Standard Operating Procedure for Testing and Analysis for Shallow Infiltration Facilities

Seattle-Tacoma International Airport

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1 Introduction

This technical Standard Operating Procedure (SOP) is provided by the Port of Seattle (Port) to assist developers in design and approval of Low Impact Development (LID) stormwater management facilities that employ shallow infiltration methods. Shallow infiltration facilities are characterized as infiltration facilities that discharge into unconfined receptor soils at relatively shallow depths, generally less than 10 feet below final ground surface. Depending on the type of infiltration facility selected, it may or may not be classified as an Underground Injection Control (UIC) facility.

The methods presented here include summaries of the testing and design procedures prescribed in the 2019 Stormwater Management Manual for Western Washington prepared by the Washington State Department of Ecology (SWMMWW, 2019; Volume 5) and in accordance with the Port's LID Guideline (RKI, 2019). This document summarizes many complex analyses and decisions that must be made when siting and designing infiltration best management practices (BMPs) and is not intended to replace detailed guidance within the SWMMWW. Readers should review the referenced SWMMWW sections during infiltration design projects.

To help project managers understand implications on development project schedule and budget, Section 2 of this document provides a summary of major steps for shallow infiltration planning, testing, analysis, and design, as well as an example schedule and cost estimate for a larger and more complex shallow infiltration site. Sections 3 through 5 provide more detailed shallow infiltration planning, testing, analysis, and design guidance.

Attachments 1 through 3 are included as tools for project planning, and include:

- An example project timeline, broken down by anticipated tasks
- A planning-level example project budget
- A checklist of key infiltration related criteria, information, and data required for Port approval of the facility

2 Summary of Shallow Infiltration Steps, Example Duration and Costs

Section V-5.2 of the SWMMWW describes eight steps for design of infiltration LID facilities[1], which have been updated and adapted by Aspect. The revised steps are summarized below.

- ***Preliminary Steps:***
  - Determine if Proposed Site is Mapped as Infeasible for Shallow Infiltration (Figure 1, from Aspect, 2018)
  - Early Coordination with Port
- ***Step 1:*** Select Preliminary Locations for Shallow Infiltration Facilities, Complete Initial Site Investigation, Groundwater Monitoring
- ***Step 2:*** Estimate Stormwater Runoff from the Project Using Hydrologic Modeling
- ***Step 3:*** Develop Trial Shallow Infiltration Facility Details, Sizes, and Depths
- ***Step 4:*** Complete Detailed Site Characterization and Shallow Infiltration Testing
- ***Step 5:*** Analyze Infiltration Test Data and Determine Aquifer Properties and the Treatment Capacity and Design Infiltration Rates of the Receptor Unit
- ***Step 6:*** Size and Design Shallow Infiltration Facilities to Meet Performance Standards, Initial UIC Registration (If Needed)
- ***Step 7:*** Conduct Groundwater Mounding Analysis (if needed)
- ***Step 8:*** Construct the Infiltration Facility, Conduct Performance Monitoring and Update UIC Registration (If Needed)

For facility approval, each of the steps listed above must be addressed in a report prepared by a licensed engineer, geologist, or hydrogeologist and submitted to the Port. Refer to Section 4 for additional reporting and contractor selection requirements. The checklist in Attachment 3 must also be completed and signed by the Project Manager or the licensed professional.

The remainder of this section provides an example of overall activities, costs, and durations associated with shallow infiltration planning, testing, analysis, and design for a larger and more complex site, typical of significant Port/STIA development projects. To establish a baseline for estimating costs and durations, the following example site characteristics are assumed:

[1] Subsurface infiltration systems such as infiltration trenches or conventional drywells will be classified as Underground Injection Control (UIC) facilities. Refer to Sections I-2.14 and I-4 of the SWMMWW for additional siting, design, treatment, and registration requirements for these facilities. Also see the SOP for Deep Infiltration Testing and Analysis in this Manual if applicable.

- Planned redevelopment site is 20 acres, will be mixed office/commercial, and is not served by any existing on-site or regional stormwater treatment or flow control facilities.
- Site runoff would discharge to a non-flow control exempt water body.
- The redevelopment site has been identified by the Port as potentially feasible for shallow infiltration.
- Redevelopment site has active businesses/operations that need to be accommodated until later in the development process.
- The shallow infiltration receptor soil is estimated be a 15 ft thick sandy gravel outwash deposit with some silt, expected to have medium to high infiltration rates.
- Local well logs indicate the groundwater aquifer under the infiltration receptor soils is an around 30 ft thick sandy silt soil bounded on the bottom by a clay layer.
- Groundwater hydraulic properties and flow direction are unknown.
- No steep slopes, contamination sites, or drinking water wells are known to exist within likely set-backs.
- Initial stormwater management approach involves pre-treating stormwater as required followed by infiltrating stormwater onsite to meet Port SWMM standards.
- The goal is to use permeable pavements where allowed and otherwise infiltrate pre-treated runoff using bioretention swales (for the water quality flow) and shallow infiltration trench galleries (for higher flows) located in four different drainage basins on the site. Shallow infiltration trench galleries will be classified as UIC facilities.
- 12 Pilot Infiltration Tests (PITs; see SWMMWW Section V-5.4) will be conducted to determine measured infiltration rates.

An example Gantt chart schedule and an order of magnitude budget have been prepared for the assumed site conditions (Attachments 1 and 2). Note that order of the steps in the example Gantt chart and budget show the mounding analysis being conducted before and partially in parallel with the design of the infiltration facility, which reflects the proper flow of work when a mounding analysis is required. The schedule and budget account for some uncertainties and situations that could drive the need for extra time or work, such as:

- The need to conduct groundwater monitoring to establish the maximum expected groundwater level.
- The need for the geotechnical and hydrogeologic fieldwork to sometimes avoid disrupting active businesses.
- Exploration results that indicate a portion of the planned infiltration area is not suitable, which requires extra work to identify a new location.

- Infiltration testing results that indicate additional, unplanned, shallow infiltration BMPs will be needed to handle the targeted maximum cumulative infiltration flow rate.
- BMPs serving large drainage areas where less than 15 ft of separation exists between the bottom of infiltration facilities and high groundwater, thereby triggering a formal groundwater mounding analysis (MODFLOW Groundwater Model). The mounding analysis results in revision to infiltration BMP spacing and flow rates, ultimately requiring BMPs to be more dispersed across the site along with maximizing use of permeable pavements where allowed.

The example schedule and budget do not include the time or money to construct infiltration systems (Step 8).

The Gannt chart is included as Attachment 1 and illustrates that the process from initial investigations and preliminary layout through detailed design and permitting can take on the order of 19-20 months for a larger and complex site. Smaller, simpler sites could require substantially less time.

