NCHRP 25-31

Guidelines for Evaluating and Selecting Modifications to Existing Roadway Drainage Infrastructure to Improve Water Quality in Ultra-Urban Areas

Interim Report

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Contents

1 Introduction

Transportation departments (DOTs) are facing increasing regulatory requirements to construct and maintain stormwater treatment control facilities (referred to as Best Management Practices or BMPs) in conjunction with highway improvement projects or even as standalone water quality retrofits. In ultra urban (UU) highway environments, BMP retrofits can be very difficult to implement due to space limitations, high pollutant loadings, hydrologic flashiness, hydraulic constraints, and utility conflicts. Consequently, DOTs potentially face costly and challenging BMP retrofit mandates in UU environments.

The objective of NCHRP Project 25-31 is to prepare a guidance document for performing BMP retrofits of highway facilities in UU environments. The guidance document will include retrofit procedures for evaluating and selecting modifications to existing drainage infrastructure. The NCHRP 25-31 Project Team is led by Geosyntec Consultants (Geosyntec) and Oregon State University (OSU), and includes Wright Water Engineers (Wright Water), Venner Consulting, and the Low Impact Development Center (LIDC).

The Project Work Plan is divided into two phases. Phase I includes initial research consisting of:

Task 1 – Literature Review

Task 2 – DOT Survey

Task 3 – BMP Certification Procedures

Task 4 – Research Plan

Task 5 – Guidelines Outline

Phase II of the project includes implementation of the research plan, demonstration and evaluation of the retrofit procedures, and development of project recommendations and project documents.

This interim report presents results of Phase I of the project as described in the Project Work Plan. Results from initial research under tasks 1 through 3are presented in Section 2 through 4 of this report, respectively. This work has led to the identification of constraints and DOT concerns for BMP retrofits in UU environments. Through this understanding we have developed a research plan for investigating and developing guidance for a sensible retrofit approach of UU highway environments. The research approach and draft outline of the guidelines document are presented in Sections 5 and 6, respectively.

2 Literature Review

The literature review concentrated on the following topic areas related to water quality retrofits in UU highway environments:

- Characterization of UU Highway Runoff
- Structural BMP approaches for UU Highways
- Retrofitting practices for UU Highways

2.1 Characterization of Ultra Urban Highway Systems

2.1.1 Physical Characteristics of the Ultra Urban Highway Environment

There is no commonly accepted definition of UU highways. The FHWA (2002) report on Stormwater BMPs in UU Settings describes the UU environment as areas that are characterized by high population density, high land cost, and high densities of paved surfaces with impervious cover greater than 50 percent and typically in the range of 75 to 100 percent. Based on this guidance, the general characteristics of UU highway environments include:

- High impervious cover (75-100%)
- High traffic densities
- Limited to no right-of-way for drainage and water quality controls
- High land costs for offsite treatment
- High potential for utility conflicts
- Limited ability to retain runoff on-site, including
    - High potential for difficult infiltration situations from poor soils, underground infrastructure, geotechnical considerations, high water tables, higher likelihoods of underground contamination issues, etc.
    - Little area to use for evapotranspiration
    - Little to no use for any harvested stormwater

2.1.2 Ultra Urban Highway Runoff Characteristics

Understanding the water quality characteristics of highway runoff is vital for selection and design of appropriate and effective treatment BMPs. DOTs routinely monitor water quality of highway runoff and there are many reports available that provide information on highway runoff data sources, data summaries, and general characterization of highway runoff data (e.g. NCHRP; 2004, 2006). This literature review has focused on UU highway runoff and the associated implications on BMP selection and design.

Land Use and Traffic Density Influence on Stormwater Quality

UU highway environments are typically located in dense urban areas (with associated wet and dry deposition of pollutants from surrounding sources) and commonly have high annual average daily traffic (AADT) volume. Both of these factors have been associated with higher pollutant levels in highway runoff. However, it is difficult to separate their influence as higher AADT is typically found in dense urban areas (Driscoll et al. 1990; Irish et al. 1985), as are air pollution sources.

Several studies describe observations of increasing concentrations of contaminants in highway runoff as the surrounding setting becomes increasingly urban (e.g. Driscoll et al. 1990, Kayhaniana, et al. 2003, 2006). Driscoll et al. (1990) concluded that surrounding land use is the most important factor that influences constituent loads in highway runoff. They found that constituent loadings in industrial areas are generally greater than residential or commercial areas. In general Driscoll, et al. observed that highway runoff was more polluted than available Nationwide Urban Runoff Program (NURP) data. Caltrans (2003) found that greatest highway runoff concentrations were predominately associated with neighboring commercial and agricultural land usesBarrett et al. (1995b) states that surrounding land use has a major impact on the amount of pollution in dustfall deposited on a highway and the ensuing quality of stormwater runoff.

There is also a significant body of literature that shows an association between AADT and increasing levels of pollutants in highway runoff (Driscoll et al. 1990; Barrett et al. 1985; Caltrans, 2003). Caltrans (2003) characterized highway runoff from different facility types. They found that facilities expected to have the highest vehicle traffic (*e.g.* highways and toll plazas) exhibited elevated runoff concentrations of most pollutants when compared to runoff from lower traffic facilities (maintenance facilities, park-and-ride lots, Caltrans vehicle inspection facilities, and rest areas). This pattern was consistent for the categories of conventional constituents and trace metals with few exceptions, and somewhat less consistent for nutrients. The authors suggested that AADT is an important predictor of pollutant concentration and an important factor in prioritizing management alternatives.

The findings from Caltrans (2003) are consistent with earlier studies by Barrett et al. (1995) who monitored runoff quality from three highways with traffic volumes ranging from 8,700 (rural setting) to 60,000 (dense urban setting) vehicles per day. Measured runoff concentrations were consistently higher at the site with higher AADT. Teng and Sansalone (2004) also found a weak, but statistically significant correlation of increasing TSS concentration with increasing AADT.

While AADT has been associated with higher pollutant levels, studies have found that AADT alone does not correlate well with pollutant concentrations. There likely are contributing cofactors. Regression analyses have found an absence or only weak correlation between AADT and pollutant concentrations (Driscoll et al. 1990; Barrett et al. 1995; Kayhanian et al. 2003), although, AADT did contribute to significant multiple regression relationships when combined with other factors (Kayhanian et al. 2003). Similarly, Barber et al. (2006) found that pollutant concentrations correlated to AADT only in conjunction with numerous other factors, including total event rainfall, seasonal cumulative precipitation, antecedent dry period, AADT, surrounding land use, vegetation, soil characteristics, pervious versus impervious area, and rainfall intensity.

Collectively the literature indicates that pollutant levels in UU highway runoff are expected to be greater than in runoff from other highway facilities. Elevated pollutants levels may pose challenges and constraints as well as opportunities in BMP selection and treatment performance, especially in areas with established loading limits (TMDLs) to receiving waters. Because land use and AADT only partially explain elevated pollutants concentrations, other factors must be considered for the estimation of runoff concentrations when there is an absence of site-specific monitoring data. Knowledge or estimation of runoff quality characteristics is needed for sound BMP selection and design.

Particle Size Distribution

The particle size distribution (PSD) of sediments in runoff is a key consideration when assessing the effectiveness of a BMP utilizing sedimentation and/or filtration, particularly for small footprint proprietary BMPs that frequently use sedimentation and filtration processes. Larger particles (>100 µm) are typically removed in BMPs through gravitational settling, while smaller particles <25 µm will be more difficult to treat, requiring longer settling times or use of filtration processes. In addition, pollutants such as metals and phosphorus are often associated with finer particles due to larger surface area, although there is significant variability (Sutherland, 2003; Lau and Stenstrom, 2005; Wilson et al. 2007).

There is considerable variability in reported PSDs, even on different shoulders of the same highway section (Sansalone and Tribouillard, 1999). However, as a broad generalization particle sizes in urban runoff are dominated by fine particulates (<75um) typical of fine sands and silts. Kim and Sansalone (2008) recently reported PSDs from paved surfaces and compared results to an extensive of published PSD. They found that fine particles (<75um) accounted for 25 to 80% of the particle on mass basis, which was found to be consistent with previously published urban street surface PSDs. Other studies have reported coarser PSDs in highway and street runoff. Shaheen (1975) found that about 10% of the particles were <75µm, 32% between 75 and 250 µm, 58% were >250 µm. Sansalone et al. (1998) investigated runoff from a freeway and found 20% of particle mass was from 600 to 1000 um and 30% was from 1000 to 10,000 um. Kim and Sansalone (2008) attribute variability in PSD to sampling and analytical methods.

The overall transport of solids has also been found to be heavily influenced by traffic flow during storm events and preceding dry days. Sansalone et al. (1998) found that low runoff volume events in high traffic situations typically exhibited a wash-off trend that is flow limited (more solids available for discharge than could be washed off). However, when the preceding dry days were smaller, the amount of solids available for discharge showed a trend similar to the high runoff volume events. In comparison, high runoff volume events in low traffic situations typically show that wash-off of solids is mass limited (fewer solids available for further discharge) (Sansalone et al. , 1998). These results suggest that sediment wash-off from UU highway environments with high AADT will often be flow limited, particularly for more frequently occurring smaller events with long antecedent dry periods.

First Flush Phenomena

First flush is the concept that the highest pollutant concentrations and loads occur in the first portions of the runoff hydrograph (note: sometimes the term first flush has also been used in a seasonal context in areas with long dry periods; in this document we are using the term to refer to the first portions of the runoff hydrograph). Many studies have noted the occurrence of first flush for a variety of constituents and land uses; however, first flush is not always present for all constituents or for all land uses (e.g. Roseen et al. 2006; Flint, 2004; and WERF, 2005 provides a good description). There are various quantitative definitions of mass first flush, for example 50% of the mass load in the first 25% of runoff (Wanielista and Yousef, 1993).
Some researchers have suggested that BMP design strategies should focus on the early portions of the runoff hydrograph and jurisdictions have implemented sizing criteria based on treating the first flush (i.e. half-inch rule). However, WERF (2005) states that generalizations cannot be made about whether or not there will "always" be a first flush and therefore using first flush as a design basis for BMPs is not a reliable practice. Similarly, NCHRP (2006) states that a more demonstrably justifiable BMP design practice will usually be based on the ability to capture up to a specified volume for all storms.

The relevant issues for UU highways are: 1) to what extent does a first flush occur in UU highways environments, and 2) can first flush phenomenon be used to improve treatment efficiency or to justify treatment of smaller design storms due to space-constraints. The literature provides some insights into these issues but there is no consensus.

Many studies have reported first flush in highway runoff (e.g. Barrett et al., 1995; Irish et al. 1995; Sansalone and Buchberger, 1997; NCHRP 2006; Caltrans, 2003). Barrett et al. (1995) states that concentrations of particle-associated pollutants show a more complex temporal variation related to rainfall intensity and the flushing of sediment through the drainage system.

No studies were found that show a prevalence or greater incidence of first flush in UU highways environments. However, Stenstrom and Kayhanian (2005) note that drainage area and impervious cover affect first flush. The nature of highway runoff is that runoff response can be comparatively rapid and flow velocity can be high, providing more opportunity for first flush. In follow-on studies Kang et al. (2008) evaluated the relationship between mass first flush metrics to time of concentration. Caltrans (2003) also found that smaller watersheds tend to produce higher runoff concentrations. This suggests that UU highway environments, which typically are characterized by small drainage areas and high impervious cover, may be more likely to exhibit first flush runoff for some constituents. This is further supported by the work of Maestre et al (2004). They conducted a statistical analysis of monitoring data in the National Stormwater Monitoring Database and found that first flush was more likely to be observed from land uses with high impervious cover (commercial areas) and in simple watersheds where the peak intensity occurs near the beginning of the storm. The authors state that on relatively small paved areas it is likely that there will always be a short initial period of relatively high concentrations associated with washing off of the most available material. However, this peak period of high concentrations may be overwhelmed by periods of high rain intensity that may occur later in the event.

The work of Stenstrom and Kayhanian (2005) is relevant to UU highway environments. This study specifically assessed first flush behavior in runoff from highways located in dense urban areas with AADT ranging from 260,000 to 328,000. Monitoring results showed significant and generally consistent first flush behavior for many dissolved and particulate bound pollutants. Trash monitoring showed limited and inconsistent first flush behavior. The authors state that generally 30 to 50 percent of the pollutants in highway runoff from a single storm event are contained in the first 10 to 20 percent of the runoff volume.

Stenstrom and Kayhanian (2005) and Kayhanian and Stenstrom (2008) conclude that first flush behavior in highway runoff poses opportunities for more efficient or effective BMP design. Accordingly they developed a quantitative measure of treatment performance that accounts for first flush behavior. In follow-on work Kang et al. (2006) used modeling tools to assess BMP design for first flush. Simulation results showed an optimum watershed size that maximizes first flush, which can be used to help design highway collection systems. Examples of first flush friendly BMPs are inlet control devices to limit mixing and dilution with bypass flows, detention basins that are operated in batch mode, and two-compartment basin designs. Such approaches are potentially suitable in space constrained highway environments. In earlier work, however, Sansalone and Cristina (2003) measured first flush behavior from two small impervious transportation catchments and investigated the capture performance of BMPs. They found that "a relatively large runoff volume must be captured to effect meaningful reductions in mass and concentrations despite a disproportionately high mass delivery in the event."

Hydrologic and Climatic Considerations

Studies have shown an association between runoff quality and antecedent dry period. In the arid west where there is a distinct wet and dry season. Monitoring studies have observed higher pollutant concentrations in the early season storms, higher concentrations with increasing duration of antecedent dry period, and decreasing concentration with increasing cumulative rainfall during the wet season (Stenstrom and Kayhanian, 2005; Caltrans, 2003). This provides evidence of a seasonal wash off and has led to the concept of a seasonal first flush. Seasonal variability was found in the Caltrans study to be consistent for all pollutant categories and constituents. Stenstrom and Kayhanian (2005) state that seasonal first flush provides opportunities for designing BMPs that target the early season storms. For example they suggest that infiltration basins that have dried out over the summer can be designed to capture and retain the first few storms of the wet season. Another option might be to have seasonally focused source control efforts to remove any accumulated pollutants from surfaces and drainage systems prior to the on-set of storms.

Storm characteristics (volume, duration, intensity) will influence retrofit scoping, design, and cost considerations. Irish et al. (1995) found that pollutant loadings in highway runoff are positively correlated with runoff volume, which depends on storm duration and storm intensity. Therefore, BMP sizing requirements for UU retrofits will be based on runoff volumes and runoff flowrates. Irish et al. (1995) found that rainfall intensity was not correlated to runoff concentration based on analysis of the NURP dataset. However, others have found that storm duration and rainfall intensity have an inverse relationship with runoff concentrations – shorter storm durations and lower rainfall intensity produce higher runoff concentrations (Caltrans, 2003). The Caltrans study found the correlation between intensity and concentration was not consistent for all parameters, which suggests that rainfall intensity is not a reliable indicator of runoff concentrations. Increasing rainfall intensity, however, has been found to significantly increase sediment concentrations in runoff from highway construction sites (Pitt, 2001).

In cold climate regions, highway runoff quality is influenced by snow accumulation and snow removal practices. Studies report snow melt contributes higher loadings and concentrations of sediment, particulate bound pollutants, salts from chemical deicers, COD, and oil and grease in comparison to rainfall runoff (Glenn, 2001; Driscoll et al., 1990). This occurs because pollutants from vehicles, vehicle exhaust and atmospheric deposition can partition into accumulated snow banks over extended periods. Snow removal practices such as plowing and removal of snow, use of chemical deicers and traction sands also affect runoff concentrations or are direct sources of pollutants. Large runoff volumes are a concern in the spring thaw or from large rain on snow events. Freezing temperatures also present issues for BMP design and performance (Center for Watershed Protection, 1997). All of these factors can complicate BMP selection and design for stormwater retrofits in space constrained environments. Targeted snow removal may be a method to reduce loadings associated with melting snow or rain on melting snow. For example, in Lake Tahoe, snow is moved to specific snow melt areas that drain to BMPs vs. allowing the snow to stay in areas where it cannot be treated.

2.2 Structural Water Quality BMPs for Ultra Urban Environments

There is a wide body of literature on the design and performance of stormwater BMPs. This literature review has focused on studies that relate to applicability and performance of BMPs used in retrofit situations and in space constrained UU highway and similar environments.

2.2.1 General BMP Guidance and BMP Performance Data

There are few guidance manuals that specifically address the selection and design of BMPs for UU environments. FHWA (2002) prepared a guidance document for implementing BMPs in UU environments. The document provides an overview of BMP types and performance, and provides planning level guidance for BMP selection and implementation in UU environments.

BMP selection and design strategies are discussed in Strecker et al. (2000) as a result of work conducted in the evaluation and testing of monitoring equipment and strategies for highway runoff for the Federal Highway Administration (FHWA). Other guidance documents including WERF (2005) and NCHRP (2006) provide general guidance on BMP selection and design that can be utilized with the constraints of UU to select and design BMPs.
Most state DOTs or state environment agencies have developed catalogs and/or fact sheets of treatment BMPs (e.g. Caltrans, 2008b, WSDOT, 2008; NCDOT, 2008; others…) These manuals and fact sheets provide general guidance about BMP performance, cost, space requirement, suitability, and/or maintenance requirements that can be useful selecting BMPs.

More specific information on BMP performance is available from the International BMP Database (BMPDB), a repository of BMP effectiveness studies that have met monitoring protocol standards. The BMPDB was established in 1997 by the ASCE and USEPA and now includes more than 300 studies of traditional and proprietary BMPs from around the country, including many studies from state DOTs (Strecker et al., 2001, 2004; Clary et al., 2006). The BMPDB can be accessed online at: www.bmpdatabase.org. Available information includes the BMP performance data, cost data, BMP monitoring guidance, and protocols for BMP performance assessment. Another repository of BMP performance data is the Massachusetts Stormwater Evaluation Project (MASTEP) at http://www.mastep.net/. This database is focused more on proprietary BMPs, as performance data is sought from product vendors. The searchable database includes a catalogue of various proprietary BMPs, their intended use and the status of verification of their performance claims. Technologies submitted to MASTEP undergo a performance data review before being added to the database.

2.2.2 Post Construction Treatment BMPs

Post construction BMPs for UU environments are typically based on traditional approaches that have been adapted or modified for space constrained environments. Many are proprietary systems designed for small footprints and/or underground installation.

Surface Detention Basins

Extended detention basins are among the most commonly used and widely accepted treatment BMPs. The advantages of extended detention basins include: acceptable treatment performance, some volume reduction, simple design and construction, low hydraulic head requirements, low cost, and simple and low cost maintenance requirements. The Caltrans retrofit study (2005) found that dry surface detention facilities are one of the most applicable technologies for stormwater treatment. Caltrans notes advantages in flexibility in siting, small head requirements, and comparatively low construction and maintenance cost. Caltrans suggests that unlined vegetated basins are preferred where feasible because of benefits from infiltration (and soil soaking and drying) and the associated load reduction.

The main disadvantage of detention basins in linear ultra urban environments are the surface area requirements, which typically are on the order of two percent of the tributary drainage area. However, pervious areas near freeway interchanges and ramps may provide opportunities for using surface detention in UU environments (Center for Watershed Protection, 2008). Diversion to offsite detention basins could also be considered, especially for areas such as close-by public parks or other public open spaces if they can be made available. Surface detention facilities will be mainly applicable in UU environments if drainage can be conveyed to nearby pervious areas.

Outlet Design

The design of the basin outlet structure can strongly influence sedimentation and the water quality of basin discharges. A number of studies have examined alternative outlet designs and outlet retrofits to improve sedimentation efficiency and effluent water quality. Improved outlets include perforated risers that can be designed with multiple draw-down rates over different stages of the basin. The allows for slower draw-down rates for the lower portion of the basin to ensure that smaller storms still receive effective sedimentation times.

Floating outlets structures are designed to improve outlet water quality by draining water from the surface, which in principle will have less suspended sediment due to gravitational settling. The Texas Transportation Institute (2008) evaluated use of skimmer outlets in underground detention vaults and found significant improvement in sedimentation efficiency. However, the researchers expressed concerns about the long-term maintenance of moving components in the outlet structure. Caltrans has initiated studies on skimmer outlets (Caltrans 2008a).

The Texas Transportation Institute (2008) also examined the effects of outlet location on sedimentation efficiency in underground vaults. They observed better removals of TSS when the outlet was located close to the inlet, which was attributed to reduced effects of resuspension.

Batch Operation

Detention basin outlets are typically an orifice or riser outlet structures that is sized to drain the entire design volume over an extended period (i.e. 24 to 48 hours). However, flows from smaller more frequently occurring storms that do not fill the basin will receive shorter detention times. The concept of batch operation (hold-and-release) is to increase sedimentation time by modifying the outlet with a dynamic controller. The controller is programmed to close the outlet at the beginning of a storm (at a predetermined water level) and to open the outlet after a predetermined settling time (i.e. 24 to 48 hours). This provides the full design detention time for distinct storms with runoff volumes that that do not exceed the design capacity of the basin.

Batch operation may have several benefits in UU highways environments. It will in principle promote trapping and sedimentation of the initial “first flush” portions of the runoff hydrograph. Secondly, batch operation can also allow the basins to function as a hazardous materials trap by manually overriding the opening of the outlet after a spill event. It may also be useful in areas where highway runoff enters a combined sewer system and delaying runoff is desirable.

Several studies have examined the effectiveness of batch operation. Middleton et al. (2006) tested the concept of batch operation on two retrofitted detention basins in the Austin Texas. Effluent concentrations for TSS, particulate metals, COD, TKN, and nitrogen were lower in the retrofitted basins than the pre-retrofit basins. The effluent quality from the retrofitted basins was comparable to the treatment performance of Austin sand filters, but with smaller footprint and hydraulic head requirements. The improvement in effluent quality due to batch operation was found to be statistically significant.

