Stormwater Quality Improvement through Bioretention in a Continental, Cold Climate

by

Hannah H Kratky

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Environmental Engineering

Department of Civil and Environmental Engineering
University of Alberta

Abstract

Bioretention is a widely used best management practice of low impact development. It uses an engineered soil media with amendments and vegetation to manage stormwater runoff near its source through volume reduction, peak flow reduction, and physical, chemical, and biological contaminant treatment. Bioretention has been well studied in warm climates but gaps of knowledge exist in bioretention implementation and performance in cold regions with clay rich soils like in Edmonton, Alberta. Here, annual precipitation is on average 456 mm and freezing temperatures typically last 7 months.

Therefore, this research was initiated to better understand the hydraulic and water quality performance of bioretention designed for and operated under local conditions. Four large columns of 0.36-meter diameter were filled with approximately 0.90 meters of bioretention media. Two columns contain loam soil (soil media "A") and two columns contained sandy loam soil (soil media "B"). All four columns contained a surface layer of mulch, a top layer of compost/soil mixture, and two switch grass plants. One column containing loam soil and one column containing sandy loam soil each also contained nutrient amendment layers intended to encourage nutrient removal or degradation. One layer consisted of steel wool to enhance phosphate adsorption/precipitation and another layer was submerged at room temperature and contained woodchips for a supplemental carbon source, both of which promote denitrification.

All four columns underwent five stages of laboratory operation equating to 1.6 years of precipitation volume in Edmonton. These stages consisted of synthetic stormwater application for 1st summer operation, winter operation, spring runoff, 2nd summer operation, and slightly larger rainfall events (i.e. a single 1:5 year and a single 1:10 year event). All stages except for winter operation and spring runoff were simulated in a room temperature laboratory. For winter and spring runoff, all four large columns were moved into a cold room and frozen to -20°C and thawed to approximately 1-3°C repeatedly. Design rainfall events were applied during this intermittent thawing to simulate Edmonton's intermittent warming periods throughout winter in which the snowpack may melt multiple times.

This research investigated the change in concentration from the influent to the effluent of each column of total suspended solids (TSS), phosphorus (phosphate and total phosphorus), nitrogen (ammonium, nitrate, and total nitrogen), chloride, organics as measured by chemical oxygen demand (COD), and heavy metals (copper, zinc, lead, and cadmium). Excellent removal of TSS, phosphate, and ammonium (i.e. $\geq$ 90% average concentration reduction) were observed in both the loam and sandy loam columns without the nutrient amendment layers during summer operation of 1:2 year events and the 1:5 and 1:10 year events conducted. The columns containing the nutrient amendment layers also reduced TSS, ammonium, and phosphate, but the removal efficiency was decreased for TSS in the 1st summer and for ammonium in all conditions as compared to the columns without the nutrient amendment layer.

TSS was physically removed via the processes of sedimentation and filtration, phosphate was dominantly removed via precipitation/adsorption and subsequent filtration, and ammonium was quickly and dominantly removed via adsorption to bioretention media and likely degraded to nitrate via nitrification during subsequent intermittent drying between applied storm events. This research discovered that even during winter and spring runoff, if infiltration of snowmelt can eventually occur, the physical removal of TSS, phosphate, and ammonium can still be achieved, even only days after the complete freezing (and subsequent thawing) of bioretention media at -20°C.

After an initial maturation, nitrate was well removed (≥ 59.8% average concentration reduction) via denitrification when in the presence of woodchips and anoxic conditions. This removal occurred in the columns with both loam and sandy loam soil with the nutrient amendment layers during summer operation of 1:2 year events and the 1:5 and 1:10 year events conducted. Typically, in all other conditions, nitrate leached substantially from every column. Chloride did not appear to accumulate in any columns in this research and simply leached from each system without causing an obvious negative impact to the columns functionality. Organic matter continued to leach considerably from each column, but with a decreasing trend over time. Heavy metals appeared to be well removed by each column likely due to the high cation exchange capacity of the bioretention media utilized in this research.

Preface

Some of the research conducted for this thesis forms part of a research collaboration, led by Professor Tong Yu at the University of Alberta. The four large columns referred to in Chapter 3 were designed as a joint effort between me, Mia Yu, Dr. Tong Yu, and James McKinnon. The experiments carried out as described in Chapter 3 were carried out by Zhan Li and me with equal responsibility.

Section 2.3 of this thesis has been published as H. Kratky, Z. Li, Y. Chen, C. Wang, X Li, and T. Yu, "A critical literature review of bioretention research for stormwater management in cold climate and future research recommendations," Frontiers of Environmental Science and Engineering, vol. 11, issue 4, article 16, pages 1-15. This article will serve as the cold climate literature review for my thesis. As there are multiple authors of this paper, the following are my contributions:

- Hand drawing and digital editing of the graphic abstract, shown in Figure 2.
- Composition of the abstract.
- Composition of the introduction, water quality improvement, and summary and recommendations (sections 2.3.2, 2.3.4, and 2.3.5, respectively) with contributions from C. Wang, X. Li, and T. Yu.
- Revisions and grammatical edits to the remainder of the paper.

The remaining literature review in Chapter 2 and the data analysis, results, discussion, and conclusions of Chapter 4 and Chapter 5 are my original work.

A portion of the work in this thesis has been published as the following:

Kratky H, Li Z, Li X, and Yu T. 2018. Laboratory study on the performance of bioretention for stormwater management in cold climates. *In Proceedings of the International Low Impact Development Conference: Getting in Tune with Green Infrastructure*. ASCE, Nashville, Tennessee, United States, 12-15 August 2018.

The above publication included part of the results discussed in section 4.1, 4.2, 4.3.1, 4.3.2, and 4.4 for only the 1st summer and winter operation detailed in this thesis.

Acknowledgments

This work is financially supported by a Collaborative Research and Development Grant jointly sponsored by Natural Sciences and Engineering Research Council (NSERC) of Canada, the City of Edmonton, and EPCOR Water Services, Inc. in Alberta, Canada. It is also partially supported by a Queen Elizabeth II Graduate Scholarship from Government of Alberta.

I would like to sincerely thank my supervisor, Dr. Tong Yu, for his continued support, patience, and guidance on this project, Dr. Xiangfei Li for her excellent industrial expertise and serving on my supervisory committee, and Dr. Wenming Zhang for your helpful comments and serving on my supervisory committee. Thank you all for your valuable time.

Thank you to Chen Liang, David Zhao, Yijun Chen, Lei Zhu, and Ziang Zhu for being so incredibly helpful and a joy to work with over the last three years!

I would also like to give my deepest thanks to Zhan Li for always being wonderful to work alongside with! Your great work ethic, intelligence, and ability to problem solve and stay on task were vital for this project and made us the perfect team. I could not have done it without you.

Finally, I would like to thank my mom, dad, and sister for always believing in me and thank you Tiger, for being my rock of a lap dog and putting up with all the missed “W’s”.

Table of Contents

List of Tables ix

List of Figures xi

List of Symbols xiv

Chapter 1. Introduction 1

1.1 Background of Research 1

1.2 Objectives of the Research 3

1.3 Structure Overview 3

Chapter 2. Literature Review 4

2.1 Bioretention 4

2.2 Stormwater Pollutants 4

2.2.1 TSS (total suspended solids) 4

2.2.2 Nutrients (phosphorus and nitrogen) 5

2.2.3 Heavy metals 6

2.2.4 Chloride 7

2.2.5 Organics 7

2.3 "A critical literature review of bioretention research of stormwater management in cold climate and future research recommendations" 8

2.3.1 Abstract 9

2.3.2 Introduction 10

2.3.3 Hydraulic performance 12

2.3.4 Water quality improvement 18

2.3.5 Summary and recommendations 31

Chapter 3. Research Design and Methods 35

3.1 Experimental Apparatus Design 35

3.1.1 Column Construction 35

3.1.2 Bioretention Media Selection and Installation 42

3.1.3 Vegetation 48

3.2 Experimental Methods 52

3.2.1 Large Column Simulated Runoff Events 52

3.2.2 Small Column Phosphate Adsorption Capacity Analysis 59

3.2.3 Soil Media and Amendment Leachate Analysis 61
3.3 Analytical Methods 63
Chapter 4. Results and Discussion 67
4.1 Total Suspended Solids (TSS) 70
4.2 Phosphorus 77
4.2.1 Small Column Adsorption Experiment........ 86
4.3 Nitrogen........ 89
4.3.1 Ammonium 90
4.3.2 Nitrate 98
4.3.3 Total Nitrogen........ 105
4.4 Chloride........ 108
4.5 Vegetation 118
4.6 Organics 120
4.7 Metals........ 126
4.8 Leachate 133
Chapter 5. Conclusions and Significance........ 136
5.1 Conclusions........ 136
5.2 Significance of these Findings 140
5.3 Lessons learned 141
5.4 Future Research........ 142
References........ 144
Appendix A : Experimental Setup Details........ 158
Appendix B : Raw and Intermittent Data 161
Appendix C : Second Nature Compost Final Analytical Report........ 308

List of Tables

Table 1: Summarized gaps in current cold climate studies and recommended areas of research. 33
Table 2: Column media composition and preparation of materials prior to installing in the columns. Details for where the materials were purchased can be found in Table 29 in Appendix A. 44
Table 3: Target composition of simulated stormwater influent used in this experiment.. 52
Table 4: Detailed chronological list of events conducted. 56
Table 5: Weight of media added to each Erlenmeyer flask for leachate analysis. 63
Table 6: List of water quality parameters analyzed and associated methods. 64
Table 7: List of soil parameters analyzed by Exova of Edmonton and associated methods. 66
Table 8: Inventory of chemical analysis conducted on samples collected for each event ran. 68
Table 9: Average TSS percent concentration reduction by all columns throughout all stages of operation. 70
Table 10: Average effluent TSS concentration of all columns throughout all stages of operation. 71
Table 11: Average phosphate percent concentration reduction by all columns throughout all stages of operation. 78
Table 12: Average effluent phosphate concentration of all columns throughout all stages of operation. 78
Table 13: Phosphorus leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 83
Table 14: Phosphorus extracted from different media types. 84
Table 15: Bioretention media characteristics that act to remove phosphorus from stormwater as measured by Exova of Edmonton. 85
Table 16: Average ammonium percent concentration reduction by all columns throughout all stages of operation. 90
Table 17: Average effluent ammonium (as N) concentration of all columns throughout all stages of operation. 91
Table 18: Nitrogen leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 97
Table 19: Nitrogen in different media types as measured by Exova of Edmonton. 98
Table 20:Average nitrate percent concentration reduction by columns 3 and 4 during operation in which the submerged zone is present. Omitted weeks of maturation in 1st and 2nd summer (i.e. week 4, 5, 6, 37, and 38). 98
Table 21: Average effluent nitrate (as N) concentration of all columns during operation in which the submerged zone is present. Omitted weeks of maturation in 1st and 2nd

summer (i.e. weeks 1, 2, 3 (columns 1 and 2), weeks 4, 5, 6 (columns 3 and 4), and weeks 37.. 99
Table 22: Nitrate leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 105
Table 23: Nitrate in different media types as measured by Exova of Edmonton. 105
Table 24: Chloride leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 111
Table 25: Organic compound leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 122
Table 26: Organic matter content of different media types as measured by Exova of Edmonton. 122
Table 27: Metals leachate from different media types. µg/L measurements utilized 180 mL of deionized water and approximately 9 g of media. 126
Table 28: Available metals in different media types as measured by Exova of Edmonton. 126
Table 29: Approximate mass of media prone to contaminant leaching installed in the four large columns used in this research. 133
Table 30: Details of products used in this research and their supplier. 159
Table 31: TSS influent and effluent concentrations and percentage concentration reduction for columns 1 and 2. 162
Table 32: TSS influent and effluent concentrations and percentage concentration reduction for columns 3 and 4. 172
Table 33: Phosphate influent and effluent concentrations and percentage concentration reduction for columns 1 and 2. 185
Table 34: Phosphate influent and effluent concentrations and percentage concentration reduction for columns 3 and 4. 195
Table 35: Ammonium influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4. 208
Table 36: Nitrate influent and effluent concentrations and percentage concentration reduction for columns 1 and 2. 221
Table 37: Nitrate influent and effluent concentrations and percentage concentration reduction for columns 3 and 4. 233
Table 38: Chloride influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4. 250
Table 39: COD influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4. 263
Table 40: Influent and effluent concentrations and concentration percent change for heavy metals for column 1. 275
Table 41: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 1. 279

Table 42: Influent and effluent concentrations and concentration percent change for heavy metals for column 2. 283
Table 43: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 2. 287
Table 44: Influent and effluent concentrations and concentration percent change for heavy metals for column 3. 291
Table 45: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 3. 295
Table 46: Influent and effluent concentrations and concentration percent change for heavy metals for column 4. 299
Table 47: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 4 303

List of Figures

Figure 1: Nitrogen transformation and removal processes in oxic and anoxic conditions (Bernhard, 2010). 6
Figure 2: Graphic abstract of a typical bioretention design. 9
Figure 3: Overall view of one empty large column. Dimensions are in cm. Taken April 12, 2016. 36
Figure 4: View of sampling ports along the media depth. Taken October 1, 2018. 37
Figure 5: 2” diameter effluent drain pipe and shut off valve (blue). Taken October 1, 2018. 38
Figure 6: Raised effluent piping network (i.e. with black tips; white tipped pipe was existing). Dimensions are in cm. Taken October 1, 2018. 39
Figure 7: Uniform water distribution apparatus. A) Top view B) Bottom view C) Close up of outflow hole pattern. Dimensions are in cm. Taken October 1, 2018. 40
Figure 8: Uniform water distribution apparatus under high flow rate. Taken April 12, 2016. 41
Figure 9: View of column equipped with two SunBlaster™ fluorescent lights for plant health. Taken April 12, 2016. 42
Figure 10: Schematic of bioretention column composition. Annotations are in centimeters. 43
Figure 11: USDA soil textural triangle (Groenendyk et al., 2015). 46
Figure 12: Particle size distribution graph for the two soil media types used. 47
Figure 13: Visual depiction of vegetative health of the three different species planted in columns 1 and 2. Taken August 3, 2017. 49
Figure 14: One Heavy Metal Blue Switch Grass plant in plastic pot. Taken August 19, 2017. 50

