[M.L. 2016, Chp. 186, Sec. 2, Subd. 04t] **Project Abstract**
For the Period Ending June 30, 2020

PROJECT TITLE: Surface Water Bacterial Treatment System Pilot Project
PROJECT MANAGER: Brian Corcoran
AFFILIATION: Vadnais Lake Area Water Management Organization
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FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: $500,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Vadnais Lake Area Water Management Organization to reduce bacteria and nutrient loads to Vadnais Lake, a drinking water supply reservoir, through implementation and evaluation of a subsurface constructed wetland as a best management practice for potential statewide use. The Vadnais Lake Area Water Management Organization must consider contracting with the University of Minnesota Department of Civil, Environmental, and Geo-Engineering to evaluate the effectiveness of the pilot treatment system so that it maximizes benefits and can be replicated elsewhere. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

APPROPRIATION AMOUNT: $500,000
AMOUNT SPENT: $456.644
AMOUNT REMAINING: $43,536

<u>**Sound bite of Project Outcomes and Results**</u>

The effectiveness of the subsurface constructed wetland clearly show that all three of the experimental cells were very effective in removing *E. coli* (a member of the fecal coliform group and a common fecal indicator bacteria) and nutrients (total phosphorus and nitrate) from stormwater in Lambert Creek. Pathogen results from the University of Minnesota monitoring were all negative.

Overall Project Outcome and Results

The main objective of this Project was to assess the effectiveness of the subsurface constructed wetland in removing pollutants commonly found in urban stormwater. One of the most striking observations of the Project was the dramatic reduction in *E. coli* concentrations. During the three storm events monitored in 2019, *E. coli* concentrations were reduced two to three orders of magnitude (95 to 100%) when compared to stormwater samples collected from Whitaker Pond. These results were similar to Pathogen Analyses conducted by the University of Minnesota (Section 5.2), which suggested that the treatment wetland reduced *E. coli* levels by at least 95%. Concentrations were reduced in the first layer of treatment (the gravel layer at the bottom of each of the three cells) to less than 10 MPN/100 mL in the first two storm events and to less than 100 MPN/100 mL in storm event 3. In general, E. *coli* concentrations remained low throughout the remainder of the treatment train as the stormwater passed through subsequent treatment layers (sand, growth media, and post-treatment, which included a layer of iron-enhanced sand). The effluent of the treatment wetland was discharged to groundwater through an additional layer of gravel, which very likely decreased *E. coli* concentrations even further.

The treatment wetland was also very effective in reducing concentrations of nutrients in urban stormwater. Although nutrient reductions were not as dramatic as those observed for *E. coli*, reductions were still substantial and were observed from the first layer of treatment (gravel). Total phosphorus concentrations were reduced dramatically (76% to 98% across all three storm events) in the gravel layer and concentrations remained low throughout the remainder of each of the wetland cells as stormwater flowed up through the subsequent

treatment layers. The results were most obvious in storm event 3, where TP concentrations were reduced nearly two orders of magnitude (100-fold) from pre-treatment stormwater levels.

Large reductions in nitrate concentrations were also observed during the first two storm events monitored over the course of the Project, where concentrations in stormwater were reduced nearly 10-fold after treatment in the gravel layer and remained low throughout the subsequent layers of treatment. The results were most dramatic in the media layer where concentrations were reduced to non-detect levels in nearly all samples, presumably due to the exposure of nitrate to the root zone within the media layer and uptake of the nutrient by the native plants growing on the top of each cell. This pattern in the media layer was also observed during storm event 3, but the overall pattern of nitrate removal during this storm event was inconsistent with those observed in storm events 1 and 2.

The Project clearly demonstrated that the unique design of the Lambert Creek treatment wetland design is effective at removing *E. coli* and nutrients from stormwater and is a viable BMP for improving water quality in urbanized watersheds to meet TMDL compliance targets and other regulatory goals.

Project Results Use and Dissemination

Signage was installed at site explaining Project, how it works and reason for the Project. Posting summary of Project, Project photos and Project updates on VLAWMO website. An on-site open house was held for public officials and residents August 2018. Preliminary results of Project were presented at the 2018 MN Water Resource Conference “Bacterial Source Tracking in the Lambert Creek Watershed – An Integrated Approach to Identifying and Reducing Bacterial Loads to Meet Regulatory Requirements”. Project finding presented at the City of Minneapolis “Urban Runoff Bacteria Sources Reduction and Identification Conference” February 2020. Final peer reviewed report completed on project.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan Final Report

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Date of Report: June 1, 2020

Final Report

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2020

PROJECT TITLE: Surface Water Bacterial Treatment System Pilot Project

Project Manager: Brian Corcoran

Organization: Vadnais Lake Area Water Management Organization

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Location: **Ramsey County and Statewide**

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$500,000**
	Amount Spent:	**$456,644**
	Balance:	**$43,356**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04t

Appropriation Language:
$500,000 the second year is from the trust fund to the commissioner of natural resources for an agreement with Vadnais Lake Area Water Management Organization to reduce bacteria and nutrient loads to Vadnais Lake, a drinking water supply reservoir, through implementation and evaluation of a subsurface constructed wetland as a best management practice for potential statewide use. The Vadnais Lake Area Water Management Organization must consider contracting with the University of Minnesota Department of Civil, Environmental, and Geo-Engineering to evaluate the effectiveness of the pilot treatment system so that it maximizes benefits and can be replicated elsewhere. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Surface Water Bacterial Treatment System Pilot Project

II. PROJECT STATEMENT:

In Minnesota today, there are over 500 waterbodies that are impaired due to elevated concentrations of fecal coliform bacteria (e.g., *Escherichia coli*) (http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/minnesotas-impaired-waters-and-total-maximum-daily-loads-tmdls.html). Reducing concentrations of fecal coliform bacteria in streams (particularly during storm events) has proven to be very difficult in urban settings and common engineering solutions (e.g., ultraviolet or reverse osmosis systems) are often prohibitively expensive. Thus, there is an urgent need for a cost-effective and innovative bacterial reduction best management practice (BMP). This project proposes to address the need by developing an experimental and subsurface constructed wetland (SSCW) BMP that can be used to improve water quality throughout the state. In addition to testing the effectiveness of the SSCW in reducing *E. coli* in Minnesota surface waters, the project will also be used to test the effectiveness of the SSCW design in reducing other common, problematic pollutants found in surface waters throughout the state: phosphorus, nitrates, pathogens, and polycyclic aromatic hydrocarbons (PAHs). The project will be located in Columbia Park, just west of Whitaker Pond in White Bear Township, MN. Whitaker Pond captures 640 acres of the primarily urban upper Lambert Creek Watershed (the watershed is currently impaired by *E.coli and total phosphoru*s) and is typical of many urban streams throughout Minnesota.

The goals of the project are to test the effectiveness of three experimental treatment cells within the SSCW with varying treatment media and upland wetland vegetation (see description below) to remove the most problematic pollutants from stormwater. The specific objectives of the project are to determine the most effective SSCW design for removing *E. coli*, nutrients (phosphorus and nitrate), and PAHs from stormwater. The project will also be used to assess the potential for implementing SSCW technology in removing the most common pollutants from urban waterbodies throughout the state. The University of Minnesota will study the effectiveness of the project on pathogen removal. The outcomes of the project will be a peer-reviewed publication detailing the findings of the research project. Per our acceptance letter from the LCCMR dated October 23, 2015 we were asked to consider contracting with the University of Minnesota Civil, Environmental, and Geo-Engineering Department to evaluate the effectiveness of the pilot treatment system so that it maximizes benefit and can be replicated elsewhere. Dr. Tim La Para from the University of Minnesota Civil, Environmental, and Geo-Engineering Department has agreed to consult on the project and assist with the evaluation and effectiveness of the pilot treatment system through help and guidance with the final peer reviewed paper, monitoring plan and design along with evaluating the effectiveness of the system through two years of undergraduate monitoring for specific pathogens. Educational signage will be installed at the site to disseminate information on the LCCMR-funded BMP and how it improves water quality, and a fully implemented BMP that will be used to improve water quality in Lambert Creek. The project activities and methods discussed below will be used to achieve these goals.

Because the surface elevation of Whitaker Pond is roughly 10-15 feet lower than the proposed location of the 130-foot by 30-foot SSCW in Columbia Park, a packaged solar powered pump system will be used to move water at a rate of approximately 5 gallons per minute from the vault adjacent to Whitaker Pond up to a distribution manifold at the SSCW site. The distribution manifold will deliver pollutant-laden storm water to each of three 10 by 130 foot experimental cells. Each cell will consist of (from the bottom up) an impermeable liner, followed by layers of gravel, sand, sorption media (unique combinations of limestone, tire crumbs, high-iron sand, and sawdust), and growth media (expanded clay, vermiculite, and peat moss to promote plant growth). The total depth of each cell will be approximately 3 to 4 feet. The top of each cell will be planted with upland wetland plants (one of the three cells will have no vegetation and will serve as a control). The thickness of the media layers, the constituents comprising the sorption media, and the vegetation type will be varied for each of the three experimental cells producing three unique combinations to be tested for pollutant removal effectiveness.

Stormwater will flow from the distribution manifold through each of the three experimental cells from the bottom up, through each of the unique media combinations, and through an outlet at the far end of the cells that discharges to an unlined infiltration gallery for groundwater recharge. The infiltration gallery will consist of a buried gravel layer over native soils. A geotechnical investigation will characterize the local subsurface soils and identify the allowable treated water infiltration rates. The unique vertical up-flow pattern in the experimental cells will maximize pollutant removal while maintaining wetted conditions in the growth media to promote plant growth. A series of monitoring ports will be installed at the interfaces between the media in each experimental cell to determine the effectiveness of the media layers (as well as the overall effectiveness of each experimental cell) in removing different pollutants(*E. coli*, phosphorus, nitrate, pathogens and PAHs). Details of the study design and monitoring procedures are described in more detail in Activity 3 (Effectiveness Monitoring), below. The results of the research project will be assessed for pollutant removal efficiencies and applicability of SSCWs throughout the state. This information will be disseminated through a journal article that will be published on the research project, informational signage at the site, presentations at technical conferences, Webex presentations to technical and non-technical target audiences, and the VLAWMO website.

The project has broad implications for treating surface waters throughout Minnesota for removal of the most common stormwater pollutants and provides a unique approach for reducing bacteria, which is among the most common receiving water impairments throughout the state. The results of this research project will allow development of site-specific treatment wetlands that specifically target pollutants of a given waterbody (e.g., storm ponds with elevated PAH levels, bacteria from recreational streams or high phosphorus loading from watershed runoff) while minimizing the BMP footprint. This type of scalable BMP is particularly advantageous in urban settings with inherent space constraints where streams are frequently impacted by multiple pollutants. In addition, as opposed to typical treatment wetlands, this innovative design uses a unique sub-surface vertical up-flow system with a combination of aerobic and anaerobic media layers and vascular plants specifically designed for treating the most common pollutants found in stormwater (e.g., nutrients and PAHs). Moreover, the project will provide important empirical data on the effectiveness of this unique SSCW design in removing bacteria, pathogens and other common pollutants from stormwater and improving the quality of surface waters throughout the state.

III. OVERALL PROJECT STATUS UPDATES:

Project Status as of *[December 1, 2016]***:** Lead contractor was chosen for project through bid process this summer. Burns & McDonnell will be lead contractor/engineer. License contract with White Bear Township for use of Columbia Park has been finalized, touching up final contract details between Burns & McDonnell (lead contractor/engineer) and VLAWMO.

Project Status as of *[June 1, 2017]***:** Lead engineer established a health and safety plan for the project and project meetings were held for design and permitting. Field survey and geotechnical characterization was completed and topographic map of project site was developed. Drawing list, project design and specifications were completed along with permitting requirements for project. Specifications for pump, solar power, and meters for project were determined as well as vendors for supplies and treatment media for project. Bid documents have been prepared and are currently out for solicitation for project construction.

Project Status as of *[December 1, 2017]***:** Construction began on project. Treatment cells dug, liners and media installed and piping in. Pump, solar panel and testing of proper cell function to be done in spring along with plantings for treatment cells. Monitoring plan will be completed this winter.

Project Status as of *[June 1, 2018]***:** Treatment cells are complete and system is being tested. Native plants will be installed mid-June and sampling will begin. Monitoring plan is complete.

Project Status as of *[December 1, 2018]***:** First year of monitoring was complete. Three storm events were tested and treatment system performed well.

Project Status as of *[June 1, 2019]***:** Beginning second year of monitoring. University of Minnesota will also be doing their pathogen testing on the system this summer.

Project Status as of *[December 1, 2019]***:** Monitoring complete. Working on data analysis and report.

Project Status as of *[June 1, 2020]***:** Draft report is ready

Overall Project Outcomes and Results: The main objective of this Project was to assess the effectiveness of the subsurface constructed wetland in removing pollutants commonly found in urban stormwater. One of the most striking observations of the Project was the dramatic reduction in *E. coli* concentrations. During the three storm events monitored in 2019, *E. coli* concentrations were reduced two to three orders of magnitude (95 to 100%) when compared to stormwater samples collected from Whitaker Pond. These results were similar to Pathogen Analyses conducted by the University of Minnesota (Section 5.2), which suggested that the treatment wetland reduced *E. coli* levels by at least 95%. Concentrations were reduced in the first layer of treatment (the gravel layer at the bottom of each of the three cells) to less than 10 MPN/100 mL in the first two storm events and to less than 100 MPN/100 mL in storm event 3. In general, E. *coli* concentrations remained low throughout the remainder of the treatment train as the stormwater passed through subsequent treatment layers (sand, growth media, and post-treatment, which included a layer of iron-enhanced sand). The effluent of the treatment wetland was discharged to groundwater through an additional layer of gravel, which very likely decreased *E. coli* concentrations even further.

The treatment wetland was also very effective in reducing concentrations of nutrients in urban stormwater. Although nutrient reductions were not as dramatic as those observed for *E. coli*, reductions were still substantial and were observed from the first layer of treatment (gravel). Total phosphorus concentrations were reduced dramatically (76% to 98% across all three storm events) in the gravel layer and concentrations remained low throughout the remainder of each of the wetland cells as stormwater flowed up through the subsequent treatment layers. The results were most obvious in storm event 3, where TP concentrations were reduced nearly two orders of magnitude (100-fold) from pre-treatment stormwater levels.

Large reductions in nitrate concentrations were also observed during the first two storm events monitored over the course of the Project, where concentrations in stormwater were reduced nearly 10-fold after treatment in the gravel layer and remained low throughout the subsequent layers of treatment. The results were most dramatic in the media layer where concentrations were reduced to non-detect levels in nearly all samples, presumably due to the exposure of nitrate to the root zone within the media layer and uptake of the nutrient by the native plants growing on the top of each cell. This pattern in the media layer was also observed during storm event 3, but the overall pattern of nitrate removal during this storm event was inconsistent with those observed in storm events 1 and 2.

The Project clearly demonstrated that the unique design of the Lambert Creek treatment wetland design is effective at removing *E. coli* and nutrients from stormwater and is a viable BMP for improving water quality in urbanized watersheds to meet TMDL compliance targets and other regulatory goals.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Preliminary and Final Design and Permitting

Description: Complete subsurface investigation including soil borings and test pits to determine infiltration rates and characterize underlying soils. Finalize design plans and specifications and prepare bid documents.

Task 1 – Field Survey

The team will conduct a site topographic survey as needed to accurately represent field conditions. Horizontal and vertical controls for the project will be identified on the ground survey. On-site utilities and utility easements will be identified along with property boundaries in the vicinity of the project. Topography will be in one-foot contours. The coordinate system will be North American Datum of 1983 State Plane Minnesota South, and NAVD 88 Elevations. In addition to the basic surveying, the team will provide survey locations for:

- All major trees and shrubs that are native and invasive
- Locations for test pits and borings and monitoring wells required for Task 3

Surveying the location of trees and shrubs that are native and invasive will assist us in preparing the restoration construction plans where select invasive plants will be replaced with native plants. Native plant species will be incorporated into the restoration of the construction area and general vicinity of the project site.

Task 2 – Geotechnical & Hydrogeologic Characterization

The team will solicit proposals from geotechnical firms to provide the geotechnical professional services for the project. The following is a summary of the geotechnical and hydrogeologic characterization work to be done under this task:

- Characterize the infiltration capacity of the native soils in the SSCW's discharge area using American Society of Testing Materials (ASTM) methodology.
- Drill three soil borings by a limited access drilling rig into shallow groundwater estimated to be approximately 10 feet below grade. The soil borings will be completed as two-inch polyvinyl chloride (PVC) piezometers with 10 feet of 0.010-inch slot well screen. The piezometers will be completed as locking above-grade well boxes. The three piezometers will be installed around the perimeter of the SSCW so that groundwater elevation and flow direction can be consistently measured over time. The water level data will be tabulated and compiled to produce a groundwater flow map for the wetland area. Aquifer slug testing and data analysis can also be completed in one piezometer if needed to supplement the field and laboratory soil testing to estimate hydraulic conductivity of the native soils in the vicinity of the SSCW.
- Collect soil samples for field logging per ASTM D2488 (field classification per Unified Soil Classification System [USCS]), and collect laboratory samples for grain size, vertical hydraulic conductivity, and Atterberg limits/USCS classification per ASTM methodology.

- Prior to drilling, locate and map potential existing utility lines and related infrastructure in the area such as telephone, electric, water, cable, fiber optic, or natural gas and other lines.
- Prepare a summary report of the subsurface investigation summarizing the results and recommendations.

