Taylor Aquatic Science and Policy

Technical Memo

To:	Eric Christensen, City of Olympia Brandi Lubliner, SAM Coordinator, Ecology
From:	William J. Taylor, Taylor Aquatic Science and Policy Douglas Beyerlein, Clear Creek Solutions, Inc. Jenny Saltonstall, Associated Earth Sciences, Inc. Bryan Berkompas, Aspect Consulting Anne Cline, Raedeke Associates, Inc. Chris Wright, Raedeke Associates, Inc.
Date:	October 27, 2020
Re:	Bioretention Hydrologic Performance (BHP) Study II Summary of Final Conclusions and Recommendations Deliverable 5.4

Introduction

Even as the use of bioretention as stormwater treatment increases in new and redevelopment in the Puget Sound region, surprisingly little assessment has been conducted of the hydrologic performance of constructed facilities. As population grows and developable space in the Puget Sound region is increasingly scarce, natural stream channel ecosystems remain vulnerable to stormwater runoff. Evidence is needed that stormwater control measures are efficiently using space available to achieve protection of local waters.

This memo provides a summary of findings and recommendations from the Bioretention Hydrologic Performance Study Phase II site data, and performance of the design model to represent 10 bioretention facilities located in western Washington State.

As with the previous Phase I project, this Phase II project involved an initial review of many candidate sites, discussions with local jurisdiction owners, design engineers and maintenance staff; and site-specific documentation of dimensions and elevations, bioretention soil media (BSM) structure, infiltration rates, vegetation conditions, and measured hydrologic response of the facility. The measured site conditions and hydrology were then used to evaluate the sites and the performance of the Western Washington Hydrology Model (WWHM) 2012 to represent constructed facilities.

This Phase II project selected ten facilities that were designed using the updated WWHM 2012, while Phase I selected and studied ten facilities that used the previous version of the WWHM and other models as well. This enabled evaluation of the performance of the WWHM 2012 model itself against facilities designed using the model, in addition to performance of the facilities themselves.

The distinction between the two models is that the 2012 model version uses updated infiltration algorithms within a dedicated bioretention design module, where previously the WWHM used a more simplified representation. The results are intended to be more accurate in predicting the continuous hydrologic performance of designed facilities, and therefore better achieve the Minimum Requirement goals of the SWMMWW (2012/14) for bioretention facilities.

The use of the WWHM 2012 also meant the ten facilities selected in Phase II have more recently been constructed (the 2012 version of the model was available in 2012 but not more broadly used until year 2015 and later). As a result, these facilities were not “aged” by years of infiltration, maintenance, and plant growth, and more represent initial conditions as represented by the designer’s model.

This memo is Deliverable 5.4 and is intended to be discussed at the next Stormwater Work Group meeting.

As a result of the comprehensive nature of the assessment, it should be noted that many of the insights and conclusions come not just from the physical measurements, vegetation composition, hydrologic performance data, and modeling, but also from the more anecdotal observations gained from owners, engineers and operators of the facilities, as well as our own site-specific observations.

In addition to conclusions learned from these steps, some new questions emerged that could further address the performance of bioretention facilities but were not evaluated as the analyses require unavailable or uncollected data, or are beyond the scope of the project (for example sensitivity analysis of the effect of variability of infiltration rates, contributing area, and site specific rainfall).

The main goals of the project were to:

1. Provide a hydrologic assessment of how ten constructed bioretention facilities designed using WWHM 2012 and located throughout Puget Sound are performing.

2. Identify major influences of the site designs and performance constraints affecting the performance (e.g. BSM, infiltration rates, percent of drainage area, vegetation composition), to help inform the design and modeling process for more efficient and predictably performing facilities.

3. Provide recommendations for engineers and jurisdiction reviewers to better model, design and review future bioretention facility designs.

Results

Representativeness of Sites Assessed
As with the previous Phase I project, over seventy individual bioretention cells were evaluated through site visits in the field and review of design documents. After affirming a site was designed using WWHM 2012 as a bioretention facility (and not a conveyance swale or pond for example) the decisive selection criterion was the feasibility of monitoring flow at the site inflow and outflow locations. As a result of the wide range of geographic locations and site conditions, the selected projects represent a wide cross section of meteorological and geomorphic and hydrogeologic conditions, as well as drainage area ratios.

Design Conditions
Design dimensions and other information for each of the ten sites was collected from the original design drawings and, when available, from hydraulic and geotechnical reports supporting the design. The modeling approaches were evaluated to assess the original modeling approach (model version, approach to modeling, etc.) to help ascertain whether design features and performance were related to the modeling approach taken.