Figure 15: Column 1 experiencing its first simulated storm event. Taken September 26, 2017 ... 51
Figure 16: External air temperature fluctuation during all five stages of operation. ... 54
Figure 17: All four columns set up in the room temperature laboratory. Taken November 17, 2017 ... 55
Figure 18: All four columns set up in the temperature-controlled room. Taken May 28, 2018 ... 55
Figure 19: Set up for small columns for phosphate adsorption capacity analysis of soil media "A" and "B". ... 61
Figure 20: Arrangement of Erlenmeyer flasks for soil media and amendment leachate analysis. ... 62
Figure 21: TSS removal during the 1st summer, winter, spring runoff, and 2nd summer operation. ... 72
Figure 22: TSS removal during room temperature events. ... 75
Figure 23: Phosphate removal during the 1st summer, winter, spring runoff, and 2nd summer operation. ... 79
Figure 24: Phosphate removal during room temperature events. ... 81
Figure 25: Total phosphorus concentration reduction during select events. ... 82
Figure 26: Phosphate adsorbed/precipitated by small soil columns. ... 86
Figure 27: Ammonium removal during the 1st summer, winter, spring runoff, and 2nd summer operation. ... 92
Figure 28: Ammonium removal during room temperature events. ... 96
Figure 29: Nitrate removal and leaching during the 1st summer, winter, spring runoff, and 2nd summer operation. ... 100
Figure 30: Nitrate removal and leaching during room temperature events. ... 103
Figure 31: Volume interval sample analysis of nitrate in columns 3 and 4. ... 104
Figure 32: Total nitrogen concentration change during select events. ... 106
Figure 33: Total nitrogen concentration change during select events zoomed in. ... 107
Figure 34: Sodium chloride phase diagram (DeVoe, 2017). ... 110
Figure 35: Chloride concentration change during 1st summer and winter operation. ... 112
Figure 36: Chloride concentration change during 1st summer operation zoomed in. ... 114
Figure 37: Chloride concentration change during winter operation zoomed in. ... 115
Figure 38: Chloride concentration change during spring runoff. ... 116
Figure 39: Chloride concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events. ... 117
Figure 40: COD concentration change during 1st summer and winter operation. ... 121
Figure 41: COD concentration change during spring runoff. ... 124
Figure 42: COD concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events. ... 125
Figure 43: Copper removal during select events. ... 127

Figure 44: Zinc removal during select events. 128
Figure 45: Lead removal during select events. 129
Figure 46: Cadmium removal during select events. 130
Figure 47: Leachate concentration from the different soil medias used as found in the leachate analysis. 134
Figure 48: Leachate concentrations of metals from the different soil medias used as found in the leachate analysis. 134
Figure 49: Approximate leachate mass available in the large columns. 135
Figure 50: Approximate metals leachate mass available in the large columns. 135
Figure 51: Influent hydrographs for the three storm frequencies used in this research. 160
Figure 52: Influent hydrograph for the low concentration, high volume "major melt" spring runoff event. 160
Figure 53: TSS concentration reduction during 1st summer and winter operation. 182
Figure 54:TSS concentration reduction during spring runoff. 183
Figure 55:TSS concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events. 184
Figure 56: Phosphate concentration reduction during 1st summer and winter operation. 205
Figure 57: Phosphate concentration reduction during spring runoff. 206
Figure 58: Phosphate concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events. 207
Figure 59: Ammonium concentration reduction during 1st summer and winter. 218
Figure 60: Ammonium concentration reduction during spring runoff. 219
Figure 61: Ammonium concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events. 220
Figure 62: Nitrate concentration change during 1st summer and winter operation. 245
Figure 63: Nitrate concentration change during 1st summer and winter operation zoomed in. 246
Figure 64: Nitrate concentration change during 1st summer and winter operation with effluent outliers omitted (week 8 and 10 from columns 1 and 2 and week 7 from column 4). 247
Figure 65: Nitrate concentration change during spring runoff. 248
Figure 66: Nitrate concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events. 249
Figure 67: NPOC concentration change during select events. 307

List of Symbols

LID	Low impact development
BMP	Best management practice
PVC	Polyvinyl chloride
RPM	Rotations per minute
(v/v)	On a volume basis
(w/w)	On a weight basis
TSS	Total Suspended Solids
TP	Total phosphorus
TN	Total nitrogen
COD	Chemical Oxygen Demand
NPOC	Non-purgeable organic carbon
mg/L or mg·L^{-1}	Milligrams per litre
μg/L or μg·L^{-1}	Micrograms per litre
mg/kg or mg·kg^{-1}	Milligrams per kilogram
μg/kg or μg·kg^{-1}	Micrograms per kilogram
cm/hr	Centimetres per hour
mL/min	Millilitres per minute

Chapter 1. Introduction

1.1 Background of Research

As communities undergo urbanization, natural, pervious ground cover transitions into impervious features such as buildings, roads, parking lots, and sidewalks. This change causes greater stormwater runoff volumes which would otherwise infiltrate to deeper layers of the soil. During intermittent periods between storm events, human activities lead to deposition of urban pollutants on the impervious surfaces that accumulate and are captured by runoff from the next storm event. This leads to water quality degradation of downstream water bodies if the runoff is left unmanaged.

Low Impact Development (LID) is a form of stormwater management that helps to mitigate the negative impacts of urbanization by enabling sites to mimic predevelopment hydrologic characteristics and treat stormwater very near to its source. Bioretention is a commonly implemented LID technology that is typically designed to manage all 1:2 year frequency rainfall events by infiltrating the whole volume quickly and enhancing water quality to protect downstream receptacles.

Bioretention cells or facilities utilize an engineered soil media and vegetation to function as a physical, chemical, and biological treatment system. A variety of amendments or configurations can also be employed to enhance stormwater contaminant reduction, such as iron filings and water treatment residuals to capture phosphate and the formation of anoxic conditions to promote denitrification. Bioretention can be designed with underdrains and impermeable liners if sensitive ground water tables exist in the area or they can be lined with existing soils to promote deeper infiltration. Bioretention also employs a variety of native vegetation that can contribute to evapotranspiration and therefore volume reduction and nutrient and heavy metal uptake. Pretreatment systems are also vital features of bioretention that function to settle larger sediments that could cause premature clogging and slow flow velocities to minimize erosion of the bioretention filter bed.

Extensive research has been conducted on the performance of bioretention utilizing different medias, configurations, and amendments, typically in temperatures above 10℃. A few studies have also been conducted in cold climates such as Norway, Calgary, Alberta, and cities in Ontario. However, this research is the first of its kind to study bioretention performance in Edmonton, Alberta, a region characterized with extreme cold temperatures during a long dry winter, short growing season, clay soils, and relatively low precipitation volumes. Average low and record low temperatures in Edmonton's winter are -11℃ and -48.3℃, respectively, with an average annual snowfall of 123.5 cm and rainfall of 347.8 mm, which equates to 455.7 mm of precipitation (GoC, 2018a). Freezing temperatures in Edmonton typically last for 7 months, however, in recent years, intermittent warming periods with stretches of above freezing temperatures that can melt the snowpack have been observed. With global climate change, instances of these warming periods may be occurring even more frequently in years to come. 108.2 mm

The City of Edmonton is invested in retaining the health of Edmonton's local watershed by minimizing the impact of human activities on surface waters. To do this, the City of Edmonton has developed a series of strategic plans which include the Combined Sewer Discharge Strategy (CoE, 2000), the Stormwater Quality Control Strategy and Action Plan (CoE, 2008), the Total Loading Plan (CoE, 2009), The Way We Green (CoE, 2011), and the River for Life Strategy (Urban Systems Ltd., 2012). The implementation of LID technologies, including bioretention, adheres to the objectives of these strategic plans and is listed as a Best Management Practice (BMP) for stormwater control.

The City of Edmonton has developed the LID BMP Design Guide (CoE, 2014a) to help designers integrate LID into their projects. However, this document has yet to be supported by Edmonton based experimental evidence. There are approximately 19 bioretention sites currently existing in Edmonton but their designs make it difficult or costly to collect ample samples to fully evaluate their hydraulic and water quality improvement performance. Therefore, the City of Edmonton began commissioning this research in 2012 to better understand the performance of locally designed bioretention facilities under local climate and stormwater contaminant characteristics. This will allow the LID BMP Design Guide, which is a living document, to evolve and enhance the design of bioretention in Edmonton and expand its successful implementation.

1.2 Objectives of the Research

This research aims to investigate and determine:

- Local Edmonton soil and amendments suitable for use in bioretention media.
- Hydraulic performance of bioretention during simulated Edmonton storm events (results found elsewhere (Li, 2018)).
- Water quality improvement or fate of typical Edmonton runoff through bioretention for the following stormwater contaminants:
    - Total suspended solids (TSS), nitrogen (ammonium, nitrate, and total nitrogen), phosphorus (phosphate and total phosphorus), salts (chloride), organics (as measured by COD and NPOC), and heavy metals (copper, zinc, lead, and cadmium).
- The impact of Edmonton's extreme cold winter temperatures and corresponding increased contaminant concentrations on hydraulic performance (results found elsewhere (Li, 2018)) and water quality improvement of bioretention.
- The fate or impact of winter road maintenance salts (as measured by chloride).
- The ability of bioretention to maintain hydraulic and water quality improvement performance during intermittent warming periods, shortly after experiencing severe cold temperatures (e.g. -20°C), throughout winter and during spring runoff.

This research aims to push the current bioretention application limits to achieve acceptable performance in cold temperatures and warm temperatures.

1.3 Structure Overview

This thesis provides the water quality results of the four large bioretention column laboratory experiments conducted to provide guidance for implementing bioretention in regions like Edmonton, Alberta. The hydraulic performance results from the same experiments are detailed in in Zhan Li's 2018 MSc thesis titled "Laboratory study on the hydraulic performance of bioretention for stormwater management in cold climates" (Li, 2018). Chapter 2 presents a literature review on stormwater contaminants of concern investigated in this study and the current state of knowledge of bioretention performance in cold climates. “A critical literature review of bioretention research for stormwater management in cold climate and future research recommendations” published in 2017 in Frontiers of Environmental Science and Engineering makes up section 2.3 of the literature review. Chapter 3 describes the custom large bioretention columns and water distribution system designed for this research, as well as the engineered media utilized and the methodology of all stages of the experiments. Chapter 4 evaluates the experimental results and discusses the meaning of the data. Finally, Chapter 5 summarizes the conclusions, significance of this research, and future research recommendations.

Chapter 2. Literature Review

2.1 Bioretention

Non-point sources of pollution, such as stormwater from urban and agricultural lands, are difficult to manage. In fact, the leading source of surface water degradation is now from stormwater runoff in which siltation, nutrients, bacteria, and metals are the primary contaminants causing degradation (U.S. EPA, 2000). Bioretention employs the removal mechanisms of sedimentation, filtration, physical and chemical adsorption and precipitation, microbial degradation, and vegetative uptake with subsequent evapotranspiration to treat these non-point source contaminants. Bioretention systems contain mulch, soil, organic matter, and vegetation and are a landscaped biofiltration cell that infiltrates and treats stormwater runoff from nearby, impervious land prior to releasing the runoff to either underlaying soils or other grey and green stormwater infrastructure (Davis et al., 2003).

2.2 Stormwater Pollutants

2.2.1 TSS (total suspended solids)

TSS in stormwater has an extremely broad range of sources and concentrations. It can originate from road maintenance activities which include applying grit and sand to increase road traction, the physical breakdown of litter and debris deposited by vegetation and humans, and construction, demolition, and other land disturbing activities. Particles can also be released into the air when various items are burned and later deposited onto impermeable ground surfaces. Not only are high TSS deposits aesthetically unpleasant in an urban environment, but they are easily picked up by stormwater runoff and can provide transportation to other contaminants sorbed to them. Runoff TSS that reaches surface water systems may lead to reduced light penetration necessary for aquatic plant growth and the eventual sedimentation alters the habitat of bottom-dwelling aquatic species (U.S. EPA, 1999).

2.2.2 Nutrients (phosphorus and nitrogen)

Nutrients in stormwater runoff originate from fertilizer application, animal/plant waste, sewage, and atmospheric deposition (Weiss et al., 2008). Nutrients are of the most concern in excess concentrations in runoff because they cause algae blooms which deplete dissolved oxygen and cause the death of aquatic species in a process called eutrophication. Severe enough algae blooms can also lead to the growth of toxic cyanobacteria. Eutrophication is not only a serious environmental issue, but it has caused significant economic impacts greater than $2.2 billion USD per year in the United States based on decreased waterfront property value and impacts to recreation, habitat, and drinking water treatment (Dodds et al., 2009).