A budget corresponding with the Gant chart is included as Attachment 2 and indicates that multidisciplined shallow infiltration related investigations, testing, analysis, design, and permitting costs for a larger and complex site is on the order of $243,000, including roughly $182,000 in consultant costs; $55,000 in survey, driller, well installer, and excavation costs; and $6,100 in miscellaneous instrumentation, equipment, travel, and laboratory costs. Costs for could easily increase above this level depending on the required level of documentation, team coordination, drilling/testing/excavation/survey needs, detailed design effort, and site challenges encountered. Similarly, smaller and simpler sites could require substantially less cost. In addition, while non-stormwater infiltration related costs were generally excluded from the cost estimate, some costs included in the example budget may be partially redundant when accounting for the survey, exploration, and testing needs of an overall development project. For example, sometimes surveying and some infiltration related geotechnical and hydrogeologic/aquifer explorations are required for other site development purposes, and hydrologic modeling is needed for designing non-infiltration BMPs as well as infiltration BMPs.

3 Detailed Steps for Planning, Designing, and Constructing Shallow Infiltration Facilities

When completing the investigations and analyses described below, it is important to be consistent with the infiltration feasibility criteria and procedures described in the Port's LID Guideline – *Low Impact Development Guideline for the Seattle-Tacoma International Airport* (RKI, 2019). For instance, Section 3.4 of the Port's LID Guideline provides an overview of the general steps involved in assessing the feasibility of on-site infiltration, and Figure 3.3 provides a flow chart illustrating the feasibility assessment process, including infeasibility off-ramps.

A checklist of key infiltration related criteria, information, and data has been prepared to help project managers successfully track and complete the detailed shallow infiltration planning, testing, analysis, and design process. The checklist can also help Port plan reviewers determine the completeness of stormwater development submittals and ensure that the proper types of analyses have been completed. The checklist is included as Attachment 3.

Preliminary Step - Determine if Proposed Site is Mapped as Infeasible, Early Coordination with Port

Shallow infiltration facilities can only be considered in areas not previously identified by the Port as infeasible for infiltration (Aspect, 2018; Appendix B of the Port's LID Guideline) and where measured infiltration rates are 0.3 inches per hour (in/hr) or greater, as outlined in the Port's LID Guideline. The Port's LID Guideline includes infiltration infeasibility maps that need to be reviewed early in the planning stages. The Shallow Infiltration Infeasibility Map is included with this document as Figure 1. In addition, to reduce risk, it is recommended that project proponents communicate and coordinate early with Port regarding the planned use of shallow infiltration facilities.

3.1 Step 1 – Select Preliminary Locations for Shallow Infiltration Facilities, Complete Initial Site Investigation, Groundwater Monitoring

Given that stormwater infiltration testing and site suitability checks must be based on the planned location and depth of stormwater infiltration BMPs, it is important for detailed geotechnical explorations and infiltration testing work to proceed after the development of at least a conceptual site and drainage plan that considers preliminary geotechnical and hydrogeologic information.

As described in Section V-5.2 of the SWMMWW, base the location of a shallow infiltration BMP on the ability to convey flow to the location and the expected receptor soil conditions of the location. Based on preliminary information: (a) plan and conduct a preliminary surface and sub-surface characterization study; (b) complete a preliminary check of Site Suitability Criteria (Section V-5.6 of the SWMMWW); and (c) initially estimate feasibility of locating an infiltration BMP on the site. If shallow UICs are proposed, refer to Section I-4.10 of the SWMMWW which provides minimum siting requirements as well as design and construction requirements for new UIC wells. In addition, review to Section 3.4 of the Port's LID Guideline to review horizontal setbacks and site constraints specific to the Port (RKI, 2019). Note that if State or Federal funds are involved in the project, it is likely that an Executive Order 05-05 Section 106 cultural resources review and approval process will need to be coordinated with Ecology and completed prior to conducting any ground disturbing activity, including borings and/or monitoring well installation. When required, the cultural resources review and approval process can require 2 months or more to complete.

The recommended process for this step involves:

a. Call for initial utility locates, review available site geotechnical and hydrogeologic data, assess data needs, and develop an initial field work plan, including a safety plan as needed.

b. Complete site survey and initial geotechnical and hydrogeologic site characterization work, including preliminary identification of stormwater receptor unit characteristics and placement of groundwater monitoring wells when needed.

c. Analyze the initial geotechnical (and hydrogeologic) site characterization data and estimate preliminary infiltration rates at key locations across the site. Grain size data and/or published soil classification and hydraulic conductivity information, such as from an NRCS Soil Survey, can be used to help develop preliminary estimates of design infiltration rates.

d. Prepare a conceptual development site layout (grading, buildings, landscaping, parking, stormwater BMPs, etc.). Note that to help maintain adequate infiltration rates over the long term, Ecology requires that all shallow stormwater infiltration BMPs, including treatment infiltration BMPs such as bioretention swales, should be preceded by a “pre-settling basin” at a minimum, or a basic (solids removal) treatment BMP. Pre-settling basins and other pretreatment BMPs are intended to achieve at least 50% solids removal, often with some oil, scum, and debris control as well.

e. Continue groundwater level monitoring through at least one wet season (December 1 through April 1) as needed.

3.2 Step 2 – Estimate Stormwater Runoff from the Project Using Hydrologic Modeling

Estimate stormwater runoff from the development site following the methods and guidelines described in Volume III of the 2017 Port of Seattle Stormwater Management Manual (SWMM) for Port Aviation Division Property and Section V-5.2 of the SWMMWW:

a. Determine the continuous hydrograph and volume of stormwater runoff using an approved continuous runoff model (Western Washington Hydrology Model [WWHM], MGSFlood, or King County Runoff Time Series [KCRTS]) as approved by the Port. Utilize existing Port of Seattle hydrologic models when possible. The runoff hydrograph data file developed for the project site serves as input to the shallow infiltration facility, sometimes with modifications.

b. Estimate the peak flow rate that will need to be accommodated by infiltration BMPs located in each infiltration area of the site in order to meet standards. Sometimes storage/detention BMPs are located upstream of an infiltration BMP in order to reduce peak infiltration flow rates. This is acceptable if the overall required system drain-down period is met.

If preferred by the developer and approved by the Port, this step (runoff modeling) may be completed later in the project. For example, the developer may prefer to first evaluate Site

Suitability Criteria (Step 1) and conduct several initial infiltration tests to confirm site infiltration rates are likely to exceed the required minimum of 0.3 in/hr before moving forward with the hydrologic modeling effort.

