**City of Seattle**
Seattle Public Utilities

October 6, 2014

Municipal Permit Comments
Washington State Department of Ecology
PO Box 47600
Olympia, WA 98504-7600

Re: NPDES Phase I Municipal Stormwater Permit and Stormwater Management Manual for Western Washington

Thank you for the opportunity to provide comments on the Draft NPDES Phase I Municipal Stormwater Permit, Stormwater Management Manual for Western Washington (SWMMWW), and Draft Definition Guidance (8.14.14). Attached are Seattle's comments in the comment template provided. In addition, we have included one document in support of our SWMMWW comments. We hope our comments and suggestions will be helpful in finalizing the permit modification.

Please feel free to contact Kate Rhoads, of my staff, if you have any questions regarding this letter. Kate is the lead for the Municipal Stormwater Permit for the City of Seattle and can be reached at (206) 684-8298 or at kate.rhoads@seattle.gov.

Sincerely,

Nancy Ahern

Nancy Ahern, Director
Utility System Management Branch
Seattle Public Utilities

Attachments

cc: Helge Ferchert, SPU
Julie Crittenden, SPU
Ingrid Wertz, SPU
Kate Rhoads, SPU
Sherell Ehlers, SPU
Cris Horbelt, SPU
Tracy Tackett, SPU
Theresa Wagner, Seattle City Attorney's Office

Ray Hoffman, Director
Seattle Public Utilities
700 5th Avenue, Suite 4900
PO Box 34018
Seattle, WA 98124-4018

Tel (206) 684-5851
Fax (206) 684-4631
TDD (206) 233-7241
ray.hoffman@seattle.gov


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| Phase I & WWA Phase II Modification Comments | | | |
|---|---|---|---|
| **Permit** | **Section** | **Page** | **Comment** |
| Phase I | S5.C.5.a.iii | 17/77 | Make the date to apply the code requirements consistent with the effective date of the code, which is June 30, 2015.<br><br>"The local program adopted to meet the requirements of S5.C.5.a.i through ii shall apply to applications submitted <<on or>> after June 30, 2015 and shall apply to applications submitted <<prior to ~~no later than~~>> June 30, 2015, which have not started construction <<prior to>> ~~by~~ June 30, 2020." |
| Phase I | S5.C.5.b | 19/77 | This section already provides that the deadline is changed when an alternative date is established by S5.C.5.a.iii. To add clarity, insert "automatically or otherwise" as follows:<br><br>"No later than ~~July 1~~ June 30, 2015, or by an alternative date if established <<automatically or otherwise>> in accordance with S5.C.5.a.iii. |
| Both | Def'n: "Discharge Point" | Ph.I: 71-77; App.1, 3/55 | Stormwater facilities/BMPs, and conveyances, that inadvertently infiltrate such as ditches and swales should not be considered "discharge points" and should be excluded in each definition and explanation in the Permit, Statement of Basis and Definitions Guidance. Inclusion is not mandated by federal or state law, and as Ecology points out, Ecology did not intend permittees to map features or areas that provide inadvertent infiltration as discharge points. Specifically excluding these features would resolvethe problen Ecology identified. An example of the necessary edits for each "discharge point" definition:<br><br>"... 'Discharge point' also includes the location where a discharge leaves the permittee's MS4 and discharges to ground, except <<for stormwater facilities/BMPs, or conveyances, that inadvertently infiltrate such as ditches and swales or>> where such a discharge occurs via an outfall." |
| Both | Statement of Basis | 10 | Edits to support previous comment regarding "discharge point." "For discharge points to ground:<br>- <<~~Includes~~ Excludes>> facilities/BMPs <<, and conveyances,>> that inadvertently infiltrate such as ditches and swales*<br>- Includes stormwater conveyances that have no outlet, such as dispersion BMPs."<br><br>"*Please Note: The settlement language that resulted from the appeal process (provided above) <<~~includes~~excludes>> "inadvertent infiltration through ditches or swales" as a type of discharge point. <<~~This language assumes that any unlined ditch or swale used for conveyance may have incidental infiltration, and creates an inherent conflict as swales are commonly designed to infiltrate and may need to be mapped as an outfall.~~>> "<br><br>"<<~~Within the context of the Permit, the settlement language would require all ditches and swales to be mapped as discharge points.~~ >> Many, if not all, permittees have established mapping programs. It is not Ecology's intent to require permittees to map inadvertent infiltration, such as ditches, as a discharge point or to review previously mapped features and require these to be re-labeled as discharge points according to the new definition (although this may be helpful for permittees and their programs to do so)." |