Constructed Dimension
Constructed cell dimensions were measured in the field and found to be generally as per project design dimensions. Inflow volumes were also assessed through the WWHM model developed for each site by matching apparent inflow volumes with measured ponding or well depths. Field documentation of contributing areas was not conducted.

Following are a summary of findings for the various disciplines evaluated at each of the sites.

Issues with Existing Designs or Construction Practices

Site Design Review

- All the selected study facilities were designed using WWHM 2012.
- Approach to modeling was often not set up properly, even with the available new WWHM 2012 bioretention module. Some engineers using WWHM 2012 fail to use the bioretention element to represent bioretention facilities in their models. Others use the bioretention element but do not input the correct values that represent the actual design conditions.
- Where any site facility surface area to drainage area ratio was smaller than recommended (5%) the site did not meet performance standards.
- In-field hydrologic performance of the facilities was most often due to oversizing or undersizing of facilities beyond current safety factors, and/or not following BSM criteria.
- Using long term county precipitation records and using the SWMMWW-prescribed lower infiltration rates equally across the entire lifespan (rather than what was actually measured at the site), six of the facilities did not meet Minimum Requirement (MR) #5 and four of the facilities did not meet MR #6; in reality much of each facility life span will reflect the higher initial infiltration rate thus actually meeting these MRs for some period.

Hydrologic Monitoring Data and Findings

- 8 months of continuous wet season monitoring (November 2018 – June 2019) – however this data was highly confounded by frequent freezing, snow accumulation, and owner maintenance practices during the winter. Full records were collected and delivered.
- Only 3 months of data, April 2019 – June 2019 was usable for comparison to modeling results.
- Volumetric runoff at each site is variable even for apparently near 100% impervious contributing areas. Measured continuous runoff records were overall considered less dependable than the simulated, so simulated volumes were used in the model evaluation. However, a regression of measured runoff volumes for a range of storm events still often had good R2 values.
- Ponding and well point responses for infiltrating sites (not underdrained) showed good reflection of the BSM infiltration rates and subgrade conditions. Underdrained sites showed rapid runoff of infiltrated waters, resulting in well point elevations reflecting underdrain elevations.
- Evidence of water movement not captured in the modeling occurred through possible subsurface leakage into subsurface utility trenches.
- At one site near a tidal shoreline, well point data had a clear tidal signal but groundwater did not affect infiltration rates.

Geotechnical and Hydrogeologic Findings

- Sites covered a wide range of geomorphic and hydrogeologic conditions.
- Bioretention soil texture was generally coarser than current guidelines, resulting in greater infiltration rates than would be expected under the current media guidelines.
- Wide range of measured infiltration rates, with measured rates in the field for both the media and subsurface soils much greater than site design values used in all but one case.
- Compaction of the bioretention soil was documented in three facilities and is interpreted to have reduced the bioretention soil infiltration rate in two underdrained facilities.
- Bark mulch floated and was re-distributed during controlled infiltration testing and can be a source of clogging if conveyed to a small-diameter orifice-controlled outlet.
- Bioretention without underdrains on outwash sites provides recharge to shallow aquifer settings. Shallow aquifer levels remained below the facility base, and groundwater mounding did not affect infiltration rates.
- Bioretention on low-permeability sites resulted in mounding on hydraulic restrictive layers. The mounded water was collected by the underdrain.

Vegetation Findings

- Phase II facilities studied were only very recently planted (within 2 years) so still showing original plantings.
- Plantings generally followed the specified planting plans.

- Bioretention soils and native soils drain rapidly in most cases and hydrophytic plants appeared not to survive well at one example site - even within 2 years since installation.

- Shrubs have higher survival rates than herbaceous vegetation and appear to reduce the maintenance of cells.

Modeling Findings

- Viewing long-term graphical trends, the WWHM 2012 models reproduced the monitored bioretention hydrologic performance data with accurate results.

- An additional bioretention "limiting" surface leaf layer was utilized to best represent four of the facilities. This suggested some surface infiltration was limiting in these facilities, while not visually obvious.

Major Influences and Recommendations for Improved Bioretention Designs and Performance

Given the above findings, major influences and recommendations intended for engineers, geotechnical specialists, and landscape architects, as well as development reviewers at local jurisdictions for each of the design elements include:

Design Features

- Contributing drainage areas, inflows, and minimum facility sizes are a major influence on projects.
  Recommendations:
  - Conduct as-built surveys of inlets, overflows and bioretention surface.
  - Conduct a field inflow test to confirm positive drainage into the cell.
  - Provide better review of design plans and models before accepting for construction. This review should include contributing area calculations and reviewing the design model to determine the appropriate minimum facility size as a percentage of drainage area.

