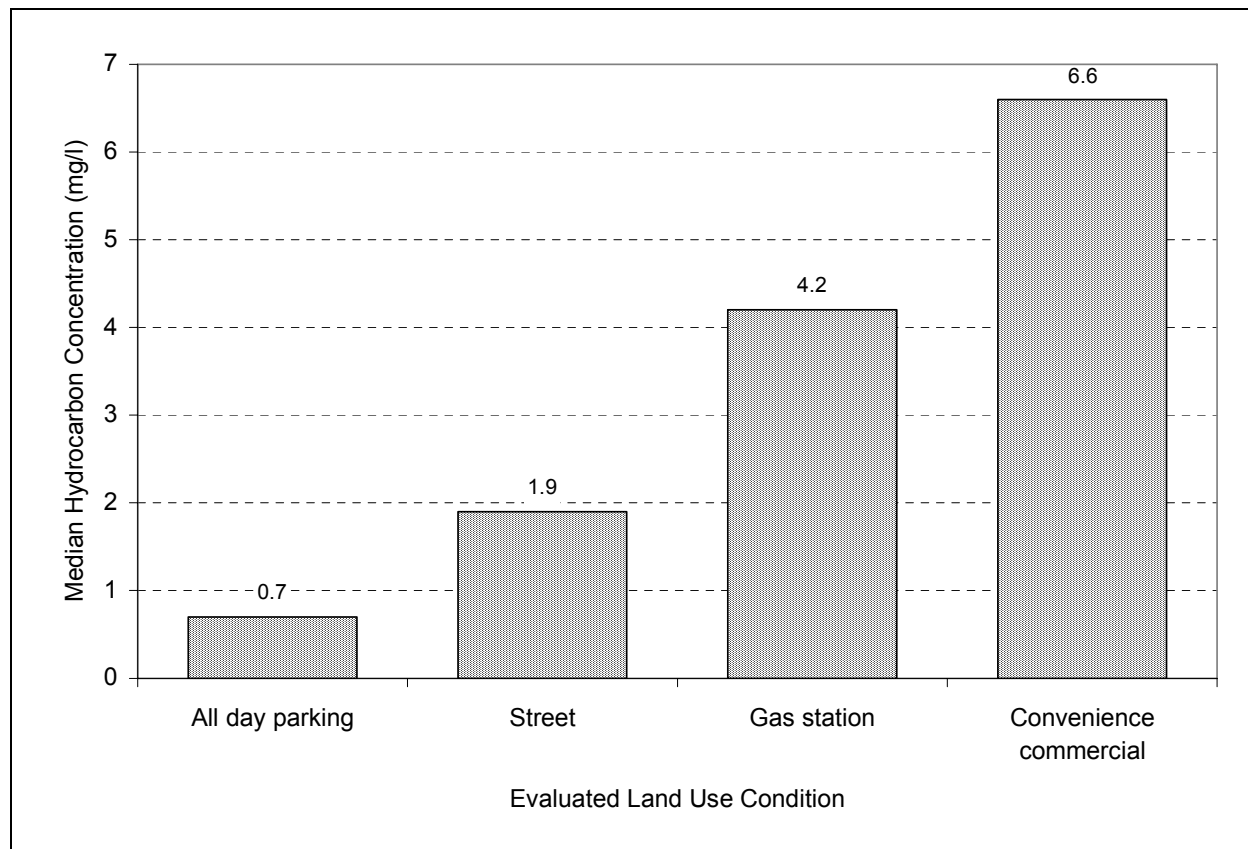


Figure 7.1: Median hydrocarbon concentrations by land use (Shepp, 1996).

The National Water Quality Assessment Program (NAWQA) of the U.S. Geological Survey (USGS) recently conducted studies on water pollution related to sprawl-induced traffic. These studies show a consistently positive correlation between increases in vehicular traffic associated with urban sprawl and the buildup of polycyclic aromatic hydrocarbons (PAHs) in 10 lakes and reservoirs in six metropolitan areas across the country. PAH sources related to motor vehicle use include tire wear, roadway wear, exhaust and soot, and crankcase oil releases (Van Metre et al., 2000). A study in Austin, Texas, demonstrated that elevated levels of PAHs found in Barton Springs sediments, although not toxic on their own, yielded 100 percent mortality in test invertebrates (amphipods, *Hyalella azteca*), when the organisms were exposed to UV radiation (Hayward et al., 2002). Mahler and Van Metre (2004) identified abrasion of coal tar emulsion sealants on parking lots as contributing significant amounts of PAHs to local water bodies and speculated that they could be the dominant source of PAHs in some urban watersheds. The U.S. Fish and Wildlife Service (USFWS) found that 50 to 68 percent of brown bullhead catfish collected from the Anacostia River in Washington, DC, had liver tumors and 13 to 23 percent had skin tumors (Reel, 2004). The USFWS attributed these tumors to DNA changes linked to PAHs from vehicle emissions and runoff.

Roads tend to accumulate particulate matter from roadsides, salting and sanding, dirty cars, brake pad dust, aerial deposition, and surface deterioration. Sansalone and Tribouillard (1999) and Sansalone et al. (1998) measured the deposition and size distribution of particles deposited on highways. They found that accumulation of particulate matter was significantly greater along the

downslope of the highway than along the upslope and that particle size distributions (PSDs) along the downslope were consistently coarser across the entire size gradation than the upslope and pavement PSDs (Sansalone and Tribouillard, 1999). Solids in the 2 to 8 μm range generated the largest counts and were rapidly washed from the pavement in a “first flush” effect (Sansalone et al., 1998). Lateral pavement sheet flow rate and duration controlled the yield and size of transported solids; particle transport was mass-limited during extended, high-intensity events, but was flow-limited during intermittent, low-intensity events with high traffic (Sansalone et al., 1998).

These particles, when transported in runoff to receiving waters, contribute to high levels of total suspended solids and turbidity and act as carriers for pollutants that adhere to their surfaces. Because of this adsorption phenomenon, surface area can be an important determinant in pollutant loading from highways. A relationship exists between particle size and surface area. Sansalone et al. (1998) found that particles 425 μm to 850 μm in size contributed the greatest total surface area. Sansalone and Tribouillard (1999) found that total surface area decreased with decreasing particle size. Particle-specific surface area, however, increased with decreasing particle size (Sansalone and Tribouillard, 1999; Sansalone et al., 1998), but measured values deviated from the monotonic pattern expected for spherical particles (Sansalone et al., 1998).

Because total surface area is predominantly associated with the coarser fraction, heavy metal mass (adhered to particle surfaces) is also strongly associated with this fraction (Cristina et al., 2000). Cumulative analyses for lead, copper, cadmium, and zinc in snow residuals indicated that more than 50 percent of these heavy metals (by mass) was associated with particles greater than 250 μm , and more than 80 percent was associated with particles greater than 50 μm (Sansalone and Glenn, unpublished).