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| Both | Definition Guidance | 6 | More edits to support previous comment regarding "discharge point." "For discharge points to ground:<br>- <<~~Includes~~ Excludes>> facilities/BMPs <<and conveyances>> that inadvertently infiltrate, such as ditches and swales.<br>- Includes stormwater conveyances that have no outlet, such as dispersion BMPs.<br>Issues to keep in mind:<br>MS4 MAPPING- According to the language developed through the settlement of the western Washington Phase II Permit appeal, all known discharge points must be mapped according to the requirements of the Permits. The definition for outfall contained in the permits issued August 1, 2012 and effective August 1, 2013 captured all points where discharges occur from one MS4 to surface water, ground waters, other MS4s, and private or unregulated stormwater infrastructure. As such, the requirement to map outfalls is modified to reference outfalls and discharge points under the proposed new definitions. <<~~Strict application of the agreed upon settlement language results in a requirement to map locations of inadvertent infiltration (such as ditches) as discharge points.~~ >><br>It is not Ecology's intent to require permittees to map features or areas that provide inadvertent infiltration as discharge points. Nor is it Ecology's intent that Permittees must re-label previously mapped outfalls as discharge points according to the new definition, although this may be helpful for permittees' programs. Ecology welcomes comments on these implementation issues during the public comment period for the permit modification. " |
| Both | Definition Guidance | | Delete all language characterizing stormwater as a "water of the state" for NPDES permit purposes. These statements are unnecessary to the permit modification and are inaccurate and misleading. They misconstrue state water pollution control law, including but not limited to RCW 90.48.020, are inconsistent with federal law, and exceed the scope and substance of the Phase II settlement agreement. Seattle is available to discuss this comment with Ecology and its legal counsel. |
| | | 1; Background, paragraph 3 | "~~There are two important aspects of the definition of *waters of the state* that affect the terms and conditions in the Washington State Municipal Stormwater Permits:~~" |
| | | 1; Background, #2 | "~~2. Waters of the state include stormwater, such as that found within municipal stormwater systems.~~" |
| | | 2; Background, 1st paragraph | "~~, not in a *water of the state* , which would include the stormwater itself~~" |
| | | 2; Background, 3rd bullet | "<<~~The definition of outfall used in the permits cannot be based entirely on the federal definition of outfall, which relies heavily on use of waters of the US. If an outfall were defined solely by its discharge to *waters of the state* , any point in a municipal stormwater conveyance could be considered an outfall because stormwater in one pipe is being discharged to stormwater in another pipe (and stormwater is considered a *water of the state* ). >>~~" |
| | | 2; Background, 4th bullet | "The definition of receiving water, or receiving water body, must appropriately include *waters of the US* and some<<~~, but not all,>>~~ *waters of the state* .<br><<~~Because stormwater itself is a *water of the state* , t~~T>> he permits' definition of receiving water is intended to exclude stormwater within system conveyances, facilities and BMPs." |

| Permit | Section | Page | Comment |
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| Both | Definition Guidance | 5 or elsewhere | Add text consistent with the former definition of "receiving water" to clarify that while groundwater may be a receiving water for a facility/BMP that is designed to infiltrate, questions of fact will remain regarding whether or not there is a receiving water and what receiving water is involved. To add at p. 5 or elsewhere in the Definitions Guidance: "• Groundwater <<~~is~~ may be>> a receiving water body where a facility/BMP is designed to infiltrate. <<In each case, there are questions of fact as to whether or not flow from an infiltrating facility/BMP to ground reaches any receiving water and which receiving water is involved.>>" |