3.3 Step 3 – Develop Trial Shallow Infiltration Facility Details, Sizes, and Depths

By estimating runoff volumes, peak infiltration flow rates, and a minimum infiltration rate of 0.3 in/hr (or other initial infiltration rate estimate), a designer can estimate the preliminary characteristics, number, and individual flow rates for proposed infiltration facilities and identify areas for testing and construction that consider the setback requirements outlined in the Port's LID Guideline and site characterization and suitability criteria detailed in Section V-5.5 and 5.6 of the SWMMWW. If shallow UICs are proposed, then designers need to consider Sections I-4.10 through I-4.17 of the SWMMWW for site suitability, design criteria, and treatment requirements. Trial BMP geometries should be used to help locate BMPs for planning purposes and for developing the detailed geotechnical and hydrogeologic subsurface investigation plan.

For shallow infiltration facilities sized to meet the LID Performance Standard and/or the Flow Control Performance Standard (see the LID Guideline), the facility must infiltrate either all of the influent hydrograph data file, or a sufficient amount such that any overflow/bypass meets the standard.

Shallow infiltration BMPs, including shallow UIC facilities, may be used to provide flow control for stormwater runoff where pollutant concentrations that reach groundwater will meet the Washington State groundwater water quality standards in the following situations:

- For flows greater than the water quality design flow rate in accordance with SWMMWW Section III-2.6 Sizing Your Runoff Treatment BMPs.
- Where stormwater discharging into a UIC facility is treated in accordance with SWMMWW Section I-4.16 Determining Treatment Requirements.

Completing Step 3 generally involves:

a. Developing preliminary estimates of shallow infiltration facility details and depths based on peak infiltration flow rates and estimated geotechnical and hydrogeologic conditions.

b. Refinement of the number, locations, and details of preliminary shallow infiltration facilities through iterative modeling and BMP revisions and layout updates to meet performance standards.

c. Preliminarily verifying that Site Suitability Criteria are met (setbacks, groundwater protection areas, groundwater depth, contamination, etc.). See SWMMWW Sections V-5.5 and V-5.6.

d. When shallow UICs are proposed, preliminarily verifying that UIC related Site Suitability Criteria and design and construction requirements are met. See SWMMWW Section I-4 for additional siting, design, treatment, and registration requirements for UIC facilities.

3.4 Step 4 – Complete Detailed Site Characterization and Shallow Infiltration Testing

The SWMMWW (Section V-5.5 and 5.6) and the Port's LID Guideline (Section 3.4) detail the subsurface and surface suitability criteria for constructing shallow infiltration facilities. SWMMWW Sections I-4.10 and I-4.15 should be reviewed when shallow UICs, such as infiltration trenches or conventional drywells, are proposed. These criteria can be evaluated from new or, in part, from existing studies.[2] A substantial portion of the suitability criteria can be evaluated concurrent with infiltration testing, so an assessment of existing data should be completed prior to field investigations to identify data gaps to be addressed.

Detailed site characterization and shallow infiltration testing generally involves the following overall activities:

a. Based on the preliminary information developed in the preceding steps, determine the number, location, and depths of geotechnical test pits or borings, soil samples, groundwater aquifer tests, and Pilot Infiltration Tests (PITs; see SWMMWW Section V-5.4); determine instrumentation requirements; estimate test water needs; secure water sources, and develop a detailed field and testing work plan, including a safety plan as needed. Call for utility locates, survey utilities, and update the exploration and testing plan as needed. Note that sometimes the amount of excavation can trigger grading permit requirements, which should be coordinated with the Port.

b. Install PITs using a qualified contractor with ample involvement and oversight by the infiltration specialist or their representative.

c. Complete detailed field geotechnical/hydrogeologic explorations and PITs. Aquifer slug tests can be used to determine the transmissivity/hydraulic conductivity and Storativity of the material the well is completed in. Log soils and submit samples for laboratory analysis.

The Port's infiltration infeasibility map considers mapped surficial geologic conditions and general setbacks presented in the Port's LID Guideline. Aside from soil infiltration rates, other Site Characterization details that must be addressed for each project include:[3]

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[2] Existing studies and data may include geologic maps, cross sections, and models for the area; well logs from Ecology's online well log database; water levels, including seasonal variations, taken from well logs, groundwater studies, or collected from local monitoring wells; and/or geotechnical reports for nearby sites.

[3] The final characterization evaluation will also need to evaluate whether the site has any known contaminated soils (from existing environmental databases) and consider whether there would be any adverse effects from groundwater seepage from the infiltration facility on nearby structures.

1. **Continuously logged soil conditions** below the base of the infiltration facility, to at least 10 feet and 2.5 times the maximum designed ponded water depth. Visual grainsize classification is required. Large infiltration facilities (serving drainage areas of more than 10 acres) also require laboratory grainsize analysis.

2. **Seasonal high groundwater levels (through at least one wet season) and groundwater flow direction**. The wet season is defined as December 1 through April 1. This can be accomplished through evaluation of existing groundwater data, where present. Otherwise, determining groundwater flow direction typically involves installation of at least three groundwater monitoring wells. Smaller facilities (receiving less than 1 acre of drainage) need only to establish that the seasonal high-water level or low permeability layer is more than 10 feet below the base of the infiltration facility.

3. **Horizontal Hydraulic Conductivity of the soil below the water table to** determine groundwater mounding potential. This may be estimated from aquifer grainsize data, field testing, or existing data sources, if appropriate.

4. **Volumetric Holding Capacity of the receptor soil** (soil layer between the base of the facility and the seasonal high-water level). This may be determined from laboratory testing of site samples.

5. **Soil Cation Exchange Capacity (CEC) and Organic Matter Content** for facilities designed for runoff treatment, within each distinct soil type to a depth of at least 6 feet or 2.5 times the maximum design ponded water depth, whichever is greater. See the SWMMWW Section V-5.6 regarding the CEC and Organic Contents necessary for the vadose zone soil to count as a treatment media.

Elements 1, 4, and 5 can potentially be evaluated concurrent with the excavations completed for field infiltration testing (Field Infiltration Testing and Analysis described below) and can be completed within several weeks. Element 2, if not addressed through existing sources, will likely require contracting a licensed well driller for monitoring well construction, and Element 3 will require consultation of a qualified professional to complete hydraulic conductivity testing and/or analysis.

Depending on the existing data, the site characterization process may require up to 3 to 6 months to complete over the wet season (December 1 through April 1). A developer should consider completing Elements 2 and 3 after infiltration testing so that shallow infiltration feasibility is confirmed prior to investing in additional groundwater characterization.

