Development of an Online Load Reduction Estimation Tool for Performance of Bioretention in Seattle, WA, USA

S.D. Struck[1]*, D.C. Pankani[2], and S.R. Colwell[3]

[1]*Geosyntec Consultants, 1376 Miners Drive, Suite 108, Lafayette, Colorado, 80026 USA*

[2]*Geosyntec Consultants, 920 SW Sixth Avenue, Suite 600, Portland, Oregon, 97204, USA*

[3]*Seattle Public Utilities, 700 Fifth Ave, Suite 4900, Seattle, Washington, 98104, USA*

**Corresponding author email: sstruck@geosyntec.com*

Highlights

- Presents online tool that calculates annual load reductions based on monitored flow data and laboratory results for bioretention systems to support Integrated Stormwater Management.
- Details a companion online tool that uses monitored data to estimate and predict annual performance of implemented bioretention systems.
- In the absence of monitored data, performance is estimated using modelled data to allow for analysis of conceptual designs and built systems.
- Allows for scenario analyses and assessment towards reaching water quality goals.

Introduction

The City of Seattle (City) operates a combined sewer system and a municipal separate storm sewer system (MS4), both of which are permitted under the National Pollutant Discharge Elimination System (NPDES) by the Washington State Department of Ecology (Ecology), the state regulatory agency. The storm sewer system serves approximately two-thirds of the city, discharging approximately 49,000,000 m^3 (13 billion gallons) of stormwater to receiving waters in and around the city during an average year. The combined sewer system serves approximately one-third of the city, conveying stormwater and sewage to regional wastewater treatment plants (WWTPs) owned and operated by King County.

The City has completed numerous combined sewage overflow (CSO) control projects during the past 50 years, resulting in substantial reductions in CSO discharges. Through this effort, the City expended significant resources on CSO controls but only limited resources towards addressing water quality impacts of discharges from the City's separate storm sewer system. Ecology determined that stormwater runoff was a main pathway through which toxic pollutants enter Puget Sound (Ecology, 2011). Ecology also estimated that stormwater contributed more than 50 times as much flow and 30 times as much solids loading to the Lower Duwamish Waterway, a major Seattle receiving water, compared to CSO discharges (Ecology, 2013).

To address the stormwater-related impacts, the City developed an "Integrated Plan" (City of Seattle, 2015). This Plan allows the City to implement stormwater control projects that will significantly benefit water quality in receiving water bodies, while deferring lower-benefit CSO projects as demonstrated by CSO and stormwater project modelling. The Integrated Plan is composed of three major projects. One project - Natural Drainage Systems (NDS) Partnering includes the installation of bioretention stormwater management systems along City roadways. The bioretention systems will manage flow and provide water quality treatment of urban runoff. The bioretention projects will also provide additional community benefits such as improved mobility, traffic calming and beautification, and increase community awareness of stormwater quality impacts generated by impervious surfaces.

For Ecology and the Environmental Protection Agency (EPA -the Federal regulatory agency) to accept the City's Integrated Plan approach, the City agreed to demonstrate that the stormwater projects provide water quality benefits (e.g., load reductions) beyond those that would be achieved by the CSO projects

alone. To assist in demonstrating the success, post-construction monitoring is required from at least six completed facilities from three watersheds, Longfellow, Pipers, and Thornton Creeks. The monitoring data from these facilities can be used to estimate performance of other similarly implemented facilities and provide estimates of progress toward achieving the volumetric and pollutant load reduction goals defined by and accepted by Ecology.

This paper discusses the development of a simplistic tool to track, estimate performance, and allow scenario analyses to determine the precise number of stormwater investments through implementation of bioretention systems to meet regulatory load reduction and volumetric goals mandated by Ecology.

Methodology

Pollutant Load Model

To evaluate stormwater projects considered in the Integrated Plan, a Pollutant Load Model (PLM) was developed in 2013 to determine the pollutant load reduction goals for each watershed. The model used land use information for existing conditions and predicted load reductions for each proposed project and associated benefits. A separate cost-benefit analysis for the NDS Partnering projects was completed using present-value costs of the proposed projects based on costs per unit of pollutant load reduced compared to benefits. Each stormwater candidate project was then assessed qualitatively on other factors, such as proximity to other planned stormwater quality projects and level of treatment (pretreatment, basic, or enhanced). Information was then scored and ranked using a collective Multiple Objective Decision Analysis (MODA) matrix. Factors used in the MODA scoring included: performance risk, project flexibility, relationship with other agencies, water quality load reduction, other positive environmental outcomes (assist to meet the City's Green Goal by reducing stream flow and/or add green space and habitat), construction impacts (short-term disruption during project construction), community impacts (long-term project or operations and maintenance [O&M] impacts to the community), environmental and social justice inequities, safety, and ease of O&M.

The development of the PLM was completed in previous efforts to determine the necessary load reduction goals for contaminants of concern (e.g., PCBs, metals, bacteria, solids, and nutrients) for Longfellow, Pipers, and Thornton Creeks. The model determined that a collective annual average volume of 121,000 m^3 (32 MG) must be treated or removed per year to meet the load reduction goals. Table 1 shows the accepted pollutant loading goals that must be met through NDS Partnering projects based on the PLM. The target date for complete implementation is 2025 with proven success (monitored) shown by 2029.