Phosphorus exists in many different forms in the environment. For the purposes of evaluating it in stormwater, it can be divided into particulate and dissolved phosphorus. Particulate phosphorus is removed via the same sedimentation and filtration mechanism as TSS and is therefore typically removed well. Dissolved phosphorus is also the more abundant form of phosphorus and ranges from 45-90% of total phosphorus concentrations (Erickson et al., 2012). Of dissolved phosphorus, the reactive form (i.e. orthophosphate) is the bioavailable form and therefore most likely to lead to eutrophication when in excess amounts in stormwater runoff.

Many forms of nitrogen exist naturally in the environment. The two forms of most concern in stormwater runoff are nitrate (NO_3^-) due to its bioavailability to algae and ammonia

(NH_3) due to its rapid transformation to nitrate, as seen in Figure 1, and toxicity to some aquatic organisms at low concentrations (Leisenring et al., 2010).

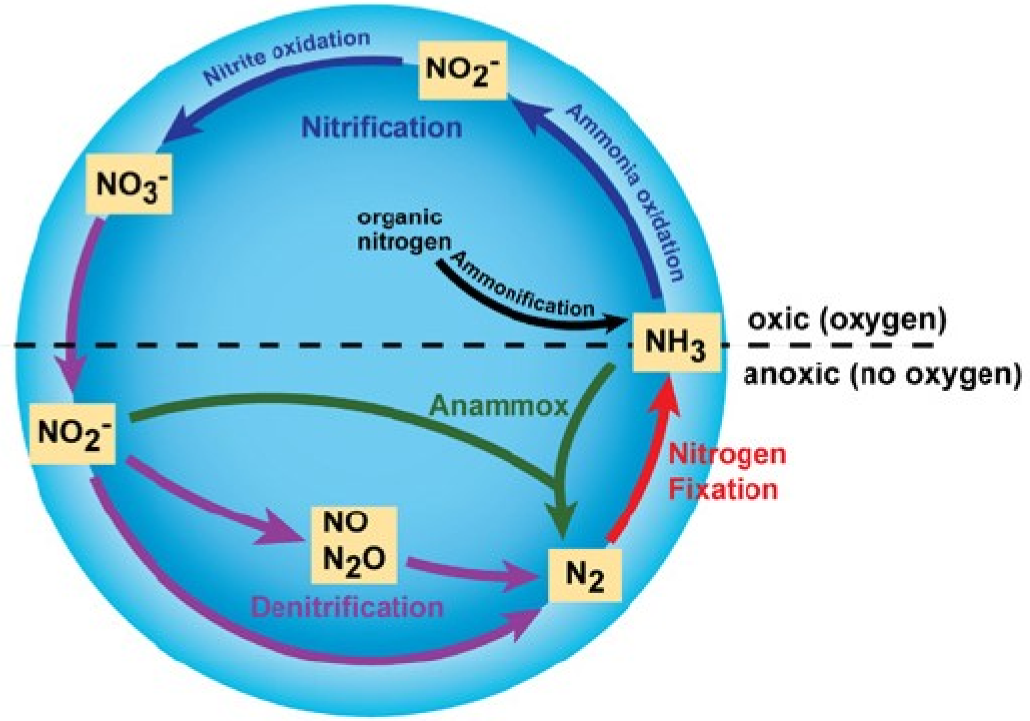


Figure 1: Nitrogen transformation and removal processes in oxic and anoxic conditions (Bernhard, 2010).

2.2.3 Heavy metals

The most commonly studied heavy metals in stormwater runoff are copper, zinc, lead, and cadmium due to their prevalence in stormwater and toxicity. Copper and cadmium have been found to partition equally between particulate and dissolved phases; zinc generally was found as particulate bound; lead was highly bound by particles (Dean et al., 2005). This is valuable information as dissolved metals are readily assimilated by aquatic organisms and therefore of concern in terms of acute toxicity (Yousef et al., 1985). However, even particulate metals may eventually desorb or partition back into their dissolved phase. Lead typically releases into the environment from the weathering of older paints (Davis and Burns, 1999). Heavy metals can also originate from the degradation of building siding, vehicle wear, and atmospheric deposition (Davis et al., 2001). These contaminants cause issues in stormwater runoff that reaches surface waters as they are toxic to aquatic life and recalcitrant.

2.2.4 Chloride

Chloride ions originate typically from winter de-icing salts and are problematic in stormwater runoff as chloride increases soil salinity and therefore water stress in vegetation (Taiz et al., 2015) and due to its mobility in soil, can easily migrate into groundwater (EC&HC, 2001). Road salts represent a complex issue due to their effects on soils, vegetation, infrastructure, processes in receiving waters, drinking water, microorganisms, and biodiversity (Marsalek, 2003). Acute toxic effects on aquatic life has been observed in some species at concentrations of 1400 mg Cl^-/L (EC&HC, 2001). Chronic toxicity of aquatic organisms has also been observed and it's been estimated that 10% of certain species may be impacted at concentrations as low as 240 mg Cl^-/L. Behavioral and toxicological impacts have been observed in mammals and birds exposed to road salts. Therefore, road salts have been classified as toxic under the Canadian Environmental Protection Act making it vital to evaluate their fate through bioretention.

2.2.5 Organics

Organic matter in stormwater runoff typically originates from plant and animal waste, as well as vehicle exhaust or leaking storage tanks (i.e. as petroleum hydrocarbons). Combined sewer overflows (CSOs) can also contribute to organic loadings in receiving surface water bodies; if onsite stormwater management such as LID are not employed, then greater volumes of stormwater runoff can overflow combined sewers and cause raw municipal sewage to release directly into surface waters. This is an issue for surface water quality because aerobic bacteria consume oxygen to breakdown the organic matter which will lead to depleted dissolved oxygen concentrations and diminished aquatic biodiversity. Petroleum hydrocarbons are also acutely toxic (U.S. EPA, 1999) and recalcitrant.

2.3 “A critical literature review of bioretention research of stormwater management in cold climate and future research recommendations”

The following is a review article published in Frontiers of Environmental Science and Engineering in 2017, vol. 11, issue 4, article 16, pages 1-15. This article will serve as the cold climate literature review for my thesis. As there are multiple authors of this paper, the following are my contributions:

- Hand drawing and digital editing of the graphic abstract, shown in Figure 2.
- Composition of the abstract.
- Composition of the introduction, water quality improvement, and summary and recommendations (sections 2.3.2, 2.3.4, and 2.3.5, respectively) with contributions from C. Wang, X. Li, and T. Yu.
- Revisions and grammatical edits to the remainder of the paper.

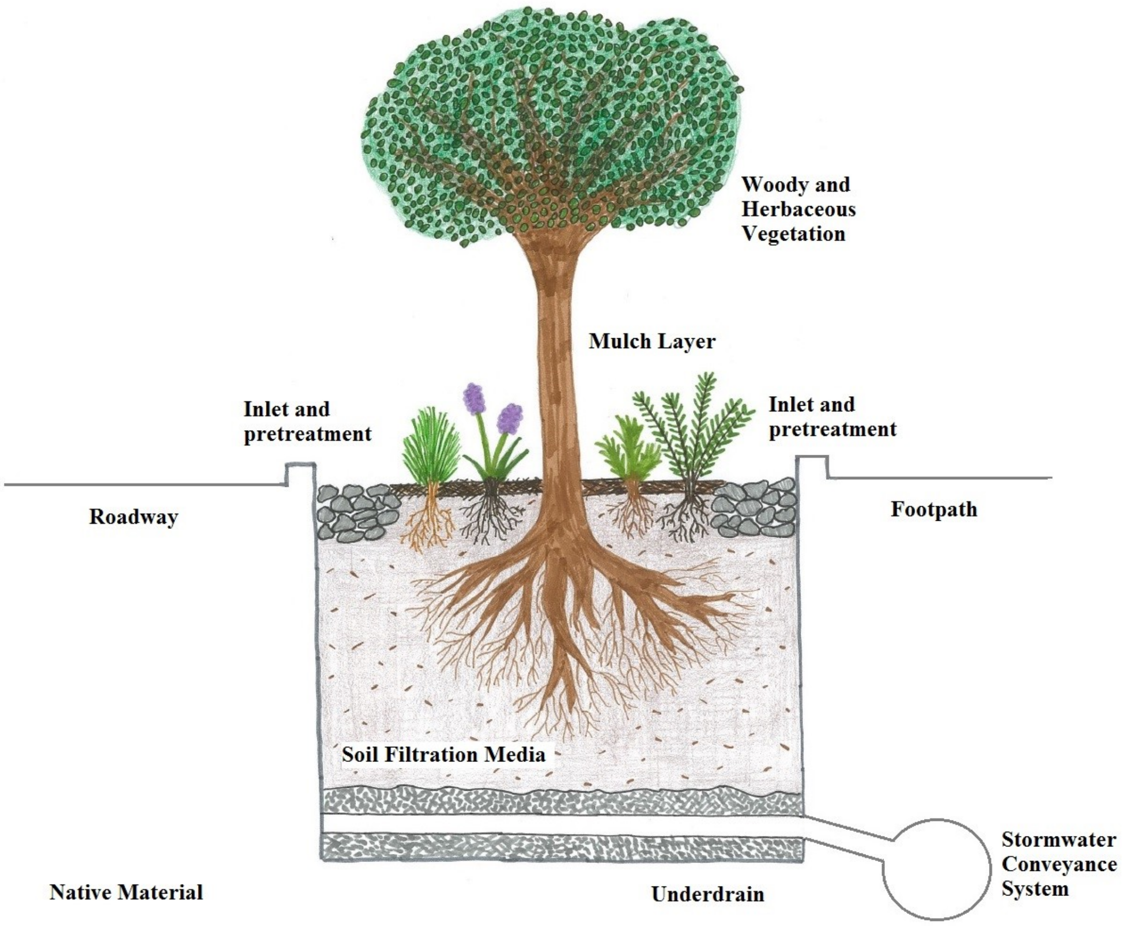


Figure 2: Graphic abstract of a typical bioretention design.

2.3.1 Abstract

Bioretention is a popular best management practice of low impact development that effectively restores urban hydrologic characteristics to those of predevelopment and improves water quality prior to conveyance to surface waters. This is achieved by utilizing an engineered system containing a surface layer of mulch, a thick soil media often amended with a variety of materials to improve water quality, a variety of vegetation, and underdrains, depending on the surrounding soil characteristics. Bioretention systems have been studied quite extensively for warm climate applications, but data strongly supporting their long-term efficacy and application in cold climates is sparse. Although it is apparent that bioretention is an effective stormwater management system, its design in cold climate needs further research. Existing cold climate research has shown that coarser media is

required to prevent concrete frost from forming. For spring, summer and fall seasons, if sufficient permeability exists to drain the system prior to freezing, peak flow and volume reduction can be maintained. Additionally, contaminants that are removed via filtration are also not impacted by cold climates. In contrary, dissolved contaminants, nutrients, and organics are significantly more variable in their ability to be removed or degraded via bioretention in colder temperatures. Winter road maintenance salts have been shown to negatively impact the removal of some contaminants and positively impact others, while their effects on properly selected vegetation or bacteria health are also not very well understood. Research in these water quality aspects has been inconsistent and therefore requires further study.

2.3.2 Introduction

Bioretention is one of the most commonly applied low impact development (LID) practices in urban watersheds (Davis et al., 2009). Its goal is to manage stormwater runoff as close to its source as possible to mimic predevelopment conditions by reducing peak runoff flow and volume and improving water quality. This technology decentralizes stormwater management and proves small-scale actions can create sustainable solutions. Bioretention function relies on the hydraulic, chemical, physical, and biological processes occurring in the integrated plants, soil, and microorganism components (DER, 2007). A conventional bioretention system consists of vegetation, a surface mulch layer, biofiltration medium, and underdrains. The need for underdrains depends on the volume of water and level of contamination exiting the system, regional groundwater usage, and native soil permeability.

Investigations have demonstrated that bioretention is considered an intuitive technology and was welcomed by some residents that were questioned (Hoban and Kennedy, 2012). In Australia, 78% of Bellvista residents agreed or strongly agreed that bioretention should be included in new developments. Bioretention research and application are gaining popularity throughout the world including the United States, Canada, Norway, Australia, New Zealand, Britain, China, and Singapore, most often in warm, temperate regions due to its ability to store, treat, and infiltrate stormwater (Jia et al., 2013). Relatively few cold climate bioretention studies (e.g. Norway and Canada) have been conducted.

The characteristics of cold climates are cold temperatures, frozen soils during winter, deep frost lines, repeating freeze-thaw cycles, short growing seasons, significant snowmelt volume, and changes to stormwater characteristics, such as water density, ion exchange capacity, increased contaminant concentrations, and reduced dissolved oxygen under ice cover. These characteristics result in bioretention application challenges including: reduced biological processes, reduced soil infiltration, high concentrations of sediment and pollutants during snowmelt in spring, impact of salt and de-icing agents on vegetation, high runoff volume during snowmelt and rain on snow, ice blocked inlets, and soil compaction (especially if used for snow storage). These challenges must be carefully considered for effective bioretention applications in cold climates. The Koppen-Geiger scheme of climate classification identifies cold (or snow) climates as having a temperature ≤ -3°C and warm climates being from -3°C to +18°C (Kottek et al., 2006). Therefore, 24.6% of global land is classified as cold climate and includes 13 of 100 of the world's largest cities which typically have moderate precipitation (544-1,451 $\mathrm{mm \cdot year^{-1}}$), up to 40% of which is snow (Peel et al., 2007). Edmonton, in Alberta, Canada, has even less precipitation (approximately 460 $\mathrm{mm \cdot year^{-1}}$) (NRCC, 2014), making bioretention application here a challenge.