3.4.1 Field Infiltration Testing and Analysis

The Port requires infiltration tests that are reasonably representative of full-scale operating conditions. Therefore, while grain size analyses may be used to estimate infiltration rates for conceptual BMP layout and sizing, PITs with appropriate safety/correction factors are required as the basis for determining design infiltration rates.

Field infiltration testing and analysis should be completed by an experienced professional during the wet season (December 1 through April 1) to best represent anticipated conditions. A typical duration for planning, fieldwork, and analysis is approximately 30 to 60 days. Costs and duration vary greatly with the number of tests, and whether additional concurrent site characterization is completed.

The following subsections identify the considerations for planning and execution of the shallow infiltration testing program.

Test Program Design

PITs are required by the Port for designing shallow infiltration facilities and provide initial measured infiltration rates[4] that are later adjusted during the design process to account for uncertainties and future performance declines. Generally, the water depth during the constant head portion of a PIT should be kept at the same water depth as the planned BMP so the measured infiltration rate can be easily corrected to determine the long-term design infiltration rate. The horizontal and vertical locations of the PITs must be surveyed by a licensed land surveyor and accurately shown on the design drawings. A minimum of two PITs is recommended for design of each infiltration facility, or one PIT per 2,000 square feet of facility area (King County, 2016), with additional tests conducted if subsurface conditions are highly variable and/or at the direction of a consulting engineer, geologist, or hydrogeologist.

There are two scales of PITs:

- **Large Scale PITs** include a test pit with a horizontal bottom of approximately 100 ft^2 and are the preferred method for estimating the initial infiltration rate of the soil layer targeted for infiltration (the receptor soil). Large scale PITs best address site variability and are typically used for projects with drainage areas greater than 1 acre but can require substantial water during testing.

- **Small Scale PITs** include a test pit with a horizontal bottom of 12 to 32 feet can be used in place of a large-scale PIT if any of these conditions exist: (1) the drainage area to the infiltration site is less than one acre; (2) testing is for Bioretention or Permeable Pavement BMPs that either serve small drainage areas and/or are widely dispersed throughout a project site; (3) the site has an anticipated infiltration rate greater than 4 in/hr and the site geotechnical investigation suggests uniform subsurface characteristics.

Refer to Section V-5.4 of the SWMMWW for large- and small-scale PIT procedures. In designing the PIT program, the following should be considered:

- The planned layout of the completed project. Testing should be completed within the anticipated footprint of the infiltration facility.

[4] It should be noted that the PIT results in a measured infiltration rate, not saturated hydraulic conductivity (Ksat) as presented in Section V-5.4 of the SWMMWW. Refer to Step 5 of this SOP for guidance.

- The anticipated depth of the facility. Testing must be completed at the base of the planned facility bottom.
- Whether any compaction of the infiltration receptor material will be required. If so, to avoid overestimating the as-constructed infiltration rates, the test should replicate the compaction effect.
- Whether any additional Site Characterization elements described in Step 4 will be addressed concurrently.
- The number of PITs required, the separation between PITs, and whether multiple PITs can be conducted concurrently.
- Access for excavation and water conveyance equipment.
- Anticipated infiltration rates and associated water supply availability.
- Proximity of buried utilities.
- Traffic control requirements.

3.4.2 Site Access Survey and Utility Locates

Utility locates are required at least 72 hours before ground disturbance, and the area(s) to be disturbed must be marked in advance with paint. Public utility locate information is available from www.callbeforyoudig.org/Washington. For liability reasons, the excavation contractor must call in the public locates. A private utility location provider must also be contracted for remote areas.

Site access should be considered for all contractors, including limitations for:

- Excavator loading and offloading
- Drill rigs and excavators to the project site during wet conditions
- Water supply trucks and conveyance
- Traffic revisions
- Excavator and equipment access.

3.4.3 Secure a Water Source

Infiltration tests require several hours of uninterrupted potable water flow. Flow rates typically required for large-scale PITs range from 0.3 to more than 20 gallons per minute (gpm) to maintain a constant water depth during testing. To estimate water quantities for testing, the area of the PIT and an initial infiltration rate should be considered. Some common water sources are listed below.

- **Fire Hydrants** may be accessible if authorized by the Port Fire Department and/or through the City of Seatac. A certified backflow prevention device (reduced pressure backflow assembly [RPBA]) must be used and tested by Port AV/Maintenance prior to approval.

- **Water Trucks** can be used in remote areas but supply a finite amount of water for testing. If operated under gravity flow, constant valve adjustments will be required as the truck empties and multiple trucks may be required to avoid stopping the tests early if high infiltration results are encountered.

- **Other On-site Sources**, including hose bibs, which are typically limited to a capacity of about 5 gpm and may not provide sufficient supply to conduct testing.

3.4.4 Infiltration Testing (PIT) Procedures

General procedures and best practices for conducting PITs are presented below for planning purposes. Step-by-step instructions and additional details are provided in Section V-5.4 of the SWMMWW.

- Since execution of a single PIT often takes one full day, all water conveyance and metering equipment should be staged, and the test pit(s) excavated the day before testing when feasible. Pits must be properly barricaded for safety.

- The test pit should be excavated to the anticipated base of the infiltration facility. It is important to have a level bottom of known geometry for the test. Depending on soil characteristics and the depth of the excavation (equivalent to the proposed facility bottom), the side walls of the excavation may need to be laid back at a 50 percent slope for safety and to allow access to the pit.

- Water must be metered and added to the test pit for a minimum of 6 hours, with stable water level and flow conditions maintained for at least the final hour (this is the “constant-rate” portion of the PIT).[5] The water level within the test pit should remain constant at a level equal to or less than the design water level depth (the Port’s LID Guideline limits ponded water in open surface facilities to no more than 4 inches to avoid waterfowl attraction). Bucket measurements should be used to periodically verify flow rates and may also be needed at sites with low infiltration rates where flows might be below the lower limit of the flow meter.

- A pressure transducer is recommended for installation at the bottom of the excavation to monitor water level changes. It can be challenging to identify changing infiltration rates (water levels under a constant flow rate) during large PITs with lower infiltration rates, and a pressure transducer can provide advanced insight on water level changes.

[5] Throughout the PIT, water levels should be maintained as constant as possible, with flow rates being adjusted by no more than 5 percent during the constant-rate portion of the test.

- At the conclusion of constant-rate portion of the PIT, monitor the rate of water level change in the excavation, known as the “falling-head” portion of the test (this is best done through use of a logging pressure transducer). This portion of the test helps to assess the head dependency of the infiltration rate, and should ideally be completed several times (for example, after the constant-rate portion of the test, fill the excavation several times and allow the water level to drop to the base of the excavation).