Batch operation of small underground detention vaults was also found to improve sedimentation and reduce effects from resuspension (Texas Transportation Institute, 2008). Caltrans has initiated pilot testing of basin retrofits for batch operation at several locations but the report is not due until 2010 (Caltrans, 2008a).

Additional uses of “smart controllers” for outlets could include using weather predictions to alter release rates. For example, although a 24 to 48-hour settling time may be desired, if a runoff event were predicted, the controller could speed releases at that point to minimize bypass by making the storage volume available for the next storm. These types of systems are currently being evaluated in the New York Combined Sewer Overflow control evaluations for example.

Amended Soils

The Center for Transportation and environment has sponsored ongoing research on retrofitting existing detention basins with amended soils to improve retention and treatment functions (http://itre.ncsu.edu/CTE/Research/project.asp?ID=165). Soil amendments help to increase evapotranspiration losses and can increase infiltration by increasing storage within the soils where underlying soils and groundwater table heights are able to allow for deeper infiltration.

Sizing

Space constraints in UU environments can restrict the size of detention facilities below typical water quality design requirements. Caltrans (2008a) has initiated studies to examine the effects of decreasing detention volume on detention times and pollutant removal performance.

Tucker (2007) describes an interesting field study to quantify effectiveness of an undersized wetland for treatment roadway runoff. They found that the wetlands provide good removal effectiveness, especially for storms without bypass. The study concluded that undersized wetlands with "flow through" design might provide effective and efficient pollutant removals if designed to safely pass the larger storms without scouring. The study results also "suggests that in watersheds with limited and expensive land area it is more efficient to use multiple smaller BMPs near the source that capture the smaller more frequent storms."

Inlet Regulators

Caltrans (2008) is examining the use to splitter boxes that regulate inflows to the basin such that bypass flows are routed around the basin instead of through the basin. There are a lot of different proprietary systems used to control, spilt and direct flows to BMPs.

<u>Underground Detention</u>

In highly space constrained environments with limited options for surface facilities, detention storage can be located in underground vaults and/or oversized conveyances.

The Texas Transportation Institute tested the use of underground detention tanks for reducing TSS and associated pollutants from highway runoff (Texas Research Institute, 2007, 2008). They assessed factors that affect sedimentation efficiency and resuspension, primarily outlet type and location. They also conducted pilot testing of low-cost pre fabricated concrete vaults for use in UU environments. Major findings of the study were:

- Underground detention can provide satisfactory sediment removal of about 75 percent. Resuspension was found to be a significant problem that limits sedimentation efficiency. Caltrans (2004) also noted that resuspension was primarily a problem in small underground vaults. One possible approach to alleviate resuspension issues in smaller systems is the use of inlet controller that bypass flows above some rate or when the vault is full. Other options could include the use of baffles in the vault to limit velocities near settled materials.
- Skimmer outlets resulted in better removals than traditional outlets but the researchers expressed concerns about long term maintenance of the moving and flexible components of outlet structure.

- Batch operation with a detention period of three hours was found to diminish the problems of resuspension and to improve removal efficiency to greater than 80 percent. Standard outlet designs worked well in conjunction with batch operation. One of the factors for improved performance could be that batch systems typically would be designed to by-pass flows when vaults are full. Batch operations do require a smart controller, which must be maintained.

Vendors have developed prefabricated underground detention vaults that are traffic rated and have modular designs for variable sizing. Some vendors have added baffles, screens, and energy dissipaters to reduce resuspension, and oil absorption mats to promote removal of oils and hydrocarbons. A number of reports document performance testing of proprietary systems by independent testing organizations and vendor sponsored testing projects. Several studies report very good removal performance for sediments and particulate bound pollutants (e.g. Wright Water, 2002; Fassman, 2006; NJCAT, 2007).

The available literature suggests underground detention vaults are suitable BMP options for UU environments. They can potentially provide high levels of treatment performance for sediment and associated pollutants.

Wet Ponds and Constructed Wetlands

Caltrans (2005) investigated the use of a wet basin in a highway retrofit pilot study. They found excellent treatment performance for both dry and wet weather flows. However, siting was a problem because it was difficult to locate areas with sustained base flow, which is common in the arid southwest. There were also questions and concerns about the area requirements, long term maintenance costs, and vector control issues. Wet ponds, like surface detention basins, will be most applicable in UU environments when drainage can be diverted to nearby pervious areas. It is expected that in UU environments finding locations for wet ponds or wetlands will be very limited due to space constraints as well as typically limited base flow. However, in some cases there may be upstream base flows that could be incorporated into linear wet pond or wetland channels.

The Center for Transportation and environment has sponsored ongoing research on the water quality benefits of linear wetlands in North Carolina and to access retrofit approaches for improving treatment performance (http://itre.ncsu.edu/CTE/Research/project.asp?ID=165). The study is also accessing retrofit opportunities using detention/retention in highway interchanges. The report is due in June 2009.

Proprietary Underground BMPs

Much of the BMP research for UU environments has focused on the development, design, and evaluation of small-footprint underground proprietary systems. Underground proprietary BMPs have been divided into four general categories (Brueske, 2000): 1) gravity separation system (in essence a vault system as described above); 2) swirl concentration separators (vortex separators); 3) screening technologies; and 4) filtration technologies. In additions some systems are combinations of the above, for example Aquishield manufactures a system that combines a swirl concentration separator with a media filtration system.

Charbeneau et al. (2004) found through analysis of field studies submitted by the BMP manufacturers that one configuration does not provide better removal efficiencies over another one. The TSS removal efficiencies ranged from about 0 to 98 percent for all BMP products analyzed, and was found to be more a function of the size rather than configuration of the BMP. This is consistent with the effectiveness evaluations on grit chambers which found that effectiveness is greatly influenced by retention time and thus volume of BMP.

In an interesting field study Roseen et al. (2006) conducted parallel field performance testing of proprietary and traditional BMPs for treatment of parking lot runoff. Runoff was collected and evenly distributed to the treatment BMPs, which provided uniform influent loadings. Performance of 12 treatment strategies was compared, including two conventional BMPs (a rip-rap swale and retention pond), three low impact development devices (surface sand filter, bioretention system, and subsurface gravel wetland), and six manufactured devices (four vortex separators, a stormwater media filter, and a subsurface infiltration device). The BMPs were uniformly sized for 90 percent volume capture, thereby allowing for direct comparison of treatment performance. The best treatment performance was obtained with the LID devices (gravel wetland and bioretention systems) and the wet pond. The rock swale and sand filter performed poorly. The manufactured proprietary devices exhibited a range in treatment performance. The infiltration system had the best performance, and the "hydrodynamic separator was routinely one of the poorest performers." The media filtration had "midrange" performance, and was the best performer of the non storage systems.

A more rigorous approach for evaluating the effectiveness of underground proprietary systems was recently developed by Wilson et al. (2007). In this work controlled field testing was conducted to quantify the sediment removal capabilities of four different proprietary units (2 gravity separation and 2 swirl concentration systems). The experiments utilized predetermined discharge rates and synthetic particle size distributions. Performance curves were developed that relate the sediment removal efficiency to the Peclet number, which in turn depends on the flow rate, the particle diameter, and a hydraulic length scale of the device. It was found that the many of the devices tested approach a plateau in removal efficiency at Peclet numbers of about 3, where further increases in the size of the device have a negligible impact on performance. The performance curves can in principle be used to predict performance of proprietary systems for design and sizing of the structures in UU settings. However, further studies need to be conducted to verify of the predictive capabilities of the performance curves in actual field installations.

In similar work, Gulliver et al.(2009) recently described a number scaling relationships that can be used to relate various types of manufactured BMPs. Scaling laws were proposed for head loss, settling, scour and filtration. The scaling laws are intended to help with selection and design of manufactured BMPs, though have not yet been applied through experimental testing.

Oil Grit Chambers and Baffled Tanks

Oil-water or oil-grit separators are designed to remove gross pollutants and solids and petroleum hydrocarbons. They typically have multiple chambers separated by baffles that promote sedimentation and trapping of floatable materials including oils and grease.

Oil-water separators have been frequently used to treat highway runoff. They are suited for retrofits in UU environments because they have small footprints, they are typically located underground, and they can usually be integrated with existing drainage facilities. The storage volume in oil-water separation is generally much smaller than in underground detention facilities.

Monitoring studies have shown moderate to poor treatment performance of oil-water separators. The USGS (2002) conducted a performance evaluation of grit chambers for removing sediment and PAHs from an UU highway in Boston. Measured load reductions were low, in the range of 30 to 35 percent. The poor treatment performance was attributed to short retention time in the chambers. Schueler (2000) also concluded that oil-grit chambers generally provide poor treatment performance due to short retention times. Yu and Stopinski (2001) found similar performance in field evaluations of three proprietary oil-grit separators. TSS removal efficiency was found to be below the manufactures performance data, but better efficiency was found for units that were oversized for the flows provided. Thus higher retention type apparently resulted in improved performance. WERF (2005) notes that treatment performance of oil-water separators also depends on the treatability of the incoming particulates (settling velocities), pollutant loading rates and maintenance frequency. Maintenance is typically performed with a vector truck and is suggested up to two times per year.

The Caltrans retrofit study (2004) evaluated the performance of oil-water separations for reducing concentrations of petroleum hydrocarbons in runoff from highway maintenance facilities. They found that runoff concentrations of free oil were not sufficiently high to warrant use of oil-water separators and that other technologies provided better removals for oils and other constituents. Oil water separators may be more valuable as a spill protection measure (i.e. broken crank case or larger oil spills) where appropriate.

Literature information indicates that oil-grit separators are suitable for retrofits in UU environments in terms of space requirements, acceptability, and hydraulic functions. Performance information suggests they may be most suitable as a part of treatment train rather than stand alone treatment, or where some spill protection is appropriate.

Swirl Concentration and Screening System

Hydrodynamic separators and continuous deflection systems (CDS) primarily rely on swirl action and particle settling to remove pollutants. CDS systems additionally include screens. Hydrodynamic separators are primarily effective at removing coarse particulates and gross solids, and generally have limited effectiveness for dissolved pollutants and fine particulates (USEPA, 1999; Roseen et al., 2006; Kim and Sansalone, 2008). Some include oil adsorbent materials to target removal of oil and grease. These systems typically have small footprints and can be readily installed underground. Several models are certified by various testing organizations and approved for use by DOTs. Other DOTs do not allow their use

The Caltrans retrofit study (2004) found that CDS units performed well at removing gross solids (trash and debris) from runoff, which was the principal target constituent of the study. They also effectively removed coarse sediments. The study found that the majority of the gross solids were comprised of vegetative debris, even though the facilities were located in elevated freeway sections. They speculate that the facilities could have excessive maintenance requirements in areas with more vegetation. They also expressed concerns about vector problems from standing water in the units. Others have noted issues with bacteria growth within these wet systems with typically little to no base flow.

Massachusetts Highway also evaluated the use of hydrodynamic separators in conjunction with studies performed with the USGS (Barbaro and Kurison, 2005). They provide recommendations for evaluating the performance of hydrodynamic separators. They suggest hydrodynamic separators do not provide effective treatment for dissolved constituents, but are appropriate for retrofit applications where sand is the target contaminant and where the operator has adequate maintenance capabilities.

Stormwater Media Filters

Stormwater media filters are passive flow-through filtration systems that trap particulates and remove pollutants such as metals, nutrients, and hydrocarbons. There are a variety of proprietary systems available. The StormScreen system manufactured by Contech, and the CDS Media Filtration System manufactured by CDS technologies are examples of commercially available systems. Media filtration units are typically two-stage systems. Sediments and gross solids are trapped in a vault or pretreatment chamber followed by flow through a cartridge that contains sand or adsorptive media. Commonly used media are sand, engineered media, peat, zeolite, perlite and compost.

There are many independent field verification studies that have documented moderate to good treatment performance of media filtration systems, particularly for particulate bound constituents (e.g. NSF, 2004; Minton 2004; Roseen et al., 2006). Other studies have demonstrated less effective performance, notably the Caltrans retrofit study (2004). This study concluded that StormFilters did not result in a statistically significant reduction for many pollutants, and that life cycle costs were higher than the Austin sand filter. For these reasons Caltrans determined that StromFilters are not a preferable technology for Caltrans facilities. However, a number of state environmental agencies have tested and verified good treatment performance of media filtration systems. Media filtration systems have received certification by New Jersey Department of Environmental Protection, the Environmental Technology Verification program for the Stormfilter using perlite media, the Massachusetts Stormwater Evaluation Project, and general use designations from the Washington State Department of Ecology under its TAPE certification protocols.

Proprietary media filtration systems have also been configured as highly compact systems within precast catch basins or adjacent to existing catch basins. Examples include the catch basin StormFilters, UpFlo filter systems, and the Filterra bioretention system. Field verification studies have found good treatment performance with these types of catch basin filtration systems (Pitt and Khambhammettu, 2006; Yu and Stanford, 2007). Claytor and Schueler (1996) state that stormwater filters have their greatest applicability for small development sites, and can generally provide reliable rates of pollutant removal if design improvement are made and regular maintenance is performed. They further note that stormwater filters appear to have particular utility in treating runoff from urban "hotspot" source areas. Thus, catch basin and compact filtration systems are potentially viable for UU retrofits to the extent that these systems can be integrated with existing drainage infrastructure.

Researchers and venders have studied the design, selection, and optimization of media type and composition in stormwater filtration systems. Studies have examined media size on hydraulic performance (Hatt et al., 2008) and media type on pollutant removals (Woelkers et al. 2006) . Researchers have tailored media to target treatment for specific pollutants such as metals (Farm, 2002), phosphorus (Ryan, 2008), and organics (Milesi et al., 2006). Geosyntec together with Bob Pitt, University of Alabama and Shirley Clark, Pennsylvania State University are involved with ongoing research to evaluate the hydraulic and treatment effectiveness of alternative media types in bioretention facilities, particularly targeted at heavy metals (copper and zinc) and dioxin.

Catch Basin Inserts and Catch Basin Retrofit

There a large number of proprietary low-cost catch basin inserts with a wide variety of designs. Many target removal of gross solids and particulates with the use of coarse screens and sediment traps. Some include oil-adsorbent media to target removal of oil & grease.

The Caltrans retrofit study (2004) evaluated two types of catch basin inserts that were selected on the basis of water quality improvement potential. They found poor treatment and hydraulic performance for both types. A major issue was clogging at the start of the storm. This posed safety concerns due to surface ponding that was not considered allowable for unattended operation. Caltrans concluded that inserts are not appropriate for roadside use due to frequent maintenance needs and safety concerns. Several respondents to the DOT survey noted similar findings with inserts.

The Caltrans study also noted that there is a wide variety of inserts on the market which were not evaluated and are potentially feasible for specific applications, or may be suitable for other highway facilities such as maintenance facilities or park-and-ride lots. Many devices include flow bypass elements that could help to alleviate safety concerns. A number of devices have undergone independent testing and some received high ratings (Massachusetts Stormwater Evaluation Project) and use approval from local jurisdictions.

Vegetated BMPs

Biofiltration Swales and Filter Strips

Studies have shown that vegetated roadside buffers and conveyances can provide significant water quality benefit, particularly for sediment and total metals (Barrett et al., 1997, 1998; Walsh et al., 1998; Lantin and Alderete, 2002; Kearfott et al., 2005). Significant benefits are obtained with filter strip widths of 4 m, and performance is affected by vegetation density and height.

Biesboer and Elfering (2003) found that retrofitting existing roadside ditches with check dams to create retention areas provided significant water quality benefits. While useful and effective along rural highways, such retrofit approaches may have limited applications in highly UU highway environments. In areas where vegetated surfaces conveyances are present, such practices may provide a simple, low cost and effective retrofitting approach. (i.e. enhancing their effectiveness by re-grading, soil amendments, berms, etc.). In some cases existing vegetated conveyance systems may in fact be providing the water quality benefits desired.

The Caltrans retrofit study (2004) evaluated swales and filter strips in highway retrofit applications. They found swales and filter strips were among the least expensive devices evaluated and among the best performers in reducing sediment and heavy metals. Treatment performance for nutrients was poorer than literature data, which was attributed to the leaching of phosphorus from salt grass. They recommend use of native drought resistant vegetation and additional research on the effect of sizing and vegetation type on performance. They note that swales and strips can be conveniently located in vegetated shoulders and drainage channels, but that siting in highly urban areas may be difficult.

Sand Filters

The Caltrans retrofit study (2004) observed very good performance with the Austin and Delaware sand filters for particulate bound and dissolved phase constituents. They found that maintenance to alleviate clogging was not excessive and that siting requirements are compatible with small impervious watersheds. The multi-chambered treatment train (MCTT) developed by Bob Pitt for retrofitting stormwater hotspots, had performance similar to the Delaware filter but life cycle costs were higher. Also the Delaware and MCTT filters both have permanent pools that presented vector concerns (note: the permanent pool could potentially be eliminated if slow draining underdrains or infiltration could be included). All three filter types are considered technically feasible for retrofits, but the Austin filter has advantages of lower cost and no permanent pool. The Delaware filter has a longer and narrower footprint, which may be more suitable to UU environments; however space requirements are generally high.

Caltrans (2004) notes that maintenance and operation of pumps was a recurring problem at sites with insufficient hydraulic head. Similarly, Roseen (2006) found poor performance of sand filters, which was related to installation and maintenance issues. One of the DOT survey respondents noted that sand filters can promote mosquito breeding and that maintenance costs can be high. Collectively, the literature information indicates sand filters can achieve moderate to good treatment and are applicable to UU retrofits. A main opereatal issue is clogging of the surface layer by sediment, which can lead to rapid failure and significant maintenance requirements. Proper design and maintenance are crucial for ongoing treatment performance. Detailed design and maintenance considerations are discussed by Claytor and Schueler (1996) and Urbonas (2002).

Infiltration Systems

Infiltration basins and trenches are attractive from the perspective that discharge to surface receiving waters are greatly reduced or eliminated entirely. Caltrans (2004) states that infiltration is a challenging technology with the main issues and constraints being: 1) locating appropriate soils; 2) concerns about potential risks to groundwater; and 3) failure due to clogging. The Center for Watershed Protection (2007) notes that infiltration is generally not suitable for UU environments as compaction can greatly affect infiltration capacity. Similarly Caltrans (2004) states that siting these devices under marginal soil and subsurface conditions entail a substantial risk of early failure. Finally, UU areas are likely to have other underground infrastructure that could be impacted and/or contaminated soil and/or groundwater conditions that infiltration could negatively impact. Where it can be safely and environmentally done, infiltration can be one of the most effective BMPs.

Porous Pavement

There are several categories of porous pavements including porous asphalt, porous concrete, and various types of permeable pavers. Porous pavements are most commonly used in lower traffic areas, such as parking lots and low traffic streets. In highway environments, porous pavements have been tested for use along shoulders, and as porous overlays and to reduce splash and hydroplaning and improve safety (see below). Although studies have demonstrated significant water quality benefits, porous pavement is not commonly used as standalone water quality BMPs. Potential DOT concerns include:

- Unknown water quality benefits;
- Concerns about clogging;
- Long-term durability and effectiveness; and
- Cost and maintenance requirements.

Water Quality Performance

The literature includes a number studies that report significant water quality benefits of porous pavements, particularly for reduction in sediment and particulate bound pollutant and for runoff volume reduction. WSDOT (1997) found that porous asphalt used for shoulder pavement reduced runoff volume by 85 percent for typical storms. Correspondingly, solids loadings were reduced by 90 percent or more. Pollutants associated with solids had the overall greatest reductions. Gunderson (2008) conducted a 4-year monitoring study of porous asphalt parking lots and found substantial removal of sediment and associated pollutants. Hunt and Collins (2008) summarize extensive research on permeable pavers and asphalt. Their research findings are consistent with other researchers showing that permeable pavement provide significant runoff volume reduction and removals of sediments and associated constituents. Literature on the water quality benefits of permeable pavement overlays are discussed below. In some cases, evapotranspiration of runoff that is held within the pavement or sub-base has been found to be a major portion of the volume losses found.

Permeable Friction Course

A porous asphalt overlay is course aggregate porous asphalt that is placed on top of impervious roadways such as concrete or conventional asphalt base. Porous asphalt overlays are also referred to as permeable friction course (PFC) or open-graded friction course. Stanard et al. (2008) report that many DOTs use or are testing PFCs, primarily in the western and southern states. PFCs improves highway safety in wet conditions and reduces highway noise, but PFC requires more maintenance, costs more to install, and usually has a shorter service life than conventional pavement (Stanard et al., 2008).

Studies have assessed the water quality benefits of PFCs and a good recent literature review in provided in the report by Stanard et al. (2008). Kearfott et al. (2005) found that water quality improvement with PFC was on the same order or better than vegetated filter strips. Ongoing studies of water quality benefits are reported by Caltrans (2008a).

Barrett (2006) monitored the water quality of highway runoff from a PFC on an Austin highway with a AADT of 38,000. Comparing the water quality from before and after the installation of PFC, Barrett found that the PFC significantly reduced the concentration of TSS and pollutants that are associated with particulates, but had little effect on the concentration of dissolved constituents. The test lasted more than one year, but long-term performance data are needed.

Results of a follow-on study are reported by Stanard et al. (2008). They continued to monitor the PFC site in Austin and additionally installed a second monitoring site with side by side monitoring PAO and non-PAO shoulder areas. Runoff monitoring of the original PFC site continued to show reductions in sediments and sediments associated pollutants up to 4 years after initial installation. Monitoring of the second side-by-side site similarly showed that runoff from the PFC had an order magnitude reduction in TSS concentration, significant reductions in other particulate bound pollutants, and no reduction in dissolved constituents. Interestingly, the study revealed clogging to be less of a problem than anticipated because vehicle spray provides a cleansing mechanism.