**WWA Stormwater Manual Modification Comments**

| Volume | Section | Page | Comment |
|---|---|---|---|
| III | 2.3.2 | 2-13 | Seattle agrees with Ecology's footnote to Table 2.3.1 to allow soils with a measured rate less than 0.3 inches per hour to be modeled as Class C, but this is contrary to what is included in the definitions of the soil classes in Ecology's text associated with the table above and may be confusing to the user. Suggest deleting the infiltration rates from the soil class definitions, or explaining the inconsistency. |
| III | 3.1.2 | 3-11 | Seattle disagrees with the modeling parameters prescribed to this BMP. A dispersion trench that is a minimum of 10 feet wide with a minimum 25 foot flow path should get the same credit as a splash block that is a minimum 2-3 foot wide and a minimum of 50 feet long (i.e. both modeled as landscape). |
| III | 3.4.2 | 3-107 | Seattle recommends not requiring a small-scale PIT when permeable pavement receives only what falls directly on it, as this is like rain falling on grass. Seattle recommends adding in the following sentence to the "Field Testing Requirements based on Project Size" section:<br><br>"<<When permeable pavement infiltrates only direct rainfall, and does not receive significant run-on from adjacent areas, an infiltration test is not required if only using MR#5 List Approach.>>" |
| III | C.2.3 | C-3 & 4 | The modeling requirements are unclear as changed in this section. Provide clarity as to when scenarios apply. Also, Seattle does not agree with this change as Seattle commented for Volume III, p. 3-11. |
| III | C.10.1 | Pgs. C-6 & C-7, and Vol. V, p. 7-20 | Seattle disagrees with the inconsistent use of BSM infiltration rates for modeling stormwater performance for water quality and flow control facilities. Seattle recommends prescribing the 6"/hr rate for all BSM applications as discussed in Seattle's comment for Vol. V, Section 7, p7-12. If there are concerns regarding fouling, pre-settling should address this concern for water quality treatment.<br><br>Additionally, the language added is inconsistent with "Determining Bioretention soil mix infiltration rate:" section in Vol. V, Section 7, p7-12. |
| III | C.10.1 | C-6 & 7 | Seattle disagrees with the inconsistent use of BSM infiltration rates for modeling stormwater performance for water quality and flow control facilities. Seattle recommends prescribing the 6"/hr rate for all BSM applications as discussed in Seattle's comment for Vol. V, Section 7, p7-12. If there are concerns regarding fouling, pre-settling should address this concern for water quality treatment.<br><br>Additionally, the language added is inconsistent with "Determining Bioretention soil mix infiltration rate:" section in Vol. V, Section 7, p7-12. |
| III | Part 2 | C-12 | Seattle disagrees with the modeling parameters prescribed to this BMP. A gravel trench that is a minimum of 10 feet wide with a minimum 25 foot flow path should get the same credit as a splash block that is a minimum 2-3 foot wide and a minimum of 50 feet long (i.e. both modeled as landscape). |
| V | Various | Various | "Underdrain" and "under-drain" are both used throughout the manual. Please make consistent so it is easier to find text. |
| V | 5.3.1 | 5-4 | Seattle disagrees with the modeling parameters prescribed to this BMP. A dispersion trench that is a minimum of 10 feet wide with a minimum 25 foot flow path should get the same credit as a splash block that is a minimum 2-3 foot wide and a minimum of 50 feet long (i.e. both modeled as landscape). |
| V | 5.3.1 | 5-7 | Seattle disagrees with the modeling parameters prescribed to this BMP. A dispersion trench that is a minimum of 10 feet wide with a minimum 25 foot flow path should get the same credit as a splash block that is a minimum 2-3 foot wide and a minimum of 50 feet long (i.e. both modeled as landscape). |

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| V | 7.4 | 7-12 | Seattle generally supports Ecology's revision to the bioretention soils mix (BSM) infiltration rate when using BSM provided in the Ecology Manual, but requests Ecology change Option 1 based upon one of the following two edits:<br><br>A. "Option 1: If using the Bioretention Soil Mix recommended herein, the WWHM assumes a default infiltration rate of 6 inches per hour (15.24 cm/hr) <<which includes a factor of safety. Therefore, if selecting Option 1, use "none" as the infiltration rate Ksat safety factor.>>", OR<br><br>B. "Option 1: If using the Bioretention Soil Mix recommended herein, the ~~WWHM assumes~~ use a default infiltration rate of ~~6~~ 12 inches per hour (<<~~15.24~~>> <<30.48>> cm/hr).<< Use 2 as the infiltration rate Ksat safety factor>>."<br><br>For Ecology's proposed 2014 language, the long term design rate for Option #1 did not actually change. Later in the same section, safety factor adjustments are required such that the long term design rate required are the overly conservative values provided previously in the 2012 manual. Those safety factors are inappropriate to be applied to Option #1. Based on observed performance from BSM mesocosm data and monitoring of full scale planted bioretention facilities, the 6"/hr infiltration rate already includes a safety factor adjustment consistent with Ecology's recommendations for safety factors. See attached memo that supports a long term design infiltration rate of 6"/hr for Option #1 (Ecology's BSM spec). |
| V | 7.4 | 7-12 | Based upon Seattle's comment regarding Option 1 of "Determing Bioretention soil mix infilatration rate" (Vol. V, Section 7, p. 7-12) and for the same reasons, Seattle also requests the following change:<br><br>"<<~~After~~>><<If >>selecting option <<~~1 or~~>> 2 above, determine the appropriate safety factor for the saturated hydraulic conductivity (Ksat) <<based upon the contributing areas noted below>>. If the contributing area of the bioretention cell or swale is equal to or exceeds any of the following limitations:" |
| V | 7.4 | 7-6, 7-19 | Seattle does not support Ecology's edits that remove the use of underdrains for bioretention from the practices credited toward MR#5. This is a substantive change to MR#5. Seattle strongly requests keeping the original 2012 SWMMWW language allowing an elevated underdrain for use in bioretention when meeting MR#5, especially for soils with measured infiltration rates greater than or equal to 0.3 inches per hour and less than 0.6 inches per hour (unless other feasibility restrictions apply).<br><br>Systems with elevated underdrains are an important tool in the toolbox due to the stormwater volume reductions that can occur from these systems combined with their applicability in urban environments when other approaches are not feasible. When the risk of a system without an underdrain are too high (due to considerations such as: horizontal water migration along utility corridors and associated unintended consequences; not meeting drawdown requirements), significant stormwater value can still be achieved by using a system with an elevated underdrain.<br><br>Systems with an underdrain have the potential for substantial flow volume reduction. As stated by Ecology (Volume V, p 7-9) "If the underdrain is elevated within a base course of gravel, the bioretention facility will also provide some modest flow reduction benefit." Seattle's experience indicates moderate to high flow reduction and attenuation benefit of bioretention systems with elevated underdrains. Seattle has monitored two bioretention projects with elevated underdrains, High Point and Ballard Roadside Raingardens Phase 1, and found significant average annual volume reduction from these systems. The same flow reduction and attenuation benefits have been documented in Redmond, where lined and underdrained bioretention systems were monitored for flow and treatment per TAP-E. Most recent monitoring of cells within the Ballard Phase 1 project that were retrofitted to add an underdrain (after it became apparent that native soils could not infiltrate the volume of stormwater entering the system quickly enough to meet drawdown requirements) estimates 50% average annual volume loss from those cells in 2012-2013 and up to 89% average annual volume loss in 2013-2014. |