Task 3 – Construction Documents

The team will prepare all drawings, specifications, schedules, and cost estimates for the project. Concept drawings will be discussed in-person with municipal (White Bear Township, White Bear Lake) staff, with whom the team will discuss constructability and maintenance issues and provide recommendations. When directed, construction documents for the final recommended project will be prepared. To support the development of the project construction documents, the team will:

- Prepare a detailed project description to facilitate permitting
- Prepare a 30% complete plan set for permitting
- Design pipe conveyances from existing storm water piping into new system
- Design a pump station for dry weather surface water withdrawal from Whittaker Pond
- Prepare 90% complete plan set for municipal review
- Prepare 100% complete plan set for bidding

Task 4 – Permit Coordination & Application

The Team will prepare permit applications for construction. The permitting schedule will be dependent on agency review time for the permit documents and agency availability for meetings and consultation. It is anticipated that the project will be required to comply with the following regulatory agencies, including the White Bear Township:

- U. S. Army Corps of Engineers – Section 404 Permit (as needed for the project)
- Minnesota Department of Natural Resources (MnDNR), Board of Water and Soil Resources and the local government unit – Wetland Conservation Act (WCA) permit (as needed for the project)
- MnDNR – Surface Water Appropriations Permit
- White Bear Township – Grading and Wetland Permit

Summary Budget Information for Activity 1:	**ENRTF Budget:**	**$ 101,500**
	Amount Spent:	**$ 101,094**
	Balance:	**$ 406**

Outcome	**Completion Date**
1. Field Survey - Conduct a site topographic survey ($5,000)	August 30, 2016
2. Geotechnical & Hydrogeologic Characterization - Complete three soil borings and five infiltration test pits. Prepare subsurface investigation report. ($30,000)	August 30, 2016
2. Construction Documents - Complete design plans and specifications and produce procurement and bid documents. ($59,500)	January 31, 2017
3. Permit Coordination and Applications - Prepare permit (404 permit, dewatering, grading and etc.) applications for construction ($7,000)	April 1, 2017

Activity Status as of *[December 1, 2016]*: Field survey and geotechnical & hydrogeoligic sub contractors are lined up to do their work once final details of lead contractor/engineer contract are finalized.

Activity Status as of *[June 1, 2017]***:** Field survey, geotechnical characterization, construction documents and permit coordination have been completed. The first two invoices for these services have been received and paid. Invoice #1 for $6,929.39 for a portion of geotechnical services and invoice #2 for $19,496.56 for a portion of engineering design.

Final Report Summary for Activity 1: *[Dec 1, 2017]*: Field survey, geotechnical characterization, construction documents and permit coordination have been completed.

ACTIVITY 2: Construction Management and Construction of Treatment Cells.

Description: Select contractor and construct project.

Vadnais Lake Area Water Management Organization will solicit via competitive bid for the project engineering firm. The team will complete the following activities during the procurement and construction phase of the project.

- Conduct bid evaluation
- Prepare addenda(s), as required.
- Facilitate one pre-bid meeting, one preconstruction meeting, and regular site progress review meetings
- Address requests for information (RFIs)
- Review shop drawings
- Review and process submittals
- Conduct regular site visits during construction

We have assumed the construction phase will be 3.5 months in duration. To complete the activities listed above, the team will use the tools listed below that have proven to be effective in managing similar projects.

Project Coordination
Beyond the standard weekly and monthly emails and calls, the team will establish a hierarchical and peer based communication plan. This plan will encourage each manager and lead from each department to be in constant communication with their company counterpart, contractor etc. through an informal process on a potentially daily basis.

Project Meetings
Each meeting will include agendas and the proceedings will be documented. These meeting minutes will include attendees, items discussed, decisions, and action items. Minutes will be distributed to all attendees for review and agreement. The first order of business in each meeting will be to review the action items from the previous meeting to confirm that scheduled items have been completed.

Schedule
The team will develop a clear schedule for the project and monitor that schedule daily. Schedule metrics will be included in weekly and monthly reports. Should the schedule become an issue the team will alert the granting agency.

Progress Reports
Prior to each formal progress meeting, the team will produce a progress report that summarizes the status of each task, including budget, schedule analysis, work completed, work anticipated, future milestones, and potential deviations from those milestones of each task. The report will also itemize outstanding issues or questions that need to be resolved as the project progresses. We have assumed one site visit per week during

construction. We have assumed the contractor will prepare the project SWPPP and complete the SWPPP inspections.

Final Report Summary for Activity 2:

Summary Budget Information for Activity 2:	**ENRTF Budget:**	**$ 321,400**
	Amount Spent:	**$ 310,222**
	Balance:	**$ 11,178**

Outcome	**Completion Date**
1. Construction Administrations ($20,000)	September 1, 2017
2. Construction of the Subsurface Constructed Wetland (mobilization - $18,000, Wetland Area - $60,000, Infiltration area - $22,000, Pumps and Piping - $201,400)	September 1, 2017

Activity Status as of *[December 1, 2016]***:** No work has been completed, finalizing contract with lead contractor/engineer.

Activity Status as of *[June 1, 2017]***:** Bid documents have been completed for project construction and are currently out for solicitation. Construction on schedule to begin in September 2017.

Activity Status as of *[December 1, 2017]*: Construction of treatment cells are complete. Due to weather the pumps, solar panel, battery packs and vegetation will be installed in the spring. Testing of system will be completed in early spring and monitoring will begin.

Activity Status as of *[June 1, 2018]*: Solar panel, battery packs and vegetation installed. System testing completed. Begin monitoring.

Activity Status as of *[December 1, 2018]:* System is complete. Still waiting on final bills.

Final Report Summary: *[June 1, 2019]*: The University of Minnesota along with VLAWMO completed all storm monitoring activities. The University of Minnesota along with VLAWMO and Burns & McDonnell worked together to write and review the monitoring plan. All data was collected and analyzed by both the University of Minnesota as well as VLAWMO. The University of Minnesota along with VLAWMO and Burns & McDonnell worked together to write and review the final Lambert Creek Treatment Wetland Pilot Project report. All University of Minnesota conditions were met per work plan.

ACTIVITY 3: Effectiveness Monitoring

Description: Finalize monitoring plan and perform long-term monitoring to assess system performance and pollution-reduction effectiveness for phosphorus, nitrates, polycyclic aromatic hydrocarbons and E. coli. Produce project report including summary of monitoring results. As requested, the project has secured the consulting assistance of Dr. Tim La Para, University of Minnesota Department of Civil, Environmental, and Geo-Engineering to evaluate the effectiveness of the pilot treatment system so that it maximizes benefits and can be replicated elsewhere.

Task 1 – Monitoring Plan

Following construction, the team will produce a detailed monitoring plan that details the steps involved in assessing the overall performance of the project and the effectiveness of the SSCW in reducing stormwater pollutants. The monitoring plan will include the methods for field work and sample collection, described sample handling and chain of custody procedures, define appropriate parameters required by the analytical laboratory, identify quality control and quality assurance (QA/AC) procedures to be followed in the field and laboratory, and discuss statistical analyses and reporting requirements. Monitoring plan will address the specific parameters to be sample, those being phosphorus, nitrates, E. coli and PAH's. A draft monitoring plan will be produced for the project, which will be reviewed by technical experts at the University of Minnesota, specifically Dr. Tim La Para who has agreed to be a consultant for the project, help with the final peer reviewed paper, monitoring plan and design. The University will be contracted to assess the effectiveness of the system in removing pathogens. Once edits and comments from reviewers have been incorporated into the draft monitoring plan, a final monitoring plan for the project will be produced. The monitoring plan will be produced and approved prior to any sample collection. Vadnais Lake Area WMO anticipates continuing monitoring of the project at least 5 years after final reporting in 2020.

Task 2 – Sample Collection and Analysis

Sample collection and analysis for assessing project performance and effectiveness will be conducted following the procedures detailed in the monitoring plan. The SSCW will contain a series of monitoring ports (where samples for phosphorus, nitrates, E. coli and PAH's will be taken) consisting of 2-inch PVC pipes inserted vertically into the SSCW at the interface of the various media layers (the top of the monitoring ports will be capped to prevent surface contamination and the bottom of the ports will be surrounded by a mesh material to prevent clogging). During construction, the monitoring ports will be placed in a series of monitoring arrays. Each array will consist of three PVC pipes installed at three locations within the SSCW: top of gravel layer, top of sand layer, and top of sorption media layer. There will be three arrays placed at the upstream, middle, and downstream ends of each experimental cell. In this way, each of the three experimental cells will have nine monitoring ports (27 monitoring ports overall for the project). During a monitoring event, samples from a given depth in an experimental cell will be collected and composited prior to analysis of chemical pollutants (nitrates, phosphorus, and PAHs). Separate samples will be collected for *E. coli* analysis and analyzed individually (not composited). A total of three post-construction monitoring events will be conducted.

BMP effectiveness will be determined by comparing pollutant concentrations in the untreated stormwater (prior to distribution into the treatment cells) to pollutant concentrations from samples collected from the 27 monitoring ports after treatment in the various media layers of each of the three experimental cells. This study design will allow for a statistical assessment of the effectiveness of each of the media layers as well as each overall experimental cell in reducing pollutant concentrations in stormwater.

Task 3 – Reporting and Final Report Summary

The results of the effectiveness monitoring will be summarized in a report following QA/QC procedures, statistical analyses, and reporting requirements detailed in the monitoring plan. The report will assess the effectiveness of the project in reducing stormwater pollutants and will include an executive summary, introduction, materials and methods, results, and conclusions sections. A draft report will be produced for the project, which will be reviewed by Dr. Tim LaPara at the University of Minnesota, as well as LCCMR staff. Once edits and comments from reviewers have been incorporated into the draft report, a final report for the project will be produced.

Final Report Summary for Activity 3: December 1, 2020

Summary Budget Information for Activity 3:		
	ENRTF Budget:	**$ 77,100**
	Amount Spent:	**$ 45,328**
	Balance:	**$ 31,772**

Outcome	Completion Date
1. Complete Monitoring Plan ($3,000)	March 1, 2018
2. Conduct sample collection and analysis ($37,100)	November 30, 2018
3. Produce Draft and Final Assessment Reports ($7,000)	March 29, 2019
4. University of Minnesota ($30,000)	March 29, 2019

Activity Status as of *[December 1, 2016]***:** No work completed yet.

Activity Status as of *[June 1, 2017]***:** No work completed yet.

Activity Status as of *[December 1, 2017]***:** Beginning work on monitoring plan and coordination with the U of M.

Activity Status as of *[June 1, 2018]***:** Monitoring plan completed, sampling to begin.

Activity Status as of *[December 1, 2018]***:** Three storm events were sampled during the season. System worked well and reduction in bacteria and nutrients levels was good. Will begin sampling again in spring 2019.

Activity Status as of *[June 1, 2019]***:** Sampling has started for season two. University of Minnesota has started their pathogen testing on the system.

Activity Status as of *[December 1, 2019]***:** Sampling is competed. Four storm events were sampled. Currently working on data analysis and final report.

Final Report Summary: See attached final report

ACTIVITY 4: Education and Outreach
Description: Install informational signage at the site. Distribute BMP information and performance results via conference presentations, webinars and an academic paper. The tasks and deliverables included in this Activity will be conducted by project participants as in-kind services.

Task 1 – Educational Signage at the Project Site

An informational graphic sign will be prepared for the project and installed at the project site. The project is adjacent to a soccer field, baseball diamond, and other recreational facilities at Columbia Park and the area receives substantial amounts of visitors from spring through fall. The signage will highlight the experimental design, objectives, and outcomes of the LCCMR-funded project, the anticipated improvement in water quality, and the benefits to the community.

Task 2 – Conference Presentations

After the results of the effectiveness monitoring have been analyzed, the research project will be presented at technical conferences that focus on stormwater and water resource issues. The presentations will highlight the objectives of the LCCMR-funded project, discuss the results of the SSCW BMP effectiveness monitoring in reducing levels of bacteria and other pollutants in stormwater, and identify areas throughout the state where the technology may be applied. The conference presentations are not part of the project budget and will be conducted as in-kind services by the project manager and other technical experts associated with the project.

Task 3 – Webinars

After the results of the effectiveness monitoring have been analyzed, the research project will be presented by project team members via webinars to individuals and entities throughout the state that might be interested in this BMP technology. Target audiences for the webinars will likely include cities, watershed districts, watershed management organizations, MN Department of Transportation (MnDOT), MN Pollution Control Agency (MPCA), and/or soil and water conservation districts (SWCDs). The format of the presentations will depend on the results of the research project and the target audience, but will likely highlight the objectives of the LCCMR-funded project, discuss the results of the SSCW BMP effectiveness monitoring in reducing levels of bacteria and other pollutants in stormwater, and identify areas within the jurisdiction of the target audience where the technology may be applied.

Task 4 – Peer-reviewed Journal Article

After the effectiveness monitoring has been completed and the final report for the project has been produced, the results of the research project will be used to prepare an article for submission to a peer-reviewed scientific journal for publication. The journal article will reflect the information in the final report for the project (see Activity 3, Task 3) and will be used to communicate the technical information gained from the project to the scientific community interested in stormwater treatment and water resources management.
Final Report Summary for Activity 4: December 1, 2020

Summary Budget Information for Activity 4:

ENRTF Budget:	**$ 0**
Amount Spent:	**$ 0**
Balance:	**$ 0**

Outcome	**Completion Date**
1. Educational signage at the project site.	September 1, 2017
2. Present project and monitoring results at water resources related technical conferences (e.g., MN Water Resources Conference, MN Association of Watershed Districts, WEFTEC).	October and December 2018
3. Present project results via webinars targeted to entities within MN interested in implementing this BMP (e.g., cities, watershed districts, watershed management organizations, MnDOT, MPCA, SWCDs)	December 1, 2018
4. Prepare and submit academic paper to peer –reviewed journal.	June 30, 2020

Activity Status as of *[December 1, 2017]***:** Working on educational signage for project site.

Activity Status as of *[June 1, 2018]***:** Educational signage at project site ordered, to be installed late June. Project updates on website.

Activity Status as of *[December 1, 2018]***:** Educational signage was installed at project site. An on-site open house was held for public officials and residents in August explaining the project and how it works. Open house was well attended. Project updates on website. Preliminary results were discussed at the 2018 MN Water Resource Conference presentation on Bacterial Source Tracking in the Lambert Creek Watershed – An Integrated Approach to Identifying and Reducing Bacterial Loads to Meet Regulatory Requirements.

Activity Status as of *[June 1, 2019]***:** Project updates continue on website. Webinar has been postponed to end of season so University of Minnesota pathogen results can be included.

Activity Status as of *[December 1, 2019]***:** Project updates continue on website. Webinar is planned for January once all data analysis has been completed.

Final Report Summary: Signage was installed at site explaining Project, how it works and reason for the Project. Posting summary of Project, Project photos and Project updates on VLAWMO website. An on-site open house was held for public officials and residents August 2018. Preliminary results of Project were presented at the 2018 MN Water Resource Conference "Bacterial Source Tracking in the Lambert Creek Watershed – An Integrated Approach to Identifying and Reducing Bacterial Loads to Meet Regulatory Requirements". Project finding presented at the City of Minneapolis "Urban Runoff Bacteria Sources Reduction and Identification Conference" February 2020. Final peer reviewed report completed on project.

V. DISSEMINATION:

Description: Disseminate information on the project, the results of the effectiveness monitoring, and the applicability of the technology for applications throughout the state.

Information about the project will be disseminated by the following means:

- Educational signage at the project site at Columbia Park
- Conference presentations that focus on stormwater and water resource issues
- Webinars to technical and non-technical target audiences that might be interested in this BMP technology
- Submittal of article on the results of the research project to a peer-reviewed scientific journal for publication.

These tasks that will be used to disseminate project information are discussed in Activity 4 above. In addition, to these tasks, information on the project will also be made available on the VLAWMO website at www.vlawmo.org.

Status as of *[December 1, 2016]***:** Project page is up on the VLAWMO website detailing project.

Status as of *[June 1, 2017]***:** Project page is up on the VLAWMO website detailing project.

Status as of *[December 1, 2017]***:** Project page is up on VLAWMO website detailing project and progress.

Status as of *[June 1, 2018]***:** Project page is up on VLAWMO website detailing project and progress.

Status as of *[December 1, 2018]***:** Project page is up on VLAWMO website detailing project and progress.

Status as of *[June 1, 2019]***:** Project page is up on VLAWMO website detailing project and progress.

Status as of *[December 1, 2019]***:** Project page is up on VLAWMO website detailing project and progress.

Final Report Summary for Dissemination: August 15, 2020 Signage was installed at site explaining Project, how it works and reason for the Project. Posting summary of Project, Project photos and Project updates on

VLAWMO website. An on-site open house was held for public officials and residents August 2018. Preliminary results of Project were presented at the 2018 MN Water Resource Conference "Bacterial Source Tracking in the Lambert Creek Watershed – An Integrated Approach to Identifying and Reducing Bacterial Loads to Meet Regulatory Requirements". Project finding presented at the City of Minneapolis "Urban Runoff Bacteria Sources Reduction and Identification Conference" February 2020. Final peer reviewed report completed on project.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
University of Minnesota	$30,000	Pathogen monitoring, project consulting assistance
Professional/Technical/Service Contracts:	$470,000	Engineering firm will complete the engineering design, construction administration and data analysis. Additional services will be solicited via competitive bid for geotechnical, construction, and restoration services.
TOTAL ENRTF BUDGET:	**$500,000**	

Explanation of Use of Classified Staff: N/A

Explanation of Capital Expenditures Greater Than $5,000: N/A

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 0

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0.4

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
Vadnais Lake Area WMO	$30,000	$	Staff Time to oversee project
State			
City of White Bear Lake	$2000	$	Maintenance of pump station
TOTAL OTHER FUNDS:	**$**	**$**	

VII. PROJECT STRATEGY:

A. Project Partners:

Project Partner	Responsibilities/Role
Vadnais Lakes Area WMO	Project owner and manager, conduct monitoring/prepare reports, disseminating funds and project information and results, conduct monitoring/prepare reports
White Bear Township	Property owner
St. Paul Regional Water Service	Provide design information and review
Ramsey County	
City of White Bear Lake	

University of Minnesota	Provide comments, review and assistance with design and monitoring of project, peer-review paper assistance and evaluation of effectiveness of project

B. Project Impact and Long-term Strategy:

The direct, long-term impact of this project will be to implement a novel, cost-effective BMP to reduce bacteria in drinking water supplied to East Vadnais Lake and aquifer recharge. BMP design and construction information and performance results will be disseminated to entities throughout the State so that they may implement this type of BMP to address elevated bacteria levels within their water resources.