As mentioned above, the Stanard et al. (2008) report includes a comprehensive literature review. The water quality monitoring results from the Austin highway studies are generally consistent with other studies in the US, Europe, and Israel that included a range of highway and climate conditions. Table 1 below is a summary of literature data compiled by Stanard et al. (2008).

Table 1: Summary of highway runoff monitoring data reported by Stanard et al. (2008)

Pollutant Concentration Range	*Impervious Pavement*	*Porous Asphalt Overlay*
Total Suspended Solids (mg/L)	46 - 354	2 - 70
Nitrogen, Kjeldahl, Total (mg/L)	1.4 - 3.0	0.3 - 2.3
Chemical Oxygen Demand (mg/L)	80 - 149	16 - 80
Hydrocarbons, Total (mg/L)	1.2 - 3.2	0.09 - 1.7
Copper, Total (μg/L)	16 - 163	6 - 107
Lead, Total (μg/L)	< 2 - 106	< 1 - 22
Zinc, Total (μg/L)	190 - 493	18 - 133
Cadmium, Total (μg/L)	< 0.1 - 0.9	< 0.1 - 0.28

Studies on the effect of PFCs on runoff hydrographs were also reviewed by Stanard et al. (2008). Studies have shown that PFCs reduce the runoff response time (time between the start of rainfall and runoff) by up to a factor of 2. PFCs were also found to reduce peak flows and extend the duration of flows. Mixed results were found on the effect of PFCs on total runoff volume - both increases and decreases have been reported. Increases in runoff volume were attributed to the decrease of water spray resulting in less evaporation and wind losses. However, it can also be difficult to determine exact tributary areas for the sizes of catchments that are typically monitored (0.3 to 2 acres), so it is possible that observations are indicative of the uncertainty in watershed tributary areas.

Cold Climate Performance

Gunderson (2008) describes research findings on the performance of pervious asphalt in cold climates. He states that a common perception is that cold weather diminishes the performance of porous asphalt due to permeability reduction from freezing and that the material is not durable enough to withstand freeze-thaw conditions. Findings from their 4-year monitoring study of a pervious asphalt parking lot at the University of New Hampshire are contrary to the common perceptions of cold weather performance. Measured infiltration rates were consistently higher in the winter. They found that because of the high permeability, the pores were readily drained during thaw periods and thus remained open during freezing periods. The higher infiltration capacity during the cold months was attributed to the swelling of the asphalt binder during the hot summer months. They also found that the porous asphalt required less salting for snow and ice control than nearby nonporous asphalt. Although the study does not have longer term durability data (longer than 4 years), the author states that design criteria and construction practices are important considerations for durability and performance. Porous asphalt parking lots that incorporate significant pavement depth will have a longer life cycle from reduced freeze-thaw susceptibility and greater load-bearing capacity than conventional parking lot pavements.

Gunderson (2008) also describes work that has been initiated on the performance assessment of pervious concrete in cold weather climates. No data were reported, but there is considerable discussion on the importance of design criteria and construction practices for cold weather climates. Schaefer et al. (2006) published a report on the development of mix designs for pervious concrete in cold weather climates. They concluded that Portland cement pervious concrete (PCPC) made with single-sized aggregate has high permeability but not adequate strength. Adding a small percent of sand to the mix improves its strength and freeze-thaw resistance, but lowers its permeability. Gunderson (2008), however, pointed out that the void content in pervious concrete installations is so high that it is possible to add fines into the mix without affecting infiltration rates. Schaefer et al. (2006) found that the freeze-thaw resistance of PCPC mixes with a small percentage of sand showed 2% mass loss after 300 cycles of freeze-thaw. Gunderson (2008) similarly states that the most significant factor in the durability of porous asphalt is the rate of cycling between freeze and thaw, which is highest near the coast.

Long-term effectiveness and clogging potential

Clogging and long-term effectiveness of porous pavements are significant concerns. WSDOT (1997) found no reduction in infiltration capacity in only one year of monitoring. Similarly Barrett (2006) and Stanard et al. (2008) did not observe significant decrease in performance of PFCs after more than four years of monitoring. They indicate that the longevity of water quality performance has not yet been established and that reductions are expected over time. Gunderson (2008) states that clogging potential can be reduced through regular maintenance (sweeping) conducted 2 to 4 times per year. He also states that clogging potential can be reduced through appropriate selection of a binder mixtures to minimize binder draindown.

Collectively, the literature information suggests that porous pavements, including porous overlays, are potentially suitable for use in UU highway environments because they do not utilize additional surface area and because available performance information indicates promising and significant water quality benefits. Porous pavement is likely most suitable as part of treatment train, given the lack of longer term performance and durability data and because it is not commonly accepted as a standalone BMP.

Low Impact Development

Low impact development (LID) is a stormwater management approach that uses on-site tools and systems to result in surface hydrology that is similar to the pre-development conditions. The degree to which pre-development surface hydrology can be attained will be largely controlled by the ability to infiltrate runoff into the subsurface, augmented by the potential for evapotranspiration. In UU situations it is highly unlikely that pre-development evapotranspiration rates can be matched, so the choice becomes whether to have runoff more than natural or deeper infiltration. Water balance considerations need to be assessed in making decisions regarding LID approaches. LID also includes the use of bioretention systems with underdrains where infiltration conditions are difficult. In this case, the hydrographs will be dampened, but the runoff volumes will not be reduced nearly as significantly as when infiltration is possible.

Guo and Cheng (2008) present an on-site metric to relate the required incremental storm water retention volume to the alteration of surface imperviousness. In UU areas, the baseline is not 0% impervious, but already developed, imperviousness >0%. By using the change in imperviousness as the index, this metric assesses incremental runoff volume and suggests the retrofit storm water storage.

Harvest and Use Stormwater

Some MS4 permits are now including stormwater harvesting and use on site requirements for new/re-development. Such MS4 requirements may eventually find their way into DOT permits for re-construction of highways in UU areas. Three respondents to our DOT survey indicated the use of cisterns and reuse BMPs in UU environments.

Stormwater harvesting and use is a general description referring to the capture and storage of runoff and subsequent use of that water. Such a system could take a variety of forms. In the case of UU environments, the typical storage component consists of some form of an enclosed tank or “cistern” that accepts runoff from storm drains. Some level of treatment (e.g. screening, filtration, etc.) is typically required upstream of the cistern to prevent the introduction of debris into the system. In addition, some form of treatment would be required, depending on the planned use. The effectiveness of harvest and use systems primarily depends on the ability to identify sufficient demand for use captured runoff within a short time period following storm events. Potential use demands in residential neighborhoods are generally limited to irrigation of lawns and landscaped areas and/or to meet non-potable demands in homes such as toilet/urinal flushing (USEPA, 2008). However, captured stormwater has been used for toilet flushing on a pilot test basis and increasingly as part of LEEDs projects. In UU highway environments use would likely be limited to landscaping irrigation within the ROW. These areas are likely not sufficient to draw down the cistern fast enough to allow capture of subsequent storm events. It is likely that offsite use in adjacent areas would need to be identified, such as landscape or golf course irrigation or non-potable water supply or perhaps a process use of some type.

Hydraulic Head Requirements

Landphair et al. (2001) extensively discuss hydraulic head requirements for proprietary BMPs in retrofit situations and note the limitations imposed by these requirements, particularly in flat terrains. The Caltrans retrofit study (2004) found recurring problems with the maintenance and operation of pumps associated with proprietary sand filters. Their findings would be applicable to other BMP types that require pumping. They recommended that other technologies should be considered at sites with insufficient hydraulic head for operation of media filters and sand filters.

2.2.3 Cost Data

Capital and maintenance costs are critical evaluation criteria for BMP retrofits, particularly in UU environments where costs can be quite high. The Center for Watershed Protection (2007) recently compiled cost data from 100 retrofit projects and provides guidance for estimating construction costs. The data reflect all types of retrofits projects and they note cost data for highway retrofits are fairly sparse. Summary results from this work are shown in the following figure.

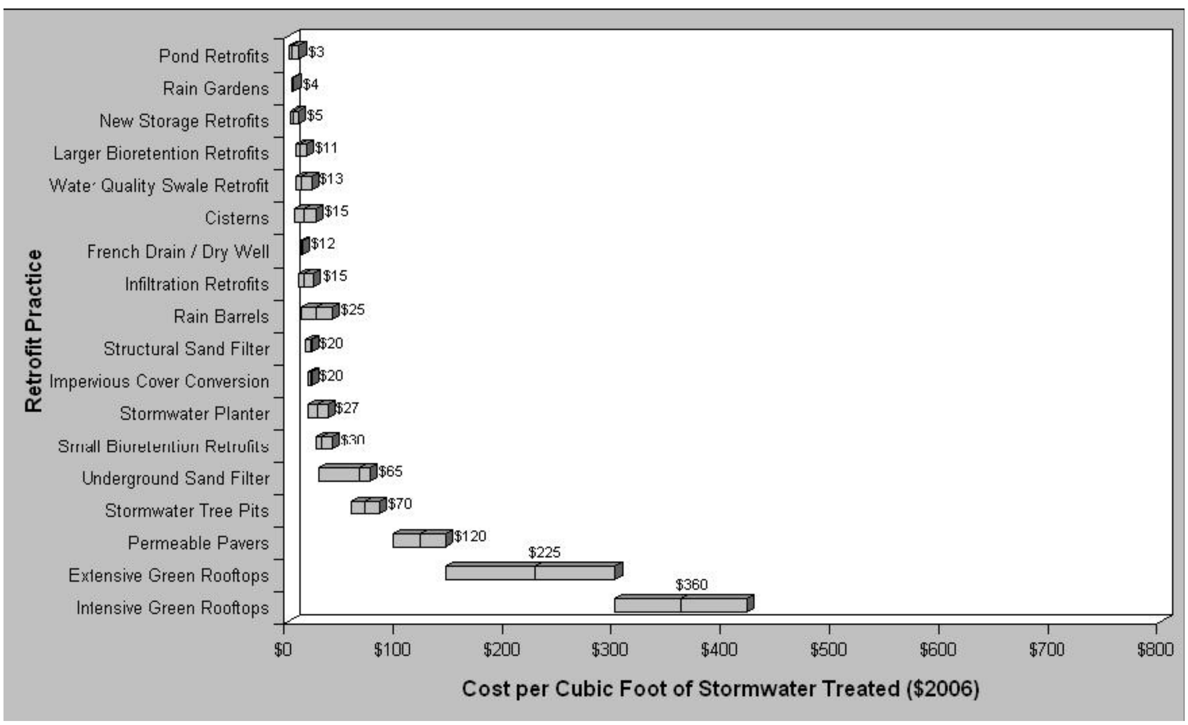


Figure 1: Range of base construction costs for various retrofit options.
(Note: Boxes show 25% and 75% quartiles; the line represents the median)

The Caltrans retrofit study (2004) included detailed accounting of capital and maintenance costs which were also subjected to independent third party review. These are likely among the most comprehensive cost data for highway WQ retrofits. The final report notes that there is uncertainty about how well the cost data may reflect actual costs in a large scale retrofit program due to the pilot-specific nature of some of the costs and the lack of standard competitive bidding. They also state that cost data may not reflect costs in other locations. Despite these qualifications, the data are quite detailed and comprehensive, and provide a means for comparing and ranking costs associated with various BMP technologies in retrofit situations. Summary results from the Caltrans report are shown in Table 2 below.

Table 2: Retrofit Cost Summaries from the Caltrans Retrofit Study

BMP Type (No. of installations)	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m³ of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m³	Life-Cycle [a] Cost/m³
Wet Basin (1)	$ 448,412	$ 1,731	$ 16,980	$ 452	$ 2,183
Multi-chambered Treatment Train (2)	$ 275,616	$ 1,875	$ 6,410	$ 171	$ 2,046
Oil-Water Separator (1)	$ 128,305	$ 1,970	$ 790	$ 21	$ 1,991
Delaware Sand Filter (1)	$ 230,145	$ 1,912	$ 2,910	$ 78	$ 1,990
Storm-Filter™ (1)	$ 305,355	$ 1,572	$ 7,620	$ 204	$ 1,776
Austin Sand Filter (5)	$ 242,799	$ 1,447	$ 2,910	$ 78	$ 1,525
Biofiltration Swale (6)	$ 57,818	$ 752	$2,750	$ 74	$ 826
Biofiltration Strip (3)	$ 63,037	$ 748	$2,750	$ 74	$ 822
Infiltration Trench (2)	$ 146,154	$ 733	$ 2,660	$ 71	$ 804
Extended Detention Basin (5)	$172,737	$590	$ 3,120	$ 83	$ 673
Infiltration Basin (2)	$ 155,110	$ 369	$ 3,120	$ 81	$ 450
Drain Inlet Insert (6)	$ 370	$ 10	$1,100	$ 29	$ 39

[a] Present value of operation and maintenance unit cost (20 yr @ 4%) plus construction unit cost.

The cost data above are from retrofit projects in many types of highway facilities and do not necessarily reflect costs associated with UU environments, which would be expected to be higher. The report also notes that much of the construction costs were associated with modifications to existing drainage configurations, a problem that would likely be magnified in spaced constrained settings. In general, the construction cost for highway BMP retrofits can be quite high, as much as ten times more expensive that new construction (Currier et al., 2001).

2.2.4 Maintenance Considerations

The FHWA (2002) UU Manual states that maintenance requirements must be carefully planned and implemented when BMPs are located completely below the surface and access is limited to access hole openings or the removal of concrete panels. They note that underground BMPs may be considered confined spaces and require additional measures to ensure safe access for inspection or maintenance. For example for BMP located in areas where traffic must be controlled, maintenance may need to be restricted to off-hours. Due to these potential restrictions or additional measures, BMP technologies that require periodic maintenance on an annual or semiannual basis are often preferred to those requiring more frequent maintenance efforts. Difficulty in performing the maintenance (increased level of effort) increases the cost of the required maintenance.

The Center for Watershed Protection provides the following guidance maintenance considerations in the design stormwater retrofits for UU highways.

- Consult highway maintenance crews to determine how proposed retrofit will influence maintenance routine and adjust design accordingly
- Specify how traffic will be managed to permit access for maintenance.

The Washington state DOT specifically requires consideration of maintenance requirements in the BMP design process. The WSDOT Highway Runoff Manual (2008) requires the design engineer to contact the Region Maintenance Office to discuss treatment options available for use, once the list of permanent stormwater BMPs is determined based on the site assessment. Overall maintenance costs must be considered when selecting BMPs. The project design office must consult with the region maintenance staff regarding the proposed drainage alternatives and evaluate maintenance needs, including personnel, equipment, and long-term costs through the BMP's expected life cycle.

2.3 Retrofitting Highway Facilities for Water Quality

2.3.1 BMP Selection Criteria and Guidance

Systematic BMP selection criteria are detailed in several BMP guidance documents. The FHWA (2002) guidance document provides an overview of BMP selection practices for UU environments including case study descriptions. More comprehensive guidance on BMP evaluation and selection is presented in WERF (2005) based on rigorous unit processes approach combined with observational data. The NCHRP Project 565 Report (2006) similarly uses a unit process based approach for selection of BMP in highway runoff applications. Both of these manuals provide information that is highly relevant for BMP retrofits in UU highway situations.

2.3.2 Guidelines for Stormwater Retrofits Practices

An early research report on retrofit practices was prepared by the USEPA (2000). The focus of this research was on evaluating the feasibility of retrofitting existing storage, conveyance, and flood control facilities to reduce loadings from SSOs, CSOs, and stormwater discharges. The most applicable sections to the current study are case studies describing retrofits of existing detention and flood control facilities. The report concludes that retrofitting existing control facilities can be a cost effective alternative to the construction of new treatment facilities. The appropriateness of retrofitting is a function of site-specific needs and conditions.

Recently the Center for Watershed Protection (CWP) published a comprehensive guidance document on urban stormwater retrofit practices (2007). Although largely focused on watershed restoration goals, this manual includes many recommendations and strategies that are directly applicable to UU highway environments, including sections on identifying retrofit opportunities in highway environments and tips on implementing underground retrofits. The CWP guidance manual includes an 8-step procedure for finding and implementing retrofit projects. The document provides ample fact sheets for locating storage opportunities, for selecting BMP options, and for evaluating the retrofit feasibility. The appendices include: reconnaissance forms and field guide templates; BMP performance data; sizing criteria and procedures; unit cost data and cost estimation equations, and design examples.

Collectively, the WERF (2005), NCHRP (2006), and CWP (2007) guidance documents provide the general framework for retrofitting procedures as follows:

- **Identify Retrofit Objectives**. The objectives are based on receiving water impacts that are to be addressed such as: the impairing pollutants to be treated; geomorphic conditions to be mitigated; or watershed or habitat restoration goals. For DOTs, retrofit objectives may be based on meeting permit requirements, reducing pollutants to meet TMDL or other requirements, or reducing runoff volumes for geomorphic or habitat restoration.
- **Determine the Pollutant Properties and Unit Processes**. The properties of the pollutants of concern include physical, chemical, and biological properties. Based on the pollutants properties, the fundamental unit operations needed to treat these pollutants and to meet the retrofit objectives evaluated (WERF, 2005; NCHRP, 2006). Unit operations include hydrologic operations (e.g. flow attenuation and volume reduction); physical operations (e.g., screening, sedimentation, volatilization); biological operations (e.g. degradation); and chemical operations (e.g. sorption, disinfection).
- **Identify Applicable BMPs**. Based upon the unit operations, identify the appropriate BMP types that should be considered.
- **Sizing Criteria.** Once the BMP type(s) have been selected**,** then BMP sizing options based on rainfall-runoff relationships should be explored. The BMP sizing requirements are used to guide retrofit scoping and to evaluate retrofit opportunities, although in UU retrofit situations space constraints may ultimately dictate BMP sizing. Several different BMP types that include the appropriate unit operations should be considered.
- **Locating BMPs – The Search for Storage and Connections with Existing Drainage Facilities**. Many BMPs require storage as a significant component, either as part of the primary unit operations or to help regulate flow through other unit operations (such as media filters). In retrofit situations the designer must identify candidate sites where the BMP can be located and feasibility connected with the existing drainage infrastructure while simultaneously anticipating potential problems. Depending on the BMP type, the siting requirements may include the need to identify significant storage within the existing environment. Above ground BMP are preferred and are the primary consideration. Tips for locating above ground BMPs in highway environments include (CWP, 2007):
  - Look for storage opportunities in cloverleaf interchanges
  - Look for storage adjacent to approach ramps
  - Modify existing conveyances and treatment facilities
  - Look for opportunities to divert highway drainage to adjacent public lands
  - Target opportunities in highway widening/realignment construction

  Underground retrofits are considered a last resort, suitable only when surface treatment is not feasible.
- **Evaluate Operations and Maintenance Considerations**. O&M are key retrofit considerations for UU highway environments. BMP reliability and maintenance access,

frequency, and cost are all considerations for BMP selection. In general surface BMPs will be easier and less costly to maintain.

- **Economics**. Quantifying the capital and maintenance costs is an essential component of the retrofit process, especially in UU environments where costs are high and DOT funding is limited. The document includes an assessment of capital costs from 100 retrofit projects. Data are used to develop ranges of unit costs and cost estimate equations for various retrofit projects. Some guidance on maintenance costs for selected BMPs is also included.
- **Consider Post-Construction Monitoring and Evaluations.**

2.3.3 DOT Retrofits Practices

Available literature indicates that there is a range of retrofit practices and policies among state DOTs. Retrofit practice development falls into the following three general categories among DOTs:

1. Established Retrofit Program and Requirements. Some DOTs have established stormwater retrofit practices that are well documented and formalized through policy and programmatic procedures. Many other state DOTs simply have policies that require consideration and/or implementation water quality BMPs in conjunction with highway improvement projects.
2. Developing Retrofit Procedures. Based on available literature of public documents available from DOT websites and information provided in our DOT survey, some DOTs have started to address stormwater retrofitting procedures through development and research on retrofit prioritization procedures or through general retrofit guidelines in public documents. These DOTs have not yet developed formal retrofit programs (as described in stormwater manual or management plans) but appear to recognize a need to prepare retrofit procedures and guidance.
3. No Documented Retrofit Information. Many DOTs have not addressed retrofit practices in their stormwater manual, hydraulic design manuals or management plans, particularly in the smaller more rural and Phase II states. This finding is based solely on the lack of easily obtainable information or public documents and does not suggest that the DOTs are not conducting or evaluating retrofit projects and policies.

The accessibility of DOT policy information on retrofit practices is variable. Based on the literature review and our DOT survery, there is considerable range in retrofit practices among DOTs. The following is a cross section of some of the DOT information on retrofit practice that we have reviewed.

WSDOT

The Washington State DOT (WSDOT) has a well advanced stormwater retrofit program. The recent WSDOT Phase I NPDES Permit requires three categories of stormwater retrofits: 1) capital improvements funding for standalone stormwater retrofits; 2) project-triggered stormwater retrofits – required retrofits implemented in conjunction with highway improvement projects; 3) opportunity based retrofits. The Permit also requires a system wide inventory of stormwater facilities and an outfall prioritization process.

WSDOT is currently implementing the system wide inventory of their stormwater facilities (WSDOT, Sept 2008). WSDOT has developed an outfall prioritization scheme (WSDOT, 1996; Barber et al. 1997). The methodology provides a numeric scoring of high priority outfalls based on the following considerations:

- Type and size of receiving water body
- Beneficial uses of receiving water body
- Pollutant loading
- Percentage contribution of highway runoff to watershed
- Cost/pollution benefit
- Values trade-off

The highest priority outfalls are concentrated in urban areas that discharge to small streams. According to the annual stormwater report WSDOT has implemented more than 65 stand-alone stormwater retrofit projects since 1995, inventoried more than 6000 outfalls, and made retrofit recommendations at 555 outfalls (WSDOT, Sept 2008).