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| V | 7.4 | 7-6 | Based upon Seattle's comment regarding underdrains, bioretention facilities, and MR#5, Seattle requests the following change to remove the exclusion of bioretention with an elevated underdrain from meeting MR#5:<br><br>"Bioretention facilities that infiltrate into the ground can also serve a significant flow reduction function. They can, but are not required to fully meet the flow control duration standard of Minimum Requirement #7. Because they typically do not have an orifice restricting overflow or underflow discharge rates, they typically don't fully meet Minimum Requirement #7. However, their performance contributes to meeting the standard, and that can result in much smaller flow control facilities at the bottom of the project site. When used in combination with other low impact development techniques, ~~<<and not underdrained, >>~~they can also help achieve compliance with the Performance Standard option of Minimum Requirement #5." |
| V | 7.4 | 7-19 | Based upon Seattle's comment regarding underdrains, bioretention facilities, and MR#5, Seattle requests the following change to remove the exclusion of bioretention with an elevated underdrain from meeting MR#5:<br><br>"~~<<Note that if an underdrain is used in a bioretention facility design, the bioretention facility is no longer considered an LID BMP and cannot be used to satisfy Minimum Requirement #5. However, a bioretention facility with an underdrain may still be used to satisfy Minimum Requirement #6 (Runoff Treatment). If the underdrain is elevated within a base course of gravel, the bioretention facility will also provide some modest flow reduction benefit that will help achieve Minimum Requirement #7 (Flow Control).>>~~" |
| V | 7.4 | 7-20 | Seattle disagrees with the inconsistent use of BSM infiltration rates for modeling stormwater performance for water quality and flow control facilities. Seattle recommends prescribing the 6"/hr rate for all BSM applications as discussed in Seattle's comment for Vol. V, Section 7, p7-12. If there are concerns regarding fouling, pre-settling should address this concern for water quality treatment.<br><br>Additionally, the language added is inconsistent with "Determining Bioretention soil mix infiltration rate:" section in Vol. V, Section 7, p7-12. |

**MEMORANDUM**

**DATE:** October 5, 2014 (based on original memo dated September 20, 2013)

**FROM:** Curtis Hinman, Brian Busiek, PE, and John Lenth; Herrera
(original author, Kathryn Gwilym, PE; SvR Design Company)

**TO:** Shanti Colwell, SPU

**CC:** Tracy Tackett, SPU
John Phillips, WTD

**RE:** **Long Term City of Seattle Bioretention Soil Mix Design Infiltration Rate Assumption for Modeling**
**GSI Program TASK #2-4f, SvR # 12034**

This memorandum documents our review and recommendations for the long-term design infiltration rate to be used when sizing bioretention systems in the City of Seattle (Seattle) for water quality treatment, flow control, and/or flow mitigation for reducing combined sewer overflows. Per the Seattle Bioretention Soil Standard Specification 7-21, the default bioretention soil mix (BSM) used in these systems generally consists of a mixture of 60% sand and 40% compost (60/40 soil mix). Guidance in the *2012 Stormwater Management Manual for Western Washington* (SWMMWW) for sizing systems with the 60/40 mix currently recommends using a default initial infiltration rate of 6 inches per hour (in/hr) and safety factors of 2 or 4 depending on the contributing area. The design infiltration rates after applying the safety factors are then 3 to 1.5 in/hr, respectively. Based on compiled data from regional research and best professional judgment, we believe the initial and corrected infiltration rates are likely too conservative and may result in oversized facilities.