- At the conclusion of the test, over-excavate the pit to the maximum extent allowed by the equipment to assess subsurface mounding or “perching” of test water. This is ideally done within 1 hour of the conclusion of the falling head test. Mounding or “perching” of test water would indicate that a restrictive layer is present below the test pit, or that the shallow aquifer does not have the capability to readily convey the infiltrated water.

All PIT data, including recorded field data, instantaneous flow rate measurements, electric wire tape readings, raw/final data files from pressure transducers and dataloggers should be compiled and reviewed for accuracy by a qualified professional.

3.5 Step 5 – Analyze PIT Data and Determine Aquifer Properties and the Treatment Capacity and Design Infiltration Rates of the Receptor Unit

PIT analytical methods are described in Section V-5.4 of the SWMMWW. Both the constant-head and falling-head portions of the tests should be analyzed. An assessment of the uncertainty in flow rate and constant-head stabilization should be conducted, and the lowest estimate of the measured infiltration rate should be used in design. If the measured rate is less than 0.3 in/hr, the evaluated location is not suitable for infiltration, and no further assessment is needed.

After using the field exploration results to verify the suitability of the receptor soil, design infiltration rates for shallow infiltration facilities are determined from the measured infiltration rates (PIT analysis). A series of correction factors are applied to the measured infiltration rates to account for uncertainty and derive design infiltration rates. Refer to the procedures for calculating the design infiltration rate in Section V-5.4 of the SWMMWW. This analysis generally requires effort by an experienced professional. The treatability of the receptor soil and need for any soil amendments should be determined from lab tests of CEC and Organic Matter Content.

Infiltration facilities serving 1 acre or more of drainage area and/or those that require a groundwater mounding analysis (Step 7) are required by Ecology to use the “detailed approach” to determine a design infiltration rate (see Section V-5.4 of the SWMMWW). The detailed approach is intended to adjust the measured infiltration rate to account for the likely hydraulic gradient and the planned geometry of the infiltration facility. Note that at present, Ecology’s guidance for completing the detailed approach is in error due to misunderstanding the difference between saturated hydraulic conductivity (K_{sat}) and infiltration rate. In lieu of attempting to apply the "detailed approach" to PIT results, Aspect recommends applying the corrections factors in Table V-5.1 of Section V-5.4 of the SWMMWW to the PIT measured infiltration rates to determine the design infiltration rate, and then proceeding with further analysis and design. In addition, Aspect recommends that the qualitied professional determining design infiltration rates apply a supplemental correction factor to better account for the likely decline in infiltration rate due to the inevitable accumulation of stormwater sediments over time. Course sandy soils (sandy gravels, gravely sands, course through fine clean sands) will experience a proportionally large decrease in infiltration rate due to sediment loading compared to a silty soil with an already low infiltration rate. Therefore, the professional should apply a supplemental correction factor ranging from 0.2 (clean course soils with very high measured infiltration rates) to 1 (silty soils with low measured infiltration rates). The exact supplemental correction factor should be chosen based on the judgement of the professional, and the reasoning should be documented in the stormwater permitting submittal.

Analysis of the PIT results must be included in the technical report submitted to the Port (Section 4).

3.6 Step 6 – Size and Design Shallow Infiltration Facilities to meet Performance Standards, Initial UIC Registration (If Needed)

Note that for sites requiring a mounding analysis (Section 3.7), it will be necessary for the design process to account for the mounding analysis results. Addressing groundwater mounding related impacts can require changes in the layout and size of infiltration BMPs and/or restricting infiltration flow rates. Therefore, the mounding analysis should be conducted before the final BMP layout, sizing, and design process.

The stormwater designer should coordinate across design disciplines, update site hydrology and adjust the development site plan, stormwater treatment BMPs, and shallow infiltration facility layout, details, specifications, and cost estimates as needed to meet standards and proceed with permitting and full design. Shallow infiltration facility testing methods, results, and design information need to be included in a site geotechnical/hydrogeology report and stormwater permitting submittal documents. Infiltration system Operation and Maintenance (O&M) procedures are also typically required, which should be included in an overall Stormwater O&M Manual.

Refer to SWMMWW Sections V-5.3 for general design criteria for infiltration BMPs and sizing to meet alternative performance standards. Also refer to the design guidance for each specific infiltration BMP located in Section V of the SWMMWW. Be sure to cross-check the design requirements in the SWMMWW with the BMP selection and modification requirements located in Sections 3.5 and 3.6 of the Port's LID Guideline. It is also necessary to register shallow infiltration UICs, such as infiltration trenches with perforated pipe, with Ecology's Underground Injection Control Program prior to construction. Aspect recommends initially registering UICs based on approximately 60% to 90% design information so that any Ecology comments can be included in the final design.

3.7 Step 7 – Groundwater Mounding Analysis

Groundwater mounding analysis cannot be completed until the Site Characterization and the infiltration testing described Step 4 are completed. A detailed groundwater impact and mounding analysis can involve numerical groundwater modeling by a qualified professional to determine the subsurface buildup of groundwater levels that result from operation of an infiltration facility. Completing the mounding analysis is often an iterative process with Step 6, where: (a) information about groundwater, aquifer properties, and infiltration BMPs and flowrates is input into numerical groundwater modeling software; (b) the model is run; (c) the infiltration well system is modified if needed; and (d) the model is updated and ran again, and so on.

The primary reasons to perform a groundwater mounding analysis are to verify that mounding of infiltrating water will not rise to the point where it impedes infiltration, causes the infiltration facility to prematurely overflow, causes slope stability or seepage problems, negatively impacts adjacent buildings or other infrastructure, or interacts with contaminated soils. For UIC facilities, a mounding analysis is also helpful to verify that the mound does not rise to the point where stormwater is directly injecting into the mound (prohibited by the UIC Program Rule, WAC 173-218 as outlined in Section I-4 of the SWMMWW).

Mounding analysis will be required for: (a) an infiltration BMP serving a 1 acre or larger drainage area where groundwater is less than 15 feet below the bottom of the facility; (b) an infiltration BMP serving a 1 acre or larger drainage area where a low permeability soil layer is less than 15 feet below the bottom of the facility; and (c) infiltration basin or trench BMP serving a less than 1 acre drainage area where groundwater is less than 5 feet below the bottom of the facility. Ecology also recommends that a groundwater mounding analysis be performed for BMPs with drainage areas less than 1 acre if a restrictive layer is identified within 10 feet of the base of the infiltration facility (Section V-5.4 of the SWMMWW).