To implement the Permit requirements, WSDOT has established programmatic retrofit procedures that are integrated into the Highway Runoff Manual (WSDOT, 2008). The procedures are first used to determine the minimum flow control and treatment control requirements for all new and redevelopment highway projects. Next a retrofit decision flowchart is used if the project triggers stormwater retrofit requirements: 1) if retrofit of existing impervious areas beyond the minimum requirements is cost-effective; or 2) for assessing if project-driven stormwater retrofit obligations can be met off-site by retrofitting an equivalent area of state highway in targeted environmental priority locations.

North Carolina DOT

The NCDOT Phase I Permit requires a stormwater facility inventory, implementation of stand-alone stormwater retrofits, and development of a prioritization process. NCDOT is actively implementing these requirements. NCDOT has constructed 43 stand alone retrofit projects, with another 23 in the planning stages (NCDOT, June 2008). They have implemented a variety of conventional BMPs including dry and wet ponds, bioretention, sand filters, infiltration basins, swales wetlands, and catch basin inserts. They are developing a GIS based prioritization method to identify areas and sites for water quality improvement.

Caltrans

The California Department of Transportation (Caltrans) routinely implements stormwater retrofits in conjunction with major redevelopment projects (Caltrans, 2008). In addition Caltrans implements stand alone stormwater retrofits to comply with NPDES Permit requirements; to comply with court orders or state water resources board orders, or to meet watershed specific requirements (e.g. TMDLs, Lake Tahoe Environmental Improvement Program (EIP), Areas of Special Biological Significance (ASBS), and the California Ocean Plan (COP)).

Caltrans also has an active retrofit pilot test program for evaluating alternative BMPs. The program is designed to study and evaluate all aspects of stormwater retrofits for highway facilities, including design and construction, capital and maintenance costs, treatment effectiveness, and O&M requirements. The program is also used to support BMP certification.

The ongoing program had produced a number of pilot test data report on a wide variety of BMP types.

Hawaii DOT

HDOT is starting to address stormwater retrofits but does not yet have a documented retrofit program. NPDES MS4 Permit conditions require the HDOT to complete a feasibility study for retrofitting existing MS4 discharges to 303(d) listed receiving waters (HDOT, 2009). The main pollutants of concern are sediment, turbidly, and trash. The study appears to be ongoing and a report is not yet available. The objectives of the feasibility study are to identify and evaluate potential pollutant sources from HDOT MS4s, to identify management measures to reduce hydromodification and water quality impacts; to identify retrofit opportunities; and to rank and prioritize source and treatment control BMPs.

Texas DOT

Texas appears to be similar to Hawaii in that it is pursuing and developing retrofitting strategies, but does not appear to have a publically available documented retrofit program. Landphair et al. (2001) prepared a planning level guidance report for the Texas DOT that provides a framework for water quality retrofit practices of Texas highway facilities. The authors evaluated various retrofit practices, retrofit issues, BMP technologies, and BMP retrofit selection processes. Conclusions from their work include:

- Planning and Cost. There will be increasing requirements for water quality retrofits and capital and maintenance costs will be significant, especially in dense urban areas. Planning strategies should be adopted that address water quality facilities in the early stages of the project planning process. Due to the lack of cost data, the researchers recommend an effort to collect long-term cost data for various BMP technologies.
- Siting and Prioritization. In dense urban areas, underground BMPs may be needed, but there are still opportunities for locating BMPs in interchanges and setback areas. These resources should be inventoried. The researchers recommend that Texas test a prioritization scheme presented in the report that is based on the WSDOT procedures.
- BMP technologies. BMP selection should focus on use of simple surface facilities and limit use of underground proprietary systems. In flat terrains, hydraulic head requirements are major constraint of proprietary systems; more information is needed from manufacturers about head requirement. They recommended research into BMP effectiveness and development of small footprint BMP technologies using precast units. Research is also recommended into hydraulic head performance of selected BMP technologies.

2.3.4 Retrofit Case Studies and Lessons Learned

Lessons learned from the California BMP retrofit study are discussed by Currier and Moeller (2000) and Currier et al. (2001). This program has evaluated the effectiveness of a wide range of BMPs types that are installed as retrofits in highway settings. The program includes cost information, performance monitoring data, and information about maintenance practices. The authors found that siting and design are the most critical phases of the retrofit process. Broad and early coordination with regulators, local officials and personnel familiar with the site can benefit the later project stages. Specific lessons include the following:

- Regulatory. Identify local and regional permit requirements that could impact construction. Consider construction and maintenance impacts on sensitive species and coordinate with Fish and Wildlife. Coordination in the early planning stages will help to identify constraints and establish construction and maintenance schedules.
- Siting. Coordinate with local inspectors, maintenance workers, and public works officials during retrofit scoping. Coordination can help to identify unmapped utilities and constraints. Setback requirements for safety must be considered during scoping. There is a limited amount of suitable and available surplus area within the right-of-way owned by Caltrans. Existing drainage patterns were also significant siting constraint.
- Design. Coordinate construction with other planned construction activities. This can save costs and help to get more bids for smaller jobs. Coordination can also expand the scope of the retrofit by including larger drainage areas. Designs should address maintenance access.
- Unknown Field Conditions and Utility Conflicts. This was one of the most significant construction and cost issues. One or two exploratory borings were conducted at each site, but in many cases unsuitable materials, buried manmade objects, undocumented utilities, and hazardous materials were encountered. When a thorough site investigation cannot be performed, a preliminary excavation (pot holing) should be conducted prior excavation to confirm accuracy of as-builts and to discover items that may need relocation. This can save costly change orders. If below ground issues are discovered, then costs can significantly increase due to re-design and/or removal of the contamination or infrastructure. Therefore a thorough site investigation is highly recommended.
- Vital Operations. Work orders should include provisions to allow vital operations on site to continue. This can help to identify vital operations in the design stages and to reduce the need for change orders.
- BMP specifications. Order materials with long lead times as soon as possible, and check availability. Check and confirm specifications of ordered product. Include material quality specifications with orders; e.g. vegetation conditions.
- Flexibility. Avoid pre-cast units in cases when there are tight tolerances because as-built maps can be inaccurate. Cast in-place features allow for adjustments that may be needed to match actual field conditions or changes due to construction.
- Vectors. BMPs designs should consider and avoid standing water that may promote mosquito breeding. Energy dissipaters and flow spreaders were found to be effective mosquito incubators.
- Construction. Manufacturer installation instructions should be viewed as guidelines and followed, otherwise poor performance can result. Quality control during surveying and construction is critical and can help to avoid subsequent adjustments. Allow for time contingency to address unforeseen problems.
- Construction Cost. Construction costs were relatively high, and were affected by issues such as traffic control, limited work space, conflicts with existing improvements, unsuitable soils, and unknown buried manmade objects. Retrofit costs for some devices

may be as high as ten times that of the same device constructed as a part of new construction.

3 Survey of Current DOT Practices

3.1 Approach

Geosyntec prepared an initial draft of the DOT survey form and distributed the form to team members for review and input. A revised draft survey form was then distributed to the Panel for review and comment. A principal concern of panel reviewers was that draft survey form was awkward and burdensome. In response to panel comments and suggestions we simplified and shortened the survey form. We also developed an on-line survey form in an effort to promote response rate.

With the assistance of panel members, the survey form was distributed to environmental personnel in all 50 state DOTs. Marie Venner distributed the surveys and conducted telephone follow-ups.

3.2 Summary Results

The DOT survey had 55 respondents representing 39 state DOTs, the Washington DC DOT, and the USEPA.

The vast majority of respondents (89%) stated that UU stormwater retrofit is a concern for their DOT. Some noted that this is an important and emerging issue that will receive increasing attention. The EPA representative noted the it is “important for State DOTs to get ahead of the MS4 permit movement toward precise, enforceable and sometimes numeric permit conditions, as well as trend to a hydromod based approach overall, even for linear systems.”

The top three listed issues for BMP implementation in UU environments were BMP maintenance requirements, construction cost, and maintenance cost. The least important listed issues were aesthetics, subsurface impacts, and vehicle traversability.

Many respondents provided comments on lessons learned about BMP implementation in UU areas (see attachment). Comments generally reflected rankings above. Maintenance requirements and access were often mentioned as the biggest issues, with cost and space constraints also a frequent topic. Several respondents noted the importance of coordination during project planning.

The most commonly reported BMPs used in UU environments are surface detention, swales, oil/water separators, and hydrodynamic devices. Use of underground BMPs was report by about 40-60% or respondents. The least used BMPs were cisterns (harvest and use) and porous pavement.

About half the state DOT responding indicated that water quality retrofits are not currently required, while some states indicated that retrofits are required only in conjunction with redevelopment. The most common regulatory drivers for retrofits are NPDES permit requirements and TMDL compliance.

6 of 34 state DOTs (18%) have prepared stormwater retrofit policies or guidance, and 11 of 32 state DOTs (39%) indicated they have conducted stormwater retrofits. Several respondents provided feedback on lessons learned from retrofit projects. Several noted that retrofit in UU highway environments is a difficult and costly undertaking. Several noted the need to for planning (streamlining prioritization) and coordination with local municipalities, regulators, and construction oversight.

The most common issues for cold climates were BMP performance and treatment of cold weather pollutants of concern (deicers).

3.3 Detailed Results

Question-by-question responses are detailed below and a summary of state DOT responses is provided in Attachment 1

Question 1: Please provide your name, organization, and title.

There were total 55 responses. Seven respondents did not provide identifying information, however, in three cases the representing organization was inferred from subsequent questions. Four responses did not include any information identifying the state representation. The survey participants are listed below in order of response.

ID	Name	Organization
1	John Taylor	Mississippi State DOT
2	NP	Washington DC DOT *
3	Stephen D. Kindy	Virginia State DOT
4	Paul A. Lambert	California State DOT
5	Larry Schaffner	Washington State DOT
6	Vince Davis	Delaware State DOT
7	Ronald Chlopek	Illinois State DOT
8	Mark Masteller	Iowa State DOT
9	NP	Oregon DOT *
10	NP	Oregon DOT *
11	Peter Newkirk	Maine DOT
12	Daniel C. Gunther	Oregon DOT
13	Ronald Poe	Nebraska DOT
14	Matthew S Lauffer	North Carolina DOT
15	Parviz Eftekhari	New Mexico DOT
16	Wendy Terlizzi	Arizona DOT
17	Alexis Strauss	USEPA Region 9

ID	Name	Organization
18	Amy Foster	Texas DOT
19	Paul Ferry	Montana DOT
20	Judy Ruszkowski	Michigan DOT
21	Tom Ballestero	University of New Hampshire
22	John Samson	Wyoming DOT
23	Karen Coffman	Maryland DOT
24	David R. Graves	New York DOT
25	Robert Lang	Ohio DOT
26	Stacy J. Hill	Montana DOT
27	Michele Dolan	Oklahoma DOT
28	Bill Ballard	Alaska DOT
29	Michelle Gerrits	Wisconsin DOT
30	John Shill	Alabama DOT
31	Curtis Matsuda	Hawaii DOT
32	Paul Corrente	Connecticut DOT
33	Jeffrey S. MacKay	Consultant to Pennsylvania DOT
34	Rick Renna	Florida DOT
35	NP	NP
36	Denis D. Stuhff	Utah DOT
37	Alvin Shoblom	Oregon DOT
38	NP	NP
39	Paul Frost	Nevada DOT
40	Lotwick I. Reese	Idaho DOT
41	Alfred Gross	Colorado DOT
42	David Ahdout	New Jersey DOT
43	Allison LeBlanc	Rhode Island DOT
44	Dennis Cress	Colorado DOT
45	Walter Buckholts	Colorado DOT
46	NP	NP
47	John Howland	Missouri DOT
48	Stuart Gardner	Colorado DOT
49	Daniel Ham Mark Goodman	Montana DOT
50	Karen Olson	South Dakota DOT
51	NP	NP
52	Brett Troyer	Minnesota DOT
53	NP	Colorado DOT
54	Steven Griffin	Colorado DOT
55	Henry Barbaro	Massachusetts DOT

NP = not provided; * inferred from responses to other questions

Question 2: ULTRA URBAN STORMWATER MANAGEMENT: Ultra urban highway environments are space-constrained highway areas with little right-of-way available for surface facilities. They typically occur in dense urban areas with high traffic volumes.

Is your DOT concerned about stormwater treatment in ultra urban highway environments?

DOT is concerned about WQ treatment in UU environments	No of responses	Percent
Yes	49	89%
No	6	11%

Question 3: ULTRA URBAN BMP SELECTION AND DESIGN: Rate your DOTs concerns about the selection and design of stormwater treatment facilities (BMPs) in ultra urban environments?

This question received 54 responses. The table below shows the number of responses to each category. A score for each BMP selection criteria was calculated by:

$$\%\,score = \frac{\sum(3N_h + 2N_m + 1N_l) \times (54/N_t)}{162}$$

where N_h, N_m, N_l are the number of responses to the high, moderate, and low concern categories, respectively; $N_t = N_h + N_m + N_l$ is the total number of responses; and 162 is the maximum possible score. Based on this scoring we have grouped the selection and design criteria into three categories as shown in the table below: 1) very high concern (shown in red); 2) high concern (green); and 3) moderate concern (blue).

16 respondents provided written comments regarding BMP selection and design, which are provided below. Maintenance and cost were the mostly frequently covered topics, followed by BMP performance, design criteria (GW, pumping), and regulatory compliance.

BMP Selection and Design Criteria	No. of responses	High Concern 3	Moderate Concern 2	Low Concern 1	Weighted Score (%)
Maintenance requirements (frequency, procedures, access)	53	44	9	0	94%
Construction cost	54	44	9	1	93%
Maintenance cost	53	42	11	0	93%
Constructability	53	43	8	2	92%
BMP size and space requirements	54	44	7	3	92%
Reliability, long term performance	54	38	15	1	90%

BMP Selection and Design Criteria	No. of responses	High Concern 3	Moderate Concern 2	Low Concern 1	Weighted Score (%)
Regulatory compliance	53	38	13	2	89%
Ability to incorporate BMP into existing infrastructure	54	36	14	4	86%
Safety	53	33	15	5	84%
Avoidance of stormwater pumping	52	33	13	6	84%
Ability to apply BMP above ground	54	32	18	4	84%
Treatment effectiveness (general or pollutant specific)	53	28	21	4	82%
Ability to apply BMP underground	51	21	26	4	78%
Runoff volume reduction	54	23	24	7	77%
Avoidance of nuisance conditions (e.g., standing water, vectors)	53	20	28	5	76%
Cold climate performance and maintenance	50	20	18	12	72%
Vehicle traversability	52	14	29	9	70%
Hydraulic head requirements	54	18	22	14	69%
Impacts to subsurface (GW quality, moisture content)	53	17	22	14	69%
Public perception/aesthetics	52	10	30	12	65%

Other concerns or considerations for BMP selection and design:

ID	State	Comment	Topic
1	Mississippi	Until our DEQ issues more stringent requirements to meet runoff standards we will continue to rely on our approved structural BMPs	Regulatory
7	Illinois	High water table, political pressures, input from CIGs	Groundwater, policy, coordination
9	Oregon	A primary concern from the design perspective is a mechanism to recoup funds required for the additional maintenance of many of the newer facilities.	Maintenance
10	Oregon	Our Maintenance forces generally are barely funded for activities outside of maintaining stormwater management facilities, so encumbering them with filter vaults and the like is practically cruel and unusual treatment.	Maintenance
11	Maine	Treating off-site runoff that currently drains to our system - the volumes and politics of ownership.	Offsite run-on
14	North Carolina	Value of Stormwater Controls in an Ultra Urban setting. Would DOT controls be effective? What are the relative load from the roads compared with other sources?	BMP effectiveness

ID	State	Comment	Topic
15	New Mexico	Coordination with contractors	Coordination
24	New York	1)Maintenance Agreements with local municipalities, 2) Availability of special soil mixtures, 3) Evaluation of proprietary practices	Maintenance, BMP design and effectiveness
27	Oklahoma	ultra-urban conditions are not really an issue	Regulatory
28	Alaska	AK only has two communities of concern. A bigger issue for AKDOT is BMP and storm water compliance in sub-arctic, arctic conditions and temperate rain forests	Climate
31	unknown	Maintenance (staff resources) is the biggest issue. A lot of these are high priorities because have a consent decree and EMS. They think the bar may be raised the next time around. Permit expires in Sept this year.	Maintenance
32	Connecticut	Extremely high concern: avoidance of pumping	Pumping requirement
36	Utah	Forgiving attributes if a Maintenance Cycle is missed I.E. No back up onto traveled way. The nature of the waste - some BMPs can require costly hazardous waste disposal. Retention/infiltration systems that endanger ground water or weaken pavement subgrade	Maintenance, cost, groundwater
42	New Jersey	Regulatory compliance issues are very high - quality, quantity, and recharge - reliability and LT performance are also. Cost is critical and tough. ROW, maintenance, financial	BMP Performance, regulatory, cost, maintenance
49	Montana	Collection of sanding material on high mountain passes. Bridge deck runoff.	Maintenance
55	Massachusetts	Ease of inspection, proven track record/effectiveness	BMP Performance, maintenance

Question 4: BMP APPLICATIONS: Please indicate which of the following BMP types your DOT has used in ultra urban environments?

This question received 53 responses representing 37 states. The table below shows the number of states that reported they are employing a particular BMP type. Other reported BMPs and lessons learned about BMP applications in UU environments are listed in tables below. All responses by state are shown in Attachment 1.

BMP	Number of States using BMP	Percent of States using BMP
Surface detention (Dry ED/wet/infiltration basins, wetlands)	30	81%
Vegetated/rock swales	29	78%
Hydrodynamic separators	23	62%
Oil/water separators	22	59%
Infiltration trenches	18	49%
Underground detention	17	46%

Catch basin inserts	16	43%
Low Impact Development BMPs (e.g., Bioretention, amended soils)	16	43%
Proprietary media filters (e.g., Stormfilter)	15	41%
Sand filters	14	38%
Filter strips	14	38%
Diversion to treatment facilities	10	27%
Multi-chamber treatment train systems (MCTT)	7	19%
Porous pavements	7	19%
Cisterns and use	3	8%

Other BMP types implemented:

ID	State	Other BMPs used and comments
1	Mississippi	typical silt fences, hay bales, gutter filters, grassy swales
4	California	biofiltration swales
6	Delaware	Underground infiltration.
7	Illinois	ECBs and TRMs
10	Oregon	street sweeping
20	Michigan	Retention Basins as opposed to detention basins are used by MDOT
25	Ohio	Exfiltration trench
31	Hawaii	Use a lot of proprietary environments
32	Connecticut	Use some of the above but not in ultra urban environments
42	New Jersey	Mostly proprietary and wetland based
50	South Dakota	Flocculent System
55	Massachusetts	sediment traps/forebays, source control (e.g., less winter sanding, repair of eroding shoulders), deepsump catch basins, leaching catch basins

Question 5: What lessons has your DOT learned about water quality BMPs in ultra urban environments?

This question received 39 responses. All comments are shown below.