Table 1 summarizes measured infiltration rates from ten in-situ field tests that were conducted in the region on bioretention systems which incorporate different soil mixtures of sand and compost. The sand and compost used in these mixtures generally met Washington State Department of Ecology (Ecology) or Seattle specifications for these components. Mean infiltration rates across the individual tests ranged from 11.8 to 45.1 in/hr with an overall mean of 26.9 in/hr. The lowest single infiltration measurement of 3.8 in/hr was recorded by the City of Redmond (Herrera 2014) and the highest single measurement of 100.8 in/hr was recorded by Seattle Public Utilities (SPU) at a High Point roadside bioretention cell.

Results from laboratory tests on soil mixtures comprised of sand and compost are also provided in Table 1. Although results from the regionally accepted lab permeability test (ASTM D2434) have not been correlated to actual in-situ test results, they do provide an important point of comparison. For example, measured infiltration rates from lab testing performed by SPU on the 60/40 soil mix ranged from 5 to 22 in/hr with compaction between 84% and 85% (Aspect 2012). The mean hydraulic conductivity from laboratory tests (ASTM D2434) performed by the City of Redmond on the same soil mix ranged from 15.2 in/hr with compaction and 78.4 in/hr without compaction (Aspect 2014). See below for descriptions of methods used for the in-situ infiltration tests.

In addition to the data presented above, the following observations support the use of a higher default design infiltration rate for sizing bioretention facilities in Seattle:

- Studies show infiltration rates are maintained over time and may actually increase due to root growth and bioturbation within the soil column (Ralston 2004; Culbertson and Hutchinson 2004), while still maintaining water quality properties at the higher rates.

- Falling head tests conducted by Washington State University from 2011 to 2013 on the 60/40 soil mix in mesocosms (using the current aggregate particle size distribution in the 2012 SWMMWW) showed saturated hydraulic conductivity increased from a mean of 28.8 in/hr in 2011 to 45.1 in/hr in 2013. The rate most likely increased due to root growth of the plantings (Hinman 2012). See Figure 1 for a plot of average hydraulic conductivity measured over time and Table 1 for field and lab infiltration and permeability test results.

- The mean infiltration rate of 11.8 in/hr for the 60/40 mix that was measured by the City of Redmond using in-situ field testing was for a newly installed system.

- SPU measured a field infiltration rate of 14 in/hr in planted bioretention facilities in Ballard using the 60/40 soil mix.

- Recent infiltration tests at Barton and High Point roadside bioretention cells (west Seattle) measured infiltration rates of 20.2 in/hr and 100.8 in/hr, respectively. High Point bioretention cells are approximately 8 years old.

If a designer uses a lower infiltration rate for sizing bioretention facilities than what has been typically observed in the field, the following adverse consequences may result:

- More facilities may be required than necessary resulting in additional capital and maintenance costs.

- The amount of bypass flow (flow that does not pass through the bioretention soil media but continues to flow downstream) may be overestimated resulting in unnecessary improvements to overflow drainage structures or oversizing of an underground detention facility.

Based on these considerations, we believe use of the lowest mean value of 12 in/hr from the in-situ field tests (rounded from 11.8 in/hr) provides a rational and conservative initial infiltration rate. Seattle bioretention design guidelines include use of pre-settling for all bioretention systems with contributing areas greater than 5,000 square feet. With this design safeguard in place, a blanket safety factor of 2 is likely adequate. For regional application where pre-settling is not required, the current safety factor guideline of 2 and 4 depending on contributing area size is appropriate.

Accordingly, we recommend that when sizing bioretention systems in Seattle with the 60/40 soil mix, the modeling design infiltration parameter for the long-term design infiltration rate (i.e., the rate entered into the model after the application of safety factors) should be set at 6 in/hr. These recommendations are based on the assumption that the bioretention system has been designed properly, i.e., pre-settling is sized according to the tributary area draining to the facility and the frequency of routine operations and maintenance activities are adhered to in order to ensure that sediment build-up is addressed (such as SPU Level of Service C or greater).

We would also recommend that this rate only be applied to modeling of the bioretention system and that other considerations and design guidance should be considered for sizing downstream facilities (e.g., underdrains, UIC wells, detention facilities) and conducting other hydrogeologic analyses. For example, mounding or slope stability analysis should follow the guidance within Seattle's draft stormwater manual and not be based on the bioretention soil design infiltration rate described herein.