Cold climate pollutants of concern remain the same as in warm climate (i.e. TSS, TP, TN, Cu, Pb, Zn, Ni); however, hydrocarbon, salt, and TSS concentrations increase considerably in cold climates due to vehicles producing more pollutants from engine inefficiencies and the use of de-icing salts and sand for road maintenance (Géhéniau et al., 2015). Also, associated low temperatures change pollutant chemistry and concentrations. Urban snowmelt often has high soluble contaminant concentrations (Oberts, 2003). Snowmelt has significantly higher sediment loads and a stronger correlation between TSS, sediment size, and metal concentration than rain runoff (Westerlund and Viklander, 2006). Snowmelt is also considerably enriched with dissolved pollutants (compared to rain runoff) by a certain factor in the early stages of melt and is transported with the first flush and followed by larger particulate matter (Viklander and Malmqvist, 1993). Bioretention performance in cold climates and warm climates is still limited to short-term studies but long-term performance data are needed to understand lifetime and maintenance needs, the potential for system failure, and performance changes over time (Khan et al., 2012a).

2.3.3 Hydraulic performance

2.3.3.1 Peak flow reduction and lag time

Bioretention systems smooth stormwater runoff hydrographs by reducing peak flow, which reduces erosion, scour, and sediment transport to the receiving stream (Davis, 2008). Bioretention is a buffer to runoff peak flow by: forming ponding water on the surface and retaining water within the media and releasing it slowly via exfiltration and evapotranspiration. Different peak flow reduction rates have been reported and range from 44% (Davis, 2008) to 95% (Ping and Tao, 2011). Bioretention systems also delay the peak flow of runoff and this is often reported in different forms, such as lag time, lag coefficient, or peak delay ratio (Davis, 2008; Roseen et al., 2009). Lag time, expressed in minutes, is the time from the beginning of inflow into the bioretention cell to when outflow reaches the underdrain and has been observed to range from approximately 60 to 600 minutes (Muthanna et al., 2008; Khan, 2011). Lag coefficient is the ratio of effluent hydrograph time to effluent hydrograph centroid over influent hydrograph time to influent hydrograph centroid and can range from 1.3 to 2.0 (Roseen et al., 2009). Peak delay ratio is calculated as the elapsed time of outflow peak over the elapsed time of inflow peak, and a target ratio of 6 has been set by some research (Davis, 2008).

2.3.3.2 Stormwater volume reduction

Stormwater volume reduction is a result of bioretention systems' media storage capacity, evapotranspiration, exfiltration, and ponding water depth (He and Davis, 2011). Media porosity has water storage capacity and when the soil is saturated, this capacity is referred to as maximum retentive capacity, which may be reached during a large rainfall event. However, in the long-term (e.g. one day after the rain event), once macropores have drained of water, the soil's field capacity is most important for stormwater volume reduction (Nyle and Ray, 2008). The water remaining in the soil's micropores is then reduced via evapotranspiration or infiltration as capillary water. Therefore, the volume of the micropores influences the volume reduction rate. This can partially explain why sandy clay loam (i.e. more micropores) media can have a higher volume reduction rate than loamy sand media (He and Davis, 2011). Deeper bioretention media can also have a higher volume reduction rate due to having more micropores in certain media. For example, bioretention systems with deeper media depths (0.9 m) had significantly more outflow reduction than shallower media (0.6 m) (Brown and Hunt, 2012).

Evapotranspiration (i.e. the combination of evaporation and transpiration) as a stormwater volume reduction mechanism varies between different bioretention systems. Evapotranspiration is influenced by climate and weather, but also by heat supply (i.e. primarily solar radiation). For example, night time evapotranspiration is only about 1.7% to 14% of 24 hour evapotranspiration (Malek, 1992). Evapotranspiration is also influenced by the type of soils within and surrounding the system. Therefore, a variety of evapotranspiration rates within bioretention have been reported by various researchers; while evapotranspiration accounted for only 3% of total volume reduction in one study (Brown and Hunt, 2012), it has also been observed to release 50% of the inflow as evapotranspiration in a different study (Lucas and Hunt, 2005). Evapotranspiration is a slow process and could take 30 days to regain 1 inch of field capacity (Palhegyi, 2010). However, compared to percolation, it functions anytime there is heat and the total effect might be significant.

Exfiltration is influenced by the native soil's texture and moisture that surrounds bioretention cells. Bioretention systems surrounded by soil with high conductivity (e.g. sandy clay loam) will encourage lower outflow in the underdrains (He and Davis, 2011). Depending on the native soil type, only 25% of inflow might be exfiltrated (Lucas and Hunt, 2005) or it may be predominantly exfiltrated out the bottom compared to the sides (He and Davis, 2011). Volume reduction efficiency of bioretention not only depends on the system's design, which affects the above mechanisms, but also on rainfall event intensity. In Trowsdale and Simcock's (2011) research in Auckland, New Zealand, the average ratio of outflow to inflow was 41%, and the smallest volume reduction efficiencies corresponded to the largest rainfall events. In Khan et al.'s (2012b) research in Calgary, Canada, for events less than 32 mm, bioretention captured 100% of the runoff, but for events with long return periods, the removal rate decreased to 91.5%. Stormwater volume reduction relies heavily on both the hydrological conditions and hydraulic performance of bioretention.

2.3.3.3 Factors affecting hydraulic performance in cold climate

The hydraulic performance of bioretention can be evaluated by several indicators including, peak flow reduction, lag time, the time delay of the flow rate, and stormwater volume reduction, which can all be quite variable based on bioretention design and rainfall event. These factors are impacted even more under cold climate conditions and when subjected to snowmelt, as infiltration and transpiration are limited and spring runoff consists of significantly higher volumes of water to treat. Cold climates impact stormwater volume reduction efficiencies by causing significantly lower evapotranspiration rates, low water uptake due to plant dormancy (Muthanna, 2007; Géhéniau et al., 2015; Paus et al., 2014a), and decreased soil pore volume due to freezing water creating channelized flows (Muthanna, 2007). To counteract this decrease in hydraulic performance, bioretention cells designed for cold climates should employ a smaller catchment area relative to its surface area compared to facilities designed for warm climates.

A study conducted in North Carolina supports the conclusion of bioretention having poor hydraulic performance in cold climate as the ratio of stormwater in outflow to inflow was 0.07 in summer and 0.54 in winter (i.e. significantly more was retained in summer) which was possibly due to the lower evapotranspiration rate and exfiltration rate in the winter (Hunt et al., 2006). Reduced hydraulic bioretention performance in cold climate has also been observed in other studies; for example, total volume reduction decreased from 25% in August to 13% in April (Muthanna et al., 2007a) and total volume reduction declined from 59.7% ± 3.3% to 35.0% ± 11.6% from the warm to cold season, respectively (Géhéniau et al., 2015). Winter conditions also decreased average peak flow reductions from 42% in summer to 27% in winter and the hydraulic detention time decreased with temperature and snowmelt events generally decreased hydraulic performance (Muthanna et al., 2008). If snow storage is included in the bioretention design, issues such as snow depth (not to exceed 2 m) (Muthanna et al., 2007b) and soil compaction are of concern because they may significantly reduce hydraulic performance as well.

In cold climate, the moisture in the soil can freeze, block soil pores, and reduce infiltration rates. The frost formed within the soil can be concrete, granular, or porous: concrete frost forms in saturated soils and permits little water movement due to formation of an ice lens (Muthanna, 2007); granular frost forms in unsaturated soils and maintains high permeability (LeFevre et al., 2009); porous frost is the most permeable type (LeFevre et al., 2009). Interestingly, the hydraulic conductivity of soil with granular or porous frost can be greater than unfrozen soils due to the presence of preferential flow paths (Stoeckeler and Weitzman, 1960; LeFevre et al., 2009). LeFevre et al. (2009) tested hydraulic conductivity of bioretention in cold climate and concluded that the most important design parameter is the ability of the media to drain efficiently such that granular or porous frost forms rather than concrete. Concrete frost formation on the surface can restrict water movement and impact the application of bioretention in cold climates. Freeze-thaw cycles, however, have been observed to increase infiltration by generating greater pore volumes during freezing through expansion of the water in the soil, which do not return to their original volume when the water thaws (Denich et al., 2013). A study in New Hampshire (Roseen et al., 2009) illustrated the same trend of increased infiltration rates in winter. Another explanation of greater hydraulic conductivity in winter is that the organic matter has a macropore structure that helps maintain infiltration even in partially frozen soils (Dietz, 2007).

Many bioretention studies in cold climate have selected coarse materials as the filter media (Muthanna et al., 2007a; Muthanna et al., 2007c; Muthanna et al., 2008; LeFevre et al., 2009; Blecken et al., 2011; Denich et al., 2013; Géhéniau et al., 2015; Søberg et al., 2017) to avoid ice blockage but also to prevent the higher TSS concentrations in snowmelt from blocking pore spaces. For instance, several studies in Norway selected low clay content and high sand (90%) content soils for bioretention units to improve winter infiltration (Muthanna et al., 2007a; Muthanna et al., 2007c; Muthanna et al., 2008). Moghadas et al. (2016) conducted a laboratory scale study on infiltration of water into two frozen engineered bioretention soils (one with coarse soil and one with fine soil). It was found that finer, more compacted soils reduced porosity, extended water breakthrough times, and steadied percolation rates. Fine solids entering the bioretention facility also must be controlled by pre-treatment (Moghadas et al., 2016). One concern of using coarse media (sand) and less clay content in cold climates is that heavy metals and TSS removal may be impaired. Blecken et al. (2011) used coarse filter media in a 10-week laboratory bioretention column study. This media consisted of two 400 mm layers: an upper sand layer (<4% silt and 14% fine gravel (2–4 mm), D_{50}=620µm) and a lower fine to medium sand layer (D_{50}=280µm) with 100mm of topsoil on the surface to enhance sorption capacity. Heavy metals were effectively removed and most retained dissolved metals were captured by the thin layer of topsoil, even at low temperatures (2°C). It is recommended that topsoil or mulch on the surface be used to increase sorption in the media. Similarity, Søberg et al. (2014) also found that large grain sizes and therefore pore sizes do not impact bioretention performance as similar TSS and metal removal efficiencies were seen in fine and coarse bioretention media.

Designing bioretention for cold climates is especially challenging due to the inherent contradiction between designing for stormwater quantity while still maintaining sufficient water quality improvement. By utilizing coarser media, water quality improvement may be sacrificed and by using fine media to improve contaminant removal, concrete frost would form in cold climate and the system's hydraulic performance would be inadequate. The goal of research on bioretention in cold climate is to strike a balance between these two vital aspects of stormwater runoff treatment. It is also critical to analyze the specific goals the system is being designed to achieve as most sites have diverse characteristics and treatment requirements. For example, perhaps flooding is the major concern in a region; therefore, peak flow and volume reduction are the most important design objectives and water quality improvement might not be a priority.

A study of field and column experiments in Calgary, Canada, demonstrated good hydraulic performance in both summer and winter conditions, with the average peak flow reduction of 96.2% in summer and 93.5% in winter (Khan et al., 2012b). In this study, cold conditions had a significant effect on hydraulic performance (i.e. lower volume reduction, lower peak flow reduction, and longer lag times) during intense rainfall events. An analysis of soil moisture in this study showed that the frozen surface soil can change the water path through the bioretention cell so that the water moves laterally until finding a preferential pathway vertically (Khan et al., 2012b). This causes less soil volume wetting and, therefore, higher effluent peak flow rates, less water volume retention, and decreased permeability causing longer peak delays. However, these impacts were only seen up to a certain media depth; the sensors in Khan's study (2012b) showed no variation between warm and cold weather at 300 mm and 500 mm depths meaning that the bioretention media in cold climate is not the issue, but rather, the surface boundary effects caused by frozen media. This is a common phenomenon in prairie regions under freeze-thaw cycles. Local conditions need to be considered when designing a bioretention system.

2.3.3.4 Long-term performance

The main concern for long-term peak flow reduction and hydraulic performance in bioretention is reduced hydraulic conductivity due to compaction and clogging in the media (Khan et al., 2012b; Le Coustumer et al., 2012). However, vegetation growth could help to maintain the soil structure and enhance infiltration without requiring much maintenance of the system (Stephens et al., 2012). Various studies have reported a diminishing trend in hydraulic conductivity over a period of operation (Le Coustumer et al., 2007; Hatt et al., 2008; Khan et al., 2012b; Le Coustumer et al., 2012). A large-scale column study in Australia observed clogging over 72 weeks causing the hydraulic conductivity to decrease by an average of 73% (Le Coustumer et al., 2012). This research also evaluated the impact of plant species and system catchment size on hydraulic performance and concluded that plants with thick roots tend to maintain the conductivity and that small systems are more prone to clogging than large systems due to their high loading rate. Interestingly, hydraulic conductivity has been seen to initially decrease for a period and then recover to an average value (Hatt et al., 2008; Li and Davis, 2008; Le Coustumer et al., 2012). The initial decline of hydraulic conductivity results from compaction of bioretention media under hydraulic loading. After this decline, the vegetation growth and root systems improve the porosity of the media and create new pathways for water movement (Khan et al., 2012b).

However, an increase in saturated hydraulic conductivity (K_{sat}) was observed in a bioretention system in Minnesota, United States, over four-years of operation (from 2006 to 2010), and there was a positive relationship between K_{sat} and service time, with a slope of 10.2 ± 2.4 $cm \cdot h^{-1}$ per year (Paus et al., 2014a). This relationship is likely attributed to

(1) reduced bulk density, (2) increasing organic matter, (3) development of macropores by earthworm activities and plant roots, and (4) freeze-thaw cycles (Paus et al., 2014a).