ID	State	Comment	Topic
1	Mississippi	We are anticipating the reality of new standards in the future	Regulatory
2	Washington DC	Long term performance and maintenance costs is biggest issue.	Maintenance; BMP Performance
3	Virginia	Space constraints and right of way costs limit locations drastically.	Space constraint
4	California	Need to examine all potential future issues (constituents of concern)	BMP selection and performance

ID	State	Comment	Topic
5	Washington	Land acquisition for siting facilities can be very expensive.	Space constraint; cost
6	Delaware	Sand filters can lead to increased mosquito breeding and maintenance costs can be quite high.	Sand filter
7	Illinois	Get a consultant that is familiar with the area. They usually know where the existing problems are located. Get familiar with the soils, water table and sensitive areas.	Planning, site conditions
9	Oregon	The facilities are hard to fit in and cost more to maintain	Space constraint; Maintenance
10	Oregon	It often is quite difficult to construct access roads for maintenance forces.	Maintenance access
11	Maine	We haven't been required to implement retrofits in UUE, but now through a Residual Designation Authority ruling by EPA we will be. Regulators and their consultants are pushing unproven technologies (tree filter boxes for one) that raise the concerns you listed above. We are left with the responsibility of installing, monitoring, and maintaining. I guess I have no lessons learned but have grave doubts of our abilities to effectively treat the runoff within these UUEs.	BMP Performance
12	Oregon	Cartridge filters seem to be the BMP that is thought of first when additional Right-of-Way is very expensive. But we do not seem to have the staff, vehicle jib cranes, budgets or safe access available to maintain cartridge filters, so we have tried not to use them. Developers of commercial properties adjacent to state highways use them. We do not know if they are maintaining them.	Maintenance
13	Nebraska	Currently revising and developing post construction BMP's for urban areas	Planning
14	North Carolina	Achievement of Design Storm may be difficult due to corridor constraints Interaction with agencies during design has been valuable to achieve workable solutions and identify MEP (maximum extent practicable) for project. Project as a whole must be considered when discussing potential range of treatment options.	Space constraints; Coordination & planning
15	New Mexico	Constantly to be monitored and maintained	Maintenance
17	USEPA Region 9	I am not a DOT, but I oversee compliance with stormwater permits and note use of these BMPs in our four western states.	Compliance
19	Montana	Montana has a few very limited sites that can be considered ultra-urban. Consequently, we have little experience in this field. In the section above on BMPs used, surface detention and vegetated/rock swales appear to be more practical for a suburban environment and we have used them in htis situation. We have not used them in an ultra-urban environment.	BMP Selection
20	Michigan	Quantity controls are often more difficult to address than quality due to the existing drainage law.	Volume control
21	New Hampshire	No enforcement, no monitoring, no funds	Cost

ID	State	Comment	Topic
22	Maryland	Accessibility for inspection and maintenance is often not considered in design but essential to life cycle particularly for underground storage and treatment facilities. Facilities that utilize plants are often not successful due to stress of pollutants, wetness or drought, improper species selection in conflict with desire to utilize native species.	Maintenance; Vegetated treatment
23	New York	Getting credit for treating stormwater that comes from outside of the highway right-of way (e.g. treating runoff from parking lot instead of from the highway)	Off-site run-on
24	Ohio	Sometimes a BMP simply cannot be fit into a project area. As long as flow does not contribute to a CSO, separating combined sewers may not be the best choice for storm water quality. It may not be feasible to install a BMP and/or storm water receives a high level of treatment at a WWTP.	Space constraint; CSO
26	Oklahoma	They are expensive!	Cost
27	Alaska	Typical BMP used in urban settings don't work in Alaska	BMP performance; Cold climate
28	Wisconsin	Most of the BMPs we have used have given moderate results, ongoing research is needed.	BMP Performance
30	Hawaii	Biggest issue is maintenance	Maintenance
31	Connecticut	Damn hard to do. Connecticut is a developed state. Ultra urban is 100s of years old, in the ground. They have to know what is down there. They have to do a lot of test pits. The plans from the 40s don't make sense. Biggest problem in urban areas.	Utility conflicts; Planning
32	Pennsylvania	Underground detention facilities have been banned from application on DOT projects; infiltration trenches are not frequently used. Underground features end up ranking last on the priority list of maintenance forces because they are out of sight. Do not use catch basin inserts along major arterials or interstates; the risk of flooding from a poorly maintained inlet is a major safety hazard. Vegetated filter strips, vegetated swales, amended soils, and (sometimes) bioretention are favored BMPs in ultra urban settings.	Underground BMPs; Catch basin inserts; Vegetated BMPs
35	Utah	Maintenance cycles should be minimized to promote the safety of both Maintenance Forces and the Motoring Public. Life Cycle Costing methodology is needed to insure that a balanced BMP is selected. Special disposal requirements makes catch basin inserts less attractive. Bypass capability is almost always necessary to assure safety of the public.	Maintenance; Cost; Hydraulic design
38	Nevada	Source control is much more effective than sediment control.	Source control
40	unknown	Acquiring ROW early on is key.	Planning; Space requirements
41	New Jersey	Not enough ROW. Don't want to create any standing water, due to mosquitoes. Look at soil tests before any construction of BMPs. Maintenance and ongoing costs are a problem	Space constraints; Vectors; Maintenance; Cost
43	Colorado	One solution does not exist. Each situation is different.	Planning
44	Colorado	Expensive, Hard to Monitor, Space that’s required, Public understanding of need and cost.	Cost; Space constraints

ID	State	Comment	Topic
47	Colorado	It's practically impossible to implement in any sort of cost effective way.	Cost
48	Montana	Make sure there is good access to the BMPs for maintenance. Training for our Maintenance Personnel on maintenance of BMPs. Maintenance of BMPs requires considerable manhours.	Maintenance
52	Minnesota	Managing BMP's during construction phasing that is very restrictive. No place for temporary traps	Construction BMPs
53	Colorado	Our current permit is poorly written and too restrictive! WQ is not an exact science...	Permitting
54	Colorado	The amount of pollutants which our BMPs treat is quite insignificant when compared with the discharge of pollutants from other sources! Few people in our maintenance forces have the training needed to understand how to maintain these structures. This is not their fault - they have a multitude of more pressing duties.	Maintenance
55	Massachusetts	When BMPs are underground, covered by a manhole(s), they are out-of-sight, out-of-mind and do not get the clean-out attention required. They also are not nearly effective at TSS removal as they are purported to be.	Maintenance, BMP Performance

Question 6: BMP POLICIES, GUIDANCE, AND RESEARCH: Please select all of the topics below for which your DOT has policies, reports, or data:

This question received 43 responses representing 31 states. The table below shows a summary of responses. Individual responses by state are shown in Attachment 1.

BMP Policies and Research	Number of States	Percent of States
DOT has design guidelines or specific practices for stormwater management facilities in ultra urban (space constrained) environments	11	35%
DOT has a stormwater manual with a list of approved BMPs	26	84%
DOT has evaluation and certification procedures for water quality treatment BMPs	10	32%
DOT has conducted research on water quality treatment for ultra urban environments	15	48%
DOT has a BMP maintenance manual or policies/guidelines for BMP maintenance	13	42%
DOT has compared construction and maintenance costs for water quality treatment BMPs	8	26%
DOT has researched water quality treatment BMPs in cold climates	5	16%

Question 7: WATER QUALITY RETROFIT REQUIREMENTS: Indicate your DOTs regulatory requirements for conducting water quality retrofits.

This question received 49 responses representing 35 states. Respondents could list more than one requirement. Responses are summarized below and individual responses by state are shown in Attachment 1. There were 15 comments on other regulatory drivers for WQ retrofits, which are listed below.

Retrofit Drivers	Number of States	Percent of States
WQ retrofits are not required	17	49%
NPDES	20	57%
TMDL compliance	12	34%
UIC regulations	4	11%
ESA	4	11%
Other (list below)	7	20%

Other regulations requiring water quality retrofits:

ID	State	Other WQ Retrofit Driver/Comment
4	California	401 Certification requirements (in conjunction with 404 USACOE permits)
6	Delaware	Our NPDES section has an annual budget of $150,000/yr to do retrofits, but as of right now it is not spelled out which/any retrofits are required (under phase I). Could write more, but not enough space....
7	Illinois	any State or local ordinances would regulate us.
9	Oregon	Local agencies (City of Portland, Washington County)
11	Maine	Residual Designation Authority under CWA
20	Michigan	Current permit requires retrofit only in coordination with new/reconstruction of a roadway. This is especially important in relation to an existing TMDL.
23	Maryland	State regulations and water quality banking agreement.
27	Oklahoma	Regulatory entity hasn't gotten to the point of asking for it. Required under Phase I. ODOT is co-permittee and cities may be doing it, but ODOT hasn't been asked to do so.
32	Connecticut	Even if they are asked, they don't do them - only on new projects
36	Utah	Section "15.1.4 Sensitive Surface Waters" in Chapter 15 of the "UDOT Drainage Manual"; designers are guided in assuring anti-degradation of beneficial uses of and TMDL concerns of degraded waters even if not identified in an Environmental Document
39	Nevada	New TMDLs are coming soon that may require retrofits.
43	Rhode Island	Rhode Island Pollutant Discharge Elimination System (RIPDES)
45	Colorado	MS 4 areas
52	Minnesota	Watershed Districts
55	Massachusetts	MassHighway typically does not retrofit due to the excessive costs of contractor mobilization, the extravagant cost, and the lack of Federal participation. BMP installation happens in concert with other highway projects.

Question 8: WQ RETROFIT POLICIES: Has your DOT prepared guidance or policies for water quality retrofits of highway facilities?

This question received 46 responses representing 35 states. One state provided both yes and no responses and is not included in the tally below.

DOT has WQ Retrofit Policy	No of States	Percent
Yes*	6	18%
No	25	74%
Not applicable	3	9%

Question 9: WQ RETROFIT PROJECTS: Has your DOT conducted any water quality retrofits of highway facilities?

This question received 45 responses representing 34 states. Two states provided both yes and no responses and are not tallied below. There were 17 respondents who provided comments and lessons learned for WQ retrofits. The results from questions 7 and 8 indicate that more states are conducting WQ retrofits than have retrofit policies.

DOT has conducted WQ Retrofit	No of States	Percent
Yes	11	34%
No	21	66%

What lessons has your DOT learned about retrofitting highway facilities for water quality enhancement?

ID	State	Retrofit Lessons / Comment
5	Washington	Important to streamline methodology to prioritize retrofit needs so one does not spend more on prioritizing the need rather than actually retrofitting the system.
6	Delaware	It costs money
7	Illinois	We can make it more efficient than before.
9	Oregon	Just starting to do this process.
10	Oregon	We haven't done enough to be able to provide any relevant information.
11	Maine	When we have the real estate it is straight forward and effective, when it is not practices are eyewash.
14	North Carolina	Construction oversite is required by an experienced staff. Facilitating treatment of entire design storm may be difficult. Retrofits are beneficial in the process to determine what might well. Design cost are about 30-40% of the construction costs.
20	Michigan	Early retrofits have used hydrodynamic separator. Not enough information on design,

ID	State	Retrofit Lessons / Comment
		construction and maintenance requirements to document they are working as marketed.
23	Maryland	Roadside safety is sometimes in conflict especially when placing facilities in median areas; wet or dry swales with underdrains seem to be best suited; infiltration trenches clog and fail at an alarming rate and are difficult to reconstruct; underground storage is useful for attenuation of flow but not we haven't used it for water quality.
24	New York	1) Difficult to develop coordination or share services with local municipalities, 2) Difficult agreeng with regulators on the value of specific retrofit projects (i.e. determine pollutant removal effectiveness)
32	Connecticut	Refusing to do them has worked thus far.
36	Utah	Frequently the scope schedule & budget of a project has already been fixed by the time a knowledgeable hydraulic engineer has a chance to present innovative appropriate retrofitting strategies. Similarly the most polluting outfalls [which should be retrofitted first] are often owned and maintained by others. This writer is convinced that if MOU's and/or MOA's were created at the highest levels of the various Regulators, the FHWA and the DOT's creating a simple “flow based banking*” of the improved water quality benefits then there would be a marked increase in retrofits and water quality in most Urban environments. [*Say The 5 year discharge times a stream specific pollutant]
39	Nevada	Again, source control is preferred. We are concerned the new TMDLs will be very difficult and expensive to attain.
42	New Jersey	Retrofitting is not the problem. Sometimes when they are doing retrofits they used to put the ball in front of the casting and that wasn't working with snow removal.
45	Colorado	N/A none done that I know of.
52	Minnesota	Developing maintenance costs and providing personnel.
55	Massachusetts	MassHighway only "retrofits" as part of a larger construction project. Stand-alone retrofits are too expensive, especially without Federal participation.

Question 10: COLD CLIMATE BMP SELECTION (IF APPLICABLE): Please rate your concerns regarding water quality treatment BMPs in cold climates.

This question received 42 responses representing 31 states. Results are summarized in the table below. The weighted score was calculated with the expression:

$$\%\,score = \frac{\sum(3N_h + 2N_m + 1N_l) \times (42/N_t)}{126}$$

where N_h, N_m, N_l are the number of responses to the high, moderate, and low concern categories, respectively; $N_t = N_h + N_m + N_l$ is the total number of responses; and 126 is the maximum possible score. Based on this scoring we have grouped the cold weather considerations in two categories: 1) high concern (shown in pink) and 2) moderate concern (shown in blue).

Seven respondents provided written comments on other cold weather consideration and concerns, which are listed below.

Cold Climate BMP Considerations	No. of responses	High Concern 3	Moderate Concern 2	Low Concern 1	Weighted Score (%)
BMP maintenance requirements & cost	42	28	12	2	87%
Highway drainage	42	22	19	1	83%
Effects on snow removal and storage	42	18	17	7	76%
BMP performance in cold climates	42	16	18	8	74%
BMP sizing	41	14	21	6	72%
Treatment effectiveness for cold weather pollutants of concern	42	12	22	8	71%

Other concerns regarding water quality treatment BMPs in cold climates:

ID	State	Other cold climate concerns
2	Washington DC	effect of road salt on LID plantings
9	Oregon	This is not a significant problem in our area.
10	Oregon	needs more work
28	Alaska	For Alaska its not just compliance in cold climates but our geological setting as well. Many of our receiving waters are in excess to water quality standards. AKDOT may not be able to meet the TMDLs being considered by EPA.
36	Utah	Avoidance of any bmp that seems likely to malfunction due to ice etc.
45	Colorado	Installation in Frozen Conditions
52	Minnesota	Snow melts during the so called winter/ cold months and the spring thaw snow melt and the issues that are attributed to each.

Question 11: Are there any future projects in your DOT that would be a good candidate for evaluating the retrofit guidelines?

ID	State	Response
1	Mississippi	Maybe
2	Oregon	We are required per our NPDES permit to begin replacing standard catch basins with water quality catch basins beginning in FY10. Will be implementing city wide, majority of work will not take place on city highways.
5	Washington	Possibly interested in learning more on this as WSDOT in deploying a new retrofit prioritization scheme and has worked with regulatory agencies to develop an alternative compliance pathway to meet project-trigger stormwater retrofit obligations.
6	Delaware	Best contact concerning this would be the folks in our NPDES section.
7	Illinois	The Mississippi River Bridge project.
10	Oregon	Perhaps the upcoming US26: 185th Ave - Cornell Rd Section project.
11	Maine	Yes, I am going to be designing a series of "tree filter boxes" this spring for installation in an UUE. We will be monitoring there effectiveness and survivability in a cold climate.
14	North Carolina	NCDOT will have several projects in the next 18 months that would be good

ID	State	Response
		candidates.
24	New York	Contact info provided
32	Connecticut	Some special maintenance in cold weather but no treatment problems
36	Utah	Our current Urban projects are Design Build in nature making them more problematical for such studies for the usual reasons.
39	Nevada	We have several projects in the Lake Tahoe basin specifically to improve water quality. However, at this time there is no real set criteria for retrofit, just guidelines. We are simply trying to reduce and/or eliminate erosion by stabilizing slopes and adding sediment control features.
43	Rhode Island	RIDOT will install 3 hydrodynamic separators as retrofits as part of 2 construction projects in 2009 RIDOT is evaluating retrofits for the Greenwich Bay watershed in Warwick, RI - anticipated installation 2010-2011
55	Massachusetts	As the result of a recent lawsuit, MassHighway has been mandated to retrofit three sites along I-495 and I-190.

Question 12: Additional comments?

ID	Organization	Response
1	Maine DOT	Thank you for doing this. If we are all held to this standard this is a huge issue. I am thankful that I am in a rural state with a small urban sector.
2	USEPA Region 9	Important for State DOTs to get ahead of the MS4 permit movement toward precise, enforceable and sometimes numeric permit conditions, as well as trend to a hydromod based approach overall, even for linear systems. Need for State DOTs to get much further forward on creating their own large-scale mitigation banks at the front end.
3	Montana DOT	We would like to see what water quality retrofits are used by other states. We would also like information on BMPs used in ultra-urban environments.
4	Montana DOT	I filled out the survey to the best of my knowledge, but I had also passed it along to someone else within the organization that would better address the remaining questions that I could not complete. Montana is a very rural state, so ultra urban issues have not been at the forefront. TMDL & MS4 issues and directives from our resource agencies are also behind other areas and are just now coming into play. We'd be interested in your survey results as we'll certainly be looking at these issues in the not to distant future.
5	Wisconsin DOT	This is an area where we have barely gotten our feet wet, we have done some experimental projects with varying results.
7	Connecticut DOT	We always get the money to build but not to maintain.
8	Utah DOT	The potential detrimental effects of saturating the subgrade leading to poor performance and premature failure of the costly pavement section is easily overlooked when selecting a bmp and always needs to be included in any life cycle costing of alternatives; especially some forms of porous pavements. Note that a saturated subgrade can easily have only 1/2 or even 1/3 of the supporting value of an unsaturated subgrade requiring a beefed up pavement

ID	Organization	Response
		section for equal pavement life. These additional materials are both economically and environmentally costly.
9	Oregon	We will just begin to install various bmp devices for the alocated tmdl sites.
10	Montana DOT	MDT is currently not conducting Water Quality Retrofit. We have completed portions of this form based on usage of BMPs on newly designed projects.
55	Massachusetts	The performance of hydrodynamic separators has been grossly overstated over the years, and are exceedingly difficult to inspect and clean out (see link to "Evaluating Hydrodynamic Separators" white paper). Given the dilute nature of most highway storm water, DOTs cannot and should not install sophisticated BMPs that are difficult to inspect and to clean out. Source control is oftentimes overlooked as an effective storm water BMP. Furthermore, the end-pipe TSS-removal approach to storm water management is not endorsed by the US EPA.

4 DOT Certification Procedures

The purpose of this task was to determine the current procedures used by DOTs to evaluate, test, and certify water quality BMPs for highway facilities, including BMPs for ultra-urban retrofit applications.

In the DOT survey, 25 of the 38 state DOT respondents (66%) indicated their DOT has an approved list of BMPs for use in highway projects. Interestingly, only 10 of the 38 state DOTs indicated their DOT has evaluation and certification procedures for treatment BMPs. Apparently, most DOTs do not use formal internal certification and evaluation procedures to approve BMPs. These DOTs may rely on, or may be required to use, testing and evaluation results from other agencies (state environmental or permitting agencies, outside organizations), or may use informal internal review to select and approve BMPs.

Of the ten state DOTs that indicated they had established certification procedures, documents describing BMP certification policies were easily located for only four states: California, New Jersey, Oregon, and Virginia. Additionally we located BMP certification policies for Massachusetts and Washington. We also recognize that several state DOTs have active retrofit programs or pilot retrofits programs, including North Carolina, Rhode Island, and Maryland. While these programs could presumably be used to evaluate both approved and non-approved BMPs, we could not readily locate information that formalized such policies (e.g., stormwater management plans, fact sheets, etc.).

We reviewed the available BMP certification and evaluation policies from six states with regards to the following:

- What state agency oversees the certification of stormwater BMPs;
- What are the protocols used by each agency to evaluate if the performance data collected for "new" BMPs is adequate for determining the effectiveness of the BMPs;
- What are the allowances and procedures for deviating from each states standard BMPs; and
- Additional information about the states program for evaluating and certifying innovative BMPs.

Table 3 summarizes the BMP certification and evaluation practices for the six states that were reviewed.

Table 3: Summary of DOT BMP Certification and Evaluation Practices

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
California *Caltrans operates its own approval and certification program as defined in their SWMP, Project Planning and Design Guide, Stormwater Management Program Annual Reports, and Treatment BMP Technology Report.* *The Caltrans BMP Technology Report includes listing of BMPs that are being considered for a pilot-study, BMP that are approved, or BMPs that have been rejected.*	When site conditions prohibit the use of approved BMPs, the designer should consult with the District/Regional Storm Water Coordinator, which has an option of proposing a non-approved BMP as a pilot project. Use of the BMP must be approved by the Storm Water Advisory Teams and appropriate Headquarters' functional units. Over thirty (30) specific ongoing applied research studies are being conducted to provide information of stormwater pollution, evaluate existing and potential BMPs, and meet the monitoring and characterization assessment requirements of the SWMP and Permit.	Guidance Manual: Stormwater Monitoring Protocols, Caltrans 2000; or other recognized protocol, such as the International BMP Database. Caltrans has four Storm Water Advisory Teams (SWAT) • Maintenance SWAT • Project Design SWAT • Construction SWAT • Water Quality SWAT The SWATs annually evaluate not only new technologies but also those in pilot-studies and those in use by Caltrans and other municipalities and DOTs. Actual approval/rejections are done by headquarters division chiefs from each of the four groups based on SWAT recommendations.	Caltrans conducts thorough investigations of many BMP technologies. Over thirty (30) specific ongoing applied research studies are being conducted to provide information of stormwater pollution, evaluate existing and potential BMPs, and meet the monitoring and characterization assessment requirements of the SWMP and Permit. Caltrans regularly publishes results of their pilot-studies and status of stormwater monitoring and Best Management Practices (BMP) technology development. BMP evaluation criteria include relative effectiveness, technological feasibility, costs and benefits and legal institutional constraints. Caltrans also provides the BMP performance study to the International BMP Database New technologies are proposed to Caltrans by universities, consultants, regulators, third parties, and manufacturers.

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
Massachusetts *MassHighway and Department of Environmental Protection (DEP) worked together on creating the DEP's* Stormwater Management Volume 2: Stormwater Policy Handbook *that identifies BMPs that are acceptable for use in Massachusetts.* *MassHighway has also prepared the MassHighway Storm Water Handbook for Highways and Bridges. For critical source areas, MassHighway also requires the additional BMPs, above and beyond those required in the DEP Stormwater Policy Handbook*	Alternative BMPs may be used if their performance is documented and equivalent to accepted BMPs. However, the DEP identified restrictions on the use of certain BMPs within certain watersheds. If a particular BMP does not appear on the list in the Policy guidance, then the designer needs to provide documentation of the anticipated treatment performance of the device and an independent demonstration should be provided to demonstrate achievable treatment efficiencies.	The designer of a particular project that uses innovative BMPs should consider available evaluation protocols and resources. Acceptable protocols for determining if a BMP will adequately achieve the water quality goals of the project include those from the Massachusetts Strategic Envirotechnology Partnership (STEP), the Technology and Reciprocity Partnership (TARP), and the Environmental Technology Verification Program (ETV).	DEP uses TSS removal as an indicator for BMP performance. When a BMP has been evaluated a TSS removal efficiency is assigned (

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
New Jersey *Department of Environmental Protection (DEP) lists certified manufactured treatment devices as well as those being evaluated on www.njstormwater.org* *Acceptable BMPs are listed in Section of the NJDEP (Department of Environmental Protection) Stormwater Best Management Practices Manual that NJDOT helped write. NJDEP is still reviewing (3/31) Section 10 for the 2008 revision.* *The New Jersey Roadway Design Manual references the NJDEP Stormwater Best Management Practices for acceptable BMPs.*	New technologies may be proposed to NJDEP or NJCAT (Corporation for Advanced Technology). NJCAT is a non-profit public/private partnership created to provide third party credible and independent verification of vendors technology performance claims. NJDEP maintains a list of Structural Stormwater Management BMPs in their BMP Manual, which NJDOT references as acceptable BMPs. The Drainage Design Manual, August 2006 states, "When other water quality measures are not feasible, the use of Manufactured Water Quality Treatment Devices are permissible."	NJCAT screens emerging technologies and allows only the best candidates into the acceptance program. The NJDEP Division of Science, Research & Technology (DSRT) is responsible for certifying final pollutant removal rates for all manufactured treatment devices. This final certification process must be based verification of the device's pollutant removal rates by one of the following: 1. The N.J. Corporation for Advanced Technology (NJCAT) in accordance with the protocol "Stormwater Best Management Practices Demonstration Tier II Protocol for Interstate Reciprocity" as developed under the Environmental Council of States (ECOS) and Technology Acceptance and Reciprocity Partnership (TARP). 2. Another TARP state, or another state or government agency that is recognized by NJ through a formal reciprocity agreement. 3. Other third party testing organizations (i.e., NSF).	New Jersey adopted official TSS, nitrogen, and phosphorus removal rates for each of the BMPs. The TSS removal rates for manufactured treatment device are to be determined on a case-by-case basis.

