Appendix J

BMP Case Study Reports

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BMP Case Study Reports

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Foreword:

These case studies were developed through interviews/meetings with DOT representatives and review of project information obtained from these DOTs. The research team intentionally focused on case studies that were biased toward BMP failures. By focusing on failures, these case studies provided lessons learned and findings that helped inform this Guidance Manual. These case study reports may also directly helpful for users.

CASE STUDY REPORT

Arizona DOT: SR 303L Basin at Waddell Road

Case Study Introduction

BMP Type:	Retention Basin
Geographic Location:	Maricopa County, AZ
Project Setting:	Retention Basin located north of SR 303L Interchange at Waddell Road. Part of a regional system of other basins and channel improvements.
Notable Factors in Success or Failure of BMP	Inadequate design guidance and documentation factors

ADOT has constructed a number of on-line retention basins connected in series by a drainage channel that flows along the west side of SR 303L towards I-10. Along this stretch of highway, multiple retention basins have failed. Collected runoff failed to percolate within the design criteria and resulted in multiple citizen complaints regarding vectors and mosquitos. Just north of the interchange at Waddell Road, one of the failed basins also experienced run-on that was not anticipated, from nearby agricultural fields. This resulted in severe erosion of the basin slopes. As a result, ADOT evaluated contractor claims as to the adequacy of the design. The retention basin near Waddell Road is the primary subject of this case study, although references are made periodically to other basins constructed as part of the regional system. A photograph depicting the damage at the Waddell Road Basin is shown in Figure 1.

Figure 1. Erosion Damage at Waddell Road Basin (SR 303L)

Information Obtained for Case Study

Materials received for the study:

- Photographs of the Waddell Road Basin provided by ADOT
- *"Estrella Freeway, SR303L Initial Drainage Report Stage II Design (30%) Thomas Road – Peoria Avenue"* (PB Americas, Inc., 2008)
    - *"Appendix F Storm Drain Calculations"*
    - *"Appendix H Retention Basin Calculations"*
- Project 303-A-202 Design Drawing Nos D-5.5 – D-5.18 (Parsons Brinckerhoff, 2008) – including layout and design details for basins at McDowell Road, Camelback Road, and Northern Avenue.
- Project 303-A-202 Design Drawing Nos D-4.1 – D-4.5 (Parsons Brinckerhoff, 2008) – including drainage key map, plan and profile information for west channel from McDowell Road Basin to Existing Olive Avenue Basin.
- *"Inert Materials/Seeding Plan (Sheet 40 of 11)"* (J2 Engineering and Environmental Design, 2013) depicting repairs to the Waddell Road Basin.

Agency Communication:

- Leigh Padgitt, Municipal Stormwater Program Coordinator
- Lisa Andersen, Central District Environmental Coordinator

Case Study Setting

Project Context

The Arizona Department of Transportation (ADOT), the Maricopa Association of Governments (MAG), and key local transportation agencies recently expanded the metropolitan Phoenix freeway system to address regional travel needs. The Estrella Freeway or State Route Loop 303 (SR 303L) is a 40-mile long new freeway. It extends from the future SR 30 (I-10 Reliever) near MC85 north to Interstate 10 (I-10), across US60 (Grand Avenue), and then to the northeast to connect with Interstate 17 (I-17). SR 303L is planned to ultimately have five lanes; four general purpose lanes and one high occupancy vehicle (HOV) lane in each direction (the 4+1 freeway concept).

Construction of SR 303L has occurred in several phases. Collectively, these resulted in the creation of a regional drainage system that included several basins (including the one at Waddell Road), a concrete lined conveyance channel, as well as smaller system of storm drain inlets and underground conduits. The regional system is primarily intended to reduce peak discharge downstream towards I-10. The 100-year, 24-hour storm event was used for design.

Site Location and Physical/Watershed Setting

The study segment is in northwestern portion of the Greater Phoenix Metropolitan, SR 303L between Peoria Avenue and I-10. It is situated within the middle Gila River Watershed, depicted within Figure 2. The portion of the Gila River between Centennial Wash and Gillespie Dam is considered by the Arizona Department of Environmental Quality (ADEQ) to be impaired for Boron and Selenium. The US EPA approved a TMDL for these constituents in December 2015. SR 303L and the surrounding lands contribute runoff to the impaired reach of the Gila River. Recent aerial photographs indicate that the surrounding lands are used for agricultural purposes and there has been some residential development as well. Although less evident in aerial photographs, ADEQ also cites municipal and industrial discharges as point/non-point sources within the middle Gila River Watershed.

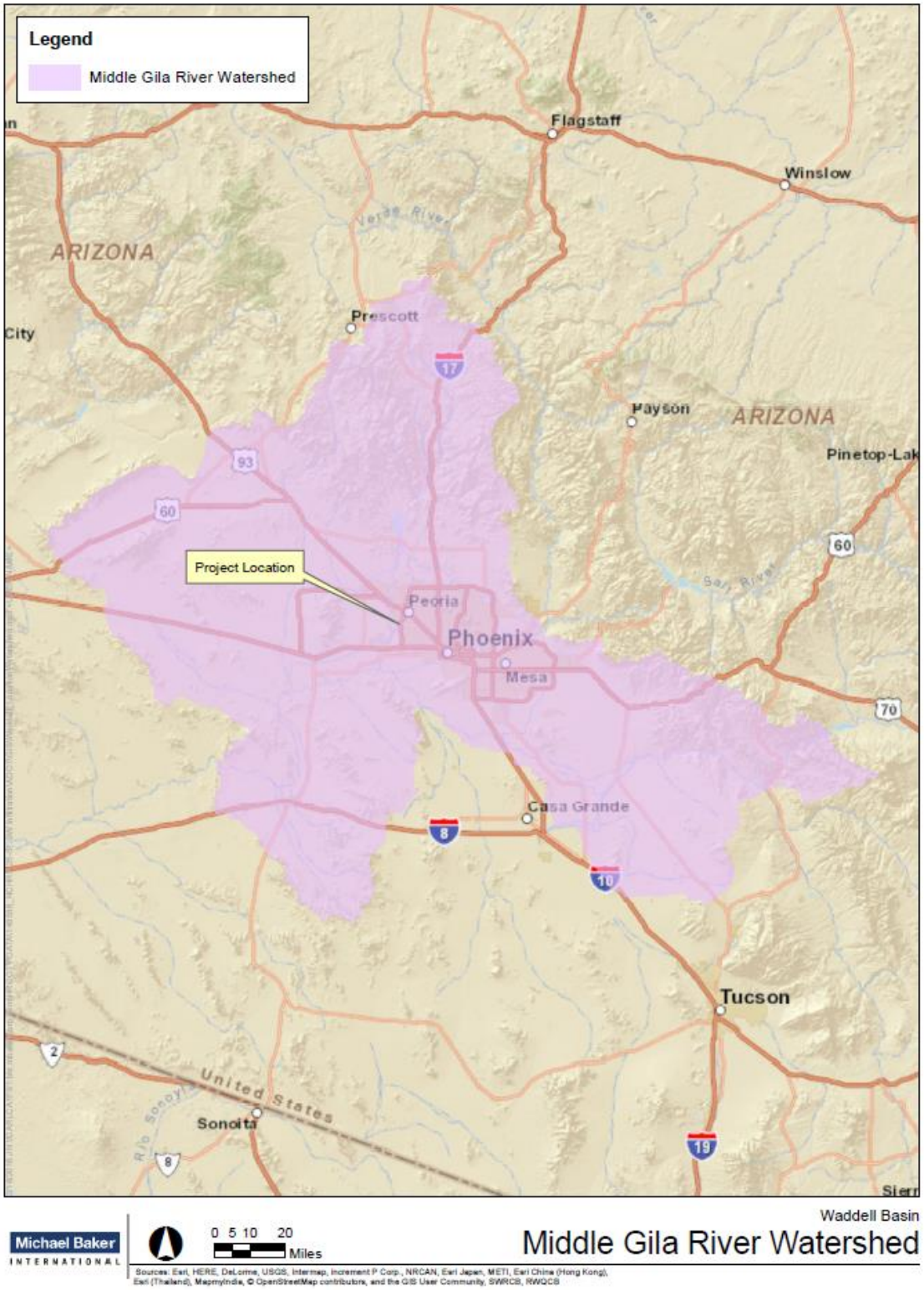

Figure 2 Location of Case Study within Gila River Watershed

Applicable Regulations and Available Guidance

ADOT is under an Arizona Pollutant Discharge Elimination System (AZPDES) municipal separate storm sewer system permit (MS4 Permit) that requires ADOT to develop, implement, and maintain comprehensive planning procedures and control measures to reduce the discharge of pollutants to the maximum extent practicable from new development and significant redevelopment within the MS4. Therefore, ADOT developed a Statewide Stormwater Management Plan or SSWMP (ADOT, 2005) that describes its program to reduce the discharge of pollutants associated with stormwater drainage facilities that serve highways as well as related facilities and activities. The SSWMP describes the use of a Post Construction Best Management Practices Manual by ADOT to:

1. Identify factors for consideration during selection of post construction BMPs
2. Provide Design Guidance for post construction BMPs

As of September 18, 2008, all ADOT new construction or redevelopment projects beyond 15% design were required to incorporate post-construction water quality BMPs, but only if the project discharged to unique[1] or impaired waters

Chapter 600 of ADOT's 2012 "*Roadway Design Guidelines*" provides design guidance for detention or retention basins within the context of attenuating peak flows. No guidance for other types of basins is provided, such as infiltration basins. The design storm mentioned within these standards varies from the 10- and 50-year recurrence interval as a function of project type – with the potential to increase the upper end of this range to the 100 year based upon flood control considerations. There is no specific mention of a water quality or "first flush" type event. More recently, ADOT updated its post-construction manual in January 2016 (*Post-Construction Water Quality Control Measures* ADOT, 2016). This manual has served as a general guidance to assist ADOT staff and consultants in understanding when and where to include post-construction control measures or best management practices in new construction and redevelopment projects to achieve water quality improvements. It cites infiltration as the most common treatment mechanism along ADOT roadways. The program guidance manual discusses other pertinent factors respect to infiltration basins:

1. Consideration of site-specific soil conditions and subsurface geology (including permeability rate). Infiltration basins are required to maintain a minimum of 0.5 inch per hour permeability rate.
2. Design storm, standards cross reference "*Roadway Design Guidelines*"
3. Maximum hydraulic head – Infiltration is prohibited in circumstances where the required head exceeds 12'.
4. Impact *to* groundwater
5. Influence *of* groundwater – Infiltration basins are prohibited where groundwater depth is less than 4' from the basin bottom
6. Temperature
7. Cost
8. Sedimentation effects

[1] Unique is now referred to as Outstanding Arizona Waters

9. Excavation practices – Soil compaction below the basin is to be avoided. Basins with 4' of excavation require proper stabilization and benching under the supervision of a geotechnical engineer. Side slopes are limited to a 4:1 maximum inclination.
10. Sequencing – Proper erosion and sediment controls are to remain in effect until the risk of sediment from tributary areas has been eliminated through permanent stabilization.
11. Pretreatment – In scenarios under which dense vegetation cannot be established, perimeter filter strips of dense vegetation or decomposed granite are required. Sacrificial layering of sand in the basin bottom is also suggested to prevent clogging of the underlying soil (15% fines, minimum permeability of 20 inches per hour).
12. Use of a *bypass or overflow* discharge mechanism
13. Use of an "optional" observation well to inspect for standing water and sediment accumulation.

Planning and Design Phase

Site Investigation and BMP Selection Findings

No specific documentation was provided concerning an investigation into the suitability of the basins for infiltration from a geotechnical perspective. Furthermore, no documentation was provided discussing the intent or functionality of the basins from a water quality perspective.

BMP Sizing and Design

No design documentation (i.e. plans or engineering calculations) were provided specifically for the Waddell Road Basin. Plans and calculations for the construction of other basins associated with SR 303L suggest that design was based upon the 100-year, 24-hour event, and that the analysis was limited to controlling peak flow rate to downstream infrastructure and the Gila River. Plans for these other basins specify the use of low flow channels, and clearly indicate outflow pipes at an elevation equivalent with the basin invert – bringing into question the intended function of these basins for water quality improvement through infiltration. Refer to Figure 3.

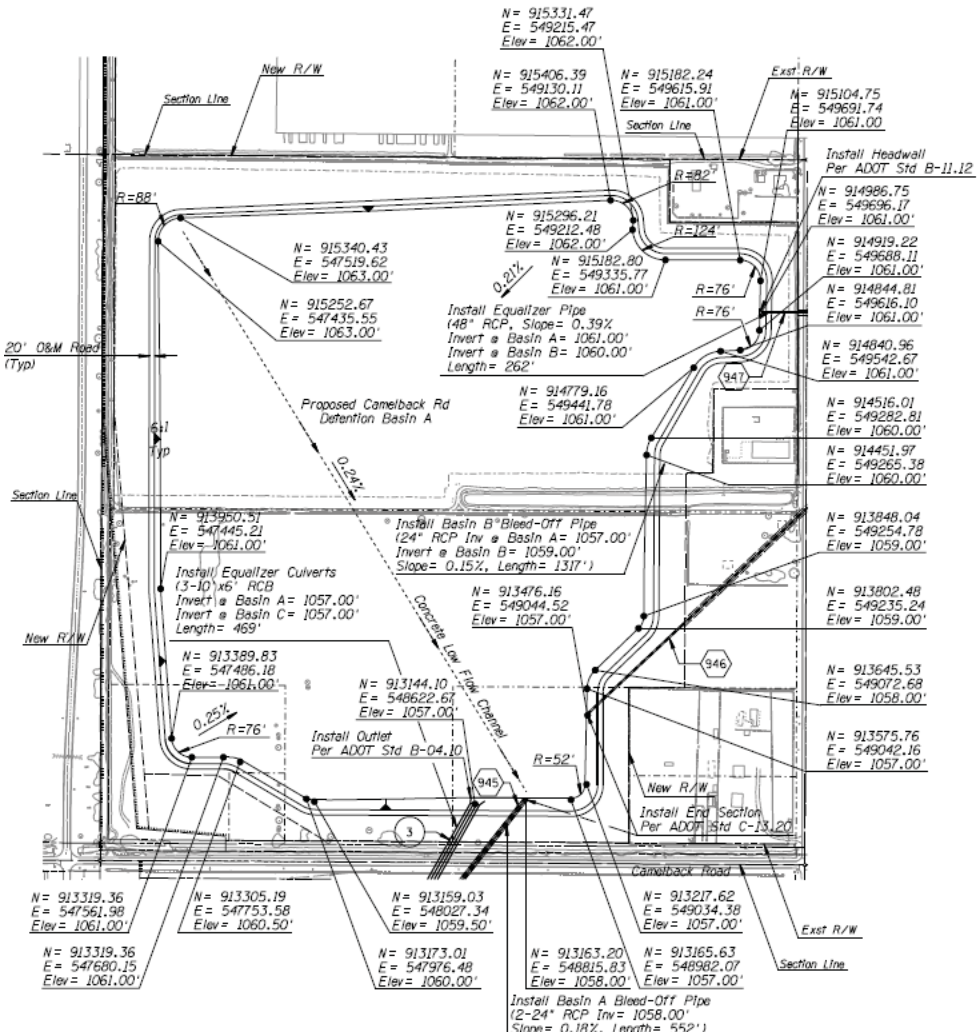

Figure 3 Representative Construction Detail of Basins along SR 303L

Construction Phase

There is no documentation that significant changes or contractor error occurred during construction. It is assumed that all basins were constructed consistent with the approved design and that ADOT performed standard construction inspection procedures for infiltration best management practices (BMPs).

Operation and Maintenance

BMP Operation and Maintenance Observations and Records

ADOT's Post Construction Water Quality Control Measures manual briefly describes operational inspection requirements for infiltration basins. It cites the requirement to:

1. Inspect for drawdown of water within 48 hours,
2. Identify the presence of trash and sediment, as well as vector development.

Inspections are required within 24 hours following each storm event.

BMP Failure and Resolution

Description of Failure

It is understood through prior correspondence with ADOT personnel that for several basins along SR 303L, collected runoff failed to percolate within the design criteria (48 hours). This resulted in multiple citizen complaints regarding vectors and mosquitos. At Waddell Road, concentrated overflow from a nearby agricultural pond resulted in severe erosion and flooding of the basin (Figure 4. A repair plan was developed to stabilize the outer perimeter using granite mulch and class 2 aggregate base material to restore maintenance access.

Figure 4. Failure of a nearby agricultural pond resulted in severe erosion and flooding of the basin

Summary and Lessons Learned

Factors Contributing to Failure

It is likely that several potential factors contributed to the failure of the Waddell Road Basin, as well as standing water issues at other similar basins constructed along SR 303L. They include:

1. Inadequate documentation:
    a. It is unclear if these basins were intended to provide water quality improvement through infiltration. Design documents in many cases describe basins as functioning through

"retention" and, in some instances "detention". The ADOT Post Construction BMP Water Quality Manual clearly distinguishes detention from infiltration. If the latter were intended, basin outfall pipes should have been elevated above the basin invert.

b. It is unclear if any geotechnical analysis was conducted. It is possible that underlying soils did not possess the minimum required permeability rate of 0.5" hour.

c. It is also unclear if ADOT requirements for the use of a sand layer at the bottom of the basins were applicable, and if so, were followed.

d. It is unclear if any blockages in outflow pipes or the channel were contributing to standing water problems within the basins.

e. It is unclear if the bottom of the basin was compacted beyond applicable standards.

2. Inappropriate design standards for infiltration BMPs

a. It is not typical to permit infiltration BMPs to store water at depths greater than 1' to 2'. Basins constructed along SR 303L were designed significantly beyond this limit. Excessive head is known to contribute to clogging risk and amplify the maintenance implications if standing water or sediment deposition were to occur.

b. On-line configuration and siting – It is generally desirable to orient infiltration BMPs "off line" to reduce scour potential at inlet and outlet points and reduce overall sediment load to the basin. Reduction of scour in turn reduces the clogging risk. Design standards should incorporate guidance for siting basins away from potentially significant run-on or overflow sources, such as the case at Waddell Road.

CASE STUDY REPORT

Caltrans: Chollas Creek Metals TMDL BMP Retrofit

Case Study Introduction

BMP Type:	Modular Infiltration System
Geographic Location:	On SB SR-15 Just South of the SR-94 Interchange: 32.715615°, -117.118134°
Project Setting:	BMP retrofit project within the existing freeway corridor to address Metals, as well as Diazinon, and Bacteria TMDL's in the Chollas Creek Watershed.
Notable Factors in Success or Failure of BMP	1. Inadequate measures taken to prevent clogging of influent pipe within diversion structure 2. Potential future issues from extended drawdown as a consequence of excessive design depth (i.e. 7.5')

The system constructed for this project a high-density polyurethane plastic to form a lightweight modular cell system designed for infiltration and attenuation (Figure 5, Figure 6). Manufactured from recyclable plastic, each cell has a 97% void ratio reducing the cost associated with excavation and aggregates. Open on all four vertical sides, this design offers access for the inspection and maintenance of the system and reduces the potential for silt build up or blockage.

Figure 5. View of BMP During Construction

Figure 6 Ground Level View of Infiltration System

Information Obtained for Case Study

Materials received

1. Project Design Plans (81 Sheets, Project Number and Phase 11000003141)
2. Draft Post Storm Technical Memorandum (Dated 1/28/16)
3. Power Point File of Time Lapse Photographs from Construction (Chollas Creek TMDL Project Report May 2012)
4. ACO StormTank – Manufacturer's Technical Data
5. Power Point File "*Earthen Austin Vault Sand Filter Implementation in Response to Chollas Creek Metals TMDL, Statewide SWAT March 2015"* (Johansson, 2015)
6. Location 7 (11-337) and Location 8 (11-336) Monitoring and Treatment Schematic
7. *"StormTank Stormwater Storage Modules"* Manufacturer's Data (Brentwood Industries, 2008)
8. *Final Submittal "Appendix E, Storm Water Data Report Project ID 1100000314/282401"* (Caltrans, 2013)
9. Load Testing Certification PenCell DT-2-1324 (Appian Consulting Engineers, 2011)
10. Memorandum "*Geotechnical Design Report for Percolation Tests*" 1100000314 (Caltrans, 2012)
11. Memorandum *"Modified Modular Infiltration Trench Maintenance Activities"* (Caltrans, 2013)
12. Bid Summary Contract 11-282404 (Dated 11/14/13)

Agency Communication:

1. Kenneth Johansson, PE, MSPM, MSTM, QSD, QSP: Storm Water Design Engineer, California Department of Transportation
2. Caltrans Interview Panel Transcription (Michael Baker International, 2015)

Case Study Setting

Project Context

NPDES permit Order (2012-0011-DWQ) was adopted by State Water Resources Control Board (SWRCB) on September 19, 2012 and subsequently, on May 20, 2014, the SWRCB, adopted amendments to the Caltrans Statewide Stormwater Permit. Attachment IV was amended to incorporate specific requirements for 84 Total Maximum Daily Loads (TMDLs). Attachment IV to the Caltrans NPDES permit outlines a methodology for prioritizing stream segments included in TMDLs in which Caltrans is subject to. The permit establishes BMP implementation requirements, evaluated in terms of compliance units. Caltrans is expected to achieve 1650 compliance units per year through the implementation of retrofit BMPs, cooperative implementation, and post construction treatment beyond permit requirements. This prioritization list has been finalized and Chollas Creek has been assigned a reach ranking of 80 out of 275 due to the TMDL's for Metals (Copper, Lead and Zinc), Diazanon, and Indicator Bacteria.

The Total Maximum Daily Load (TMDL) program is required under Clean Water Act (CWA) Section 303(d). There are streams, lakes and coastal waters within the RWQCB Region 9 that do not meet water quality standards. CWA Section 303(d) addresses these waters by requiring states to identify the waters and develop total maximum daily loads (TMDLs) to limit the pollutant load to the waterbody.

A TMDL is a quantitative assessment of water quality problems, contributing sources, and load reductions or control actions needed to restore and protect receiving waters. The TMDL does not replace existing water pollution control programs. It provides a framework for evaluating pollution control efforts and for coordination between federal, state and local efforts to meet water quality standards. TMDLs are adopted as amendments to the Basin Plan.

In 1996, Chollas Creek Watershed was placed on the Clean Water Act (CWA) Section 303(d) List of Impaired Water Body Segments (303(d) List) as impaired for copper, lead, and zinc, and toxicity because of diazinon. In 2002, the San Diego Regional Water Quality Control Board (Regional Board) adopted Resolution No. R9-2002–0123, *Total Maximum Daily Load (TMDL) for Diazinon in Chollas Creek Watershed, San Diego County* (Diazinon TMDL) (Regional Board, 2002). In June 2007, the Regional Board adopted Resolution No. R9-2007-0043, amending the *Water Quality Control Plan for San Diego Basin* (Basin Plan) to establish TMDLs for dissolved copper, lead, and zinc in Chollas Creek (Dissolved Metals TMDL) (Regional Board, 2007). The approved TMDLs identify the California Department of Transportation (Caltrans) as a point source discharger to Chollas Creek. Caltrans has been assigned waste load allocations (WLAs) and is responsible for reducing its pollutant load and demonstrating that runoff is not contributing to exceedances of the TMDL numeric targets.