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
Vadnais Lake Area WMO for Burns & McDonnell to put together proposal to address impairment	November 2015	$14,800

VIII. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:

IX. VISUAL COMPONENT or MAP(S):

X. RESEARCH ADDENDUM:

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than [*December 1, 2016*], [*June 1, 2017*], [*December 1, 2017], [June 1, 2018], [December 1, 2018], [June 1, 2019], and [December 1, 2019].* A final report and associated products will be submitted between June 30 and August 15, 2020.

Environment and Natural Resources Trust Fund
M.L. 2016 Project Budget

Project Title: Surface Water Bacterial Treatment System Pilot Project
Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04t
Project Manager: Brian Corcoran
Organization: Vadnais Lake Area Water Management Organization
M.L. 2016 ENRTF Appropriation: $ 500,000
Project Length and Completion Date: 3 Years, June 30, 2020
Date of Report: June 1, 2020

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance				TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	**Preliminary and Final Design and Permitting**			**Construction Management**			**Effectiveness Monitoring**							
Professional/Technical/Service Contracts														
Engineering Design,Construction Administration and Data Analysis	$71,500	$71,177	$323	$21,000	$11,081	$9,919	$10,000	$1,941	$8,059				$102,500	$18,302
Geotechincal Services	$30,000	$29,917	$83										$30,000	$83
Wetland Construction and Restoration Services			$0	$300,400	$299,141	$1,259							$300,400	$1,259
University of Minnesota							$30,000	$29,564	$436				$30,000	$436
Monitoring Services							$37,100	$13,824	$23,276				$37,100	$23,276
COLUMN TOTAL	**$101,500**	**$101,094**	**$406**	**$321,400**	**$310,222**	**$11,178**	**$77,100**	**$45,328**	**$31,772**				**$500,000**	**$43,356**

Lambert Creek Treatment Wetland Pilot Project

Final Report

Vadnais Lake Area Water Management Organization

Project No. 97161

7/28/2020

Lambert Creek Treatment Wetland Pilot Project

Final Report

prepared for

Vadnais Lake Area Water Management Organization

Vadnais Heights, MN

Project No. 97161

7/28/2020

prepared by

Burns & McDonnell Engineering Company, Inc.
La Jolla, CA 92037

TABLE OF CONTENTS

Page No.

LIST OF TABLES

Page No.

LIST OF FIGURES

Page No.

LIST OF ABBREVIATIONS

Abbreviation	**Term/Phrase/Name**
BACI	Before, After, Control, Impact
BMP	Best Management Practice
Burns & McDonnell	Burns & McDonnell Engineering, Inc.
^{o}C	degrees Celsius
COC	Chain of Custody
DNA	deoxyribonucleic acid
FCSV	final concentrated sample volume
gpm	gallons per minute
HRT	hydraulic residence time
M	Molar
mL	milliliter
MPCA	Minnesota Pollution Control Agency
Project	Treatment Wetland Pilot Project
QA/QC	Quality Assurance/Quality Control
qPCR	polymerase chain reaction
SSCS	subsurface constructed wetland
TMDL	Total Maximum Daily Load
Township	White Bear Township
µg	microgram
µL	microliter
VFB	vertical flow bed

Abbreviation	**Term/Phrase/Name**
VLAWMO	Vadnais Lake Area Water Management Organization
WLCS	water level control structure

1.0 INTRODUCTION

Lambert Creek is located in the northeast Twin Cities Metropolitan Area of Minnesota in the Upper Mississippi River Basin. The Lambert Creek Watershed covers an area of approximately 25 square miles and includes portions of the Cities of North Oaks, White Bear Lake, Gem Lake, Vadnais Heights, Lino Lakes, and White Bear Township (Township), Minnesota. The watershed falls within the jurisdiction of the Vadnais Lake Area Water Management Organization (VLAWMO) and consists of a mix of urban, open space, parks, and agricultural land uses.

Lambert Creek does not currently meet Minnesota state standards for the indicator bacteria *Escherichia coli* (*E. coli*) and has been placed on the state's 303(d) List of Impaired Water Bodies. As a result, in August 2013, the Minnesota Pollution Control Agency (MPCA) developed a Total Maximum Daily Load (TMDL) for *E. coli* in Lambert Creek (Wenck, 2013), which is the total amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant. In response to the TMDL, VLAWMO contracted Burns and McDonnell Engineering, Inc. (Burns & McDonnell) to conduct a bacterial source identification study to identify the sources of *E. coli* in the Lambert Creek Watershed and recommend best management practices (BMPs) that can be implemented to meet the load reduction requirements of the TMDL.

Reducing concentrations of fecal indicator bacteria (e.g., *E. coli*) in streams has proven to be very difficult in urban settings and common engineering solutions (e.g., ultraviolet or reverse osmosis systems) are often prohibitively expensive. Thus, there is an urgent need for cost-effective, innovative bacterial reduction BMPs. One of the BMPs that has been implemented as a result of the source identification study is a Treatment Wetland Pilot Project (Project) that has been constructed adjacent to Lambert Creek in Columbia Park, within the jurisdictional boundaries of White Bear Township (Figure 1-1). Design, construction, and monitoring of the Project is a joint effort between the Township, VLAWMO, Burns & McDonnell, the University of Minnesota, and Belair Sitework Services. Funding for the Project was provided by the state of Minnesota through the Environment and Natural Resources Trust Fund. Construction of the treatment wetland was completed in July 2018 and effectiveness monitoring was conducted in the summers of 2018 and 2019.

This report summarizes the results of the monitoring program, which focused on assessing the effectiveness of the treatment wetland in reducing concentrations of *E. coli*, a suite of pollutants typically found in stormwater runoff, and several pathogens that have been identified in stormwater samples collected throughout Minnesota. A map of the study area is shown in Figure 1-1.

Figure 1-1: Map of Project Area

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Issued: 4/28/2015

Path: C:\Users\djmurphy\Desktop\LCCMR Grant\LCCMR Location Map.mxd djmurphy 4/28/2015

1.1 Project Objectives

The goals of the Project are to test the pollutant-reduction effectiveness of three experimental treatment cells within a subsurface constructed wetland (SSCW). Each cell contains varying treatment media and upland wetland vegetation to remove the most problematic pollutants from stormwater. The specific objectives of the project are:

- Determine the most effective SSCW design for removing *E. coli*, nutrients (phosphorus and nitrate), and other pollutants from stormwater.
- Assess the potential for implementing SSCW technology in removing the most common pollutants from urban waterbodies in other areas of the state.
- Provide educational signage installed at the site to disseminate information on the Project and how it improves water quality in Lambert Creek.
- Provide a report detailing the findings of the research Project.

1.2 Project Team

This Project was conducted by a team of scientists and water quality experts. Team members and their responsibilities are listed below.

- VLAWMO
    - Responsible for maintenance of SSCW, collection of field samples during monitoring events, and coordination with the laboratories and other team members.
- Burns & McDonnell
    - Responsible for overall project coordination, monitoring plan preparation, data analysis, and report preparation.
- University of Minnesota (Dr. Timothy Lapara)
    - Responsible for monitoring design, sample analysis, data analysis, and reporting of stormwater pathogens.
- RMB Environmental Laboratories
    - Responsible for analyzing non-pathogen related water samples and associated reporting.

2.0 TREATMENT WETLAND DESCRIPTION AND STUDY DESIGN

This Chapter describes the design of the SSCW as well as the study deign used to test its effectiveness in reducing pollutant concentrations in stormwater.

2.1 SSCW Description

The Project is located in Columbia Park on a vacant lot adjacent to a soccer field, just east of Whittaker Pond in White Bear Township, Minnesota (Figure 1-1). Whitaker Pond captures approximately 640 acres of the primarily urban upper Lambert Creek Watershed (this reach of Lambert Creek is currently impaired by *E.coli* and total phosphorus) and is typical of many urban streams throughout Minnesota.

The SSCW consists of three experimental vertical flow bed (VFB) cells, with each cell consisting of (from the bottom up) an impermeable liner, a layer of gravel, a layer of sand, a layer of sorption media (engineered soil), and a layer of growth media. A schematic of a single VFB cell showing the direction of water flow is provided on Figure 2-1. A cross-section of the three VFB cells in the SSCW are provided on Figure 2-2. Each VFB cell is approximately three feet deep, 19 feet wide (at the top, 13 feet wide at the bottom) and 54 feet long. The sorption media in each of the three VFB cells contains different combinations of sorptive materials that have been shown in other studies to reduce concentrations of fecal indicator bacteria and other constituents. Stormwater from Whitaker Pond enters the bottom of each of the cells, flows up through the filter media layers, then across the growth media at the top of the SSCW and out the far end.

Figure 2-1: Schematic of Stormwater Flow Through a VFB Cell

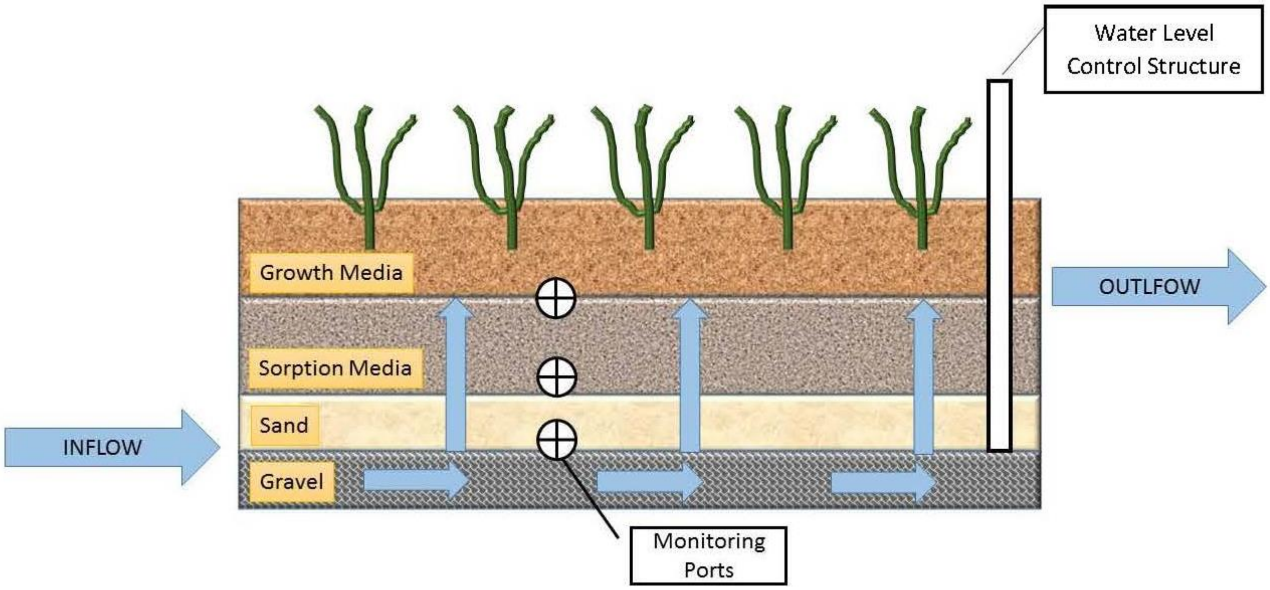
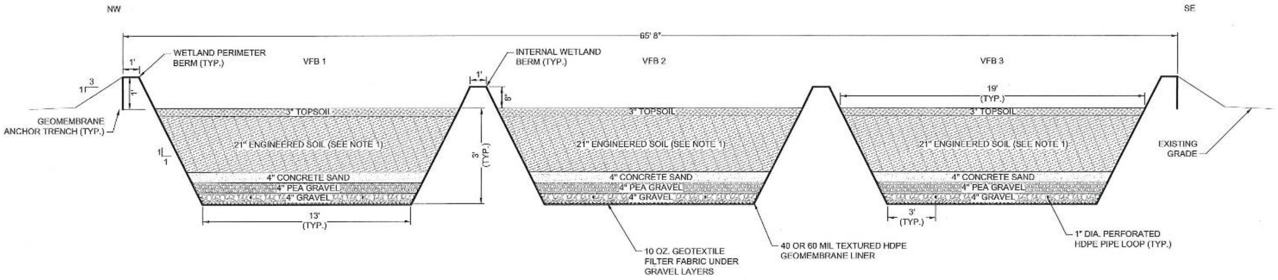
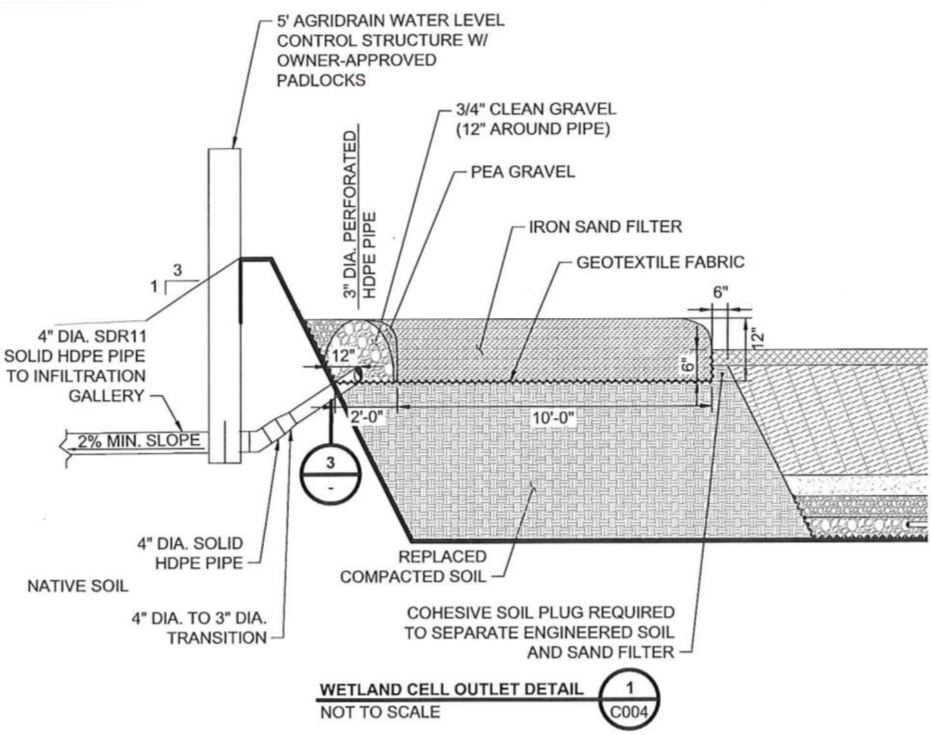


Figure 2-2: Cross Section of the Three VFB Cells



The far end of each cell contains a final layer of iron-enhanced sand, approximately 12 feet long by 12 inches deep, as depicted on Figure 2-3. After passing through the media layers in each VFB cell, treated water passes horizontally through the iron enhanced sand layer, then leaves the cell through a final collection pipe. Treated water in the pipe flows through the bottom of an inline water level control structure (WLCS) – a stainless steel metal box fitted with stoplogs that control the water level in each of the cells. After passing through the bottom of the WLCS, the treated water is discharged to an infiltration gallery (consisting of an unlined gravel trench over native soils), where the water will infiltrate to groundwater. The top of the SSCW is planted with native plants, which are irrigated with the treated stormwater from the SSCW. The unique vertical up-flow pattern in the VFB cells maximizes pollutant removal while maintaining wetted conditions in the growth media to promote plant growth.

Figure 2-3: Schematic of Final Iron Sand Filter and WLCS



Because the surface elevation of Whittaker Pond is roughly 10-15 feet lower than the location of the SSCW in Columbia Park, a packaged solar powered pump system was installed inside a pump house at the near end of the SSCW to move water from the pond to the VFB cells. The pump moves stormwater at a rate of approximately 5 gallons per minute (gpm) through a three-inch diameter pipe submerged in the pond to a distribution manifold at the SSCW site. The distribution manifold delivers pollutant-laden stormwater to each of the three VFB cells through a three-inch diameter perforated distribution pipe placed on top of the liner at the bottom of each VFB cell.

In order to test pollutant-removal effectiveness, a series of monitoring ports were installed at the interfaces between the media layers in each VFB cell to determine the effectiveness of the media layer (as well as the overall effectiveness of each VFB cell) in removing *E. coli* and other pollutants from stormwater. Each port consists of a 2-inch diameter PVC pipe inserted vertically into the SSCW at the interface of the various media layers (the top of the monitoring ports are capped to prevent surface contamination and the bottom of the ports are surrounded by a mesh material to prevent clogging). During construction, the monitoring ports were placed in a series of monitoring arrays. Each array consists of three PVC pipes installed at three locations within each VFB cell: top of gravel layer, top of sand layer, and top of sorption media layer (See Figure 2-1). There are three arrays placed at the upstream, middle, and downstream ends of each VFB cell. In this way, each of the three VFB cells has nine monitoring ports (27 monitoring ports overall for the project).

Figure 2-4: Photograph of Three Sampling Ports of a Monitoring Array Used to Collect Treated Water from Gravel (G), Sand (S), and Sorption Media (M) Layers in VFB Cell 1

2.2 Study Design

The Study Design for the Project is based on a BACI (Before, After, Control, Impact) design used for assessing BMP effectiveness in reducing pollutant concentrations before and after stormwater is pumped through the various layers of the SSCW. In addition to assessing the overall effectiveness of the SSCW, the design allows for an assessment of each of the three VFB cells and each of the three media layers within each cell (gravel, sand, and sorption media).

To achieve this goal, samples were collected from the sampling locations listed in Table 2-1.