Sediment accumulation over time could be of concern as it will lead to clogging in bioretention cells. Khan et al. (2012b) used column experiments to mimic 20 years of equivalent TSS loading to analyze long-term performance; K_{sat} decreased in the first period of sediment accumulation but ultimately remained constant. This indicates that bioretention cells could maintain constant hydraulic conductivity after long-term operation without any maintenance and that surface filtration (top 20 cm of these columns) is the primary function of sediment capture (Khan et al., 2012b). Considering field experiments have better plant maturity and larger catchment sizes, acceptable and stable hydraulic performance can be expected for long-term operation. A bioretention cell located in Oslo, Norway, reported that after 7-years of operation, 98% of runoff infiltrated the cell, and it maintained sufficient K_{sat} of 45 ± 15.3 $cm \cdot h^{-1}$ (Paus et al., 2016). Even in cold regions, although vegetation becomes dormant and therefore pore reopening by root growth is diminished, the freeze-thaw cycle can counteract this adverse effect (Paus et al., 2014a).

Additional organic matter in the media has generally been observed as beneficial for physical properties and the slowing of media compaction, which ultimately maintains hydraulic performance. However, in some long-term operation studies (Le Coustumer et al., 2012; Paus et al., 2016), bioretention cells with organic matter have poor performance compared to cells without it. This may be because the media with compost tends to be more non-uniform and has an increased bulk density due to compaction. Additionally, high compost content in the media could lead to phosphorus leaching (Bratieres et al., 2008; Fletcher et al., 2007) and needs further investigation.

2.3.4 Water quality improvement

2.3.4.1 TSS (total suspended solids) removal

Bioretention is the most effective LID BMP for TSS removal via filtration and sedimentation (Brown and Hunt, 2011; Elizabeth, 2012) at generally over 80% total removal efficiency (Melbourne Water, 2005) and 96% removal efficiency for particles larger than 50 μm (Khan, 2011). A 0.6 m bioretention media depth achieved a 60% TSS concentration reduction (from 25 mg/L in runoff to 9.9 mg/L in effluent) (Brown and Hunt, 2011), whereas other research observed 90% TSS concentration reduction (from 30 mg/L to 3 mg/L) (Trowsdale and Simcock, 2011). Although bioretention systems are highly effective at capturing TSS, newly installed systems have been seen to leach significant TSS from the media, prior to stabilization (Blecken et al., 2010). Over time, smaller pore sizes will be progressively blocked and media fines' washout will come to completion, thus significantly decreasing effluent TSS concentrations. Once the system stabilizes, this decreasing trend in effluent concentrations continues but is usually not of any practical importance as effluent concentrations are already very low. Although TSS is effectively removed via bioretention, the continuous blockage of finer pore spaces makes TSS one of the leading factors causing reduced hydraulic conductivity (Le Coustumer et al., 2012) and a minimized lifetime of the media. This is especially an issue when the systems are subjected to large rainfall events causing massive runoff volumes able to transport large quantities of sediment that generally are not picked up in smaller storms (Trowsdale and Simcock, 2011).

In cold climates, bioretention systems experience even heavier loadings of sediments due to sanding for winter road maintenance and huge volumes of spring runoff. In Calgary, Alberta, Canada, average TSS concentrations in snowmelt can reach 444 $mg \cdot L^{-1}$ due to excessive sanding when temperatures are too cold for salt to work (Khan et al., 2012a). This could potentially lead to decreasing the lifetime of a bioretention cell by prematurely clogging the media or allowing higher effluent sediments to reach surface waters.

However, TSS removal has been observed as very effective in cold climates, even when other constituents' removal diminished (Khan et al., 2012a). In Khan et al.'s study, bioretention columns subjected to temperatures between -4°C and +5°C saw a 90% decrease in TSS concentration from the influent to the effluent. Field cells and long-term performance columns exceeded the city's requirements for TSS removal (i.e. > 85 % removal of particles > 50 μm) at 97% removal of particles > 50 μm; cold conditions and media depth were determined not to affect their controlled field and laboratory experiments' TSS removal performance.

TSS can be effectively removed through bioretention systems in cold climate nearly as well as warm climate (94%-95% removal efficiency compared to 98%-100% removal efficiency, respectively) (Roseen et al., 2009) and mass retention of TSS has been seen at greater than 99% (Muthanna et al., 2007c). TSS removal has also exceeded 94% at all tested temperatures (i.e. between 2°C and 20°C) in separate cold climate studies (Blecken et al., 2007; Blecken et al., 2010). Other studies have reported TSS concentration decrease to be only 74.5%, however, this is misleading due to already low influent concentrations (i.e. while the effluent concentrations may be sufficiently low, low influent concentrations result in removal percentages that only appear poor because the typical 90%+ removal cannot be achieved); TSS average effluent concentrations in winter were sufficiently low, at 4.1 $mg \cdot L^{-1}$ (Géhéniau et al., 2015).

As TSS removal is due to mechanical filtration rather than temperature dependent factors, it's to be expected that particle bound contaminants should be effectively removed, if frozen soils are not present (Blecken et al., 2007). Even increasing salt concentrations in snowmelt was seen to significantly increase TSS removal (Szota et al., 2015), likely because high salinity causes suspended solids to flocculate and settle (House et al., 1998), thus increasing the size of TSS particles and providing for easier filtration.

2.3.4.2 Heavy metals removal

Stormwater runoff into receiving water bodies contributes a substantial source of metals which can be toxic to aquatic life and recalcitrant (Davis et al., 2001). Very few studies have been conducted to evaluate dissolved metal removal in bioretention cells and they have reported both effective removal and leaching (Muthanna et al., 2007c; Blecken et al., 2011; Lim et al., 2015; Søberg et al., 2017). Heavy metals of concern in stormwater are typically cadmium, copper, zinc, and lead, in particulate and dissolved phase, and potentially bound with organic compounds or carbonates (Dean et al., 2005). Heavy metals are primarily removed via mechanical filtration (Blecken et al., 2011), cation exchange, adsorption, precipitation, complexation (Rieuwerts et al., 1998), and fixation (usually to clay minerals) (Bradl, 2004), which are all relatively unaffected by cold climate. Particulate metals are easily intercepted by the filtration media but dissolved (more bioavailable and toxic) forms depend mainly on medium sorption capacity, which, when exhausted, would result in metal breakthrough (Clark and Pitt, 2011; Hatt et al., 2011). Generally, total metals removal efficiency in bioretention is at least 80%-90% and mainly deposited in the top 10-15 cm of the media (Li and Davis, 2008).

Adding organic matter, such as compost, wood chips, or straw (Blecken et al., 2009a) to the soil could enhance the cation exchange capacity and improve heavy metal removal, but could also increase nutrient leaching (due to the often high nutrient contents of these amendments) or they could have significant metal contents in themselves already (Clark and Pitt, 2011). Copper has the highest affinity (lead with the next highest affinity (Bradl, 2004)) to form a complexation with solid and dissolved organic matter within soil media (Yin et al., 2002; Ponizovsky et al., 2006; Blecken et al., 2011). While the solid complexation enhances copper removal, the dissolved complex increases its mobilization (Temminghoff et al., 1997; Rieuwerts et al., 1998). Biofilm surrounding plant roots forms and likely encourages the uptake of some heavy metals (Warren and Haack, 2001), which may be temperature dependent (Blecken et al., 2011).

Cold climate studies have shown that metals are primarily captured in the top mulch layer (Muthanna et al., 2007c; Søberg et al., 2017); a 5-cm mulch layer in a bioretention cell retained the most metals compared to its 55-cm soil column, making the mulch an extremely effective metal sink (Muthanna et al., 2007a). This is likely because the top layer has higher organic content and percentage of fines, both of which have a high affinity to form complexes with metals (Yin et al., 2002; Bradl, 2004; Ponizovsky et al., 2006) or provide a metal sorption surface (Rieuwerts et al., 1998). Increasing organic content of bioretention media by increasing its compost volume fraction or amending it with an additional carbon source has been shown to improve metal removal (Blecken et al., 2009a; Blecken et al., 2009b; Paus et al., 2014b; Zhang et al., 2014; Søberg et al., 2017) and mitigate the negative impact of salts (Søberg et al., 2017). However, an underlayer within the bioretention media should be amended with iron filings, or something similar, to minimize the leaching of excess phosphorus introduced by the often nutrient rich compost amendment (Paus et al., 2014c).

Removal efficiency of total copper, lead, zinc, and cadmium in cold climate via bioretention has typically been observed at > 85% and is quite comparable to warm climate conditions (Muthanna et al., 2007a; Muthanna et al., 2007c; Roseen et al., 2009; Blecken et al., 2011; Denich et al., 2013; Paus et al., 2014b; Géhéniau et al., 2015; Søberg et al., 2017). Generally, if sufficient percolation capacity is maintained, total metal removal should be excellent at all temperatures (Bäckström and Viklander, 2000). Roseen et al. (2009) observed no change in total zinc removal between cold and warm climate in one bioretention cell, but saw its removal efficiency decrease from 96% in warm weather to 67% in cold weather for another bioretention system. Géhéniau et al. (2015) saw a decrease in total zinc removal efficiency in winter as well, although the winter influent concentrations were higher, so it is difficult to compare. Salt concentrations and filter media composition would have been valuable variables to analyze to determine why such a discrepancy exists.

Dissolved metal removal is considerably more variable than total metal removal; for example, dissolved cadmium and zinc removal in cold climate may be comparable to their total metal removal, whereas dissolved copper and lead removal were considerably less than their total metal removal (Blecken et al., 2011; Søberg et al., 2014). However, in another study, dissolved copper, zinc, and cadmium were all leached from a system (Muthanna et al., 2007c). Therefore, the mechanisms of dissolved metal removal are not well understood, vary by bioretention design and conditions, and require further research.

Dissolved copper removal experiences an interesting positive effect in cold climate conditions. With increasing temperature and therefore biological activity, dissolved copper had a decreased removal efficiency and leached from the system, likely due to biological degradation of organic matter causing the release of previously complexed copper (Muthanna et al., 2007a; Blecken et al., 2011). In cold climates, with slower degradation rates, dissolved copper had a higher removal efficiency. Luckily, this leaching in warm climate did not impact total copper removal efficiency significantly (Blecken et al., 2011). The complete opposite phenomenon affecting dissolved copper has been observed in other studies in which lower temperatures decreased its removal efficiency (Paus et al., 2014b). This was likely because the bioretention media was sand with no topsoil layer and the decreasing temperatures caused increased fluid viscosity and decreased particle diffusivity (Yao et al., 1971). Géhéniau et al. (2015) saw a similar leaching effect for nickel and copper in winter. This analysis of previous cold climate studies proves the importance of further mechanistic studies on heavy metal removal.

Although only a small fraction of total retained metals in bioretention have been seen to accumulate in vegetation root and shoot tissues (approximately 2%-8% (Sun, 2004; Muthanna et al., 2007a; Muthanna et al., 2007c)), there is a potential for metal hyperaccumulating plants to become more prominent in this field of research. Therefore, the dormancy of plants in cold temperatures or their response to salts is important to consider as they likely retard plant uptake capabilities. Significantly decreased plant uptake of cadmium, lead, and zinc have been observed in low temperatures (Hooda and Alloway, 1993; Antoniadis and Alloway, 2001), likely from decreased root activity causing less bioavailable metals (Rieuwerts et al., 1998). Cold climate and salt can also impact soil bacteria which help accumulate and immobilize metals (Ledin, 2000) by either consuming the metals or producing organic compounds to complex with them and therefore reduce their mobility (Bremer and Geesey, 1993).

De-icing salts used in winter road maintenance increase salinity in spring runoff and can cause increased metal solubility (Goodison et al., 1986; Calmano et al., 1992; Warren and Zimmerman, 1994; Marsalek, 2003) which can cause previously captured metals in bioretention media to leach from the system and/or increase the dissolved fraction of metals in snowmelt influent (typically in the order of cadmium > zinc >> copper) (Paus et al., 2014b; Søberg et al., 2014; Szota et al., 2015). Sodium ions may compete with heavy metals for sorption sites within the media (Amrhein et al., 1992; Bäckström et al., 2004; Søberg et al., 2014), even at low salt concentrations (Paus et al., 2014b; Søberg et al., 2014). Chloride ions may bind to the metals directly (Benjamin, 2002) and inhibit their adsorption to the media. Fortunately, Paus et al. (2014b) saw ≤ 3.5% of the retained metals released under salt applications, but the process was also linked to temperature (i.e. higher mobilized cadmium and zinc masses were observed in warmer temperatures). This indicates rapid spring warming could cause some serious effluent metal leaching into receiving waters. Salt also causes significant potassium, calcium, and magnesium release, concurrently with heavy metals, from bioretention media. Generally, bioretention implementation to control metals in ambient winter conditions and with saline stormwater was encouraged by various lab and field experiments as typically only a small fraction of metal remobilization occurred (Paus et al., 2014b; Søberg et al., 2014; Søberg et al., 2017) and may be offset by increasing the fraction of organic matter.