The roads and highways operated by Caltrans discharge stormwater from their municipal separate storm sewer systems (MS4s), which are currently regulated by State Water Resources Control Board (State Board) Order WQ 2014-0077-DWQ, amending the *National Pollutant Discharge Elimination System (NPDES) Statewide Stormwater Waste Discharge Requirements (WDRs) for State of California*

Department of Transportation Order 2012-0011-DWQ (Caltrans NPDES Permit) (State Board, 2014). Provision E2.c of the Caltrans NPDES Permit details the compliance monitoring and discharge characterization requirements for Caltrans Tier 1 sites in TMDL watersheds (excluding watersheds listed only for bacteria impairments); Attachment II and Attachment IV present the compliance monitoring constituents list and implementation requirements for approved TMDLs, respectively.

The Phase I and II Chollas Creek BMP retrofit projects have installed innovative infiltration treatment BMP technology within existing freeway corridors throughout the Chollas Creek watershed to achieve Compliance Units and work toward Waste Load Allocations set forth in the Chollas Creek Dissolved Metals, Diazanon, and Indicator Bacteria TMDLs.

Site Location and Physical/Watershed Setting

The Chollas Creek BMP Retrofit project is located within San Diego County, Caltrans District 11. The modular infiltration trench that is the focus of this case study was constructed on southbound SR-15, just south of the SR-94 interchange. Figure 7 shows the project location and within the context of the Chollas

Creek Watershed.

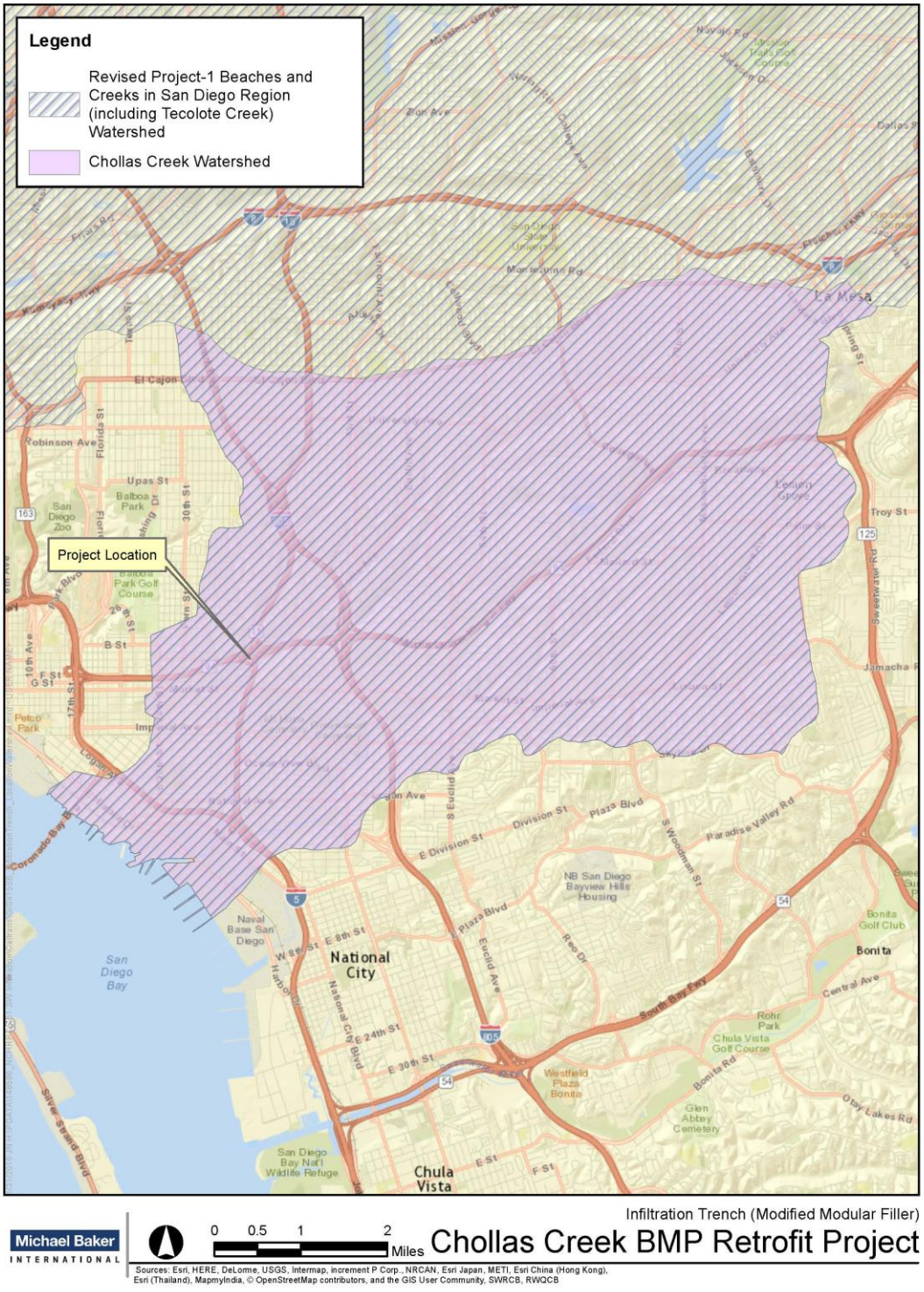

Figure 7 Project Location Caltrans Infiltration System

Applicable Regulations and Available Guidance

1. Water Quality Control Plan for the San Diego Region (Basin Plan)
2. Chollas Creek Dissolved Metals TMDL (RWQCB Order No. R9-2007-0001)

Other Support Information

1. Chollas Creek Diazanon TMDL (RWQCB Order No. R9-2002-01213)
2. Revised Total Maximum Daily Loads for Indicator Bacteria, Project I – Twenty Beaches and Creeks in the San Diego Region (RWQCB Order No. R9-2010-0001).
3. Caltrans National Pollutant Discharge Elimination (NPDES) statewide permit (CAS000003) Order (2012-0011-DWQ)
4. Attachment IV amended the NPDES permit to incorporate specific requirements for 84 Total Maximum Daily Loads (TMDLs), adopted by the SWRCB on May 20, 2014.Construction General Permit (CAS000002) *National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated with Construction and Land Disturbance Activities* (Order No. 2009-0009-DWQ) (SWRCB, 2009), as amended by Order No. 2010-0014-DWQ.
5. Project Planning and Design Guide (PPDG) CTSW-RT-10-254.03
6. Caltrans Infiltration Basins Design Guidance, February 2011
7. Caltrans Infiltration Trenches Design Guidance, September 2010

Planning and Design Phase

Site Investigation and BMP Selection Findings

A site-specific investigation was conducted that included detailed evaluation of the effects of climate, soil and sub-surface physical characteristics, groundwater presence and depth, topography and drainage patterns, receiving waters, and other local conditions that would potentially impact the effectiveness of infiltration best management practices to remove pollutants of concern in highway runoff. This evaluation included preparation of a Geotechnical Design Report (Caltrans, 2012), as well as a Storm Water Data Report (Caltrans, 2013).

The project Geotechnical Design Report (GDR) was prepared by the Office of Geotechnical Design-South 2 (OGDS 2, Branch C) specifically to support the design of Best Management Practices as part of the Chollas Creek Watershed Project, which was related to the widening of SR-94. The GDR is based upon percolation tests conducted at six locations near the intersection of SR-94 and I-15. A power auger, shovel, and hand auger were used to drill test pits. Sub-surface materials that were encountered consisted predominately of clayey silt, sandy silt, and silty sand. Groundwater was not encountered during the subsurface investigation, which extended to a minimum of 10 feet below each percolation test pit elevation. Percolation tests were performed using California Test Method (CT) 749 (1986) for 12-inch test holes, in which the test holes were presoaked for a minimum of 12 hours prior to percolation testing. Typically, 3 test pits are required for each location, however due to the homogeneous nature of site soils and close proximity and number of locations, only one percolation test pit was performed for each location. Measured percolation rate in the 6 test pits ranged from as low as 2,450 minutes/inch (GB#7, SR-94) to 534 minutes/inch (GB#8, I-15). To account for variability in the material encountered within the test hole as

well as the corresponding measured percolation rate, OGDS staff recommended an "average" percolation rates of 667 minutes/inch (0.09 inch/hr.) for use as a conservative basis of design.

Appendix E of the Project Report, the Long Form Project Storm Water Data Report (SWDR) cross references the results of the percolation testing performed by OGDS. Appendix E also evaluates suitability of infiltration devices according to Checklist T-1, Parts 1 and 4. The discussion of implementation of a "modified modular filler" is justified by citing its high void ratio, corresponding smaller footprint, ease of maintenance, and suitability of bypassing high flows. It also discusses the ideal effectiveness of infiltration to achieve the reduction of metals required by the TMDL. This section of the SWDR acknowledges the low permeability of local soils as "not ideal" but justifies the design approach since the system will maintain a 97% effective void ratio and is located underground (presumably avoiding risks associated with vectors and hydraulic backwater upon the influent storm drain system). The inter-event time for storms in southern California can average about 4 days in wet years, but frequently is substantially longer. Accordingly, the relatively long predicted drawdown time of the system is not expected to greatly reduce the long-term performance of the system.

BMP Sizing and Design

The SWDR indicates that infiltration trenches 2, 3, and 4 (located along I-15) are all sized to capture approximately 0.65" of runoff from the contributing impervious area. The contributing impervious area accounts for a portion of future build-out of the SR-94 HOV project considered hydraulically feasible to capture. Other pertinent aspects of the infiltration system design discussed in Appendix E and indicated on the project plans include:

1. Incorporation of pretreatment techniques (sediment trap) – discussed generally within SWDR. Plans and site photographs taken by Caltrans do not appear to indicate this approach at location 8.
2. Separation of trash and gross solids within an upstream diversion structure
3. Use of drought tolerant and native plants requiring low water use for the areas on top of the infiltration system.
4. Use of Class 4 Permeable Material to backfill the exterior trench zone.
5. Use of Class D Filter Fabric to line the top and side perimeter of the system modules.
6. Bottom of the modular system and sub-excavation limit of Class 4 Base were unlined.
7. The maximum depth of stored water in the system, including the Class 4 permeable base material is 7'6".

A graphic depicting the design of the infiltration system from the project plans is shown in Figure 8.

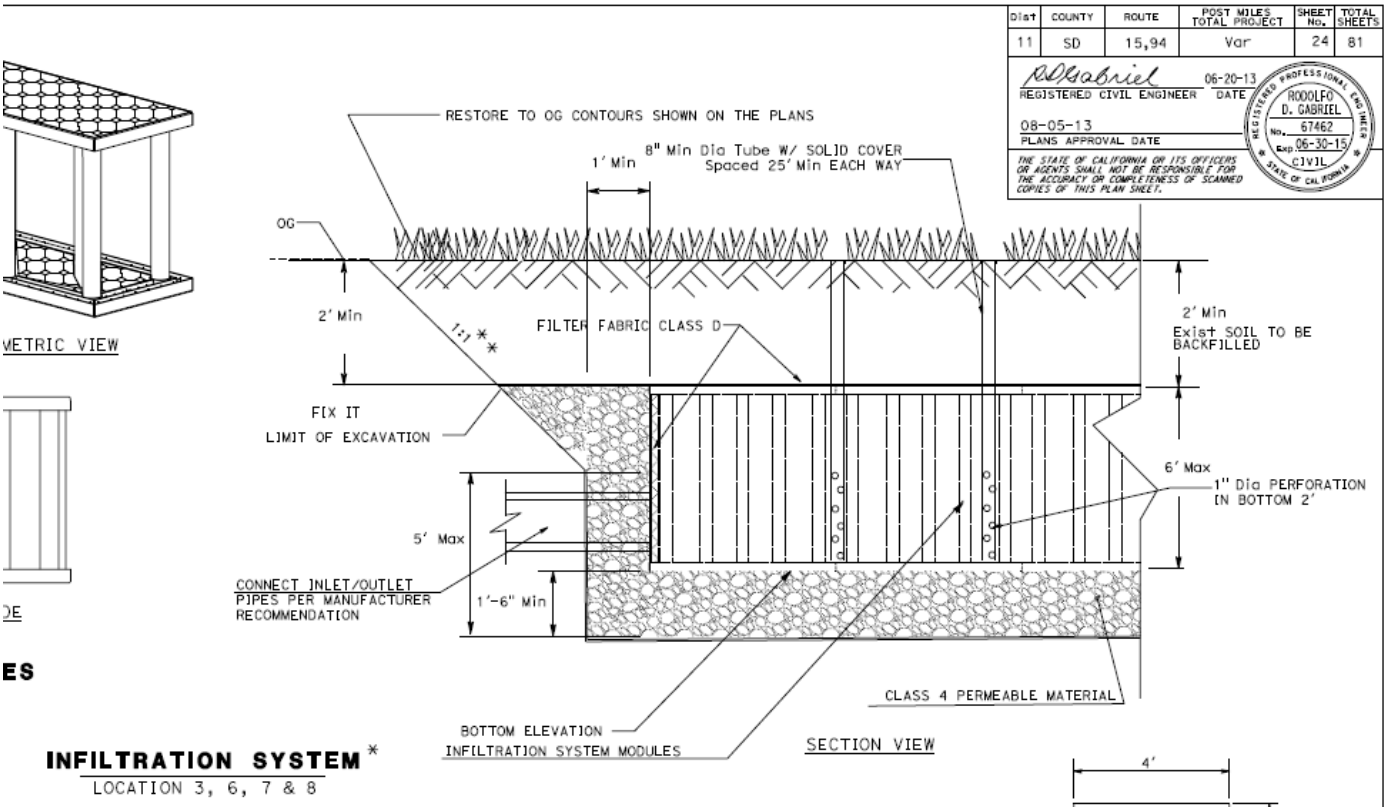

Figure 8 Section View of Modular Infiltration Trench at Location 8 (SB 15, south of SR-94)

Construction Phase

During construction, measures were provided to prevent the mobilization of sediment within the work area. These measures are indicated within the Temporary Water Pollution Control Plans. Most noteworthy on these drawing are sediment control measures specified for ground disturbance associated with construction of an Austin Sand Filter upstream of the modular infiltration system. Measures specified on the plans consisted of perimeter inlet protection and temporary fiber rolls. Potential sediment risk to the modular infiltration system at location 8 is considered low due to the relatively small area of ground disturbance (both at site 8 as well as at the Austin Sand Filter site), the use of sediment controls, and, most importantly, the fact that photos reviewed from the construction phase do not indicate any signs of rainfall or runoff producing events (Caltrans, 2013).

However, the Caltrans site photographs do suggest some deviation from the plan details. It appears as though filter fabric was laid beneath the prefabricated modular system, contrary to the plan details. Refer to Figure 9. It is worth mentioning that this design approach (i.e. lining the bottom with a filter fabric) was used at other locations within the Phase II Chollas Creek BMP Retrofit project, presumably without incident. It is assumed to be the same Class D filter fabric specified for the side and top areas.

Figure 9 Construction of Sub-Grade

Operation and Maintenance

A 2013 memorandum from District 11 Stormwater Design to Caltrans Headquarters Maintenance Division was developed to supplement the Storm Water quality Handbook – Maintenance Staff Guide (Staff Guide) by providing detailed instruction for maintenance activities associated with modified infiltration trenches, such as the one used south of the I-15, SR-94 Interchange. It discusses a number of important routine maintenance activities:

1. Inspect for the presence of trash and debris at a minimum of twice per year. Remove and dispose of trash and debris as required with each inspection.

2. Inspect for visible signs of sediment accumulation and/or standing water at least once per year during the dry season. Flush and vactor the infiltration system as necessary from the upstream access port based upon inspection results. Dispose of liquid waste in suitable manner.

3. Inspection of inlet and outlet structures, or other design features of physical damage and repair as necessary. Inspections should be performed twice a year, late in the wet season and late in the dry season.

It is assumed these activities have taken place as specified in the 2013 memorandum, since no documentation was provided by Caltrans that would suggest otherwise.

A recent post-storm technical memorandum from Caltrans District 11 documents hydraulic performance of the modular infiltration system at both the influent and effluent points. Excerpts from this memorandum are provided below (Caltrans, 2016).

> *Consistent precipitation began at approximately 02:20 on Tuesday January 5, 2016, and lasted until 16:50. The storm produced 2.13 inches of total rainfall. Although the storm forecast met*

mobilization criteria, no inline bypass flow was observed at the monitoring point, likely the result of debris obstruction at the BMP location influent, and therefore no samples were collected. Furthermore, the site recorded more than half of the total event rainfall in just 30 minutes (1.09 inches). As a result, field crews suspended monitoring activities as flows from the adjacent creek rose above the invert of the inline effluent bypass pipes and contaminated the sample collection point, eliminating the potential for successful capture.

Prior to flooding, the field team observed complete inundation in the pretreatment junction structure, while depth measurements taken from inside the infiltration BMP observation port revealed the trench was only partially full, indicating a debris obstruction was likely impeding the functionality of the BMP system. Amec Foster Wheeler notified District 11 of the blockage issue; on January 11, 2016, the system was snaked and vactored, and Amec Foster Wheeler installed a temporary trash screen to prevent future clogging until a more permanent solution could be put in place."

Diagnosis of Failure and Failure Resolution

The Caltrans post storm technical memorandum discusses a significant quantity of trash that accumulated, and ultimately blocked the influent pipe to the modular infiltration system. This trash had originated from surrounding areas. Of significance were several soccer balls from a nearby recreational facility that were the ideal size to clog the 12" influent pipes. The in-line check valves also showed signs of significant clogging. A maintenance contractor assisted in vactoring the upstream junction structure. The trash clogging the influent pipes was removed using a high-pressure jet with a tip to reverse out any debris. A 3/8" stainless steel mesh was attached to cover the influent pipes to avoid this clogging from recurring over the short term. Additionally, a construction change order was issued to attach a more permanent measure of protection against clogging. It will be used to retrofit all of the modular infiltration systems constructed as part of the Chollas Creek BMP Retrofit. Another lesson learned by Caltrans was to create an infiltration soft bottom at the upstream junction sump in order to eliminate standing water. A construction change order has been issued to retrofit the junction structures by cutting out an 18" square infiltration area that will incorporate gravel to assist in draining the two-foot sump area. This will result in less liquid material to vactor out and allow the vactor truck to clear sediment and debris that has accumulated in the upstream junction structure.

Factors Contributing to Success or Failure

The District 11 Chollas Creek TMDL Implementation Monitoring Program, performed by consultant contract, will continue to conduct and summarize monitoring data generated at specific modular infiltration system sites. The pressure transducers will log the water level rise and fall within these systems to flag issues such as clogging and to compare against pre-construction infiltration rates. Effluent discharge (flow weighted composite samples) will be compared to influent and complete bypass discharge to determine if heavy metals are re-suspended and conveyed with effluent bypass discharge. This monitoring program should pay attention to system bypass. Of concern are the low rate of hydraulic conductivity used during design (0.09" per hour) in combination with the depth of water within the structure when full (approximately 7.5'). These two parameters in theory would translate to an extensive drawdown time, on the order of 1,000 hours. This anticipated drawdown time greatly exceeds the average inter-event duration during the rainy season within the San Diego

region, and consequently could result in frequent bypass for storm events equal to or less than the 0.65” design depth.

CASE STUDY REPORT

Florida DOT: State Road 55 Linear Infiltration Basins

Case Study Introduction

BMP Type:	Linear Infiltration Basins
Geographic Location:	Port Richey, Florida. 40 miles northwest of Tampa.
Project Setting:	BMP located within right-of-way adjacent to turn lane addition
Notable Factors in Success or Failure of BMP	Existing site evaluation insufficient—(1) seasonally high groundwater elevation higher than expected and (2) impermeable clay lenses and limerock not identified

The roadway project was the construction of additional continuous turn lanes along State Road 55 (US 19) in Port Richey, Florida northwest of Tampa. State Road 55 is within a heavily developed corridor with both commercial and high-density residential land uses. Stormwater quality treatment and flood attenuation for the runoff over the new impervious areas was required. The best management practices (BMPs) selected were longitudinal ponds (e.g., linear infiltration basins) designed by a consulting engineer by converting the existing roadside ditches (Figure 10).

Near completion of construction in June 2015, two of these infiltration basins (Ponds 18 and 21) were observed to retain water beyond the design recovery period (i.e., drawdown time) of 72 hours. These two sites were investigated and retrofitted to meet the stormwater regulatory requirements. In December 2015, an addendum to the project indicated that Pond 18 was redesigned into a retention pond and Pond 21 was redesigned to provide adequate infiltration.

Figure 10. Example infiltration basin installed for the State Road 55 Continuous Turn Lane project.

Information Obtained for Case Study

The following materials were received, and communication contacts were made for the case study.

Materials received:

- Design plans and specifications
- Drainage Report
- Drainage Report Addendum for Pond 18 and Pond 21
- Design Handbook for Stormwater Treatment and Management Systems

Agency and consultant communication via conference call and email:

- Daniel Lauricello, Florida DOT, District 7 Drainage Engineer (January 2016)
- Bruce Hasbrouk, Fowler Davis Associates, Consultant/Environmental Scientist (February 2016)

Case Study Setting

Project Context

FDOT determined the need for continuous turn lanes along State Road 55 in this region to increase public safety and relieve traffic congestion. New impervious area was added by the widening of the roadway (Figure 11, Figure 12), which required post-construction stormwater treatment per the state's NPDES construction general stormwater permit. This case study is focused on two of the 16 infiltration basins included in this project, from Pond 18 and Pond 21.