Table 2-1: Sampling Designations, Locations, and Labels

Sample Designation	Location	Label (number of replicates) [(a)]
Pre-treatment	Pump spigot located in pump house	Pre-# (six)
Monitoring ports within each of the VFB Cells	VFB Cell 1	VFB1-A-M-# (one) VFB1-B-M-# (one) VFB1-C-M-# (one) VFB1-C-G-# (one) VFB1-C-S-# (one)
	VFB Cell 2	VFB2-A-M-# (one) VFB2-B-M-# (one) VFB2-C-M-# (one) VFB2-C-G-# (one) VFB2-C-S-# (one)
	VFB Cell 3	VFB3-A-M-# (one) VFB3-B-M-# (one) VFB3-C-M-# (one) VFB3-C-G-# (one) VFB3-C-S-# (one)
Post-treatment	Bottom of WLCS located at the end of each VFB Cell	Post-VFB1-# (three) Post-VFB2-# (three) Post-VFB3-# (three)
QA/AC [(b)]	**Duplicates:** Either sampling port used above and/or WLCS – 2. separate ports/drains should be used	VFB1-Dup VFB2-Dup
	Blanks: Using blank water from the lab, fill two bottle sets with blank water in the field using same techniques	TW-Blk-1 TW-Blk-2

(a) # refers to the replicate number
(b) Quality Assurance / Quality Control

For this Project, a batch-flow design was used, where effectiveness was determined by treating a single batch of stormwater at a time (as opposed to continuous treatment). Thus, the protocols described below were used to treat water from a single, discrete storm event, with multiple events treated over the course of a year. The frequency and timing of sample collection is important to properly characterize the pre- and post-treatment pollutant concentrations and assure the appropriate hydraulic residence time (HRT) for pollutant removal. Initial flow monitoring determined that the maximum flow rate of 1.4 gpm yielded an HRT of 48 hours (2 days). Therefore, a flow rate of 0.7 gpm (the initial design specifications) yielded an HRT of 4 days and a flow rate of 1.05 gpm yielded an HRT of 3 days.

Based on these values, the sampling protocol outlined below was used to achieve an HRT of 3 days:

- **Pre-storm assessment**
    - Check to see that the all three VFB cells have been drained of any water and that the wetland drain pipe is closed.
- **Pump Start up**
    - At least one hour after the onset of rain, open the intake and pump valves and turn the pump on at a flow rate of 1.05 gpm for all three VFB cells. The goal is to make sure that the water being collected and tested for the pre-treatment samples represents stormwater conditions in Lambert Creek. One hour should be sufficient to allow the upstream drainage to “flush” and produce water in the basin that is representative of storm conditions in the creek (i.e., turbid water with elevated pollutant levels). However, due to the high variability of pollutant levels in urban creeks during storm events, the operator should use discretion in determining the appropriate length of time after the onset of rain needed to achieve these conditions.
- **Pre-treatment sample collection**
    - After the pump has been turned on, collect 6 sample sets (a suite of bottles for the pollutants to be analyzed) from the pump spigot and label the bottles in each set as described in Table 2-1 (e.g., all the bottles in bottle set 1 will be labelled Pre-1). Collect a total of six bottle sets from the pump spigot at this time.
- **Post-treatment sample collection**

  - Run the pump continuously for a period of at least 3 days (72 hours), then check to see if the VFB cells are full and water is flowing out through the WLCSs.
  - Once flow has been determined, collect a single sample set (suite of bottles) from each of sampling ports in VFB-1 as follows:
    - VFB1-A-M,
    - VFB1-B-M
    - VFB1-C-M
    - VFB1-C-G
    - VFB1-C-S
  - Collect three sample sets from the WLCSs at the end of the VFB1 cell.
  - Label the bottles in each sample set as described in Table 2-1.
  - Repeat the sequence above for VFB-2 and then VFB-3.
- **QA/AC**
  - Using the same techniques as above, collect two duplicate samples from either the monitoring ports, or the WLCSs and label the bottles in each sample set as described in Table 2-1.
  - Using the same techniques as above, fill two sample sets with blank water from the laboratory and label the bottles in each sample set as described in Table 2-1.
- **Post-storm assessment**
  - After all the sample sets have been collected, increase the flow to the maximum flow rate in all three cells and flush the system with “clean” water (water in the basin after the storm has passed) for 2 days.
  - Close the valve at the intake, then close the valve at the pump and turn the pump off.
  - Open the wetland drain valve and drain the system.

3.0 SAMPLING AND ANALYSIS PROCEDURES

This Chapter describes the techniques used to collect and analyze samples for the Project.

3.1 Sample Collection for Water Quality Analyses

Water samples from each of the sites described in Section 2.2, were collected by field technicians wearing sterile latex gloves. Four types of samples were collected: Pre-treatment, VFB Cell, Post-treatment, and QA/QC. The sampling technique for each sample type is described below.

- **Pre-treatment samples** were collected directly from the spicket in the pump house as unfiltered stormwater was pumped from Whitaker Pond to the VFB cells. The field technician opened the spicket and directly filled the suite of pre-labelled sample bottles, as described above.

- **VFB Cell samples** were collected from each of the sampling ports as described in Table 2-1. Samples were collected by removing the sampling port cap and inserting a sterile, disposable, polyethylene bailer into the sampling port. When the bailer was full, water from the port was decanted into the pre-labelled sample bottles for that sampling port. When all the bottles from that sampling port were full, the sampling port cap was replaced and the bailer was properly disposed of.

- **Post-treatment samples** were collected directly from the WLCS at the end of each VFB Cell. Samples were collected by removing the WLCS lid and inserting a sterile, disposable, polyethylene bailer into the bottom of the WLCS. Once the bailer was filled, it was retrieved and the water was decanted into pre-labelled sample bottles as described in Table 2-1.

- **QA/QC samples** were collected as described above for two types of QA/QC samples: duplicates and blanks. Duplicate samples were collected either from one of the sampling ports or from WLCS-2, immediately after the original sample from that location was collected. Blank samples were collected by decanting sterile, blank water provided by the laboratory into a suite of sample bottles. Two duplicate samples and two blank samples were collected for each round of sampling (e.g., two duplicates and two blank samples for each storm event to be monitored). Duplicate and blank samples were labelled as described in Table 2-1.

3.2 Sample Bottle Identification

Each sample collected over the course of the study received a unique alphanumeric code (sample I.D. number) for tracking as described in Table 2-1. All sample bottles were labeled with the following information:

- Project name
- Sample I.D. number
- Date
- Time
- Preservative
- Collector’s initials
- Analyte(s) to be analyzed

Immediately after collection, each sample bottle was stored on ice in the dark in a closed cooler from the time of sample collection until delivery to the analytical laboratory. All samples were delivered to RMB Environmental Laboratories in Detroit Lakes, Minnesota within the required holding time. The samples were transferred to the laboratory using standard chain of custody (COC) procedures discussed in Chapter 4. The cooler and sampling equipment were cleaned with biodegradable soap prior to use.

3.3 Field Observation Form

During each sampling event (e.g., storm event), a Field Observation Form was filled out by the field technician conducting the sampling. The Field Observation Form was to document conditions during the sampling event. Information documented on the Field Observation Form included the date and time of collection, physical conditions during the sampling event (e.g., weather conditions), water quality data collected at the time of sampling (temperature, pH, dissolved oxygen levels, etc.), any observations made during the sampling event that have the potential to affect results (e.g., debris in the sampling port), and a recording of any photographs taken during sample collection.

3.4 Sample Collection for Stormwater Pathogen Analyses

Sample collection and analysis of pathogens was conducted by the University of Minnesota under the direction of Dr. Timothy LaPara, Department of Civil, Environmental, and Geo- Engineering. Samples were collected over the course of five storm events during the summer of 2019. During each event, a single pre-treatment stormwater sample was collected from the pump spigot located inside the pump house. Stormwater was moved through each of the three treatment wetland cells for a period of approximately three days (as described above), then a single sample of treated water was collected from the bottom of the WLCS at the far end of each of the three cells. A total of 20 samples were collected over the course of the monitoring period, including five pre-treatment samples from the pump house spigot and five post-treatment samples from each of the WLCSs.

Microorganisms were captured from each sample location using REXEED 25S ultrafiltration membrane cartridges (Asahi Kasei, Tokyo, Japan) as described by Smith and Hill (2009). The total volume of sample was determined empirically based on water quality. Membrane cartridges were transported from the field on ice to the laboratory at the University of Minnesota for subsequent backflushing and concentration of microorganisms. Method blank ultrafilter samples were collected by backflushing fresh, unused ultrafilter cartridges.

3.5 Laboratory Analyses for Water Quality Samples

All samples collected as part of the Project were delivered to RMB Environmental Laboratories and analyzed in the lab following the parameters identified in Table 3-1.

Table 3-1: Analytes and Corresponding Analytical Parameters

Analyte	Method	Reporting Limit	Sample Volume	Container (Size, Type)	Preservation	Holding Time
Escherichia coli	SM 9223-2004	1.0 MPN/ 100 mL	100 mL	sterile,100-mL plastic	None	6 hours
Phosphorus, Total as P (TP)	SM 4500-P B/E	0.003 mg/l	50 mL	250-mL glass	H_2SO_4	28 days
Orthophosphate, as P (OP/SRP)	SM 4500-P B/E EPA 300.0	0.003 mg/l	50 mL	125-mL HDPE	None	48 hours
Nitrogen, Ammonia as N (NH_3)	SM 4500-NH_3 B/C	0.04 mg/l	500 mL	1-L Amber glass	H_2SO_4	28 days
Nitrogen, Nitrate and Nitrite (N+N)	SM 4500-NO_3 E / SM-4500-NO_2 B	0.01-0.03 mg/l	100 mL	125-mL HDPE	H_2SO_4	28 days
Total Suspended Solids, (TSS)	SM-2540-D	5.0	1 L	1-L HDPE	None	7 days

(a) °C = degrees Celsius

3.6 Laboratory Analyses for Pathogen Samples

Samples for pathogen analyses and method blank ultrafilters were backflushed using 500 mL of a sterile solution containing 0.5% Tween-80, 0.01% sodium hexametaphosphate, and 0.001% Y-30 anti-emulsion. The microbial cells were collected from the backflush solution via coagulation with a solution containing

0.2 Molar (M) sodium chloride, 8% (w/v) polyethylene glycol, and 1% beef extract, settling for 24 hours, and finally centrifugation at 12,000 × g for 45 minutes. The supernatant was decanted and the remaining pellet was resuspended using 1- 5 mL of 10× TE buffer. The resulting final concentrated sample volumes (FCSVs) were stored at – 20°C prior to deoxyribonucleic acid (DNA) extraction. Concentration factors using this method have been ~10^3 to 10^4-fold.

DNA was extracted from the FCSVs using the FastDNA™ SPIN Kit (MP Biomedicals, Santa Ana, CA). Lysis buffer (5% m/v SDS, 120 mM sodium phosphate buffer, pH 8.0) was added to a 300 μL aliquot of concentrated samples, which were subjected to three freeze-thaw cycles, followed by a 90-minute incubation at 70°C. DNA was stored at -20 °C until further use.

Quantitative polymerase chain reaction (qPCR) was performed on DNA extracted/purified from each sample and target 8 genes specific to bacterial pathogens as well as the 16S rRNA gene for quantifying total biomass. The targeted organisms included *Campylobacter* spp. (2 genes) and *E. coli*-like organisms (6 genes). Assays were performed using a CFX Connect™ Real-Time PCR Detection System (Bio-Rad, Hercules, CA). Final reaction mixtures were 20 μL and consisted of nuclease-free water, 10 μL SsoAdvanced™ Universal Probes Supermix (EvaGreen for the 16S rRNA gene assay), 20 μg bovine serum albinum, 1 μL template DNA, and varying concentrations of primers and probes depending on the assay (Table 3-2). Methods for all taxonomic targets were taken from Ishii et al. (2013), except for All Bacteria (Muyzer et al., 1993) and Adenovirus (Lambertini et al., 2012).

Table 3-2: qPCR gene targets, primer and probe sequences, and references

Taxonomic Target	Target Gene Name	Gene Product	Primer(a) & Probe(b) (5'-3' sequence)
Campylobacter jenjuni	*cadF*	Fibronectin-binding protein	F: TGC TAT TAA AGG TAT TGA TGT RGG TGA
			R: GCA GCA TTT GAA AAA TCY TCA T
			P: UPL 039
Campylobacter jenjuni	*ciaB*	Invasion antigen B	F: GCG TTT TGT GAA AAA GAT GAA GAT AG
			R: GGT GAT TTT ACT TTC ATC CAA GC
			P: UPL 137
			R: GCA ACC ACT ATC CAA TAC TCA AAC AC
			P: CCG TGT GGA GTC CCT CCA TCT TGG
E. coli	*ftsZ*	Cell division protein	F: CTG GTG ACC AAT AAG CAG GTT
			R: CAT CCC ATG CTG CTG GTA G
			P: UPL 071
E. coli	*uidA*	Beta-D-glucuronidase	F: CCC TTA CGC TGA AGA GAT GC
			R: TTC ATC AAT CAC CAC GAT GC
			P: UPL 113
	eaeA	Intimin	F: GGC GAA TAC TGG CGA GAC TA
			R: GGC GCT CAT CAT AGT CTT TCT T

Enterohemorrhagic *E. coli* (EHEC)			P: UPL 028
Enterohemorrhagic *E. coli* (EHEC)	*stx1*	Shiga toxin 1 subunit A	F: TGT AAT GAC TGC TGA AGA TGT TGA T
			R: TCC ATG ATA RTC AGG CAG GA
			P: UPL 060
Enterohemorrhagic *E. coli* (EHEC)	*stx2*	Shiga toxin 2 subunit A	F: TCT GGC GTT AAT GGA GTT YAG
			R: GTG ACA GTG ACA AAA CGC AGA
			P: UPL 126
Shigella spp. and enteroinvasive *E. coli*	*virA*	Secreted VirG-processing protein	F: GGC AAT CTC TTC ACA TCA CG
			R: TTC GGA CAT AAT TTG GGC ATA
			P: UPL 006
All Bacteria	16S rRNA	Small subunit, ribosomal RNA	F: ACT CCT ACG GGA GGC AGC AG
			R: ATT ACC GCG GCT GCT GG
Adenovirus	*hex*	Hexon protein for capsid coat	F: GGA CGC CTC GGA GTA CCT GA
			R: CGC TGI GAC CIG TCT GTG G
			P: CAC CGA TAC GTA CTT CAG CCT GGG T

(a) Forward and reverse primer sequences are preceded by the letters ‘F’ and ‘R’, respectively.

(b) Probe sequences are preceded by the letter ‘P’. Items containing "UPL" followed by a number represent proprietary probe sequences from the Universal ProbeLibrary® (Roche Molecular Systems. Inc, Pleasanton, CA)

4.0 SAMPLE HANDLING AND TRACKING

Samples were kept properly chilled and transferred to the analytical laboratory within holding times to achieve the highest quality data possible. To ensure proper tracking and handling of the samples, documentation accompanied the samples from the initial pickup to the final extractions and analysis. This documentation was in the form of COC forms (provided by VLAWMO and/or participating laboratories.

Completed COC forms were placed in a plastic envelope and kept inside the container containing the samples. Once delivered to the laboratory, the COC form was signed by the person receiving the samples. The condition of the samples was noted and recorded by the receiver. COC records were included in the final reports prepared by the analytical laboratories.

Upon delivery to the laboratory, the laboratory manager inspected the condition of the samples and reconciled the label information to the COC form. The time of sample delivery was noted and the samples were stored at the appropriate temperature until analysis began, always within the holding times identified in Table 3-1.

Upon completion of analyses, any remaining sample material was stored until the holding time expired, at which point the samples were disposed of.

5.0 RESULTS

5.1 Results of 2018 Water Quality Analyses

Three storm events were monitored in 2018: August 20 (storm event 1), September 4 (storm event 2), September 20 (storm event 3). Pollutant concentrations are presented graphically by storm event for 2018 on Figure 5-1 for *E. coli*, TSS, and ammonia and on Figure 5-2 for TP, orthophosphate, and nitrate. Analytical data summary tables are provided in Attachment 1.

5.1.1 *E. coli*

The mean *E. coli* concentration in the pre-treated stormwater during storm event 1 was 9,195 MPN/100 mL (mean of six stormwater samples from Whitaker Pond) (Figure 5-1). The mean concentration at the top of the gravel layer was 359 MPN/100 mL, representing a 96.1% decrease in *E. coli* concentrations and similar reductions were observed at the top of the sand layer. Further reductions were observed at the top of the media layer with mean *E. coli* concentrations of 25 MPN/100 mL in cells 1 and 2 and 280 MPN/100 mL in cell 3 (reductions of 99.7%, 99.7% and 97.0%, respectively compared to pre-treatment concentrations). During storm event 1, *E. coli* concentrations in post-treatment samples were below detection limit in five of the nine samples collected from the three cells and 1 to 2 MPN/100 mL in the others, representing a mean reduction of 100%.

During storm 2, pre-treatment *E. coli* concentrations in Whitaker Pond were much lower than those measured in storm event 1 and storm event 3, with a mean concentration of 2,233 MPN/100 mL (Figure 5-1). *E. coli* concentrations were reduced 99.7% and 99.9% in the gravel and sand layers, (mean *E. coli* concentrations of 8 and 5 MPN/100 mL, respectively). Similar reductions were observed in the media layers of the three cells. Mean post-treatment *E. coli* concentrations were 131, 53, and 3 MPN/100 mL for cells 1, 2, and 3, respectively, representing slight increases in concentrations from the previous treatment layers, but still showing an overall mean decrease of 97.2% compared to pre-treatment concentrations during storm event 2.

The mean pre-treatment *E. coli* concentration from Whitaker Pond during storm event 3 (9,655 MPN/100 mL) was similar to that during storm event 1 (Figure 5-1). Concentrations decreased an average of 99.7% in the gravel layers and 98.0% in the sand layers of the three cells. Concentrations increased in the media layers of all three cells, particularly cell 1, which actually increased substantially from the sand layer. Among the three storm events in 2018, storm event 3 had the lowest overall *E. coli* removal efficiency with a mean reduction of 94.1% when the mean post-treatment concentration is compared to the mean pre-treatment concentration.

