WSDOT NPDES Municipal Stormwater Permit Compost-Amended Biofiltration Swale Monitoring Final Report

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Prepared by

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Compost-Amended Biofiltration Swale Effectiveness Monitoring Final Report

Approved by:

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Signature: Signature on file Date:

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Executive Summary

From 2016 through 2019, the Washington State Department of Transportation (WSDOT) attempted effectiveness evaluations of shortened Compost Amended Biofiltration Swales (CABS) at three locations, two in western Washington and one in eastern Washington (WA). All three CABS were unique, with differences in length, subsurface monitoring (for the eastern WA CABS), and the placement of treatment media sumps. The studies were to include water quality and hydrologic data collection and analysis in an attempt to support issuance of a General Use Level Designation (GULD) for basic and dissolved metals treatment for the shortened CABS.

These studies were developed and being implemented to satisfy requirements under Special Condition 7.C (S7.C) of WSDOT's *National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge Municipal Stormwater General Permit* (permit) (Ecology 2014). The permit required an effectiveness evaluation of best management practices (BMPs) at three WSDOT facilities.

Due to unobserved site characteristics and study design flaws, WSDOT was unable to complete the study as represented in the Quality Assurance Project Plan (QAPP). WSDOT learned many lessons, which are described in more detail in Section 5 of this report, regarding site selection and study design. These lessons will better inform future study design and site selection.

1 Introduction

1.1 Permit Overview

On March 6, 2014, the Washington State Department of Ecology (Ecology) reissued a *National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge Municipal Stormwater General Permit* (Ecology 2014) to the Washington State Department of Transportation (WSDOT). Under Special Condition S7.C of the permit, WSDOT developed and implemented a monitoring program to evaluate the effectiveness of stormwater treatment and hydrologic management best management practices (BMPs) at WSDOT facility sites. This work was continued under Section S7.B of the 2019 Municipal Stormwater Permit (Ecology 2019), reissued to WSDOT by Ecology on March 6, 2019.

Under Special Condition S8.G of the 2019 Municipal Stormwater Permit, WSDOT must submit a final report that includes analysis of effectiveness data collected (Section 5.1) and an estimated cost of the effectiveness monitoring (Appendix A). The following report is meant to satisfy this reporting requirement and provide a summary of monitoring activities at WSDOT maintenance facilities from October 1, 2016, through September 30, 2019 (water years 2017-2019).

1.2 Monitoring Requirements

In accordance with the 2014 and 2019 Municipal Stormwater Permits, WSDOT must evaluate stormwater BMPs selected to address concerns identified during runoff characterization monitoring of WSDOT facilities (water year 2012-2013). An additional requirement is to evaluate BMPs at two facilities in western WA and one facility in eastern WA. WSDOT chose to monitor compost-amended biofiltration swales (CABS) for treatment of stormwater runoff and hydrologic management at three maintenance facilities.

2 Monitoring Program Implementation

2.1 Site Selection Strategy

WSDOT conducted a runoff characterization monitoring study, from 2012-2013, of several maintenance facilities, rest areas, and ferry terminals to meet requirements in the 2009 Municipal Stormwater Permit. Stormwater monitoring program staff reviewed baseline-monitoring data from this study and identified analytical results with comparatively high concentrations of metals, total petroleum hydrocarbons, and chlorides. During site selection, staff weighed these baseline results against complicating site factors such as safety concerns and ease of site retrofit.

Monitoring staff used the following evaluation criteria to select maintenance facility sites for monitoring.

- Personnel safety
- Site accessibility
- Equipment security
- Discharge and precipitation measurement capability
- Site design limitations

2.1.1 Personnel Safety

For any WSDOT project, staff safety is a high priority. The following site attributes expose monitoring field teams to potentially unsafe conditions:

- Sites located near heavy maintenance vehicle traffic.
- Sites with poor access.
- Slopes that encourage slips, trips, and falls.

To minimize the effects of these hazards, staff had to be capable of performing all tasks required for sample collection and be familiar with WSDOT's *Safety Procedures and Guidelines Manual* (WSDOT 2015 and 2018). Staff also developed site-specific Health and Safety Plans (HASPs) for each monitoring site to minimize the effect of these hazards.

2.1.2 Site Accessibility

WSDOT selected monitoring sites to provide safe and feasible access. To make sure personnel could quickly locate and access monitoring sites, staff developed site-specific HASPs to include a description of parking and work zone safety procedures. Information in the HASPs included lists of physical and biological hazards, standard emergency procedures, site maps, and directions.

2.1.3 Equipment Security

Selected sites had to provide adequate secure and level areas for monitoring station installation in locations with sufficient space for monitoring equipment. Additionally, the Western Washington sites were located within the perimeter fence of each maintenance facility. Staff installed data collection equipment in locked metal enclosures on level ground or concrete platforms to reduce the risk of tampering. Locked metal enclosures provided a secure location as well as protection from wind, rain, and snowfall.

2.1.4 Discharge and Precipitation Measurement Capability

Staff selected monitoring sites in locations that allowed for discharge measurement and automatic sample collection. In order to monitor runoff from WSDOT facilities, field personnel constructed conveyance systems to collect, direct, and measure sheet flow moving through the CABS.

Staff installed monitoring sites in locations that allowed for accurate precipitation monitoring. Requirements for accurate precipitation monitoring included adequate distance from biasing factors, such as trees, and the ability to mount rain gages high enough above the ground to avoid rain splashing from maintenance vehicle traffic.

2.1.5 Site Design Limitations

WSDOT established monitoring stations to collect water quality and quantity data from influent, mid-CABS, and effluent sampling locations. Personnel considered the following site design limitations when establishing monitoring stations for effectiveness evaluation:

- The physical space needed for monitoring infrastructure and data collection platform establishment.
- A monitoring site design that would provide easy access for water quality sampling.
- Monitoring equipment and site infrastructure that enabled accurate flow measurements and reduced required maintenance.

2.2 Resource and Logistical Constraints

Staff identified two western WA sampling locations within 30 miles of the monitoring program headquarters. These site locations reduced staff travel time, providing quick access to sites for station maintenance and sampling. For the eastern WA location, WSDOT utilized a region staff member to perform sampling duties, though headquarters monitoring staff still visited the site for station maintenance.