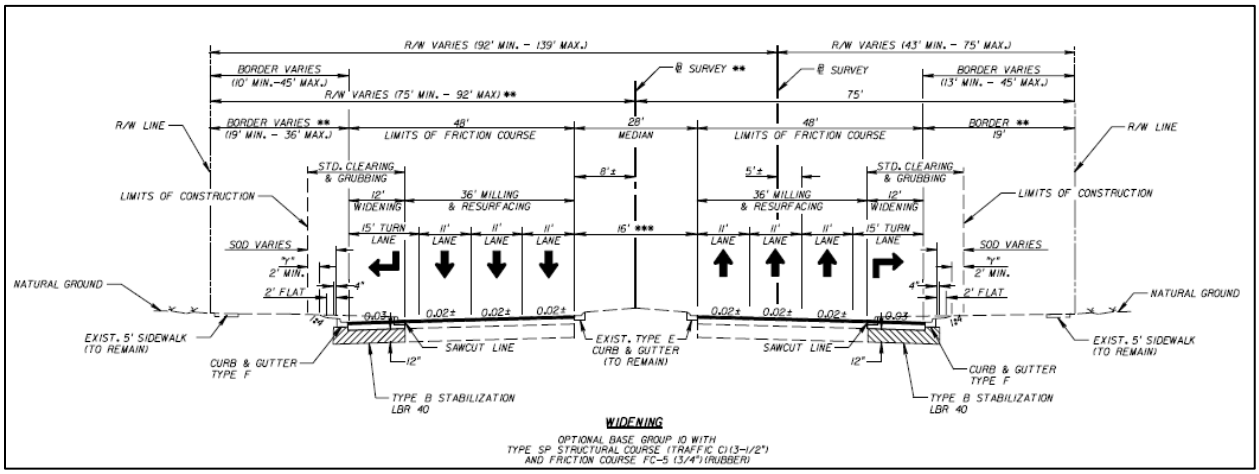

Figure 11. Example cross section of project showing turn lane addition.

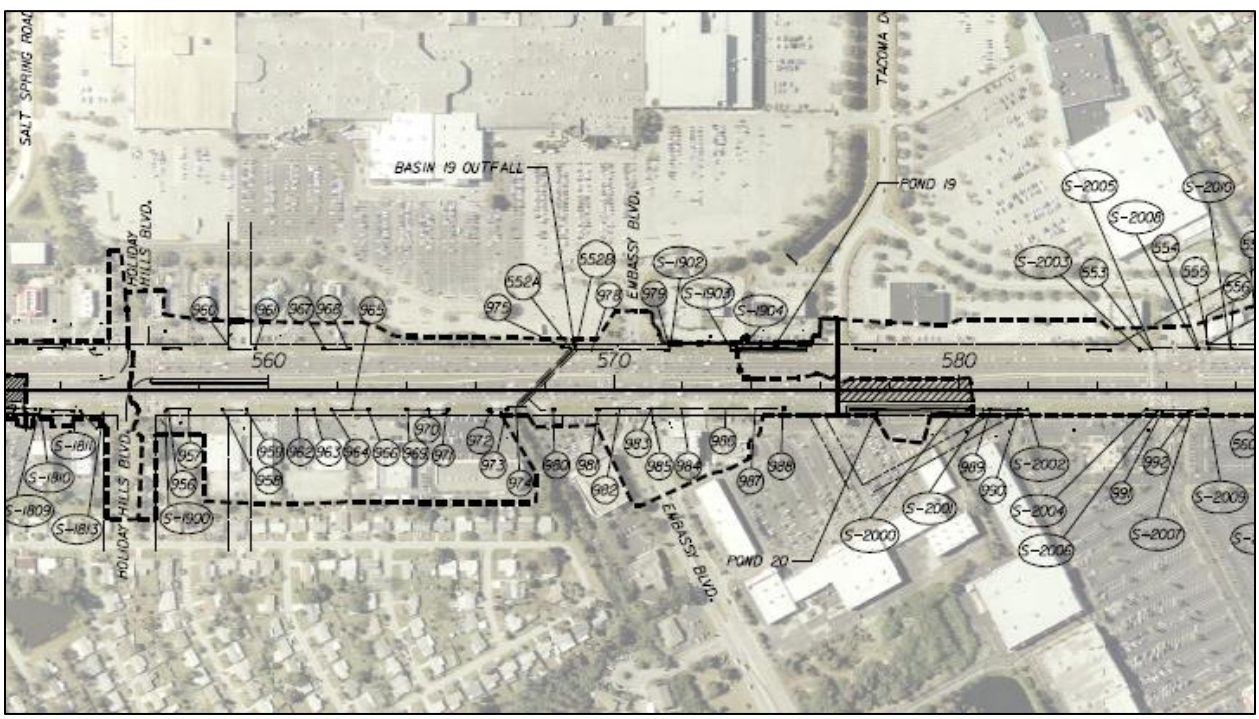

Figure 12. Example plan view of project, showing drainage basin boundary.

Site Location and Physical/Watershed Setting

The State Road 55 Continuous Turn Lane project is located in Port Richey, Florida, 40 miles northwest of Tampa (Figure 13). Both of the case study drainage basins consist of the roadway right-of-way, as well as some offsite area. Drainage basin 18 and basin 21 cover 15.04 acres and 19.83 acres respectively. Both drainage basins drain to existing ditches and storm sewers that convey runoff to the basin outfalls, ultimately discharging to the Gulf of Mexico. The infiltration basins were installed directly adjacent to the roadway by converting the existing roadside ditches into the stormwater BMPs.

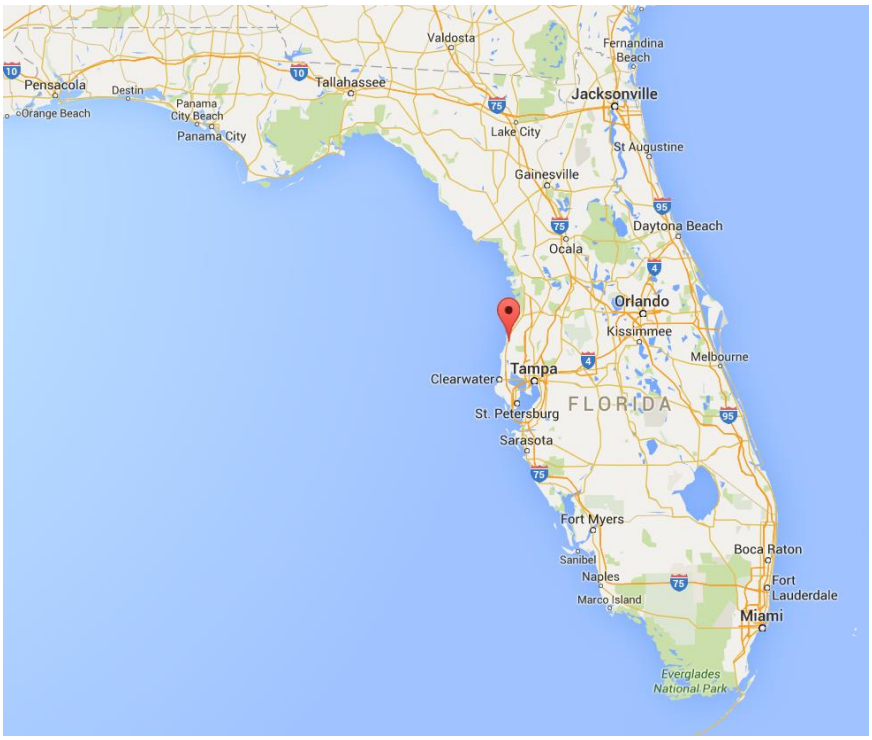

Figure 13. Project general location map.

Applicable Regulations and Available Guidance

The State of Florida Department of Environmental Protection issued an NPDES Generic Permit for Stormwater Discharge from Large and Small Construction Activities (e.g., construction general permit). The Southwest Florida Water Management District (SWFWMD) is the regional agency with oversees stormwater controls under the permit. Regulatory requirements and design guidance are provided by SWFWMD in its Environmental Resource Permitting Manual (10/1/2013), requiring stormwater treatment volume of one-half inch over the new impervious area. FDOT also has a stormwater facility handbook which provides design guidance for DOT projects.

From the potentially applicable BMPs available, FDOT selected linear infiltration basins. The designer determined the attenuation volume by calculating the difference in the post-condition versus the pre-condition runoff volume for the FDOT 100-year/72-hour design storm. Per the design manual requirements, infiltration basins must “recover,” or drain completely, within 72 hours.

Planning and Design Phase

Site Investigation and BMP Selection Findings

Geotechnical borings and double-ring infiltrometer tests were conducted at each of the pond locations. The in-situ infiltration rate was determined to be acceptable for infiltration and used for BMP design. The seasonally high groundwater table was estimated from these site investigations and checked against the guidance for minimum separation distance from the basin floor.

BMP Sizing and Design

For BMP design, the water quality volume was calculated based on one-inch of runoff rather than the required one half-inch, which FDOT often uses as a design safety factor to account for variability in site conditions and actual BMP performance. Hydraulic and hydrologic modeling software was used as a design tool. Refer to Figure 14 for plan and section view of Pond 18.

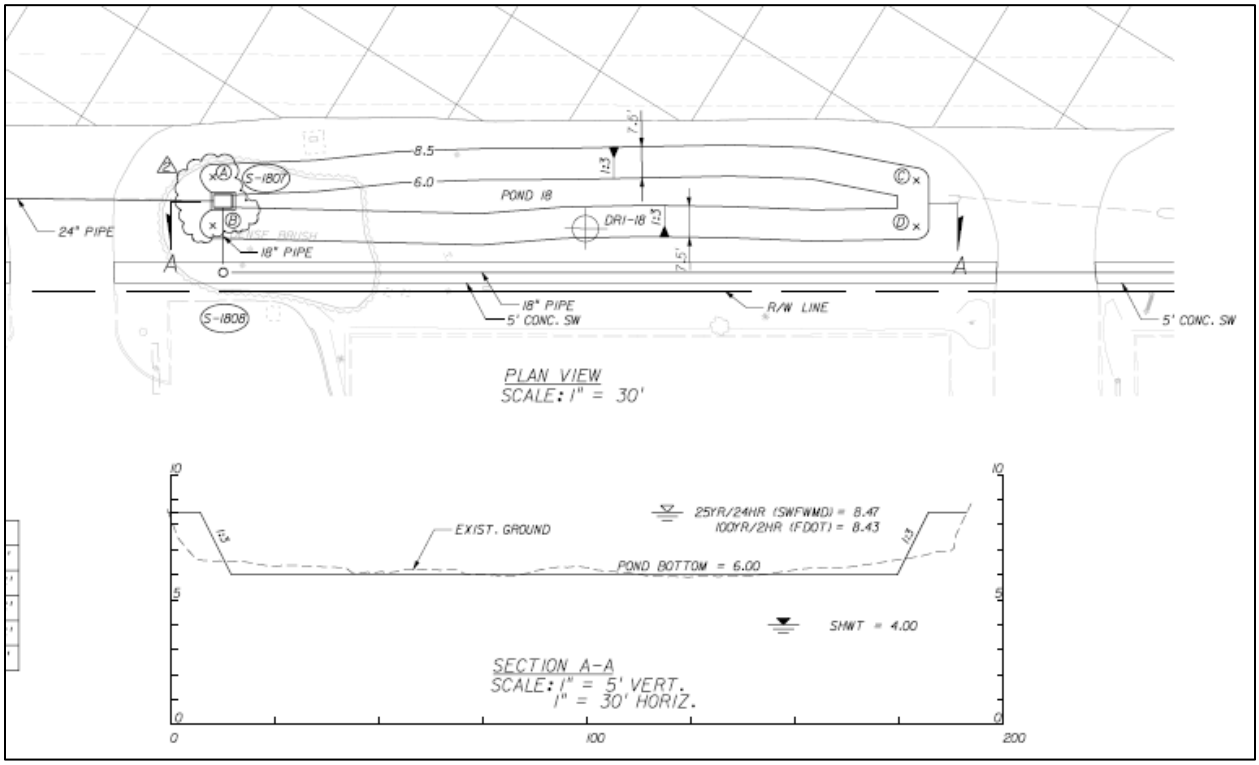

Figure 14. Example design plan and section of a linear infiltration basin.

Construction Phase

BMP Construction

Since the BMPs were essentially modified ditches, no unusual construction practices were employed during construction. The new storm sewers and drainage structures were installed, along with the roadway and sidewalk pavements. The existing ditches were then excavated and regraded per the plans and

vegetated with sod. No deviations from BMP construction guidance or design plans were observed by the resident engineer during construction.

Operation and Maintenance

BMP Operation and Maintenance Observations and Records

No operations and maintenance have been conducted since the ponds are not yet in service. SWFWMD has an operations and maintenance guidance manual for stormwater management systems, which provides recommended tasks for infiltration and other stormwater BMPs.

BMP Failure and Resolution

Description of Failure

Pond 18 and Pond 21 were observed to not meet the 72-hour recovery period in the month following construction. Some areas in Pond 18 had continuously standing water and wetland vegetation growing. Pond 21 exhibited patches of dead grass which could not get established due to extended durations of standing water (Figure 15).

Figure 15. Pond 21 not meeting the 72-hour recovery (drawdown) time.

Diagnosis of Failure and Failure Resolution

Each pond was diagnosed for the cause of failure to meet the design conditions. For Pond 18, the seasonally high water table (SHWT) was reevaluated based on site conditions and other geotechnical data available. The new SHWT elevation was increased by three feet, making infiltration infeasible at the site. Pond 18 was redesigned as a wet detention pond instead, by modifying the outlet structure with an orifice to meet the SWFWMD requirements (Figure 16).

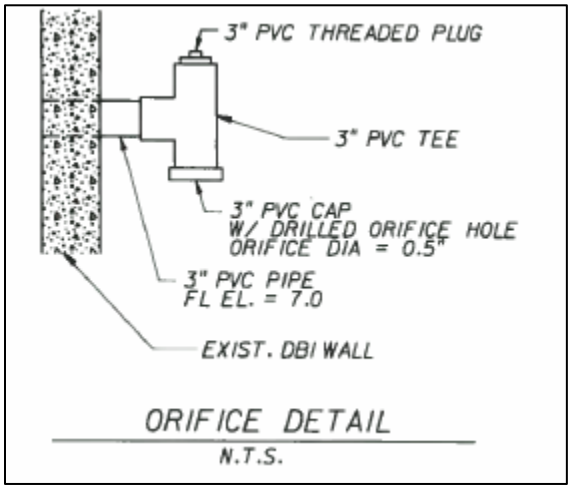

Figure 16. Revised design to address Pond 18 initial lack of infiltration

During the investigation of Pond 21, the site soils were found to have previously unidentified impermeable layers of clay and limerock. The designer determined that excavating a depth of two feet of the basin floor would remediate the situation (Figure 17). Sand backfill was specified to replace the excavated material prior to revegetation.

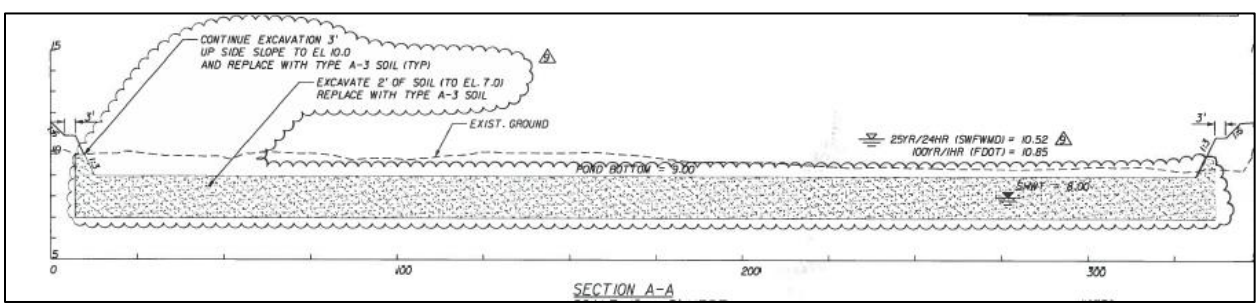

Figure 17. Revised design to address Pond 21 initial lack of infiltration

Although not an apparent issue in this case study, FDOT noted a common source of failure for infiltration BMPs has been inadequate protection during construction. For example, some past cases have demonstrated contractors allowing stormwater to enter infiltration BMPs prior to the construction site stabilization. Sediment entering the infiltration basin can clog the pore spaces in the soil which can

significantly reduce permeability and prevent proper infiltration. In other cases, heavy equipment has inadvertently been used on the floor of the BMP, causing over-compaction of the soil reducing infiltration function.

Summary and Lessons Learned

Factors Contributing to Success or Failure

A thorough evaluation of the existing site conditions including geotechnical surveys prior to final design are key to the success of infiltration BMPs. Fourteen of the 16 BMPs designed for this project were functioning as designed, yet two were not. In one case, it appeared that the seasonally high water table data was possibly misinterpreted or not accurately incorporated in to the design. In the other case, the survey did not identify impermeable soil layers which affected the infiltration performance. In both cases, the BMPs were redesigned and repairs were planned for construction at last contact with FDOT.

FDOT pointed out that existing soils in roadway projects, especially in an urban setting, are often disturbed, non-native soils which are harder to evaluate for geotechnical properties related to infiltration. Fill soils are often found adjacent the roadway and compaction may vary widely. Extra care is recommended when developing the soil sampling plan, including the location and number of samples, to ensure representative results are gathered and used in the design of infiltration BMPs. Additional data may also be incorporated in the site evaluation, such as existing and historical vegetation and hydrology, as well as visual inspection of the soils for redoximorphic features or gleying.

CASE STUDY REPORT

Massachusetts DOT: I-195 Infiltration Swales

Case Study Introduction

BMP Type:	Infiltration Swales
Geographic Location:	Swansea, Massachusetts
Project Setting:	Median of I-195 on both sides of the highway bridge over the Cole River
Notable Factors in Success or Failure of BMP	Geotechnical investigation; Compaction of subgrade from temporary vehicle traffic

The Massachusetts Department of Transportation, Highway Division (MassDOT) installed two infiltration swales in the median of Interstate 195 (I-195), with each swale discharging into the Cole River, as part of a bridge replacement over the Cole River in Swansea, Massachusetts in 2015. The installation of the infiltration swales was included in the project for treatment of stormwater runoff to meet the requirements of MassDOT's Impaired Waters Program. The infiltration swales were observed to have standing water during construction and were not infiltrating as intended (Figure 18). The swales lack in infiltration is believed to have been due to one or two factors: (i) compaction of the existing subgrade soils from temporary vehicle traffic loading while the median was being temporarily used as a travel lane during bridge replacement; and/or (ii) low permeable soils that do not promote infiltration. It has not yet been determined to what extent the swales need to be redesigned or repaired to improve infiltration and continue to function as vegetated water quality swales discharging to the Cole River.

Figure 18. **Photos from site visit during construction. MassDOT. 2015**.

Information Obtained for Case Study

Materials Received:

- Design drawings: "Plan and Profile of I-195 over Cole River (Structure No. S-35-018)" (MassDOT, 2013)
- Construction specifications: "Special Provisions Swansea – Replacement of Bridge No. S-35-018 over Cole River" (MassDOT, 2013)
- Construction Progress Status Reports (MassDOT, 2014-2015)
- Impaired Waters Program submittal: "NPDES MS4 General Permit Compliance Water Quality Impaired Waters Assessment and Mitigation Plan – MassDOT Semi Annual Submittal" (MassDOT, 2011)
- Guidance document: "Storm Water Handbook for Highways and Bridges" (MassDOT, 2004)
- Archived emails from Annie Bastoni (2015)
- Site photos (2015)

Agency Communication:

- Email correspondence and discussions with Annie Bastoni, Stormwater Program Coordinator for Massachusetts Department of Transportation, and Henry Barbaro, Stormwater Program Manager for Massachusetts Department of Transportation between 10/6/2015 and 1/29/2016;
- In-person project discussion on 1/29/2016 with Annie Bastoni; and
- Phone interview on 2/11/2016 with Annie Bastoni.

Additional References Cited:

- MassDOT, 2012. "NPDES MS4 General Permit Compliance Water Quality Impaired Waters Assessment and Mitigation Plan – MassDOT Semi Annual Submittal."

Case Study Setting

Project Context

The Cole River, an impaired water located in southern Massachusetts, receives runoff from three distinct sections of MassDOT properties: Route 6, Route 103, and I-195. Due to the large amounts of impervious cover on these MassDOT properties, the MassDOT Impaired Waters Program identified the Cole River watershed as a location for installation of additional stormwater BMPs. Upon initiation of a planned bridge replacement project over the Cole River on I-195, the existing median swales, which collect runoff from both the eastbound and westbound lanes of I-195 and discharge directly into the Cole River, were identified as possible BMP retrofit locations.

Site Location and Physical/Watershed Setting

The project is located in a coastal area in the town of Swansea in Bristol County, Massachusetts [Figure 2]. The Cole River consists of two segments: northern (MassDOT code: MA61-03) and southern (MassDOT code: MA61-04). The project site is located within the subwatershed of the southern segment of the Cole River, as shown in Figure 19 and Figure 20. The site and BMPs are split into two areas: east and west of the Cole River.