Geotechnical and Hydrogeologic Conditions

- Outwash sites are good settings for bioretention systems. More precisely known subsurface conditions are a major influence on project performance.
  Recommendations:
  - Collect site-specific data to understand shallow soil, geologic and groundwater conditions affecting subsurface infiltration rates.
  - Consider potential for lateral flow, and the ultimate path of the infiltrated water, for sites with low or spatially variable infiltration rates.
  - Consider potential for utility corridor capture of infiltrated waters, particular in retrofit applications.
- Soil media composition is a major influence on the infiltration rate, especially at the smaller particle range, resulting in rapid infiltration in most cases.
  Recommendations:
  - Provide testing of soil media for consistency with the specifications provided in the Ecology Manual, especially the less than sieve 40, 100, and 200 fractions.

- Conduct a study of “aging” of facility infiltration rates over time, whether decreasing, increasing, or staying the same.

- Plan reviews by permitting jurisdictions seemed to miss some important geotechnical design elements.
  Recommendation:
  - Conduct geotechnical plan review of permit plans and during construction so that plans adequately incorporate geotechnical recommendations (e.g. are bioretention cells located near infiltration test locations or at different elevations; does the grading plan (improperly) remove the permeable horizon?).

- Actual conditions observed during construction can be important to appropriately modify the design.
  Recommendations:
  - Conduct observations during construction to observe whether the subsurface geologic and groundwater conditions are consistent with the basis of design (i.e. if site design is based on outwash soils being present, and subsurface conditions are consolidated glacial till, a design change is required).
  - Soil compaction can occur during bioretention soil placement, irrigation installation, placement of inlet protection or energy dispersion elevation or from planting; compacted soil should be remediated prior to acceptance.
  - We speculate based on limited observations that soil compaction impacts are more common for narrow facilities. Evidence for surface compaction was exhibited in five of the ten facilities.

<u>Vegetation Plant Composition and Survival</u>

As discussed in the previous study, bioretention units with underdrains tend to drain very quickly. Units with underdrains, especially large cells with underdrains, need to be planted with extremely adaptable plants that err on the side of having a wetland indicator status of facultative upland or upland plants (not wetland plants). Plant schedules should include the wetland indicator status of plants used in the design.
Recommendations:

- Cells that were planted with only herbaceous species, or where the woody plants had been heavily browsed by deer, tended to be growing a greater density of noxious weeds. Shrubs tend to compete better with noxious weeds and therefore should be used more frequently in units to reduce maintenance.
- Herbaceous species tend to have poor survival rates in bioretention cells compared to shrubs. Units should be planted with a variety of shrubs and herbs. Native shrubs tend to be large and might be inappropriate for some units due to limited sight lines. Consider using smaller shrubs such as (*Cornus sericea ‘Kelseyi;*) and shiny-leaf spirea (*Spiraea betufolia var. lucidaf).*
- Specify water tolerant plants in bottom areas near the inflow, and fan out to more facultative, facultative upland plants farther away from the inflow.

- Cells tend to be planted with plants that commonly occur in wetlands, however wetland soils are anaerobic, waterlogged, and poorly draining. Bioretention soil is very-well draining. Wetland species that require constant water-logged soil will not grow well in bioretention cells and should be avoided (except for *Carex obnupta*).
- Maintenance plans and contingency plans should be developed along with the planting designs to allow adaptive changes. Designers should follow-up on the effectiveness of the design a year or two after installation.

<u>Modeling Influences and Recommendations</u>

- Some input surface BSM default infiltration rates did not provide results consistent with an accurate model of measured conditions.
  Recommendation:
  - Use of a limiting "leaf litter layer" surface modeling layer in the model may improve model results where non-wood mulch will be applied.

- Using the default evapotranspiration rate appeared to have a substantial effect on results.
  Recommendation:
  - Use a higher evapotranspiration rate than the default 0.5, especially for solar exposed sites.

- Rapid infiltration to underdrains resulted in rapid drainage of subsurface water after infiltrating.
  Recommendation:
  - Jurisdictions that encourage infiltration even in soils that have low infiltration rates should include a capped underdrain as a back-up discharge management option.