2.3.4.3 Nutrient removal

Nutrient removal is typically quite variable in both warm and cold climate and depends heavily on bioretention media composition and design. Warm climate bioretention research has shown great variation in total phosphorus removal due to differences in media, influent concentration, and phosphorus forms and can range from leaching 240% to removing 99% of total phosphorus (Melbourne Water, 2005; Roy-Poirier et al., 2010; Zhang et al., 2011). If the media used has a medium to high phosphorus-index (e.g. from the organic soil horizon or has a compost amendment) it will not be effective for the adsorption of phosphorus (Treese et al., 2012) and will bacterially convert the organic matter into orthophosphate (Denich et al., 2013). To enhance phosphorous removal, conventional bioretention systems can be modified with a saturated zone (to enhance vegetative uptake) or an aluminum or iron oxide amendment (Zhang et al., 2011). Media amended with phosphorus-sorbing materials, such as water treatment residual, red mud, or Krasnozem soil, also effectively improve phosphorous removal (O'Neill, 2010; Lucas and Greenway, 2011a). Adsorption and precipitation enhancements, whether from media amendments or selection of soils with higher cation exchange capacity, are vital to minimizing effluent phosphorus; however, care must be taken to ensure preferential flow paths do not limit this capacity (Denich et al., 2013).

In cold climate research, total phosphorus removal efficiency has been observed to decrease compared to warm climate (Roseen et al., 2009; Géhéniau et al., 2015) but also increase (Blecken et al., 2007; Muthanna et al., 2007a). Phosphorus (often in particulate form) contamination is often seen in snowmelt, likely due to sand and salt application in winter (Oberts, 1986). Removal of total phosphorus depends mainly on adsorption to bioretention media (Roseen et al., 2009), such as iron or aluminum oxides in the soil (as total phosphorus largely exists as phosphate ions with a strong affinity to sorb to soil particles) or via precipitation by calcium or aluminum (Erickson et al., 2007; Yang et al., 2010). Total phosphorus sorption rates have been shown to increase with temperature (Gardner and Jones, 1973; Barrow and Shaw, 1975). When total phosphorus consists mainly of particulate phosphorus (effectively removed via physical filtration) temperature is not expected to impact its removal, unless frozen soils are present (Blecken et al., 2007). Plants have also been shown to take up phosphorus, depending on the species, and could retain 6% (Lucas and Greenway, 2008) to 71% (Zhang et al., 2011) of influent phosphorus.

The key mechanisms of nitrogen removal in bioretention cells are organic nitrogen mineralization, ammonium adsorption, microbial and plant uptake, and nitrification and denitrification (Blecken et al., 2010). Dissolved nitrogen is primarily removed through assimilation via biomass growth (Henderson et al., 2007; Read et al., 2010; Barrett et al., 2013; Payne et al., 2014). Usually, ammonium is the only nitrogen species effectively removed by bioretention (approximately 80%) via adsorption and nitrification (Dietz and Clausen, 2005; Lucas and Hunt, 2005). Nitrate is a highly mobile ion that does not sorb to soil particles and requires long retention times and saturated conditions to be removed (Lucas and Greenway, 2011b) and is therefore not removed by conventional designs (Kim et al., 2013). Conventional systems in warm climate have achieved -64% to 9% nitrate removal (Hunt et al., 2006). Although it may be beneficial overall, disturbing native soils via amendments can break chemical bonds and accelerate nitrogen release (Treese et al., 2012) and has been reported to cause 0.7-1.3 $mg \cdot L^{-1}$ nitrate-N leaching directly from the media (Yang et al., 2010).

Modifications to conventional bioretention design to enhance nitrate removal include adding a submerged zone or using media with a slower hydraulic conductivity to enhance denitrification; 50% nitrate and 73% total nitrogen removal was observed in the presence of a submerged zone compared to only 17% and 50% removal, respectively, in traditional systems (Lucas and Greenway, 2011b). However, in cold climates, slower hydraulic conductivities may cause freezing issues and submerged zones would need to be drained prior to freezing. Also, media containing little nutrients and organic matter is preferred (Treese et al., 2012) (as nutrient leaching from media degradation can be more significant compared to influent runoff nutrient concentrations). Having vegetated bioretention systems rather than barren is overall beneficial for various hydraulic and water quality aspects, but is especially important for nitrogen removal (Zhang et al., 2011).

The optimum soil temperature for nitrification to occur in Canadian soils was determined to be 20°C (Malhi and McGill, 1982), while the minimum temperatures for nitrification may be 2°C (Blecken et al., 2010). Below 12°C, nitrite ions accumulated in the soil, indicating nitrate oxidizing bacteria growth was hindered more compared to ammonia oxidizing bacteria (Russell et al., 2002). Nitrification has been observed in cold climate conditions but, like warm climate systems, without anoxic zones or additional carbon, subsequent nitrate removal is poor; warmer temperatures simply increase this issue due to higher nitrification rates producing more nitrate (Blecken et al., 2007). As nitrification can still occur at low temperatures and because ammonium is effectively adsorbed to soil, the removal efficiency of ammonium was still 18% on average at 2°C, while total nitrogen, dissolved nitrogen, and nitrate/nitrite leached from the bioretention system (Blecken et al., 2010). Finer soils may help to create anoxic zones (Blecken et al., 2010), but could also lead to frozen filtration media in winter. Total nitrogen leaching has also been seen in other cold climate studies but was not solely attributed to temperature because effluent concentrations decreased over time, indicating the bioretention media was likely the source of the effluent total nitrogen (Khan et al., 2012a).

Vegetation uptake has been suggested to contribute to most of the nitrate removal within a bioretention system, depending on the species selected (Payne et al., 2014). Additionally, soil microbes, even when exposed to high and medium salt concentrations, have been observed to reduce nitrate effluent concentrations significantly by either direct microbial uptake or denitrification in anaerobic microsites with organic matter (Endreny et al., 2012). However, the same study showed the microbes had a varied impact on effluent phosphates, sometimes exporting it at low and medium salt concentrations. Another study showed improved total phosphorus removal in low temperatures due to decreased biological degradation of organic matter (Blecken et al., 2007; Muthanna et al., 2007c). Regardless, cold temperatures and high salt loads impact vegetation and bacteria, thus potentially limiting nutrient removal efficiency. In fact, ammonia fixation and nitrogen uptake by microbes and plants have been observed as temperature dependent (Reay et al., 1999; Juang et al., 2001).

Saline stormwater can impact nutrient uptake in vegetation as salt-sensitive species generally do not survive salt concentrations >10.4 $mS \cdot cm^{-1}$ and therefore lose their ability to take up nitrogen (Szota et al., 2015) and can lead to previously assimilated nitrogen release from senescing biomass (Payne et al., 2014). Salt-tolerant vegetation maintains nitrogen uptake in higher salt concentrations but this would likely not be sustained for long due to stomatal closure (Szota et al., 2015). On the other hand, saline stormwater can improve total phosphorus removal by promoting conversion of dissolved to particulate phosphorus to be more easily filtered by the media. As there is little difference in effluent total phosphorus between vegetated and unvegetated bioretention mesocosms, the primary removal mechanism is likely filtration and adsorption. Prolonged salt application to bioretention systems resulted in only nitrate removal, likely due to anoxic, micro-sites of denitrification in the fine media while leaching of ammonia, organic nitrogen, total nitrogen, ortho-phosphate, and total phosphorus was evident (Denich et al., 2013).

2.3.4.4 Organic compound removal

Bioretention is also quite effective at removing organics. Systems amended with sand and peat moss have been reported to remove > 94% of the total petroleum hydrocarbons by mass (Tremante, 2005). Bioretention with a 3-cm thick leaf compost mulch layer achieved 80% to 95% removal of oil and grease pollutants, including associated dissolved and particulate naphthalene, dissolved toluene, and dissolved motor oil, mainly via sorption and filtration in the mulch layer and subsequent biodegradation (Hong et al., 2006). Atrazine has also been removed by 84%-89% via soil sorption (Yang et al., 2010). More than 90% removal of 5-day biological oxygen demand (BOD_5) (Khan, 2011) has been reported, but other research has not been as promising. Total organic carbon appeared to leach from a bioretention system when the media had a high organic matter content (Li and Davis, 2009).

Generally, organics removal via bioretention in cold climate has been assumed to be problematic because the known removal mechanism of biodegradation, via microbial and vegetative activity, declines in cold temperatures. Although few studies have analyzed the effect of cold climate or high salt loads on organic removal, this assumption has not been definitively substantiated. Total petroleum hydrocarbons (in the diesel range) have in fact seen slightly improved removal efficiencies in cold climate and were generally 100% removed in cold and warm climates (Roseen et al., 2009). Effluent petroleum aromatic hydrocarbons and petroleum hydrocarbons were both below their respective detection limits (i.e. $<0.2\ \mu g\cdot L^{-1}$ and $<0.3\ \mu g\cdot L^{-1}$) between January and May and they tended to be stored in the bioretention media and concentrated in the mulch layer (Géhéniau et al., 2015). *E. coli* and fecal coliforms concentrations in the effluent have been lower than in the influent, indicating the potential for pathogen removal and these bacteria were not leached from the system in cold or warm temperatures. BOD_5 mass and concentration significantly decreased through bioretention media and this trend was not impacted by temperature or media depth. Effluent BOD_5 also decreased throughout the course of the experiment, likely due to increasing biomass within the media able to degrade the BOD_5 (Khan et al., 2012a). Organic substances (i.e. measured via chemical oxygen demand) in snowmelt were decreased 57% by mass through a bioretention system (Muthanna et al., 2007c).

2.3.4.5 Salt application in cold climate

Road salts are used in significant quantities in cold climates for maintenance of icy roads and can consist of any of the following four inorganic salts: NaCl, $CaCl_2$, $MgCl_2$, or KCl (Mayer et al., 1999). NaCl is most commonly applied because of its low cost, accessibility, and easy application (Ramakrishna and Viraraghavan, 2005). Salts in solution can generally only be removed via precipitation when their concentration exceeds their solubility (Mayer et al., 1999). Bioretention has limited capacity to remove chloride, therefore bioretention systems in cold climate that could potentially recharge groundwater should be lined with an impermeable material and have underdrains (Stephens et al., 2012). It may be difficult to find salt-tolerant, native vegetation that is also aesthetically pleasing and suitable for bioretention applications, thus enhancing the importance of discovering and researching appropriate plants for cold climate bioretention application.

In cold climate regions, salt in snowmelt runoff caused > 1000 mg $Cl\cdot L^{-1}$ in Toronto streams (Williams et al., 2000). Canada applies approximately 5 million tonnes of de-icer to winter roads annually (EC, 2004). Sodium and chloride do exist in soils prior to infiltrating runoff (Denich et al., 2013), but at lower concentrations than in snowmelt. In cold climates, the sodium adsorption rate, exchangeable sodium percentage, and electrical conductivity of the media are important soil parameters to consider (Paus et al., 2014b). Sodium ions may negatively impact soil cation exchange capacity by promoting cation (and contaminant) leaching and thus impacting the soil exchange pools (Norrström and Bergstedt, 2001; Clark and Pitt, 2011). High levels of exchangeable sodium will have adverse impacts on soil structure, reducing infiltration rate, decreasing aggregate stability, and causing clay dispersion and swelling of expandable clays (Suarez et al., 2008). Reductions in infiltration were observed for sodium adsorption ratios above 2 and the reductions became more severe with increasing sodium adsorption ratios (Suarez et al., 2008).

Saline stormwater runoff can reduce metal uptake by plants (Fritioff et al., 2005; Szota et al., 2015), by causing water stress, ion toxicity, and nutrient imbalance in salt sensitive vegetation leading to reduced function and growth (Marschner, 1995), and inhibit microbial activity (Marsalek, 2003; Yuan et al., 2007) and therefore possibly metal removal (Blecken et al., 2011). Endreny et al. (2012), however, studied the effect NaCl has on soil microbes' ability to treat metal and nutrient contaminants at temperatures between 5 and 10°C. Salt concentrations ranging from 80 to 935 mg $Cl\cdot L^{-1}$ caused significant separation between bacteria taxa and affected bacteria evenness, but no difference in richness or diversity of bacteria was apparent. However, this experiment was only carried out over 5 weeks; therefore, long-term studies are required to determine the true impact that high salt loads have on bacteria efficacy.

Although Na^+ ions may be temporarily adsorbed to soil particles, they have been shown to easily wash out of soils during subsequent infiltration events (Denich et al., 2013). Cl^- is highly soluble and not prone to retardation or degradation (Ramakrishna and Viraraghavan, 2005) and easily leaches from bioretention systems (Khan et al., 2012a; Søberg et al., 2014); for example Muthanna et al. (2007c) observed 10% mass leached. Na^+ and Cl^- from winter road maintenance would likely pass through bioretention media and eventually into native sub-soils (Denich et al., 2013; Søberg et al., 2017); therefore, the reduction of de-icer use is critical for surface and ground water protection (Denich et al., 2013).

High Na^+ and Cl^- mass removals may be observed through bioretention cells, but it is likely only due to volume reduction via evapotranspiration or water retention in pore spaces (Khan et al., 2012a). This observed mass removal is insignificant as the ions remain in the system, cannot be degraded, and can leach from the system later. Cl^- can also be stored within bioretention media over winter and be released throughout the rest of the year, as indicated by higher influent than effluent chloride between November and April and higher effluent than influent chloride from May to October in Géhéniau et al.'s (2015) study. It was also observed that the medium was permanently contaminated with Cl^- as it was not all depleted by fall. However, even after 5 years of operation, this contamination did not appear to harm the system.