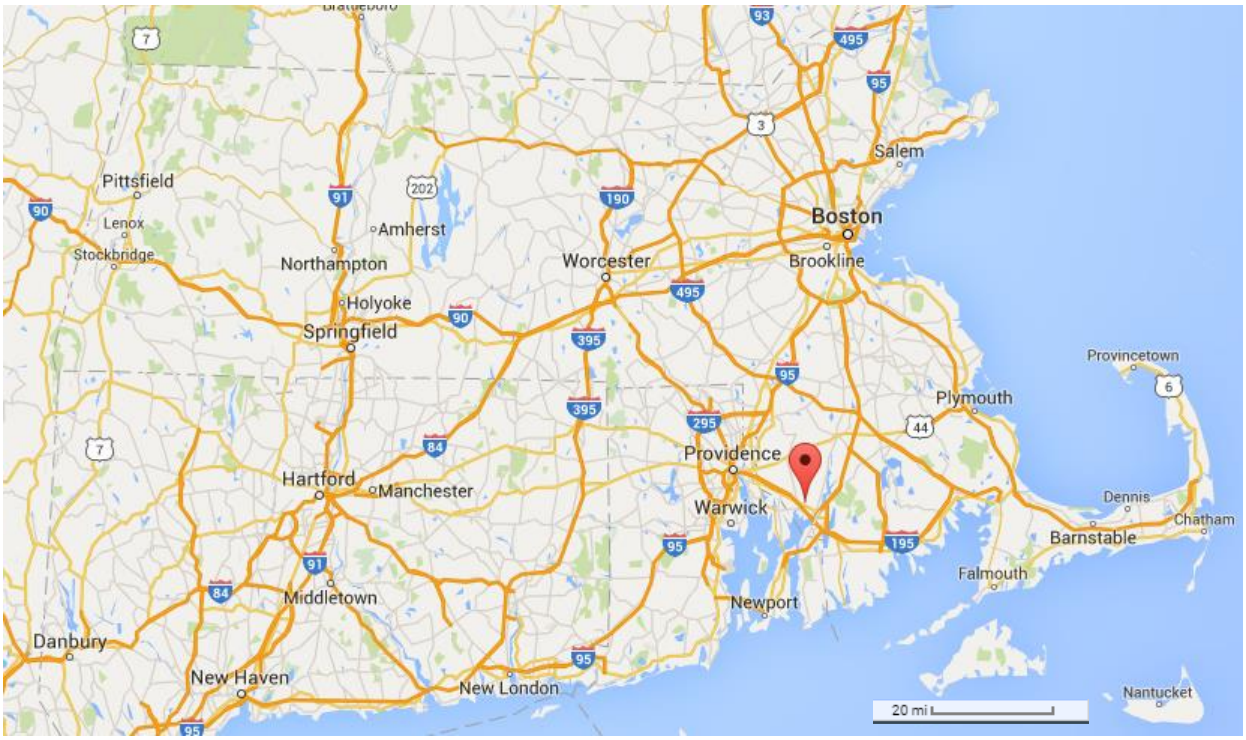

Figure 19. Project Location Map. Map data © 2016 Google

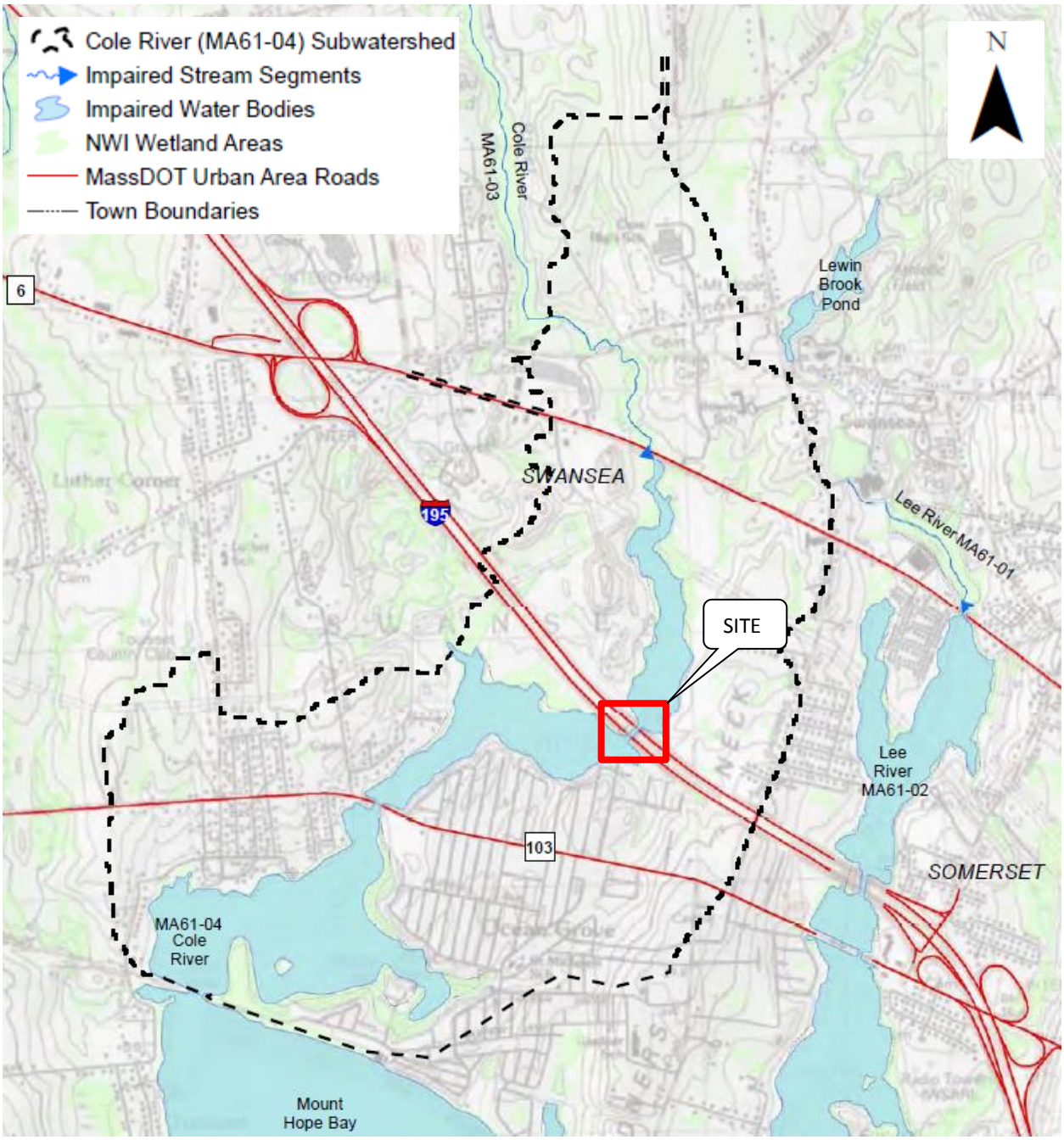

Figure 20. Cole River Subwatershed and Site Location (MassDOT, 2011)

Applicable Regulations and Available Guidance

The project was conducted under the MassDOT Impaired Waters Program, a requirement of MassDOT's National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit. The program requires MassDOT to assess and work towards mitigating their effect on impaired water bodies through the installation of stormwater best management practices (BMPs). The Cole River was listed on the Massachusetts Year 2008 and 2012 Integrated List of Waters as impaired for low dissolved oxygen, elevated total nitrogen, elevated chlorophyll a, and elevated total fecal coliform

bacteria due to general urban storm water, discharges from municipal separate storm sewer systems, failing septic systems, and illicit connections to storm sewers. The EPA and others have found that when a watershed contains less than 9% impervious cover, stormwater is not likely the cause of impairments. The Cole River subwatershed in which the project is located was found to be 18.4% impervious. Therefore, the subwatershed was selected for the implementation of BMPs to reduce the effective impervious cover.

MassDOT maintains a Stormwater Handbook for Highways and Bridges, published in 2004, which was used at the time of the design. However, this guidance document does not include a section on infiltration swales. The document does include such screening criteria for BMP installation such as, "recharge BMPs must have at least two feet of clearance (and sometimes more) between the infiltration surface and seasonal high groundwater" and "recharge BMPs cannot be located in Hydrologic Group D soils, and may be problematic in other soils as well (e.g., where receiving soils are prone to clogging under anticipated design conditions)."

Planning and Design Phase

Site Investigation and BMP Selection Findings

The site investigation for this project was focused primarily on the immediate areas surrounding the bridge where the existing bridge structures would be demolished and replaced with precast bridge piers. Information from soil borings including soil classifications and the results of Standard Penetration Testing (SPT) collected in 1959, 2011, and 2012 were utilized in the design of the bridge replacement; however, these borings were limited to areas directly adjacent to the bridge footings and within the Cole River and did not contain soil permeability results. No geotechnical investigation (water table elevation, infiltration rates, soil porosity) was conducted in the areas of the infiltration swales.

Geotechnical data for the site was limited to typical infiltration rates associated with the soil types identified on a Natural Resources Conservation Service (NRCS) soil map of the area. The soils in the area were identified as Hydrologic Soil Group A, indicating conditions were favorable for infiltration. The site is located on fill material that was placed as part of the highway installation.

Site investigations included a wetland study, which classified the existing vegetated wet swales in the median as jurisdictional wetlands. Infiltration swales were selected to be installed to replace the wetlands impacted during construction in order to meet the requirements of the impaired waters program, to mitigate the wetland impacts, and to accommodate permit requests for infiltration swales from the Office of Coastal Zone Management (under the Executive Office of Energy and Environmental Affairs for the Commonwealth of Massachusetts). Though infiltration swales were selected, according to MassDOT, the presence of wetlands may indicate that soils with poor infiltration capacity are present.

BMP Sizing and Design

The design of the infiltration swales, as shown in Figure 21, includes (in order from top to bottom) turf reinforcement mat (TRM), 2 inches of compost soil, 4 inches of topsoil, 12 inches of gravel borrow material, and then existing, undisturbed soil. The infiltration swales were designed with longitudinal slopes varying from approximately 0.1% to 5.8%.

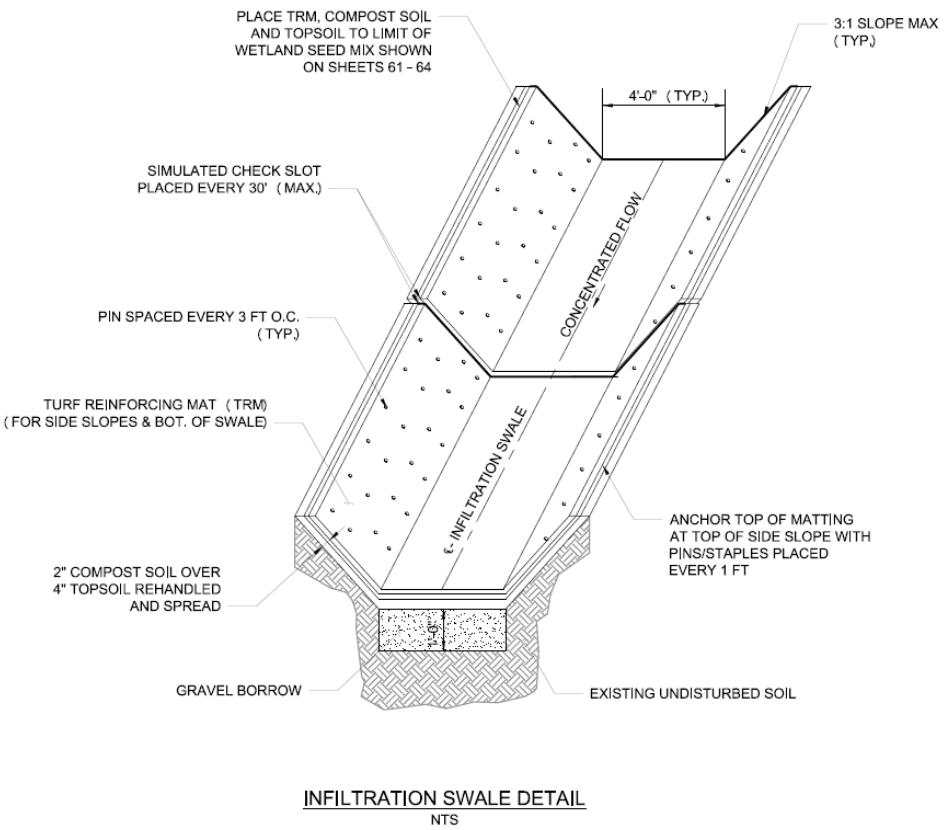

Figure 21. Infiltration Swale Design – Detail (MassDOT, 2013)

The design included permanent check dams that were installed along the entirety of the swales. The check dams were designed as dense graded crushed stone topped with 6 inches of topsoil and TRM. While the MassDOT Stormwater Handbook did not include specific design guidance for infiltration swales, "Attachment 6 – The MassDOT TMDL Method" included in the Semi-Annual Report (dated 6/8/12) submitted under the MassDOT's Impaired Waters Program included the following description regarding the design of infiltration swales:

> "The infiltration swale is a vegetated, flat or gently sloped channel designed to provide retention and infiltration within cells defined by impermeable check dams or other structures. Infiltration swales should also be constructed in permeable soils. The storage volume provided by an infiltration swale consists of the volume stored behind the check dam within each cell, therefore conveyance swales with no outlet control or check dams would not be characterized as infiltration swales."

According to MassDOT, the check dams included in the design were required to categorize the designed swales as infiltration swales. Additionally, this project included wetland replication areas to be installed to replace wetland areas in the median that were disturbed as part of construction. These wetland replication areas were installed in areas outside of the infiltration swales.

Prior to construction, but after design and permitting, the MassDOT landscaping team reviewed the permitted construction plans and indicated that the TRMs needed to be replaced due to issues with ripping

caused by mowing operations. Jute netting was installed in place of the TRMs to mitigate any future issues with maintenance activities at the site.

Construction Phase

BMP Construction

The construction of these BMPs was conducted by the general contractor responsible for the bridge replacement. Construction quality assurance (CQA) for the overall construction project was conducted by a MassDOT "resident engineer," a MassDOT employee assigned to the project; however, it was not clear how much CQA was performed for the infiltration swales. The Environmental Construction Team, a MassDOT group that works to ensure compliance with environmental permits for MassDOT construction projects, was not involved in the CQA associated with the BMP installation.

Construction generally followed the following sequence: (1) shift eastbound (EB) and westbound (WB) lanes to construct work zone access areas, crossovers, etc.; (2) shift EB traffic to crossover to WB side, demolish and replace EB bridge; (3) return EB traffic to previous alignment and shift WB traffic to crossover to EB side, demolish and replace WB bridge; (4) return WB traffic to previous alignment, remove crossovers, install infiltration swales, complete final paving and striping. Crossover required the median (i.e. infiltration swale location) to be used as a travel lane. Construction, especially related to the BMP installation, was completed in accordance with the plans without any reported major issues; however, the construction plan is believed to have impacted infiltration swale performance during storm events and resulted in standing water in the median, as explained in following sections.

The construction specifications associated with the BMPs required the contractor to excavate the existing topsoil from the swales prior to installation of the crossover travel lane for vehicle traffic. The material was stockpiled and re-lain in the median after removal of the crossover travel lane and prior to constructing the infiltration swales. This was intended to prevent compaction of the topsoil layer within the median. However, the subgrade was not required to be removed or tested after the crossover travel lanes were removed.

During construction, prior to installation of the jute nets or stabilization of the median area, a storm event washed away the permanent check dams and temporary silt fence check dams. Rill and gully erosion were observed on the unstabilized side slopes and swale bottoms and the resulting eroded sediment had accumulated in the outlets of the swales, which were located adjacent to the Cole River. The erosion that occurred as a result of the storm event could have transported sediment into the gravel borrow material installed directly above the existing soils, clogging void spaces and reducing the infiltration capacity of the swales. The swale construction was restored following the storm event including repair of rill and gully erosion, replacement of topsoil and check structures, and replacement of seed and the jute nets. Riprap was installed within the steepest section of the eastern swale, adjacent to the Cole River. Perimeter control filter socks were also installed around the infiltration swales as a corrective measure after the storm event.

Operation and Maintenance

BMP Operation and Maintenance Observations and Records

Failure of the BMPs was observed during construction in the form of ponded water in the infiltration swales and as a result, post-construction BMP operation and maintenance did not occur. Maintenance of the BMPs did occur during construction due to a sizeable storm event. Resolution of the issues associated with the storm event was addressed by the removal of accumulated sediments and the installation of riprap along the swale bottoms in the steepest sections of the swales, adjacent to the Cole River.

Vegetation establishment was also observed to be a problem during construction. Although BMP construction occurred prior to the fall seeding season, a lack of vegetative cover was not believed to have caused BMP failure.

BMP Failure and Resolution

Description of Failure

Standing water was observed within the infiltration swales during construction after four to five days of dry weather. The infiltration swales were designed to infiltrate and drain within 72 hours of the storm completion. The standing water was observed throughout the swales, but standing water was specifically observed within the areas (STA 221-228 and 243-250) where the traffic crossover travel lanes were installed. Additionally, the permanent check dams had eroded; a channel was observed through the middle of each check dam (though they were observed to still be capable of attenuating water flow).

Diagnosis of Failure and Failure Resolution

Possible causes for the swales failing to infiltrate include: (1) compaction of subgrade soil in the area of the proposed infiltration swales due to traffic loading at the crossover travel lanes installed during bridge replacement; (2) subgrade soils that that are characterized as low permeability soils and do not promote infiltration (which were not investigated prior to installation); and/or (3) clogging of the infiltration media due to sediment migration of unstabilized soils caused by a large storm event that occurred during construction.

As noted above, the standing water was observed within STA 221-228 and STA 243-250. Based on the construction drawings, the traffic crossover travel lanes were installed directly over the center of the median (the future location of the infiltration swales) at STA 219+50-225 and STA 243+50-250. The bridge sections were each removed for approximately nine days, resulting in eighteen days of traffic loading over the infiltration swale areas. This traffic loading may have caused the compaction of the existing subgrade soils and the eventual failure of the infiltration swales at these locations. As noted above, the topsoil present in the median had been removed, stockpiled, and reinstalled to remove the possibility of compaction of the top layer of soil. However, compaction of the subgrade soil could likely have occurred and reduced the infiltration capacity of the existing underlying soils.

The permeability of the soils at the site were assumed to promote infiltration at the time of design and construction, but a geotechnical investigation in the area of the BMPs was not conducted prior to installation. A site-specific infiltration rate was not determined; therefore, the failure could also have

been due to existing low permeability soils that were further compacted by the additional traffic loading. Finally, the erosion that occurred during construction could have transported sediment into the gravel borrow material installed directly above the existing soils, clogging void spaces and further reducing infiltration capacity of the BMPs. However, since the standing water was observed throughout the swales and not just in down gradient sections, it is thought that sediment migration was not the sole contributor to the failure.

Failure resolution included performing test pits on-site. The test pits were excavated six inches into the infiltration swales to determine if compaction of the top layer of subgrade soil was causing the failure. The test pits were filled with water and visually monitored. The test pits still contained standing water that had not drained into the subgrade after multiple days. Additional steps to resolve the failure at the site (of the infiltration media or the permanent check dams) were not taken due to the expiration of the US Army Corps of Engineers permit for work in the area, the demobilization of the general contractor and expiration of their contract at that time, and limited buy-in from other regulatory agencies to further investigate the cause of the problem. The BMPs are currently performing as water treatment swales to provide water quality benefit by filtering the runoff through vegetation and allowing for sediments and associated pollutants to settle.

MassDOT plans to complete deeper test pits than previously used (greater than six inches into the infiltration swales) to classify the cause of failure as either a result of compaction or poor existing soils. Following the test pits, the swales will be aerated or reconstructed with an underdrain system. Additionally, MassDOT plans to model the swales under their current operating states to quantify the water quality benefit and effective impervious cover reduction provided by the swales.

Summary and Lessons Learned

Factors Contributing to Success or Failure

Engineering design and analysis of the infiltration swale BMPs were based on available NRCS soils maps which indicated the site was underlain with permeable soils. Site specific soil investigations were not performed in the vicinity of the BMPs to verify soil conditions and measure infiltration capacity. Ponded water was observed in the swales during construction which indicated premature failure of the system. Test pits later showed that the subsoils did not infiltrate as indicated in the NRCS data. The key observations and transferrable findings gleaned from this project are that geotechnical site investigations are an integral part of the pre-design activities, and that consideration be given to temporary traffic routes and the potential for traffic loading during construction. Traffic loading onto future BMP locations is likely to compact subsoils and reduce the site’s potential for infiltration.

CASE STUDY REPORT

Minnesota DOT: Pine Bend Infiltration Basin on Highway 52

Case Study Introduction

BMP Type:	Infiltration Basin
Geographic Location:	Inver Grove Heights, Minnesota. Ten miles south of St. Paul.
Project Setting:	Roadway extension
Notable Factors in Success or Failure of BMP	Sediment and erosion control practices insufficient.

The Pine Bend Infiltration Basin (Figure 22) was constructed as part of a frontage road extension project for the City of Inver Grove Heights (City). The frontage road was installed to increase traffic safety and limit the number of direct access points to Trunk Highway (TH) 52. The Minnesota NPDES construction stormwater general permit requires post-construction stormwater best management practices (BMPs).

An infiltration basin was selected by the Minnesota DOT (MnDOT) as the BMP for water quality treatment. Following construction, part of the basin was found to have some ponding and wetland vegetation growing. Two issues were identified as the cause of the poor infiltration performance on the southern end of the basin. First, a roadway underdrain installed on the east side of the basin became a constant source of water into the basin which was not there before. Second, erosion on the upper part of the basin, where vegetation was not fully established after construction, deposited approximately five to six inches of sediment clogging the permeable soils at the south end of the basin.

Figure 22. Pine Bend Infiltration Basin after construction, from basin floor facing north.

Information Obtained for Case Study

The following materials were received, and communication contacts were made for the case study.

Materials received:

- Geotechnical reports
- Project design drawings
- Construction observation reports
- Minnesota Stormwater Manual
- Site photographs

MnDOT communications via email, phone and in-person interview (February 2016)

- David Bauer, P.S.S., Metro District—Water Resources Engineering
- Lee Daleiden, Metro District—Water Resources Engineering
- Barb Loida, P.E., Metro District—Water Resources Engineering

- Beth Neuendorf, P.E., Metro District— Water Resources Engineering, also MN Minimal Impact Design Standards Team
- Nicklas Tiedeken, Office of Environmental Stewardship, also MN Minimal Impact Design Standards Team

Case Study Setting

Project Context

MnDOT determined the need for a frontage road extension to increase traffic safety by providing a local access route and limiting the number of direct access points on Trunk Highway (TH) 52. The frontage road project created new impervious area, which according to the Minnesota NPDES construction general permit, required treatment of the water quality volume. The original concept for a stormwater treatment BMP was situated adjacent to the frontage road. Due to site-specific design constraints, the treatment BMP location was moved to the median of TH 52 (Figure 23). Through a memorandum of understanding, MnDOT agreed to own and maintain the infiltration basin itself and the City will own and maintain the pretreatment stormwater pollution control device prior to discharge to the basin.

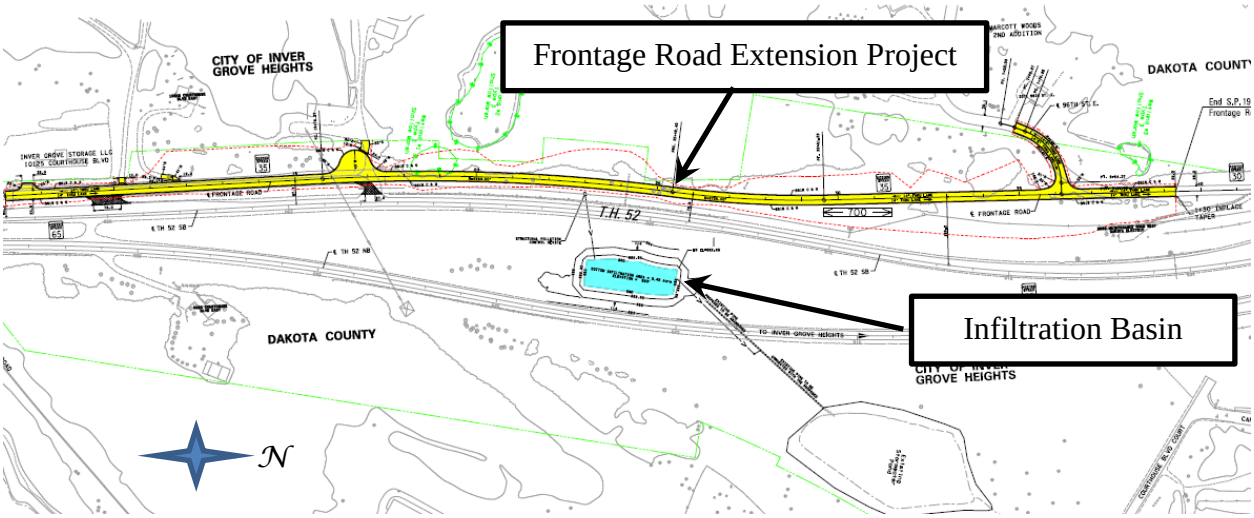

Figure 23. Project layout and BMP configuration.