Heavy metals such as lead, iron, and aluminum are typically particulate-bound in urban runoff (Sansalone and Buchberger, 1997). Sansalone and Glenn (2000), however, found that lead was predominantly dissolved in highway runoff, a phenomenon they attributed to low urban rainfall pH and alkalinity and relatively short pavement residence times. Other metals predominantly found in the dissolved phase in highway runoff were zinc, cadmium, and copper (Sansalone and Buchberger, 1997; Sansalone and Glenn, 2000).

The California Department of Transportation (Caltrans) conducted a study of highway runoff quality from 1999 to 2000 at 100 locations throughout the state. Caltrans found a positive correlation between the concentration of most pollutants and traffic volume. In addition, more than 30 percent of the total arsenic, cadmium, chromium, copper, nickel, silver, and zinc were found in the dissolved state (Kayhanian et al., 2001).

The partitioning of heavy metals between the particulate-bound and dissolved fractions raises important questions for watershed managers regarding storm water treatment. It was previously thought that metals were associated with particulates and that removing sediment and reducing turbidity would address these pollutants. However, new research indicates that event mean concentrations of dissolved zinc, cadmium, and copper can exceed surface water quality discharge standards and can exhibit a “first flush” effect that cannot be mitigated by settling. In addition, the dissolved nature of these metals makes them highly mobile and bioavailable.

Other pollutants found in highway runoff, along with their likely sources, are shown in Table 7.1. Although runoff characteristics tend to be site-specific, a number of studies have been performed to compile typical concentrations of highway pollutants from a range of different locations from Northampton, England, to Durham, North Carolina. Table 7.2 shows the range of values for highway contaminants presented by Newberry and Yonge (1996). These concentration levels vary significantly among the different locations. Suspended solids, for example, had concentration levels ranging from 45 mg/L to 798 mg/L; ranges for other parameters were even greater. For some pollutants, such as solids, heavy metals, and organics, concentration levels have been found to correlate with traffic volume.

Table 7.1: Primary sources of highway runoff pollutants (Adapted from NCHRP, 1999).

Pollutants	Primary Source
Particulates	Pavement wear and vehicle maintenance
Lead, cadmium, copper	Tire wear, lubricating oil and grease, bearing wear
Nitrogen, phosphorus	Roadside fertilizer application
Chromium, copper, nickel, cadmium	Metal plating, moving engine parts, brake lining wear
Chloride, sulfates	Deicing salts
PCBs, pesticides	PCB catalyst in synthetic tires, spraying highway rights-of-way
Cyanide	Anti-cake compound used to keep deicing salt granular
Petroleum, ethylene glycol	Spills and leaks of motor lubricants, antifreeze, hydraulic fluids

Table 7.2: Range of average values for runoff contaminant concentration for selected highway contaminants (Newberry and Yonge, 1996).

Contaminant	Concentration (mg/L)	Load (kg/ha/yr)	Load (kg/ha/event)
Suspended solids	45–798	314–11,862	84–107.6
Lead	0.073–1.78	0.08–21.2	0.008–0.22
Phosphorus	0.073–1.78	0.6–8.23	—
Biological oxygen demand	0.113–0.998	30.6–164	0.98
Polycyclic aromatic hydrocarbons	12.7–37	0.005–0.018	—

Runoff from the construction, operation, and maintenance of highways and bridges can adversely affect vegetation, surface waters, and wetlands with a variety of pollutants, including sediments, heavy metals, hydrocarbons, and toxic substances. Runoff issues associated with construction of highways and bridges are addressed in Management Measure 8—Construction Site Erosion, Sediment, and Chemical Control. Although the runoff constituents and concentration levels vary with highway type and location, the sources of highway runoff pollutants fall into three basic categories: vehicle traffic, snowmelt and ice-melt containing deicing chemicals, and chemicals used to manage roadside vegetation.

The specific impacts of highway and bridge runoff on aquatic ecosystems are both site-specific and runoff event-specific. In general, highway pollutants can affect water quality through either acute toxicity or gradual accumulation. Potential adverse environmental effects associated with specific constituents include the following:

- *Suspended solids* increase turbidity, transport other pollutants adhered to particle surfaces, and reduce runoff storage capacity in ponds and lakes.

- *Heavy metals* are toxic to many aquatic organisms and can bioaccumulate in fish tissues, thus posing potential health risks to humans.
- *Nutrients* degrade water quality by stimulating the growth of algae and aquatic weeds. Rapid increases in these populations can then deplete oxygen levels to the extent that fish and other aerobic organisms die off.
- *Biochemical oxygen demand (BOD)* reduces dissolved oxygen levels as a result of the biological processes that break down organic constituents in runoff.
- *PAHs* include compounds such as benzo(a)pyrene that are found in petroleum products and are carcinogenic. These compounds can pose risks to human health if drinking water or fish become contaminated with them. PAHs in streams and lakes usually do not pose a health risk for people because they tend to adhere to sediment particles rather than dissolve in water. As a result, the risk of drinking water degradation is low (Van Metre et al., 2000). Aquatic invertebrates were impacted in the previously identified study from Austin, Texas (Hayward et al., 2002).

Paved roadways often generate higher loads of metals and toxicants than other nonpoint source pollutants¹. Nutrient loadings from highways tend to be of concern when they are located upstream of a reservoir or estuary.

Winter maintenance activities to prevent ice and snow buildup on highways can also be significant contributors to loadings of particulates, salts, and various other chemicals. Salts in particular can harm both vegetation and aquatic ecosystems. Other highway maintenance activities, including roadside vegetation management, can also contribute herbicides, pesticides, and nutrients to runoff pollutant loads.

In several studies, Sansalone and Glenn (2002a, 2002b, and unpublished) examined the characteristics of snowbanks and snowmelt. Table 7.3 summarizes their findings for several pollutants and physical characteristics. From their research, they concluded the following:

- Traffic and winter maintenance practices generate significant levels of inorganic and organic constituents, many of which become predominantly particulate-bound in the snowbank with increasing residence time.
- The accretion of traffic-generated constituents in urban highway snow is relatively rapid within the first 12 hours of the snowbank's exposure to traffic.