Table 1. *Performance monitoring reduction goals for Natural Drainage System Partnering (bioretention). Values represent the 95% lower confidence limits from the regional pollutant load model.*

Average volume treated or removed (m^3/yr)	Fecal coliform bacteria (billion CFU/yr)	PCBs (g/yr)	Total phosphorus (kg/yr)	Total copper (kg/yr)	TSS (kg/yr)	Total zinc (kg/yr)
121,000	10,649	1.3	11	1.1	6,478	9.2

On-line Monitoring and Load Estimation Tool

A website containing two complementary tools was developed to calculate and track estimated load reductions achieved through bioretention implementation. The *Monitoring-based Load Reduction Calculator (MLRC*) is the first tool which estimates load reductions based on actual monitored data for each bioretention system. The tool allows for data entry or easy upload of bioretention monitoring data for single or multiple events to calculate and display a water balance performance summary (influent, effluent, and bypass volumes), event mean concentrations (EMCs), as well as influent, effluent, and bypass loads for each monitored location. It also supports manual entry or bulk upload of Geographic Information Systems (GIS) data including land uses for pervious and impervious areas. The MRLC provides downloadable tabular and graphical summaries by event and determines annual load reductions.

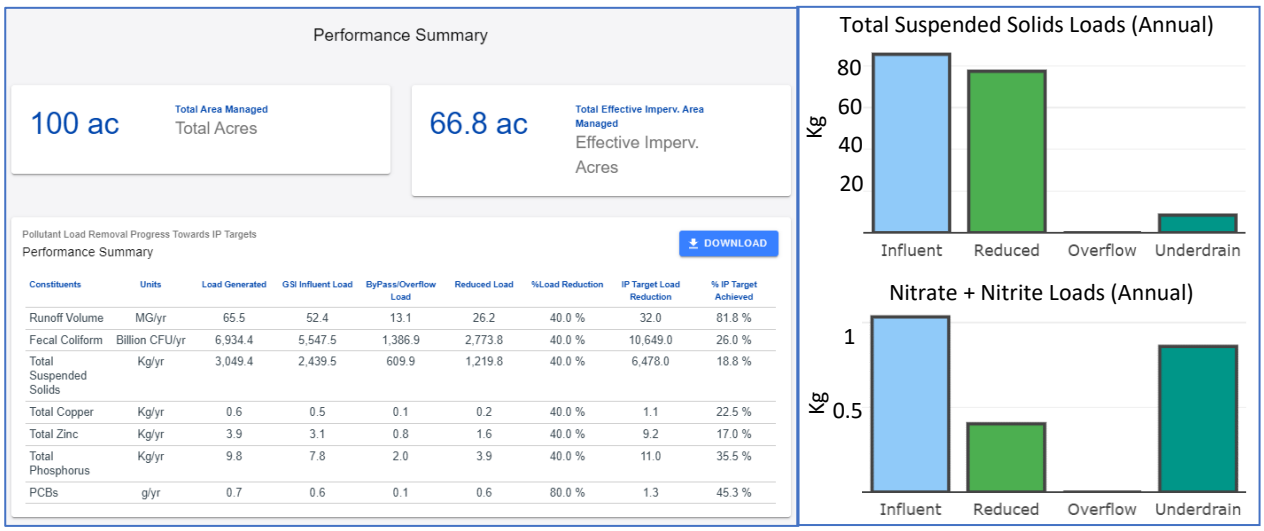
The second tool, called the *Project Performance Estimator Tool (PPET)* uses the monitoring data entered in the MLRC tool or applies modeling input data based on the approach used in the PLM to estimate load reduction of existing and potential future projects. This tool provides the following:

- Determines estimates of bioretention performance of existing and future facilities based on scaling results from monitored bioretention data that have similar designs;
- Determines estimates of bioretention of existing and future facilities based on scaling modeled data of similar bioretention with similar designs; and
- Predicts progress towards achieving stated goals at the watershed scale (e.g., all basins) of individual or multiple facilities.

These two tools allow for quantitative tracking and assessment towards achieving regulatory goals.

Results and Discussion

The tools were successfully developed to provide simplistic tracking and performance of right-of-way bioretention systems. The tools provide performance using monitored and/or modelled data with output of estimated long-term annual load reduction, estimated annual bypass load, estimated annual volume reduction, and collective performance for all systems entered into the tool database (Figure 1).



Constituents	Units	Load Generated	GSI Influent Load	ByPass/Overflow Load	Reduced Load	%Load Reduction	IP Target Load Reduction	% IP Target Achieved
Runoff Volume	MG/yr	65.5	52.4	13.1	26.2	40.0 %	32.0	81.8 %
Fecal Coliform	Billion CFU/yr	6,934.4	5,547.5	1,386.9	2,773.8	40.0 %	10,649.0	26.0 %
Total Suspended Solids	Kg/yr	3,049.4	2,439.5	609.9	1,219.8	40.0 %	6,478.0	18.8 %
Total Copper	Kg/yr	0.6	0.5	0.1	0.2	40.0 %	1.1	22.5 %
Total Zinc	Kg/yr	3.9	3.1	0.8	1.6	40.0 %	9.2	17.0 %
Total Phosphorus	Kg/yr	9.8	7.8	2.0	3.9	40.0 %	11.0	35.5 %
PCBs	g/yr	0.7	0.6	0.1	0.6	80.0 %	1.3	45.3 %

Figure 1. Example performance summary of the PPET for a conceptual bioretention system (left). Graphical output of scaled annual influent, overflow, and underdrain loads of total suspended solids and nitrate + nitrite based on monitoring data using the MRLC tool. Reduced loads are those infiltrated or retained by the bioretention systems.

Conclusions and Future Work

The tools developed for the City of Seattle provide an easy-to-use tracking and performance estimation platform to understand and report progress towards meeting regulatory load reduction requirements and volumetric goals. The tools can also be used to predict performance based on modelling or monitored information allowing for scenario analyses to determine necessary investments in stormwater management. The City plans to test and validate the tool over the next year.

References

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