2.3.4.6 Long-term performance

The main issue with long-term performance of bioretention in terms of water quality improvement is the eventual clogging that will reduce hydraulic performance thus decreasing pollutant removal capacity and pollutant accumulation over time which will eventually breakthrough if the media is not replaced (Le Coustumer et al., 2012). Few studies have examined the long-term (i.e. 15-20 years) performance of bioretention and none have collected thorough data. After the equivalent of 12-15 years of operation, heavy metals such as cadmium, copper, and zinc would accumulate to levels that exceed human health or ecological guidelines (Hatt et al., 2011). The adsorption capacity change over long time periods is not well studied but it is not likely to be reliable as, over time, the moisture content and organic content will change, therefore affecting heavy metal or other sorbed pollutant mobility. However, some research estimated that bioretention sized at 2-3% of the catchment area or with a deep filter layer (at least 0.5 m) would not have heavy metal breakthrough for at least 10 years given that the accumulated heavy metals in the top 2-5 cm of soil should be replaced as needed (Hatt et al., 2011). In unvegetated column studies, it was observed that phosphorus retention by sandy media could be exhausted in only 5 years of simulated operation under typical urban runoff; therefore, media amendments to extend phosphorus retention capacity would be necessary (Hsieh et al., 2007).

Long-term cold climate studies on bioretention performance are even sparser. However, as cold climate runoff typically contains higher heavy metal, TSS, and phosphorus concentrations, the top layer of media and mulch may need to be replaced more frequently than in warm climates (Denich, 2009; Blecken et al., 2011). Muthanna et al. (2007a) evaluated annual metal loadings and their media's sorption capacity and estimated their bioretention system could successfully operate for 10-20 years before reaching exhaustion, whereas the mulch would likely need replacing within 4-5 years and would require constant maintenance as it gradually decomposes. Simulating 2 to 15 years of de-icing agent applications did not show an effect on the bioretention cell's ability to retain heavy metals; however, their long-term accumulation may become an issue (Denich et al., 2013) and long-term research on the impact of repeated salt applications on metal retention is needed (Paus et al., 2014b). Interestingly, nitrogen and phosphorus were most efficiently removed in the mesocosm subjected to 15 years' worth of salt runoff, likely due to the nitrogen and phosphorus content of the bioretention media being more depleted in the older soils compared to younger soils (Denich et al., 2013). Long-term simulations have indicated that ammonia effluent concentrations significantly decrease over time and may depend on media ammonia concentrations (Khan et al., 2012a). One of the most important issues to consider is the long-term disposal of bioretention media; if the systems do survive for 15-20 years, how will these potentially extremely polluted cells be handled and will there be a mechanism available to sustainably decontaminate them? This is an area with no sufficient, long-term studies existing to answer the question.

2.3.5 Summary and recommendations

Through various bioretention studies conducted world-wide, it is apparent that, while generally considered an effective stormwater treatment technology, bioretention's design and application is extremely dependent on site and climatic conditions. Types of soil available to create the media can be a constraint depending on geographical region, therefore, amendment studies are necessary to suit local runoff characteristics. Native vegetation that is drought, water, and contaminant tolerant, is aesthetically pleasing, and requires minimal maintenance may be difficult to locate in some regions. Cold climates present additional challenges to bioretention design as course media, more frequent maintenance, and cold and salt tolerant plants are required. Contaminant concentrations are also increased in cold climates, therefore, potentially limiting the life-time performance of bioretention cells.

To better understand bioretention's hydraulic and water quality performance, significantly more mechanism and long-term studies are needed both in the laboratory and field. Bioretention systems need to be designed specifically for different geographical regions that experience vastly different climatic conditions, but designs must also be consistent so that data can be compared between studies and designs can be improved. Although numerous people have already invested years of research into bioretention, it is still a relatively new technology with many unanswered questions when applied in all climates. Mechanism and long-term performance studies on the removal of both total and dissolved fractions of metals, nutrients, and organics, as well as pathogens and even contaminants of emerging concern in warm and cold climate are needed. Studies on alternative chemical additives and sustainable amendments to enhance the adsorption and degradation capacity of various contaminants (i.e. metals, nutrients, salts, and organics) while also not introducing other nuisance contaminants (for example, increasing organic matter to enhance metal removal also introduces additional nutrients), are necessary. Various studies have shown that the removal of dissolved metals, nutrients, and organics can be temperature dependent but also likely rely on other factors at play, such as soil media factors, making it difficult to definitively determine if their removal is improved or deteriorated in cold climates. Further research is required to determine the temperature dependence of the removal of various contaminants.

TSS and other particulate contaminants are understood to be well removed via filtration in bioretention; however, long-term research regarding the decreased lifespan and the increased maintenance requirements of bioretention in cold climate due to the substantially increased concentrations of particulate contamination is unavailable but vital. It has been hypothesized that the freeze-thaw cycle in cold climates and that growing plant roots will mitigate the clogging effect of the increased TSS, but substantiated data does not exist.

Long-term freeze-thaw cycles could even potentially lead to decreased contaminant removal by significantly increasing permeability, especially in the deep, frozen soils of Canada that last for many months. With the radical variations in Canadian weather increasing due to climate change, this problem may become even worse; further research is needed to study this effect.

Impacts of de-icing salts on contaminant removal, vegetation, and bacteria efficacy, are not well understood, especially under long-term applications. This needs further research, especially if bioretention facilities are intended to store snow throughout winter and treat it in spring. Additionally, native plants suitable to improve runoff quality and their dormancy impacts during winter need to be studied further; more research should be conducted into breeding plants that are metal hyperaccumulators, promote a vast mycorrhizal fungi network to enhance nitrogen degradation, and are also salt tolerant. Future research must also analyze the potential release of long-term accumulated metals and salts within the soil and vegetation as well as soil and plant toxicity and, therefore, disposal requirements. Eventually, once the mechanisms of contaminant removal via bioretention are better understood, modelling software should be developed for local application and validation with field data to aid in city-wide designs. Table 1 summarizes the above described gaps in cold climate knowledge and recommends topics of required research.

Table 1: Summarized gaps in current cold climate studies and recommended areas of research.

Recommended areas of future research in cold climates	Purpose
vegetation studies	• to determine drought, water, and contaminant tolerant vegetation that can safely be utilized in all cold climate areas of broad geographical regions (e.g. in North America) • these studies should also determine the impact that vegetation dormancy in winter has on the bioretention systems and analyze the potential of breeding hyperaccumulating plants

media studies	• to determine a sufficient balance between using coarse media to enhance hydraulic performance in cold climate while maintaining sufficient water quality improvement
designing bioretention for both warm and cold climate	• to determine the appropriate catchment basin required in cold climate as its treatment capacity will be decreased • to determine if more rigorous pre-treatment designs may be required to account for the increased pollutant loads and if so, design these pre-treatment technologies
mechanism and long-term performance studies	• to further investigate total and dissolved contaminant removal in both warm and cold climate
media amendment studies	• to determine alternative amendments that are sustainable and enhance contaminant removal • studying their long-term performance is also vital
temperature dependence studies	• to determine the impact of cold climate on the physical and chemical interactions of various contaminants in bioretention to better design the systems for water quality improvement
studies on the impact of the freeze-thaw cycle on particulate contaminant removal	• as long-term cold climate studies are rare, this research is required to determine if the freeze thaw cycle is an advantage or disadvantage for particle removal and if it is a disadvantage, how to mitigate it
de-icing salt studies	• to further investigate their impact on contaminant removal, bacteria efficacy, and the potential for bioretention to permanently capture and treat the salts
bioretention disposal studies	• to determine the end-of-life disposal requirements of these heavily polluted cells of bioretention media and trapped contaminants

Chapter 3. Research Design and Methods

The following three sections will describe the design of the custom, experimental columns and medias used in this research, the methodology for meeting the research objectives, and the procedure for carrying out chemical analysis of water quality parameters under investigation. The detailed supplier information and product number (if available) for all products and materials used in this research can be found in Table 30 in Appendix A.

3.1 Experimental Apparatus Design

3.1.1 Column Construction

Four large columns were designed by Mia Yu and Dr. Tong Yu and their construction was completed in 2015. Each column consists of four 0.36 m diameter vertical PVC pipes held together with glue and three bolted flanges to a total length of 143.3 cm. Two lengths of the pipes have a section cut out of one side that was replaced with clear, plastic windows so that the interior media can be viewed throughout most of the depth. These windows are each 30.5 x 7.5 cm. Each column has one overflow collection port that is 21.5 cm from the top of the column to the bottom of the port. As this overflow port ranges from being only 8 to 11 cm above the soil media in the four columns, the port was sealed off with Parafilm® during most of the experimental operation to allow for more water to pond and therefore infiltrate the media. Each large column is supported by a powder coated steel frame that has four wheels so that it can be easily moved even when filled with soil. One of the four nearly identical columns is shown in Figure 3, along with dimensions. Each flange is approximately 4 cm thick vertically (i.e. one side of the flange is 2 cm thick).

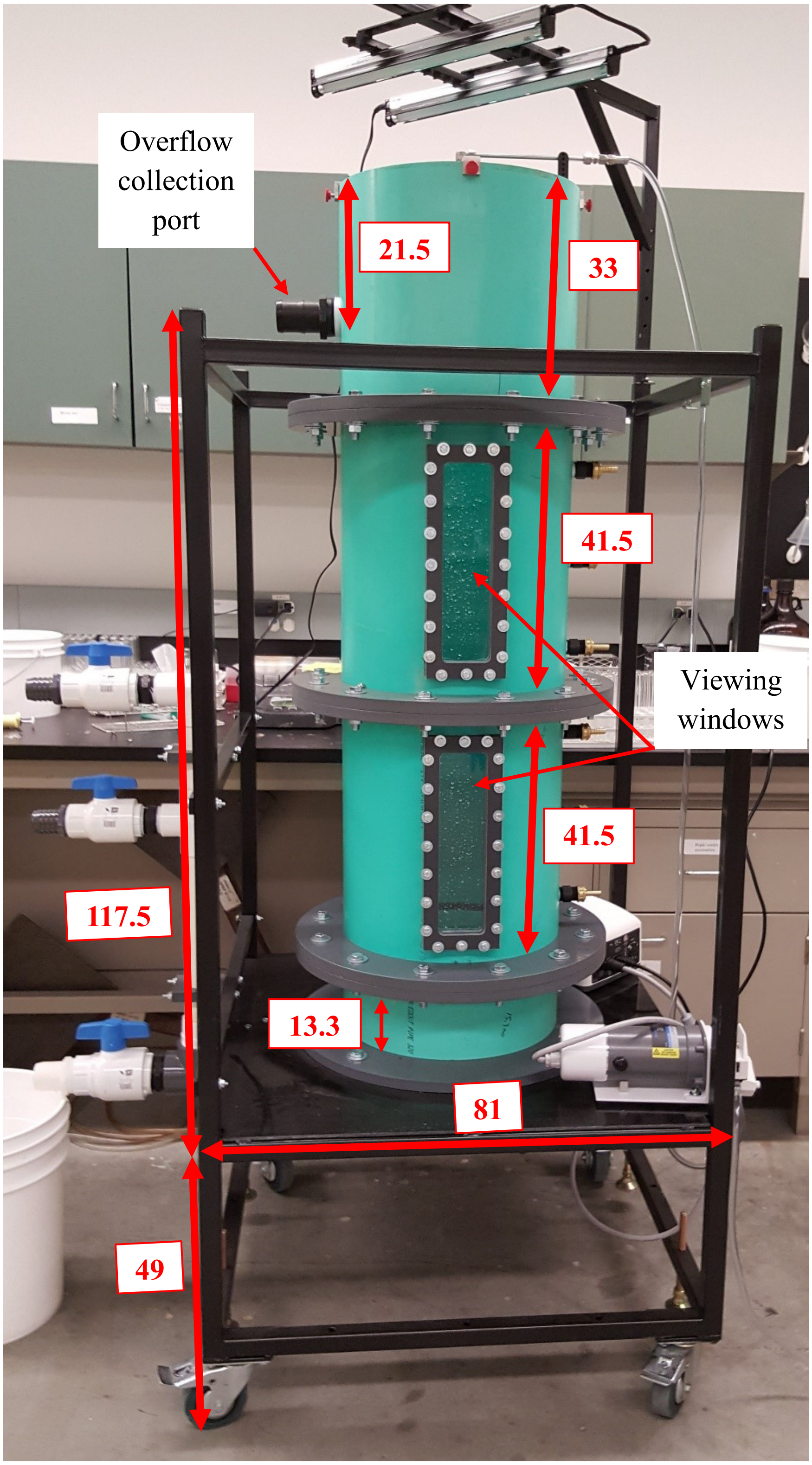


Figure 3: Overall view of one empty large column. Dimensions are in cm. Taken April 12, 2016.

Each column also has 6 sampling ports along the side so that water samples throughout the depth can be taken and a depth profile can be evaluated for certain water quality parameters. These sampling ports are shown in Figure 4. Each column has a base that is slightly sloped downwards to a central 2” outer diameter elbow that connects to a horizontal effluent 2” inner diameter tube that connects to a 2” outer diameter pipe that has a shut off valve. This configuration is shown in Figure 5.