Finally, based on the similarity in results from the infiltration tests performed on systems with aggregates that meet Ecology's and Seattle's respective specifications (Table 1), we do not recommend that Seattle modify their specification with one exception. The Seattle gradation does not include a #100 sieve criteria which can significantly influence permeability; accordingly, we recommend adding 4 to 10 percent passing the #100 sieve to Seattle's size gradation requirements. This recommendation is based on project experience and discussions with suppliers that suggest the requirements for meeting a tighter specification may result in increased costs given the inherent variability of the aggregate supply. In this situation, meeting a tighter specification may not provide significant benefit given performance seems to be controlled by the aggregate at the bottom end of the size gradation where Ecology's and Seattle's specifications are more closely matched.

*References:*

Aspect Consulting. Recommended Modification of the ASTM D2434 Procedures for Permeability Testing of Bioretention Soils. Draft Memorandum to Shanti Colwell, Seattle Public Utilities, dated January 10, 2012. (Aspect 2012).

Aspect Consulting. Bioretention Soil Permeability Testing. Memorandum to Andy Rheaume, City of Redmond, dated January 28, 2014. (Aspect 2014).

Culbertson, T.A.; Hutchinson, S.L. Assessing Bioretention Cell Function in a Midwest Continental Climate. Presented at the 2004 ASABE Annual International Meeting, Ottawa, Ontario, Canada, August 1-4; American Society of Agricultural and Biological Engineers: St Joseph, Michigan. (Culbertson and Hutchinson 2004).

Herrera. Infiltration Testing Memorandum: City of Redmond Six Bioretention Swales Monitoring. Prepared for the City of Redmond, dated July 29, 2014. (Herrera 2014).

Hinman, Curtis. Power point presentation entitled "2012 LID Research Program Annual Review: Focus on bioretention media, plants and storm water toxicology," and presented at the Washington State University Extension campus in Puyallup, Washington, on August 1, 2012. (Hinman 2012).

Ralston, M. R. (2004) "Fox hallow Stormwater Infiltration Facility" Proc. First National Low Impact Development Conference. College Park, Maryland, September 21-23, 2004. (Ralston 2004).

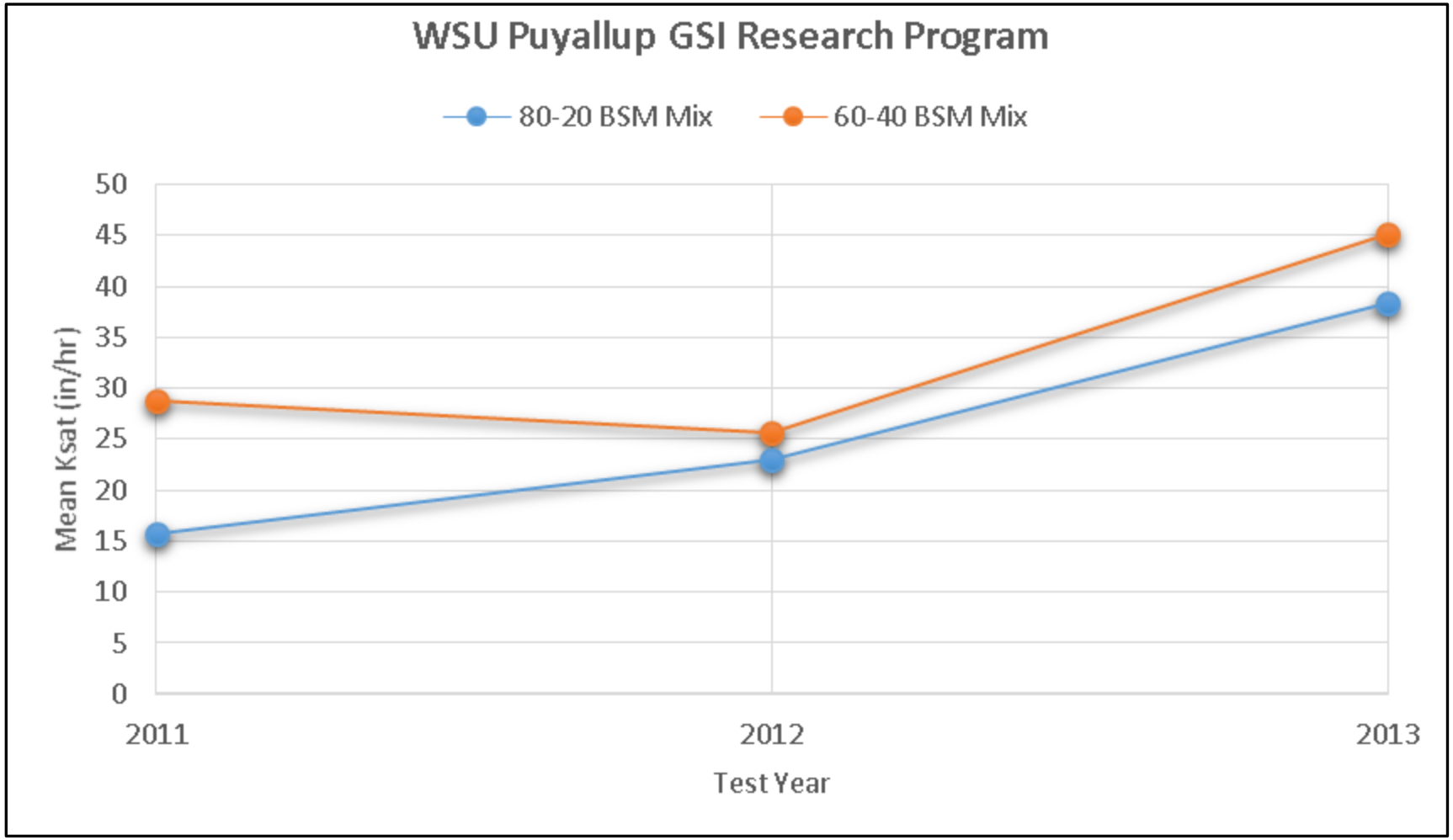
## Table 1: Comparison of Bioretention Soil Mix Measured Infiltration Rates