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
Oregon *Department of Transportation is currently revising their Hydraulics Manual to include a chapter on water quality and a listing of "Preferred BMPs." Currently there is a memo outlining ODOTs new Stormwater Treatment Program, which discusses the proposed process for selecting BMPs for highway projects.*	If a project chooses to use a BMP from the Preferred BMP list based on the target pollutants and site feasibility, the formal evaluation and scoring process can be by-passed. If a project can't use a BMP that is on the Preferred BMP list, then the regulatory agency should be notified and treatment train alternatives of Preferred BMPs considered. Alternative methods may be proposed and evaluated on a project-by-project basis. The proponent of the alternative method must submit a Hydraulic Design Deviation Request including: • A description of the issues • A brief description of the project • Detailed location (bridge or highway number and mile post) • A justification for the deviation, and • Supporting documentation	Preferred BMPs were identified as part of literature review for treatment effectiveness. There is no defined formal process other than assigning each BMP primary unit processes and judging performance based on unit processes. Hydraulic Design Deviation Requests are submitted to the Regional Hydraulics Engineer who reviews the request and submits recommendation to Technical Services Geo-Environmental and/or Bridge Section Senior Hydraulics Engineer for final review. Hydraulic Engineering Staff in Technical Services will conduct the review and provide approval, suggested revisions, or deny the request.	BMPs are defined in terms of primary treatment mechanisms rather than by removal efficiency data. 1. Hydrologic Attenuation 2. Sedimentation/density separation 3. Sorption 4. Filtration 5. Uptake/Storage and 6. Microbially mediated transformation

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
Virginia *Virginia's Department of Conservation and Recreation (DCR) Stormwater Management Handbook that includes approved BMPs. This handbook appears to apply to the Virginia Department of Transportation.* *DCR also maintains a website entitled, "Virginia Stormwater BMP Clearinghouse."*	Procedures for deviating from approved BMPs are unclear. The DCR Stormwater Management Handbook has a section on Manufactured BMP Systems. The handbook states, "The Manufactured BMP Systems presented in this standard have been presented to the Virginia Department of Conservation and Recreation (DCR) by industry manufacturers. DCR acknowledges that there may be additional Manufactured BMP Systems available at this time that are not presented in this handbook. Presentation of the following products does not preclude the use of other available systems, nor does it constitute endorsement of any one system."	According to the Virginia Stormwater BMP Clearinghouse, BMP evaluation is based on the TARP protocols and Virginia specific requirements to the TARP protocol.	In April of 2008, Virginia's DCR revised the list of approved proprietary and non-proprietary BMPs. The following performance measures were assigned to each BMP: • Removal of Total Phosphorus by Runoff Volume Reduction (RR, as %) (based upon 1 inch of rainfall --90% storm) • Removal of Total Phosphorus by Treatment – o Pollutant Concentration Reduction (PR, as %) o Total Removal of Total Phosphorus (TR, as %)

State	Procedure for deviating from approved list	Evaluation (Protocol)	Additional comments
Washington *BMPs that are acceptable for use in highway projects are listed in WSDOT Highway Runoff Manual (HRM). Acceptable highway BMPs are approved by the Washington Department of Ecology and are a subset of the BMPs presented in Ecology's Stormwater Management Manuals for Eastern and Western WA.*	If the project requires a BMP that is not on the list of approved BMPs in the HRM, there is an approval process that must be followed. The approval process varies based on the BMP being evaluated. 1. BMPs that are approved by Ecology, but not included in the HRM, only require approval from the Region Hydraulics Office and Maintenance Superintendent (or WSDOT). 2. Emerging Technologies (public domain or proprietary) require approval from WSDOT and Ecology. 3. For projects seeking compliance with water quality regulation, demonstrative approach requires approval from Ecology – timeline and expectations for providing technical justification may be extensive (depending on complexity of project and receiving water conditions); may require a dilution analysis to demonstrate that the project will not adversely affect the receiving waters.	Ecology has developed Technology Assessment Protocol (TAPE) for evaluating emerging technologies, which is intended for ultra-urban treatment technologies, short detention flow based BMPs. The TAPE protocols specify sampling criteria, site and technology information, quality assurance and quality control measures, target pollutants, and evaluation report content. The TAPE protocols also suggest that technologies are evaluated on factors other than treatment performance, including costs, operations and maintenance, reliability, and longevity.	WSDOT has an extensive Stormwater Quality Research Program, which includes an Ultra-urban Stormwater Research Facility. This facility is specifically designed to evaluate the performance of innovative BMPs. The facility can be used to test the manufacturer's performance claims, whether the BMP effectively treats urban stormwater, how it performs in a treatment train (if possible) and operation and maintenance costs, safety, and other operational issues.

Certifying Agency

Of the six state's programs detailed in the table (Table 3), two of the states DOTs, California and Oregon, operate their own stormwater BMP approval programs, including evaluation and certification programs without the assistance of their states environmental agency. BMPs are evaluated and certified through internal procedures.

Three of the six states, New Jersey, Virginia, and Washington, rely heavily on their states environmental agency for support and approval of stormwater BMPs for highway applications.

In Massachusetts, MassHighway worked with the Massachusetts environmental agency to develop the initial statewide list of BMPs was created. However, MassHighway is the responsible agency for assessing and approving additional or proprietary BMPs for use on highway projects.

BMP Certification Criteria

In three of the six state programs, BMPs are certified and assigned specific performance ratings for percent removal of TSS, TP and/or nitrogen (Massachusetts, New Jersey, and Virginia). Percent removal values are provided to support BMP selection and design, and are based on established testing protocols.

In the other three states, BMP Certification is conducted with internal procedures based on review of literature information and testing data.

BMP Evaluation and Certification Protocol

There are a variety of testing protocols used by the state programs to evaluate BMP performance and certify BMPs. These include:

- Massachusetts Strategic Envirotechnology Partnership (STEP);
- The Technology and Reciprocity Partnership (TARP);
- The Environmental Technology Verification Program (ETV);
- Washington State Department of Ecology's Technology Assessment Protocol (TAPE); and
- BMP Monitoring Protocols from the USEPA database.

Many states that accept data from one of the above protocols require state specific criteria (e.g., different inter-event periods) to be considered in addition to those required by the individual protocols before the will approve a BMP.

There is an ongoing effort within the ASCE to unify evaluation and certification protocols.[1] The ASCE/EWRI has formed a Task Committee on Guidelines for Certification of Manufactured Stormwater BMPs (see http://watertech.rutgers.edu/). The function of the committee is to review existing certification programs for various manufactured stormwater BMPs and seek input on certification methods and contents from a variety of stakeholders. This review and input will be used to develop new guidelines. This work is ongoing.

Use of non-approved BMPs

A key consideration for stormwater retrofitting is flexibility in BMP selection and design, and allowances for the use of non-approved BMPs (or reduced sizing, etc. as compared to BMPs for new highways). This is especially important in space limited UU environments, as site constraints may not easily allow the use of approved BMPs, or may provide opportunities for use of innovative approaches. All of the states whose policies were examined allow for use of BMPs that are not included on their approved lists; however, it is not always clear what process must be followed to use a different BMP. Many of the processes are focused on proprietary/manufactured BMPs that will be most applicable in space-constrained ultra-urban environments and appear to be receptive to introductions of new products. All of the evaluation and certification procedures are rigorous and require monitoring, but this may be done during a pilot-study.

[1] Development of Certification Guidelines for Manufactured Stormwater BMPs, prepared by Q. Guo, G. England, and C.E. Johnson.

5 Research Approach

The proposed research approach is divided into two parts based on the proposed outline of the guidelines document (Section 6) and the project work plan. The research plan initially focuses on compiling supporting data and developing BMP selection, design, and sizing strategies for UU retrofit projects. Using results from this work, we will then develop the retrofitting approach in the second part of the research plan, and prepare the guidance document. As we summarize information and prepare the guidance document, we expect that some portions of the report may point to other studies/guidance documents for detailed guidance (e.g. the NCHRP Report 565 and others that are readily available). As part of this effort we will demonstrate the retrofitting approach to DOTs, develop recommendations for future research, and prepare the final research report.

Compile Supporting Data and Develop Design Guidance

5.1 Characterize UU Highway Environments

Retrofitting requires the identification of BMP opportunities and limitations within the existing highway environment. Understanding the characteristics and limitations of the UU highway provides a basis for identifying practical retrofit locations, for selecting BMPs that provide effective treatment of target constituents, as well as recognizing inefficient or costly retrofit approaches. Research efforts will focus on developing a detailed characterization of the UU highway environment.

***UU highway characterization and example scenarios*:** There is no commonly accepted definition of UU environments. Characteristics that are typically associated with UU highway environments are severe space constraints, high impervious cover, dense urban surrounding environments, high land costs, and high traffic densities.

We will develop example UU highway catchments to illustrate UU characteristics in the guidance document and to provide test cases for quantitative analyses (discussed later). Example scenarios will be based on actual sites to the extent possible. We will solicit candidate sites from DOT contacts and/or use available literature information. GIS resources will also be employed. Ideally the example scenarios will illustrate a cross-section of UU highway characteristics and range of climatic conditions. For each example scenario we will quantify and highlight important features of UU catchments such as catchment area, highway ROW, impervious cover (and, by implication, pervious cover control opportunities), location and drainage infrastructure and outfalls, elevation head, and the potential for heavy equipment access for construction and maintenance.

UU highway environments are highly site specific and some sites will be more amenable to retrofit than others. In the guidance document we will categorize UU highway features into difficult and amenable retrofit features. The purpose is to help users recognize constraints and think about alternative approaches and opportunities for highway retrofits.

Runoff Characterization and Pollutant Descriptions: There is a substantial body of literature on the characterization of highway runoff water quality. Monitoring studies generally show higher pollutant concentrations in highway runoff from UU environments, and a general association of increasing runoff concentrations with increasing density of urban land uses, with higher AADT, and with snow storage in high traffic areas.

BMP selection is based on identification of pollutants of concern and their associated properties. We will develop descriptions of typical pollutants in highway runoff that are the focus WQ retrofits. We will compile and evaluate runoff quality data and we will develop tables of typical runoff quality for common highway pollutants in UU environments (TSS, metals, organics, nutrients, and others). We will attempt to characterize runoff water quality from snowmelt conditions separate from non-snow melt conditions (FHWA, 1989). In addition, we will discuss the pollutant properties and UU influences on runoff water quality. We will also list water quality data sources. Much of this work will build on our experience with NCHRP project 25-20 (NCHRP 2006).

Another consideration is the particle size distribution of sediments in highway runoff. Underground proprietary BMPs in highway applications (oil/grit chambers, CDS units) often target sediments and associated pollutants. In selecting these BMPs for retrofit applications, engineers would ideally consider the particle sizes that are effectively removed by the BMPs and the pollutants that are associated those particle size fractions. Recently, BMP performance data have been developed for underground BMPs that specifically address treatment efficiency for specific particle sizes. To support performance assessment related to particle size, we will compile available literature information and develop tables of particle size data and associated pollutant concentrations in highway runoff.

***Cold Climates*:** In many parts of the county, snow melt comprises a significant fraction of the annual runoff. Cold climates regions face additional considerations and challenges for BMP retrofits. BMP performance can be affected by freezing temperatures, higher pollutant concentrations and loadings due to partitioning from exhaust and atmospheric fallout, and larger runoff volumes (e.g. rain on snow events). The DOT survey indicated that BMP performance was the most common issue of concern in cold climate areas. The research plan will include the following efforts to develop guidance for evaluating and addressing cold climate influence on BMP selection and design:

- Compile and summarize data on cold climate influences on runoff water quantity and quality in UU highway environments.
- Compile and summarize data on BMP performance in cold climates, and develop general guidance for BMP selection in cold climates; and
- Compile information and develop guidance on retrofit design considerations in cold climates.

***First Flush*:** The literature review revealed that highway runoff quality exhibits a first flush behavior for many pollutants, but not all pollutants. Small highly impervious catchments that are typical in UU highway environments may have more potential for first flush. Researchers have suggested that a flush phenomenon presents opportunities for BMP design enhancements. To support BMP design considerations for targeting first flush runoff, we will compile and summarize available monitoring information on pollutant first flush in highway runoff.

5.2 Compile and Evaluate Structural BMPs Options

Knowledge of structural BMP options and configurations is essential for planning and identifying water quality retrofit opportunities and alternatives. The guidance document will include a section describing the variety of BMP options, BMP design considerations, and applicability in UU environments. This section will also include general guidance on sources of BMP information and general approaches for selecting BMPs.

The goals of this portion of the study are: 1) develop general guidance for BMP selection; 2) investigate BMP configurations, treatment trains, and design alternatives for retrofit application in UU settings; and 3) develop an appendix of BMP fact sheets that focuses on attributes and applicability for UU environments. The fact sheets will include the following information:

- BMP type and general description
- Use in surface or underground configurations and alternative design configurations for UU environments
- Main unit processes
- Target constituents and forms
- General space requirements
- General elevation head requirements
- Treatment effectiveness and sources of performance data
- Volume reduction effectiveness
- Maintenance practices and frequency
- Assessment and information on overall reliability
- Broad cost information
- Overall applicability, constraints, and usage in UU environments
- Example applications

As part of the effort we will develop general BMP sizing and design guidance. We will also investigate the performance of BMPs when they are undersized (as compared to general new and re-construction requirements) to fit to space constrained areas. The following describes proposed efforts to compile resource data and guidance on BMP options and applicability in UU environments.

BMP Information Sources**:** We will compile information and provide guidance on sources of BMP information, including: various guidance documents (FHWA, Center for Watershed Protection, NCHRP, WERF, EPA web site, and EPA documents); DOT manuals and reports (e.g. Caltrans BMP Manual); manufacturer reports and websites; and websites of research centers and independent testing organizations.

BMP Selection Considerations and BMP Unit Processes**:** The literature review and DOT survey indicates that most DOT have policies and handbooks that define the acceptable BMPs that can be used for highway projects. However, fewer DOTs appear to have formal procedures or guidance for selecting among the approved BMPs. The literature information and survey responses suggest some DOTs have clear preferences for certain types of BMPs.

The BMP selection strategy will be a key element of the guidance document. We will develop guidance for BMP selection based on consideration of the pollutant properties and the fundamental treatment processes of the BMPs. The approach will follow previous guidance developed for NCHRP and WERF using the following three general steps:

1) Identify the project pollutants of concern and their properties. We will provide descriptions of general pollutant properties of highway pollutants as well as guidance on developing pollutants of concern for local projects.
2) Identify candidate BMPs based on the underlying unit operations. We will describe the fundamental unit processes associated with BMP options and the typical pollutant properties that are addressed these processes.
3) Conduct a practicality assessment to select from candidate BMPs by taking into consideration the site constraints, BMP costs, BMP maintenance requirements, and BMP effectiveness.

***BMP Sizing Methodology*:** We will prepare guidance on general BMP sizing approaches for volume and flow based BMPs. We will also discuss alternatives general sizing considerations for UU retrofits such as: treatment implications from the use of undersized BMPs due to space constraints; the potential for targeting BMP sizing for first flush and smaller storms; and sizing considerations for cold climates. We will also explore combinations of volume and flow-based BMPs where the volume portion could be both an initial settling system and also a metering mechanism for flows through a flow-based component. Guidance on sizing approaches will be based in part on previous research studies for NCHRP and WERF and on investigations described below.

***Surface Detention Facilities*:** The DOT survey revealed that detention facilities are the most commonly reported BMP in UU environments. The advantages afforded by detention basins address many of the concerns expressed by DOT personnel in the survey:

- Surface detention basins are simple to design and maintain and generally have lower construction and maintenance costs than many other BMPs. Costs and maintenance requirements were the highest rated concerns for BMP selection in the DOT survey.
- Surface detention basins have lower head requirements than many other BMPs which generally simplifies the integration with existing drainage. The ability to incorporate BMPs into exiting drainage facilities and the avoidance of stormwater pumping were rated as high concerns by a large majority of respondents to the DOT survey.
- Detention basins are widely accepted by regulators and generally provide good treatment performance. Regulatory compliance and BMP performance were also rated as high concerns by a large majority of respondents to the DOT survey.
- Detention basins can be designed to include filtration/media treatment at the outlet, thereby enhancing their performance for a number of pollutants that detention basins alone may not be that effective.

The availability of pervious areas in UU environments is the primary constraint for surface detention basins in retrofit applications. BMP space and size requirements were rated as very high concerns in the DOT survey. However, the literature review and DOT survey also suggest that even in UU urban environments there may be opportunities for locating surface detention and that UU does not necessarily equate with use of underground BMPs. There may also be opportunities for below surface facilities or detention on hardened surfaces. Finally, pervious embankments might be employed as filter strips and additional opportunities for infiltration.

Surface facilities are the first choices for retrofit BMPs due to cost and maintenance considerations. We will develop guidance on locating surface detention facilities both within and outside of the highway ROW. Strategies may include: searches for pervious areas adjacent to access ramps and within interchanges and landscape margins; identifying potential pervious areas outside of the highway ROW through coordination with local authorities and GIS screening approaches; determining if there are options for detention on impervious surfaces within or outside of the ROW, and identifying design modifications to locate basins within narrow or restricted spaces.

Underground Detention Facilities**:** About half of the state DOTs reported use of underground detention facilities. Prefabricated underground detention facilities can potentially provide acceptable treatment for sediments and associated pollutants. In UU environments with no surface options, underground detention may be a viable and effective alternative. We will conduct more detailed investigation and cataloging of proprietary detention vaults, including different configurations and flexibility in UU environments, methods for controlling resuspension, and available cost and performance data. We will also compile and evaluate information on the suitability of alternative lower cost approaches such as prefabricated concrete vaults and oversized pipes. In addition, we will assess the ability of below ground detention to serve as a means of initial treatment and flow equalization for flow-through treatment (e.g. media filtration).

"Undersized" BMPs: The literature review identified studies examining the performance of undersized BMPs. In UU environments space constraints and costs may prohibit treatment of the full design storm and therefore the resulting smaller facilities would be considered undersized as compared to new or re-development BMPs that follow local or DOT design standards. Monitoring studies have shown that undersized volume based BMPs (detention basins and wetlands) can provide substantial treatment performance. Therefore undersized detention facilities can be appropriate and practical for retrofit applications in space constrained settings with high land costs. However, the trade-offs between sizing and treatment performance have not been fully established.

One approach for assessing basin sizing is to evaluate the runoff capture efficiency (i.e. runoff that is captured and treated versus bypassed) similar to the commonly used WEF method[2]. The

[2] WEF Manual of Practice No. 23/ASCE Manual and Report on Engineering Practice No. 87, 1998: *Urban Runoff Quality Management.*

basis of the WEF method is to determine a cost-effective basin size that will maximize runoff capture efficiency without over sizing to the point of diminishing returns; i.e. identify the “knee of the curve” for runoff capture efficiency. This optimized basin size is termed the “maximized water quality capture volume.”

Continuous hydrologic simulation is a tool that is well suited for analyzing the influence of basin size on capture efficiency. The example plots below were developed by continuous hydrologic simulation using the USEPA Storm Water Management Model (SWMM). The plots in Figure 1 show runoff capture efficiency of alternative detention basin sizes and impervious cover. In this example, the knee of the curve approximately coincides with a runoff capture efficiency of 80 to 85 percent. Notice that the curves also show that significant runoff capture efficiency is still provided with much smaller basins, especially for high impervious cover. SWMM is a tool that can help quantify tradeoffs in runoff capture efficiency and detention volume.

Another approach for evaluating basin sizing is to evaluate sediment capture efficiency assuming ideal settling conditions. In the plots shown in Figure 2, sediment trapping efficiency was modeled with SWMM for two particle sizes. The plots suggest there is a range of basin size that optimizes the theoretical sediment trapping efficiency. Smaller basin sizes reduce sediment trapping efficiency because there is less runoff captured as more runoff is bypassed rather than detained in the basin. At larger basin sizes, sediment capture efficiency also diminishes even though there is very high runoff capture efficiency. This occurs because the outlet diameter must be increased to maintain a 48-hour drain time. The effect of a larger outlet is a shorter detention time for the smaller more frequently occurring storms that do not fill the basin. This results in less overall sediment trapping for the finer sized particulates.