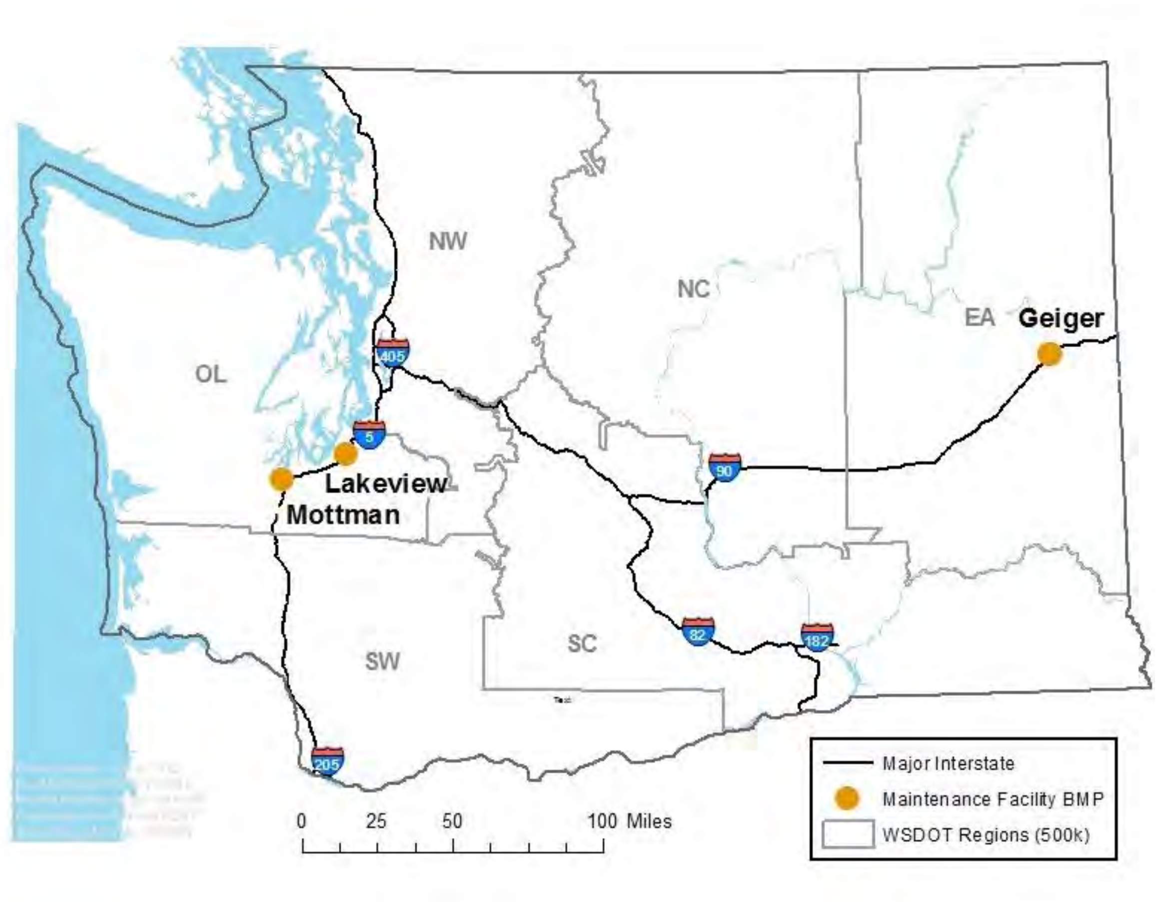

Figure 1. WSDOT CABS study sites.

2.3 CABS Effectiveness Monitoring Sites

Staff evaluated several maintenance facilities, identified during the initial runoff characterization study, as potential monitoring locations. WSDOT reviewed data collected during the baseline study and identified two facilities with comparatively high concentrations of water quality pollutants. Staff identified a third site following a review of maintenance activities occurring at that site. Table 1 lists the three representative maintenance facilities chosen for BMP effectiveness monitoring.

Table 1. CABS effectiveness monitoring sites.

Facility Name	Facility Location	BMP Type	Sample Location Code	Sample Location Description
Mottman Maintenance Facility	Western WA, City of Tumwater	Modified CABS (Flow Length Reduction)	MOT-01	Influent sump
			MOT-02	Post sump at 30’
			MOT-03	Post sump at 73’
			MOT-04	Pre sump basin at 120’
		Modified CABS (Oyster Shell amendment)	MOT-01	Influent sump
			MOT-02	Post sump at 30’
			MOT-03	Post sump at 73’
			MOT-04	Pre sump basin at 120’
			MOT-05	Post sump basin at 123’
Lakeview Maintenance Facility	Western WA, City of Lakewood	Modified CABS (Flow Length Reduction)	LAK-01	Influent sump
			LAK-02	Post sump at 81’
			LAK-03	Post sump at 95’
		Modified CABS (Oyster Shell amendment)	LAK-01	Influent sump
			LAK-02	Post sump at 81’
			LAK-03	Post sump at 95’
Geiger Maintenance Facility	Eastern WA, City of Spokane	Modified CABS (Flow Length Reduction)	GEI-01	Influent sump
			GEI-02	Subsurface tee at 25’
			GEI-03	Surface sump at 27.5’
			GEI-04	Effluent at 100’

Data from the baseline characterization study at the Lakeview facility showed relatively high concentrations for dissolved zinc. Monitoring results from the Geiger facility showed comparatively high concentrations for total petroleum hydrocarbons, copper, and total suspended solids. Although the Mottman facility was not part of the original runoff characterization study, the site had many of the same issues as other maintenance facilities (see Table 2). WSDOT collected several samples at Mottman that showed relatively high concentrations for total petroleum hydrocarbons, total and dissolved metals, and total suspended solids.

WSDOT constructed novel CABS at each facility to treat the pollutants of concern. The selected designs modified a standard CABS to test variations in stormwater treatment and flow control, such as increasing hydraulic residence time with compost amendment, flow length reduction, and incorporation of oyster shells for phosphorous removal.

2.4 Preliminary Assessments of the Maintenance Facilities

Prior to construction of the BMPs, staff conducted visits to each maintenance facility to verify the layout, stormwater drainage areas, catchment basins, and possible pollutant-source activities.

The activities and structures with potential to generate polluted stormwater varied from location to location, but generally, there existed consistent representation among the sites. Table 2 lists maintenance facility activities that occurred within the drainage area of the selected monitoring sites at the time of the study. WSDOT identified these activities as possible pollutant-generating sources when exposed to rainfall or stormwater runoff.

Table 2. Maintenance facility monitoring locations and materials/activities matrix.

Region	Facility	Activities														
		Galvanized Metals	Treated Lumber	Prewash Pad	Sand	Salt	Deicer	Highway Sweepings Storage	Landscaping	Truck Parking	Storage Buildings	Maintenance Buildings	Transportation Equipment Fund Shop	Offices	Fuel Island	Herbicide/Fertilizer
Olympic	Lakeview	X	X	X			X		X	X	X	X	X	X	X	X
Olympic	Mottman	X		X	X	X		X		X	X	X		X	X	
Eastern	Geiger		X	X	X					X	X	X	X	X	X	X

The Mottman and Lakeview sites had existing swales or ditches to treat stormwater runoff, which were retrofitted to address the study goals. WSDOT constructed the CABS at Geiger to address the study goals and site concerns related to on-site flooding.

2.5 Mottman Compost-Amended Biofiltration Swale Description

The Mottman Maintenance Facility is located at 2120 R.W. Johnson Boulevard Southwest in Tumwater. The Mottman CABS was a retrofit of an existing swale located at the facility. The previous swale did not meet Highway Runoff Manual (HRM) CABS design standards (WSDOT 2014).

The Mottman CABS is located east of the site's primary maintenance activities, and receives runoff from a 1.23-acre drainage area highlighted in Figure 2. Site observations during multiple storm events confirmed the delineated drainage area. Since stormwater flows to multiple discharge points, the CABS does not receive all of the runoff from the maintenance facility. This report only addresses pollutants generated in the drainage area that discharges to the CABS.

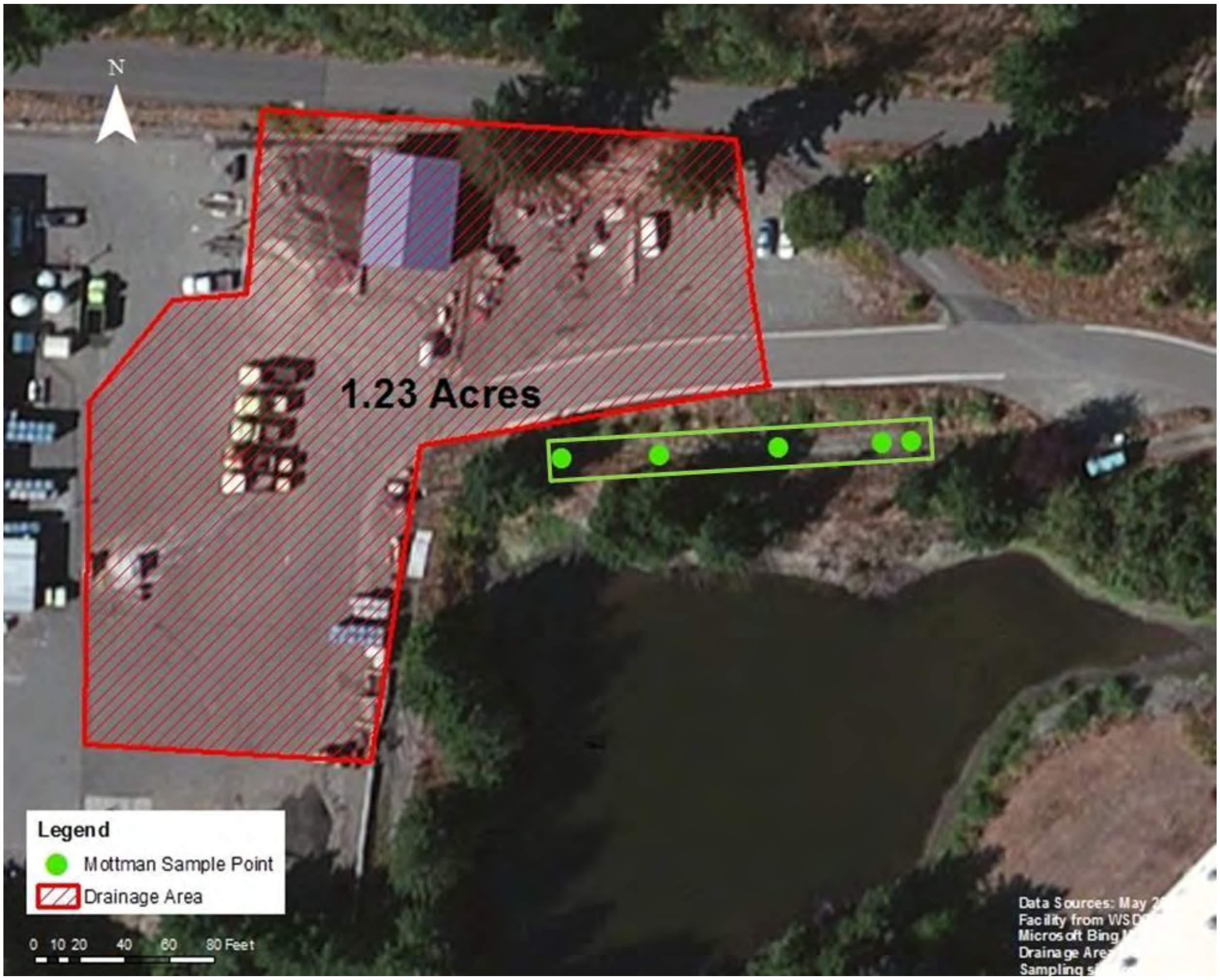

Figure 2. Mottman CABS monitoring points and associated drainage area.

Potential pollutant sources in the drainage area include: trucks and heavy equipment parking, uncovered galvanized metal, a large sand pile, and a salt shed.

The Mottman CABS was designed to address three primary stormwater treatment goals:

- Assessing the effectiveness of using a 3-inch compost blanket to increase hydraulic residence time to reduce pollutants.
- Evaluating whether treatment goals can be accomplished in a shorter length CABS (i.e., shorter than the 100-foot minimum currently required for biofiltration swales) (WSDOT 2014).
- Evaluating whether the addition of crushed oyster shells can reduce, primarily via adsorption, exports of phosphorus from the compost blanket.

Construction of the Mottman CABS required retrofitting the existing swale and existing soils to the standards outlined in the *HRM* (WSDOT 2014), as well as incorporating design features to facilitate the stated treatment goals.

2.5.1 Mottman CABS Basic Design Features

The retrofitted Mottman CABS is 123 feet long with several sample points meant to ascertain if and where along the swale treatment occurred. The swale had a flat bottom (10 feet wide) and trapezoidal sloping sides as presented in Figure 3. The CABS consisted of one foot of tilled soil covered by a 3-inch compost blanket (WSDOT 2014) hydroseeded with a seed mix that met WSDOT erosion control Standard Specifications (WSDOT 2016b). Stormwater entered the CABS through a catch basin, drainage inlet, and a 12-inch pipe. Stormwater flowed from the pipe into a flume, and discharged onto a concrete flow spreader.

The flow spreader ended at a concrete sump that extended from one wall of the CABS to the other, capturing all the water coming into the BMP. Except for sample collection and flow monitoring points, stormwater was meant to flow the entire length of the CABS as sheet flow.

Flow monitoring and sample collection points were located at the following locations:

- Influent sump (sample point 1).
- 30 feet down the length of the CABS, immediately after a sump/flow spreader that would have contained oyster shell amendments during the next phase of the study (sample point 2).
- 73 feet down the length of the CABS, immediately after a sump/flow spreader that would have contained oyster shell amendments (sample point 3).
- Effluent, 123 feet down the length of the CABS, immediately before and after a sump/flow spreader that would have contained oyster shell amendments during the next phase of the study (sample points 4 and 5).

WSDOT intended to add the oyster shell treatment to the sumps after testing stormwater treatment performance at different lengths of the CABS.

Each monitoring and sampling location consisted of a flume, stage-measuring equipment, and an autosampler collection point. Equipment for monitoring and sampling was located immediately outside of the CABS. Staff housed the equipment in enclosures with attached masts for rain gages and solar panels. Station equipment monitored precipitation and discharge. A data logger recorded and used internal processes to direct flow-weighted sample collection from sample points within the CABS.

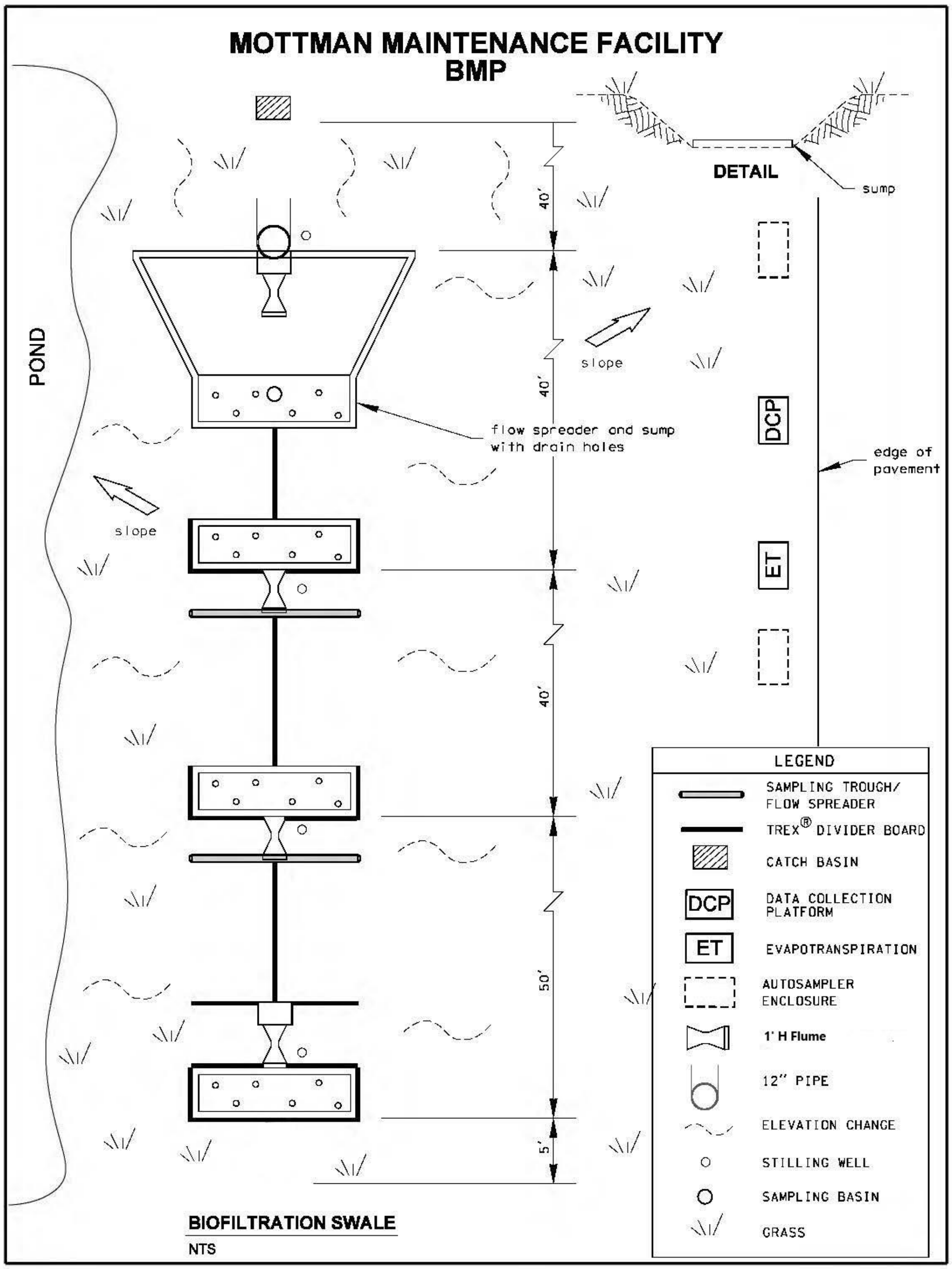

Figure 3. Mottman CABS monitoring design and equipment placement.

2.6 Lakeview Compost-Amended Biofiltration Swale Description

The Lakeview Maintenance Facility is located at 11211 41st Avenue Southwest in the City of Lakewood. Interstate 5 borders the facility to the east. Side streets and commercial properties surround the facility in all other directions.

Lakeview is a maintenance facility with a stormwater system that collects runoff from nearly the entire facility into a large Type-2 catch basin with an integrated oil-water separator. This catch basin discharges to the Lakeview CABS. Figure 4 shows the drainage area of 2.56 acres.

Sources of potential pollutants in the drainage area included uncovered galvanized metal, treated lumber, a prewash pad, deicer tanks, landscaping equipment, truck parking, maintenance buildings, and herbicide and fertilizer storage.

Figure 4. Lakeview CABS and associated drainage area.

The Lakeview CABS was designed to address three primary stormwater treatment goals:

- Assessing the effectiveness of using a 3-inch compost blanket to increase hydraulic residence time to reduce pollutants.
- Evaluating whether treatment goals can be accomplished in a shorter length CABS (i.e., shorter than the 100-foot minimum currently required for biofiltration swales) (WSDOT 2014).
- Evaluating whether the addition of crushed oyster shells will reduce, primarily via adsorption, exports of phosphorus from the compost blanket.

Construction of the Lakeview CABS required retrofitting the existing swale and existing soils to the standards outlined in the HRM (WSDOT 2014), as well as incorporating design features to facilitate the stated treatment goals. The previous swale performed the functions of a standard swale, receiving and treating stormwater runoff, before eventually discharging water to a wet pond.

2.6.1 Lakeview CABS Basic Design Features

The retrofitted CABS was 95 feet long, with a flat bottom (12 feet wide) and trapezoidal sloping sides as presented in Figure 5. The CABS consists of one foot of tilled existing soil covered by a 3-inch compost blanket (WSDOT 2014) hydroseeded with seed that meets the WSDOT erosion control Standard Specifications (WSDOT 2016b). Stormwater entered the CABS through a 6-inch pipe. During high stormwater flow events, an 18-inch pipe delivered additional water from a catch basin. Events during which the 18-inch pipe delivered water were rare, as the pipe functioned as a catch basin overflow protection feature. A composite board directed the stormwater from the pipes over a concrete pad into a concrete sump where influent samples were collected. A flume received water from the concrete sump for flow measurement.

Except for flow monitoring and sample-collection stage monitoring points, stormwater flowed the entire length of the CABS as sheet flow.

Flumes at the monitoring locations were attached to stilling wells and pressure transducers were utilized to monitor stage through the flumes. Flow monitoring and sample collection points were located at the following locations:

- Influent flume, using the pre-flume container for sample collection (sample point 1).
- 81 feet down the length of the CABS, using composite boards to concentrate stormwater to a flume, with a post-flume basin for sample collection (sample point 2). From this monitoring point, stormwater flowed to a sump containing crushed oyster shells.

- Effluent (95 feet down the length) and immediately following the sump holding oyster shells (sample point 3). Water from the sump flowed to a flume that discharged to a sampling basin that functioned as the final discharge point.

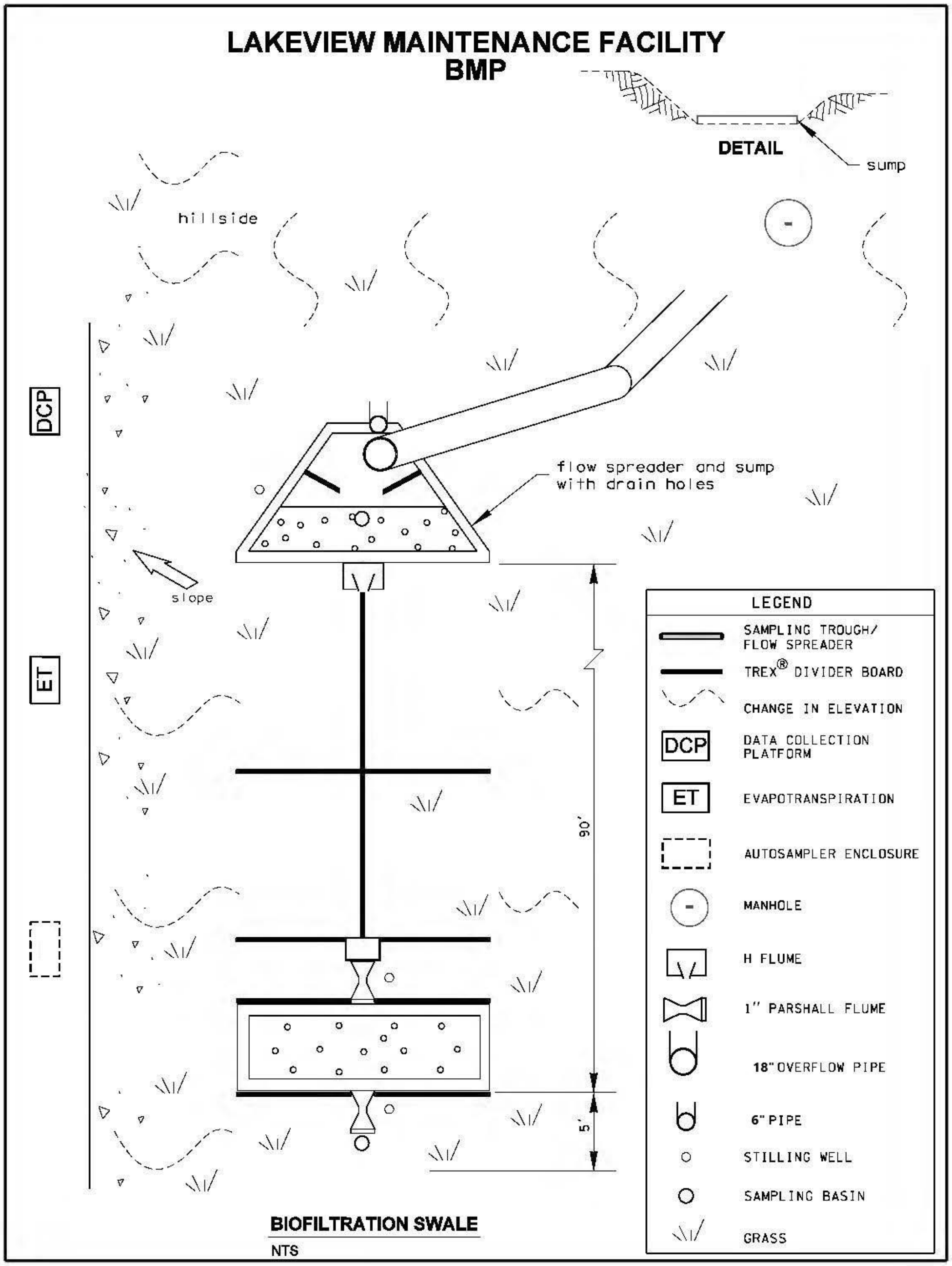

Figure 5. Lakeview CABS monitoring design and equipment placement.

2.7 Geiger Compost-Amended Biofiltration Swale Description

The Geiger Maintenance Facility is located at 7211 Westbow Blvd in the City of Spokane. Westbow Blvd and Interstate 90 border the facility to the north. Side streets, commercial properties and residential surround the facility in all other directions.

Geiger is a maintenance facility with a stormwater system that collects runoff from a portion of the facility into an asphalt ditch. This ditch discharges to the Geiger CABS. Figure 6 shows the 1.89 acre drainage area.

Sources of potential pollutants observed in the drainage area included a fueling station, prewash pad, sand pile, vehicle parking spaces, and incidental runoff from materials storage areas.

The Geiger CABS was designed to address three primary stormwater treatment goals:

- Assessing the effectiveness of using a three-inch compost blanket for improving hydraulic residence time to reduce pollutants.
- Evaluating whether treatment goals can be accomplished in a shorter length CABS (i.e., shorter than the 100-foot minimum currently required for biofiltration swales) (WSDOT 2014).
- Assessing the subsurface infiltrated stormwater quality and volume, down to approximately two ft., within the first 25 feet of the CABS.

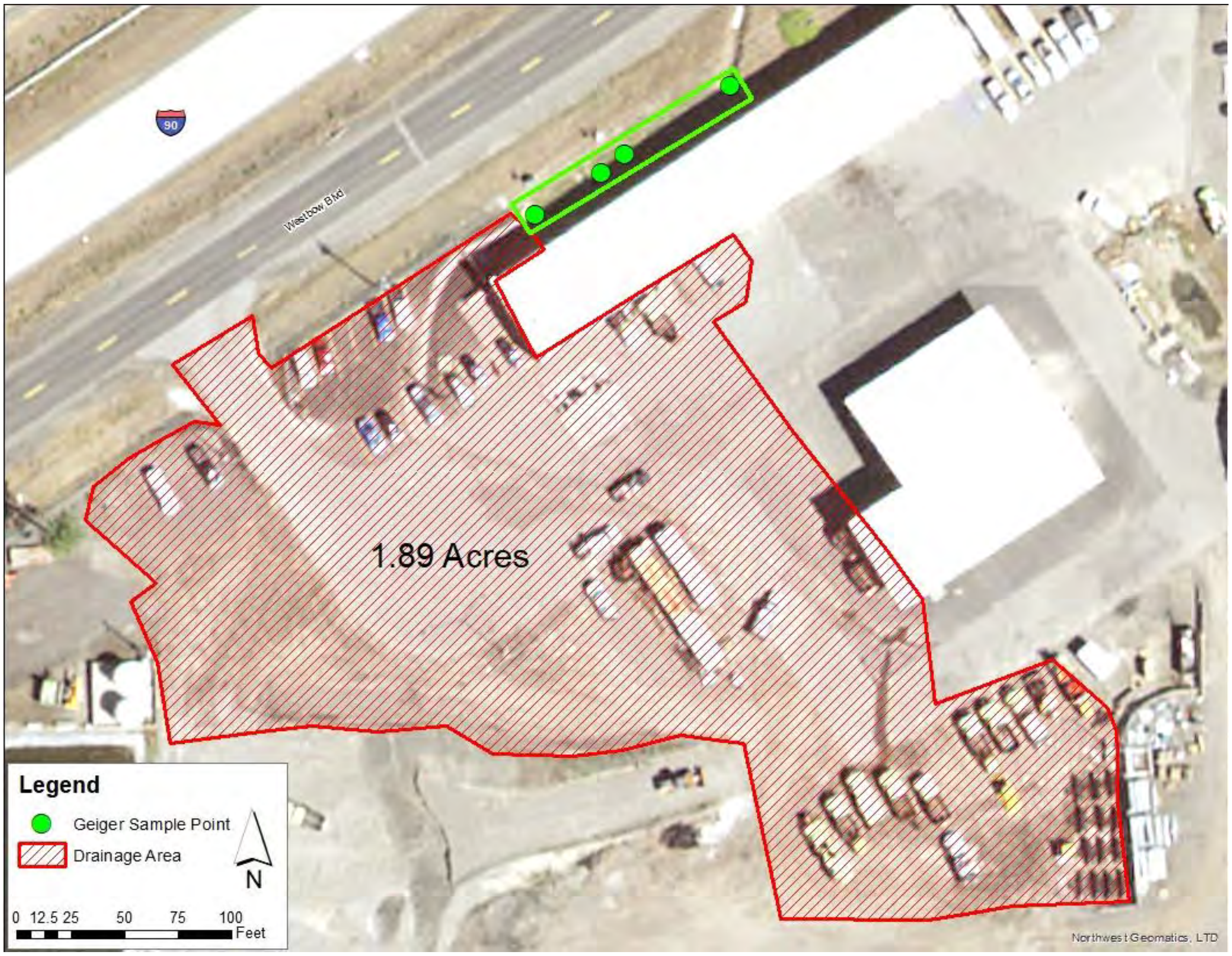

Figure 6. Geiger surveyed catchment area.

2.7.1 Geiger CABS Basic Design Features

The CABS was constructed by excavating and adding soil mix to promote infiltration, covered by a 3-inch compost blanket (WSDOT 2014) hydroseeded with seed that meets the WSDOT erosion control Standard Specifications (WSDOT, 2014d). A diagram of the Geiger CABS is presented in Figure 7. The CABS was 100 feet long, with a flat 12-foot wide bottom and trapezoidal sloping sides. The CABS consisted of an impermeable polyethylene liner, approximately two feet below the ground surface, placed under the first 25 feet of the CABS. Three four-inch perforated drainage pipes were placed on top of the liner to direct subsurface flow to a single box for sample collection and stage measurement at the end of the liner. Three six-inch observation wells extended vertically between the western-most and middle four-inch drainage pipes, reaching the surface of the CABS to allow observation of subsurface flow at multiple points in the CABS. Water from the subsurface sample/stage measuring box exited through a subsurface weir into a six-inch perforated drainage pipe that exited several inches beyond the liner. This drainage pipe then teed out to allow the subsurface water to infiltrate into the ground.

Stormwater entered the CABS through an asphalt diversion trench leading to an H-flume. Runoff flowed through the flume and into an eight foot long, 2.42 foot wide, and nine inch deep concrete sump. This sump extended from one wall of the CABS to the other, to capture all water coming into the CABS.

The sump provided some treatment through settling and acted as a flow spreader for water entering the CABS. A composite divider board was installed immediately after the sump in the center of CABS. The divider board effectively bisected the CABS, and extended approximately 3.5 inches above the CABS surface. Except for a monitoring location 25 feet into the CABS, stormwater was intended to flow the entire length of the CABS as sheetflow.

Flumes at the monitoring locations were attached to stilling wells and pressure transducers were utilized to monitor stage through the flumes.

Flow monitoring and sample collection points were located at the following locations:

- Influent flume, post flume sump for sample collection (sample point 1).
- 27.5 feet down the length of the CABS using composite boards to concentrate stormwater to a flume that discharges to a sump/flow spreader for sample collection.
- At the sample collection/stage monitoring box 25 feet subsurface into the CABS.
- Effluent flume (100 feet down the length). Water from the flume drains to a sampling basin that functions as the final effluent point in the CABS.

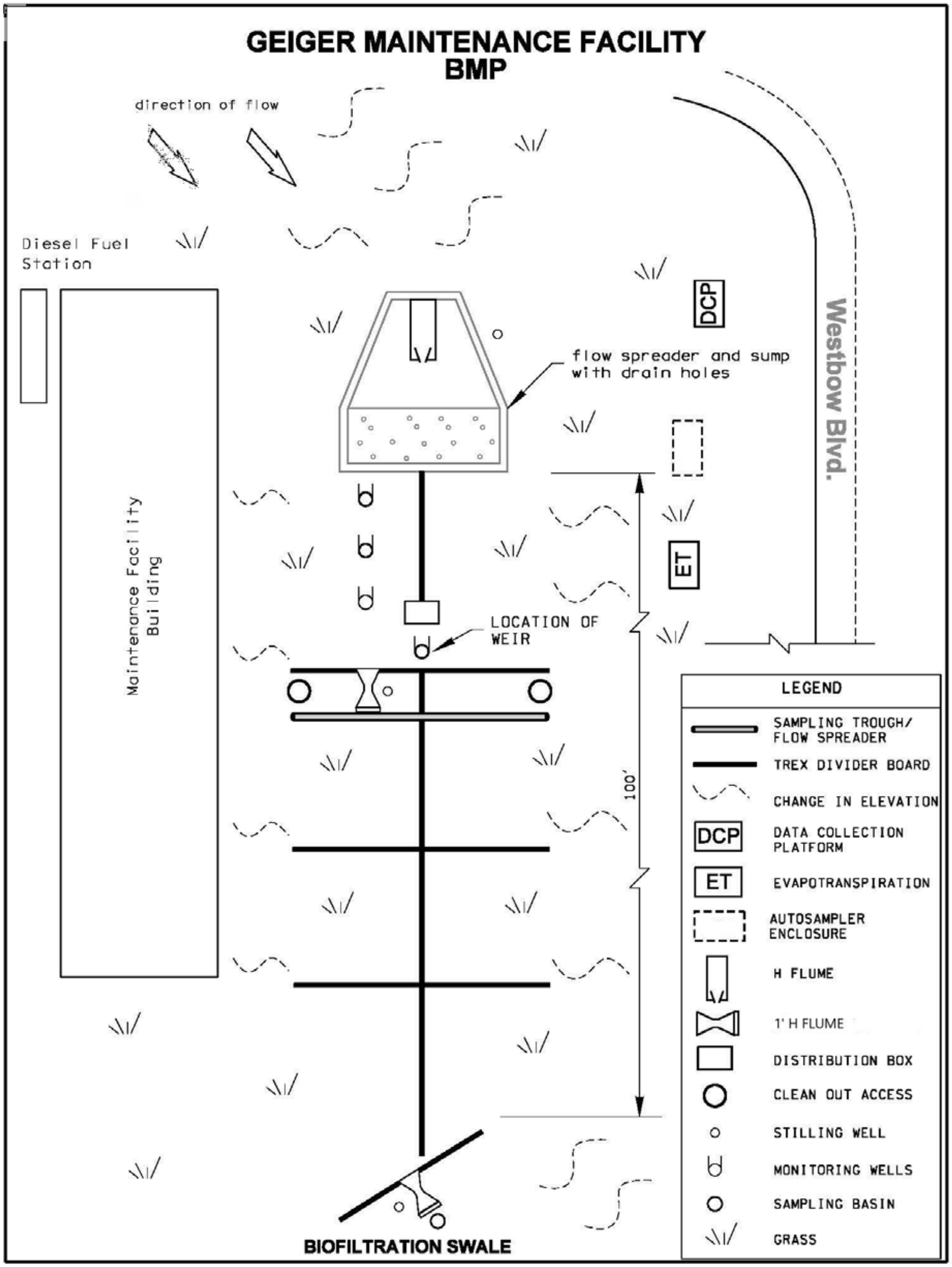

Figure 7. Geiger CABS monitoring design and equipment placement.

