Photo: Jonathan Cutrer

Integrating Stormwater Infrastructure into State Department of Transportation Processes

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Above: Bluebonnets splashed with Indian paintbrush carpet the more than 80,000 centerline miles of Texas roadways in spring. Well-maintained vegetated rights-of-way—such as this swath of bright blossoms—are Texas DOT's most prolific and successful stormwater quality control measure.

Functional stormwater infrastructure is necessary on a roadway, as properly managed stormwater reduces the likelihood of water-related hazards that motorists may encounter and helps to safeguard the quality of natural waters. Stormwater infrastructure must be considered in the design of a roadway, during the construction of the roadway, and in maintenance activities conducted throughout the life of the roadway. For a state department of transportation (DOT) responsible for maintaining, improving, and adding to a large network of roadways, integrating activities related to stormwater infrastructure into established, complex state DOT processes can be especially challenging.

This article describes the experiences of three state DOTs that have performed such integration. Alabama DOT incorporated postconstruction stormwater management (PCSWM) design into the overall roadway design process. Texas DOT developed the approval process for products used in the construction of a roadway to promote vegetation. And Virginia DOT improved the management of data associated with stormwater infrastructure best management practices (BMPs) to effectively focus maintenance efforts.

Postconstruction Stormwater Management Design at Alabama DOT

Roadway design at a state DOT requires meeting multiple, conflicting goals and coordination among various state DOT parties. Many factors—such as traffic capacity, motorist safety, subgrade integrity, and historic site preservation—are considered during the roadway design process. Hydrologic and environmental impacts are also important factors addressed in the process and can serve as formidable constraints on roadway design. With all of these factors in play, a state DOT aims to establish and then maintain a calibrated, effective roadway design process. When a major change in the process is needed, some discomfort and disorientation

Stormwater collects in a Birmingham, Alabama, detention pond under construction in 2014.

Photo: Alabama DOT

among state DOT personnel may occur. Alabama DOT had to undergo such a change in its roadway design process and navigate the subsequent challenges when it formally implemented PCSWM.

PCSWM is now an established municipal separate storm sewer system (MS4) permit requirement for Alabama DOT and many other regulated public entities. The broad objective of PCSWM is the management of stormwater runoff from developed land such that it does not adversely affect the water body into which it drains. PCSWM methods include traditional practices—such as detention ponds—focused more on regulating the discharge rate of channelized runoff, as well as low-impact development–green infrastructure (LID/GI) practices designed to mimic the infiltration of rainwater into subsurface soil and the evapotranspiration of rainwater captured by vegetation that occurs on undeveloped land.

Employing PCSWM practices is contrary to the decades-old approach governing roadway stormwater design, which promotes the removal of runoff from the roadway as quickly as possible. Alabama DOT designers had to adjust to the different stormwater design approach.

Adding to the initial disorientation, the nuances of PCSWM requirements (e.g., type of development eligible for PCSWM regulation and threshold of land disturbance triggering PCSWM requirements) were not intuitive for designers. There were (and still are) only a few studies in literature and limited technical guidance concerning the selection and design of PCSWM practices.

Even with more orientation, Alabama DOT designers encountered implementation challenges unique to state DOTs. PCSWM regulations and guidance are typically developed with municipalities and similar entities in mind, but the linear nature of roadways and the small amount of roadside space available limit the feasible options for the selection and sizing of PCSWM BMPs. Maintenance demands must also be considered in BMP selection, as finite maintenance resources are spread over an entire state. Additional discussion about state DOT–specific challenges can be found in a white paper summarizing the outcomes of the 2012 AASHTO National Stormwater Practitioners Meeting (*1*).

To lay the groundwork for success in meeting PCSWM challenges, Alabama DOT relied heavily on its Office of Environmental Coordination and other mechanisms to coordinate internally during the implementation of the PCSWM program. This effort allowed Alabama DOT design, construction, and maintenance personnel to understand the intricacies of PCSWM concepts and requirements, express any general concerns, and explain any conditions that would make BMP implementation especially difficult or infeasible.

With functional coordination in place, Alabama DOT established an official, agencywide PCSWM policy. This policy concisely mandates accounting for hydrologic changes resulting from the development of Alabama DOT facilities, encourages LID/GI practices, and outlines the key definitions and applicability criteria for PCSWM. The policy was approved by the Alabama DOT chief engineer and the Alabama DOT director, thereby giving the policy proper authoritative support.