If a formal mounding analysis is required, the analysis can range from using a relatively simple spreadsheet model to developing a full MODFLOW groundwater model. Following/adapting the mounding analysis requirements in Section 5.2.1 of the 2016 King County Surface Water Design Manual,, it is necessary to model the groundwater response under a continuous infiltration flowrate hydrograph, which is derived from a project's overall continuous simulation runoff model output. Mounding levels must be assessed for a water year (October 1 through September 30) with the wettest 30-day (cumulative rainfall) volume on record as well as a water year with a 100-year precipitation event included. In addition to the effort to derive the infiltration hydrograph, when a mounding model is required, it is also necessary to verify or estimate aquifer properties such as thickness, soil type, and porosity, and estimate additional aquifer properties such as horizontal and vertical hydraulic conductivities, Specific Yield, and Specific Storage. Sometimes this will require extra hydrogeologic field work and aquifer tests.

3.8 Step 8 – Construct the Infiltration Facility, Conduct Performance Monitoring and Update UIC Registration (If Needed)

Refer to Subsection 8 of Section V-5.2 of the SWMMWW for details associated with post-construction performance testing for infiltration BMPs. In general, Ecology recommends that following construction and site stabilization, infiltration BMPs be tested to verify that they will operate at the intended infiltration rate. If testing indicates that infiltration rates are lower than intended, then mitigation/restoration steps must be taken. While post-construction performance testing is desirable, it is not necessarily feasible for large systems, in which case long term overflow monitoring may be appropriate.

It may also be necessary to update shallow UIC registrations if needed based on construction as-built conditions.

4 Contractor Selection and Reporting Requirements

The Port's LID Guideline requires that a report addressing the elements of site suitability and characterization and infiltration facility design are signed and sealed by a qualified Engineer, Engineering Geologist, Geologist, or Hydrogeologist. A qualified consultant or team member licensed in one or more of these areas and with proper stormwater infiltration expertise should be consulted early in project development to assist in scoping. In addition to stormwater, geotechnical, and hydrogeologic engineering/consulting services, the following may also need to be contracted:

- Surveying services.
- Excavation services, preferably with experience in Pilot Infiltration Tests (PITs).
- Water truck and water conveyance in remote areas (often provided by excavation companies).
- Geotechnical drilling/boring (for site characterization and soil sampling).
- Well Construction (for groundwater monitoring well installation).

5 References

Aspect Consulting, LLC incorporated as Appendix B of the LID Guideline (Aspect) 2018, Infiltration Infeasibility Assessment, Seattle-Tacoma International Airport, SeaTac, Washington, prepared for Port of Seattle, July 17, 2018.

Washington State Department of Ecology (Ecology), 2019, Stormwater Management Manual for Western Washington, Publication No. 10-10-021, July 2019.

King County, 2016, King County Washington Surface Water Design Manual. Chapter 5: Flow Control Design. Published Online April 24, 2016.

Port of Seattle, 2017, Seattle Tacoma International Airport Stormwater Management Manual for Port Aviation Division.

Robin Kirschbaum, Inc. (RKI), 2019, Low Impact Development Guideline, Seattle-Tacoma International Airport, SeaTac, Washington, prepared for Port of Seattle, 2019.

FIGURES

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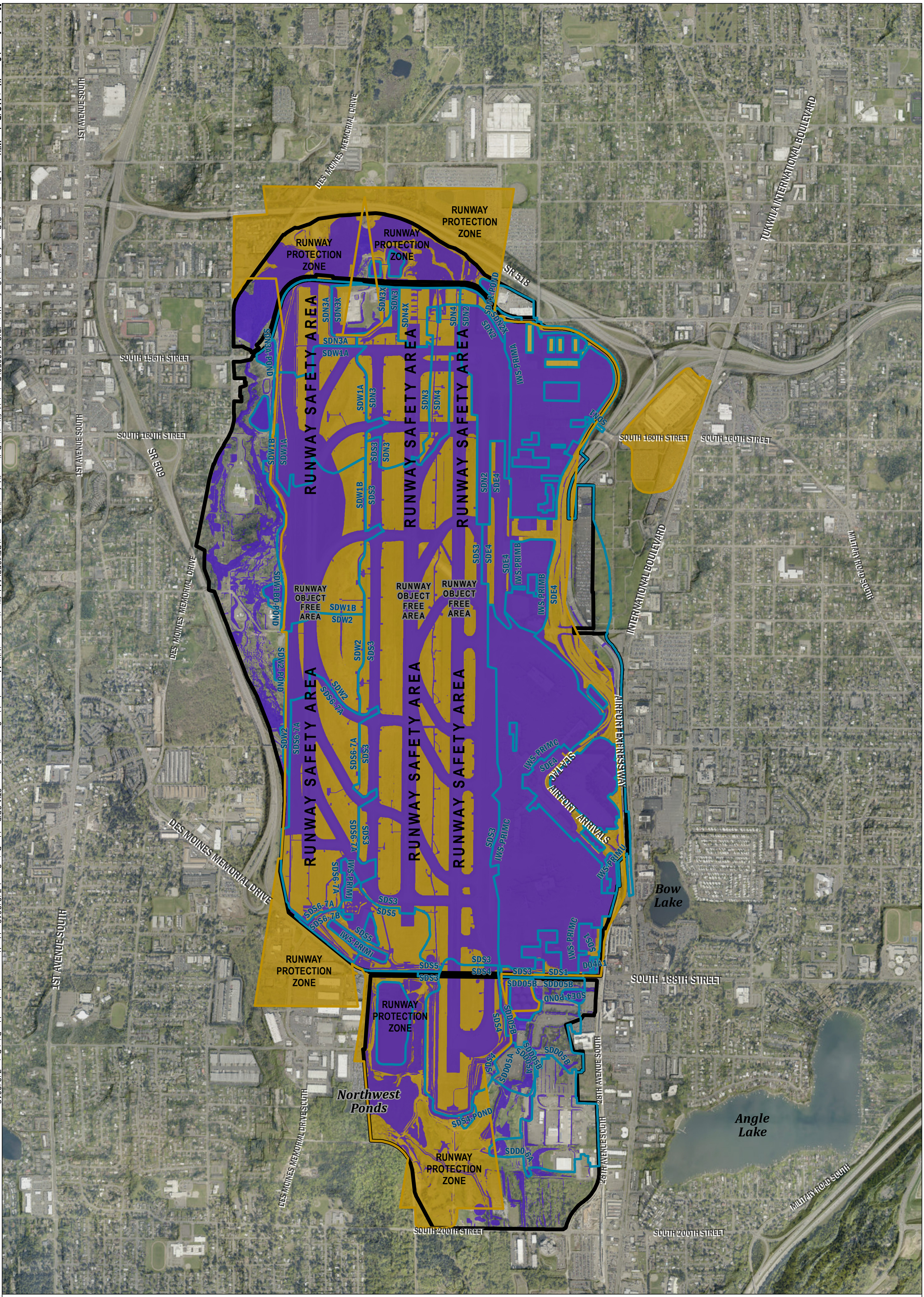
Map by Aspect Consulting, LLC (Parker Wittman): F:\projects_8\Port_of_Seattle\SurfaceWater\DIQ_150050\Projects\Infiltration\Delivered\InfeasibilityReport\REVISED_11 Infiltration Infeasibility Map.mxd || Coordinate System: STIA GRID || Date Saved: 7/3/2018 || User: ecrumbaker || Print Date: 7/3/2018