3 Sampling and Monitoring Procedures

3.1 Monitoring Stations

Monitoring stations at CABS effectiveness sites included an equipment enclosure with lock, Global Positioning System, antenna, solar panel, and rain gage. WSDOT mounted the antenna, solar panel, and rain gage on a mast attached to the side of the equipment enclosure.

The equipment enclosure housed a data logger, refrigerated automatic sampler, sample tubing, stage measuring devices, and a 12-volt battery. Sample tubing ran from the automatic sampler to the designated sampling point through protective conduit. The stage measuring equipment cables ran through the conduit to a stilling well where pressure transducers recorded stage and temperature. The locked enclosure provided a secure location for equipment as well as protection from wind, rain, and snowfall.

3.1.1 Precipitation Measurement

WSDOT installed a pole-mounted, tipping-bucket rain gage at each monitoring station to measure rainfall. Using National Weather Service criteria as guidance (NWS 2010), WSDOT installed rain gages where no trees, buildings, overpasses, or other objects obstructed or diverted precipitation. Rain gages collected data every 15 minutes and stored the data in the data logger's memory. WSDOT used these data to track and record site-specific precipitation measurements.

3.1.2 Temperature Measurement

WSDOT used water temperature measurements at each of the CABS effectiveness monitoring sites to determine when to discontinue sampling in the event of freezing or near freezing conditions. The data logger recorded temperature sensor data every 15 minutes and transmitted these records hourly to WSDOT's database.

3.1.3 Hydrology Measurement

WSDOT used pressure transducers in stilling wells attached to flumes to measure stage height within the flume. Stage height was recorded by the data logger and converted, using the flume equation, to an accumulated volume measurement.

3.2 Weather Tracking

WSDOT used weather information, from satellite imagery, prediction models, the National Oceanic and Atmospheric Administration National Weather Service, and private forecasters, to forecast potentially qualifying storm events on a daily basis. As candidate storms approached, radar observations and hourly reports from land-based weather stations helped track and evaluate storm potential. WSDOT used telemetered data transmitted from individual monitoring stations to track the progress of a storm event, the beginning of runoff, and to direct field team deployments for sample collection.

To qualify, storms had to meet rainfall depth and antecedent dry period criteria. Table 3 lists storm event criteria in effect for the CABS effectiveness monitoring sites.

Table 3. Storm event criteria for CABS monitoring.

Criteria	BMP Effectiveness Monitoring
Monitoring Period	Year round
Rainfall Depth	0.15” minimum; no fixed maximum
Rainfall Duration	1-hour minimum; no fixed maximum
Antecedent Dry Period	< 0.04” rain in the previous 6 hours
Inter-event Dry Period	Not specified
Minimum Intensity	Range of rainfall intensity[1]

[1] To assess performance on an annual average basis and performance at the peak design rate, Ecology suggests that samples are over a range of rainfall intensities (Ecology 2011, 2018).

3.3 Sampling Parameters

Sampling requirements listed in the Municipal Stormwater Permit and Technology Assessment Protocol – Ecology (TAPE) (Ecology 2011 and 2018) specify parameters for BMP effectiveness monitoring. Table 4 lists these parameters in the priority order of analysis. If insufficient sample volume existed, WSDOT processed samples in order of priority taking into account volume requirements for laboratory analysis.

Table 4. Sampling water quality parameters.

BMPs
Total suspended solids
Copper, zinc (total)
Copper, zinc (dissolved)
Particle size distribution
pH
total phosphorus
Orthophosphate
Hardness

3.4 Sampling Methods

WSDOT established BMP effectiveness monitoring sites to measure stormwater quality and quantity. Table 5 lists parameter categories, sampling frequency, and methods.

Table 5. Sampling methods overview.

Parameter Category	Sampling Frequency	Sampling Method	Telemetered Data?
Rainfall	Continuous, year round	Rain gage	yes
Stage (flow)	Continuous, year round	Stage measuring device	yes
Temperature	Continuous, year round	Stage measuring device	yes
Chemical	Discrete storm events	Autosampler	no

For further information regarding fieldwork activities, sample processing details, and analytical requirements for BMP effectiveness monitoring, see the *Quality Assurance Project Plan for WSDOT Facility Stormwater Treatment Evaluation: Best Management Practices* (WSDOT 2016a).

3.5 Station Maintenance

WSDOT performed the routine site maintenance listed below on a three-week schedule following the *Standard Operating Procedure for Monitoring Station Maintenance* (WSDOT 2019b):

- Visual inspection of the monitoring site to identify possible damage to equipment and any new or unsafe conditions.
- Inspection of stations including testing and replacement of parts
- Inspection of equipment enclosures for signs of tampering or forced entry.
- Inspection and cleaning of outlet pipes, sampling basins, and the sampling conveyance system to ensure the monitoring station was in good condition prior to a sampled storm event and representative data collected from the system was unaffected by accumulated debris and sensor drift.
- Inspection of internal wires and cables to evaluate wear and ensure cable connections to the data logger were in good condition.
- Inspection of station antennae declinations and bearings, and cleaned solar panels to remove accumulated debris.
- Service or calibrate of scientific equipment at monitoring stations, when required staff followed manufacturers' specifications and conducted servicing and calibration of equipment on site or in a controlled environment, as appropriate.

3.6 Equipment Decontamination

Unless certified as pre-cleaned from the equipment source, a contract lab decontaminated churners, sample containers, filters, and other materials that contacted sampled stormwater prior to each use. The lab also cleaned intake and pump head tubing prior to installation.

For detailed descriptions of decontaminated procedures, see the *Quality Assurance Project Plan for WSDOT Facility Stormwater Treatment Evaluation: Best Management Practices* (WSDOT 2016a).

3.7 Staff Roles and Responsibilities

WSDOT used Stormwater Monitoring Program staff in its Headquarters Environmental Services Office and staff from region offices to implement its monitoring program. Seven staff from the Headquarters Environmental Services Office played key roles in the stormwater monitoring strategy.

4 Quality Assurance and Quality Control

The *Quality Assurance Project Plan for WSDOT Facility Stormwater Treatment Evaluation: Best Management Practices* (WSDOT 2016a) included a comprehensive description of quality assurance and quality control activities.

WSDOT implemented quality control procedures through all phases of data collection and analyses. Quality control procedures included field collection and laboratory processing for all permit-required samples. Additionally, verification and validation of both field- and laboratory-generated data occurred as part of data management activities. The quality of raw, unprocessed, and processed data was subject to review and management, including the following areas of work:

1. Field quality control
    - Implementation of standard operating procedures.
    - Field instrument inspection, calibration, and maintenance.
    - Water conveyance systems inspection and maintenance.
    - Collection of field notes and maintenance documentation.
    - Collection of composite field duplicate samples.
    - Collection of field equipment blanks.
2. Laboratory quality control
    - Laboratory instrument maintenance and calibration.
    - Analysis of laboratory duplicate/split samples.
    - Analysis of laboratory matrix spike and matrix spike duplicate samples.
    - Analysis of laboratory blanks and standards.
3. Data management
    - Hydrology and precipitation data validation.
        - Checking for concurrence between adjacent pressure transducers.
        - Checking for consistency and similarity between site rain gage measurements.
        - Examining hydrology and precipitation data compared to historical and expected patterns at the site.
        - Verifying that no equipment malfunctions biased the data.
        - Verifying that conveyance systems operated accurately.
        - Checking field notes to ensure no outside factors biased the data.