Specific and straightforward PCSWM guidance was developed for the designer. The guidance is a step-by-step procedure to determine the net increases in total runoff volume and peak runoff flow rate due to development using a design precipitation depth, which is based on the amount of precipitation resulting from a 95th-percentile storm event. To aid the designer in determining the design depth at a particular location, a map of Alabama with zones of particular precipitation depths was generated (Figure 1). Alabama DOT's roadway design process now includes steps for conducting this hydrologic analysis and coordinating with Alabama DOT's offices involved in stormwater management early in the process so that PCSWM feasibility issues and unique

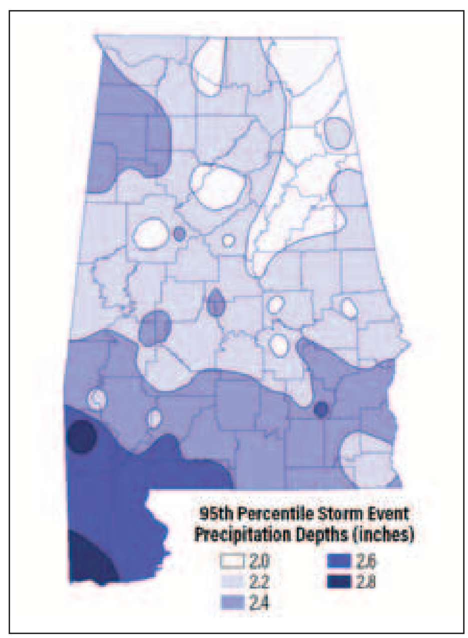

FIGURE 1 **Alabama precipitation depths for the 95th-percentile storm event.**

site conditions can be explored thoroughly before right-of-way acquisition and major design deadlines.

PCSWM BMP selection is less straightforward for the designer. Knowledge is increasing about the performance of BMPs that are appropriate for placement alongside roadways, but it is still lacking overall. The first Alabama LID handbook was published in 2014, and the guidance it provides is somewhat general (*2*). In addition, a National Cooperative Highway Research Program guidance manual focused on roadway stormwater infiltration was only published in 2019 (*3*). Even with more knowledge, BMP design must be tailored specifically to project site characteristics. Therefore, Alabama DOT currently instructs designers to collaborate with Alabama DOT stormwater professionals during the BMP selection process.

Alabama DOT initially relied on the detention pond (see photo, page 10) as its primary PCSWM BMP. The agency now prefers LID/GI BMPs where site conditions allow for reasonable implementation. Over several years of trial and error, Alabama DOT developed its infiltration swale, a variant of the vegetated swale—as defined by the U.S. Environmental Protection Agency (*4*)—and is currently employing the infiltration swale as its primary LID/GI BMP.

Put simply, the infiltration swale looks like a standard grassed roadside ditch, but it has a designed subsurface soil matrix that promotes infiltration at a rate intended to approximate predevelopment conditions (see photo). By adapting the standard roadside ditch slightly (see left photo, page 12), Alabama DOT has developed a PCSWM BMP that feels familiar to the agency's design, construction, and maintenance personnel and has contributed to the agency's overall buy-in. Preliminary performance evaluations of the infiltration swale have shown promise (see right photo, page 12), though further study is needed to optimize design.

Alabama DOT has established a viable PCSWM program and successfully integrated it into its overall roadway design process. The agency accomplished this goal by understanding and acknowledging its specific challenges and by adapting to those challenges with functional internal coordination.

Photo: Alabama DOT

The inner workings of a Huntsville, Alabama, infiltration swale—under construction in 2017—set it apart from traditional grassed roadside ditches. Alabama DOT designed the soil matrix to allow stormwater infiltration at a rate comparable to that of the area before development.

Product Approval to Promote Vegetation at Texas DOT

Texas DOT maintains more than 80,000 centerline miles (128,000 kilometers) of roadway throughout the multiple ecoregions of Texas. By sheer quantity, Texas DOT's most prolific and successful stormwater quality control is a well-maintained, vegetated right-of-way. Vegetation characteristics, soil composition, and precipitation amounts vary greatly across the large state, and that variability creates specific challenges to vegetation maintenance on the Texas DOT right-of-way.