- WWHM is a 1-dimensional model, meaning uneven (laterally or longitudinally differential) infiltration observed at various sites both in Phase II and Phase I infiltration testing or other field observations is not represented in the model.
  Recommendation:
  - The effects of uneven infiltration should be further evaluated and incorporated in the design approach (see same issue regarding planting plans above).

- It is recognized that new and retrofit facilities have different minimum requirement criteria. As a result designers and reviewers recognize the degree of performance will differ between them.
  Recommendations:
  - Ecology conduct a sensitivity analysis of the magnitude of effect of the variability of safety factor infiltration rates, contributing drainage area, and use of regional rainfall records on new facility performance on long-range ability to meet MR #5 and MR #6.
  - Reviewers should run the WWHM 2012 model for the site and analyze results for compliance with MR #5 and MR #6 before approving new development site design.

Discussion

This Bioretention Hydrologic Performance Phase II study included study of facilities distinctly different from those in Phase I: these facilities were all modeled using the updated WWHM 2012 hydrologic model which includes a specifically designed bioretention modeling module. The use of this more current model would presumably result in more consistent outcomes in accuracy and precision of the performance. In addition, these facilities were all more recently designed and constructed, suggesting they may provide insight to current practices in bioretention.

As with Phase I, most Phase II facilities showed rapid infiltration due to high measured infiltration rates of their bioretention soil media; the exceptions were RSH and BCK where compacted soils were observed in combination with a low overflow elevation. Notably combined with these high infiltration rates were several undersized retrofit facilities (as a percent of their drainage area), many cells using underdrains, one cell had a very low and uncontrolled overflow elevation of the outlet structure, and some cells had apparent lateral flow (possibly through utility trenches). These conditions occurred either alone or in combination. As a result of these conditions long term modeling of many of the facilities did not meet MR #5 and MR #6 (meeting the pre-developed flow duration curve at 8% of the two year to 50% of the 50 year, and infiltrating 91% of the total runoff volume, respectively).

This combination of the number of undersized facilities and the much higher rates of infiltration than designed, together with deficient structural features (e.g. allowing rapid outflow to underdrains and overflows, and lateral flow), was the greatest influence on the apparent success or lack of success of these facilities overall.

Interestingly, a second, co-occurring property of many facilities' performance was identified in both this and the previous Phase I project study: spacially uneven infiltration of the inflowing water. This observation simply recognizes the reasonable expectation that inflows to the facility will tend to infiltrate first near the inflow point and will tend to do so until near surface infiltration is saturated before surface flows progress across the facility. This adds a complex second dimension to the conceptual model and design plans regarding how bioretention facilities hydrologically perform. For example, planting plans should anticipate differential moisture conditions to improve planting plan performance. How to model this effect and to what extent it may affect the hydrologic performance of any one facility is difficult to predict.

Other than the higher number of undersized facilities seen in this set of study sites, many of the findings and observed (or inferred) performance was in many way similar to Phase I: highly infiltrating conditions, influence of underdrains, highly variable shallow native soil infiltration rates, and the use of plants with a wetland indicator status of obligate or facultative not surviving long-term.

The project sites evaluated were in most cases either over-sized or under-sized relative to their drainage areas. High infiltration rates occurred at half the sites compared to the site design rates. The lower site design infiltration rates may have resulted from either jurisdictionally mandated limits on assumed infiltration rates through bioretention soil or from correction factors applied to the native subgrade infiltration rate based on the type of infiltration testing. Alternatively, the area available at the site may simply have allowed the facility to be oversized (relative to the infiltration design rate) to serve as a landscape amenity and not just a stormwater facility. The undersized facilities appeared to underperform simply based on their small size, even with high actual infiltration rates.

Retrofit and new development sites where space is limited and where more efficient sizing is desired would likely benefit from greater subsurface hydrogeological investigation for greater accuracy of the potential infiltration capacity. Anecdotally, some engineers' apparent level of discomfort with the complexity of bioretention facilities' design and the uncertainty of subsurface infiltration rates may be contributing to discounting of the feasibility of bioretention at some sites. Similarly, vegetation composition and maintenance appear to become an afterthought in design of the facilities relative to the institutions' needs or commitment to maintenance and may contribute to owner's disinclination to include bioretention in site designs.

Nonetheless, these findings should not distract from the benefit of these bioretention facilities that they still perform: reducing flows from conventional curb and gutter runoff and discharge to receiving waters. These facilities, even with the above recommended design improvements, still served the function to reduce runoff delivery rates and volumes and provided water quality treatment for protection of receiving waters.

Recognizing the facilities in this study were only recently constructed, they appear to be serving an adequate function without large shortcomings that could result in under capacity or local flooding.