A research team at Oregon State University, under the National Cooperative Highway Research Program (NCHRP, 2000) identified potentially mobile constituents from highway construction and repair materials and measured their potential impact on surface and ground waters. The

¹ Several recent studies cited by the Federal Highway Administration (FHWA) indicate that few significant environmental impacts have been associated with roads with an average daily traffic volume of less than 30,000 vehicles (USDOT, 1996).

materials tested were conventional, recycled, and waste materials; and excluded constituents originating from construction processes, vehicle operation, maintenance operations, and atmospheric deposition. The research team established laboratory methods to realistically simulate the leaching of constituents from construction and repair materials in typical highway environments. They also established methods to evaluate the removal, reduction, and retardation of leached constituents by environmental processes in the highway right-of-way. The team produced extensive data sets of laboratory test results for highway construction and repair materials, and they expressed the results as aquatic toxicity and chemical concentrations. They then developed a software program called IMPACT, which estimates the fate and transport of leachates surrounding the highway right-of-way. IMPACT contains an extensive, readily accessible database of laboratory test results for materials ranging from common construction and repair products to waste and recycled materials proposed for use in highway construction.

Table 7.3: Results of three studies that analyzed chemical and physical parameters of snowmelt (Sansalone and Glenn, 2002a, 2002b, and unpublished).

Parameter	Result
Bulk density	Bulk densities increased as TSS accumulation continued and the snow matrix began to melt or evaporate.
Particle size distribution and bulk density	For all sites, particle sizes ranged from 10,000 μm to less than 25 μm , with a mean bulk density of 1,225 μm .
Specific gravity	Specific gravity of residual solids ranged from 2.5 to 3.2 g/cm^3 across the gradations; the lower specific gravity was associated with particles less than 100 μm .
Chloride and conductivity	Conductivity and chloride concentrations increased rapidly at first because of initial deicing salt applications at each site. Strong correlations indicated that conductivity trends were mainly a function of chloride trends.
Hardness	Hardness increased rapidly to nearly 100 mg/L during initial snow accumulation and remained relatively constant (100–300 mg/L) for most of the study. This increase is likely a result of liquid CaCl_2 mixed with rock salt and CaCO_3 as part of the TSS captured by the snow matrix.
COD	Temporal trends toward increasing total chemical oxygen demand (COD) exerted by roadway snow are similar to trends in TSS, with COD values of 100,000 mg/L .
TDS and TSS	Although accretion of total dissolved solids (TDS) was initially rapid with a decrease late in the event, total suspended solids (TSS) accretion demonstrated a more gradual increasing trend for the duration of roadway snow, approaching 100,000 mg/L .
Cyanide	Applications of 216,000 kg of rock salt containing cyanide as an anti-caking agent resulted in a discharge of approximately 6 kg of cyanide along the interstate.
Metals	Concentrations for lead, copper, cadmium, zinc, and cyanide were orders of magnitude higher than those of the control site and exceeded storm water runoff concentrations by 1 to 2 orders of magnitude.

Note: TSS = total suspended solids, TDS = total dissolved solids, COD = chemical oxygen demand, CaCl_2 = calcium chloride, CaCO_3 = calcium carbonate.

7.2.2 Management Measure Selection

This management measure was selected to provide general guidance on practices that can be integrated into highway and bridge maintenance and repair operations. The management measure also includes guidance for siting and constructing highways and bridges. The management measures for watershed protection; site development; new development runoff treatment; and construction site erosion, sediment, and chemical control (Management Measures 3, 4, 5, and 8) are also applicable to the planning and constructing of highways and bridges.

7.3 Management Practices

The use of structural and nonstructural runoff control practices during the planning, design, operation, and maintenance of highways and bridges can significantly mitigate the adverse effects of runoff. Specifically, by using environmentally sensitive highway and bridge designs and implementing proper operation and maintenance practices, highway authorities can reduce both the volume and concentration of contaminants generated by motor vehicle traffic and maintenance and repair operations. In addition, controls can be used to store and treat contaminants so that pollutant loadings can be further reduced or prevented from entering sensitive ecosystems.

7.3.1 Site Planning and Design Practices

A wide range of environmental planning and design management practices, especially those presented in Management Measures 3 and 4, can be used to reduce the environmental impacts of highways and bridges and can be initiated long before a road is completed. In general, highways and bridges should be planned so that mileage through sensitive environments, such as wetlands and estuaries, is minimized. River crossings should be avoided if possible, and sufficient setbacks should be established during construction to minimize disturbance of the surrounding environment. During the siting process, consideration should also be given to maintaining sufficient setbacks for the protection of drinking water sources. Efforts should be taken to avoid channelization and floodplain alteration to allow natural processes to continue after roads are in place.

Highway development is most disruptive adjacent to water bodies, riparian areas, and wetland areas because it increases sediment loss, alters surface drainage patterns, changes the subsurface water table, and results in loss of wetland and riparian habitat. Highway structures should not restrict tidal flows into salt marshes and other coastal wetland areas because such restrictions might facilitate the intrusion of freshwater plants and reduce the growth of salt-tolerant species. To safeguard these fragile areas, highways should be sited with sufficient setback distances between the highway right-of-way and any wetlands or riparian areas.

Bridge construction can also adversely affect water circulation and quality in wetland areas, necessitating special techniques to accommodate construction. By locating highways and bridges away from sensitive areas and establishing buffer zones where possible, environmental degradation from erosion and runoff can be mitigated during construction, operation, and maintenance of roadways.

As discussed previously, roads and highways have been shown to accumulate pollutants that are carried in runoff. Decreasing impervious cover by reducing the area of pavement or number of road miles could lower this pollution potential. However, each individual community should weigh the benefits of alternative road designs against the use of low-impact development techniques or treatment controls (see Management Measures 4 and 5, respectively). Where road surfaces are constructed, disconnecting and infiltrating runoff using structural runoff controls can mitigate impacts of roads and provide sufficient water quality protection.

7.3.2 Soil Bioengineering and Other Runoff Controls for Highways

Soil bioengineering techniques can be used to augment or replace structural slope stabilization practices such as retaining walls. They are appropriate for relatively moderate slopes where vegetation can be established easily. Soil bioengineering techniques can create wildlife habitats and promote infiltration of rainfall and runoff in addition to stabilizing slopes. Installation of bioengineering practices can be labor-intensive, and periodic inspection and maintenance, especially after large storms, is necessary to repair slumps and replace dead vegetation. Soil engineers or scientists should confirm that the stability and structural integrity of the site are appropriate for soil bioengineering practices. Several kinds of soil bioengineering practices are described by the U.S. Department of Agriculture (USDA, 1992):

7.3.2.1 Live stakes

The use of live stakes involves inserting and tamping live, rootable vegetative cuttings into the ground to create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and extracting excess soil moisture. Live stakes are appropriate for repairing small earth slips and slumps caused by excessively wet soil and should be used only at sites with relatively uncomplicated conditions. They are especially useful when construction time is limited and an inexpensive method is desired. They can be used to secure erosion control measures and can be used in combination with other bioengineering techniques. Finally, they facilitate plant colonization by providing a favorable microclimate for plant growth. Native species that are appropriate for the soil conditions onsite should be used wherever possible.