Infeasible for Infiltration

Less Feasible Areas for Infiltration:
- Airport Operations Area
- FAA-Regulated Areas
- Areas of Historical Industrial Activity

Storm Drainage Subbasin

Project Extent

N

0 750 1,500

Feet

FIGURE 1

Shallow Infiltration Infeasibility Map

Seattle Tacoma International Airport Infiltration Infeasibility Assessment

MAP BY: Aspect CONSULTING

ROBIN KIRSCHBAUM, INC. water planning engineering

Port of Seattle

Attachment 1

Shallow Infiltration

Gantt Chart Schedule

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Attachment 1 - Example Shallow Infiltration Schedule (Steps 1 through 4)

	Month	1				2				3				4				5				6				7				8				9				10			
TASK	Approximate Duration	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Preliminary - *Verify site is not mapped as infeasible for shallow infiltration by the Port. Early coordination with Port.*																																									
Step 1: Select Preliminary Locations for Shallow Infiltration BMPs, Initial Site Investigations, GW Monitoring																																									
Task 1.1: Gather/review existing data, initial utility locates, assess data needs, prepare initial field work plan.	0.5 month																																								
Task 1.2: Site survey, initial geotechnical/hydrogeologic site characterization, install monitoring wells.	1.5 month																																								
Task 1.3: Analyze initial geotech./hydrogeo. data, estimate key parameters and potential infiltration rates.	0.5 month																																								
Task 1.4: Prepare conceptual site layout (grading, buildings, parking, stormwater facilities, etc.).	2 months																																								
Task 1.5: Continue groundwater level monitoring through at least one wet season as needed.	6 months																																								
Step 2: Estimate Stormwater Runoff from the Project, Hydrologic Modeling																																									
Task 2.1: Estimate the continuous hydrograph and volume of stormwater runoff using a continuous runoff model.	1 month																																								
Task 2.2: Estimate the peak flow rate to be infiltrated in each infiltration area in order to meet standards.	0.5 month																																								
Step 3: Develop Trial Shallow Infiltration Facility Details, Sizes, and Depths																																									
Task 3.1: Develop assumed infiltration BMP details and depths based on preliminary conditions and flowrates.	0.5 month																																								
Task 3.2: Refine preliminary infiltration BMPs using assumed infiltration rates, hydrology, and a safety factors.	0.5 month																																								
Task 3.3: Preliminarily verify other Site Suitability Criteria appear to be met.	0.25 month																																								
Task 3.4: Preliminarily verify UIC Site Suitability Criteria appear to be met for infilt trenches.	0.25 month																																								
Step 4: Complete Detailed Site Characterization and Shallow Infiltration Testing																																									
Task 4.1: Identify number/locations for geotechnical, hydrogeologic, and infiltration tests. Prepare field plan.	1.5 months																																								
Task 4.2: Contract with excavation service, excavate infiltration test pits, log soils.	1.5 months																																								
Task 4.3: Complete geotech. investigation (borings, soil logs, GW depth, CEC, %OM, etc.), aquifer tests, 12 PITs.	0.5 month																																								

Attachment 1 - Example Shallow Infiltration Schedule (Steps 5 through 7)

	Month	11				12				13				14				15				16				17				18				19				20			
TASK	Approximate Duration	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Step 5: Determine Aquifer Properties & Treatment Capacity and Design Infiltration Rates of the Receptor Unit																																									
Task 5.1: Review soil borings & grain size data to verify the suitability, depth, and continuity of the receptor soil.	0.5 month	■	■																																						
Task 5.2: Review measured infiltration rates, apply safety factors, determine design infiltration rates.	0.25 month		■																																						
Task 5.3: Review receptor unit CEC and %OM to determine treatability and need for soil amendments.	0.25 month		■																																						
Task 5.4: Review aquifer test data, determine key aquifer properties.	0.5 month			■	■																																				
Step 6: Complete Groundwater Impact and Mounding Analysis																																									
Task 6.1: Review aquifer and receptor soil data, proposed infiltration BMP info., and set-up groundwater model.	1 month					■	■	■	■																																
Task 6.2: Derive wet-year infiltration hydrographs for each infiltration area and BMP. Document sources of data.	0.5 month							■	■																																
Task 6.3: Run groundwater mounding model for wet years, estimate mound.	0.5 month									■	■																														
Task 6.4: Respond to mounding results as needed - change spacing, depths, size, flow, number of shallow infilt. BMPs.	0.5 month											■	■																												
Task 6.5: Update/repeat GW modeling as needed during Step 7 (sizing shallow infiltration BMPs).	1 month													■	■	■	■																								
Step 7: Size and Design Shallow Infiltration Facilities for Performance Standards, Initial UIC Registration (if needed)																																									
Task 7.1: Update hydrology, site plan, treatment BMPs, and infiltration BMP layouts based on prior steps.	1 month													■	■	■	■																								
Task 7.2: Coordinate across design disciplines and prepare infiltration BMP plans, details, specifications, cost estimates.	4 months																			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Task 7.3: Register any shallow UIC BMPs designs with Ecology's Underground Injection Control Program.	0.25 month																							■																	
Task 7.4: Prepare infiltration permitting documents (integrate in geotech. report/stormwater submittal docs.).	2 month																			■	■	■	■	■	■	■	■														
Task 7.5: Support stormwater permitting process, obtain approval for construction.	2 months																											■	■	■	■	■	■	■	■						

Notes

1. Refer to Section 2 of the SOP for Shallow Infiltration Testing and Analysis, Appendix C of the Port of Seattle STIA LID Guideline for example project assumptions

Attachment 2

Example Shallow Infiltration Budget

Attachment 2

Example Shallow Stormwater Infiltration Planning, Testing, Analysis, and Design Budget Summary

This table provides an example cost estimate (2019 dollars) to complete shallow infiltration planning, testing, analysis, and design for a larger and more complex site, typical of significant Port/STIA development projects.