Figure 5-1: Graphs of Treatment Wetland Reduction Efficiencies for *E. coli*, Total Suspended Solids (TSS), and Ammonia (NH_3) from Three Storms Monitored in 2018

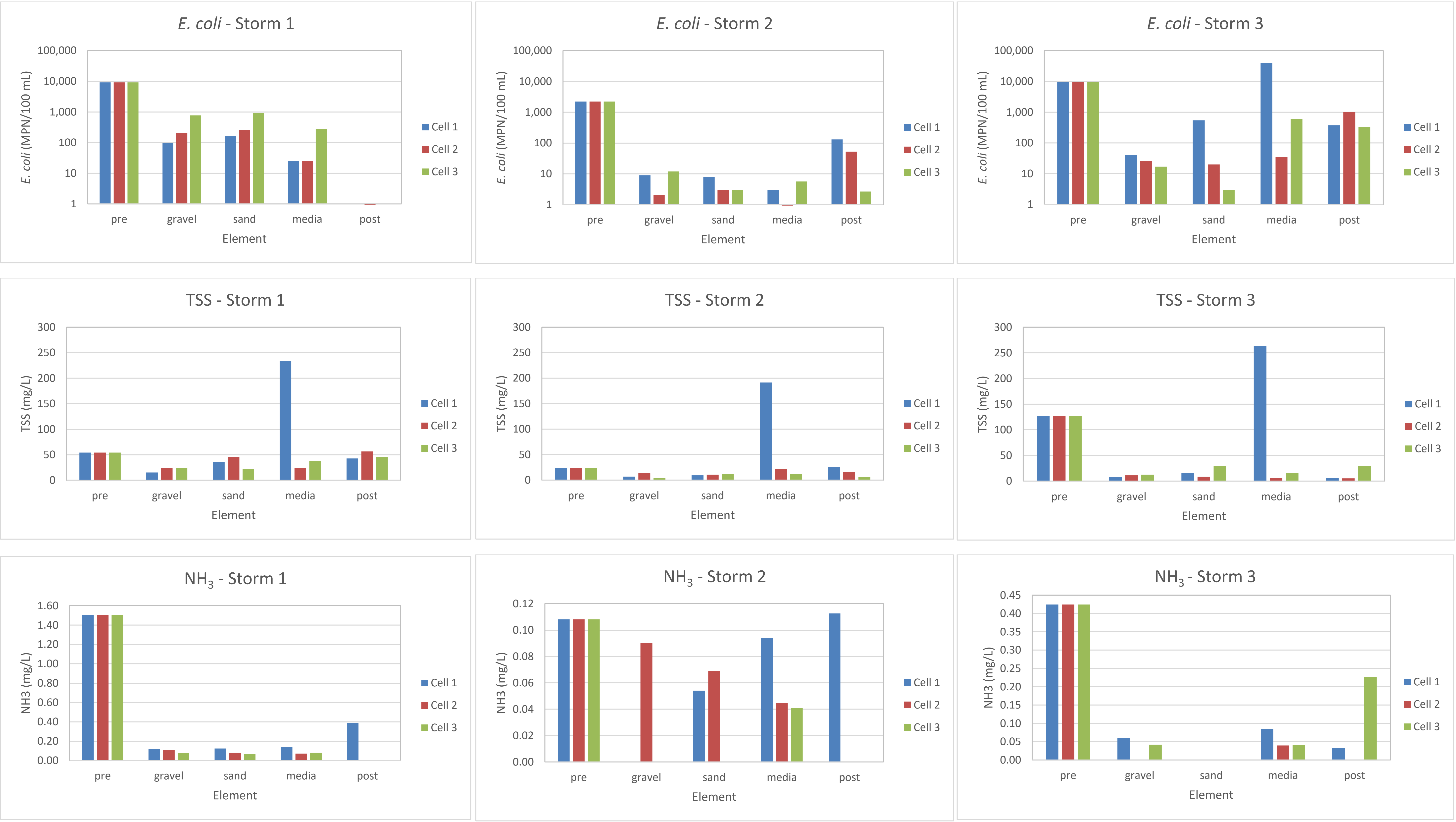
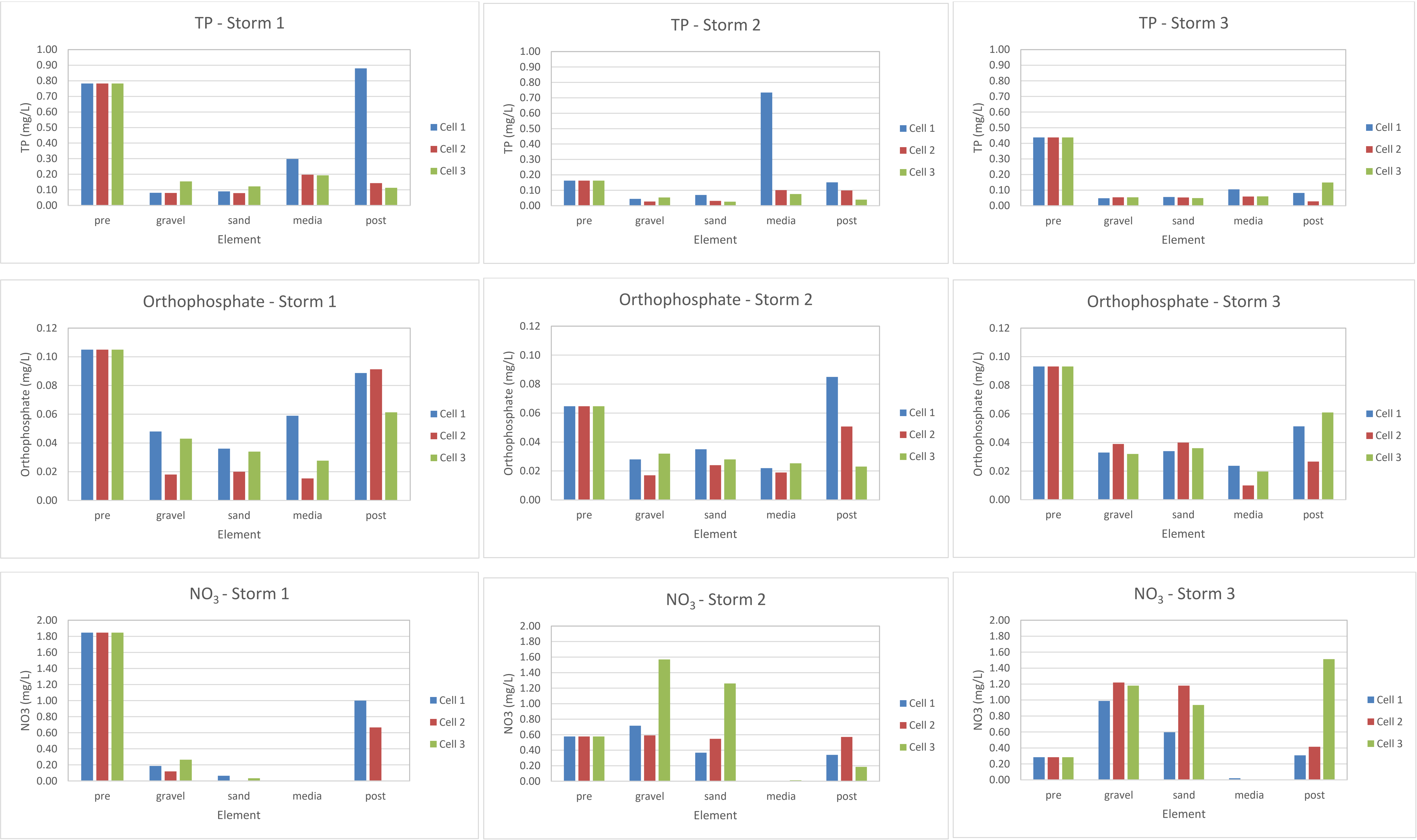


Figure 5-2: Graphs of Treatment Wetland Reduction Efficiencies for Total Phosphorus (TP), Orthophosphate, and Nitrate (NO_3) from Three Storms Monitored in 2018



TP - Storm 1

TP - Storm 2

TP - Storm 3

Orthophosphate - Storm 1

Orthophosphate - Storm 2

Orthophosphate - Storm 3

NO_3 - Storm 1

NO_3 - Storm 2

NO_3 - Storm 3

5.1.2 TSS

During storm event 1, the mean pre-treatment TSS concentration from samples collected from Whitaker Pond was 54.3 (mg/L) (Figure 5-1). At the top of the gravel layer, the mean concentration was 20.8 mg/L, representing a 61.8% reduction. TSS concentration in the sand and media layers were similar to those in gravel, except for cell 1, where the TSS concentration (233.4 mg/L) increased dramatically from the mean pre-treatment concentration due to a very high value in one of the replicate samples. The mean post-treatment concentration of TSS was 48.2 mg/L, representing an average decrease of 11.0% compared to the mean pre-treatment concentration.

During storm event 2, the mean pre-treatment TSS concentration was 23.9 mg/L, less than half that observed in storm event 1 (Figure 5-1). TSS concentrations were reduced to a mean of 8.1 mg/L at the top of the gravel layer (66.0% reduction). Further TSS removal was marginal in the sand layer (mean of 55.8%) and the media layers for cells 2 and 3. As with storm event 1, the mean TSS concentration was particularly high (320 and 230 mg/L in replicates 1 and 2 of cell 1). Mean post-treatment TSS concentrations were slightly greater than those observed in the gravel layer, with a mean reduction of 16.0% compared to pre-treatment levels.

During storm event 3, the mean pre-treatment TSS concentration was 126.6 mg/L, much greater than that observed in the first two storm events monitored in 2018 (Figure 5-1). The mean TSS concentration decreased 91.6% at the top of the gravel layer (mean concentration of 10.6 mg/L). TSS concentrations remained low throughout the remainder of the treatment layers in all three cells (less than 20 mg/L in all but two samples) except for the media layer in cell 1, which had a mean TSS concentration of 263 mg/L. This pattern was similar to that observed in storm event 1 and 2.

5.1.3 Ammonia

During storm event 1, the mean pre-treatment ammonia concentration collected from Whitaker Pond was 1.50 mg/L (Figure 5-1). The mean concentration at the top of the gravel layer was 0.10 mg/L, representing a 93.3% decrease in ammonia concentrations. Mean ammonia concentrations remained low in samples collected from the other media layers in each of the three cells. In the post-treatment samples, ammonia concentrations were below the detection limit from all samples collected in cells 2 and 3, but had increased slightly in cell 1.

During storm event 2, ammonia concentrations were much more variable than those observed during storm event 1 and the pre-treatment concentration was over ten times lower (0.108 mg/L) (Figure 5-1). Ammonia concentrations were below the detection limit in several samples collected from the gravel, sand, and post-treatment locations; however, concentrations were close to the pre-treatment concentrations in some samples and there was no discernable pattern associated with treatment.

During storm event 3, the mean ammonia pre-treatment concentration was 0.425 mg/L (Figure 5-1). The mean concentration had decreased to 0.034 mg/L at the top of the gravel layer (a 92.0 % reduction). Ammonia concentrations in all samples collected from the top of the sand layer were below detection limit. Concentrations increased slightly in the media layer and post-treatment samples, especially in cell 3.

5.1.4 Total Phosphorus

The mean concentration of total phosphorus collected from Whitaker Pond during storm event 1 was 0.783 mg/L (Figure 5-2). Concentrations decreased dramatically after treatment in the gravel layer, with a mean concentration of 0.105 mg/L (an 86.6% reduction). Concentrations remained relatively low in samples collected from the subsequent locations in the treatment cells, except for the post-treatment sample collected from cell 1, which spiked to a value greater than pre-treatment levels (mean of 0.880 mg/L).

During storm event 2, the pre-treatment TP concentration (mean of 0.163 mg/L) was much lower than that observed in storm event 1 (Figure 5-2). The mean concentrations were reduced 74.6% after treatment in the gravel layer (mean concentration of 0.041 mg/L) and concentrations remained low throughout the rest of the treatment process, except for the media layer in cell 1, which had much greater TP values in two of the three samples collected (mean concentration of 0.734 mg/L).

The largest, most consistent reductions in TP occurred during storm event 3 (Figure 5-2). The mean pre-treatment concentration during storm event 3 was 0.44 mg/L, which had dropped to 0.052 mg/L after treatment in the gravel layer. TP concentrations remained low in all subsequent samples collected from all three cells.

5.1.5 Orthophosphate

During storm event 1 in 2018, the mean orthophosphate concentration was 0.105 mg/L (Figure 5-2). The mean concentration decreased to 0.036 mg/L after treatment in the gravel layer (a 65.4% decrease) and concentrations remained at the level through the subsequent treatment layers before increasing slightly in the post-treatment samples (mean of 0.080 mg/L). During storm event 2, the pre-treatment orthophosphate concentration (mean of 0.065 mg/L) was much lower than that observed during storm events 1 and 3. The relative reduction after gravel treatment, however, was similar to that observed during storm event 1 (reduction of 60.3%). Orthophosphate concentrations remained low throughout the subsequent treatment layers (< 0.040 mg/L), but increased in the post-treatment samples in cells 1 and 2. The pattern of reduction in orthophosphate concentrations during storm event 3 was similar to those observed for storm events 1 and 2.

5.1.6 Nitrate

During storm event 1 of 2018, the mean nitrate concentration was 1.85 mg/L (Figure 5-2). After treatment in the gravel layer, the concentration had been decreased to 0.190 mg/L (an 89.7% reduction). Nitrate concentrations continued to decrease through the media layers in all three cells and were reduced to non-detect levels in the media layer (100% removal). However, spikes in nitrate concentrations were observed in cells 1 and 2 in the post-treatment samples.

During storm event 2, the mean pre-treatment nitrate concentration was 0.577 mg/L (Figure 5-2). Concentrations did not decrease substantially or increased in the gravel and sand layers. However, similar to storm event 1, nitrate concentrations in the media layer were below the detection limit (100% removal). Post-treatment samples did have detectable levels of nitrate, although relatively low.

During storm event 3, the pre-treatment nitrate concentration was 0.285 mg/L (Figure 5-2). Concentrations increased substantially in both the gravel and sand layers, but decreased to levels below the detection limit in the media layer (100% removal, similar to storm events 1 and 2). Concentrations increased in the post-treatment samples during storm event 3 as well.

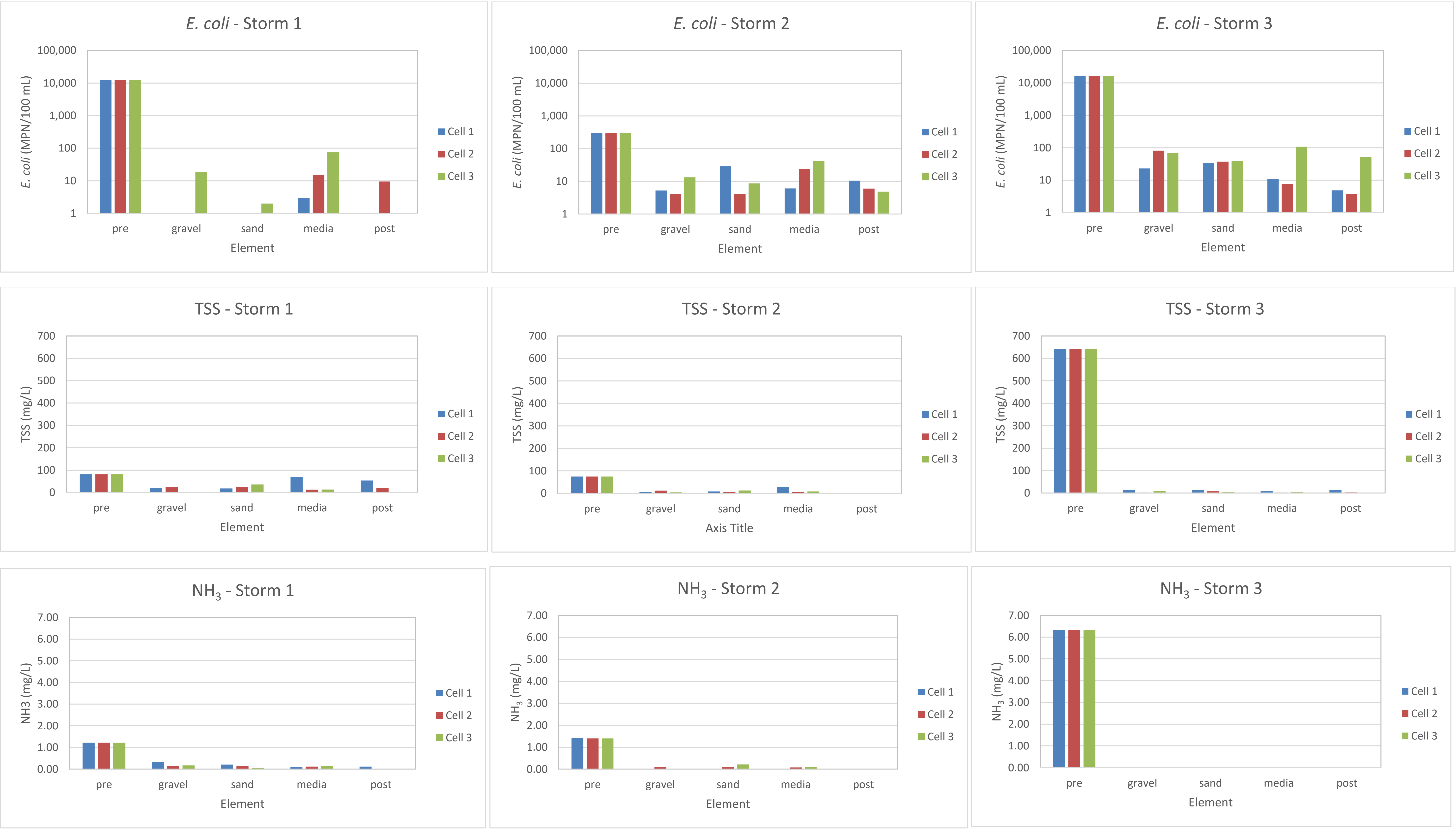
5.2 Results of 2019 Water Quality Analyses

Three storm events were monitored in 2019: June 27 (storm event 1), August 5 (storm event 2), September 11 (storm event 3). Pollutant concentrations are presented graphically by storm event for 2019 on Figure 5-3 for *E. coli*, TSS, and ammonia and on Figure 5-4 for TP, orthophosphate, and nitrate. Analytical data summary tables are provided in Attachment 1.