| Bioretention Soil Mix (BSM) Study | Researcher/ Author | BSM Specification Followed | BSM Composition | | Planted | Test Procedure | Measured Infiltration Rate (Ksat) (in/hr) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sand | Compost | | | Min | Max | Mean | 95% LCL | 95% UCL |
| **IN-SITU FIELD TESTS** [7,8] | | | | | | | | | | | |
| Mesocosms Falling Head Permeability (May-June 2011) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 60% | 40% | Yes | Falling head Ksat in large lysimeters | 21.6 | 33.3 | 28.8 | 25.9 | 31.6 |
| Mesocosms Falling Head Permeability (May-June 2011) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 80% | 20% | Yes | Falling head Ksat in large lysimeters | 5.2 | 27.7 | 15.7 | 6.1 | 25.2 |
| Mesocosms Falling Head Permeability (June 2012) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 60% | 40% | Yes | Falling head Ksat in large lysimeters | 18.2 | 31.2 | 25.7 | 21.3 | 30.2 |
| Mesocosms Falling Head Permeability (June 2012) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 80% | 20% | Yes | Falling head Ksat in large lysimeters | 20.1 | 26.1 | 23.0 | 21.1 | 25.0 |
| Mesocosms Falling Head Permeability (September 2013) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 60% | 40% | Yes | Falling head Ksat in large lysimeters | 42.9 | 48.3 | 45.1 | 43.8 | 46.4 |
| Mesocosms Falling Head Permeability (September 2013) at WSU Puyallup GSI Research Program[1] | Curtis Hinman | Ecology | 80% | 20% | Yes | Falling head Ksat in large lysimeters | 32.9 | 43.0 | 38.3 | 35.7 | 40.9 |
| Ballard Roadside Raingardens Controlled Flow Testing on 30th Avenue NW[2] | SPU | Seattle | 60-65% | 35-40% | Yes | Falling head infiltration | | 14 | NA | NA | NA |
| Barton Roadside Bioretention Swales Full-scale Flood Testing on 7536 34th Avenue SW | SPU | Seattle[6] | 60-65% | 35-40% | Yes | Falling head infiltration | | 20.2 | NA | NA | NA |
| Highpoint Roadside Bioretention Swales Full-scale Flood Testing on 31st and Raymond | SPU | Seattle | 60-65% | 35-40% | Yes | Falling head infiltration | | 100.8 | NA | NA | NA |

| Bioretention Soil Mix (BSM) Study | Researcher/ Author | BSM Specification Followed | BSM Composition | | Planted | Test Procedure | Measured Infiltration Rate (Ksat) (in/hr) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Sand | Compost | | | Min | Max | Mean | 95% LCL | 95% UCL |
| Highpoint Roadside Bioretention Swales Full-scale Flood Testing on 30th Ave SW/SW Graham St | SPU | Seattle | 60-65% | 35-40% | Yes | Falling head infiltration | | 43.2 | | | |
| Redmond Bioretention Soil Permeability Testing – Ecology Mix[3] | Herrera | Ecology | 60% | 40% | Yes | Falling head Infiltration | 3.8 | 16.8 | 11.8 | 6.9 | 16.6 |
| **LABORATORY TESTS** | | | | | | | | | | | |
| Recommended Modification of the ASTM D2434 Procedures for Permeability Testing of Bioretention Soils[4] | Aspect Consulting for SPU | Seattle | 60% | 40% | No | Lab (Constant head – ASTM D2434) | 5 | 22 | NA | NA | NA |
| Redmond Bioretention Soil Permeability Testing – Ecology Mix (compacted)[5] | Aspect Consulting | Ecology | 60% | 40% | No | Lab (Constant head – ASTM D2434) | 14.9 | 15.7 | 15.2 | 15.0 | 15.4 |
| Redmond Bioretention Soil Permeability Testing – Ecology Mix (uncompacted)[5] | Aspect Consulting | Ecology | 60% | 40% | No | Lab (Constant head – ASTM D2434) | 78.0 | 78.9 | 78.4 | 78.2 | 78.7 |