Site Location and Physical/Watershed Setting

The project is located approximately ten miles south of St. Paul, Minnesota in the city of Inver Grove Heights (Figure 24). The project site drains to the east toward a pretreatment stormwater pollution control device near the TH 52 frontage road and then to the infiltration basin in the median area of TH 52 and then connects to an existing storm sewer continuing eastward (Figure 25).

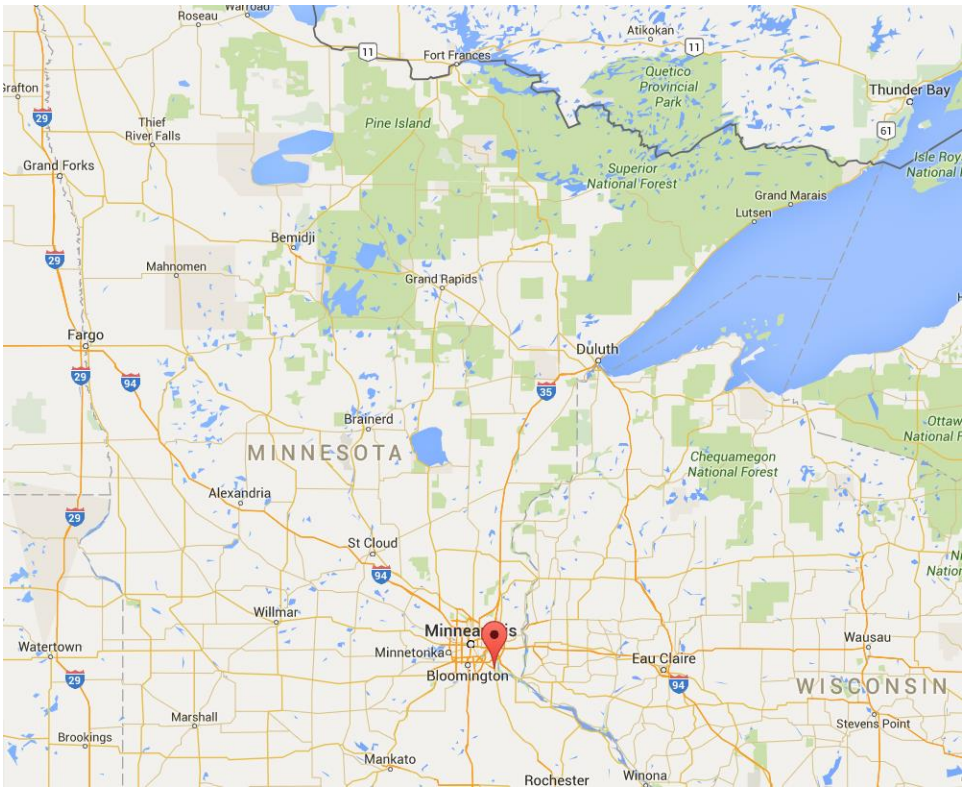

Figure 24. Project general location map.

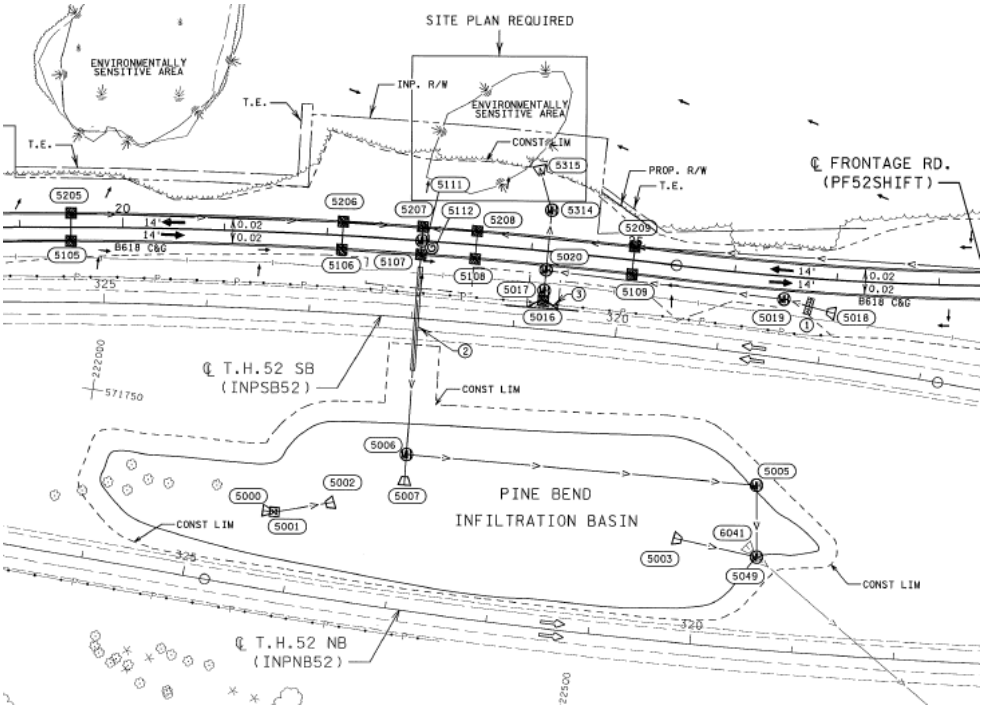

Figure 25. Project site drainage layout.

Applicable Regulations and Available Guidance

The applicable regulation for the roadway construction project was the NPDES General Permit Authorization to Discharge Stormwater Associated with Construction Activity (e.g., construction general permit) issued by Minnesota Pollution Control Agency (MPCA). Since the project created more than one acre of new impervious area, a permanent stormwater management system was required using one of the approved methods in the permit—wet sedimentation basin, infiltration/filtration, regional pond, combination of practices, or an alternative method. Per the permit, infiltration needs to be considered first. As discussed, an infiltration basin was selected as the treatment BMP and designed by MnDOT staff, using the Minnesota Stormwater Manual as guidance. Note that the Minnesota Stormwater Manual has been updated since the completion of this project. Furthermore, MnDOT has created several new specifications and is in the process of developing its own BMP design guidance (discussed in more detail under "Lessons Learned").

Planning and Design Phase

Site Investigation and BMP Selection Findings

Since a permanent stormwater management system was required, MnDOT had to select one of the options described in the construction general permit. Where practicable, infiltration basins are preferred by the MPCA and watersheds in Minnesota over wet sedimentation basins and regional ponds because infiltration provides a means of volume control. Pending feasibility MnDOT selected an infiltration basin as the treatment BMP.

For planning and design of the infiltration BMP, MnDOT used soil samples to determine soil texture for initial design infiltration rates and potential site suitability for infiltration. Favorable results allowed for a concept design to proceed. During the design process, five on-site infiltration tests were conducted in the location of the infiltration basin floor. Additionally, geotechnical soil borings were taken to identify potential subsurface issues, including the depth to seasonally high groundwater table, depth to bedrock (if present), and other soil information significant to permeability.

BMP Sizing and Design

MnDOT engineering staff used standard practices to design the basin to meet the regulatory requirements. The construction general permit required the water quality volume to be treated via infiltration, equal to ½ inch of runoff over the new impervious surfaces created by the project; the second ½ inch over the new impervious area can be treated with any of the approved control methods. MnDOT used hand calculations for sizing of the infiltration basin to infiltrate the water quality volume within 48 hours, as required by the permit. The basin was also used for flood attenuation in which hydrologic and hydraulic modeling was used to calculate the bounce and storage required. The cross section is shown in Figure 26.

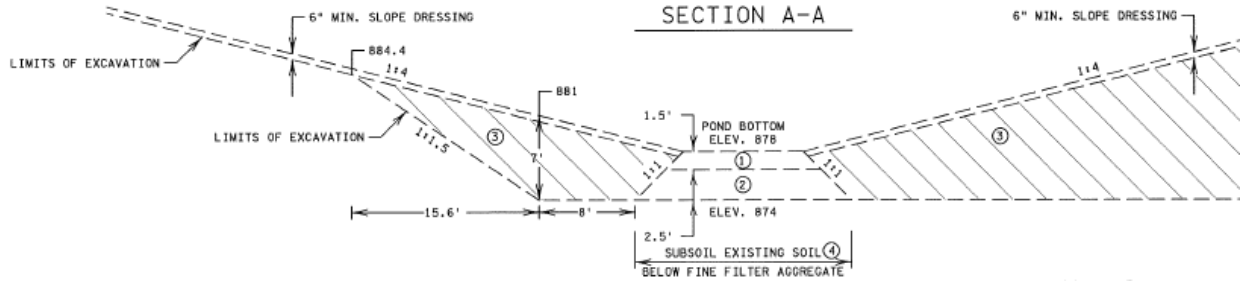

Figure 26. Cross-section of Pine Bend Infiltration Basin design.

Findings from Agency Planning and Design Process

MnDOT noted a significant challenge in the planning and design of infiltration BMPs is the variability in design between designers, including DOT designers and outside consultants. The construction general permit and the watershed rules/standards provide some design requirements, and the Minnesota Stormwater Manual provides additional guidance. Still, MnDOT identified the need for detailed specifications to establish consistent outcomes. A new specification, a new special provision, and a new pay item have been established since the subject project was completed.

1. Vegetation—Vigorous vegetation growth is known to help prevent erosion. To reduce the risk of reoccurrence of the erosion issue that occurred on this project, a new practice was implemented specifically calling out and paying contractors for watering in order to successfully establish turf and control erosion in infiltration and filtration BMPs. MnDOT is also currently amending the vegetation specifications to include both height and percent coverage criteria for final acceptance.
2. Sand backfill—Proper backfill materials are essential for infiltration BMPs function. To increase the consistency across projects and ensure appropriate backfill is being used on DOT projects, MnDOT has established a filter topsoil specification (3877). The specification not only defines the characteristics of the backfill, but also requires the contractor to meet gradation requirements.
3. Performance testing—Despite construction observation efforts to confirm construction occurs to meet design specifications, actual performance from infiltration BMPs sometimes does not meet the design intent. MnDOT has developed a special provision for performance testing of infiltration and filtration BMPs (SP2016-180). The special provision requires each BMP have a minimum of five tests per acre of basin area via double ring infiltrometer tests demonstrating the actual infiltration rates meet or exceed the design rates, or at least 2.0 and less than 8.3 inches per hour. For filtration BMPs, rates and engineered soil must meet or exceed 4 inches per hour but less than 8.3 inches per hour.

Construction Phase

BMP Construction

MnDOT staff conducted on-site construction observation for the duration of the project, as well as periodic NPDES stormwater pollution prevention plan (SWPPP) inspections. Construction was observed

to be phased appropriately. Sediment and erosion controls were implemented to prevent sediment-laden stormwater discharging into the infiltration basin (Figure 27).

During the final inspection, erosion in the upper part of the basin was discovered (Figure 28) along with a two layers of fine sediment up to six inches deep in the south end of the basin floor. The area had been seeded and mulched according to specification, yet vegetation was not well established prior to heavy rains which likely led to the erosion.

Figure 27. Infiltration basin during construction.

Figure 28. Erosion in the upper basin after seeding and mulching.

Findings from Construction and Construction Quality Assurance Process

MnDOT found their construction observation process to be robust and that construction practices followed specifications and appropriate guidance. For example, the Minnesota Stormwater Manual guidance and NPDES Construction General Permit requirements were followed which recommends not discharging stormwater into the infiltration BMP until the construction disturbance area is stabilized. The erosion issue identified was likely due to a lack of vegetation, which is now addressed in MnDOT's new pay item for watering to ensure turf establishment in infiltration and filtration areas.

Operation and Maintenance

BMP Operation and Maintenance Observations and Records

Routine maintenance of post-construction BMPs is required by the construction general permit. MnDOT staff are responsible for operations and maintenance (O&M) of the BMP. Periodic inspections are conducted, and any maintenance issues are identified, such as the need for sediment or debris removal. The performance issues described above were discovered during these inspections. Periodic mowing is also a component of BMP maintenance.

Findings Related to BMP Operation and Maintenance Guidance and Procedures

BMP maintenance and operations guidance is provided in the Minnesota Stormwater Manual. The guidance provides anticipated tasks for each stage of BMP implementation, from construction to post-construction. Information for developing a basic cost estimate of each required task is included. Other maintenance considerations are described for design and construction phases.

Regarding mowing operations, MnDOT has a concern about mowers increasing compaction and reducing infiltration of the BMP. MnDOT typically uses large tractor mowers on its' right-of-way. However, specifically for infiltration and filtration areas, MnDOT is currently pursuing using smaller, lighter equipment to conduct mowing of infiltration BMPs.

There are no applicable monitoring requirements.

BMP Failure and Resolution

Description of Failure

Despite the site being appropriately seeded and mulched, some erosion occurred in the upper part of the basin discharging a layer of fine sediment in the south end of the basin floor. The erosion was likely caused by heavy rains prior to the establishment of the grass vegetation. Another potential issue is the discovery of a seep in the hillside draining into the infiltration basin. The effect of the seep on infiltration performance is unknown, but the presence of the constant inflow has led to unwanted wetland vegetation in the basin.

Diagnosis of Failure and Failure Resolution

As described above, the erosion and sediment issue was identified during regular stormwater inspections. Ponding in the south end of the basin was not drawing down within the specified 48-hour timeframe. The discovery of the seep was discovered simultaneously. Both issues have been investigated by MnDOT staff to develop both short term and long-term solutions.

To prevent similar reoccurrence of this issue in the future, MnDOT has developed a specific pay item for watering vegetation and establishment, a new filter topsoil specification, and a new special provision for infiltration/filtration area performance testing. These changes to standard practices provide design and construction contractors new requirements to increase the likelihood of successful BMPs.

To address the immediate performance issues, MnDOT has stabilized the eroded area and is planning to remove the sediment layer, then rip and till the area before reseeding.

Summary and Lessons Learned

Factors Contributing to Success or Failure

The primary lessons learned from this case study are related to the need for protecting the infiltration basin floor from sediment. It is well understood that preventing sediment from entering the infiltration basin is key to maintain permeability. MnDOT found that current guidance for site stabilization was insufficient to ensure proper vegetation establishment and erosion prevention.

Findings from Agency Processes and Guidance

Based on experience from this (and other) infiltration BMP installation, MnDOT has identified the need to develop more consistency and predictability of post-construction BMP performance through design and specifications. MnDOT is currently in the process of developing a department-specific guidance manual for design and construction of infiltration BMPs. Prior to release of the new guidance, MnDOT has created several new practices for its projects, including the following:

- Watering pay item for vegetation establishment
- Filter topsoil specification
- Infiltration performance testing special provision

MnDOT also noted the importance of protecting the infiltration basin floor during and after construction. Contractors need to avoid driving equipment which may compact the finished basin floor. Additionally, during construction, compaction of the floor can be avoided through the use of conveyors to install the backfill media. Post-construction, mowing operations should also be controlled to avoid compaction.

MnDOT typically avoids installing infiltration BMPs in the median due to difficulty of access for construction and maintenance. This case study is a noted exception due to site limitations and local preference. MnDOT expressed an interest in additional research on infiltration BMPs to determine potential unforeseen impacts to groundwater or surface waters. First, what are the best practices to avoid potential groundwater pollution due to infiltration, especially over the long-term? Second, what is the appropriate amount of compost to use as a soil amendment in infiltration BMPs to promote healthy vegetation without leaching phosphorus?

CASE STUDY REPORT

North Carolina DOT: SR1347 Retrofit Project

Case Study Introduction

BMP Type:	Infiltration Basin (converted to Bioretention Basin)
Geographic Location:	Smyrna, Carteret County, North Carolina
Project Setting:	BMP located between two-lane road, school parking lot, and two driveways connecting the parking lot to the road
Notable Factors in Success or Failure of BMP	Location of water table; geotechnical investigation; astronomical high tides

The North Carolina Department of Transportation (NCDOT) installed an infiltration basin adjacent to State Route 1347 (SR1347) and in front of the Smyrna Elementary School (Smyrna school) located in the community of Smyrna, North Carolina in 2008 as part of their Best Management Practices (BMP) Retrofit Program. The infiltration basin was observed to contain standing water for extended periods after approximately one month of operation (Figure 29). The infiltration basin drainage failure is believed to have been caused by the presence of a higher water table than was observed during site investigation. The SR1347 project included treatment of stormwater runoff from both the adjacent NCDOT roadway and school parking lots and was intended to serve as an educational resource for the Smyrna school consistent with NCDOT's National Pollutant Discharge Elimination System (NPDES) permit external education requirements. The SR1347 project also provided NCDOT experience in preparation for their stormwater design guidance manual, the Stormwater BMP Toolbox. The infiltration basin was redesigned to function as a bioretention basin following the failure and was retrofitted with underdrains and an overflow structure. Native plantings and educational signage were installed in and around the basin.

Figure 29. Immediately post-construction and four months after construction, respectively. NCDOT. 2008.

Information Obtained for Case Study

Materials Received:

- Preliminary design drawings: "Project: WBS#34625.2.41" (NCDOT, 2008)
- Drainage area calculations: "Smyrna 0060" (NCDOT, 2008)
- Smyrna [SR1347] Retrofit Project Overview Document
- Stormwater Best Management Practices Toolbox (NCDOT, 2008)
- TMDL Report: "Total Maximum Daily Loads for Fecal Coliform for Jarrett Bay and Its Embayment, North Carolina." (NDENR, 2007)
- Site Photos (2007-2009)

Agency Communication:

- Email correspondence and discussions with Brian Lipscomb with NCDOT Hydraulics (NPDES Retrofit Program Manager; currently involved with the BMP project)
- Phone interview on 2/2/2016 with:
    - Brian Lipscomb, PE;
    - Andy McDaniel, PE – NCDOT Hydraulics – Highway Stormwater Program Manager; former project coordinator for BMP project;
    - Andy Jordan, PE – NCDOT Operations; involved in design and construction of BMP project;
    - Ryan Mullins, PE – NCDOT Hydraulics; involved in initial construction of BMP project; and
    - Joe Dunnehoo, PE – NCDOT Operations; involved in site investigation, design, and coordination of BMP project

Additional References Cited:

- NCDOT. "Highway Stormwater Program." http://www.ncdot.gov/programs/environment/stormwater/
- NCDOT. "BMP Retrofit Program." https://connect.ncdot.gov/resources/hydro/Pages/HSPProgramPages.aspx?PGM=BMPR.
- NCDOT, 2010. "Stormwater Control Inspection and Maintenance Manual." http://www.ncdot.gov/programs/environment/stormwater/download/swcontrolinspectionmaintjan2010.pdf
- NCDENR, 2015. "State of North Carolina Department of Environment and Natural Resources Division of Water Quality Permit No. NCS000250 To Discharge Stormwater and Borrow Pit Wastewater under the National Pollutant Discharge Elimination System." https://connect.ncdot.gov/resources/hydro/HSPPermits/2015_NPDES_Stormwater_Permit.pdf
- Case Study Setting

Project Context

The NCDOT is required to have a BMP Retrofit Program under their National Pollutant Discharge Elimination System (NPDES) Stormwater Permit (NCDENR, 2015). The Retrofit Program was created in 1998 as a condition of NCDOT's first term NPDES permit and has remained a condition through its current fourth term permit (NCDENR, 2015). The program entails the design and construction of BMPs to capture runoff from existing NCDOT roadways and facilities. The SR1347 infiltration basin was installed under this program.

The SR1347 project was installed in coordination with the North Carolina Coastal Federation, Smyrna school, and the Carteret County School System. The North Carolina Coastal Federation and Smyrna school approached the NCDOT to introduce the site as a possible location for an educational demonstration project of an infiltration basin. The SR1347 project was entirely funded by the NCDOT. The school and NCDOT intended to use the infiltration basin as a teaching opportunity.

Site Location and Physical/Watershed Setting

The SR1347 project is in a low-lying coastal area in the community of Smyrna, Carteret County, North Carolina as shown in **Figure 30**. **Figure 31** shows the site, labeled as "Proposed Site #1," and its proximity to Jarrett Bay.

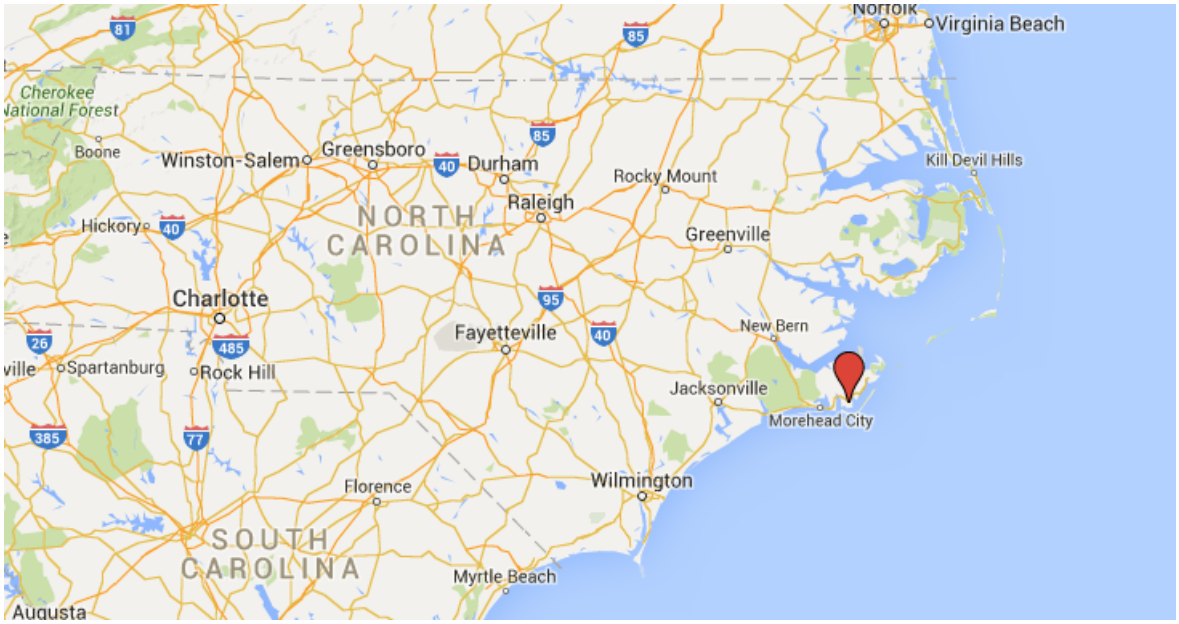

Figure 30. SR1347 Project Location Map. Map data © 2016 Google

Figure 31. Site Proximity to Jarrett Bay. NCDOT. "Smyrna Retrofit Project Overview."

A Total Maximum Daily Load (TMDL) for fecal coliform in Jarrett Bay was approved by EPA in 2007, prior to design and construction of the subject infiltration basin. The drainage area of Jarrett Bay is shown in Figure 32.