    - Verifying that precipitation and runoff patterns made logical sense. For example, an extended delay in runoff at the CABS effluent, which normally takes little time, might be indicative of issues in the equipment or site performance.
    - Verifying the volume did not flow through a sample point faster than the autosampler could pull aliquots.
- Field data verification.
- Laboratory data verification and validation. This included 2b level validation for 90% of the data and level 3+4 validation for 10% of the data (USEPA 2009).
- Self-assessment and review of project processes.

5 Monitoring Results

5.1 CABS BMP Monitoring and Site Issues

Due to initially unobserved site characteristics and study design flaws, WSDOT consulted with Ecology and received concurrence to discontinue this study. The installed hydrology measuring equipment and soil issues altered the flow dynamics at the sites so that data collected was not representative of swale treatment dynamics. Due to limited analytical data and the altered hydrology at the sites, WSDOT did not analyze the unrepresentative data. The hydrology issues experienced at each site are described in their respective sections below.

WSDOT learned many lessons regarding site selection and study design through the study process. These lessons will be used to better inform future study design and site selection to provide for successful BMP monitoring. Details of each site and lessons learned are discussed below. Appendix B lists the sample attempts and results for Mottman and Lakeview, no sample attempts were made at Geiger.

5.1.1 Mottman

Multiple mid-CABS flumes, installed to capture flow and flow weighted composite water quality samples, greatly altered the hydrology of the CABS. Slowed flows backed up water to the point that the CABS was frequently not functioning within HRM specifications (WSDOT, 2014). Water depths routinely reached 6 inches at the mid-CABS flume, this height is greater than the 4 inch depth allowed by the HRM. During multiple events, water reached depths of 8 and 12 inches. The culvert draining the swale was also installed too high, causing water to back up into the effluent sample point during high flow events. WSDOT planned to rectify this situation until it was decided to abandon sampling.

These high waters bypassed CABS vegetation eliminating the treatment function of the CABS. The slowed flows pooling prior to the flumes also allowed solid particles to fall out of suspension effectively adding treatment, which is atypical of the standard CABS performance. This backwatering may have allowed for additional infiltration or intrusion that would also change how the CABS treated stormwater.

5.1.2 Lakeview

The soils at the site exhibited such high rates of infiltration that runoff only reached the end of the CABS during short bursts of high intensity rainfall. The influent received regular flows during storms, while runoff only reached the effluent during 15-20% of storms. Due to the water reaching the effluent only during sustained high intensity rain, runoff reached the effluent only for short periods during individual storm events.

WSDOT and Ecology decided that pairing influent and effluent samples in this situation would not accurately represent treatment at the CABS as a parcel of water exiting the BMP does not represent a parcel concurrently entering the BMP. In January 2019, WSDOT changed the Lakeview monitoring to the long detention time protocol per the Technical Guidance Manual for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE), Appendix C (Ecology, 2018).

The long detention time protocol called for randomizing a number of sampling attempts according to the historic number of days with flows providing sufficient volumes for sampling at both the influent and effluent separately. Staff used hydrological data to estimate the number of sampling events required to collect 15 samples during WY19-20, and long detention sampling was attempted from January 2019-November 2019.

Intensity based flows led to the inability to collect adequate long detention time samples because of the intense, short duration effluent flows. Of the 18 attempts at the influent, three samples were collected, and of the 59 attempts at the effluent, zero samples were collected. During the 59 attempted effluent samples, only one event had enough flow reach the effluent sample point to sample, but flow duration was too short to collect an acceptable number of aliquots. Flow reached the end of the CABS a total of five times.

5.1.3 Geiger

Study design and installation flaws and a miscalculation of the catchment area led to the inability to conduct a successful study of the CABS at the Geiger Maintenance facility. Through consultation with Ecology, WSDOT installed a liner under the first 25 feet of the CABS. The liner was supposed to allow subterranean sampling to demonstrate treatment as water moved through the compost. However, the liner and the flume at the 25-foot sample point caused a bathtub effect on the CABS, not allowing infiltration and causing standing water.

Standing water and the resultant sediment deposition impeded the growth of vegetation within the CABS, and the shaded conditions and daily, instead of bi-weekly, watering also produced weakened vegetation. Insufficient vegetation cover led to the swale not functioning properly and changed how the CABS treated stormwater. Similar to the Mottman CABS, the multi mid-CABS flume system installed to capture flow and flow weighted composite water quality samples greatly altered the hydrology of the CABS. This caused water to back up to the point where the CABS was no longer within HRM specifications.

The site was also constructed with sandy soil, to promote infiltration, instead of the standard soil mixture. During large events, this soil would erode and become mobile adding to the suspended solid load of flows. Flows also undercut the flow spreaders/dividers bypassing the flow measuring device and eroding the compost/topsoil layers.

5.2 Lessons Learned

WSDOT found that developing the CABS BMP effectiveness monitoring program was a complex endeavor. The following are lessons learned from implementing the monitoring program:

1. **Increase Pre-Study Site Characteristics and Research:** Collection of additional data, such as infiltration rates, groundwater levels, soil samples, maintenance activities, and construction activities, would have alleviated some resultant problems. Gathering this information early in the study design could have led to the exclusion of some of these sites for use in this study.

2. **Troubleshoot construction early in the study**: WSDOT should have viewed flow data collection systems during storms earlier in the study. This would have allowed field observations to inform data analysis. Staff spent a large part of WY18 correcting design and construction issues that were affecting flow measurements shortly after hydrology data collection started.

3. **Conduct frequent site storm event observations:** WSDOT discovered several issues at the CABS BMPs when observing the sites during storm events, such as high infiltration rates at Lakeview and swale media mobilizing at Geiger. Staff should have conducted site visits during storm events shortly after construction to observe any design issues in a timelier manner.

4. **Install measuring and sampling equipment to have minimal impact:** During storm observation WSDOT observed the measuring and sampling equipment impacting the flow of stormwater and function of the BMP. This impact caused the BMP to operate outside of the HRM guidelines. In the future, WSDOT will use measuring equipment that cause the smallest effect possible on the BMP and that keep the function within the guidelines of the HRM.

Glossary

best management practices (BMPs) – The structural devices, maintenance procedures, managerial practices, prohibitions of practices, and schedules of activities that are used singly or in combination to prevent or reduce the detrimental impacts of stormwater, such as pollution of water, degradation of channels, damage to structures, and flooding (WSDOT 2014).

data collection platform – A collection of instruments or sensors that operate and report to a central data logger. WSDOT houses data collection platforms in a central location or "platform" at the monitoring site.

Global Positioning System – A satellite navigation system used to determine ground position and velocity (location, speed, and direction).

hydrograph – A graph of flow versus time for a given point.

National Pollutant Discharge and Elimination System (NPDES) – The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Federal Clean Water Act, for the discharge of pollutants to surface waters of the state from point sources. The Washington State Department of Ecology administers these permits referred to as NPDES permits and, in Washington State.

pH – A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Quality Assurance Project Plan – A document that describes the objectives of a monitoring project and the procedures necessary to ensure the quality and integrity of the collected data (Ecology 2004).

representativeness – The state or quality of being accurately representative of something. Expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at the sampling point, or an environmental condition (USEPA 2006).

stormwater – That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, pipes, and other features of a stormwater drainage system into a defined surface water body or a constructed infiltration facility (WSDOT 2014).

stilling well – A well or chamber that is connected to the main flow channel by a small inlet used to house a pressure transducer.

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WSDOT. 2019d. Standard Operating Procedure for Stormwater Composite Sample Collection and Delivery to Laboratory. Washington State Department of Transportation, Olympia, WA.

Acronyms and Abbreviations

BMP	best management practice
CABS	compost-amended bioswale
Ecology	Washington State Department of Ecology
NPDES	National Pollutant Discharge Elimination System
NWS	National Weather Service
pH	measure of alkalinity or acidity
TAPE	Technology Assessment Protocol – Ecology (TAPE)
USEPA	United States Environmental Protection Agency
WSDOT	Washington State Department of Transportation
WY	water year

Appendix A: Cost Estimate

The following describes program implementation, labor, equipment, materials, and laboratory analytical costs for CABS effectiveness evaluation. Table A-1 provides an equipment cost estimate, and Table A-2 presents a monitoring cost summary.

Program Implementation Costs

Costs associated with planning and implementing the CABS effectiveness evaluation study include:

Planning

- Background research (e.g., previous, similar studies).
- Develop the site selection strategy.
- Field reconnaissance for final site selection.
- Develop the project scope and sampling designs.
- Develop the monitoring Quality Assurance Project Plan.