7.3.2.2 Fascines

Fascines are long bundles of branch cuttings bound together into sausage-like structures. They are installed in contoured or angled trenches and are secured to the slope with both live and dead stakes. They reduce surface erosion and rilling, protect slopes from shallow slides, and reduce long slopes into a series of shorter slopes that trap and hold soil. They also enhance vegetative growth by creating a microclimate conducive to plant growth.

7.3.2.3 Brushlayers

Brushlayering is much like the fascine technique except branches are placed perpendicular to the slope contour. This method is more effective than fascines with respect to earth reinforcement and mass stability. Brushlayers break up the slope length, preventing surface erosion, and reinforce the soil with branch stems and roots, providing resistance to sliding or shear displacement. Brushlayers also trap debris, aid infiltration on dry slopes, dry excessively wet sites, and mitigate slope seepage by acting as horizontal drains. Brushlayers facilitate vegetation establishment by providing a stable slope and a favorable microclimate for growth.

7.3.2.4 Branchpacking

Branchpacking involves reinforcing a slope with alternating layers of live branch cuttings and compacted backfill. This technique is useful to repair small, localized slumps and holes in earthen embankments other than dams. Branchpacking produces a filter barrier that reduces

erosion and scouring and provides immediate soil reinforcement. Branchpacking is not effective in slump areas more than 4 feet deep or 5 feet wide.

7.3.2.5 Live gully repair

Live gully repair is a technique that is similar to branchpacking but is used to repair rills and gullies. Live gully repairs offer immediate reinforcement and reduce the velocity of concentrated flows. They also provide a filter barrier that reduces further rill and gully erosion. This technique is appropriate only to repair rills or gullies less than 2 feet wide, 1 foot deep, and 15 feet long.

7.3.2.6 Live cribwalls

A live cribwall is a hollow, boxlike structure of interlocking untreated logs or timber members installed with backfill material and layers of live branch cuttings. The live cuttings eventually take over the structural functions of the wall once the roots have become established. Live cribwalls are appropriate for stabilizing the toe of a slope and reducing its steepness. They should not be used in areas that are subject to large lateral stresses. Cribwalls provide both immediate and long-term stabilization and are useful where space is limited. They should be tilted if the system is built on a smoothly sloped surface, or they can be constructed in a stair-step fashion.

7.3.2.7 Vegetated rock gabions

Vegetated rock gabions consist of wire mesh or chain-link baskets layered with live branch cuttings that take root inside the gabions and bind the structure to the slope. These structures are appropriate for stabilizing the toe of a slope and reducing its steepness, especially in areas where space is limited. They should not be used in areas that are subject to large lateral stresses and should not be more than 5 feet tall.

7.3.2.8 Vegetated rock walls

Vegetated rock walls consist of a combination of rocks and live branch cuttings used to stabilize the toe of steep slopes. These structures are appropriate for stabilizing areas where space is limited and natural rock is available. The wall should not exceed 5 feet in height.

7.3.2.9 Joint planting

Joint planting stabilizes slope faces by planting live cuttings in spaces between the stones of riprap. The plantings improve drainage, bind rock materials to the slope, and help prevent washout of fine materials. Joint planting can be used where riprap has already been installed, or it can be part of a new riprap installation.

7.3.2.10 Other runoff and sediment controls for highways

Other runoff controls, such as grassed swales and filter strips, wet ponds, extended detention dry ponds, and storm water wetlands, can be used to control highway runoff. These measures are described in detail in Management Measure 5. Additionally, sediment traps and basins and inlet protection (described in Management Measure 8) can be used to collect runoff from highways, especially during construction and repair operations when pollutant loadings are great.

Highway Management Plans for Storm Water Control

In Delaware County, New York, the Department of Public Works (DPW) is extending its highway runoff management program to include town roads. This involves inventorying and assessing town roads, identifying priority storm water management needs, training highway superintendents, and evaluating and monitoring management practices. The DPW plans to dedicate a storm water/highway engineer to assist towns in prioritizing their highway storm water projects. Funding will be provided through the Catskill Watershed Corporation's Stormwater Retrofit Program and matched with capital planning funds in town highway budgets. The intent of the program is to maximize efficiency by targeting the areas critically in need of redesign, repair, and rebuilding (Delaware County Departments of Planning and Public Works, 2003). For more information, contact the Delaware County Department of Watershed Affairs, (607) 746-8914.

7.3.3 Structural Runoff Controls for Bridges

Highway runoff controls have been extensively documented and implemented. A mitigation strategy specific to bridges is crucial, however, because of the unique limitations associated with bridge building and repair. These limitations include (Transportation Research Board, 2002a):

- A lack of lateral right-of-way on which to build mitigation measures, causing runoff to be drained back onto land;
- Topographic and slope constraints at some bridges that prohibit gravity drainage back to land;
- The need to factor additional weight of storm water piping into the design of a new or retrofitted bridge; and
- The need to address maintenance constraints and safety concerns.

The Transportation Research Board (TRB) (2002b) developed a report that addresses these and other issues specific to bridge runoff. The TRB described a process for assessing sites for the potential for bridge deck runoff to cause water quality problems and for developing mitigation procedures. The process is particularly applicable in the case of large bridge construction or reconstruction projects over sensitive or highly valued receiving waters. It is also applicable in cases where regulations and policies are ambiguous or require reconsideration. This report, *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters*, is available from the TRB at <http://www.trb.org/>.

7.3.3.1 Scupper drains with runoff conveyance systems

Bridges have traditionally been designed to direct runoff away from the roadway as efficiently as possible without regard to impacts on the environment below the deck. While there is a significant body of research on the environmental impacts of highway runoff, there are few studies that directly address the chemical characteristics of runoff from bridge decks, and even fewer that also address the effects of that runoff on biota or other receiving water uses. Several studies have shown that direct scupper drainage into some types of water bodies, such as small lakes, can result in localized increases of metal concentrations in sediments and in aquatic biota. (TRB, 2002a).

More recently, bridge designs have been enhanced to address the potential effects of runoff pollutant loadings, especially on water bodies. The most prevalent mitigation practice is to direct the drainage from the bridge to an on-shore treatment system. For example, the runoff can be conveyed from scupper drains through a pipe onto the shore, from which it is sent to a retention pond or other runoff treatment practice. A scupper drain is an opening in the floor of a bridge that provides a means for rain or other water accumulated on the roadway surface to drain into the space beneath the structure (ODOT, 2001). Rather than draining directly to the water below, the runoff can be routed to the shore for treatment. The FHWA and EPA have developed recommendations on the design and use of scupper drains to address bridge deck runoff. Among the practices they recommend are:

- The spacing between scuppers should be maximized in accordance with established maximum hydrologic and hydraulic design. As scupper spacing increases, the volume of water that passes through each scupper increases, thus creating velocities high enough to flush outlets clogged by deposits from low-volume rainfalls.
- Careful detailing is critical when connecting scuppers to drain pipes. Because of poorly designed routing, drain pipes often create more problems than they prevent. For example, piping that is routed with too many elbows can easily clog, resulting in a buildup of contaminated runoff.
- Gravity flow collection systems should be used wherever possible.