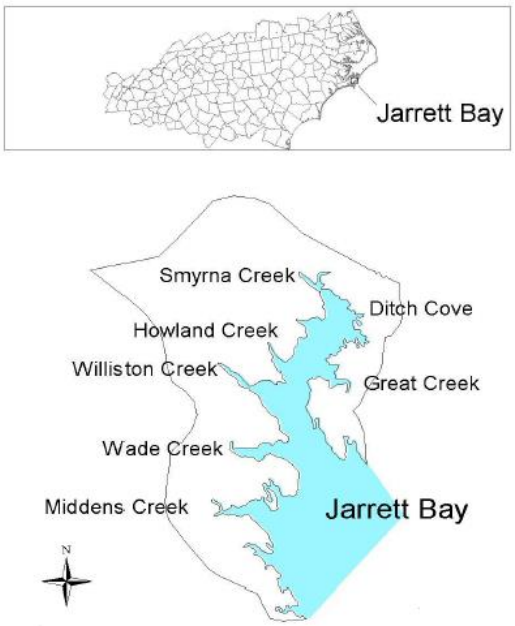

Figure 32. Jarrett Bay Watershed*. North Carolina Department of Environment and Natural Resources.* "Total Maximum Daily Loads for Fecal Coliform for Jarrett Bay and Its Embayment, North Carolina." 2007.

The site is located on the western side of SR1347 (Marshallberg Road). The infiltration (now bioretention) basin is bounded on the north and south by the ingress and egress driveways for the Smyrna school parking lot, which provides the western border of the basin. The land on which the infiltration basin was installed is partially owned and operated by the Smyrna school.

Applicable Regulations and Available Guidance

The SR1347 project was conducted under the NCDOT BMP Retrofit Program, which began in 1998. The program involves the installation of BMPs into existing NCDOT environments to reduce pollutant loading from highway activities. An additional requirement under the NPDES Stormwater Permit (NCDENR, 2015) was to maintain a guidance document for the design, operations, and maintenance of stormwater BMPs in highway environments. At the time of the SR1347project design and construction phases, NCDOT had limited stormwater-related guidance documents available. The BMP Retrofit Program, including the SR1347 project, which included NCDOT personnel involvement in all stages of the project, provided learning opportunities which were incorporated into the guidance documents developed.

The sizing goal used for the design of the basin was to treat as much of the runoff generated from the 1.5-inch (in.) storm event as possible given site constraints. The 1.5-inch storm event was, used as a target based on the requirement for new construction activities under the NC Coastal Stormwater rules that were in place at the time. The guidance document that provided the associated calculations for the water quality volume for such a storm event was not readily recalled by personnel involved in the BMP design; however, it shall be noted that the Georgia Stormwater Management Manual was referenced as being used to aid the design of the post-failure bioretention basin installed at the site.

Planning and Design Phase

Site Investigation and BMP Selection Findings

Site investigations conducted at the SR1347 site included surveying and a water table investigation. The water table investigation involved two auger borings which were allowed to equalize for 8-10 hours, followed by water table elevation measurements. The 8- to 10-hour tests were used instead of the preferred 24 hours due to time limitations. The water table measurements found that the water table was approximately located at the base of the future infiltration basin (two inches above the base of the washed concrete sand layer). The survey conducted identified an existing driveway pipe and cross pipes underneath the roadway; the invert elevations of the existing pipes were used to determine the bottom elevation of the infiltration basin. The drainage area of the infiltration basin was delineated in the field by NCDOT personnel based on survey data.

Geotechnical data for the site was limited to typical infiltration rates associated with the soil types identified on the Natural Resources Conservation Service (NRCS) soil map of the area. The infiltration rates were believed to be between 0.6-2.0 or 2.0-6.0 in. per hour, depending on depth of soil. Prior to excavation for the infiltration basin, clay material was observed within the existing sand layer. At the time of the design, the clay was assumed to be separated into lenses, rather than forming a contiguous layer within, above, or below the existing sand layer.

As the SR1347 project was part of the BMP Retrofit Program, the type of BMP was selected to investigate the viability of installing an infiltration basin in such an environment. The North Carolina Coastal Federation and the Smyrna school approached the NCDOT with the SR1347 project already envisioned and requested an infiltration basin design for the site.

BMP Sizing and Design

The infiltration basin was sized to capture as much runoff volume as possible from the 1.5-inch storm event given the site sizing constraints. The runoff volume from the 1.5-inch storm event was, used as a target based on the requirement for new construction activities under the NC Coastal Stormwater rules that were in place at the time. The surface area required to treat the runoff produced from the 1.5-inch storm event, approximately 7,000 square feet, was larger than the maximum available area within the site given the depth available for the facility, approximately 5,800 square feet.

The design of the basin, as shown in Figure 33, included 4H:1V side slopes, 4 inches of top soil and Bermuda sod (Layer A), 12 inches of washed concrete sand (Layer B), and the underlying existing sand (Layer C). The base of the washed concrete sand layer was designed to be approximately two inches below the water table elevation, as previously described.

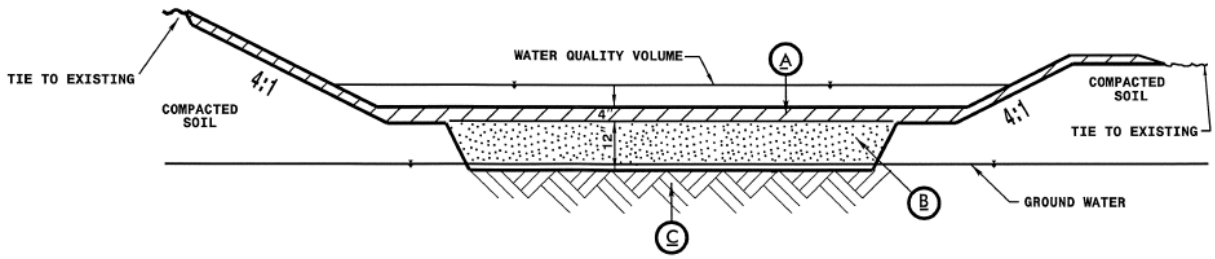

Figure 33. Infiltration Basin Design – Section. NCDOT. "Project: WBS#34625.2.41." 2008.

The notes on the plan set indicated that the clay layer to the groundwater table (approximately 12 inches) should be removed.

Findings from Agency Planning and Design Process

Neither the NCDOT BMP Toolbox manual nor the BMP Inspection and Maintenance Manual had been finalized at the time of the SR1347 project. As previously stated, one goal of this BMP Retrofit Program was to help inform a standard BMP planning and design process.

The SR1347 project provided many "lessons learned" for NCDOT to take into account in the creation of their guidance documents. The key lesson learned was the need for a proper geotechnical investigation of any site in which infiltration is vital to BMP performance. A geotechnical investigation, including infiltration rates, porosity, and location of the water table, is now a standard step in the design process for NCDOT infiltration BMP design.

Additionally, due to the proximity of the site to the coast, the water table was subject to tidal influence. The site investigation, completed in October 2007, was completed in less than one day and therefore could not have identified a seasonal or even a diurnal difference in water table elevations. The area is believed to be subject to astronomical high tides, during which the high tide elevations, and therefore the water table elevations, can rise drastically.

Construction Phase

BMP Construction

The construction process was conducted and overseen by NCDOT personnel. An "approved for construction" set of construction drawings was not produced; it was not required because construction was not performed by a third-party general contractor. Additionally, for the same reason, a specific construction sequence was not outlined. The SR1347 project was generally split into the following stages: (1) installation of construction BMPs (silt fence and a temporary sediment trap); (2) excavation; (3) fill (sand and topsoil); and (4) final stabilization with sod.

During construction, NCDOT personnel were sensitive to possible compaction of the sand and topsoil. Sand and topsoil were spread and raked by hand; sod was also placed by hand. Construction was conducted in accordance with the note on the construction drawings, which stated, "No heavy machines on the sand filter [bioretention basin]." It did not appear that the construction process led to the failure of

the infiltration basin due to the phasing of the SR1347 project and the extreme care to prevent compaction of the infiltration media.

Findings from Construction and Construction Quality Assurance Process

Construction and construction quality assurance (CQA) were conducted by NCDOT staff. Due to the involvement of the same NCDOT personnel through the site investigation, design, and construction process, there were no challenges or unexpected issues. Guidance at the time of construction related to construction phasing and implementation was not available. An additional goal of the BMP Retrofit Program was to provide information for the production of another manual in addition to the BMP Toolbox: the Stormwater Control Inspection and Maintenance Manual (NCDOT 2010). This manual, published in 2010, outlines the general inspection, maintenance, and reporting requirements for stormwater BMPs as well as individual sections for specific BMPs (including infiltration basins).

The main challenge associated with construction at the site was the timing. The infiltration basin was located directly in front of Smyrna school; therefore, construction could not occur while school was in session, to protect the safety of the students. This required construction of the infiltration basin to occur in the summer of 2008 and construction associated with failure resolution to occur during a week of school vacation in April of 2009.

The current CQA program (put into place after the SR1347 project was completed) involves a daily inspector, representing the resident NCDOT engineer, who is on-site for all NCDOT projects constructed by a third-party general contractor. The daily inspector is tasked with assuring construction occurs in accordance with the construction plans, recording manifests for trucks leaving the site, and other CQA tasks. Additionally, NCDOT representatives try to visit active retrofit construction sites approximately once per week, and retrofit design engineers are typically expected to visit the site at least once during construction.

Operation and Maintenance

BMP Operation and Maintenance Observations and Records

Construction of the infiltration basin was completed in August 2008 and standing water was first observed in the infiltration basin in September 2008. The infiltration basin was assumed to have failed shortly after construction completion. Due to the short period of time between installation and failure, operation and maintenance activities were not substantial at the site prior to failure resolution. As such, operation and maintenance activities are not considered to contribute to failure. The only maintenance activity that occurred prior to failure was watering of the sod by the local NCDOT roadside environmental unit.

Findings Related to BMP Operation and Maintenance Guidance and Procedures

As described above, the operation and maintenance of the infiltration basin was limited due to its short lifespan. Existing operation and maintenance guidance was not available at the time of the SR1347 project. However, less than two years after installation, NCDOT published the Stormwater Control Inspection and Maintenance Manual (NCDOT, 2010). This manual continues to provide guidance for the inspection, operation, and maintenance of stormwater BMP projects.

The NCDOT currently operates an online database to house all information regarding inspection and maintenance of BMPs. The system, the Stormwater Control Management (SCM) system, contains the results of every annual inspection and other maintenance that occurs as needed. The highway stormwater program is co-managed by the Hydraulics and Roadside Environmental Departments. The local roadside environmental groups are given a map of BMPs to inspect, record observations with pen and paper, and later transpose their operations and maintenance notes into the electronic system for recordkeeping. NCDOT envisions the inspections will be conducted using electronic tablets in the future. Currently, operations and maintenance occurring on-site includes annual inspections by the Roadside Environmental staff as well as landscaping and maintenance as needed.

BMP Failure and Resolution

Description of Failure

Standing water was first observed within the infiltration basin in September 2008, one month after installation. In October 2008 the sod had died, most likely due to extended inundation. Between October 2008 and April 2009, when failure resolution was conducted, standing water was consistently observed in the basin.

Diagnosis of Failure and Failure Resolution

The failure of the infiltration basin was easily diagnosed due to the constant presence of standing water. School officials reported the failure to the NCDOT. Upon learning of the failure, NCDOT observed the site and performed additional water table tests (auger borings) in areas adjacent to the site and found that the water table elevation was higher than observed during the site investigation. Due to the safety hazard of standing water adjacent to the Smyrna school, NCDOT did not consider reinstallation or major maintenance of the infiltration basin. Instead, in order to greatly reduce the potential for standing water, the basin was redesigned to function as a bioretention basin, including underdrains, drawdown pipes, mulching, and vegetation. The basin retrofit was designed in January 2009 and constructed in April 2009.

The cause of the failure is believed to be a higher water table elevation than originally measured during the site investigation. While the BMP was undersized due to space constraints, the high water table is considered to have contributed primarily to the failure, rather than the sizing. The clay lenses observed within the existing sand layer are thought to potentially have artificially lowered the water table elevation in the area, possibly due to a continuous clay layer rather than the sporadic lensing assumed during the site investigation. Once the clay layer was disturbed during excavation, it is thought that the ground water may have been able to seep upward through the soil and settle much higher within the washed concrete sand layer than is shown in Figure 5. The location of the water table observed adjacent to the site supports the theory that a higher water table was present than was originally observed.

An additional (or alternative) possible failure mechanism is the tidal effect on the water table elevation. As described, NCDOT observed this area to be subject to astronomical high tides, which can result in great variability in the water table. Even normal seasonal variability in the water table elevation due to tidal influence could have contributed to the basin failure. These high tides were not taken into account as part of the site investigation or BMP design.

Findings Related Agency Guidance and Procedures

Guidance describing infiltration basin failure resolution was not available. Lessons learned from the SR1347 project helped to inform sections of the NCDOT BMP Toolbox (2008). The redesign of the infiltration basin was developed based on previous experience that NCDOT personnel had with underdrain installations. Based on a site visit, a review of the available area, and survey data regarding the elevation of the infiltration basin bottom in relation to adjacent pre-existing pipe inverts and paved areas, it was determined that there was enough vertical clearance to install underdrains.

Summary and Lessons Learned

Factors Contributing to Success or Failure

As part of the BMP Retrofit Program, the SR1347 project provided a "lessons learned" opportunity for the NCDOT. The selection of an infiltration basin at the site was largely based on the preference of the North Carolina Coastal Federation and the Smyrna school. While basic preliminary investigations demonstrated that infiltration might be feasible, facility operation, along with water table investigations conducted post-installation, showed that infiltration was likely infeasible due to the elevation of the water table. The key observations and transferrable findings from the SR1347 project are related to the importance of site investigations, particularly considerations of water table elevations and seasonal variations in those elevations, including those caused by astronomical high tides.

The site investigation for this retrofit project included an examination of the location of the water table at a single point in time. The probable failure mechanism, a water table that was too high to promote infiltration, was not adequately investigated during the site investigation. The NCDOT used the lessons learned from the SR1347 project and other BMP retrofits to develop and maintain both the NCDOT BMP Toolbox (2008) and the Stormwater Control Inspection and Maintenance Manual (NCDOT, 2010), both of which were published after the SR1347 project was completed. The infiltration basin siting criteria currently includes the requirement that "a minimum of 2 feet is required between the infiltration basin bottom and the seasonal high water table."

Findings from Agency Processes and Guidance

This case study presents the implementation of the BMP Retrofit Program by a DOT committed to improving their stormwater program. The NCDOT used the SR1347 project to learn several things about the site investigation, design and construction of infiltration basins that were utilized in development of guidance documents. Additional research and guidance are needed to address the presence of astronomical high tides (and/or varying water table elevations) in the coastal areas and how these varying conditions could affect infiltration feasibility. BMP site investigations and design processes would benefit from this additional guidance and research.

CASE STUDY REPORT

Washington State DOT: I-5 Vegetated Filter Strip Retrofit and Monitoring Study

Case Study Introduction

BMP Type:	Vegetated Filter Strips, Compost Amended Vegetated Filter Strips, and Modified (experimental) Vegetated Filter Strips
Geographic Location:	Interstate 5 near Everett, Washington and Arlington, Washington
Project Setting:	• BMPs located parallel to Interstate 5 within the roadway prism on embankment slopes of approximately 25 percent • Roadways were in rural areas with urban and ultra-urban traffic counts ranging from 76,000 to 126,000 annual average daily traffic (AADT) • Soils were relatively permeable, but highly compacted; depth to groundwater was moderate
Notable Factors in Success or Failure of BMP	• Retrofit and monitoring project examining different variations of a vegetated filter strip BMPs immediately adjacent to the freeway • BMPs have been successful to date and appear to show substantial volume reduction performance based on preliminary data • BMP configurations provide inherent redundancy to reduce sensitivity to underlying infiltration rate

The Washington State Department of Transportation (WSDOT) retrofitted a portion of Interstate 5 and conducted a monitoring project examining three variations of a vegetated filter strip (VFS) type best management practice (BMP). These sites were in a rural setting and had urban traffic loads ranging from 76,000 to 126,000 annual average daily traffic (AADT). Three configurations of VFS were evaluated: basic VFS, compost amended VFS (CAVFS), and a modified (experimental) VFS. These BMP configurations are described in greater detail in following sections. An example of a modified VFS (background) and a CAVFS (foreground) are shown in Figure 34.

Data collected from the monitoring project is intended to develop a further understanding of vegetated filter strip performance and design parameters as well as meet WSDOT's National Pollutant Discharge Elimination System (NPDES) permit requirements. Notably, this project is evaluating the volume

reduction performance of these systems, which largely depends on infiltration of stormwater within the roadway prism.

This case study does not document a BMP failure like the other case studies prepared as part of this research effort. Rather, it is intended provide insight into:

- Investigation of infiltration conditions;
- Construction of various configurations of VFS as highway retrofits;
- Establishment, operations, and maintenance of these BMP types;
- Observations of VFS durability on slopes steeper than design guidance;
- Performance of various configurations for volume and pollutant load reduction (to be added when available); and
- Monitoring study design and execution

Figure 34. Construction of I-5 Pilchuck Vegetated Filter Strips. Photo illustrates installation of CAVFS and modified VFS. Photo provided by Fred Bergdolt.

Information Obtained for Case Study

Materials Received:

1. Ecology. 2011. Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE). August 2011 Revision. Washington State Department of Ecology, Olympia, WA.
2. WSDOT. 2011(a). Highway Runoff Manual. Washington State Department of Transportation, Environmental and Engineering Programs Design Office, Olympia, WA. Publication M 31-16.03.

3. WSDOT. 2011(b). Geotechnical Evaluation Report for BMP Effectiveness Stormwater Monitoring Sites on I-5 and SR-9. AH-0181. Washington State Department of Transportation Materials Laboratory.
4. WSDOT. 2011(c). Quality Assurance Project Plan (QAPP) for WSDOT Roadway Stormwater Treatment Evaluation: Best Management Practices. Washington State Department of Ecology, Environmental Assessment Program.
5. WSDOT. 2015(a). NPDES Municipal Stormwater Permit BMP Effectiveness Monitoring Status Report (S7.C and S7.D) Water Years 2012 – 2014. Washington State Department of Transportation Stormwater and Watersheds Program
6. WSDOT. 2015(b). Research Proposal for Stormwater Treatment Performance of Modified Vegetated Filter Strips. Washington State Department of Transportation Stormwater and Watersheds Program
7. Summary of maintenance practices
8. MGS Flood Project Report
   - Determine flow from pavement at SR 005 MP 210
   - Run date: 5/20/2014
   - Provided by Alex Nguyen
9. As-Constructed Plans
   - SR 5 Stillaguamish River Bridge to Joe Leary Slough Bridge
     - Vicinity Map (sheet 2 of 172)
     - Roadway Sections (sheet 23A of 172)
       - MP 211.0 and 214.4
10. Site Photos
    - Provided by Fred Bergdolt, WSDOT
11. Agency Communication (e.g.):
    - Interview with WSDOT staff
      - Ken Stone, Dick Gersib, Fred Bergdolt, Greg Myhr, Greg Lahti,
        - 10/14/2015
      - Alex Nguyen
        - 10/15/2015, 2/9/2016
      - Roger Wilson
        - 10/29/2015
    - Email correspondence and telephone discussions
      - Fred Bergdolt, WSDOT Stormwater Monitoring and Research Coordinator
        - 1/12/2016; 2/8/2016
      - Alex Nguyen, WSDOT Highway Runoff Program Manager
        - 2/9/2016; 2/10/2016; 3/8/2016

Case Study Setting

Project Context

WSDOT is required to conduct a full-scale monitoring program to evaluate the effectiveness, operation, and maintenance requirements of stormwater treatment and hydrologic management BMPs as part of their NPDES Permit. The I-5 VFS project was undertaken to further WSDOT's understanding of VFS performance, including existing and experimental configurations, while satisfying this permit condition.

The project included the installation of three different VFS types to enable comparisons between the basic VFS and two variations of the VFS design: compost amended vegetated filter strips (CAVFS) and a modified vegetated filter strip (modified VFS). Different VFS types were co-located at common monitoring locations to provide ease of comparison.

A basic VFS is a compacted roadside embankment that is hydroseeded with an established grass seed mix. A CAVFS is a variation of the basic VFS that incorporates compost into the top 12 inches of soil to enhance infiltration characteristics, increase surface roughness, and improve plant growth and cover. Both BMPs are also approved for use by Ecology and described in detail in the WSDOT HRM. The modified VFS is an experimental BMP that has not yet received approval from Ecology. The modified VFS includes a 3-inch compost blanket that is applied to the surface of the soil. In comparison to CAVFS, the modified VFS does not require heavy equipment to till compost into the top 12 inches of the soil, making the cost of installation less expensive. A modified VFS can also be more practical in ultra-urban environments.

One of the purposes of this study was to determine if the modified VFS configuration should be added to the HRM. Before construction, the sites were constructed with grassy roadway embankments, but were not specifically designed as BMPs. The BMP sites monitored for this study were designed in May 2010 with construction completed by September 2011. Site monitoring began in October 2011 and continues as of this writing. The sites were monitored for volume reduction, flow attenuation, and water quality improvement. Monitoring parameters for water quality included: total recoverable and dissolved metals (copper and zinc), total suspended solids (TSS), hardness, pH, nutrients: total phosphorus and orthophosphate, particle size distribution (PSD). Seasonal first flush toxicity was monitored as well but was not primary focus of the study. Seasonal first flush toxicity testing included: *Hyalella azteca* 24-hour acute toxicity test, total recoverable and dissolved metals (copper, zinc, cadmium, and lead), herbicides, TSS, chlorides, hardness, methylene blue active substances, polycyclic aromatic hydrocarbons, phthalates, total petroleum hydrocarbon: diesel and gasoline range.

Site Location and Physical/Watershed Setting

The BMPs are located in Snohomish County, Washington. Two monitoring locations were included in the study, both sites were located along I-5. These are located at I-5 milepost (MP) 197 northbound (north of Everett) and I-5 MP 210 southbound (near Pilchuck Creek, near Arlington). Figure 35 shows the locations of these BMP sites.

The drainage areas for BMPs in both locations only included highway travel lanes and the BMPs themselves. The selected sites were chosen to be representative of both "urban" (I-5 at Pilchuck) and "highly urban" (I-5 at Everett) settings. The "urban" and "highly urban" classification is based upon the

AADT for the sites, which were 76,000 and 126,000 for Pilchuck Creek and Everett, respectively. The immediate surrounding land uses for these sites were both suburban/rural.