5.2.1 *E. coli*

The mean *E. coli* concentration in the pre-treated stormwater during storm event 1 was 12,200 MPN/100 mL (mean of six stormwater samples from Whitaker Pond) (Figure 5-3). The mean concentration at the top of the gravel layer was 7 MPN/100 mL, representing a 99.9% decrease in *E. coli* concentrations and similar reductions were observed at the top of the sand layer. *E. coli* concentrations increased slightly in the media layer (mean concentrations of 3, 15, and 75 for cells 1, 2, and 3, respectively), but were below 10 MPN/100 mL in the post-treatment samples, representing a mean reduction of 100 % compared to pre-treatment concentrations.

Figure 5-3: Graphs of Treatment Wetland Reduction Efficiencies for *E. coli*, Total Suspended Solids (TSS), and Ammonia (NH_3) from Three Storms Monitored in 2019



E. coli - Storm 1

E. coli - Storm 2

E. coli - Storm 3

TSS - Storm 1

TSS - Storm 2

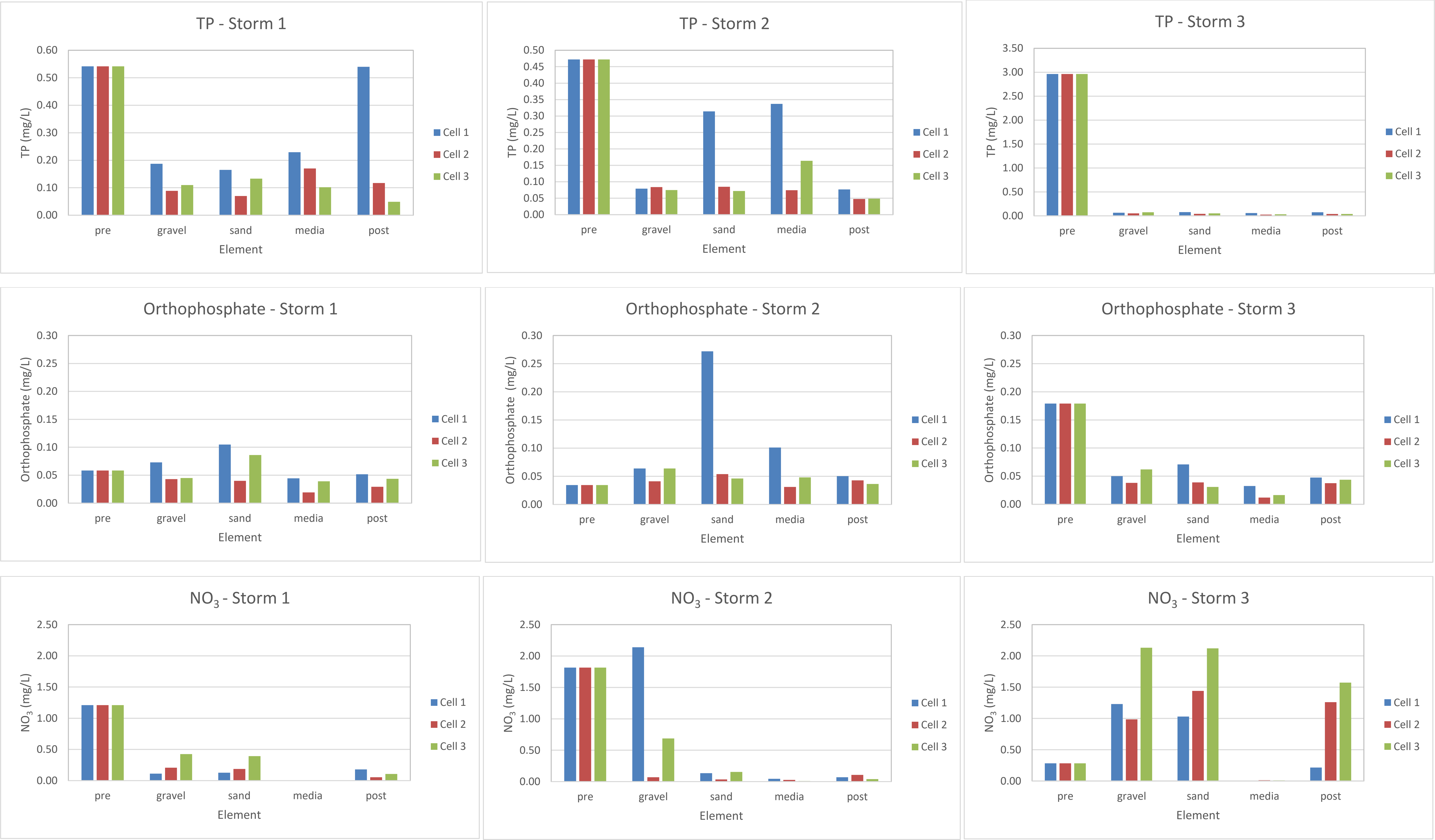
TSS - Storm 3

NH_3 - Storm 1

NH_3 - Storm 2

NH_3 - Storm 3

Figure 5-4: Graphs of Treatment Wetland Reduction Efficiencies for Total Phosphorus (TP), Orthophosphate, and Nitrate (NO_3) from Three Storms Monitored in 2019



During storm 2, pre-treatment *E. coli* concentrations in Whitaker Pond were substantially lower than those measured in storm event 1, with a mean concentration of 307 MPN/100 mL (Figure 5-3). Pollutant reduction was less than that observed during storm event 1, with mean reduction values of 97.6% reduction in the gravel layer compared to pre-treatment values, 95.5% in the sand layer, and 87 to 98% in the media layer. Mean post-treatment *E. coli* concentrations decreased 97.7% compared to pre-treatment concentrations during storm event 2.

Mean pre-treatment *E. coli* concentrations from Whitaker Pond were greatest during storm event 3, with a mean concentration of 16,165 MPN/100 mL (Figure 5-3). Reductions in concentrations were similar to those observed during storm events 1 and 2 with mean reduction values of 99.6% reduction in the gravel layer compared to pre-treatment values, 99.8% in the sand layer, and 99.3 to 100% in the media layer. Mean post-treatment *E. coli* concentrations decreased 99.9% compared to pre-treatment concentrations during storm event 3. Although the percent reduction was substantial during storm event 3, *E. coli* concentrations after each layer of treatment were slightly greater than those observed during the other two storm events.

5.2.2 TSS

The mean TSS concentration in the pre-treated stormwater during storm event 1 was 81.8 mg/L (mean of six stormwater samples from Whitaker Pond) (Figure 5-3), which is fairly low for stormwater samples. The mean concentration at the top of the gravel layer was 16.2 mg/L, representing a 80.2% decrease in TSS concentrations. TSS concentrations remained low throughout the remainder of the treatment layers.

The pattern for TSS reduction during storm event 2 was similar to that observed in storm event 1 (Figure 5-3). The mean pre-treatment TSS concentration during storm event 2 was also low (75.0 mg/L) and was reduced substantially in the gravel layer (90% reduction) and remained low throughout the remainder of the treatment system.

During storm event 3, pre-treatment stormwater samples were much greater (mean of 642.5 mg/L) than those observed during storm events 1 and 2 (Figure 5-3). A dramatic reduction in mean TSS concentration was observed from samples collected at the top of the gravel layer, where the mean concentration was 8.63 mg/L, a reduction of 98.7% from pre-treatment samples. TSS concentrations remained very low (< 10 mg/L) throughout the remainder of the treatment system.

5.2.3 Ammonia

During storm event 1 in 2019, the mean ammonia concentration was 1.22 mg/L (Figure 5-3). At the top of the gravel layer, the mean concentration was 0.211 mg/L (an 82.7% reduction from pre-treatment samples). Ammonia concentrations remained consistently low throughout the remainder of the treatment layers and were below detection limit in six of the nine post-treatment samples.

During storm event 2, a very similar pattern was produced (Figure 5-3). The mean ammonia concentration in the pre-treatment stormwater sample (1.40 mg/L) was reduced to 0.036mg/L at the top of the gravel layer (a 97.5 % reduction). Concentrations remained low throughout the remainder of the treatment cell and ammonia concentrations in all nine of the post-treatment samples were below detection limit (100 % removal).

Ammonia removal was most dramatic during storm event 3 (Figure 5-3). During this storm event, pre-treatment ammonia concentrations (mean of 6.33 mg/L) were much greater than those observed during storm event 1 and 2; however ammonia concentrations in subsequent samples taken from the various layers in all three cells were below the detection limit, representing 100 % removal.

5.2.4 Total Phosphorus

The mean total phosphorus concentration (represented as TP on Figure 5-4 in the pre-treated stormwater during storm event 1 was 0.542 mg/L (mean of six stormwater samples from Whitaker Pond). The mean concentration at the top of the gravel layer (all three cells) was 0.129 mg/L, representing a 76.2% decrease in TP concentrations in the first media layer. Similar post-treatment reductions in TP were observed in the sand and media layers as well as the post-treatment mean concentration, except for cell 1 during the first storm event, where TP concentrations spiked to near pre-treatment levels. This spike corresponded with similar spikes in TSS concentrations in cell 1, suggesting that sediment in the sample from this cell may have influenced TP concentrations.

Similar reductions in TP concentrations were observed during storm event 2 (Figure 5-4). The mean pre-treatment TP concentrations in Whitaker Pond during storm event 2 was 0.472 mg/L. The mean TP concentration decreased 83.2% in the gravel layer (0.079 mg/L) and mean concentrations remained at similar levels through subsequent layers of the treatment train and final post-treatment samples. TP concentrations in the sand and media layers of cell 1 appeared to be higher than the other cells and corresponded with elevated TSS levels (similar to storm event 1).

For the third storm event, the mean TP concentration in the pre-treatment samples (2.96 mg/L) was substantially greater than the that observed during the first two storm events (Figure 5-4), which corresponded with a mean TSS concentration during storm event 3 that was nearly ten times greater than mean pre-treatment concentrations observed in the first two storm events. TP concentration reductions were greatest in storm event 3, with a 97.9% reduction in the mean concentration after treatment in the gravel layer, 98.1% after the sand layer, 98.9% after the media layer, and 98.3% in the post-treatment samples.

5.2.5 Orthophosphate

Removal of orthophosphate by the treatment wetland cells in 2019 was less pronounced than that observed for TP (Figure 5-4). During storm 1, the mean orthophosphate concentration in pre-treatment samples was

0.058 mg/L. At the top of the gravel layer, the mean concentration was 0.054 mg/L, representing an 8.0 % reduction. Concentrations were further reduced in the sand, media, and post-treatment samples, with mean reductions of 32.0 %, 33.1 %, and 28.8 %, respectively.

During storm event 2 (Figure 5-4), orthophosphate removal by the treatment wetland cells was not observed. The mean pre-treatment orthophosphate concentration of 0.035 mg/L increased in all subsequent layers of all three cells as well as the post-treatment samples.

The largest removal of orthophosphate was observed during storm event 3, which had a much greater pre-treatment concentration (0.179 mg/L) than storm event 1 and 2 (Figure 5-4). Orthophosphate removal was observed during storm event 3, with a mean concentration at the top o the gravel layer of 0.050 mg/L (a 72.1 % reduction from pre-treatment concentrations). Orthophosphate concentrations remained close to this level in all subsequent samples with minimal further reductions in concentrations.

5.2.6 Nitrate

During storm event 1, the mean nitrate concentration (represented as NO_3 on Figure 5-4) was 1.21 mg/L in the pre-treated stormwater samples from Whitaker Pond. Nitrate concentration decreased dramatically in the gravel layer of each cell with a mean reduction from pre-treatment concentrations of 79.5%. Nitrate concentrations remained low in all three cells throughout the subsequent treatment layers, with mean reductions of 80.6% in the sand layer, 100% in the media layer (nitrate concentrations in all samples from all three cells were below the detection limit), and 90.6% in the post-treatment samples.

The results for nitrate reduction during storm event 2 were similar to those observed during storm event 1. The mean pre-treatment nitrate concentrations during storm event 1 was 1.82 mg/L (Figure 5-4). At the top of the gravel layer, the mean nitrate concentration was 0.970 mg/L (which was driven largely by a very high concentration (2.14 mg/L) in cell 1. Concentration decreased substantially at the top of the sand layer to a mean of 0.110 mg/L and concentrations were below detection limit or close to it in both the media and the post-treatment samples.

Nitrate concentration patterns during storm event 3 were quite different than those observed in the first two storm events of 2019 (Figure 5-4). Nitrate concentrations in the pre-treatment samples during storm event 3 were ten times less than those observed in the previous two storms (mean of 0.28 mg/L), but concentrations increased dramatically in the gravel layer (mean of 1.45 mg/L) and sand layer (mean of 1.53 mg/L). Similar to the first two storm events, concentrations in the media layer during storm event 3 were below detection limit; however, concentrations increased sharply in the post-treatment samples in this final storm of the season.

5.3 Results of Pathogen Analyses

Four storm events were monitored in 2019 for pathogens: July 9 (storm event A), August 5 (storm event B), August 20 (storm event C), and September 11 (storm event D). Storm events B and D coincided with previously discussed water quality analyses (storm events 2 and 3). Samples were analyzed for total Bacteria (16S rRNA genes), *E. coli* (*uidA* and *ftsZ*), enterohemorrhagic *E. coli* (*eaeA* and *stx1*), and *Campylobacter jejuni* (*cadF* and *ciaB*). All samples (both pre-treatment and post-treatment) were negative for enterhemorrhagic *E. coli* (*eaeA*; *stx1*) and for *Campylobacter jejuni* (*cadF*; *ciaB*). Pathogen data summary tables are provided in Attachment 2.

Total bacteria were quantified in all samples. In the samples collected prior to treatment, the concentration of bacteria ranged from $10^{9.0}$ to $10^{9.7}$ gene copies per liter (mean = $10^{9.3\pm0.3}$), which is typical of surface waters based on our prior experience (in contrast, drinking water typically has $10^{5.0}$ to $10^{8.0}$ gene copies per liter). The post-treatment samples contained $10^{8.2}$ to $10^{9.0}$ copies per liter (mean = $10^{8.6\pm0.3}$); that is, treatment resulted in an average reduction in the concentration of total bacteria of about 80% during treatment.

E. coli (*uidA*; *ftsZ*) was quantified in the water prior to treatment during three of the four storm events (exception = storm event C). The mean concentration of *uidA* was $10^{5.2\pm0.1}$ gene copies per liter and the concentration of *ftsZ* was $10^{5.3\pm0.3}$ gene copies per liter. In contrast, neither *uidA* nor *ftsZ* were detected in the treated water.The detection limit for each of these assays was $10^{3.9\pm0.2}$, suggesting that treatment removed *E. coli* by at least 95%.

6.0 CONCLUSIONS

The main objective of this Project was to assess the effectiveness of the subsurface constructed wetland in removing pollutants commonly found in urban stormwater. The results of the assessment clearly show that all three of the experimental cells were very effective in removing *E. coli* (a member of the fecal coliform group and a common fecal indicator bacteria) and nutrients (total phosphorus and nitrate) from stormwater in Lambert Creek. One of the most striking observations of the Project was the dramatic reduction in *E. coli* concentrations. During the three storm events monitored in 2019, *E. coli* concentrations were reduced two to three orders of magnitude (95 to 100%) when compared to stormwater samples collected from Whitaker Pond. These results were similar to Pathogen Analyses conducted by the University of Minnesota (Section 5.2), which suggested that the treatment wetland reduced *E. coli* levels by at least 95%. Concentrations were reduced in the first layer of treatment (the gravel layer at the bottom of each of the three cells) to less than 10 MPN/100 mL in the first two storm events and to less than 100 MPN/100 mL in storm event 3. In general, E. *coli* concentrations remained low throughout the remainder of the treatment train as the stormwater passed through subsequent treatment layers (sand, growth media, and post-treatment, which included a layer of iron-enhanced sand). The effluent of the treatment wetland was discharged to groundwater through an additional layer of gravel, which very likely decreased *E. coli* concentrations even further.

The treatment wetland was also very effective in reducing concentrations of nutrients in urban stormwater. Although nutrient reductions were not as dramatic as those observed for *E. coli*, reductions were still substantial and were observed from the first layer of treatment (gravel). Total phosphorus concentrations were reduced dramatically (76% to 98% across all three storm events) in the gravel layer and concentrations remained low throughout the remainder of each of the wetland cells as stormwater flowed up through the subsequent treatment layers. The results were most obvious in storm event 3, where TP concentrations were reduced nearly two orders of magnitude (100-fold) from pre-treatment stormwater levels.

Large reductions in nitrate concentrations were also observed during the first two storm events monitored over the course of the Project, where concentrations in stormwater were reduced nearly 10-fold after treatment in the gravel layer and remained low throughout the subsequent layers of treatment. The results were most dramatic in the media layer where concentrations were reduced to non-detect levels in nearly all samples, presumably due to the exposure of nitrate to the root zone within the media layer and uptake of the nutrient by the native plants growing on the top of each cell. This pattern in the media layer was also observed during storm event 3, but the overall pattern of nitrate removal during this storm event was inconsistent with those observed in storm events 1 and 2.