Collection systems for scupper drains may be used to minimize the impacts of bridge runoff, although they may be expensive. Depending on the length of the bridge and traffic volume, as well as river size and climate, bridge runoff might constitute only a small fraction of the overall pollutant load to a receiving water body. Furthermore, the topography and approach slope at some bridge locations might preclude design or retrofit for gravity drainage back to land, therefore requiring the use of a pump to discharge the runoff into a suitable water quality treatment practice (TRB, 2002a). The addition of pumps could significantly increase the cost of the collection system and operation and maintenance requirements. In some cases, controlling runoff from other pollutant sources may be more cost-effective when a watershed approach is used.

7.3.3.2 Other runoff treatment practices

Runoff treatment practices like ponds, wetlands, infiltration basins and trenches, media filters, bioretention areas, vegetated swales, filter strips, and hydrodynamic devices (see Management Measure 5) can be installed on the shore to treat runoff collected and routed by scupper drains and pipes. If a bridge does not have scupper drains, runoff can be routed to the shore via gutters. Depending on site conditions, such as the space available for the practice, the suitability of the soils for filtration or infiltration, and the quantity and quality of the bridge runoff, some practices may be more cost-effective than others.

7.3.4 Bridge Operation and Maintenance Controls

Bridge repairs are those activities necessary to maintain the structural integrity and designated use of the bridge. Bridge repairs encompass a wide array of activities, ranging from minor

operation practices, such as line painting, to major structural repairs. Bridge scraping and painting, which are required to prevent corrosion, can be significant sources of pollutant loads if proper management practices are not used.

Of the most common bridge maintenance activities, bridge painting has the greatest potential for environmental impact. A 1996 study found that up to 80 percent of steel bridges repainted each year had been painted with lead paint, and this material along with cleaners and abrasives, can directly enter the surrounding environment (Young et al., 1996). Paint overspray and solvents can be toxic to aquatic life (Dalton et al., 1985), and metal bridge cleaning has been found to pose a serious water quality problem (TRB, 2002b). The cost of implementing measures to mitigate the impacts of bridge painting are estimated to be an additional 10 to 20 percent for containment and 10 to 15 percent for waste disposal (Young et al, 1996).

Although most construction activities take place away from water bodies, bridge operation and maintenance activities occur within close proximity to a water body. Therefore, management practices to minimize potential adverse effects on the surrounding environment are recommended. It should be noted that, in some cases, federal regulations, including Section 404 of the Clean Water Act and Section 9 of the Rivers and Harbors Act (33 USC 401) might apply to these construction activities. Section 404 regulates the discharge of dredged or fill material to the aquatic environment or the nation's waters. Section 9 of the Rivers and Harbors Act prohibits the construction of any bridge, dam, dike, or causeway over or in navigable waterways without Congressional approval.

7.3.4.1 Enclosures

The following types of enclosures can be used to collect pollutants during bridge maintenance:

- (1) *Free-hanging enclosures*. Free-hanging enclosures include tarps, drapes, plastic sheeting, screens, and rigid panels of which only two corners (or one side) are supported. Free-hanging tarps generally provide relatively low containment efficiency (estimated at no more than 50 percent). Considerations for material selection include visibility inside the enclosure, material strength, and air permeability. Free-hanging enclosures are not practical for large, high bridges where high winds can rip the materials or create a “sail effect.”
- (2) *Total structural enclosures*. Total structural enclosures are drapes, tarps, screens, plastic sheeting, or rigid panels attached to a rigid steel or wood framework, scaffolding, or existing walls. Design considerations include interior air quality, visibility, structural adequacy of the enclosure, portability, and reusability. Enclosures can be used to encapsulate only part of a large structure at a time. Therefore, portability and reusability should be considered.
- (3) *Negative pressure systems*. Negative pressure containment systems are used to prevent dust from escaping from an enclosure when pressurized air blasting is used for paint removal. Such systems draw outside air into the enclosure to the surface being treated; the air then exits through a filter system. The resulting continuous air exchange eliminates leaks of paint dust and abrasives to the outside, improves worker visibility, and reduces health hazards and dust accumulation on structural surfaces and equipment. These systems can be cumbersome

and expensive, however, and it is sometimes difficult to maintain a constant negative pressure in the enclosure.

7.3.4.2 Containment and collection

Fully enclosed containment structures have been found to recover 80 to 95 percent of abrasives, paint particles, and dust (Appleman, 1992). The following practices can be used to contain and/or collect pollutants during bridge maintenance activities:

- (1) *Cofferdams*. Cofferdams are temporary structures used to displace water and provide dry access to submerged support structures for bridges. Cofferdams can be used during bridge construction and maintenance operations involving painting or repairing of steel structures that are in contact with the water body.
- (2) *Barges*. Barges situated below the bridge with tarps or shields attached from the barge to the bridge or work platform can be used for debris capture, although winds often make this practice infeasible.
- (3) *Containment booms*. Containment booms can be placed in underlying waters to capture floating debris (e.g., paint chips, fines). Lead particles and abrasives usually sink, but use of booms keeps these materials from spreading downstream while they are suspended in the water column.
- (4) *Vacuum sanders*. Vacuum sanders can be used to remove paint from bridges and collect dust and chips. Sanders have been shown to immediately capture 98 percent of the dust generated, which reduces cleanup of containment areas and offers increased safety to maintenance workers (USEPA, 2001).

7.3.5 Nonstructural Runoff Control Practices

The structural management practices for highways and bridge decks described previously are designed to reduce pollutant loadings to the environment by holding and treating the highway runoff generated by precipitation. Nonstructural management practices are designed to achieve source control and can be used to augment on-site structural or other runoff management facilities. Most of the nonstructural practices for managing highway runoff pollution are applicable to virtually all highway situations, even if a specific runoff problem has not been identified.

The following management practices for highway runoff are intended to reduce the volume of particulates available for transport by runoff or to filter and settle out suspended solids. Although the practices described do not represent the complete universe of highway management practices, they are among those commonly implemented across the United States.

7.3.5.1 Implement street sweeping

Curbs systems act as traps for particulates and other pollutants. The advantage of well-maintained, traditional curbs is that they trap pollutants on the paved surface, and when combined with regular vacuum street sweeping, they can be effective at removing pollutants

prior to mobilization in runoff. However, if they are not properly maintained, pollutants build up and are washed out by storm water.

Street sweeping is a common practice in many communities. Street sweeping programs can be optimized to significantly reduce trash and other pollutants on urban streets. Study results suggest that reductions of up to 80 percent in annual TSS and associated pollutants could be achieved by using bimonthly to weekly sweepings. Sweeping frequency would vary with patterns of precipitation, sediment accumulation, and resuspension. The effectiveness of any street sweeping operation will vary with land use, precipitation, and the accumulation dynamics of contaminated sediments (Sutherland and Jelen, 1997). Table 7.4 shows concentrations of constituents often found in street dirt.

Table 7.4: Street dirt chemical quality (Bannerman et al., 1983; Pitt, 1979; Pitt, 1985; Pitt, 2001).

Constituent	Mass of Constituent in Street Dirt (mg constituent / kg total solids)
Phosphorus	400–1,500
Total Kjeldahl Nitrogen	290–4,300
Chemical Oxygen Demand	65,000–340,000
Copper	110–420
Lead	530–7,500
Zinc	260–1,200
Cadmium	<3–5
Chromium	31–180

Sweeping technology can have a profound effect on sweeping results. Previously, sweepers were unable to pickup very fine sediments that can be highly contaminated. One study found that the effectiveness of conventional street sweeping equipment ranged from a 35 percent removal of large particles to an increase in the loading of small particles by 10 percent. The equipment performed more efficiently on a smooth asphalt street, showing a 12 percent reduction in small particles (Pitt, 2001). Today, new street sweeping technology has proven to be an effective management practice for reducing pollutant loads to waterways. High-efficiency pavement sweepers are thought to be very effective at picking up a large portion of the very fine particulate material that accumulates on street surfaces. A high-efficiency sweeper uses strong vacuums and the mechanical action of brooms, combined with an air filtration system that returns only clean air to the atmosphere. Minton et al. (1998) found that simulated results for high-efficiency sweepers in residential areas reduced annual TSS wash-off by 51 to 87 percent. Other sweepers reduced annual TSS in these same areas by up to 71 percent. When sweeping in major arterials with high pollutant loads, simulated results indicated that annual TSS wash-off was reduced by 49 to 85 percent. Other tested sweepers reduced annual TSS wash-off in major arterials by up to 24 percent (Minton et al., 1998). When a high-efficiency sweeper was tested in a tandem sweep behind a mechanical broom sweeper, it was able to pick up 141 percent more material than the mechanical broom sweeper (Schwarze Industries, 2004). When the high-efficiency sweeper swept directly after a regenerative air sweeper, it was able to pick up 44 percent additional material.

High-efficiency sweepers were also compared to wet detention vaults (see Section 5.3.1.1; Sutherland et al., 1998). Simulated results indicate that high-efficiency sweepers removed 40 to 75 percent of annual TSS, while wet detention vaults removed 75 to 91 percent. All removal efficiency ranges depended on sweeping frequency. These projected water quality benefits of high-efficiency street sweeping are based on modeling.

7.3.5.2 Consider alternatives to curbs

As a design alternative, eliminating curbs from roads and highways allows runoff to be filtered through vegetated shoulders or medians and infiltrate to the ground water. Where curbs are necessary for traffic control or other reasons, curb breaks can be incorporated to disconnect the impervious surface and direct runoff to pervious areas. This may not be feasible for streets with high traffic volume and/or on-street parking demand. The structural integrity of the pavement can be maintained by “hardening” the interface between the swale and the pavement with grass pavers, geo-synthetics, or a low-rising concrete strip along the pavement edge. Maintenance requirements for grass channels are generally comparable to those of curb and gutter systems and involve turf mowing, debris removal, and periodic inspections.

7.3.5.3 Install catch basin inserts

Catch basin inserts can be used to treat pollutants in runoff from curbs and road surfaces before entering the storm drain system. These devices are discussed in detail in Management Measure 5 (section 5.3.5.4).

7.3.5.4 Control litter and debris on roadsides

Roadside litter control practices that have traditionally been implemented to address health and aesthetic concerns can also improve runoff quality by limiting trash in runoff conveyance and treatment systems and receiving water bodies. An effective litter and debris control program should include the following source controls:

- Conducting regular trash and debris removal and disposal;
- Educating the public with signs along roads and at rest areas;
- Enforcing littering and illegal dumping laws;
- Sealing cracks and applying pothole surface treatments that minimize the loosening of aggregate and road base debris by tires; and
- Sponsoring Adopt-A-Highway or Adopt-A-Road programs. Many state highway administrations or departments of transportation sponsor Adopt-A-Highway programs that allow businesses and community groups to conduct litter removal and beautification activities on state-owned roads. The city and county equivalent is called Adopt-A-Road.

7.3.5.5 Manage pesticide and herbicide use

Over-application of pesticides and herbicides may cause excess chemicals to leach to ground waters or flow into surface waters. Herbicides and pesticides have the same toxic effect on aquatic plants and organisms as they do on the terrestrial plants and organisms to which they were applied. Practices such as applying according to label instructions, applying at the proper time, applying only the types and amounts necessary, and considering the environmental conditions and hazards at the site are important ways to prevent pesticides and herbicides from entering water bodies. Pesticides, herbicides, and integrated pest management are discussed at length in Management Measure 9 (section 9.3.2).

7.3.5.6 Reduce fertilizer use

Improper application of fertilizers along roadsides can result in excess nutrients being transported to surface waters or leaching to ground water. Methods to reduce fertilizer use are presented in detail in Management Measure 9 (section 9.3.2).

7.3.5.7 Reduce direct discharges

Direct discharges of highway runoff to receiving waters should be avoided wherever possible. This involves the use of collection/conveyance through closed conduits. Highway runoff should be routed through one or a combination of runoff treatment practices, as described in Management Measure 5, before it is discharged to receiving waters.

7.3.5.8 Practice dewatering

Dewatering is a temporary method used to filter sediment-laden water from excavated areas on construction sites prior to discharge to a storm drain or surface waters. Dewatering pumps are applicable wherever sediment-laden water must be removed from a construction site. Dewatering practices should be considered a last-resort control measure. Adequate erosion and sediment control measures must be considered first.

7.3.5.9 Practice spill prevention and control

Prevention and control of spills eliminates or minimizes the discharge of pollutants to water bodies. Water bodies adjacent to construction sites are at highest risk of contamination from an uncontained spill. Several steps can be taken to reduce the risks: handle hazardous and nonhazardous materials, such as concrete, solvents, asphalt, sealants, and fuels, as infrequently as possible and observe all federal, state, and local regulations when using, handling, or disposing of these materials. Spill control devices such as absorbent snakes and mats should be placed around chemical storage areas, and they can be used in an emergency to contain a spill.

7.3.5.10 Properly handle and dispose of concrete and cement

Concrete and cement-related mortars can be toxic to aquatic life. Proper handling and disposal should minimize or eliminate discharges into watercourses. Fresh concrete and cement mortar should not be mixed on-site, and both dry and wet materials should be stored away from water bodies and storm drains. These materials should be covered and contained to prevent contact

with rainfall or runoff. Washout should not be discharged into streets, storm drains, drainage ditches, or watercourses. A washout area should be designated, and wash water should be treated on-site or discharged to the sanitary sewer.

7.3.5.11 Manage contaminated soil and water

Soil, ponded runoff, and ground water can become contaminated if exposed to hazardous materials and should be properly managed to prevent health hazards and minimize or eliminate discharge of pollutants to storm drains and watercourses. Excavation, transport, and disposal of contaminated soil and water, as well as hazardous waste, must be in accordance with the rules and regulations of EPA, the U.S. Department of Transportation, the Department of Toxic Substances Control, and state and local regulatory agencies.

7.3.5.12 Practice environmentally friendly winter road maintenance

Some of the most damaging runoff can be generated from the melting of snow or ice that has been treated with salts or other chemicals. For example, the buildup of salts along roadsides over the course of a winter can damage and reduce the effectiveness of structural controls such as vegetative filter strips and grass-lined channels. Salts in surface or ground waters can adversely affect water quality and damage wetlands. The corrosive effects of salts also damage road infrastructure, especially bridge decks. According to TRB (1991), road salt has caused more premature bridge deck deterioration than any other factor.

Deicing chemicals deposited on road surfaces can contaminate runoff, as can chemicals that are stored in a manner that puts them in contact with precipitation or runoff. Plowed snow piled in parking lots and along roadsides often contains pollutants such as chlorides, sand, and grit, as well as hydrocarbons and heavy metals. These piles should not be deposited into water bodies or stored near water bodies. Treated snow should never be stored on a frozen pond surface because it can cause density stratification, which can prevent reoxygenation in addition to chloride problems.

Three general types of management practices can be employed to reduce the impact of salt damage on the environment. The first is to implement anti-icing operations that help reduce the amount of chemicals required to maintain safe road conditions; the second is to use alternative deicing materials, which are less corrosive and are presumably less damaging to the environment. The third is to properly store salts or other deicing chemicals to prevent runoff contamination.

- (1) *Anti-icing operations.* Anti-icing operations are performed before a storm starts. The purpose of these operations is to prevent snow or ice from accumulating on road surfaces. One of the main advantages of successful anti-icing strategies is reducing the amount of chemicals and abrasives used to keep roads clear. Since 1994, 15 states have participated in the FHWA's project to test and evaluate the effectiveness of anti-icing operations. Anti-icing operations typically use the same chemicals used for deicing, but in different forms. For example, test results found that pre-wetting deicing salt and using brine solutions are effective approaches and result in fewer handling problems.

The ultimate success of anti-icing operations depends on the timing of application. Central to this approach is the use of Roadway Weather Information Systems (RWIS), which report road conditions through pavement sensors that monitor pavement temperatures and the amount of anti-icing materials present on the pavement. When this information is combined with meteorological data and fed into a central database, various modeling techniques can be applied to accurately predict the start of ice formation on pavements and the appropriate times to start anti-icing operations. The cost of implementing and maintaining an RWIS must be compared to the cost of labor and materials for deicing and snow removal. For example, the West Virginia Parkway Authority installed four RWIS units along a 95-mile stretch of highway and calculated that the agency was able to save sufficient outlays for materials and labor to pay for the system within a year. In a state with fewer snowstorms, however, the economics of installing an RWIS may be less advantageous.

Another technology option is the installation of infrared sensors on the bottoms of snowplows. These sensors measure the actual temperature of the roadway as the truck passes over it, allowing a more accurate calculation of the amount of salt needed. As part of its “smart salting” program, the Vermont Department of Transportation installed trial sensors on the bottoms of four snowplows. The agency estimates that it was using 20 to 30 percent more salt than needed because of inaccurate temperature readings. The program has currently been expanded statewide, where the average reduction in salt usage is 28 percent, resulting in an approximate savings of \$2.2 million (Lehner et al., 1999).

- (2) *Alternative deicers.* Over the years, the FHWA and numerous states have experimented with alternative deicing chemicals, including liquid calcium magnesium acetate (CMA), liquid calcium chloride, liquid magnesium chloride, and liquid potassium acetate. Research has found that these chemicals have both advantages and disadvantages compared to salt (see Table 7.5). Calcium chloride works better at lower temperatures but is also corrosive. CMA appears to be much less harmful to the environment. Its disadvantage is that it is significantly more expensive than salt; the NRC estimated that CMA can cost 20 times more than salt and would increase the total cost of chemical application five-fold (Chollar, 1996). CMA is also less successful than other salts at lower temperatures and is slower to act than salt.

Table 7.5: Advantages and disadvantages of road salt and alternative deicing chemicals.

Type	Advantages	Disadvantages
Road salt	<ul style="list-style-type: none"> – Low cost (\$30-40/ton) – Readily available 	<ul style="list-style-type: none"> – Impact on the environment – Corrosiveness
Alternative deicing chemicals	<ul style="list-style-type: none"> – Reduced corrosivity – Reduced impact on the environment – CaCl₂ can be used in very low temperatures (-20°F) 	<ul style="list-style-type: none"> – Higher cost (from several hundred dollars per ton to several thousand per ton) – CMA starts to act at a slower rate than salt

In general, alternatives to road salt are still being researched and tested throughout the Midwest and Northeast, but overall costs tend to be higher for these products. Less environmentally damaging products such as CMA, however, can be used selectively to protect sensitive areas like wetlands without dramatically increasing overall cost to the highway authority.

- (3) *Proper storage of deicing chemicals.* Placing deicing chemicals in storage buildings minimizes the likelihood of polluting surface and ground waters with contaminated runoff and eliminates the economic loss from chemicals that are dissolved and washed away by precipitation. A permanent under-roof storage facility is the best way to protect chemicals from precipitation and runoff, but where this is not possible, salt piles and chemical containers should be stored on impermeable bituminous pads and covered with a tarp or other waterproof cover.

7.4 Information Resources

The U.S. Geological Survey (USGS) and the Federal Highway Administration (FHWA) developed an online searchable bibliography of more than 2,600 pertinent references to be published in the catalog of available information that is being collected to characterize pollutant loadings and impacts attributable to highway storm water runoff. The catalog includes reports on highway-runoff water quality, urban/storm water issues, atmospheric deposition, and highway/urban runoff management practices from the USGS, FHWA, EPA, and state transportation agencies. The database can be accessed at <http://ma.water.usgs.gov/fhwa/biblio/default.htm>.

The Local Technical Assistance Program Web site hosts a “Rural Roads Resources” page that includes a compendium of Web sites, manuals, videos, and other media pertaining to road design and maintenance. The site also hosts an email listserv pertaining to rural roads issues. The Local Technical Assistance Program Resources can be accessed at <http://www.ltapt2.org/> by clicking “Resources.”