Figure 1: Runoff Capture Efficiency as a Function of Basin Size and Impervious Cover

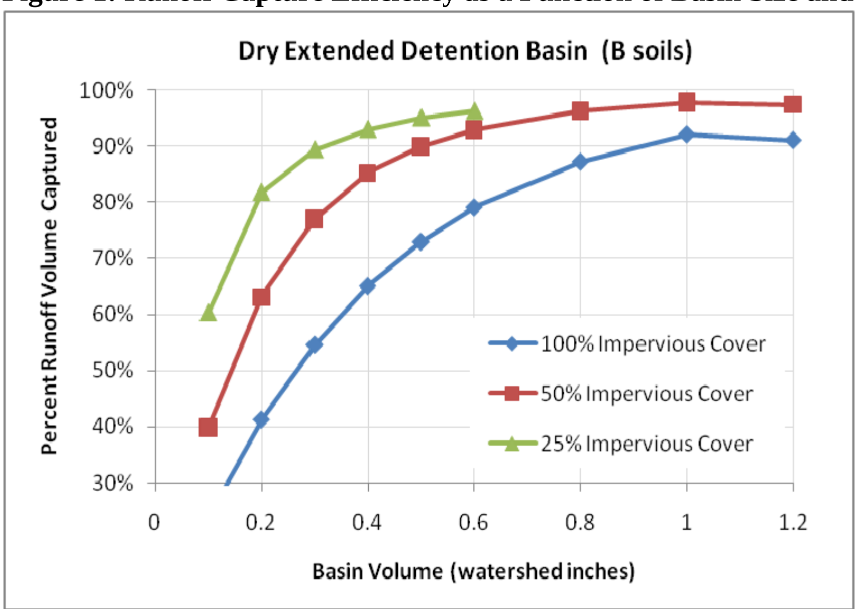
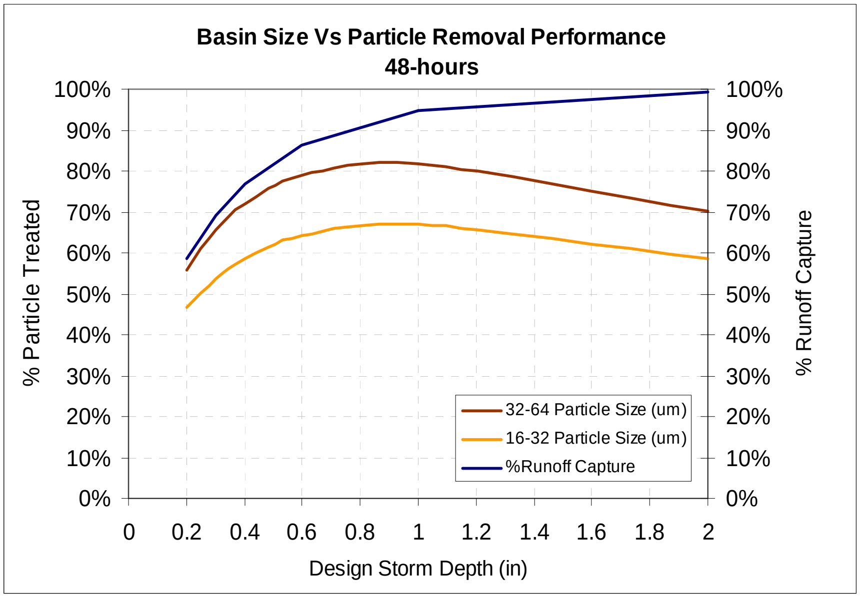


Figure 2: Sediment Capture and Runoff Capture Efficiency as a Function of Basin Size



We will use continuous hydrologic simulation to investigate the effects of basin sizing on runoff and sediment capture efficiency for detention facilities. The purpose is to gain insights into the potential effectiveness of undersized basins and for developing guidance on detention basin sizing in UU environments. This guidance would apply to both surface and underground facilities (for example using lower cost pre-cast concrete vaults). We will model a subset of UU example scenarios discussed in Section 5.1. We will also explore a variety of precipitation conditions from stations across the county, including at least one station where snow accumulation and snow melt processes will be modeled. The modeled particle size distributions will be representative of those found in highway runoff. Finally we will look at the options of by-pass vs. overflow to ascertain for what level of undersizing does adding by-pass options improve performance.

Inlet/Outlet Controls: The literature review revealed promising studies on the use of inlet and outlet controls for improving sedimentation in detention facilities. Outlet controls include alternative outlet locations and outlet structures (i.e. floating outlets). Another approach is to operate detention facilities in a fill-and-hold mode (batch operation mode) using automated controllers to open and close outlets based on water level and detention time. Inlet control devices can be used to bypass inflows once the basin is filled.

Hydrologic simulation is well suited for analyzing the influence of hydraulic inlet and outlet controls on runoff capture efficiency and sedimentation. As discussed above, we will use hydrologic simulation with SWMM to investigate the effect of alternative inlet and outlet controls in surface and underground detention facilities. In particular, we will focus on the use of batch mode operation, which has shown promising results in research studies. We will also evaluate outlet controls in combination with undersized facilities. For example, researchers in Texas found that small precast detention vaults operated in batch mode with a hold time of 3 hours could provide 80 percent sediment removal in controlled experiments.

Another consideration is the influence of first flush. Highway monitoring studies have shown first flush behavior for many pollutants and researchers have suggested first flush can provide opportunities for BMP design. This may be particularly relevant for retrofits in space constrained UU highway environments where first flush is more likely to be observed from small highly impervious catchments and where smaller facilities may be the only viable approach. For this situation it may be possible to improve load reduction by targeting treatment of the early portions of the storm using inlet and outlet controls like batch mode operation and/or by using systems that are off-line and that by-pass flows around the facility once the first flush is captured.

We will use hydrologic simulation to investigate potential benefits of inlet/outlet controls on load reductions when pollutants exhibit a first flush behavior. This modeling will focus on sediment first flush and trapping in detention facilities. We will use literature data to develop representative sediment pollutographs with and without first flush characteristics. The pollutographs will be used as input to SWMM for modeling single storm events. SWMM will be used to investigate the effectiveness of design alternatives (sizing and inlet/outlet controls) on sediment trapping in the presence and absence of first flush behavior. Through this work we will develop guidance on design considerations of detention facilities in UU highway environments.

***Swales and Other Vegetated BMPs*:** Swales were the second most reported BMP application in UU environments in the DOT survey. Literature information indicates swales provide effective water quality treatment and are among the least costly BMPs to build and maintain in retrofit settings. Bioretention and filter strips are other vegetated BMPs that also provide effective water quality treatment and have comparatively low cost. Bioretention and filter strips are less commonly used in UU environments, based on the DOT survey.

Swales and vegetated BMPs are potentially viable and effective BMPs for UU environments, provided surface area can be found and/or BMPs can be adapted or integrated into the site constraints. We will investigate approaches for siting and implementing vegetated BMPs in UU environments. This could include design approaches for small, linear, and/or isolated pervious areas, use of amended soils to promote retention and treatment performance, and use of underdrains for drainage control. We will also evaluate proprietary vegetated systems that are modular and can be integrated within catch basins and existing draining facilities. Examples are the Filterra bioretention cells and modular wetlands.

Proprietary Underground Small Footprint BMPs: The literature review showed that there is a wide variety of proprietary underground small footprint BMPs that are appealing for use in space constrained UU highway environments. This category includes: hydrodynamic separators, oil-water-grit separators, gravity separation systems, stormwater filtration systems, and catch basin inserts. There is a range of acceptance by DOTs. Some DOTs have found poor performance of proprietary systems and declined approval based on pilot testing results. Other DOTs have more broadly accepted proprietary BMPs based on criteria for meeting TSS and TP removal percentages. Between 40 to 60 percent of the DOT survey respondents reported using proprietary underground BMPs in UU environments.

Most proprietary BMPs target the removal of sediments and associated pollutants. Literature information indicates there is wide variability in sediment removal performance of proprietary devices. Treatment performance has been linked to the flow rate and size and volume of the device. Recently, controlled field experiments have been used to develop performance curves that relate performance to the particle settling velocity, flow, and a characteristic length of the device. Although these performance curves are device dependent and must be determined experimentally, they are potentially useful tools for comparing performance of different devices and for assisting with BMP sizing.

Guidance on the use of proprietary BMPs will be an important section of the guidance document given that many are well suited for space constrained settings and many are accepted for use by DOTs. Developing comprehensive guidance on the use propriety BMPs is challenging due to the wide variety and the individual characteristics of available BMPs. The research approach includes the following efforts:

- *Compile and categorize BMPs.* We will develop a database of proprietary BMPs and categorize them into related groups. Categories include: hydrodynamic devices, gravity separation devices, tanks and baffled chambers, detention tanks, filtration devices, inlet/outlet controls, and gross solids removal devices. The database will be compiled from readily available information. It will be broad-based but will not be all-inclusive.
- *Compile BMP data sources.* We will provide guidance on sources of BMP performance data and costs such as the international BMP database, independent testing organizations, DOT sponsored research, and manufacturer information and data.
- *Evaluate representative BMP types.* We will conduct more detailed literature investigations on the performance, maintenance requirements, and costs of a cross-section of proprietary BMP types. The goal is to develop BMP fact sheets for common types of proprietary BMPs.
- *Evaluate effects of sizing.* Literature information indicates that effectiveness of many proprietary BMPs is controlled and limited by the sizing of the device. We will compile available literature information and qualitatively assess sizing influences on performance. We will review available case studies where data for sizing and performance is provided. We will also evaluate and use recent studies to develop performance curves.
- *Assess applicability.* Conduct more detailed qualitative assessment on the applicability of proprietary devices in UU environments. Assessment criteria will include: 1) consideration of target pollutant characteristics and BMP performance curves during BMP selection; 2) use of proprietary BMPs in treatment trains, and 3) use of proprietary BMPs for opportunistic retrofits in highly constrained settings (i.e. MEP maximum extent practicable – designs in locations where compliance with design standards are prohibitively expensive).
- *Other factors.* We will also look at other factors that would impact selection of proprietary BMPs, including maintenance frequency and access, vector issues, etc.

***Sand Filters*:** The literature review revealed that sand filters can be designed and maintained to provide effective treatment of highway runoff without overly restrictive maintenance requirements. Another benefit is that there are a number of configurations that can be adapted to UU environments including above and underground configurations and designs for linear environments. About 40 percent of the DOTs reported using sand filter in UU settings. One respondent noted that sand filters can promote mosquito breeding and that maintenance costs were high.

We will compile design, performance, and cost information for sand filters with emphasis in highway settings. We will develop BMP fact sheets of common configurations and we will prepare guidance on the applicability, sizing, head requirements, and other design considerations of sand filters in UU environments.

***Infiltration BMPs*:** The literature review revealed that infiltration BMPs may be difficult to site in UU environments given that urban soils are frequently well compacted and that siting in marginal soils may invite premature failure. In addition, UU areas are more likely to have issues with contaminated soils and/or groundwater that may be impacted by increasing infiltration. Siting to locate well draining soils is the key design issue. The DOT survey showed that about half of the DOTs have used infiltration trenches in UU environments. One DOT respondent noted that "infiltration trenches clog and fail at an alarming rate and are difficult to reconstruct."

Infiltration BMPs are accepted practices and are commonly used. They have the potential to provide high volume and load reduction, but also have the potential for failure and high maintenance requirements. The viability of infiltration BMPs is also very significant for retrofits that address hydromodification issues in the receiving waters. We will develop guidance on the applicability of infiltration practices and in particular develop guidance for siting studies and design considerations in UU environments. As part of this work we will use SWMM to illustrate the sensitivity of infiltration rates on BMP effectiveness. For consideration of dry-wells, we will include guidance on siting requirements and potential permitting and pre-treatment requirements.

***Porous Pavements*:** Monitoring studies indicate that porous pavements can provide effective water quality treatment for particulate bound pollutants. Especially promising are porous friction overlays along roadways or roadway shoulders. Porous pavements are ideally suited for UU retrofit applications because they do not require additional ROW. However, results from DOT survey found that only 20 percent of the DOTs have used porous pavements in UU environments. The main concerns are potential clogging and uncertainty about the long term performance. Literature information suggests clogging problems are manageable with maintenance, and sustained performance over five years or more has been reported.

Given the potential suitability and benefits of porous pavement for UU retrofits, the Research Plan will include a more detailed assessment on the performance, maintenance and costs of porous pavements. This will consist of a more detailed literature review and queries of DOT personnel and leading researchers. The goal is to develop guidance on the applicability and use of porous pavements in treatment trains. For example a permeable friction coarse overlay applied to the existing roadway shoulder could potentially be used a pretreatment for a media filtration system that is designed to fit within an existing catch basins. The permeable overlay would provide pretreatment of particulate bound pollutants, and the media filtration cartridge could be tailored to target more soluble pollutants such as dissolved metals or phosphorus. This combination would likely have less disruption on existing infrastructure than other underground options, and may be less costly to construct and maintain. Porous pavement may also be employed in a multi-objective manner, since permeable friction coarse overlays are frequently used for splash and spray control, e.g., along significant portions of I-5 in Oregon.

***Unconventional and Advanced BMPs*:** DOT survey respondents have reported use of unconventional types of BMPs in UU environments, including cisterns for capture and reuse, diversion to sanitary treatment plants, and flocculation systems. Advanced treatment systems are often employed for specific target constituents such as fine sediments, turbidity, bacteria, and metals. Capture and use BMPs and runoff diversions also reduce pollutant loadings and additionally can help to address volume reduction requirements. The key to their success is to have a use for the water such that the cistern is drained within 2 to 4 days so that the storage is available for subsequent storms. This makes use for irrigation a challenge due to cold weather as well as low irrigation needs following storm events. Advanced treatment approaches are relevant for retrofit projects that target specific TMDL constituents or receiving water conditions.

Research efforts will focus on developing descriptions and fact sheets of selected advanced treatment or harvest and use approaches, their unit processes and target constituents, and assessment of their applicability in UU environments. Information will be compiled through literature searchers and follow-ups with DOT contacts.

5.3 Compile BMP Performance Data and BMP Certification Procedures

BMP treatment performance is a primary consideration for BMP selection. Long term BMP reliability and performance was rated as a very high concern for BMP selection in UU environments by a large majority of the DOT survey respondents.

When comparing treatment performance of candidate BMPs, it is important to consider the various metrics and protocols that may be used to establish BMP performance. In addition, BMP selection may also be constrained by DOT certification practices that establish acceptable BMPs types.

The guidance document will include a section to assist users with evaluating, obtaining, and using BMP performance data. This section will include descriptions of BMP performance metrics, BMP testing protocols, and DOT certification procedures. This section will also list sources for BMP performance data and will present summaries of BMP performance data. The following describes the proposed efforts.

BMP Performance Measures: Treatment performance metrics include percent removal and effluent quality. Hydraulic performance metrics include capture efficiency (amount of runoff processed and the amount bypassed), detention time, and volume reduction. Often these performance measures are simply related to BMP type or BMP categories. More comprehensive assessments relate the BMP performance measures to pollutant properties and BMP sizing and design features.

We will prepare descriptions of treatment and hydraulic performance measures, including recent approaches for performance curves for proprietary BMPs. We will discuss how these measures can be used and considered in BMP evaluation and selection for retrofits. In particular, it is important to think about performance in terms of pollutant properties of target constituents, to consider effluent quality in terms of receiving water objectives, and to think about consistency of performance measures and test conditions when comparing alternative BMPs.

BMP Testing Protocols and DOT Certification Procedures: Our research on DOT certification procedures revealed that there are a variety of testing protocols that are used to establish BMP performance. A number of these protocols are used by DOTs as a basis for BMP certification. There is also an ongoing effort to unify testing protocols.

We will describe and summarize the main features of the testing protocols. The purpose is to provide context for BMP performance data, particularly for proprietary BMPs. We will also describe DOT certification procedures and present case studies. The ability to implement or pilot tests of unapproved BMPs may be a consideration for retrofit application of proprietary BMPs.

BMP Performance Data Sources: We will describe sources of BMP performance data for inclusion in the guidance document. Sources will include DOT research reports, agency report and websites, testing organization reports and websites, and manufacturer sponsored reports.

BMP Performance Data: We will compile and summarize BMP performance data for inclusion in the guidance document. Summary tables will be presented in the main document. More detailed data and research results will be included in an appendix or in the BMP fact sheets.

5.4 Compile Information on BMP Maintenance Practices and Considerations

The DOT survey showed that BMP maintenance requirements and costs are among the top concerns of DOT personnel. Comments indicated that DOT maintenance budget are often tight and personnel are stretched. Interestingly many DOTs reported that they do not have formal maintenance manuals. Maintenance must be considered in the selection and design of retrofit BMPs.

One section of the guidance document will be devoted to maintenance requirements and practices. This section is intended to help users identify and consider maintenance requirements of BMP alternatives.

Maintenance Considerations for BMP Selection: We will develop guidance on maintenance considerations in BMP siting, selection, and design. This guidance will be based on the knowledge of DOT issues of concern and the maintenance requirements of specific BMPs. We will support discussion with representative examples. Maintenance considerations include:

- Access location. All BMPs must have access for maintenance and monitoring that is safe and has sufficient space for required equipment. This is especially important for underground BMPs that require frequent monitoring or cleaning. UU BMPs may also have access issues due to the tight constraints of UU highway environments.
- Safety. BMP selection should consider potential safety issues that result when BMPs are not correctly or routinely maintained. An example noted in the survey and literature is the clogging of catch basin inserts. Safety within UU during access is also a concern.

- Equipment and labor requirements. BMP selection should consider requirements for routine replacement of expensive components (e.g. filter cartridges), potential for major maintenance requirement that requires extensive equipment (e.g. refurbishment of clogged infiltration BMPs), or BMPs that require extensive manual labor for maintenance (manual cleaning of sumps).
- Frequency. BMP selection should consider the required frequency for BMP monitoring and maintenance.
- Cost. Maintenance costs a primary issue of concern in BMP selection. We will include representative cost data from literature sources.
- Sustainability. Some maintenance (filter media change out for example), will require materials and other efforts that impact sustainability. Many DOTs and others have to address sustainability issues in selection and design of projects as well as maintenance activities. In the maintenance section, we will also consider sustainability issues.

Maintenance Information: We will compile and describe information sources for BMP maintenance practices and requirements. Information sources include DOT maintenance manuals, manufacturer documents, DOT studies and reports, and guidance documents.

Maintenance Practices: We will compile information on routine maintenance practices for all BMP types. Information will include: typical access locations, equipment requirements, typical monitoring requirements and frequency, typical maintenance practice and frequency, and non-routine maintenance requirements and potential frequency. We will summarize these requirements in tabular form for inclusion in the guidance document.

5.5 Compile Retrofit Costs

Construction and maintenance cost of UU retrofits is likely the top issue of concern for DOTs. The literature review and survey results indicate that water quality retrofits of UU highway facilities are very costly, especially if underground facilities are required. Costs can be very high for planning and design, construction, and maintenance. Moreover, a number of DOTs commented that funds for retrofits are limited or simply not available. Cost will be a main consideration throughout the retrofit process.

One section of the guidance document will be devoted to retrofit costing. The following describes the proposed topics and research efforts.

Cost Drivers: We will develop guidance on cost considerations in BMP siting, selection, and design. This guidance will be based on literature information, case studies, and other guidance documents, in particular the Center for Watershed Protection retrofit manual. Some cost considerations are described below and others will be developed as case studies are reviewed.

- Planning and prioritization. Literature information indicates that retrofit prioritization and project planning can expend significant time and cost. The retrofit approach developed in this study is intended to help streamline retrofit planning

- Siting. Cost drivers for BMP siting include above vs underground locations, and the degree of difficulty for connection with the exiting drainage infrastructure. Possible cost savings exist when BMPs can be sited within the current DOT right-of-way
- BMP selection. Vegetated facilities and surface detention are generally less expensive than proprietary and underground BMPs. Consider treatment trains that reduce disturbance of existing facilities. Consider maintenance requirements.
- BMP design. Consider design flexibility to address unanticipated conditions and errors in as-builts. Avoid tight tolerances.
- Life-cycle costs: These include design, construction, and operation and maintenance.

Information Sources: We will compile and describe information sources for BMP costing. Sources include DOT, manufacturer documents, DOT studies and reports, and guidance documents.

Cost Data: We will compile available literature data on construction and routine maintenance costs for all BMP categories. We will summarize cost data in tabular form for inclusion in the guidance document.

Develop Retrofit Approach and Guidance Document

5.6 Develop Retrofit Approach

In the second part of the research plan we will develop a rational retrofitting approach that can be used wholly or in part to guide retrofit planning and implementation. The following six steps comprise the overall framework of the proposed retrofitting approach:

Step 1 – Define retrofit objectives

Step 2 – Site characterization

Step 3 – Identify potential BMP locations

Step 4 – Identify the BMP and treatment train alternatives

Step 5 – Conduct effectiveness and practicality assessment

Step 6 – BMP design

This framework is based on previous guidance developed for NCHRP and WERF, and on other guidance information on water quality retrofitting.

The first step for developing the details of the retrofit approach is to identify as comprehensively as possible the specific issues and topics that impact each of the six retrofit steps. Issues that we have initially identified are listed in the Guidance Document draft outline shown in Section 6. We will also address input and feedback from the NCHRP Panel, and additional topics will likely emerge as the research the progresses.

Next we will develop guidance on the considerations and methods for performing the retrofit steps. This guidance will be based upon and make use of information from the DOT survey, case studies, other guidance documents, results from previous research BMP identification and assessments (WERF, NCHRP, BMP database), and the results of analyses described under Part 1 of the Research Approach. Step 5 will include consideration of life-cycle costs. The goal is to provide practical considerations and methods for identifying BMP opportunities within existing UU environment; for recognizing site constraints and potential flaws; and for selecting and designing BMP strategies that are effective and practical. As part of this work we will develop illustrative examples using the representative UU highway catchments.

5.7 Prepare Guidance Document and Demonstrate Retrofit Approach

The team will prepare an initial draft of the guidance document based on results of the research efforts. The initial draft will be submitted to the NCHRP Panel for review. The draft guidance document will then be revised to address Panel comments.

The Team will solicit input on the guidelines document and retrofitting approach from DOTs. We will prepare a ½-day workshop to be given at three DOTs around the country and we will provide the draft guidance document to the DOTs for review and input in advance of the workshops. Potential DOTs that have expressed interest in collaborating with the study team were identified in the DOT survey.

The Team will prepare a PowerPoint presentation of the research completed along with a description of the guidance and its uses for presentation at the workshops. Ideally, the workshop will include work sessions in which we apply the guidelines to particular retrofit situations of interest to the DOT. We will attempt to coordinate with the DOTs in advance of the workshops to identify potential projects for discussion in the workshops. Following the work sessions we will request verbal and written feedback on the retrofitting approach and guidelines document. The Team will then revise the guidelines based upon the feedback and a final guidelines document would be developed and provided to NCHRP.

5.8 Prepare Recommendations for Future Research and Final Project Report

Team members will develop recommendations for potential future research to address data gaps identified during this project. The Team will also ask the NCHRP panel members to provide recommendations based upon their knowledge.