For vegetation to establish properly on a constructed roadway and maintain adequate integrity after construction, products that provide reasonable assurance of performance must be employed. To that end, starting with the 1993 edition of the Texas DOT's *Standard Specifications for Construction of Highways, Streets and Bridges*, the agency shifted from a material-based specification to one requiring the use of products on an approved product list (APL).[1]

[1] The current APL can be found online at https://www.txdot.gov/business/resources/erosion-control.html.

To be placed on the Texas DOT APL, a product must meet or exceed all adopted minimum performance standards for the application. Failure to meet any of the adopted minimum performance standards entails an automatic rejection of the product. The APL is regularly updated as products improve and become more effective. Products are added to the APL and then continue to be listed for up to 3 years. After 3 years, recertification of the product is required. Texas DOT bases minimum performance standards on statistical analysis of performance data collected in controlled performance tests.

Performance tests are conducted at the Texas A&M Transportation Institute Sediment and Erosion Control Laboratory (SEC Lab), which is supported by funding from Texas DOT. The SEC Lab is a 19-acre (7.7-hectare), full-scale, indoor–outdoor facility that recently underwent an expansion to meet industry research needs. The SEC Lab houses indoor rain simulators, runoff beds, testing flumes and channels, soil embankments at varying slopes, and a climate-controlled greenhouse for growing vegetation year-round. The SEC Lab's testing capabilities are amply robust for comprehensively evaluating product performance.

Generally, the minimum performance standards align with the following critical performance factors adopted by Texas DOT:

Photo: Alabama DOT

A covering of sod completes the Huntsville infiltration swale. Yellow lines outline the approximate swale boundaries.

Photo: Alabama DOT

The Huntsville infiltration swale impounds stormwater runoff before the water slowly drains into the underlying soil matrix. Yellow lines indicate approximate swale boundaries.

- The protection the product provides for an embankment seedbed or a drainage channel from sediment loss during simulated rainfall or channel flow events and
- The degree to which the product promotes warm-season, perennial vegetation establishment.

Texas DOT considers two categories of erosion control and revegetation products: rolled and spray-on products, which include soil retention blankets, and standard hydraulic mulches, which include cellulose fiber mulches. The minimum performance standards recognize that rolled and spray-on products are classified for use by the industry in one of the two following ways:

- Products designed for overland flows associated with typical slope or embankment protection applications (termed "Class 1" applications in Texas DOT Standard Specification Item 169) and
- Products designed for concentrated water flows associated with typical highway drainage channels (termed "Class 2" applications in Texas DOT Standard Specification Item 169).

Texas DOT's current specifications for soil retention blankets and cellulose fiber mulches do not include any of the typical ASTM material requirements, such as mass per unit area, water holding capacity, tensile strength, elongation, and pH. The agency believes performance evaluation under Texas DOT–applicable conditions is more reliable than evaluation according to generalized ASTM parameters. Hence, the agency instead bases approval of soil retention blanket and cellulose fiber mulch products on the formal evaluation conducted at the SEC Lab.

Texas DOT recognizes that the performance of a product may vary if the product is installed under less-than-ideal conditions or is not installed in complete accordance with manufacturer specifications. To supplement the robust product evaluation conducted by the SEC Lab, the agency will soon begin capturing the in-field, real-world experiences of product implementation from users on construction sites. Comments received from onsite users will be used to generate scores for products employed. The APL format will be updated to provide user recommendation ratings and other user performance evaluation information for products on the list.

The key advantage of the updated APL format will be the ability for a user to compare product performance ratings to determine the appropriate products for a real-world construction site. The updated APL format is scheduled to be released in late 2020.

For more than 25 years, the Texas DOT APL has promoted quality assurance in the products used to establish and ensure the integrity of the vast amounts of vegetation that flank agency roadways and that quality assurance should increase as Texas DOT continues to seek improvement in the product evaluation process. As a mark of validation, the Texas DOT APL is not only used and appreciated by the agency; it has been used in more than 25 states throughout the country.