The California Regional Water Quality Control Board produced *the Erosion and Sediment Control Field Manual* for the San Francisco Region in 1998. The document is available for a fee using an order form found at <http://www.swrcb.ca.gov/stormwtr/orderform.html>.

The FHWA published a study by Dorman et al. (1996) called *Detention and Overland Flow for Pollutant Removal from Highway Stormwater Runoff*, which provides guidelines for the design of management measures for the removal of pollutants from highway storm water runoff. The guidelines are based on the results of field and laboratory studies to verify design procedures and assumptions and the review of other studies. For a copy of this document, contact FHWA’s Office of the Natural Environment by sending an email to environment@fhwa.dot.gov.

Fisheries and Oceans Canada published *Protecting Fish and Fish Habitat: Bridge Construction and Demolition*, a fact sheet that details the hazards to aquatic life of bridge construction and demolition and recommends practices to reduce environmental damage. This document is available at http://www.dfo-mpo.gc.ca/canwaters-eauxcan/infocentre/guidelines-conseils/factsheets-feuillets/nfld/fact18_e.asp.

In 1992, Northern Virginia Planning District Commission and Engineers Surveyors Institute produced the *Northern Virginia BMP Handbook: A Guide to Planning and Designing Best Management Practices in Northern Virginia*. This handbook is available for download at <http://www.novaregion.org/pdf/NVBMP-Handbook.pdf>.

The Staff Transportation Board of the National Research Council produced a primer for a study entitled *Environmental Impact of Construction and Repair Materials on Surface and Ground Waters*. It is written in nontechnical language and explains how the test methods and supporting computer software can provide answers to questions about the environmental impact of new construction or the repair or rehabilitation of existing highways (NCHRP, 2000). Published reports from NCHRP are available from <http://www.trb.org>.

The Transportation Research Board (TRB) published several studies that investigate the environmental impacts of activities related to transportation infrastructure. These publications

are available at <http://www4.trb.org/trb/onlinepubs.nsf>. For example, the National Cooperative Highway Research Program developed a synthesis of information on environmental management practices for highway and street maintenance. This report, entitled *Best Management Practices for Environmental Issues Related to Highway and Street Maintenance*, is available in hard copy from the Transportation Research Board's bookstore (<http://trb.org/bookstore/>) for \$30. Other titles include *Highway Deicing: Comparing Salt and Calcium Magnesium Acetate* (available electronically at <http://trb.org/publications/sr/sr235.html> or for \$22 from the online bookstore); *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 1: Final Report*, available electronically at http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v1.pdf, and *Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters—Volume 2: Practitioner's Handbook*, available at http://gulliver.trb.org/publications/nchrp/nchrp_rpt_474v2.pdf. Publications pending as of spring 2005 include *Guidelines for the Selection of Snow and Ice Control Materials To Mitigate Environmental Impacts* (NCHRP Project 6-16) and *Winter Highway Operations* (NCHRP topic 34-10), which reports on advances and new practices since TRB's last guide for snow and ice control. Both publications will be available at <http://www.trb.org>.

The TRB's *Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* (NCHRP 25-25(04)) includes numerous management practices in highway construction and maintenance. The guidance was developed from the literature, state transportation agency manuals and procedures, and the contributions of state departments of transportation and practitioners. The document serves as a guide to the development of environmental management systems and environmental strategic plans, both at the organizational level and in specific functional areas such as road construction, vegetation management, materials recycling, winter road maintenance, and many other topics. The document can be downloaded in PDF format from [http://www4.trb.org/trb/crp.nsf/reference/boilerplate/Attachments/\\$file/25-25\(4\)_FR.pdf](http://www4.trb.org/trb/crp.nsf/reference/boilerplate/Attachments/$file/25-25(4)_FR.pdf).

TRB's *Evaluation of Best Management Practices and Low Impact Development for Highway Runoff Control*, expected to be published in late 2004, includes a users' guide for management practice selection, a design manual, and monitoring guidelines to evaluate and optimize the control of runoff from highways. Visit <http://www.trb.org>, and enter "NCHRP 25-20" into the search field to access the report.

The Natural Resources Conservation Service (1992) published *Soil Bioengineering for Upland Slope Protection and Erosion Reduction*, which provides specifications for installing bioengineering practices to reinforce slopes and prevent erosion. This document is available for download at <http://www.info.usda.gov/CED/ftp/CED/EFH-Ch18.pdf>.

The U.S. Department of Transportation's (1995) *Best Management Practices for Erosion and Sediment Control* can be downloaded from the DOT's online publications site at <http://isddc.dot.gov/>.

The FHWA (1996) published the *Manual of Practice for an Effective Anti-Icing Program: A Guide For Highway Winter Maintenance Personnel*, which can guide maintenance personnel in developing a systematic and efficient practice for maintaining roads in the best condition possible during a winter storm. It describes the factors that should be understood and addressed

in an anti-icing program, with the recognition that development of a program must be based on the specific needs of the site or region. It focuses on weather information and materials and methods that will best address site conditions such as level of service, highway agency resources, climatological conditions, and traffic. The manual can be downloaded in HTML format from <http://www.fhwa.dot.gov/reports/mopeap/mop0296a.htm>.

The Michigan Department of Transportation (1993) conducted a detailed study on the environmental effects and costs of using several deicing products, including salt, calcium magnesium acetate, an agricultural byproduct, a magnesium chloride product, calcium chloride, a type of concrete pavement, and sand. The study can be accessed at http://www.michigan.gov/documents/toc-deice_51451_7.pdf. More information on alternative deicers can be found at <http://www.betterroads.com/articles/prod801.htm>, http://www.forester.net/sw_0106_deicing.html, and <http://www.wsdot.wa.gov/partners/pns/htm/resources.htm>.

The Pacific Northwest Snowfighters Association Web site (<http://www.wsdot.wa.gov/partners/pns/>) provides resources pertaining to deicing and anti-icing products and practices, such as a list of approved products, deicing specifications, a fact sheet on magnesium chloride, and testing methods and protocols for deicing products (Washington State Department of Transportation, 2002).

Funded by EPA, the Composting Council Research and Education Foundation (CCREF), in conjunction with the United States Composting Council (USCC), developed *Compost Use on State Highway Applications* to promote compost use on state and local roadside applications. Its goal is to provide individuals and organizations—namely, roads and highways staff, policy makers, product specifiers, project designers and engineers, environmental officers, landscapers, and other interested parties—involved in the maintenance and management of roadsides and highways, with the tools necessary to use composted products to meet their specific project requirements. The document is available for download in PDF format at <http://www.epa.gov/epaoswer/non-hw/compost/highway/>.

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