[1] Hinman, Curtis. Power point presentation entitled "2012 LID Research Program Annual Review: Focus on bioretention media, plants and storm water toxicology," and presented at the Washington State University Extension campus in Puyallup, Washington on August 1, 2012. (Hinman 2012).
[2] Seattle Public Utilities. Ballard Roadside Raingardens Phase 1 Hydrologic Monitoring Report September 2012 – May 2013. Report prepared January 2014.
[3] Herrera. Infiltration Testing Memorandum: City of Redmond Six Bioretention Swales Monitoring. Prepared for the City of Redmond, dated July 29, 2014.
[4] Aspect Consulting. Recommended Modification of the ASTM D2434 Procedures for Permeability Testing of Bioretention Soils. Memorandum to Shanti Colwell, Seattle Public Utilities, dated January 10, 2012.
[5] Aspect Consulting. Bioretention Soil Permeability Testing. Memorandum to Andy Rheaume, City of Redmond, dated January 28, 2014.
[6] Generally also meets Washington Department of Ecology specifications except the sand fraction passing through the #200 sieve was 1.5%.
[7] All the systems evaluated through the in-situ field testing were constructed with underdrains except the Ballard Roadside Raingardens on 30th Avenue NW.
[8] Methods used for the in-situ field testing are described in Attachment 1 to this memorandum.

**Figure 1: Change of Mean Hydraulic Conductivity Over Time**



## Attachment 1
## In-situ Field Test Methods for Quantifying Bioretention Soil Mix Infiltration Rates

### Barton and High Point roadside bioretention swales

The bioretention soil mix (BSM) infiltration rates at the Barton roadside bioretention swales (7536 34th Avenue SW) and High Point roadside swales (31st and Raymond and 30th Ave SW/SW Graham St) were measured by introducing water to the cell and adjusting the inflow rate until ponding water stabilized at desired depth (9-12 inches depending on specific cell design). The ponding depth was maintained for approximately 1 hour. Water was turned off and the depth recorded on a staff gauge every 1 minute until all surface water infiltrated. The infiltration rate was calculated using the entire falling head depth range.

### Ballard roadside rain gardens

The BSM infiltration rate at the Ballard roadside rain gardens on 30th Avenue NW was measured as part of controlled flow testing to evaluate the cumulative performance of the bioretention system during a simulated CSO control event. Water was introduced to the curb line on consecutive days to simulate dry and wet performance conditions. After an initial wetting period of 30 minutes on the second day of testing (wet conditions) the rate of drawdown from a maximum depth of 4.5 inches to 0.5 inches was measured via a surface level logger (MiniTroll) at 1 minute intervals over 17 minutes. The infiltration rate was calculated using the entire falling head depth range. Due to the limits of the underlying native soils, further data points were not feasible as the full soil column became saturated and drawdown rates were reflective of the infiltration in the native soils.

### Redmond bioretention soil permeability

Infiltration rates at the City of Redmond BSM test facility (Redmond Maintenance and Operations Center Decant Facility) were measured by digging a 6 foot by 3 foot high density polyethylene container with no bottom (infiltration frame) into the bioretention media to a depth of 12 inches. Water was introduced to the frame and the flow rate adjusted to maintain a ponding depth of 12 inches (equal to the planter box bypass elevation). The ponding depth was maintained at 12 inches for 3 hours (saturation period). Water was then shut off and the rate of falling head measured every 15 minutes.

### WSU mesocosms falling head permeability

Media in each lysimeter (152 centimeter [cm] diameter by 122 cm depth plastic tank) at the WSU LID research facility was saturated with 3 pore volumes of water (556 liters per pore volume). Saturation was achieved by filling the lysimeter to a ponding depth of 30 cm with the under-drain closed. The drain was opened and ponded water was allowed to drain down to 15 cm and the drain reclosed. This procedure was repeated three times. The actual saturated hydraulic conductivity test was conducted by filling the lysimeter to a 30 cm ponding depth. The drain was then opened and the time required to drain the lysimeter to the following levels was recorded:

- From the 30 cm to 15 cm mark
- From the 15 cm mark to when all surface water infiltrated

Saturated hydraulic conductivity (Ksat) was calculated based on Darcy's law using the following equation:

$$Ksat = L/(t1-t2) * \ln(h1+ L/h2+L)$$

Where:
L = depth of saturated soil + aggregate drainage layer
t1 = start time and t2 = end time of test
h1 = initial height and h2 = final height
ln = natural log