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:


Table 1: Comparison of Bioretention Soil Mix Measured Infiltration Rates

<table>
<thead>
<tr>
<th>Bioretention Soil Mix (BSM) Study</th>
<th>Researcher/Author</th>
<th>BSM Specification Followed</th>
<th>BSM Composition</th>
<th>Planting</th>
<th>Test Procedure</th>
<th>Measured Infiltration Rate (Ksat) (in/hr)</th>
<th>95% LCL</th>
<th>95% UCL</th>
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</thead>
<tbody>
<tr>
<td>Mesocosms Falling Head Permeability (May-June 2011) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>60%</td>
<td>40%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>21.6</td>
<td>33.3</td>
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<tr>
<td>Mesocosms Falling Head Permeability (May-June 2011) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>80%</td>
<td>20%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>5.2</td>
<td>27.7</td>
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<tr>
<td>Mesocosms Falling Head Permeability (June 2012) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>60%</td>
<td>40%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>18.2</td>
<td>31.2</td>
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<td>Mesocosms Falling Head Permeability (June 2012) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>80%</td>
<td>20%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>20.1</td>
<td>26.1</td>
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<td>Mesocosms Falling Head Permeability (September 2013) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>60%</td>
<td>40%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>42.9</td>
<td>48.3</td>
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<td>Mesocosms Falling Head Permeability (September 2013) at WSU Puyallup GSI Research Program</td>
<td>Curtis Hinman</td>
<td>Ecology</td>
<td>80%</td>
<td>20%</td>
<td>Yes</td>
<td>Falling head Ksat in large lysimeters</td>
<td>32.9</td>
<td>43.0</td>
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<td>Ballard Roadside Raingardens Controlled Flow Testing on 30th Avenue NW</td>
<td>SPU Seattle</td>
<td>60-65%</td>
<td>35-40%</td>
<td>Yes</td>
<td>Falling head infiltration</td>
<td>14</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Barton Roadside Bioretention Swales Full-scale Flood Testing on 7536 34th Avenue SW</td>
<td>SPU Seattle</td>
<td>60-65%</td>
<td>35-40%</td>
<td>Yes</td>
<td>Falling head infiltration</td>
<td>20.2</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Highpoint Roadside Bioretention Swales Full-scale Flood Testing on 31st and Raymond</td>
<td>SPU Seattle</td>
<td>60-65%</td>
<td>35-40%</td>
<td>Yes</td>
<td>Falling head infiltration</td>
<td>100.8</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Bioretention Soil Mix (BSM) Study</td>
<td>Researcher/Author</td>
<td>BSM Specification Followed</td>
<td>BSM Composition</td>
<td>Test Procedure</td>
<td>Measured Infiltration Rate (Ksat) (in/hr)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
<td>Compost</td>
<td>Planted</td>
<td>Lab (Constant head – ASTM D2434)</td>
<td>Min</td>
<td>Max</td>
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<td>Highpoint Roadside Bioretention Swales Full-scale Flood Testing on 30th Ave SW/SW Graham St</td>
<td>SPU</td>
<td>Seattle</td>
<td>60-65%</td>
<td>35-40%</td>
<td>Yes</td>
<td>Falling head infiltration</td>
<td>43.2</td>
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<td>Redmond Bioretention Soil Permeability Testing – Ecology Mix&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Herrera</td>
<td>Ecology</td>
<td>60%</td>
<td>40%</td>
<td>Yes</td>
<td>Falling head Infiltration</td>
<td>3.8</td>
<td>16.8</td>
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</tbody>
</table>

**LABORATORY TESTS**

| Recommended Modification of the ASTM D2434 Procedures for Permeability Testing of Bioretention Soils<sup>4</sup> | 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)<sup>5</sup> | 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)<sup>6</sup> | Aspect Consulting | Ecology | 60% | 40% | No | Lab (Constant head – ASTM D2434) | 78.0 | 78.9 | 78.4 | 78.2 | 78.7 |


<sup>6</sup>Generally also meets Washington Department of Ecology specifications except the sand fraction passing through the #200 sieve was 1.5%.

<sup>7</sup>All the systems evaluated through the in-situ field testing were constructed with underdrains except the Ballard Roadside Raingardens on 30th Avenue NW.

<sup>8</sup>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

WSU Puyallup GSI Research Program

- 80-20 BSM Mix
- 60-40 BSM Mix

Mean Ksat (in/hr)

Test Year

2011 2012 2013
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:

\[ K_{\text{sat}} = \frac{L}{(t_1-t_2) \ln(h_1+ \frac{L}{h_2+L})} \]

Where:
- \( L \) = depth of saturated soil + aggregate drainage layer
- \( t_1 \) = start time and \( t_2 \) = end time of test
- \( h_1 \) = initial height and \( h_2 \) = final height
- \( \ln \) = natural log