Two BMPs (a VFS and a modified VFS) were installed at the Everett site and three BMPs (a VFS, a CAVFS, and a modified VFS) were installed at the Pilchuk Creek site. A monitoring apparatus was installed in each BMP that includes an edge of pavement collector, a 6.6-foot collector (i.e., located 6.6 feet downslope from edge of pavement) and a 13.1-foot collector. The 6.6-foot collectors were included because highways in highly urbanized areas may have limited space for stormwater treatment along the road shoulder, and much of the flow reduction and water quality treatment are expected to occur close to the edge of pavement. The 13.1-foot collector was added to investigate further treatment along the road shoulder. The drainage area to each collector type for BMPs installed at the Everett site and the Pilchuk Creek site are shown in Figure 36. Each collector was used to measure flow and volume and was used to obtain flow-weighted composite samples for water quality analysis.

The tributary roadway areas draining to the Everett VFS and modified VFS are each 2,400 square feet in total. The tributary areas draining to the Pilchuck Creek BMPs are each 1,360 square feet in total. The pavement edge interceptors were used to estimate inflow to the BMPs.

The site soils at the Everett VFS site were described as loose to medium dense poorly graded sand with silt, poorly graded sand, silty sand, and silt; the silts contain organic material. Depth to groundwater generally ranged from 12 to 14 feet below ground surface. The soils underlying the site at Pilchuck Creek were composed of loose to dense silty sands with gravels and silts. Depth to groundwater ranged from 7 feet to more than 20 feet at Site P1, from about 15 feet to more than 20 feet at Site P2, and more than 20 feet at Site P3. The geology at both sites is consistent with “glacial outwash.” In contrast, “glacial till” soils that are also present in much of Washington would be expected to be much less permeable.

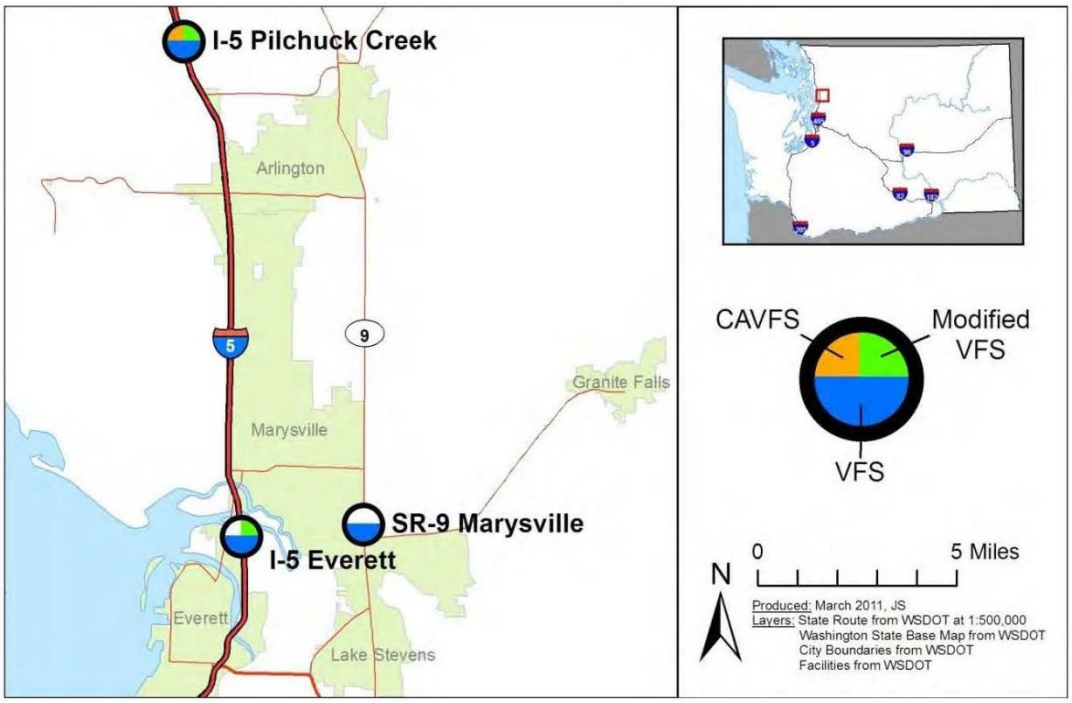

Figure 35. Location of the BMP sites; excerpted from WSDOT 2011(c).

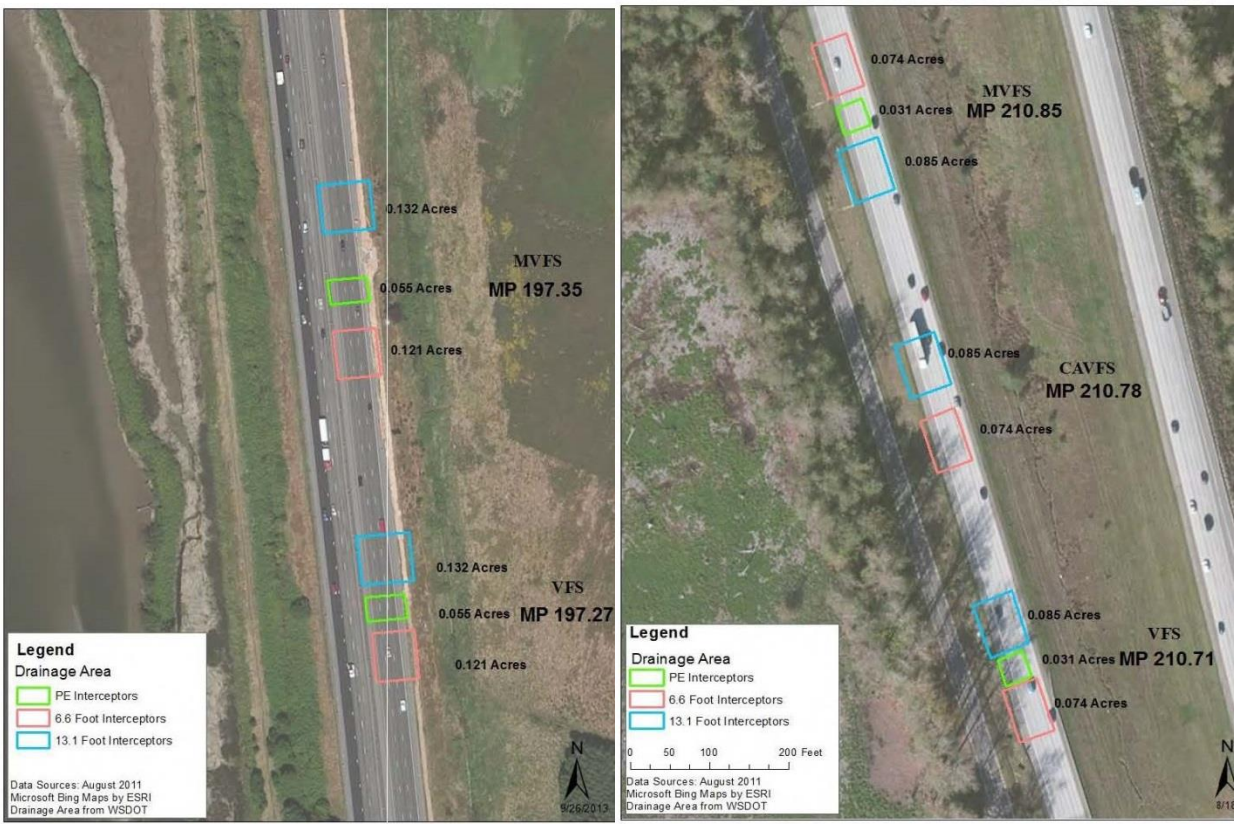

Figure 36. BMPs and Drainage Areas located at I-5 Everett (left) and I-5 Pilchuck Creek (right); excerpted from WSDOT 2011(c).

Applicable Regulations and Available Guidance

As discussed above, this monitoring study was conducted to fulfill NPDES permit requirements as well as WSDOT research interests.

With respect to stormwater control requirements for new projects or lane additions, the WSDOT Highway Runoff Manual (HRM) requires the consideration of low-impact development (LID) techniques that use the site terrain, vegetation, and soil features to promote infiltration, so the landscape retains more of its natural hydrologic function. VFS and CAVFS are the most common LID method utilized by WSDOT to meet this requirement.

The HRM provides guidance for site investigation and design of BMPs, including VFS and CAVFS. The design of the BMPs at both of the case study locations was based on the guidance provided in the HRM; however, the monitoring locations were selected to examine design parameters outside of these recommended in the HRM. The research objectives include the application of VFS in locations where slopes were approximately of 25 percent (the HRM specifies slopes between 2 and 15 percent or up to 33 percent when using aggregate or level spreaders). Other siting objectives incorporated into the case study locations included high traffic areas and limited available area for the siting of the BMPs.

Planning and Design Phase

Site Investigation and BMP Selection Findings

The HRM requires infiltration feasibility to be assessed during the scoping phase because of its direct impact on stormwater alternatives and costs. The HRM identifies several critical issues that must be considered during scoping and investigation of infiltration facilities:

- Depth to water table
- Seasonal variations of the water table
- Presence of soft or otherwise unstable soils
- Presence in soils of shallow bedrock or boulders that could adversely affect constructability
- Presence of existing adjacent facilities that could be adversely affected by construction of the stormwater facilities
- Presence of existing or planned underground utilities that could provide preferential flow paths for infiltrated water
- Presence of geologic hazards such as earthquake faults, abandoned mines, landslides, steep slopes, or rockfall
- Adequacy of drainage gradient to ensure functionality of the system
- Potential effects of the proposed facilities on future corridor needs
- Maintainability of the proposed facilities
- Potential impacts on adjacent wetlands and other environmentally sensitive areas
- Presence of hazardous materials in the area
- Infiltration capacity (infiltration and percolation rates for project sites)
- Presence of and potential impacts to floodplains

Specific factors investigated to evaluate infiltration feasibility and design parameters for the VFS, CAVFS, and modified VFS facilities include: stratification of the soil/rock below the facilities, depth to groundwater and any impermeable layers, seasonal variation in groundwater levels, existing groundwater flow direction and gradient, estimated saturated hydraulic conductivity, porosity of the soil above the water table, the impact of the infiltration rate and volume on flow direction and water table.

The site investigation that was undertaken to estimate infiltration rate included 22 geotechnical boring sites (8 at the Everett site, and 14 at Pilchuk Creek) and laboratory soil analyses for multiple horizons within each boring. Exploratory borings were drilled to depths between 16 and 20 feet below ground surface (bgs) and samples were collected every 2 feet. Undisturbed soil samples were analyzed in the field using the Unified Soil Classification System (USCS) visual classification method. Soil samples were also evaluated in the laboratory by grain size analysis to confirm field classifications, as well as to help in evaluating the infiltration properties of the soil. The laboratory analyses included soil grain size analysis and soil infiltration rate estimation using the Massmann method. The Massmann method correlates soil sample grain size distribution to saturated hydraulic conductivity (WSDOT, 2011b). Soil samples collected in the top 2 feet of the borings were considered to be representative of conditions within the VFS, CAVFS, or modified VFS; Soil sampled at depths greater than 2 feet were considered to be representative of conditions below the VFS, CAVFS, or modified VFS.

Site investigation also included the installation of 18 piezometers to determine the maximum and minimum depth to groundwater for the sites. Groundwater elevation monitoring was undertaken monthly from April through October 2011. The calculated hydraulic gradient was then used to calculate an infiltration rate for the location.

A combined factor of safety of 5.0 was applied to the calculated infiltration rate. The factor was applied to account for potential compaction at the site based and biofouling. This factor of safety was based on guidance in the HRM and professional judgment. The results of the Massmann method were presented as averages and factored results for each of the site locations. Table 1 presents the results of the laboratory soil analysis and Massmann Method.

Table 1: Laboratory Results for Massmann Method Analysis

Location	Below VFS, CAVFS, or modified VFS			
	Number of Exploratory Borings	Average Hydraulic Conductivity (ft/day)	Infiltration Rate (ft/day)	Factored Infiltration Rate (ft/day)
I-5 Everett- MP-197.27	4	77	11.0	2.20
I-5 Everett - MP-197.35	4	76	9.78	1.96
I-5 Pilchuck - MP-210.71	5	9.5	0.92	0.18
I-5 Pilchuck - MP-210.78	5	8.8	1.81	0.36
I-5 Pilchuck - MP-210.85	4	9.5	2.13	0.43

BMP Sizing and Design

BMP design generally followed HRM design guidance, with two exceptions. First, slopes were steeper than recommended. Current WSDOT design guidelines limit VFS to embankments with lateral grades between 2 and 15 percent, or up to 33 percent with a gravel spreader. These shallow slopes ensure sheet flow runoff from adjacent impervious surfaces is maintained, and sedimentation and infiltration rates are maximized. Slopes steeper than 3H:1V are not currently recommended due to cases where concentrated flows can cause erosion and reduce the VFS potential to treat stormwater.

The VFS project was undertaken to put stress on the design parameters of VFS, CAVFS, and modified VFS BMPs to determine their applicability in locations where regular design parameters are exceeded. The BMPs for this project were designed without gravel spreaders, which under the current HRM, limits lateral slopes to less than 15 percent. The slopes for the BMPs in this project were all in excess of the slopes suggested under the HRM. Second, the modified VFS design, described earlier involves surface application of compost without tilling. This design is not currently reflected in the HRM. Table 2 describes the BMP geometries associated with the study locations.

Table 2: BMP Geometries

Location	BMP Type	Traffic Designation	Average Embankment Slope (H:V)	Average Embankment Slope
I-5 Everett- MP-197.27	Basic VFS	Highly Urban 126,000 AADT	3.70:1	27
I-5 Everett - MP-197.35	Modified VFS		3.85:1	26
I-5 Pilchuck - MP-210.71	Basic VFS	Urban 76,000 AADT	4.00:1	25
I-5 Pilchuck - MP-210.78	CAVFS		3.85:1	26
I-5 Pilchuck - MP-210.85	Modified VFS		3.70:1	26

The HRM provides guidance for designing VFS to provide a minimum residence time of 9 minutes for full water quality treatment, and a 91 percent volume treatment capacity for CAVFS. The design process includes modeling the VFS and CAVFS using a continuous model, such as MGS Flood, to determine the runoff treatment design flow. The model estimates the volume of runoff infiltrated based upon data input, including infiltration rates determined during site characterization. The design of the Everett and Pilchuck sites did not necessarily follow these criteria. Rather collectors were spaced at even intervals with the intent of evaluating the trends in performance versus length and were sized to capture the full range of potential flows.

Construction Phase

BMP Construction

Construction of the BMPs was undertaken to support the continuing monitoring requirement of the permit, therefore this was effectively a retrofit application and did not involve new roadway or travel lane construction. As a result, the construction phase was undertaken by WSDOT crews based on simple study diagrams, but without a formal set of engineering design drawings or plans. Prior to the construction, the facilities were grassy roadway embankments, which are a basic VFS. The CAVFS and modified VFS test plots were built by the research team in the selected locations. The construction phase was undertaken in May 2011.

For the CAVFS, the HRM specifies that a 3-inch layer of compost be tilled to a depth of 12 inches, and then the embankment be seeded with a native “meadow” seed mix. Tilling for the CAVFS was completed by a track hoe (operated from the roadway shoulder). The maximum depth of tilling for this project was between 6 – 8 inches using the teeth of the track hoe bucket. The tilled compost was gently compacted using the track hoe bucket. The CAVFS site was hydroseeded after construction activities. The CAVFS was not irrigated to promote growth, though the facilities were watered during the plant establishment period from the side of the road using a water truck. No gravel spreaders were installed at these facilities.

For the modified (experimental) VFS, a 3-inch blanket of compost was applied to the surface and seeded with the same seed mix. The compost blanket was applied by hand using shovels to minimize site compaction. The modified VFS were not compacted during construction. The compost blanket also served as a temporary erosion control measure during construction and subsequent growth from hydroseeding. The HRM designates compost blankets as a temporary erosion and sedimentation control. The modified VFS was not irrigated to promote growth, though the facilities were watered during the plant establishment period from the side of the road using a water truck. No gravel spreaders were installed at these facilities.

In addition to the construction of the BMPs, the research team built the monitoring stations at each of the research locations. This element was solely to facilitate the research and is not a typical design element.

Operation and Maintenance and Performance Monitoring

BMP Operation and Maintenance Observations and Records

BMP maintenance for VFS, CAVFS, and modified VFS involves annual mowing. Typical maintenance (mowing) of VFS BMPs is conducted by a regional maintenance office; however, these facilities are mowed with a hand trimmer by the monitoring program staff to avoid damage to monitoring infrastructure. Additional maintenance needs include activities to address localized sediment accumulation on grass, trash and debris, erosion and scouring, and uneven flow spreading. During the monitoring program, maintenance was completed regularly by the monitoring program staff. Maintenance also included cleaning of outlet pipes, sampling basins, and the conveyance system associated with the monitoring system. These elements are only needed because this is a test site and would not be needed for typical applications.

WSDOT staff conducted inspections on monitoring infrastructure every six to eight weeks or after sampled storm events. Inspections primarily focused on the monitoring infrastructure which is not typical of VFS and CAVFS BMPs.

At Pilchuck Creek facilities, minor rilling was observed in the CAVFS. Rilling occurs when runoff follows preferential flow pathways instead of being maintained as sheet flow. Rilling causes erosion of facility surface soils along the preferential pathways. At the Everett site, the compost initially installed was found to be contaminated with trash, including plastic and metal. The compost had to be removed and replaced. Additionally, installation of a high speed cable project caused damage to the VFS and modified VFS facilities. This construction project had not been foreseen in the selection of the sites. Figure 37 demonstrates the damage done to the modified VFS during construction activities.

Figure 37. Damage to VFS at the Everett site due to construction of high speed cable project. Photo provided by Fred Bergdolt.

BMP Performance Monitoring

The monitoring program developed for this project was designed to collect high-quality data that characterized BMP effectiveness in reducing stormwater flows and pollutant loads from highway land uses (Figure 38) The monitoring program was developed to collect both water quality and flow data as required by the NPDES permit as described earlier in this case study. The monitoring program was implemented in accordance with the WSDOT's NPDES permit requirements and the Technology Assessment Protocol – Ecology (TAPE) (Ecology, 2011).

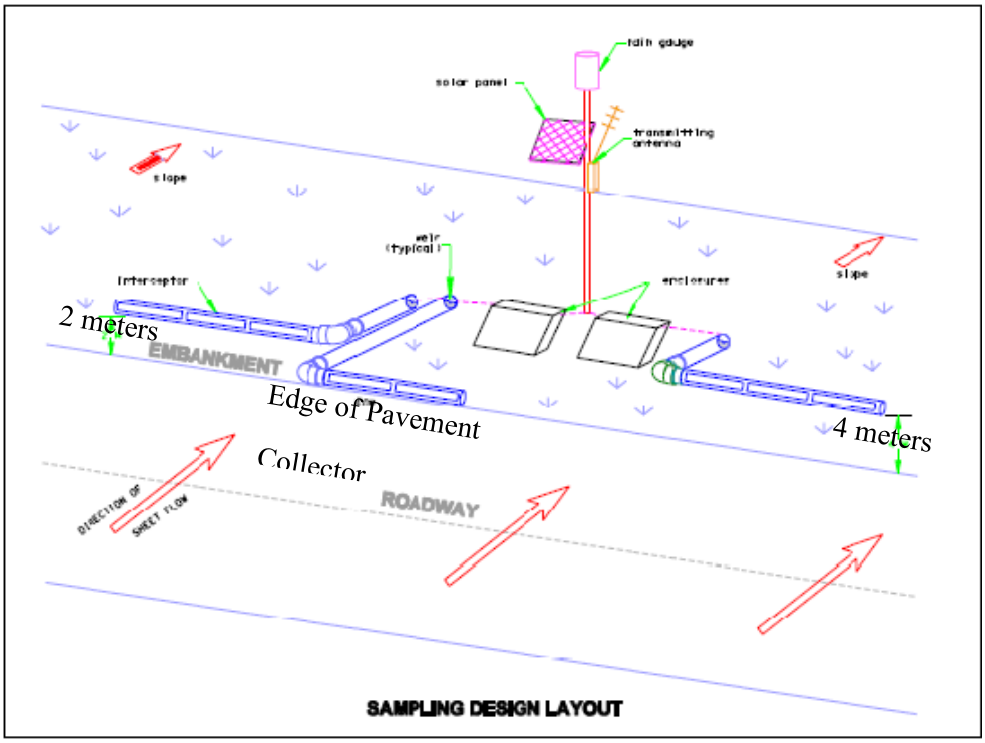

Figure 38. Sampling design layout; excerpted from WSDOT 2011(c).

Flow data is available for the project, but the data has not been analyzed by WSDOT at this time. A summary of results can be added to this case study when they become available. An example of monitored hydrographs from a representative 1.0 inch storm are provided in Figure 39 and Figure 40. Data will need to be further evaluated to correct for difference in tributary areas at the pavement edge and downstream sites, as well as to evaluate long term performance and seasonal variability.