Stormwater Infrastructure BMP Data Management at Virginia DOT

Virginia DOT is in the process of updating its information technology tools to better monitor the inspection and maintenance of various assets at the enterprise scale. This effort will improve the agency's understanding of asset life-cycle costs, which will inform decisions about the cost-effectiveness of materials and practices that may be used in future roadway and facility designs. Asset management associated with stormwater management BMPs is particularly important, as Virginia DOT currently has more than 2,400 BMPs in its inventory to manage stormwater runoff in compliance with applicable regulations and permits.

Virginia DOT recently updated its BMP inspection application for mobile devices to improve the data collected during BMP inspections and to more precisely identify specific maintenance needs. The application is built on ESRI ArcGIS Enterprise and Survey 1-2-3 software. The application can be employed in the field. As soon as data from a field inspection is uploaded to the central database, any authorized Virginia DOT manager or user can see it.

The agency will also develop Survey 1-2-3 dashboards to provide managers with an organized display of key metrics related to BMP inspection and maintenance. Also, the associated Virginia DOT *Stormwater BMP Inspection and Maintenance Manual* is being updated to align with the new inspection app and to provide more comprehensive information about BMP maintenance.

Elaborating on the improved data collection procedure, the Virginia DOT inspector first requests data corresponding to a BMP ID number using the updated inspection app. Key identifying data are displayed on the tablet screen, including the name of the logged-in inspector, current date, BMP category (e.g., basins, infiltration, or manufactured devices), and specific BMP type (e.g., extended detention basin, bioretention, or grassed swale) (Figure 2). With the BMP identified, sets of inspection questions for the applicable BMP category can be accessed by the user (Figure 3). When the inspector clicks on a question set link, a drop-down menu of one or more subsidiary question sets opens (Figure 4).

Questions asked in each set explore a variety of potential problems the BMP may be experiencing (Figure 5). Skip mechanisms are built into the app so that, if the inspector indicates—by answering a question—that a BMP is completely functional, or if a line of questioning is not applicable for a given situation, the app foregoes additional, unnecessary questioning.

The depth of inquiry conducted by the app allows for the identification of specific maintenance needs. Each inspection question corresponds to an appropriate maintenance task in the database, and the app infers the urgency of a specific maintenance need from the inspector's responses to app questions. Scores that indicate maintenance urgency are assigned according to the following rubric:

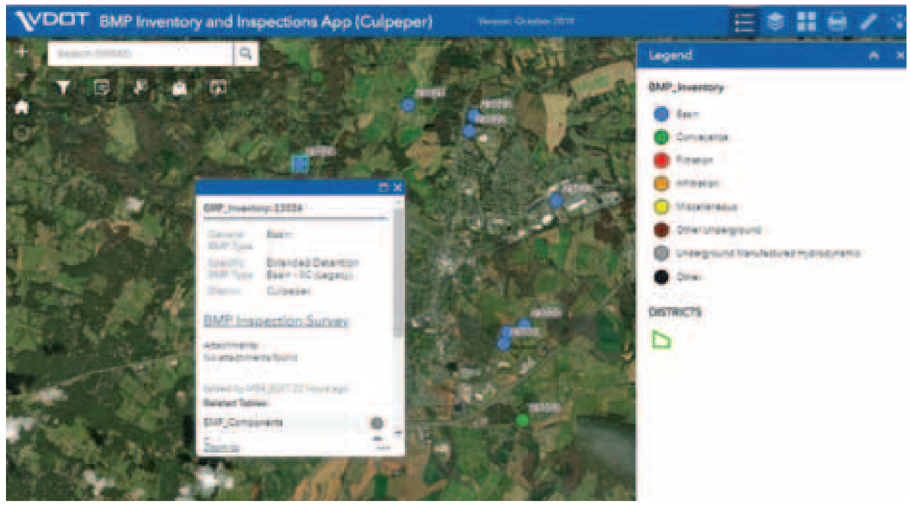

FIGURE 2 Identifying information for a selected BMP.