The Team will prepare a final research report that documents the entire research effort and summarizes results. The Team will present the study results at TRB, if accepted.

6 Draft Guidelines Outline

Chapter 1: Objectives and Approach for Highway Retrofit Guidance

a. Requirements for Water Quality Retrofits

A description of water quality retrofit requirements for highway facilities and the trend for increasing retrofit mandates. Includes a description of regulations that obligate water quality retrofits.

- NPDES Permits
- TMDLs
- Section 404 WQ Certification
- ESA Compliance
- Other requirements
- Examples of DOT regulatory requirements:
    - DOTs with permit conditions that specifically mandate implementation of standalone WQ permits.
    - DOTs with individual or general permits that require WQ retrofits in conjunction with highway improvement projects.
    - Retrofits to address specific WQ issues (e.g. TMDLs).

b. Ultra Urban Highways – A Retrofit Challenge

A general description of the UU highway environment and the challenges of water quality retrofits. Discusses the rationale and purpose of the guidance document.

c. Organization of the Guidance Document

- Part 1 - Retrofit Resource Data
  The first portion of the manual presents resource information to support highway retrofits. The following topic areas are covered in separate chapters.
    - UU highway characterization;
    - Description of BMP options and applicability in UU environments;
    - BMP effectiveness information;
    - BMP sizing and design considerations;
    - Other BMP selection considerations (safety, vectors, etc)
    - BMP maintenance requirements; and
    - BMP cost information
- Part 2 - General Retrofit Approach
  The second portion of the manual describes the general retrofit approach. The approach entails 6-steps listed below.
  Step 1 – Define retrofit objectives
  Step 2 – Site Characterization
  Step 3 – Identify Potential BMP Locations
  Step 4 – Identify the BMP and Treatment Train Alternatives
  Step 5 – Conduct Effectiveness and Practicality Assessment

Step 6 – Design, construction, and evaluation

PART 1 - RETROFIT RESOURCE DATA

Chapter 2: Characteristics of the Ultra Urban Highway Environment

a. The UU Highway

- A general description of UU highway characteristics, including AADT, ROW width, percent impervious, surrounding land use, highway features (ramps, interchanges, medians, shoulders, landscaping)
- Discussion of UU highway features that pose challenges for retrofits: space constraints, existing infrastructure, existing drainage features, hydraulic gradients, soil conditions (for infiltration)
- Illustration of UU characteristics with examples of representative UU highways
- Classification of UU features into groups based on degree of difficulty for retrofitting.

b. Ultra Urban Highway Drainage Systems

- Description of typical drainage systems: watershed areas, piped and surface conveyances systems, pumping requirements for below grade drainages and high groundwater, on and off-site contributions, outfalls, and snow storage
- Illustration of example drainage areas and drainage systems
- Description of typical receiving waters (streams, wetlands, bays, estuaries, and oceans, groundwater, combined sewers)

c. Water Quality Characteristics of Highway Runoff

- Guidance on water quality data sources
- Description of typical pollutants in highway runoff including a discussion about the potential water quality impacts in receiving waters:
    - Sediments
    - Metals
    - Organics
    - Nutrients
    - Bacteria
    - Trash and debris
    - Chlorides and snow control constituents
- Review of research on particle size distribution in highway runoff and associated pollutant.
- Summary statistics for typical pollutant levels in highway runoff.
- Discussion on the association of ultra urban characteristics and elevated pollutant levels (AADT, surrounding land use)
- Discussion on influences storm characteristic on water quality (intensity, depth, duration, seasonality)

- Description of first flush phenomena, factors that contribute to FF, pollutant types that are susceptible to FF, approaches for quantifying FF
- Discussion of cold climate issues and the influence of snow removal practices on WQ

Chapter 3: Structural Best Management Practice for the Ultra Urban Highway Environment

a. BMP Considerations in UU Highway Environments

- Area requirement
- Elevation head and ability to integrate into existing drainage system
- Performance and effectiveness
- Maintenance requirements and access
- Cost
- Sizing and adaptability to UU environments
- Safety (obstructions, flooding)
- Soil and groundwater condition

b. Sources of BMP Data and Information

- Other Guidance documents
- BMP catalogs
- BMP vendors

c. BMPs Options

Description of BMP options, including discussion on applicability and constraints for UU environments and general reliability.

- Detention basins, wet basins, wetland basins
- Swales and wetland channels
- Filter strips
- Bioretention
- Infiltration/exfiltration trenches, dry wells
- Filtration (sand filters, flow-through biofiltration)
- Porous pavement
- Pretreatment and gross solids removal (racks and screens)
- Proprietary and underground systems:
    - Hydrodynamic systems
    - Underground detention vaults and chambers
    - Baffled tanks (oil-water-grit separators)
    - Stormwater media filtration systems
    - Catch basin inserts
- Flow Control BMPs:
    - Inflow and outflow controls devices
    - Capture and use
    - Diversion to sanitary
- Advanced systems:

        - Flocculation and precipitation systems
        - Disinfection

d. Fundamental Unit Processes Procedures

e. General BMP Selection Approach

Chapter 4: BMP Performance

a. BMP Performance Measures

- Capture efficiency, percent removal, effluent quality,
- performance measures of underground devices

b. BMP Testing Protocols and DOT Certification

- Massachusetts Strategic Envirotechnology Partnership (STEP);
- The Technology and Reciprocity Partnership (TARP);
- The Environmental Technology Verification Program (ETV);
- Washington State Department of Ecology's Technology Assessment Protocol (TAPE);
- BMP Monitoring Protocols from the USEPA database; and
- DOT Certification Procedures
    - Example procedures illustrating range of policies
    - Allowances for non-approved approved approaches
    - Pilot testing and retrofit demonstration

c. BMP Performance Data

- Summary data for various BMP categories
- Performance measures of underground devices

Chapter 5: BMP Sizing and Design for UU Environments

a. Description of General Sizing Methodology

- Overview of sizing approaches for flow based BMPs,
- Overview of sizing approaches volume based BMPs
- Sizing considerations for UU retrofits (opportunistic sizing to address space constraints, targeting first flush)
- Sizing approaches for combined volume and flow-based BMPs
- Sizing considerations for cold climate regions

b. Underground proprietary BMPs

- Overview of manufacturer data and recommendations
- Performance information related to particle size
- Effect of sizing on performance (performance curves using modified Peclet number)
- Effect of off-line vs. on-line BMPs
- Hydraulic head design requirements

c. Detention Facilities

- Design alternatives for UU Environments (various underground systems, alternative surface designs)
- Treatment performance of undersized facilities (literature information; results of analyses with SWMM)
- Resuspension (issues and impacts, potential remedies)
- Outlet design (alternative designs, performance information; analyses using SWMM)
- Batch mode operation or other "smart" controllers (outlet control devices; effectiveness information; analyses with SWMM)
- Targeting First Flush (inlet control devices, batch mode, analyses with SWMM)

d. Filtration Systems

- Configurations for UU environments (surface and underground systems)
- Effect of infiltration capacity on sizing and performance (analyses with SWMM)
- Amendments and tailoring media

e. Infiltration Systems

- Configurations for UU environments
- Effect of infiltration capacity on sizing and performance (analyses with SWMM)

f. Vegetated Systems (bioretention, swales, filter strips)

- Configurations for UU environments
- Effect of sizing on capture efficiency and performance

g. Harvest and Use

- Configurations for UU environments
- Effect of sizing and use rates on capture efficiency and performance

Chapter 6: BMP Maintenance

a. Maintenance Considerations for UU Environments

- Access and staging
- Safety
- Equipment & labor
- Frequency (monitoring and maintenance)
- Cost
- Sustainability

b. Sources of Maintenance Information

- Literature information
- Overview of DOT Maintenance Documentation and Practices

c. Routine Maintenance Practices by BMP Category

Chapter 7: Retrofit Costs

a. Sources of Cost Data

b. Cost Drivers for UU Retrofits

c. Life Cycle Cost Estimate by BMP Category

PART 2 – GENERAL RETROFIT APPROACH

Part 2 of the document provides an overall approach for conducting BMP retrofits in UU environments. There are six chapters that correspond to the six steps of the general retrofit framework listed in Chapter 1.

Chapter 8: Defining Retrofit Objectives

The retrofitting approach starts with an initial set of specific retrofit objectives. The objectives will be refined as information is gathered and site constraints are defined. This section describes considerations and strategies for defining initial retrofit objectives.

a. Establish Retrofit Project Location

- Retrofit basis:
    - Retrofits associated with other highway improvement projects (Project location and outfalls are fixed and known).
    - Retrofits required to address general watershed issues such as load reduction for TMDLs will have established receiving waters but may be undefined and variable.
- Description of retrofit prioritization approaches and considerations.
- Assessment of alternative retrofit locations, including use of available GIS data
- Assessment of potential retrofit opportunities associated with future highway improvements plans (if applicable)

b. Understand WQ Issues in the Project Receiving Waters

- Data sources for identifying water quality and quantity issues in the project receiving waters
- Receiving water quality and designated uses
- Relationship of highway runoff to overall watershed issues
- Stakeholder goals and coordination
- Desired outcomes and treatment objectives

c. Identify Regulatory Compliance Requirements

- Applicable regulations and specific requirements
- Coordination and consensus with resource agencies

d. Identify DOT Practices and Criteria

- Address DOT retrofit practices and criteria (retrofit requirements, BMP selection and sizing requirements, budget constraints, and maintenance policies)

e. Specify Retrofit Objectives

- Description of potential retrofit objectives and outcomes
- Evaluation and ranking
- Example retrofit objectives and projects

Chapter 9: Site Characterization

Site characterization is critical for accurate identification of retrofit opportunities and constraints. This section describes considerations and strategies for site characterization in UU environments.

a. Data Gathering Considerations

- Description of general data sources
- Coordination with local personnel (DOT crews, local agencies and public works personnel)
- Site reconnaissance

b. Highway and Adjacent Land Use

- Current and planned (if any) highway uses and improvement plans.
- Highway design (ROW and shoulder width, safety features)
- ROW impervious and pervious cover
- Adjacent land uses and land cover

c. Highway Drainage System

- Watershed boundaries (on and off-site contributions)
- Topography (including use of GIS to identify drainage pathways, tributary catchments, and highway section low points)
- Impervious and pervious areas cover (on and off-site as applicable)
- Potential for concentrated inflows off highway overpasses
- Outfalls and receiving water system (type, condition, capacity, energy dissipation, constraints)
- Elevation head
- Existing water quality treatment facilities
- Site inspection guidance

d. Hydrology and Water Quality

- Precipitation and storm characteristics (volume, intensity, snow accumulation)
- Water quality characteristics:
    - Receiving waters (hydrologic and water quality characteristics)
    - Highway runoff quality (composition, seasonality, snow melt)
- Project pollutants and parameters of concern

e. Subsurface - Soils and Groundwater

- Geotechnical characterization (soils type and characteristics, contamination)
- Groundwater conditions (depth, fluctuations, quality, uses)

f. Utilities and Unidentified Subsurface Conflicts

- Utilities crossings and conflicts (as-builts, test pits, coordination)

Chapter 10: Identifying Potential BMP Locations

This section describes considerations and strategies for identifying potential BMP locations.

a. Feasibility Considerations for Siting Surface BMPs

Sites that can accommodate surface BMPs are preferred.

- Screening for pervious areas along ramps, landscaped areas, interchanges, adjacent to outfalls, using GIS data where available
- Roadway and shoulder areas for porous pavements
- Shoulder or other areas where pavement could be removed for surface facilities
- Diversion to offsite locations (parks, public landscape areas, diversion to sanitary or CSO systems, utility easements, public or private open areas)
- Practicality for connection to existing conveyance system (feasibility of connection, diversion, and conveyance requirements)
- Conflicts with known utility crossing
- Above ground conflicts (snow storage requirements, safety concerns, planned development or uses)
- Construction and maintenance access
- Soil and groundwater constraints
- Potential construction impacts
- Example applications

b. Feasibility Considerations for Siting Underground BMPs

- Screening based on mapping of existing conveyance system (consider available footprints adjacent to catch basins and existing storm sewers)
- Adding detention into existing conveyance system if over design capacity exists
- Elevation head (evaluate elevation head between potential diversion and outfall locations; assess pumping requirements).
- Connection with existing conveyance system (evaluate infrastructure requirement for flow diversion and conveyance)
- Construction and maintenance access (consider possible maintenance access points and potential safety concerns)
- Underground conflicts (consider known utilities and potential for unidentified conflicts)
- Soil and groundwater issues
- Construction requirements and impacts
- Example applications

c. Specify Potential Retrofit Locations

Chapter 11: Identifying BMP and Treatment Train Alternatives

This section describes an approach for selecting BMP alternatives for WQ retrofits.

a. Identify Applicable BMPs

- Determine properties of the pollutants of concern
    - Pollutant form (dissolved, particulate, chemical, or biological)
    - Pollutant properties (partitioning, speciation, transformations)
- Determine need for flow reduction
- Determine the applicable unit process categories
- Identity treatment and volume control BMPs and treatment trains that provide necessary unit processes

b. Select Candidate Retrofit Alternatives

- Screen list of candidate BMPs based on local conditions
    - DOT policies regarding acceptable BMP practices
    - BMP suitability in cold climates
    - Geotechnical and hydraulic constraints
- Identify applicable BMPs at potential retrofit location
- Develop conceptual designs
- Select retrofit alternatives for practicality assessment

Chapter 12: Practicality Assessment and BMP Selection

This section discusses methods for evaluating and selecting the retrofit BMP.

a. Evaluate Alternatives

- Develop an assessment matrix and perform quantitative and qualitative evaluations retrofit alternatives
    - Sizing issues and constraints
    - Ability to connect with existing drainage system
    - Treatment performance estimates
    - Construction cost
    - Routine maintenance practices (frequency, methods, and cost)
    - BMP reliability (long-term performance, potential failure modes, possible major repairs)
    - Construction issues
    - Safety

b. Grade and Refine Alternatives

- Grade and rank retrofit alternatives
- Assess if retrofit goals are met and need to modify goals
- Solicit input and feedback
- Identify potential refinements
- Select retrofit BMP

c. Evaluate Life-Cycle Costs

Chapter 13: Retrofit Design

a. Sizing Methodology

- Flow based sizing
- Volume based sizing
- Combined volume and flow-based sizing

b. Design Elements

- BMP Configuration
- Hydraulic controls
- Maintenance access and practices
- Component selection

c. Flexible Design / Adaptive Management

d. Construction Considerations

e. Monitoring and Evaluation

References

Appendices

- **BMP Cut sheets**
- **BMP performance data**

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Attachment 1 – DOT Survey Results by State

State or Organization	Number of responses	Is your DOT concerned about stormwater treatment in ultra urban highway environments?	Ultra Urban BMP Applications															BMP Policies and Guidance							Water Quality Retrofit Drivers					WQ RETROFIT POLICIES: Has your DOT prepared guidance or policies for water quality retrofits of highway facilities?	WQ RETROFIT PROJECTS: Has your DOT conducted any water quality retrofits of highway facilities?
			Surface detention (Dry ED/wet/infiltration basins, wetlands)	Underground detention	Oil/water separators	Catch basin inserts	Sand filters	Proprietary media filters (e.g., Stormfilter)	Multi-chamber treatment train systems (MCTT)	Hydrodynamic separators	Vegetated/rock swales	Infiltration trenches	Filter strips	Low Impact Development BMPs (e.g., Bioretention, amended soils)	Diversion to treatment facilities	Cisterns and reuse	Porous pavements	DOT has design guidelines or specific practices for stormwater management facilities in ultra urban (space constrained) environments	DOT has a stormwater manual with a list of approved BMPs	DOT has evaluation and certification procedures for water quality treatment BMPs	DOT has conducted research on water quality treatment for ultra urban environments	DOT has a BMP maintenance manual or policies/guidelines for BMP maintenance	DOT has compared construction and maintenance costs for water quality treatment BMPs	DOT has researched water quality treatment BMPs in cold climates	WQ retrofits are not required	NPDES	TMDL compliance	UIC regulations	ESA		
Alabama(AL)	1	NO																													
Alaska (AK)	1	NO	X		X						X				X										X					NO	NO
Arizona (AZ)	1	YES	X	X	X						X			X					X							X		X		NO	NO
Arkansas (AR)	0																														
California (CA)	1	YES	X				X			X		X	X						X			X	X	X		X	X			YES	YES
Colorado (CO)	6	YES	X	X	X	X	X	X		X	X	X		X	X		X	X	X	X		X	X			X	X			YES/ NO(5)	YES(2) / NO (4)
Connecticut (CT)	1	YES		X	X		X		X	X	X								X	X	X	X		X	X					NO	NO
Delaware (DE)	1	YES					X												X							X				NO	YES
Florida (FL)	1	YES	X	X	X		X	X	X	X	X	X			X	X	X		X	X	X				X	X	X				YES
Georgia (GA)	0																														
Hawaii (HI)	1	YES	X	X		X		X	X	X	X								X												
Idaho (ID)	1	NO	X	X	X	X					X	X							X			X				X				NO	NO
Illinois (IL)	1	YES	X			X					X		X	X	X					X	X		X							YES	NO
Indiana (IN)	0																														
Iowa (IA)	1	YES	X								X		X					X	X						X					NO	NO
Kansas (KS)	0																														
Kentucky (KY)	0																														
Louisiana (LA)	0																														
Maine (ME)	1	YES			X					X																				NO	YES
Maryland (MD)	1	YES	X	X	X	X	X	X		X	X	X	X	X	X											X	X			NO	YES
Massachusetts (MA)	1	YES	X		X					X	X	X	X	X				X	X		X	X	X		X					NO	NO
Michigan (MI)	1	YES			X					X	X	X	X																	NO	YES
Minnesota (MN)	1	YES	X		X		X		X	X		X	X	X	X		X	X			X	X	X	X		X	X				
Mississippi (MS)	1	NO	X								X								X						X					NO	NO
Missouri (MO)	1	NO																							X	X				NO	NO
Montana (MT)	3	YES	X		X	X	X	X	X	X	X	X	X	X				X	X			X	X	X		X	X			NO	NO
Nebraska (NE)	1	YES	X								X								X						X					N/A	NO

State or Organization	Number of responses	Is your DOT concerned about stormwater treatment in ultra urban highway environments?	Ultra Urban BMP Applications															BMP Policies and Guidance							Water Quality Retrofit Drivers					WQ RETROFIT POLICIES: Has your DOT prepared guidance or policies for water quality retrofits of highway facilities?	WQ RETROFIT PROJECTS: Has your DOT conducted any water quality retrofits of highway facilities?
			Surface detention (Dry ED/wet/infiltration basins, wetlands)	Underground detention	Oil/water separators	Catch basin inserts	Sand filters	Proprietary media filters (e.g., Stormfilter)	Multi-chamber treatment train systems (MCTT)	Hydrodynamic separators	Vegetated/rock swales	Infiltration trenches	Filter strips	Low Impact Development BMPs (e.g., Bioretention, amended soils)	Diversion to treatment facilities	Cisterns and reuse	Porous pavements	DOT has design guidelines or specific practices for stormwater management facilities in ultra urban (space constrained) environments	DOT has a stormwater manual with a list of approved BMPs	DOT has evaluation and certification procedures for water quality treatment BMPs	DOT has conducted research on water quality treatment for ultra urban environments	DOT has a BMP maintenance manual or policies/guidelines for BMP maintenance	DOT has compared construction and maintenance costs for water quality treatment BMPs	DOT has researched water quality treatment BMPs in cold climates	WQ retrofits are not required	NPDES	TMDL compliance	UIC regulations	ESA		
Nevada (NV)	1	YES	X		X	X				X	X	X						X	X	X	X		X	X	X					NO	YES
New Hampshire (NH)	1	YES	X	X	X	X	X	X		X	X			X			X													N/A	
New Jersey (NJ)	1	YES	X	X	X	X	X	X	X	X	X	X		X			X	X	X	X	X					X				YES	YES
New Mexico (NM)	1	YES	X		X						X	X	X						X						X	X	X			NO	NO
New York (NY)	1	YES	X	X			X			X	X	X		X								X			X	X	X	X		NO	NO
North Carolina (NC)	1	YES				X				X		X		X					X		X	X				X	X		X	YES	YES
North Dakota (ND)	0																														
Ohio (OH)	1	YES							X	X	X				X			X	X	X	X				X					NO	NO
Oklahoma (OK)	1	NO		X	X	X	X	X			X	X	X	X					X							X				NO	NO
Oregon (OR)	4	YES	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	NO	YES/NO
Pennsylvania (PA)	1	YES	X	X	X	X					X	X		X					X						X					N/A	NO
Rhode Island (RI)	1	YES	X		X	X		X		X	X								X							X				NO	YES
South Carolina (SC)	0																														
South Dakota (SD)	1	YES	X			X													X	X		X				X	X		X	NO	NO
Tennessee (TN)	0																														
Texas (TX)	1	YES	X	X	X	X	X	X					X								X					X				NO	
Utah (UT)	1	YES	X	X	X					X	X					X		X			X		X							YES	NO
Vermont (VT)	0																														
Virginia (VA)	1	YES	X	X				X		X					X		X		X	X	X				X					NO	NO
Washington (WA)	1	YES	X	X			X	X			X	X	X	X	X			X	X		X	X			X	X	X	X	X	YES	YES
West Virginia (WV)	0																														
Wisconsin (WI)	1	YES	X					X		X	X		X	X					X		X	X			X					NO	NO
Wyoming (WY)	1	YES	X					X		X	X														X					NO	NO
USEPA	1	YES	X		X	X					X	X	X	X												X	X			NO	
Washington DC	1	YES	X		X		X			X	X	X	X	X	X			X			X					X				NO	NO
unknown	4	YES	X	X	X	X	X	X	X	X	X	X	X				X		X	X			X		X	X	X			YES(2)/NO(2)	YES(2)/NO(2)