The Project clearly demonstrated that the unique design of the Lambert Creek treatment wetland design is effective at removing *E. coli* and nutrients from stormwater and is a viable BMP for improving water quality in urbanized watersheds to meet TMDL compliance targets and other regulatory goals.

7.0 LITERATURE CITED

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ATTACHMENT 1 - ANALYTICAL DATA SUMMARY

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2018

STORM 1 - 8/20 - 8/27 2018

Site	Date	Time	TP (mg/L)	Ortho, SRP (mg/L)	TKN (mg/L)	Total Nitogen (mg/L)	N,NH3 (mg/L)	NO2+NO3 mg/L	TSS (mg/L)	*E.coli* (MPN/ 100 ml)
pre-1	8/20/2018	2:50	0.776	0.149	4.78	6.6	1.77	1.82	51	6,870
pre-2	8/20/2018	2:50	0.74	0.136	4.83	6.73	1.49	1.9	55	9,800
pre-3	8/20/2018	2:53	0.774	0.141	4.93	6.77	1.5	1.84	53	7,700
pre-4	8/20/2018	2:54	0.824	0.042	5.32	7.12	1.55	1.8	60	11,200
pre-5	8/20/2018	2:55	0.77	0.09	5.35	7.23	1.28	1.88	53	9,800
pre-6	8/20/2018	2:56	0.815	0.072	5.56	7.4	1.42	1.84	54	9,800
			0.783	**0.105**	**5.128**	**6.975**	**1.502**	**1.847**	**54.333**	**9,195**
vfb1-a-m	8/27/2018	12:30	0.335	0.031	2.62	2.62	0.071	0	522	3
vfb1-b-m	8/27/2018	12:30	0.281	0.036	1.77	1.77	0.128	0	150	57
vfb1-c-m	8/27/2018	12:30	0.279	0.11	1.99	1.99	0.214	0	28.3	16
			0.298	**0.059**	**2.127**	**2.127**	**0.138**	**0.000**	**233.433**	**25**
Percent change from Pre:			**-61.9%**	**-43.8%**	**-58.5%**	**-69.5%**	**-90.8%**	**-100.0%**	**329.6%**	**-99.7%**
vfb2-a-m	8/27/2018	12:45	0.157	0.012	1.45	1.45	0.09	0	14.3	3
vfb2-b-m	8/27/2018	12:45	0.194	0.019	1.61	1.61	0.059	0	42	57
vfb2-c-m	8/27/2018	12:45	0.24	0.015	2.11	2.11	0.067	0	15.1	16
			0.197	**0.015**	**1.723**	**1.723**	**0.072**	**0.000**	**23.800**	**25**
Percent change from Pre:			**-74.8%**	**-85.4%**	**-66.4%**	**-75.3%**	**-95.2%**	**-100.0%**	**-56.2%**	**-99.7%**
vfb3-a-m	8/27/2018	1:00	0.202	0.029	1.79	1.79	0.065	0	30	186
vfb3-b-m	8/27/2018	1:00	0.213	0.034	1.7	1.7	0.098	0	29.3	649
vfb3-c-m	8/27/2018	1:00	0.166	0.02	1.57	1.57	0.075	0	54.4	5
			0.194	**0.028**	**1.687**	**1.687**	**0.079**	**0.000**	**37.900**	**280**
Percent change from Pre:			**-75.3%**	**-73.7%**	**-67.1%**	**-75.8%**	**-94.7%**	**-100.0%**	**-30.2%**	**-97.0%**
vfb1-c-s	8/27/2018	12:30	0.09	0.036	0.569	0.634	0.124	0.065	36.4	162
vfb2-c-s	8/27/2018	12:45	0.079	0.02	0.647	0.647	0.08	0	46	261
vfb3-c-s	8/27/2018	1:00	0.122	0.034	0.645	0.679	0.068	0.034	21.8	921
			0.097	**0.030**	**0.620**	**0.653**	**0.091**	**0.033**	**34.733**	**448**
Percent change from Pre:			**-87.6%**	**-71.4%**	**-87.9%**	**-90.6%**	**-94.0%**	**-98.2%**	**-36.1%**	**-95.1%**
vfb1-c-g	8/27/2018	12:30	0.081	0.048	0.55	0.737	0.116	0.187	15.1	96
vfb2-c-g	8/27/2018	12:45	0.08	0.018	0.703	0.823	0.106	0.12	23.8	210
vfb3-c-g	8/27/2018	1:00	0.154	0.043	0.699	0.963	0.079	0.264	23.4	770
			0.105	**0.036**	**0.651**	**0.841**	**0.100**	**0.190**	**20.767**	**359**
Percent change from Pre:			**-86.6%**	**-65.4%**	**-87.3%**	**-87.9%**	**-93.3%**	**-89.7%**	**-61.8%**	**-96.1%**
vfb1-post-1	8/27/2018	12:30	0.991	0.092	1.7	2.69	0.392	0.989	47.7	1
vfb1-post-2	8/27/2018	12:30	0.974	0.088	1.79	1.79	0.38	1	32	0
vfb1-post-3	8/27/2018	12:30	0.674	0.086	1.46	1.47	0.391	1.01	48.4	2
vfb2-post-1	8/27/2018	12:45	0.13	0.087	0.584	2.55	0	1.97	66.9	1
vfb2-post-2	8/27/2018	12:45	0.129	0.089	0.549	2.63	0	2.08	92.7	1
vfb2-post-3	8/27/2018	12:45	0.172	0.098	0.579	2.71	0	2.13	9.6	0
vfb3-post-1	8/27/2018	1:00	0.139	0.06	0.798	3.05	0	2.25	71	0
vfb3-post-2	8/27/2018	1:00	0.11	0.064	0.717	2.98	0	2.26	44	0
vfb3-post-3	8/27/2018	1:00	0.091	0.06	0.544	2.82	0	2.28	22	0
			0.379	**0.080**	**0.969**	**2.521**	**0.129**	**1.774**	**48.256**	**0.556**
Percent change from Pre:			**-51.6%**	**-23.4%**	**-81.1%**	**-63.9%**	**-91.4%**	**-3.9%**	**-11.2%**	**-100.0%**

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2018

STORM 2 - 9/4 - 9/10 2018										
Site	**Date**	**Time**	**TP (mg/L)**	**Ortho, SRP (mg/L)**	**TKN (mg/L)**	**Nitogen**	**N,NH3 (mg/L)**	**NO2+NO3 mg/L**	**TSS (mg/L)**	***E.coli* (MPN/ 100 ml)**
pre-1	9/4/2018	11:00	0.144	0.064	0.751	1.32	0.096	0.574	11.3	1,986
pre-2	9/4/2018	11:01	0.151	0.061	0.842	1.43	0.086	0.591	10.8	2,419
pre-3	9/4/2018	11:02	0.137	0.058	0.722	1.33	0.068	0.604	12.2	2,419
pre-4	9/4/2018	11:03	0.173	0.066	0.862	1.43	0.106	0.569	13.8	2,419
pre-5	9/4/2018	11:04	0.204	0.068	0.981	1.54	0.128	0.562	31.3	1,733
pre-6	9/4/2018	11:05	0.168	0.071	0.84	1.4	0.165	0.56	64	2,419
			0.163	**0.065**	**0.833**	**1.408**	**0.108**	**0.577**	**23.900**	**2,233**
vfb1-a-m	9/10/2018	10:00	1.23	0.013	6.46	6.46	0.126	0	320	0
vfb1-b-m	9/10/2018	10:00	0.876	0.018	3.8	3.8	0.112	0	230	0
vfb1-c-m	9/10/2018	10:00	0.097	0.035	0.71	0.71	0.044	0	24.4	9
			0.734	**0.022**	**3.657**	**3.657**	**0.094**	**0.000**	**191.467**	**3**
Percent change from Pre:			**351.0%**	**-66.0%**	**339.0%**	**159.6%**	**-13.1%**	**-100.0%**	**701.1%**	**-99.9%**
vfb2-a-m	9/10/2018	10:15	0.078	0.013	0.779	0.779	0.046	0	31.3	2
vfb2-b-m	9/10/2018	10:15	0.122	0.027	1	1	0	0	21.8	0
vfb2-c-m	9/10/2018	10:15	0.102	0.017	1.12	1.12	0.088	0	10.7	0
			0.101	**0.019**	**0.966**	**0.966**	**0.045**	**0.000**	**21.267**	**1**
Percent change from Pre:			**-38.2%**	**-70.6%**	**16.0%**	**-31.4%**	**-58.7%**	**-100.0%**	**-11.0%**	**-100.0%**
vfb3-a-m	9/10/2018	10:30	0.08	0.028	0.95	0.95	0	0	21.1	5
vfb3-b-m	9/10/2018	10:30	0.083	0.027	0.743	0.777	0.069	0.034	6.7	12
vfb3-c-m	9/10/2018	10:30	0.063	0.021	0.639	0.639	0.054	0	8	0
			0.075	**0.025**	**0.777**	**0.789**	**0.041**	**0.011**	**11.933**	**6**
Percent change from Pre:			**-53.7%**	**-60.8%**	**-6.7%**	**-44.0%**	**-62.1%**	**-98.0%**	**-50.1%**	**-99.7%**
vfb1-c-s	9/10/2018	10:00	0.07	0.035	0.384	0.752	0.054	0.368	9.4	8
vfb2-c-s	9/10/2018	10:15	0.031	0.024	0.372	0.919	0.069	0.547	10.7	3
vfb3-c-s	9/10/2018	10:30	0.026	0.028	0.565	1.82	0	1.26	11.6	3
			0.042	**0.029**	**0.440**	**1.164**	**0.041**	**0.725**	**10.567**	**5**
Percent change from Pre:			**-74.0%**	**-55.2%**	**-47.1%**	**-17.4%**	**-62.1%**	**25.7%**	**-55.8%**	**-99.8%**
vfb1-c-g	9/10/2018	10:00	0.044	0.028	0.355	1.07	0	0.716	6.8	9
vfb2-c-g	9/10/2018	10:15	0.027	0.017	0.422	1.01	0.09	0.591	13.6	2
vfb3-c-g	9/10/2018	10:30	0.053	0.032	0.658	2.23	0	1.57	4	12
			0.041	**0.026**	**0.478**	**1.437**	**0.030**	**0.959**	**8.133**	**8**
Percent change from Pre:			**-74.6%**	**-60.3%**	**-42.6%**	**2.0%**	**-72.3%**	**66.3%**	**-66.0%**	**-99.7%**
vfb1-post-1	9/10/2018	10:00	0.102	0.087	0.716	1.07	0.092	0.353	16.4	147
vfb1-post-2	9/10/2018	10:00	0.16	0.093	0.784	1.11	0.156	0.329	5.6	115
vfb1-post-3	9/10/2018	10:00	0.192	0.075	0.755	1.09	0.09	0.339	54.8	132
vfb2-post-1	9/10/2018	10:15	0.086	0.049	0.455	1.02	0	0.565	10.7	109
vfb2-post-2	9/10/2018	10:15	0.138	0.05	0.521	1.09	0	0.573	17.8	4
vfb2-post-3	9/10/2018	10:15	0.072	0.053	0.369	0.943	0	0.574	20	45
vfb3-post-1	9/10/2018	10:30	0.041	0.022	0.518	0.693	0	0.175	5.8	6
vfb3-post-2	9/10/2018	10:30	0.042	0.02	0.536	0.727	0	0.191	10.4	1
vfb3-post-3	9/10/2018	10:30	0.036	0.027	0.46	0.65	0	0.19	2.9	1
			0.097	**0.053**	**0.568**	**0.933**	**0.038**	**0.365**	**16.044**	**62**
Percent change from Pre:			**-40.7%**	**-18.2%**	**-31.8%**	**-33.8%**	**-65.3%**	**-36.6%**	**-32.9%**	**-97.2%**

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2018

STORM 3 - 9/20 - 9/26 2018										
Site	**Date**	**Time**	**TP (mg/L)**	**Ortho, SRP (mg/L)**	**TKN (mg/L)**	**Nitogen**	**N,NH3 (mg/L)**	**NO2+NO3 mg/L**	**TSS (mg/L)**	***E.coli* (MPN/ 100 ml)**
pre-1	9/20/2018	2:00	0.354	0.113	1.98	2.37	0.13	0.39	52.7	9,210
pre-2	9/20/2018	2:00	0.269	0.101	1.55	1.94	0.567	0.388	82.5	13,000
pre-3	9/20/2018	2:00	0.312	0.094	1.94	2.21	0.53	0.27	98.7	8,160
pre-4	9/20/2018	2:00	0.3	0.09	1.74	1.96	0.465	0.222	96	7,700
pre-5	9/20/2018	2:00	0.353	0.091	1.96	2.18	0.395	0.224	156	11,200
pre-6	9/20/2018	2:00	1.04	0.07	7.05	7.26	0.46	0.214	274	8,660
			0.438	**0.093**	**2.703**	**2.987**	**0.425**	**0.285**	**126.650**	**9,655**
vfb1-a-m	9/26/2018	12	0.149	0.02	0.895	0.895	0.083	0	384	112,000
vfb1-b-m	9/26/2018	12	0.089	0.022	0.702	0.76	0.1	0.058	362	5,170
vfb1-c-m	9/26/2018	12	0.076	0.029	0.502	0.502	0.071	0	44.5	770
			0.105	**0.024**	**0.700**	**0.719**	**0.085**	**0.019**	**263.500**	**39,313**
Percent change from Pre:			**-76.1%**	**-74.6%**	**-74.1%**	**-75.9%**	**-80.1%**	**-93.2%**	**108.1%**	**307.2%**
vfb2-a-m	9/26/2018	12:15	0.052	0.016	0.402	0.402	0	0	5.3	83
vfb2-b-m	9/26/2018	12:15	0.056	0.009	0.566	0.566	0.064	0	8.5	11
vfb2-c-m	9/26/2018	12:15	0.07	0.005	0.552	0.552	0.055	0	3.8	11
			0.059	**0.010**	**0.507**	**0.507**	**0.040**	**0.000**	**5.867**	**35**
Percent change from Pre:			**-86.5%**	**-89.3%**	**-81.3%**	**-83.0%**	**-90.7%**	**-100.0%**	**-95.4%**	**-99.6%**
vfb3-a-m	9/26/2018	12:30	0.072	0.016	0.471	0.471	0.048	0	28	29
vfb3-b-m	9/26/2018	12:30	0.053	0.026	0.392	0.392	0.072	0	10.7	1,733
vfb3-c-m	9/26/2018	12:30	0.054	0.017	0.405	0.405	0	0	7.5	46
			0.060	**0.020**	**0.423**	**0.423**	**0.040**	**0.000**	**15.400**	**603**
Percent change from Pre:			**-86.4%**	**-78.9%**	**-84.4%**	**-85.8%**	**-90.6%**	**-100.0%**	**-87.8%**	**-93.8%**
vfb1-c-s	9/26/2018	12	0.056	0.034	0.379	0.976	0	0.597	16	548
vfb2-c-s	9/26/2018	12:15	0.053	0.04	0.392	1.572	0	1.18	8.5	20
vfb3-c-s	9/26/2018	12:30	0.049	0.036	0	0.939	0	0.939	29.6	3
			0.053	**0.037**	**0.257**	**1.162**	**0.000**	**0.905**	**18.033**	**190**
Percent change from Pre:			**-88.0%**	**-60.6%**	**-90.5%**	**-61.1%**	**-100.0%**	**218.0%**	**-85.8%**	**-98.0%**
vfb1-c-g	9/26/2018	12	0.048	0.033	0	0.989	0.06	0.989	8.2	41
vfb2-c-g	9/26/2018	12:15	0.054	0.039	0.41	1.63	0	1.22	11.3	26
vfb3-c-g	9/26/2018	12:30	0.054	0.032	0	1.18	0.042	1.18	12.4	17
			0.052	**0.035**	**0.137**	**1.266**	**0.034**	**1.130**	**10.633**	**28**
Percent change from Pre:			**-88.1%**	**-62.8%**	**-94.9%**	**-57.6%**	**-92.0%**	**296.8%**	**-91.6%**	**-99.7%**
vfb1-post-1	9/26/2018	12	0.064	0.051	0.321	0.626	0.04	0.305	4.8	411
vfb1-post-2	9/26/2018	12	0.067	0.054	0.339	0.646	0	0.307	3	326
vfb1-post-3	9/26/2018	12	0.116	0.049	0.421	0.729	0.056	0.308	10.6	387
vfb2-post-1	9/26/2018	12:15	0.029	0.027	0	0.418	0	0.418	10.4	1,203
vfb2-post-2	9/26/2018	12:15	0.028	0.027	2	2.414	0	0.414	4	866
vfb2-post-3	9/26/2018	12:15	0.029	0.026	0	0.411	0	0.411	1.4	980
vfb3-post-1	9/26/2018	12:30	0.246	0.055	2.15	3.67	0.397	1.52	28.7	201
vfb3-post-2	9/26/2018	12:30	0.074	0.072	0.338	1.838	0.095	1.5	55	101
vfb3-post-3	9/26/2018	12:30	0.128	0.056	0.771	0.958	0.187	1.52	7.1	687
			0.087	**0.046**	**0.704**	**1.301**	**0.086**	**0.745**	**13.889**	**574**
Percent change from Pre:			**-80.2%**	**-50.3%**	**-73.9%**	**-56.4%**	**-79.7%**	**161.6%**	**-89.0%**	**-94.1%**