Task Title	Labor[1]	ODC[2]	Subs[3]	Total
Step 1: Select Preliminary Locations for Shallow Infiltration Facilities, Complete Initial Site Investigation, Groundwater Monitoring	$40,217	$2,100	$20,000	$62,317
Step 2: Estimate Stormwater Runoff from the Project, Hydrologic Modeling	$7,950			$7,950
Step 3: Develop Trial Shallow Infiltration Facility Details, Sizes, and Depths	$9,016			$9,016
Step 4: Complete Detailed Site Characterization and Shallow Infiltration Testing	$47,180	$4,000	$35,000	$86,180
Step 5: Determine Aquifer Properties & Treatment Capacity and Design Infiltration Rates of the Receptor Unit	$13,097			$13,097
Step 6: Complete Groundwater Impact and Mounding Analysis	$28,269			$28,269
Step 7: Size and Design Shallow Infiltration Facilities for Performance Standards, Initial UIC Registration	$35,795			$35,795
Total Project Budget	**$181,524**	**$6,100**	**$55,000**	**$242,624**

[1]Labor includes shallow infiltration related consultant staff costs at a firm providing services in: (a) stormwater engineering and infiltration; (b) geotechnical
engineering, and (c) hydrogeology. Labor for overall site drainage and non-infiltration BMP design is not included.

[2]ODCs (Other Direct Costs) includes cost items such as monitoring and testing instrumentation and equipment, and travel costs.

[3]Subs (subconsultants) include contracted surveyor, driller, and excavation costs.

Notes

1. Refer to Section 2 of the SOP for Shallow Infiltration Testing and Analysis, Appendix C of the Port of Seattle STIA LID Guideline for example project assumptions

Attachment 3
Shallow Infiltration
Review Checklist

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Shallow Infiltration Planning, Testing, Analysis and Design Review Checklist

This checklist is provided by the Port to help Project Managers track and complete required deep infiltration related analyses and designs as well as provide guidance for the content of deep infiltration permit review submittals. Initial each row and sign and submit the form when complete.

Section 1 – Shallow Infiltration Site Suitability, Layout, and Treatment Requirements		
	1.1	Proposed shallow infiltration area has not been mapped as Infeasible by the Port.
	1.2	Proposed infiltration flows do not include prohibited discharges.
	1.3	Seasonal high groundwater at each infiltration area has been determined.
	1.4	Site meets key infiltration suitability criteria (landslide, steep slopes, horizontal set-backs, contamination)
	1.5	Stormwater site plan shows the location of all shallow infiltration BMPs and preceding BMPs.
	1.6	Compliance with Underground Injection Control (UIC) treatment requirements is documented (if needed).
	1.7	Preceding BMPs include a minimum of pre-settling for the water quality flowrate or volume.
	1.8	Preceding BMPs include a settling BMP for infiltrating flows in excess of the water quality flowrate or volume.
	1.9	Documentation is provided that all preceding BMPs comply with the Ports SWMM and LID Guideline.
	1.10	Peak infiltration flowrates for each shallow infiltration BMP are documented.
	1.11	Peak infiltration flowrates for each shallow infiltration BMP have been determined using an acceptable model.
	1.12	Adequate soil borings have been conducted to illustrate the depth and extent of the proposed receptor soil.
	1.13	Adequate soil borings have been conducted to illustrate the depth and extent of the underlying aquifer.
	1.14	Receptor soil grain size distribution data and classifications support the use of infiltration.
	1.15	Grain size distribution data has been provided for the aquifer underlying the receptor soil.
	1.16	Receptor soil Cation Exchange Capacity and Percent Organic Matter data have been provided.
	1.17	Soil borings do not indicate the presence of low permeability layers between the receptor soil and aquifer.
	1.18	The separation between high groundwater and the bottom of all shallow infiltration BMPs is documented.
	1.19	Groundwater separation and BMP service area trigger a mounding analysis - **Complete Section 4.**
Section 2 – Shallow Infiltration Testing and Analysis		
	2.1	The shallow infiltration testing plan follows Port SOPs and was reviewed and approved by the Port.
	2.2	Shallow infiltration testing method, results, and analyses are properly documented and certified.
	2.3	The Port approved number and locations of shallow infiltration testing have been conducted.
	2.4	Evidence of groundwater mounding was not observed in over excavation following infiltration testing.
	2.5	Water depths used for during infiltration testing do not exceed planned BMP water depths.
	2.6	Measured infiltration rate for each infiltration area is greater than 0.3 in/hr.
	2.7	The measured infiltration rate of the receptor soil is provided for each infiltration test.
	2.8	Design infiltration rates of the receptor soil were calculated using an appropriate safety factor.
Section 3 – Shallow Infiltration BMP Design and Specifications		
	3.1	Certified shallow infiltration construction plans and specifications are included with a narrative design report.

	3.2 When needed, shallow infiltration BMP spacing, depths, and flowrates account for mounding analysis results.
	3.3 Specifications are provided for all infiltration BMP components (inlets, overflows, embankments, soil mix, etc.).
	3.4 The design flowrate for each full-scale BMP assumes water depths allowed by the Port's LID Guideline.
	3.5 A functional high flow bypass system is used to accommodate flows in excess of design infiltration flowrates.
	3.6 Plans and specifications include protection from construction sediments and system cleaning prior to service.
	3.7 Specifications include post-construction performance testing, and approval by the Port (if needed).
	3.8 Any shallow UIC BMP designs have been registered with Ecology's UIC Program.
	3.9 Specifications require update of UIC registrations as needed based on as-constructed data prior to activating.
	3.10 Proper shallow infiltration system O&M procedures are included in the project's stormwater O&M Plan.
Section 4 – Groundwater Mounding Analyses (when required)	
	4.1 Mounding analysis and results are properly documented and certified.
	4.2 Groundwater model software and version is listed.
	4.3 Aquifer test methods, data, analysis, and results are provided.
	4.4 Sources/assumptions of aquifer properties (Ksat/Transmissivity, porosity, etc.) are identified.
	4.5 Wet-year infiltration hydrographs have been properly derived and documented.
	4.6 Analytical groundwater model matches the full-scale infiltration system and simultaneous operation.
	4.7 Mounding modeling results and recommendations for shallow infiltration BMPs are discussed.
	4.8 Groundwater mound does not reach the bottom of shallow infiltration BMPs under full scale operation.
	4.9 Groundwater mound does not impact adjacent or off-site structures/infrastructure, slopes, etc.
	4.10 Groundwater mound is not predicted to create or increase seeps or springs.

____

Project Manager or Licensed Professional Signature:

____ ______________________

Port Reviewer Signature: Acceptance Date: