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Stormwater Monitoring Report

Embankment Hydrology Study
Water Years 2017-18

Approved by:

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Signature: ______________________________  Date: ______________________________
Kenneth M. Stone, Resource Programs Branch Manager
WSDOT Environmental Services Office

Signatures are not available on the Internet version.
WSDOT = Washington State Department of Transportation
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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 (permit) (Ecology 2014) to the Washington State Department of Transportation (WSDOT), effective April 5, 2014 to April 5, 2019. Under Special Condition S7 of the permit, WSDOT must begin a new highway effectiveness study that is approximately the same level of monitoring effort and cost as the previous vegetated filter strip study that concluded field data collection in July 2018.

This new study, that fulfills the requirements of S7, collects hydrologic data from roadside embankments to assess infiltration levels. These data will help validate an empirically optimized method for estimating saturated hydraulic conductivity ($K_{sat}$) developed by WSDOT’s Geotechnical Office. WSDOT intends to use the validated $K_{sat}$ estimation method to improve future best management practices (BMP) designs and help evaluate the effectiveness of currently installed vegetated filter strip (VFS) BMPs. Findings from this study will inform revisions and updates to the Highway Runoff Manual (WSDOT 2014).

Under Special Conditions S7.D of the permit, monitoring reports are required for information collected at the department’s stormwater monitoring sites. The following report helps satisfy these requirements and provides a summary of monitoring activities completed at embankment hydrology monitoring sites from October 1, 2017, through September 30, 2018 (water year 2018).
2 Monitoring Program Implementation

2.1 Site Selection Strategy

The first step in selecting sites for embankment hydrology evaluation was a thorough review of the monitoring program’s objectives. WSDOT used the program’s objectives to establish the number and types of sites needed for monitoring.

Guidance from the California Department of Transportation (Caltrans 2015) and the following evaluation criteria helped ensure WSDOT selected the most appropriate sites:

- Property ownership.
- Site representativeness.
- Personnel safety.
- Site accessibility.
- Equipment security.
- Discharge measurement capability.
- Site design limitations.

2.1.1 Property Ownership

Initially, WSDOT only considered properties owned and operated by the agency during the site evaluation and selection process. Later, staff assessed county roads when state owned sites that met site selection criteria were difficult to locate. Eventually, WSDOT found two study sites that met selection criteria and were on state owned property.

2.1.2 Site Representativeness

Screening criteria for representativeness meant study sites had to be typical of WSDOT highway conditions. The following factors were important in assessing study site locations:

- Long-Term Location – Based on information available during the site selection process, WSDOT avoided sites with plans for future development.
- Uniform Flow – Runoff flows need to be well mixed, but not turbulent. WSDOT did not select sites with slopes greater than 33 percent or slopes with abrupt grade changes.

2.1.3 Personnel Safety

For any WSDOT highway project, staff safety is a high priority. Staff avoided or minimized, whenever possible, hazards from traffic, explosive or toxic gases, poor footing on slopes, slippery conditions, and poor visibility due to adverse weather or night work.
The following site attributes expose monitoring field teams to potentially unsafe conditions:

- Sites located along a highway shoulder.
- Sites that require traffic control.
- Sites with poor access.
- Slopes that encourage slips, trips, and falls.

To minimize the effect(s) of these hazards, members of the field team had to be capable of performing all tasks required for monitoring water quantity data and be familiar with WSDOT’s Safety Procedures and Guidelines Manual (WSDOT 2018a) and Work Zone Traffic Control Guidelines (WSDOT 2018b). Staff developed site-specific Health and Safety Plans for each monitoring site to minimize the effect of these hazards.

2.1.4 Site Accessibility

WSDOT selected monitoring sites to provide safe and feasible access. Highway shoulder width and site visibility from the roadway had to be sufficient to allow safe access for vehicles leaving and reentering the highway.

Due to the nature of highway embankment monitoring, locating sites away from the highway shoulder was not an option. To minimize exposure, field teams followed WSDOT safety guidelines and minimized time spent working along the highway.

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

2.1.5 Equipment Security

Selected sites had to provide adequate level space for monitoring station installation in areas that did not stand out visually. Staff installed data collection equipment in locked metal enclosures on concrete platforms to reduce the risk of tampering.

Locked metal enclosures provided a secure location as well as protection from wind, rain, and snowfall. Staff secure equipment outside of the enclosures (antenna, rain gage, solar panels) to a mast with chains and locks. Signs applied to the outside of the enclosures identified the monitoring stations as WSDOT property.

2.1.6 Discharge and Precipitation Measurement Capability

Staff selected monitoring sites in locations that allowed for discharge measurement. In order to monitor sheet flow runoff from WSDOT highways, field personnel constructed conveyance
systems to collect, direct, and measure stormwater runoff from sections of the roadway. Stormwater monitoring conveyance systems provided suitable water depth for measuring discharge during storm events.

Staff situated 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 surface to avoid biases such as rain splashing from vehicle traffic.

2.1.7 Site Design Limitations

WSDOT had to establish monitoring stations to collect water quantity data from influent and effluent measurement 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 (DCP) establishment.
- A monitoring site design that would provide easy access for influent and effluent measuring.
- Monitoring equipment and site infrastructure installations that enable accurate flow measurements and reduce the amount of maintenance required.
2.2 Resource and Logistical Constraints

To address logistical challenges and reduce mobilization costs, staff chose study sites close to the stormwater monitoring headquarters to reduce travel time and associated costs.

Figure 1 shows the location of the embankment hydrology monitoring sites.
2.3 Embankment Hydrology Monitoring Sites

WSDOT selected the two embankment study sites based on the general guidelines listed in Section 2.1 and more specific guidelines listed below. Additional site selection criteria for this study, accounting for characteristics of both monitoring locations, are:

Embankments:

1. Safely accessible for WSDOT staff and provide access that will not put the traveling public at undue risk.
2. Within the WSDOT right-of-way.
3. Adjacent to and receiving stormwater sheet flow from a WSDOT roadway.
4. Site characteristics, including shape, slope, soil composition, and soil compaction level, that are representative of current WSDOT specifications for roadway embankments.
5. At a location that regularly receives enough precipitation and subsequent stormwater runoff to maintain a reasonable monitoring timeline.
6. Are of a 3:1 (H:V) or 4:1 (H:V) slope and a height of at least 10 feet.¹

Highway Sections:

1. Are straight for at least 200 feet long to accommodate pipe collectors.
2. Have less than five percent slope for consistent runoff.
3. Are relatively flat so that runoff from adjacent areas does not run off into any of the study drainage areas.

Table 1 Embankment Study Site Location

<table>
<thead>
<tr>
<th>Site Name</th>
<th>State Route</th>
<th>Mile Post</th>
<th>Embankment Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montesano</td>
<td>State Route 12</td>
<td>9</td>
<td>3:1 (H:V)</td>
</tr>
<tr>
<td>Silver Creek</td>
<td>State Route 12</td>
<td>80</td>
<td>4:1 (H:V)</td>
</tr>
</tbody>
</table>

¹ Horizontal to vertical or H:V.
Figures 2 and 3 show the catchment areas for the two monitoring sites.

Figure 2  
State Route 12 (SR 12) westbound at MP 9, Montesano, WA.

Figure 3  
State Route 12 (SR 12) eastbound at MP 80, Silver Creek vicinity, WA.
2.4 Embankment Hydrology Monitoring Study Design

The embankment hydrology studies evaluate and compare highway runoff volumes at stormwater collectors (6-inch-diameter, high-density polyethylene pipes) installed at three different locations along the embankment. WSDOT located collectors at the edge of pavement (EOP), 6.6 feet (2 meters) downslope from the pavement edge, and near the toe of embankments.

WSDOT staff established stormwater collectors 6.6 feet downslope because highways in highly urbanized areas often have limited space to locate stormwater treatment along the road shoulder. This study will measure how much flow reduction through infiltration occurs close to the edge of pavement.

The stormwater collectors located at the toe of slope are included in this study to evaluate the amount of runoff that infiltrates into the entire embankment. The toe of slope collectors collect infiltrated water that reemerges at the soil surface as return flow.

2.4.1 Monitoring Site Set-Up and Measurement Design Details

WSDOT staff installed pipe collectors along the pavement at each monitoring site. Staff buried pipes and mortared them to the edge of the pavement. Collector pipes slope slightly downhill to promote directional flow for measurement. Figure 4 shows the pavement edge collector pipe and highway shoulder in cross section.

Figure 4 Cross Section of the pavement edge collector
WSDOT recessed collector pipes, installed 6.6 feet downslope and at the toe of the highway embankment, into the surface of the soil and positioned them to collect surface runoff flowing from the edge of pavement over the surface of the embankment. Similar to the pavement edge collector, the 6.6- and toe of slope collectors were sloped slightly to promote directional flow for measurement. Figure 5 shows a downslope collector in cross section.

Figure 5  Cross section of the downslope collector
Figure 6 shows a generalized drawing of an embankment hydrology-monitoring site. The diagram illustrates how collector positions accumulate sheet flow runoff from the surface of the highway and downslope over the surface of the embankment. WSDOT staff installed the data collection platform (DCP) with rain gages, solar panel, transmitting antennae, Global Positioning System (GPS), and enclosures along the roadside embankment.

![Figure 6 Generalized system design](image-url)
3 Measuring and Monitoring Procedures

3.1 Monitoring Stations

Monitoring stations at embankment hydrology monitoring sites typically include an equipment enclosure with lock, Global Positioning System (GPS), antenna, solar panel, and rain gage. Staff mounted the antenna, solar panel, and rain gage on a mast attached to the side of the equipment enclosure.

The equipment enclosure houses a data logger, stage measuring devices, and a 12-volt battery. The stage measuring equipment lines run through conduit to a stilling well where pressure transducers record stage and temperature. The locked enclosure provides a secure location for equipment as well as protection from wind, rain, and snowfall.

3.1.1 Precipitation Measurement

At each monitoring station, WSDOT installed two pole-mounted, tipping-bucket rain gages. Staff utilize the second gage for quality control and as a backup in case the first gage fails. WSDOT installed rain gages, using National Weather Service criteria as guidance (NWS 2010), where no trees, buildings, overpasses, or other objects would obstruct or divert precipitation. Rain gages collect data every 15 minutes and store the data in the logger’s memory. WSDOT uses these data, transmitted telemetrically to a WSDOT database, to track and record site-specific precipitation measurements.

3.1.2 Temperature Measurement

WSDOT uses water temperature measurements at each of the embankment study sites to determine when to discontinue monitoring in the event of freezing or near freezing conditions. The data logger records temperature sensor data every 15 minutes and transmits these records hourly to WSDOT’s database.
3.2 Weather Tracking

WSDOT uses weather information—from satellite imagery, prediction models, the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), and private forecasters—to forecast storm events on a daily basis. As candidate storms approach, staff track storms through radar observations, and then evaluate station readiness using telemetered data.

3.3 Measuring Methods

WSDOT established embankment hydrology monitoring sites to measure stormwater runoff volumes. Table 2 lists parameter categories, measurement frequency, and methods.

Table 2  Measuring methods overview

<table>
<thead>
<tr>
<th>Parameter Category</th>
<th>Measurement Frequency</th>
<th>Measurement Method</th>
<th>Telemetered Data?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>Continuous, year round</td>
<td>Rain gage</td>
<td>yes</td>
</tr>
<tr>
<td>Stage (flow)</td>
<td>Continuous, year round</td>
<td>Stage measuring device</td>
<td>yes</td>
</tr>
<tr>
<td>Temperature</td>
<td>Continuous, year round</td>
<td>Stage measuring device</td>
<td>yes</td>
</tr>
</tbody>
</table>

For further information regarding fieldwork activities for embankment hydrology evaluation, see the Quality Assurance Project Plan for WSDOT Embankment Hydrology Monitoring (WSDOT 2017a).

3.4 Station Maintenance

WSDOT staff provided regular station maintenance on a three-week schedule. Monitoring staff perform a visual inspection of the monitoring site to identify possible damage to equipment and any new or unsafe conditions. Staff check equipment enclosures for signs of tampering or forced entry. Staff inspect and clean outlet pipes, pressure transducer stilling wells, and the conveyance system to ensure the monitoring station is in good condition prior to a sampled storm event. Field staff follow this inspection and cleaning procedure to ensure data collected from the system is unaffected by accumulated debris and sensor drift. In addition to the maintenance visits, staff visit sites twice weekly to reset pressure transducers to zero.

Following the Standard Operating Procedure for Monitoring Station Maintenance (WSDOT 2017b), field staff conduct station checks that include inspections, testing, and replacement of worn or missing parts. Monitoring staff inspect internal wires and cables to evaluate wear and ensure cable connections to the data logger are in good condition. Staff check station antennae declinations and bearings, and clean solar panels to remove accumulated debris. When servicing or calibrating of scientific equipment at monitoring stations is required, trained
technicians follow manufacturers’ specifications and conduct servicing and calibration of equipment on site or in a controlled environment, as appropriate.

3.5 Staff Roles and Responsibilities

WSDOT uses Stormwater and Watersheds Program staff in the Headquarters (HQ) Environmental Services Office (ESO) to implement its monitoring programs. Seven staff from the HQ ESO played key roles in the stormwater hydrology monitoring strategy.
4 Quality Assurance and Quality Control

The *Quality Assurance Project Plan for WSDOT Embankment Hydrology Monitoring* (WSDOT 2017a) includes a comprehensive description of quality assurance and quality control activities.

WSDOT implements quality control (QC) procedures through all phases of data collection and analyses. Verification and validation of field-generated data occur as part of data management activities. The quality of raw, unprocessed, and processed data is subject to review and management. This includes the following areas of work:

1. Field quality control
   - Implementation of standard operating procedures.
   - Field instrument inspection, calibration, and maintenance.
   - Stormwater conveyance systems inspection and maintenance.
   - Collection of field notes and maintenance documentation.

2. Data management
   - Hydrology and precipitation data validation including:
     - Checking for concurrence between primary and secondary 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 make logical sense. For example, an extended delay in runoff at the highway edge, which normally takes little time, might indicate problems with the equipment or site performance.
   - Field data verification.
   - Correction of data gaps, anomalies, and use qualification for precipitation and hydrology data.
   - Self-assessment and audit of project processes.
Failure to meet hydrology and precipitation validation criteria may prompt rejection of collected data. At a minimum, problems identified during data validation will prompt corrective actions in the field, with equipment, or data management activities.
5 Monitoring Results

5.1 Embankment Hydrology Monitoring

WSDOT initiated hydrological and meteorological data collection at the embankment monitoring sites in 2017. A total of 228 storms occurred at the two monitoring study sites from October 2017, through September 2018 (water year 2018) (WY18). Staff have conducted hydrology validation on all data collected from these storms.

WSDOT discovered a possible issue with pipe collector installation at both sites in October 2018. Staff deemed the problem at Silver Creek negligible, so no correction will be made. Field team staff will make any necessary corrections to the collector systems at Montesano before beginning data collection in water year 19 (WY19). As the water year progresses, staff will compare Montesano WY18 to WY19 records to evaluate whether there are unexpected or abnormal patterns in the data. WSDOT will include WY18 Montesano data in next year’s status report if the data is reliable.

5.2 Measurement Logistics and Challenges

WSDOT field staff attempted to measure highway runoff from all storms at both sites. Staff typically visit sites twice weekly to reset the pressure transducers (PTs) to the point of zero flow. Since PT readings trend negative as water evaporates in conveyance systems or leaks appear around weir gaskets, it is important to reset PTs on a regular basis. This step ensures that PTs are ready to record flow measurements as soon as runoff reaches the equipment.

Collecting flow data from smaller storms (0.08-inch or less) is problematic. Since data loggers only calculate flow when PT data is positive, negative readings during small flow events may not be enough to raise PT levels to zero. Staff need to reset PTs to zero within 18 hours prior to the start of runoff to avoid this problem. WSDOT anticipates using field observations paired with consistent improvements in the understanding of site hydrology to improve data quality in WY19.

5.3 Lessons Learned

WSDOT staff evaluated the effectiveness of monitoring practices in WY18. Staff observations helped refine existing monitoring methods and procedures. These changes should improve the accuracy and efficiency of future data collection, and make use of staff time and resources more effective.
1. **Targeting storms**: Pressure transducers (PTs) should be set to zero within 18 hours of a forecast storm. Staff will track storm forecasts and PT levels daily.

2. **Hydrology validation**: WSDOT applied a stringent hydrology validation process to ensure that collected data was valid and scientifically credible. After review of completed hydrology validation, staff identified improvements in storm targeting procedures to allow for greater data collection success. Staff will download the full data set from the data loggers at the beginning of each week so that hydrology validation can occur weekly, and identification of system issues will occur close to real time.

3. **Cross training of staff**: Cross training is an important factor for the program considering the limited number of staff. Having more staff trained to track instrument settings will improve data quality. Having more staff available to conduct site visits will improve chances for successful data collection.

4. **Conduct frequent site storm event observations**: WSDOT discovered several issues at the embankment study sites when observing sites during storm events. One example is the discovery of a vegetated berm that directed water away from an edge of pavement collector. Direct observation during storms is critical to assess the operational performance of the monitoring equipment and observe site hydrological processes only present during rain events.
Glossary

data collection platform (DCP) – A collection of instruments or sensors that operate and report to a central data logger. WSDOT houses DCPs in a central location or “platform” at the monitoring site.

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

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 (Ecology 2014) administers these permits referred to as NPDES permits and, in Washington State.

pavement edge (PE) collector – A 6-inch high-density polyethylene pipe or similar device installed to collect runoff from an impervious roadway. PE collectors also act as conveyance systems for stormwater from the road surface to pass through a flow measurement device and allow for composite sample collection.

Quality Assurance Project Plan (QAPP) – A document that describes the objectives of a monitoring project and the processes and activities necessary to develop data that will support those objectives (Ecology 2004).

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.


## Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>DCP</td>
<td>data collection platform</td>
</tr>
<tr>
<td>Ecology</td>
<td>Washington State Department of Ecology</td>
</tr>
<tr>
<td>ESO</td>
<td>Environmental Services Office</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HDPE</td>
<td>high-density polyethylene</td>
</tr>
<tr>
<td>HQ</td>
<td>WSDOT Headquarters</td>
</tr>
<tr>
<td>H:V</td>
<td>Horizontal to Vertical</td>
</tr>
<tr>
<td>NPDES</td>
<td>National Pollutant Discharge Elimination System</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Association</td>
</tr>
<tr>
<td>NWS</td>
<td>National Weather Service</td>
</tr>
<tr>
<td>PE</td>
<td>pavement edge</td>
</tr>
<tr>
<td>PT</td>
<td>pressure transducer</td>
</tr>
<tr>
<td>QAPP</td>
<td>Quality Assurance Project Plan</td>
</tr>
<tr>
<td>QC</td>
<td>quality control</td>
</tr>
<tr>
<td>WSDOT</td>
<td>Washington State Department of Transportation</td>
</tr>
<tr>
<td>WY</td>
<td>water year</td>
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