Taylor Aquatic
Science and Policy

Technical Memo

To:	Eli Mackiewicz, City of Bellingham 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 Bryan Berkompas, Aspect Consulting Anne Cline, Raedeke Associates, Inc. Chris Wright, Raedeke Associates, Inc.
Date:	May 30, 2018
Re:	Bioretention Hydrologic Performance (BHP) Study Summary of Final Conclusions and Recommendations Deliverable 5.4

Introduction

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

This memo provides a summary of findings and recommendations from the Bioretention Hydrologic Performance Study site data and modeling results on 10 early design bioretention facilities located in western Washington state. This memo is Deliverable 5.4 and is intended to be discussed at the June 6, 2018 Stormwater Work Group meeting.

The overall 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, soil structure, infiltration rate, vegetation conditions, and measured hydrologic response of the facility.

In addition, the pre-construction modeling approach used for each design (when known) was evaluated to gain insights to how each site design was formulated in the design model. Finally, each site was modeled using WWHM v.2012 (post construction and a year worth of monitoring data) to assess model parameter values and new model elements (e.g. presence of a leaf litter layer) that could provide insights to the model and site performance given the observed conditions.

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, 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 is 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 located throughout Puget Sound are performing.

2. Identify major elements of the site designs and performance constraints that can help inform the design and modeling process for more efficient and predictably performing facilities in the future.

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

Results

<u>Representativeness of Sites Assessed</u>

Because the project site selection process began in 2015, most of the sites evaluated were designed using an older versions of the Western Washington Hydrology Model (WWHM) than the current 2012 version or used other models entirely. These are an important set of facilities to assess nonetheless as many older facilities have been built and can inform the result of variable designs and aging on project performance.

Over seventy bioretention cells were evaluated through site visits in the field. After affirming a site was designed 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. Drainage area dimensions were evaluated through analysis of specific storm event rainfall inflow volumes for a given measured rainfall depth and compared to the theoretical inflow volume assume the design drainage area. 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.

Site Design Modeling Review

- Wide variety of computer models used in the design models
- Approach to modeling was often not set up properly
- Hydrologic performance of the facilities was more due to oversizing facilities beyond current safety factors, masking design errors or incorrect assumptions

Hydrologic Monitoring

- 6 months of continuous wet season monitoring (October – March 2017)
- 3 months additional monitoring for drier conditions (April – June 2017)
- Volumetric runoff at each site is variable even for apparently near 100% impervious contributing areas
- Variable ponding response depending on subsurface conditions
- Evidence of oversizing in highly infiltrating sites
- Evidence of shallow groundwater mounding in some of the sites
- Evidence of water movement not captured in the modeling, including:
    - Possible lateral subsurface flow in some of the sites
    - Evidence of subsurface leakage into an overflow outlet structure in one site
    - Evidence of short circuiting through soil directly to underdrain, resulting in almost no detention, and reduced treatment

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 in about half the cases than the site design values used
- Little site-specific hydro-geologic data; only 2 sites conducted pilot infiltration tests; other analyses sometimes "borrowed" from adjacent geotechnical work

Vegetation Findings

- Bioretention soils and native soils drain rapidly in most cases and plants need to be drought tolerant to survive unless constantly watered.
- Shrub species surviving well
- Herbaceous species are less adaptable – depending on irrigation and species selected
- Multiple herbaceous species in a site design tend to transition to a less diverse herbaceous community
- Recurring problems in cells are present, such as plant die-off, invasive species, having to replant cells, and requiring more maintenance than staff capabilities

Modeling Findings

- The pre WWHM2012 models did a 'fair job' of designing these facilities. Much of the error is due to initial model set-up.
- WWHM 2012 provided good representation of observed hydrology at the sites

Recommendations for Improved Bioretention Designs and Performance

Given the above findings, major 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

- Provide inspectors' confirmation of constructed contributing areas and overflow elevations

Geotechnical and Hydrogeologic 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
- Provide soil media that is consistent with the specifications provided in the Ecology Manual

- Conduct geotechnical plan review of permit plan set so that plans adequately incorporate geotechnical recommendations (i.e. are bioretention cells located near infiltration test locations or at different elevations or does the grading plan remove the permeable horizon)

- 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, do not over excavate into consolidated glacial till)

- Conduct an assessment of "aging" of infiltration rates over time, whether decreasing, increasing, or staying the same

Vegetation Recommendations

- Select plants that reflect the expected subsurface moisture and dry season conditions, and the solar exposure expected for the site

- Select plants species that are consistent with each other for growing success (e.g. select shrubs that are not excessively shading the herbaceous plants)

- Select a planting plan that is consistent with the institutional or residential owner's design needs and commitment to maintenance

- Install woody species at lower density to allow for plant growth and spread

- Select native herbaceous plant species that are more likely to survive in a xeric moisture regime

- Maintenance plans and contingency plans should be developed along with the design

Modeling Recommendations

- Jurisdictions that encourage infiltration even in soils that have low infiltration rates, should include a capped underdrain as a back-up discharge management option

- Investigate how to more accurately represent the soil layer depths in the model development, including possibly a leaf litter layer

- Investigate more appropriate default evapotranspiration rates based on vegetation types

- Conduct sensitivity analysis of the magnitude of effect of the variability of infiltration rates, contributing drainage area, and use of regional rainfall records on facility performance

Discussion

In general, these findings of the hydrologic performance of constructed facilities found that the sites successfully infiltrated virtually all the stormwater inflows during the monitoring period, with the exception of one site that appeared to foster infiltration that quickly bypassed to an underdrain.

The project sites evaluated were in most cases greatly over-sized given the high infiltration rates at half the sites compared to the site design rates. The low 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.

Development sites where space is limited and more precise 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, which may also become a source of undesirability of bioretention as a site element.

Overall, given their range of ages since construction, the bioretention facilities assessed appear to continue to serve a more than adequate function without unexpected shortcomings resulting in under capacity or local flooding.