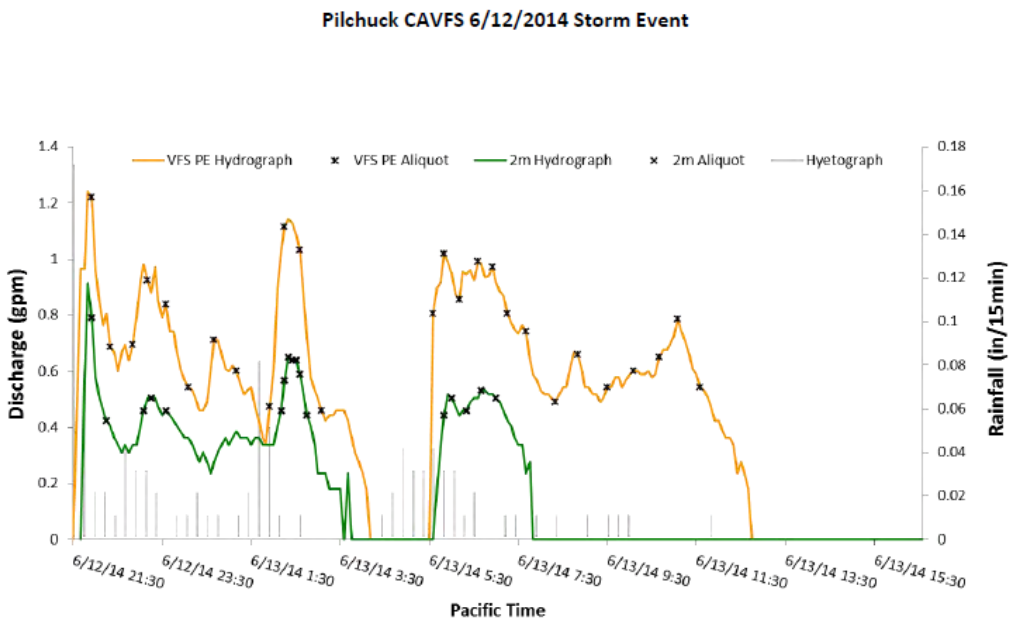

Figure 39. Example Inflow and Outflow Hydrographs for Pilchuck CAVFS (WSDOT, 2015(a))

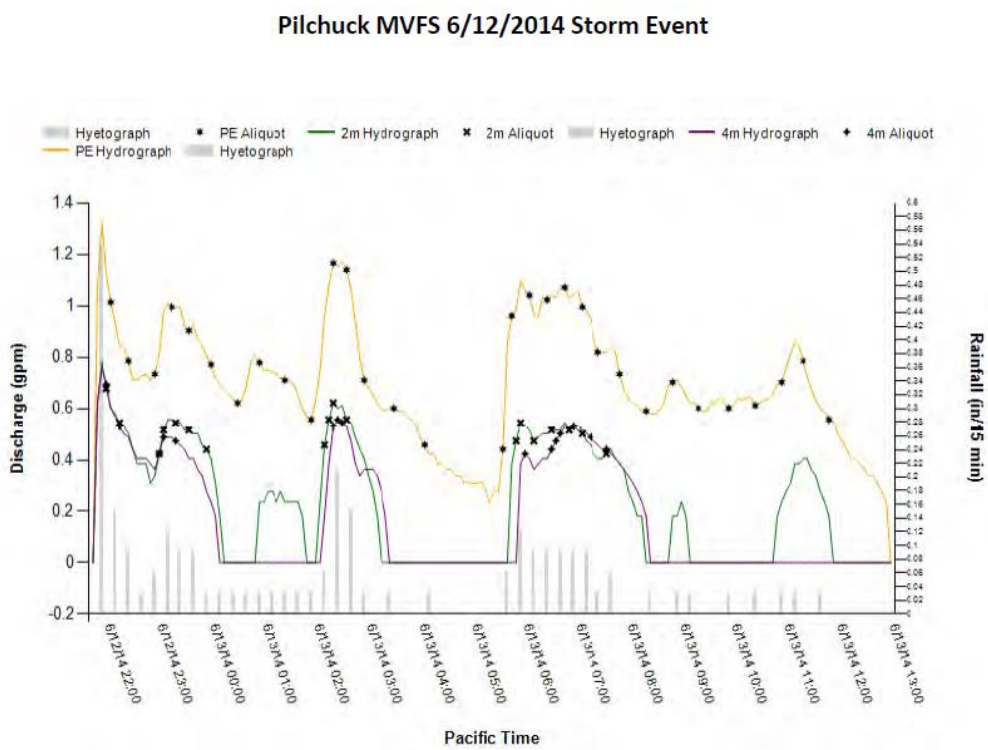

Figure 40. Example Inflow and Outflow Hydrographs for Pilchuck Modified VFS (WSDOT, 2015(a))

Summary and Lessons Learned

The following list summarizes key findings and lessons learned:

- The VFS, CAVFS, and modified VFS BMPs were installed for use in a BMP monitoring program. Before installation of the BMPs, a thorough investigation of site characterization was undertaken utilizing 22 different exploratory borings done at the site. The data gathered led to the development of site specific infiltration rates, site stratigraphy, depth to groundwater, groundwater gradient and flow direction.
- While an extensive geotechnical investigation was conducted, the design of the facilities has inherent redundancy (i.e., water that is not infiltrated is treated as it flows through the filter strips). As a result, the performance is not as heavily dependent on exact knowledge of infiltration rates as other types of BMPs without this redundancy. One reason for conducting a more rigorous geotechnical investigation was to develop high-resolution estimates that could be used to interpret monitoring data.
- Results of 45 months of monitoring data are anticipated to be published by the WSDOT in 2017. These data will provide a basis for a direct understanding of volume reduction performance. Additionally, these data could allow for comparison to model estimates, such as those provided by MGS Flood and the Volume Performance Tool prepared as part of NCHRP Report 802. This type of analysis can help evaluate whether the estimated infiltration rates derived from correlations to grain size distribution and measurement of depth water table provide a reliable estimate of actual infiltration rates observed in facility operations.
- Overall, the degree of volume reduction provided by these facilities appears to be quite significant based on preliminary data review, particularly given that they are installed on compacted embankment with steeper than 4H:1V slopes. Given the relatively low effort required for these retrofits, the cost-effectiveness for volume reduction would likely be high.
- For future facilities, the HRM could be amended to reflect the observed success of shallow tillage for CAVFS facilities or no tillage modified VFS facilities, resulting in cost and time savings during the construction phase.
- Operations and maintenance activities of the BMPs themselves (excluding the monitoring equipment) over the first four years has been relatively limited.
- The research effort led to the development of standard operating procedures (SOPs) to clarify the fundamentals of various monitoring activities and allow for efficient and consistent collection of the most reliable, representative data possible.
- Groundwater level data, coupled with flow monitoring data could serve as a dataset for future research efforts related to groundwater mounding and dissipation.

CASE STUDY REPORT

Wisconsin DOT: Silver Spring Drive

Case Study Introduction

BMP Type:	Bioretention
Geographic Location:	Village of Menomonee Falls, Waukesha County, Wisconsin
Project Setting:	Bioretention units constructed in the highway median of a 4-lane divided highway. Units accept runoff from the No. 1 lane in each direction of travel.
Notable Factors in Success or Failure of BMP	The units are functioning as-designed and have been monitored by the United States Geological Service (USGS) since Spring 2015.

The subject project is located in Waukesha County, Wisconsin and was part of the construction associated with the expansion of a rural two-lane highway to a divided four lane (two lanes in each direction of travel) highway. The No. 1 lanes in each direction of travel drain towards the median. The median consists of a series of bioretention units, each serving a sub-watershed of the new highway (Figure 41). The total project length is 3.1 miles with a total new impervious surface of 14.9 acres. There are 27 longitudinal bioretention units with underdrain systems. The No. 2 lanes in each direction of travel are tributary to vegetated filter strips and longitudinal grass swales. The objective of the project was to reduce TSS by 50% compared with a no control scenario.

Figure 41. Examples of the bioretention system shortly after construction

Information Obtained for Case Study

Materials Received:

- Overview PowerPoint® presentation for project

- Design drawings
- Soils information
- Information on USGS monitoring project
- Selected project specifications

Agency Communication (e.g.):

- Craig Donze, Principal for One Source Consulting. Various phone calls and emails. Email transmitted project information received on 4/29/16.
- Robert Armstrong, Stormwater Engineer, Wisconsin DOT. Various phone calls and emails. Email transmitting project information received on 4/28/16.

Case Study Setting

Project Context

This project constructed bioretention BMPs that include elevated subdrains due to relatively poor underlying soils. The bioretention units were installed to meet WisDOT's regulatory requirement for a minimum 40% TSS reduction on highway reconstruction projects (the project goal was 50%) as described in TRANS 401.106(3)(b) of the State of Wisconsin Administrative Code. The project is to serve the new impervious portion of a highway expansion. A portion of the project was also selected by the USGS for monitoring to assess the TSS and volume reduction achieved with the BMPs.

Site Location and Physical/Watershed Setting

The project is located in Menomonee Falls, Waukesha County, in southeastern Wisconsin. The project is in an area of generally low relief, with average longitudinal slopes ranging from 0.5 to 1.5%. Site soils generally consist of Ozaukee silt loam and Mequon silt loam, consisting primarily of hydrologic soil group C, exhibiting a relatively low infiltration rate and high runoff potential.

The project is tributary to the Fox River, which is not on the 303d list for impairments (a Fox River is listed as impaired by the Wisconsin DNR, but is located in Brown, rather than Waukesha County). The site vicinity consists of agriculture, residential and limited commercial use. Impervious cover is generally less than 20%. Figure 42 and Figure 43 show the site vicinity and location respectively.

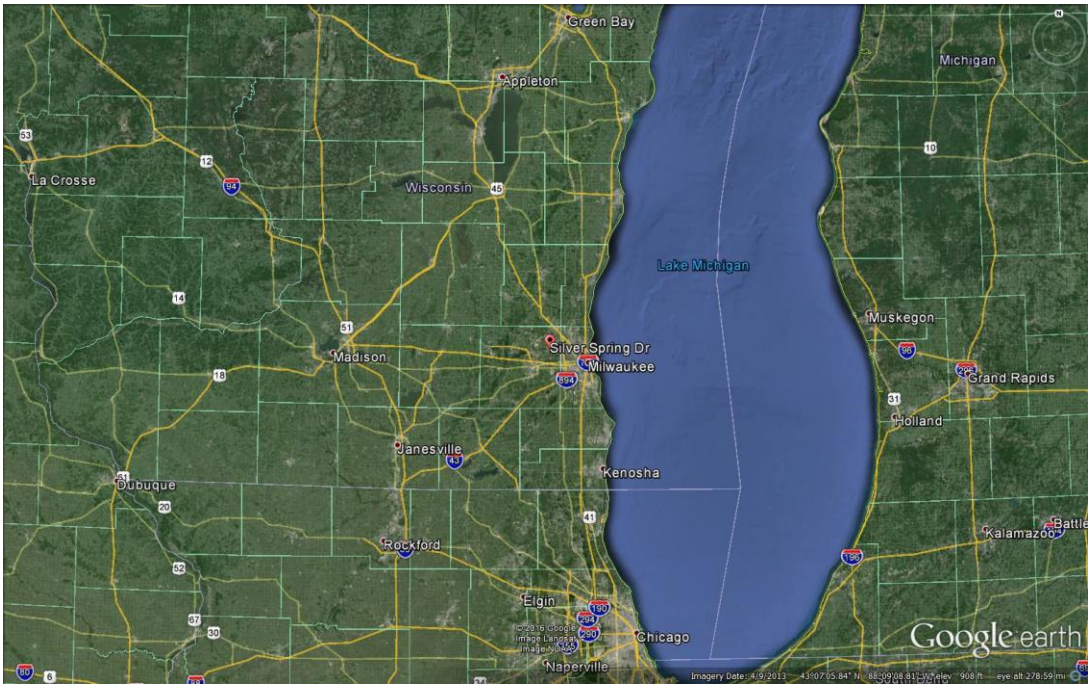

Figure 42. Site Vicinity

Figure 43. Site Location

Applicable Regulations and Available Guidance

The project had a TSS reduction goal of 50%, as determined by the project sponsor in order to maintain compliance with their municipal stormwater runoff permit. The project also had the requirement to

maintain the 2-year peak flow level consistent with existing conditions. Infiltration of stormwater was not a stated goal of the project; however, the selected design facilitates infiltration to the extent available in the site soils. The bioretention cells were sized based on the available area in the roadway median. Accordingly, the stormwater loading rate (runoff volume to bioretention surface area) varies throughout the project.

Chapter 10 of the WisDOT Facilities Development Manual (FDM) requires that stormwater treatment BMPs be sited in locations where characteristics are suitable, including soil type, watershed area, water table depth, the presence of bedrock and topography. The FDM provides design guidance for grass swales, vegetated (filter) strips, drain inlets with sumps, biofilters (future) and wet detention ponds.

Roadway projects constructed by WisDOT have a regulatory exemption from infiltration requirements due to the potential for environmental impacts to the groundwater table (Wisconsin Administrative Code NR 151.244(2)). For this reason, infiltration is generally not used by WisDOT, unless in an area where site conditions are favorable for implementation.

Planning and Design Phase

Site Investigation and BMP Selection Findings

The BMP was selected based on the available area in the roadway median, the availability of cross culverts, and the project objective to reduce the 2-year runoff to the pre-project level and TSS by 50% compared with a no-controls scenario. Bioretention was determined to be the most appropriate selection to achieve flow reduction and TSS reduction goals. The project initially was to include an impermeable barrier (to avoid infiltration of road salt) but this was not included in the final plans and specifications. Other options available to the DOT as described in the FDM that could be viable for this project include vegetated swales, strips and wet ponds. Vegetated swales and strips would likely achieve the TSS reduction goal for this project but may not achieve the peak flow reduction goal. Drain inlets with sumps would not achieve the required flow reduction. Wet ponds were not selected as a preferred alternative due to the need to acquire additional right-of-way for non-roadway purposes.

BMP Sizing and Design

The BMPs were sized based on the available area in the median. A typical bioretention cross section is show in Figure 44. The bioretention units were generally continuous longitudinally for the length of the project, divided into discrete units at locations of cross drainage culverts. Using this approach, the tributary new impervious surface area consisting of two lanes and shoulder, or about 32 feet of paved area (see Figure 45), discharge on a spatially varied per foot basis to the longitudinal bioretention unit. Accordingly, each 32 square feet of pavement was tributary to 10 square feet of bioretention. The bioretention BMP was modeled using WinSLAMM (ver. 10) to validate 50% TSS reduction and the 2-year return period flow reduction goals were obtained.

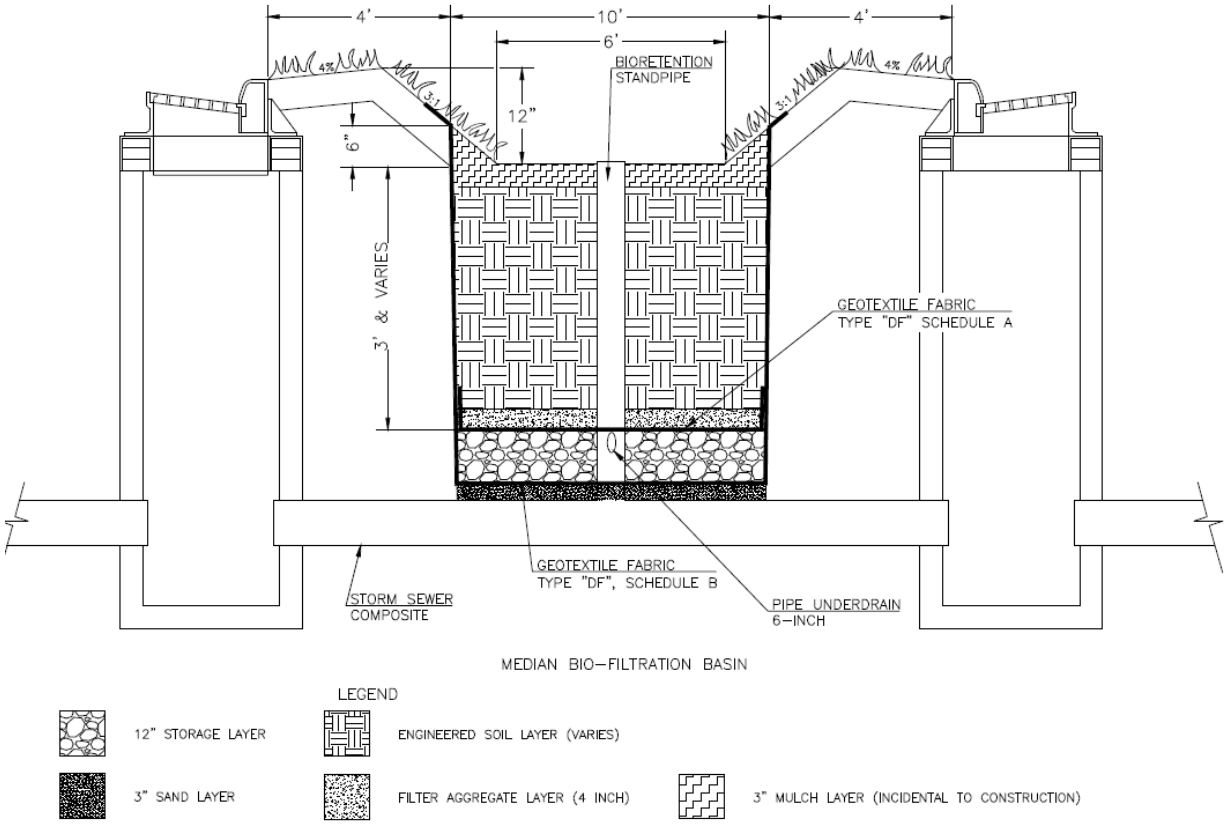

Figure 44. **Bioretention cross section**

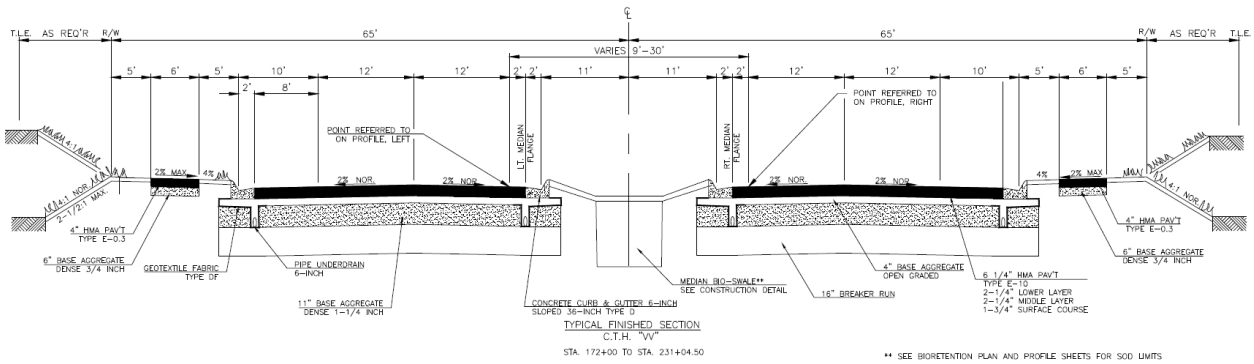

Figure 45. **Typical roadway cross section**

Findings from Agency Planning and Design Process

There is not currently guidance available from WisDOT for bioretention design. The design details for this project were developed by the consulting civil engineer of record using best management practice guidelines available from the Wisconsin Department of Natural Resources and Waukesha County. The WisDOT FDM has a future placeholder for design guidance for bioretention.

Construction Phase

BMP Construction

The engineer of record assisted in the construction oversight of the project. Pictures of the general construction sequence are shown below:

Findings from Construction and Construction Quality Assurance Process

The specifications required that construction site runoff from disturbed areas not be allowed to enter the bioretention device. Runoff was required to be diverted until the device was completed and adjacent areas stabilized. Construction was suspended during periods of rainfall. Compaction of soils below the bioretention areas was minimized. Heavy equipment was kept out of the excavation.

Some of the lessons learned from the construction process included the following:

- Construction oversight. The USGS requested that an impermeable membrane be installed to allow monitoring of the field capacity of the engineered filter media for the cell that would be monitored. The design change was requested after construction had commenced and was completed.
- Filter media. An engineered soil media was used for the bioretention mix. The engineered media was overlain by a surface mulch consisting of shredded hardwood mulch or chips, aged a minimum of 12 months. The engineered media was underlain by a storage layer, consisting of 12 inches of coarse aggregate No. 2 stone. It was not compacted during placement. The underdrain was elevated 6” from the base of the stone layer, which was 3” above native material over a sand bed. The engineered filter media was developed to reduce the potential for clogging due to road salts. The mixture is comprised of 75% sand and 25% compost. The compost is required to meet Technical Specification S100 of the Wisconsin DNR.
- Cost effective design. The design was determined to be more cost effective than a traditional wet pond design since additional right-of-way was not needed for the bioretention area. It was placed within the median and within the ROW owned by the DOT. The system also reduced the cost of the longitudinal storm sewer system that would otherwise have been required with wet detention ponds.
- Increase maintenance cost. The DOT anticipates an increased maintenance cost of the bioretention units compared to a vegetated swale system.

Performance Monitoring

The project was selected by the USGS for long-term performance monitoring. The purpose of the study is to evaluate the performance of bioretention swales as a stormwater management practice. The primary objective of this study will be focused on measuring the effectiveness of bioretention swales at reducing stormwater runoff flow and volume from urban highways. It will evaluate the infiltrative capacity of bioretention swales and their potential to reduce pollutants such as TSS. The study will evaluate two sections with different engineered soil mixtures: first mixture is using the Bioretention Technical Standard (1004) mix of 75 percent sand and 25 percent compost and the second mixture is 18-in. of sand at the bottom and 6-in. of the 75/25 compost mixture.

There are two bioretention monitoring locations to measure the inlet and outlets. Along the BMP there are curb cuts spaced about 50 ft apart, the USGS is monitoring two curb cuts (inlets), one from each side of the highway. This design was based on several factors including consistent roadway flow patterns, maintain curb-cut flow patterns into the bioretention area, and reduce cost of the project. Measured curb-cut flows can then be extrapolated to unmeasured curb-cuts.

Highway flow drains into the bioretention unit onto 2-ft of engineered soil and a drain tile below. The USGS is monitoring the drain tile (outlet) at each location. Beneath the drain tile, a geotextile stretches across the bottom of the bioretention trench, allowing infiltration into a native clay soil while retaining the reservoir gravel layer.

In fall of 2014, flow monitoring and sampling equipment was installed to measure highway flow (inlet) and bioretention tile flow (outlet) at each of the two cells. The expectation was that most of the water measured through inlets would be observed at the outlets. However, after several inlet flow events, minimal outlet flow events were recorded at the outlets. The only water-quality sample collected at the one outlet occurred during a 4-in. rainfall event. The reason for lack of flow through the outlet appears to be the ability for the cells to function effectively even with the very low infiltration rate of the native soils, and the provision for 6” of dead storage below the underdrain.

A review of the WinSLAMM results for a range of infiltration rates and rainfall depths, it was discovered that an infiltration rate as low as 0.5 in/hr. was sufficient to eliminate discharge from the drain tiles. This is likely due to the fact that the ratio of watershed size to cell size is roughly 5 to 1 for the monitored locations. Flow monitoring photos are provided in Figure 46 and Figure 47.

Figure 46. **Typical influent monitoring setup**

Figure 47. Influent monitoring setup and equipment cabinet.

Summary and Lessons Learned

Factors Contributing to Success or Failure

The project appears to be functioning well, and based on preliminary information from the USGS, is providing incidental infiltration that is exceeding expectations. This is not an unexpected outcome in that evidence from across the country indicates that bioretention typically exceeds flow and volume reduction goals compared to the modeled condition. The current project elevates the subdrain 6" above the invert of the excavation, providing initial dead storage for highway runoff in addition to the infiltration that occurs through the native substrate.

The WisDOT is also to be commended for installing bioretention prior to the development of standardized design guidance. This project appears to be a pilot to assess the function at a prototype scale, and the monitoring information provided by the USGS will provide WisDOT with valuable information relative to the performance of bioretention in soils with marginal infiltration properties. Further, the design of the bioretention units was based on what would physically fit in the available space, providing potentially additional environmental benefit over a system sized to retain a specific water quality volume. The DOT's willingness to design and construct a project using more flexible criteria will

also provide an opportunity to assess the marginal benefits from bioretention that has expanded capacity compared to systems sized for a standardized runoff volume.

Findings from Agency Processes and Guidance

It is recommended that the monitoring information from the USGS be reviewed prior to the conclusion of the NCHRP research study to augment this case study report with additional performance information. It is likely that WisDOT will have finalized its bioretention guidance for the FDM by this time, and the USGS will have concluded its study and data analysis, allowing for closure on some of the study questions discussed in this report.