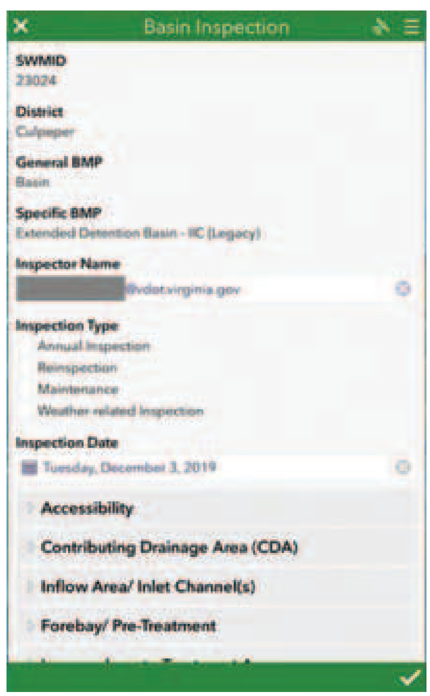

FIGURE 3 Inspection question sets displayed for the "Basins" BMP category.

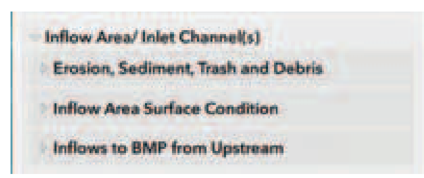

FIGURE 4 Subsidiary question sets for "Inflow Area/Inlet Channel(s)."

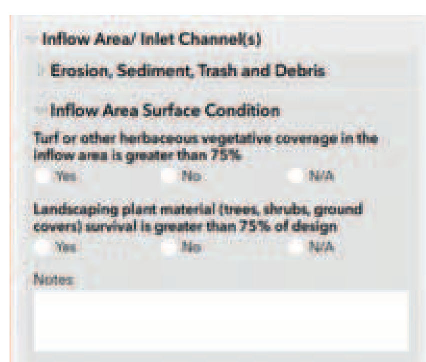

FIGURE 5 Questions for "Inflow Area Surface Condition."

A = okay
B = only routine maintenance needed
C = straightforward corrective maintenance needed
D = significant maintenance needed
E = failure or emergency repairs needed

Ratings A, B, and C indicate full functionality. Ratings D and E indicate inadequate functionality. When the inspection is completed, the app will assign an overall score to the inspection based on the lowest rating of all BMP inspection criteria considered. For example, if the lowest rating for a given BMP was associated with "inflow area surface condition," and that rating is C, the overall BMP inspection score would be C.

The inspector can print the complete BMP Inspection Report, which shows all questions asked by the app—including the questions without response—and corresponding answers, as well as the BMP Maintenance Report, which shows only the questions and answers associated with maintenance tasks to be performed (Figure 6). The BMP Maintenance Report provides the basis for a work order that is sent to a Virginia DOT maintenance crew or contractor to accomplish the needed maintenance.

Work orders are managed by a different Virginia DOT database: the Highway Maintenance Management System (HMMS). HMMS allows the agency to track maintenance activities and costs over time, including those for stormwater management BMPs. Thus, the system enables Virginia DOT to track needed stormwater management BMP maintenance, tally BMP costs throughout the life of a BMP, ensure continued BMP functionality, and monitor Virginia DOT's regulatory compliance status with respect to stormwater management.


BMP Maintenance Report

Required Maintenance

FIGURE 6 **Example of a Virginia DOT BMP Maintenance Report.**

The major outcome of these Virginia DOT data management efforts is a more meaningful connection of field evaluations of BMP performance to the agency's overall system of stormwater management. Quality data allow Virginia DOT to allocate maintenance resources to address the more important stormwater management issues proficiently and enable project designers to make better choices in the future with regard to employing BMPs to manage stormwater.

Conclusion

This article has detailed the successful experiences of three state DOTs in integrating stormwater infrastructure into state DOT processes. It is likely that many state DOTs are finding similar success by implementing change strategically. A state DOT seeking to integrate stormwater infrastructure into its processes should consider its goal attainable, given ample time and the lessons already learned by other state DOTs.

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CENTENNIAL QUOTE

I grew up in an Eastern Airlines household, building model trains, planes, and ships. That led me to major in engineering at the Massachusetts Institute of Technology. But, my interest was more in transportation policy than engineering, so I launched Reason Foundation in 1978. Five years later, my introduction to TRB was an invitation to present a paper on reforming FAA's air traffic control system, which was then published in the *Transportation Research Record.* I soon joined TRB's Congestion Pricing Committee and took part in FHWA workshops on pricing, tolling, and private finance highway projects. TRB continues to be a great resource for my colleagues and me.

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