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2019

STORM 1 - 6/27 - 7/8 2019										
Site	**Date**	**Time**	**TP (mg/L)**	**Ortho, SRP (mg/L)**	**TKN (mg/L)**	**Total Nitogen (mg/L)**	**N,NH3 (mg/L)**	**NO2+NO3 mg/L**	**TSS (mg/L)**	***E.coli* (MPN/ 100 ml)**
pre-1	6/27/2019	10:25	0.411	0.09	3.52	5.24	1	1.72	79	22800
pre-2	6/27/2019	10:25	0.632	0.07	4.53	5.92	1.61	1.39	75.5	9100
pre-3	6/27/2019	10:25	0.597	0.064	3.87	5.1	0.813	1.23	76.7	14100
pre-4	6/27/2019	10:25	0.497	0.058	3.85	4.91	1.46	1.06	77.3	6100
pre-5	6/27/2019	10:25	0.581	0.036	3.63	4.61	1.25	0.977	86	5800
pre-6	6/27/2019	10:25	0.531	0.032	3.5	4.38	1.18	0.883	96	15300
			0.542	**0.058**	**3.817**	**5.027**	**1.219**	**1.210**	**81.750**	**12,200**
vfb1-a-m	7/8/2019	10:00	0.314	0.023	1.61	1.61	0.171	0	95.3	5
vfb1-b-m	7/8/2019	10:00	0.123	0.062	1.48	1.48	0	0	84.4	1
vfb1-c-m	7/8/2019	10:00	0.251	0.048	1.52	1.52	0.117	0	30.8	3
			0.229	**0.044**	**1.537**	**1.537**	**0.096**	**0.000**	70.167	**3**
Percent change from Pre:			**-57.6%**	**-24.0%**	**-59.7%**	**-69.4%**	**-92.1%**	**-100.0%**	**-14.2%**	**-100.0%**
vfb2-a-m	7/8/2019	10:15	0.216	0.032	1.74	1.74	0	0	10	34.5
vfb2-b-m	7/8/2019	10:15	0.157	0.011	1.87	1.87	0.236	0	16.6	9.8
vfb2-c-m	7/8/2019	10:15	0.137	0.015	1.34	1.34	0.103	0	10.4	1
			0.170	**0.019**	**1.650**	**1.650**	**0.113**	**0.000**	**12.333**	**15**
Percent change from Pre:			**-68.6%**	**-66.9%**	**-56.8%**	**-67.2%**	**-90.7%**	**-100.0%**	**-84.9%**	**-99.9%**
vfb3-a-m	7/8/2019	10:30	0.146	0.066	1.61	1.61	0.153	0	25.6	214.3
vfb3-b-m	7/8/2019	10:30	0.082	0.028	1.14	1.14	0.14	0	5.3	9.7
vfb3-c-m	7/8/2019	10:30	0.077	0.023	1.26	1.26	0.122	0	9.1	0
			0.102	**0.039**	**1.337**	**1.337**	**0.138**	**0.000**	**13.333**	**75**
Percent change from Pre:			**-81.2%**	**-33.1%**	**-65.0%**	**-73.4%**	**-88.7%**	**-100.0%**	**-83.7%**	**-99.4%**
vfb1-c-s	7/8/2019	10:00	0.165	0.105	0.673	0.801	0.209	0.128	18.2	1
vfb2-c-s	7/8/2019	10:15	0.07	0.04	0.416	0.602	0.147	0.186	23.8	0
vfb3-c-s	7/8/2019	10:30	0.133	0.086	0.384	0.776	0.066	0.392	36.2	2
			0.123	**0.077**	**0.491**	**0.726**	**0.141**	**0.235**	**26.067**	**1**
Percent change from Pre:			**-77.3%**	**32.0%**	**-87.1%**	**-85.6%**	**-88.5%**	**-80.6%**	**-68.1%**	**-100.0%**
vfb1-c-g	7/8/2019	10:00	0.187	0.073	0.728	0.84	0.319	0.112	20.7	1
vfb2-c-g	7/8/2019	10:15	0.089	0.043	0.413	0.619	0.136	0.206	24.4	1
vfb3-c-g	7/8/2019	10:30	0.11	0.045	0.554	0.98	0.178	0.426	3.5	18.7
			0.129	**0.054**	**0.565**	**0.813**	**0.211**	**0.248**	**16.200**	**7**
Percent change from Pre:			**-76.2%**	**-8.0%**	**-85.2%**	**-83.8%**	**-82.7%**	**-79.5%**	**-80.2%**	**-99.9%**
vfb1-post-1	7/8/2019	10:45	0.207	0.052	0.543	0.72	0.074	0.177	70	0
vfb1-post-2	7/8/2019	10:45	0.173	0.051	0.487	0.662	0.108	0.175	36.7	0
vfb1-post-3	7/8/2019	10:45	1.24	0.052	0.655	0.839	0.163	0.184	55.1	0
vfb2-post-1	7/8/2019	11:00	0.113	0.029	0	0	0	0.054	37.3	0
vfb2-post-2	7/8/2019	11:00	0.128	0.03	0	0	0	0.056	13.2	1
vfb2-post-3	7/8/2019	11:00	0.11	0.029	0.44	0.312	0	0.056	10.9	27.5
vfb3-post-1	7/8/2019	11:15	0.05	0.043	0	0	0	0.102	1.8	0
vfb3-post-2	7/8/2019	11:15	0.047	0.044	0	0.323	0	0.124	1.1	0
vfb3-post-3	7/8/2019	11:15	0.05	0.044	0	0.301	0	0.098	1.3	0
			0.235	**0.042**	**0.236**	**0.351**	**0.038**	**0.114**	**25.267**	**3.167**
Percent change from Pre:			**-56.5%**	**-28.8%**	**-93.8%**	**-93.0%**	**-96.9%**	**-90.6%**	**-69.1%**	**-100.0%**

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2019

STORM 2 - 8/5 - 8/19 2019										
Site	**Date**	**Time**	**TP (mg/L)**	**Ortho, SRP (mg/L)**	**TKN (mg/L)**	**Nitogen**	**N,NH3 (mg/L)**	**NO2+NO3 mg/L**	**TSS (mg/L)**	***E.coli* (MPN/ 100 ml)**
pre-1	8/5/2019	1:30	0.788	0.033	5.46	8.11	2.74	2.65	104	248
pre-2	8/5/2019	1:30	0.508	0.051	3.29	5.36	1.23	2.07	69.6	144
pre-3	8/5/2019	1:30	0.244	0.064	2.83	4.76	1.06	1.93	62	99
pre-4	8/5/2019	1:30	0.403	0.03	3.21	4.86	1.13	1.65	64.3	121
pre-5	8/5/2019	1:30	0.418	0.013	3.53	4.91	1.13	1.38	80.5	1120
pre-6	8/5/2019	1:30	0.472	0.016	3.6	4.81	1.11	1.21	69.6	110
			0.472	**0.035**	**3.653**	**5.468**	**1.400**	**1.815**	**75.000**	**307**
vfb1-a-m	8/19/2019	11:00	0.309	0.079	1.8	1.84	0	0.042	14.9	10.9
vfb1-b-m	8/19/2019	11:00	0.438	0.092	1.55	1.58	0	0.033	62	2
vfb1-c-m	8/19/2019	11:00	0.264	0.132	1.16	1.22	0	0.061	8.6	5.2
			0.337	**0.101**	**1.503**	**1.547**	**0.000**	**0.045**	**28.500**	**6**
Percent change from Pre:			**-28.6%**	**192.8%**	**-58.9%**	**-71.7%**	**-100.0%**	**-97.5%**	**-62.0%**	**-98.0%**
vfb2-a-m	8/19/2019	11:15	0.101	0.036	0.744	0.791	0	0.047	7.2	24.1
vfb2-b-m	8/19/2019	11:15	0.05	0.02	1.21	1.21	0.084	0	4.2	46.4
vfb2-c-m	8/19/2019	11:15	0.072	0.037	1.15	1.18	0.145	0.031	6.7	1
			0.074	**0.031**	**1.035**	**1.060**	**0.076**	**0.026**	**6.033**	**24**
Percent change from Pre:			**-84.3%**	**-10.1%**	**-71.7%**	**-80.6%**	**-94.5%**	**-98.6%**	**-92.0%**	**-92.2%**
vfb3-a-m	8/19/2019	11:30	0.23	0.085	1.02	1.05	0	0.032	12.8	2
vfb3-b-m	8/19/2019	11:30	0.126	0.035	1.21	1.21	0.24	0	6.8	81.3
vfb3-c-m	8/19/2019	11:30	0.135	0.024	1.16	1.16	0.062	0	7.2	40.4
			0.164	**0.048**	**1.130**	**1.140**	**0.101**	**0.011**	**8.933**	**41**
Percent change from Pre:			**-65.3%**	**39.1%**	**-69.1%**	**-79.2%**	**-92.8%**	**-99.4%**	**-88.1%**	**-86.6%**
vfb1-c-s	8/19/2019	11:00	0.314	0.272	0.842	0.975	0	0.133	8.5	28.8
vfb2-c-s	8/19/2019	11:15	0.085	0.054	0	0	0.083	0.035	5.6	4.1
vfb3-c-s	8/19/2019	11:30	0.072	0.046	0.468	0.623	0.214	0.155	12.6	8.6
			0.157	**0.124**	**0.437**	**0.533**	**0.099**	**0.108**	**8.900**	**14**
Percent change from Pre:			**-66.7%**	**259.4%**	**-88.0%**	**-90.3%**	**-92.9%**	**-94.1%**	**-88.1%**	**-95.5%**
vfb1-c-g	8/19/2019	11:00	0.079	0.064	0	2.29	0	2.14	6	5.2
vfb2-c-g	8/19/2019	11:15	0.084	0.041	0	0	0.107	0.07	11.8	4.1
vfb3-c-g	8/19/2019	11:30	0.075	0.064	0	0.836	0	0.687	4.6	13.2
			0.079	**0.056**	**0.000**	**1.042**	**0.036**	**0.966**	**7.467**	**8**
Percent change from Pre:			**-83.2%**	**63.3%**	**-100.0%**	**-80.9%**	**-97.5%**	**-46.8%**	**-90.0%**	**-97.6%**
vfb1-post-1	8/19/2019	11:00	0.084	0.05	0.46	0.531	0	0.071	1.6	13.2
vfb1-post-2	8/19/2019	11:00	0.073	0.05	0.852	0.919	0	0.067	1.4	8.5
vfb1-post-3	8/19/2019	11:00	0.073	0.051	0.491	0.563	0	0.072	1.5	9.8
vfb2-post-1	8/19/2019	11:15	0.048	0.043	0	0	0	0.104	1.2	5.2
vfb2-post-2	8/19/2019	11:15	0.048	0.043	0	0	0	0.109	0	8.6
vfb2-post-3	8/19/2019	11:15	0.047	0.042	0	0	0	0.105	1.2	4.1
vfb3-post-1	8/19/2019	11:30	0.049	0.034	0	0	0	0.037	2.8	5.2
vfb3-post-2	8/19/2019	11:30	0.05	0.037	0	0	0	0.042	1.5	5.2
vfb3-post-3	8/19/2019	11:30	0.047	0.038	0	0	0	0.037	0	4.1
			0.058	**0.043**	**0.200**	**0.224**	**0.000**	**0.072**	**1.244**	**7**
Percent change from Pre:			**-87.8%**	**25.0%**	**-94.5%**	**-95.9%**	**-100.0%**	**-96.1%**	**-98.3%**	**-97.7%**

VLAWMO Treatment Wetland Pilot Project

Summary of Pollutant Reduction Effectiveness from Three Storm Events in 2019

STORM 3 - 9/11 - 9/19 2019										
Site	**Date**	**Time**	**TP (mg/L)**	**Ortho, SRP (mg/L)**	**TKN (mg/L)**	**Nitogen**	**N,NH3 (mg/L)**	**NO2+NO3 mg/L**	**TSS (mg/L)**	***E.coli* (MPN/ 100 ml)**
pre-1	9/11/2019	5:00	4.37	0.117	17.2	17.5	7.13	0.31	905	34480
pre-2	9/11/2019	5:00	9.42	0.316	39.9	40.1	22.8	0.222	1840	12033
pre-3	9/11/2019	5:00	1.88	0.224	8.8	9.11	3.27	0.308	407	9804
pre-4	9/11/2019	5:00	0.973	0.168	5.14	5.43	1.9	0.286	447	17329
pre-5	9/11/2019	5:00	0.616	0.13	3.65	3.94	1.59	0.285	117	14136
pre-6	9/11/2019	5:00	0.525	0.12	2.77	3.05	1.29	0.28	139	9208
			2.964	**0.179**	**12.910**	**13.188**	**6.330**	**0.282**	**642.500**	**16,165**
vfb1-a-m	9/19/2019	9:30	0.058	0.024	0.849	0.849	0	0	9.2	31.5
vfb1-b-m	9/19/2019	9:30	0.053	0.033	0.849	0.849	0	0	4.5	0
vfb1-c-m	9/19/2019	9:30	0.061	0.041	0.994	0.994	0	0	12.2	1
			0.057	**0.033**	**0.897**	**0.897**	**0.000**	**0.000**	**8.633**	**11**
Percent change from Pre:			**-98.1%**	**-81.8%**	**-93.0%**	**-93.2%**	**-100.0%**	**-100.0%**	**-98.7%**	**-99.9%**
vfb2-a-m	9/19/2019	9:45	0.02	0.012	0.551	0.551	0	0	2.8	16.9
vfb2-b-m	9/19/2019	9:45	0.034	0.011	0.836	0.836	0	0	2.1	2
vfb2-c-m	9/19/2019	9:45	0.024	0.013	0.918	0.958	0	0.04	1.8	4.1
			0.026	**0.012**	**0.768**	**0.782**	**0.000**	**0.013**	**2.233**	**8**
Percent change from Pre:			**-99.1%**	**-93.3%**	**-94.0%**	**-94.1%**	**-100.0%**	**-95.3%**	**-99.7%**	**-100.0%**
vfb3-a-m	9/19/2019	10:00	0.031	0.019	0.677	0.677	0	0	5.4	290.9
vfb3-b-m	9/19/2019	10:00	0.039	0.014	0.822	0.822	0	0.03	8.1	30.1
vfb3-c-m	9/19/2019	10:00	0.024	0.016	0.934	0.934	0	0	1	2
			0.031	**0.016**	**0.811**	**0.811**	**0.000**	**0.010**	**4.833**	**108**
Percent change from Pre:			**-98.9%**	**-90.9%**	**-93.7%**	**-93.9%**	**-100.0%**	**-96.5%**	**-99.2%**	**-99.3%**
vfb1-c-s	9/19/2019	9:30	0.079	0.071	0.866	1.9	0	1.03	12.7	34.5
vfb2-c-s	9/19/2019	9:45	0.041	0.039	0.741	2.28	0	1.44	7.7	37.3
vfb3-c-s	9/19/2019	10:00	0.052	0.031	0.558	2.68	0	2.12	3.9	38.9
			0.057	**0.047**	**0.722**	**2.287**	**0.000**	**1.530**	**8.100**	**37**
Percent change from Pre:			**-98.1%**	**-73.8%**	**-94.4%**	**-82.7%**	**-100.0%**	**442.9%**	**-98.7%**	**-99.8%**
vfb1-c-g	9/19/2019	9:30	0.066	0.05	0.552	1.78	0	1.23	13.4	23.1
vfb2-c-g	9/19/2019	9:45	0.05	0.038	0.693	1.68	0	0.985	2.4	81.3
vfb3-c-g	9/19/2019	10:00	0.073	0.062	0.394	2.52	0	2.13	10.1	69.1
			0.063	**0.050**	**0.546**	**1.993**	**0.000**	**1.448**	**8.633**	**58**
Percent change from Pre:			**-97.9%**	**-72.1%**	**-95.8%**	**-84.9%**	**-100.0%**	**413.9%**	**-98.7%**	**-99.6%**
vfb1-post-1	9/19/2019	9:30	0.078	0.046	1.55	1.76	0	0.215	21.9	6.3
vfb1-post-2	9/19/2019	9:30	0.067	0.048	0.667	0.884	0	0.217	6.1	6.3
vfb1-post-3	9/19/2019	9:30	0.075	0.049	0.591	0.804	0	0.213	11.3	2
vfb2-post-1	9/19/2019	9:45	0.054	0.039	0.526	1.8	0	1.27	8.2	9.4
vfb2-post-2	9/19/2019	9:45	0.034	0.037	0.434	1.67	0	1.24	1	1
vfb2-post-3	9/19/2019	9:45	0.032	0.037	0.477	1.75	0	1.27	0	1
vfb3-post-1	9/19/2019	10:00	0.04	0.043	0.461	2.03	0	1.57	1.2	26.2
vfb3-post-2	9/19/2019	10:00	0.04	0.044	0.547	2.13	0	1.58	0	54.6
vfb3-post-3	9/19/2019	10:00	0.036	0.044	0.503	2.07	0	1.57	0	73.3
			0.051	**0.043**	**0.640**	**1.655**	**0.000**	**1.016**	**5.522**	**20**
Percent change from Pre:			**-98.3%**	**-76.0%**	**-95.0%**	**-87.4%**	**-100.0%**	**260.5%**	**-99.1%**	**-99.9%**

ATTACHMENT 2 - PATHOGEN DATA SUMMARY

		16S		uidA		eaeA		cadF		ftsZ		stx1		ciaB		virA		hex	
Date	Well	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
7/9 and 7/15	1	9.2	9.0	5.2	3.9					5.1	3.9								
	2		8.7		3.8						3.8								
	3		9.0		4.0						4.0								
8/5 and 8/13	1	9.7	8.2	5.2	3.6					5.3	3.6								
	2		8.6		3.7						3.7								
	3		9.1		4.1						4.1								
8/20 and 8/27	1	9.0	8.3																
	2		8.6																
	3		8.6																
9/11 and 9/19	1	9.4	8.2	5.1	3.7					5.6	3.7								
	2		8.2		3.9						3.9								
	3		8.4		4.0						4.0								
Target organism		ALL BACTERIA		All E. coli		Enterohemorrhagic E. coli		Campylobacter jejuni		All E. coli		Enterohemorrhagic E. coli		Campylobacter jejuni					
General Commentary		all look good		Yellow = detection limit		all are below detection		all are below detection				all are below detection		all are below detection		assay failed		assay failed	

YELLOW = detection limit for the assay

All data are log(10) of gene copies per liter. Example#1: 9.0 = 9 billion per liter, Example#2: 5.0 = 100,000 per liter vir

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