Implementation

- Equipment and supplies (purchase, installation, maintenance, and replacement).
- Database development and implementation.
- Training.
- Logistics (e.g., pre-storm preparation and post-storm sample transfer).
- Sample collection (e.g., staff time, travel to study sites).
- Laboratory analysis.
- Data verification (data quality assurance and quality control).
- Data management.
- Data analysis and reporting.

Labor Costs

Seven staff from the WSDOT's Environmental Services Office played key roles in implementing the MVFS effectiveness evaluation study. These staff include:

- Monitoring Program Coordinator (position transitioned to Stormwater Monitoring and Research Program Manager in 2019).
- Monitoring Field Lead.
- Data Management and Reporting Lead.
- Monitoring and Research Analyst Lead.
- Monitoring Specialists (three positions).

Equipment, Materials, and Laboratory Analytical Costs

The following monitoring program start-up costs were excluded from this cost summary if expended to support all of the WSDOT's ongoing stormwater monitoring programs and not specific to this study:

- staff time spent conducting initial monitoring program planning.
- vehicle purchases.
- chemistry and hydrology databases (license, and maintenance fees).
- equipment storage and staging facilities.
- tools for station construction, installation, and site maintenance.
- initial purchase of equipment (e.g., automatic samplers, data loggers, pressure transducers, connecting cables, and solar panels.

Monitoring Cost Summary

Table A-1 provides an estimate of the equipment costs and an anticipated equipment replacement schedule for the CABS effectiveness evaluation study.

Table A-2 provides an estimate of WSDOT's labor, equipment, construction, laboratory analytical, and hydrology validation costs for the CABS effectiveness evaluation study.

Table A-1 Equipment and materials costs.

Equipment	Units	Cost/Unit ($)	Total ($)
Data loggers w/GOES[1]	6	5,180	31,080
GOES antenna	6	500	3,000
Refrigerated autosampler	12	5,140	61,680
Autosampler interface cables	13	600	7,800
Enclosure	8	1,700	13,600
Pressure transducer	21	1,300	27,300
Battery cable	3	225	675
SDI Cable	9	155	1,395
Rain gages	6	815	4,890
Iridium modem[2]	3	2,240	6,720
GPS antenna	6	100	600
1” Parshall flume	2	750	1,500
1’ H flume	7	1,300	9,100
1.5’ H flume	1	4,000	4,000
Solar power installation	9	1,200	10,800
120aH starved electrolyte battery	14	630	8,820
Teflon lined sample tubing	3	1,070	3,210
Misc. construction materials			3,500
Total			199,670

[1] Geostationary Operational Environmental Satellites (GOES) relay data from WSDOT monitoring stations to public servers where WSDOT accesses the information through an approved National Environmental Satellite, Data, and Information Service Internet connection.

[2] Two-way remote communication system.

Table A-2 Monitoring labor, equipment, materials, and laboratory costs.

Category	Monitoring Program Costs ($ estimate)
State-force labor costs	
Site selection	3,000
Site construction and equipment installation	130,000
QAPP development	15,000
Sample collection and laboratory submittal	8,000
Data management and verification	3,000
Site decommissioning	2,500
Equipment purchase	199,670
Laboratory analytical costs	11,600
Total	372,770

Appendix B: Facility Storm Sample Attempts

Mottman Maintenance Facility				
Date	**Influent**	**30'**	**73'**	**123' Effluent**
10/4/2018	Reject Hydro	Reject Hydro	Reject Hydro	Reject Hydro
10/25/2018	Reject Hydro	Reject Hydro	Accept	No Volume
10/30/2018	Accept	Reject Hydro	No Volume	No Volume
11/1/2018	Accept	Reject Hydro	Reject Hydro	Reject Hydro
12/9/2018	Accept	Accept	Reject Hydro	Accept
12/27/2018	Equip. Fail	Equip. Fail	Equip. Fail	Equip. Fail
1/2/2019	Accept	Accept	Accept	Accept
1/8/2019	Reject Hydro	Reject Hydro	No Volume	No Volume
1/17/2019	Reject Hydro	Reject Hydro	Reject Hydro	Reject Hydro
1/31/2019	Accept	Accept	No Volume	No Volume
3/25/2019	Accept	Accept	Accept	Low Volume
3/27/2019	Accept	Accept	Accept	Low Volume
4/4/2019	Low Volume	Low Volume	No Volume	No Volume
4/13/2019	Accept	Accept	Accept	Accept
5/14/2019	Low Volume	Low Volume	No Volume	No Volume
7/9/2019	Accept	Accept	No Volume	No Volume
7/17/2019	Reject Hydro	Reject Hydro	Reject Hydro	Reject Hydro
8/21/2019	Storm Rejection	Storm Rejection	Storm Rejection	Storm Rejection
9/8/2019	Storm Rejection	Storm Rejection	Storm Rejection	Storm Rejection
9/14/2019	Accept	Accept	Accept	Accept
9/17/2019	Accept	Accept	Accept	Accept
9/22/2019	Accept	Accept	Accept	Low Volume

Lakeview Maintenance Facility Paired Sampling			
Influent		**81' Effluent**	
Date	**Outcome**	**Date**	**Outcome**
1/11/2018	Low Volume	1/11/2018	Low Volume
2/1/2018	Equip. Fail	2/1/2018	Equip. Fail
2/28/2018	Storm Rejection	2/28/2018	Storm Rejection
3/7/2018	Accept, No Paired	3/7/2018	No Volume
6/8/2018	Hydro Reject	6/8/2018	No Volume
9/10/2018	Accept, No Paired	9/10/2018	No Volume
10/4/2018	Accept, No Paired	10/4/2018	No Volume
10/8/2018	Accept, No Paired	10/8/2018	No Volume
10/25/2018	Equip. Fail	10/25/2018	Equip. Fail

Lakeview Maintenance Facility Long Detention			
Influent		81' Effluent	
Date	Outcome	Date	Outcome
1/2/2019	No Volume	1/2/2019	No Volume
		1/3/2019	No Volume
		1/7/2019	No Volume
1/8/2019	No Volume		
1/9/2019	No Volume		
		1/10/2019	No Volume
		1/17/2019	No Volume
1/22/2019	Accept		
1/23/2019	No Volume		
		1/24/2019	No Volume
		1/28/2019	No Volume
		1/30/2019	No Volume
		2/5/2019	No Volume
		2/6/2019	No Volume
		2/19/2019	No Volume
		2/20/2019	No Volume
2/21/2019	No Volume	2/21/2019	No Volume
2/26/2019	No Volume		
		2/28/2019	No Volume
		3/4/2019	No Volume
		3/5/2019	No Volume
		3/6/2019	No Volume
		3/7/2019	No Volume
3/11/2019	No Volume	3/11/2019	No Volume
		3/13/2019	No Volume
		3/14/2019	No Volume
		3/19/2019	No Volume
		3/21/2019	No Volume
		3/25/2019	No Volume
		3/26/2019	No Volume
		3/27/2019	No Volume
		3/28/2019	No Volume
		4/2/2019	No Volume

		4/3/2019	No Volume
		4/4/2019	No Volume
		4/8/2019	Low Volume
		4/9/2019	Hydro Reject
		4/10/2019	No Volume
		4/15/2019	No Volume
		4/24/2019	No Volume
4/25/2019	No Volume	4/25/2019	No Volume
		4/29/2019	No Volume
5/13/2019	No Volume	5/13/2019	No Volume
		6/25/2019	No Volume
7/9/2019	Low Volume	7/9/2019	Low Volume
8/21/2019	No Volume	8/21/2019	Low Volume
9/8/2019	No Volume	9/8/2019	No Volume
9/14/2019	No Volume	9/14/2019	No Volume
9/17/2019	Accept	9/17/2019	Low Volume
9/22/2019	Accept	9/22/2019	No Volume
		10/1/2019	No Volume
		10/3/2019	No Volume
		10/9/2019	No Volume
		10/10/2019	No Volume
		10/14/2019	No Volume
		10/15/2019	No Volume
		10/16/2019	No Volume
		10/22/2019	No Volume
10/23/2019	No Volume	10/23/2019	No Volume
		10/24/2019	No Volume
		10/29/2019	No Volume
11/5/2019	No Volume	11/5/2019	No Volume
		11/12/2019	No Volume
		11/13/2019	No Volume