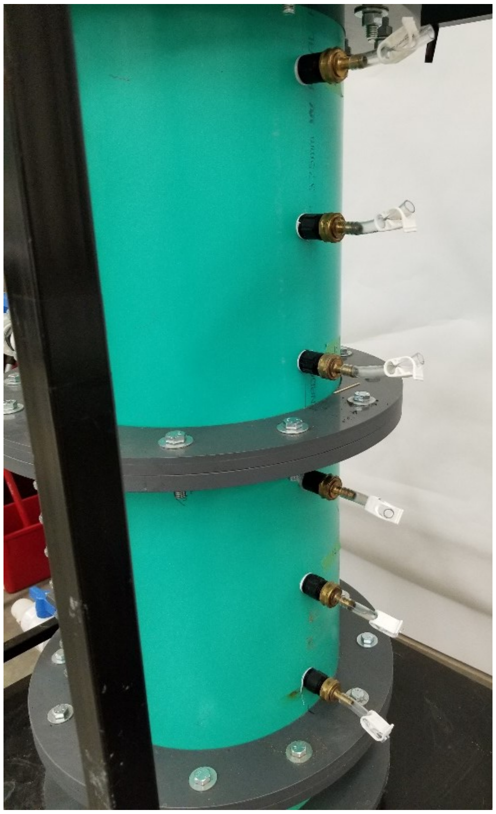
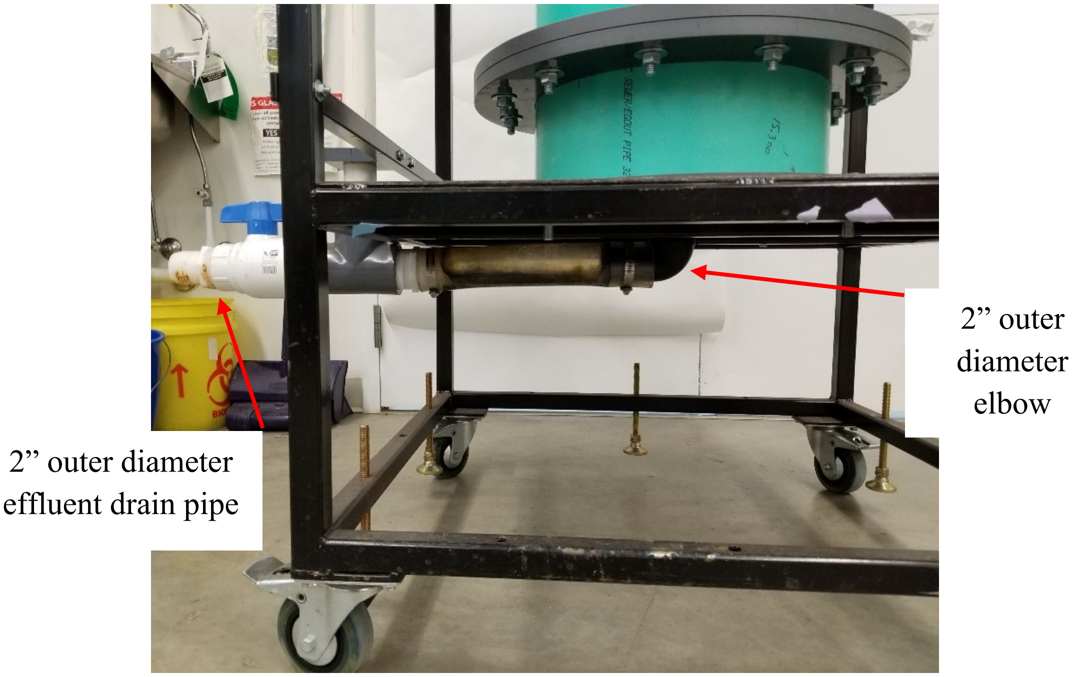


Figure 4: View of sampling ports along the media depth. Taken October 1, 2018.



2” outer diameter effluent drain pipe

2” outer diameter elbow

Figure 5: 2” diameter effluent drain pipe and shut off valve (blue). Taken October 1, 2018.

The above components of the experimental apparatus were completed by Mia Yu. The remaining components discussed henceforth were designed and completed by Dr. Tong Yu, James McKinnon of the CME Machine Shop, and I in 2015. The columns were retrofit to have a raised effluent piping network that consists of two 1.5” outer diameter effluent pipes that both have shut off valves. The new pipes are 46.5 cm and 69.5 cm (center line to center line) above the lowest, existing effluent pipe and are shown in Figure 6. These raised effluent pipes were installed to create a submerged, anoxic zone within the bioretention soil media in the columns as required. This submerged zone is created by closing the valve on the lowest effluent drain pipe so that water within in the soil column must reach the elevation of whichever raised effluent drain pipe is open before the water will begin to flow out of that effluent pipe. The ability to form an anoxic zone in the columns is required to grow denitrifying bacteria that will consume nitrate and produce nitrogen gas; this process is called denitrification.

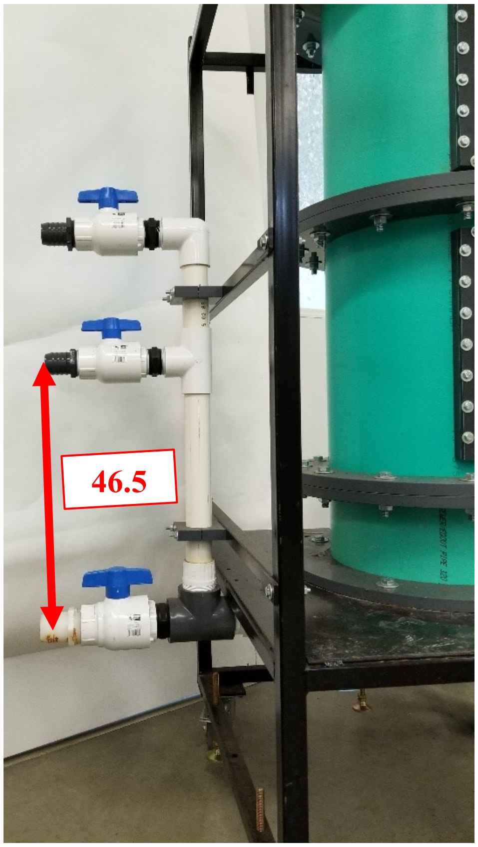


Figure 6: Raised effluent piping network (i.e. with black tips; white tipped pipe was existing). Dimensions are in cm. Taken October 1, 2018.

The influent water distribution system was challenging to design as it had to be able to operate under very low and high flow rates to simulate the whole range of a typical Edmonton rain event. The apparatus designed for this experiment, as shown in Figure 7, is unique as it can uniformly distribute a wide range of flow rates while not retaining significant amounts of TSS that flow through the apparatus. The bottom right image shows the outflow hole pattern that is the same on all four arms of each water distribution apparatus. Each arm consists of a 1/4” outer diameter stainless steel pipe and appropriate connectors. The end of each arm has a slot and clamp device that fits securely onto the top of the large PVC columns. The water distribution system is shown in operation in Figure 8.

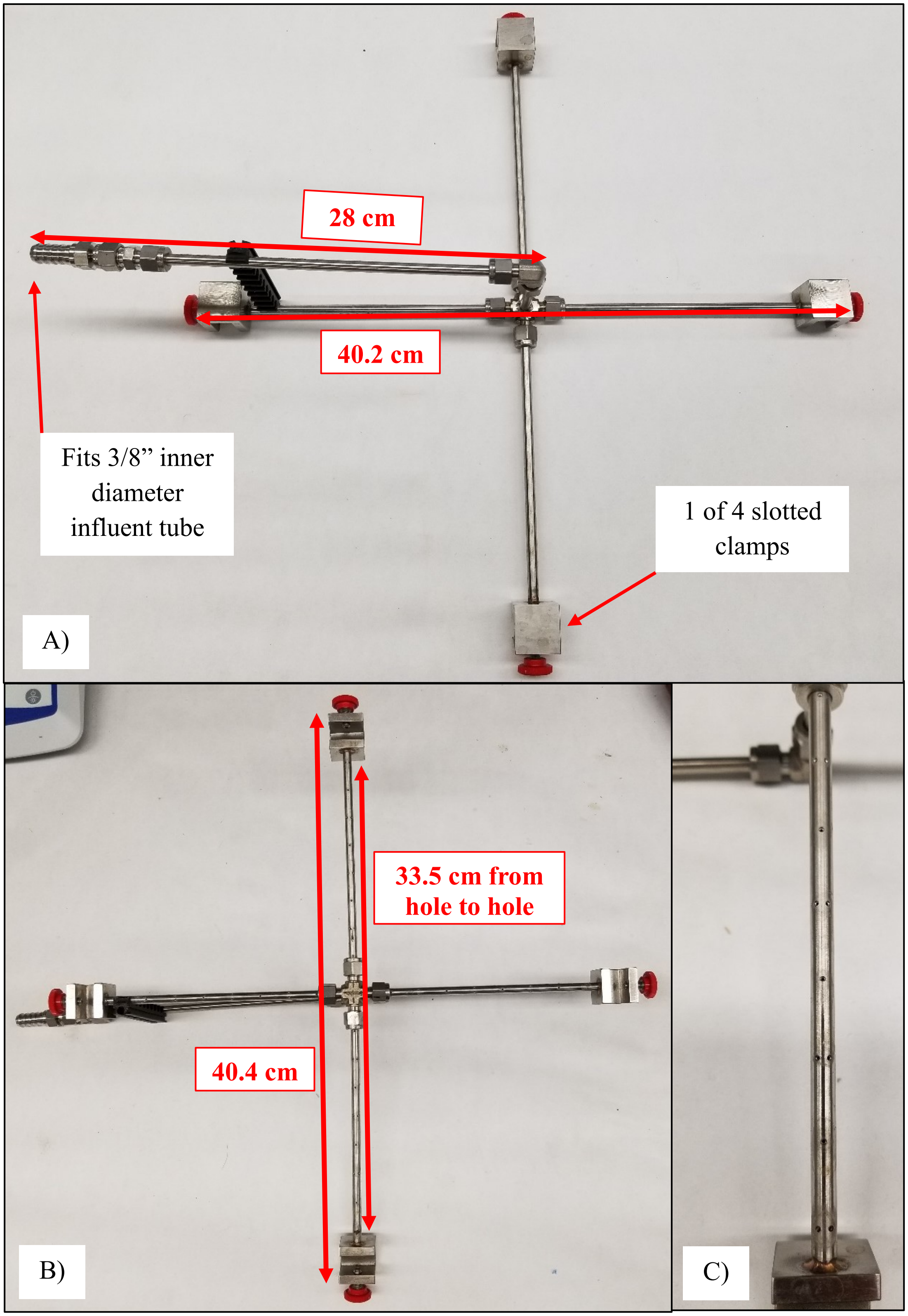


Figure 7: Uniform water distribution apparatus. A) Top view B) Bottom view C) Close up of outflow hole pattern. Dimensions are in cm. Taken October 1, 2018.

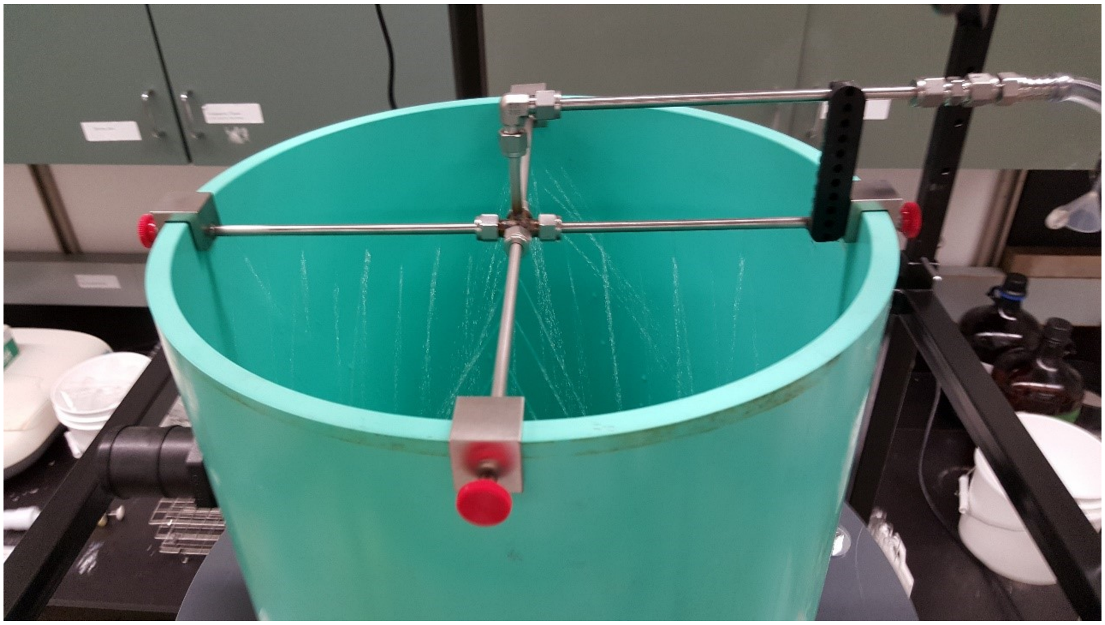


Figure 8: Uniform water distribution apparatus under high flow rate. Taken April 12, 2016.

The existing fluorescent lights in the laboratory did not have enough lumens to support healthy plant growth in the columns nor were they on an automatic timer that could turn on in the morning and shut off at night. Therefore, the four columns were equipped to share six SunBlaster™ 18” Fluorescent 6400K, 1581 Lumen Lamps (model EDJT5-117L-NAO) on a 12-hour timer to turn on at 7 am and off at 7 pm. One possible lamp configuration is shown in Figure 9. The lamps came with two plastic racks that hold up to 4 lamps comfortably. James McKinnon designed and built the steel framework to secure the lamp racks to the columns’ existing steel support. The vertical arm of the lamp framework slides inside one of the vertical edges of the column support and can be moved up and down to have the lamps sit between 34.5 and 62 cm above the top of the columns. The ability to adjust the lamp height was required to allow for different heights of plants to be grown and for the columns to be moved out of the laboratory into the cold room. As the plants grow taller, the lamp height should be increased as to not burn the leaves with too concentrated light and heat. Also, the laboratory and cold room door height restricts how tall the entire apparatus can be so the columns with the lamp fixture had to be adjusted to fit underneath of them. The cold room’s ceiling height was also too short to be able to install the lamp support frame on the columns once they were inside of the room, so they had to be installed prior to moving them into the cold room and thus, had to be adjustable to fit underneath the doors.

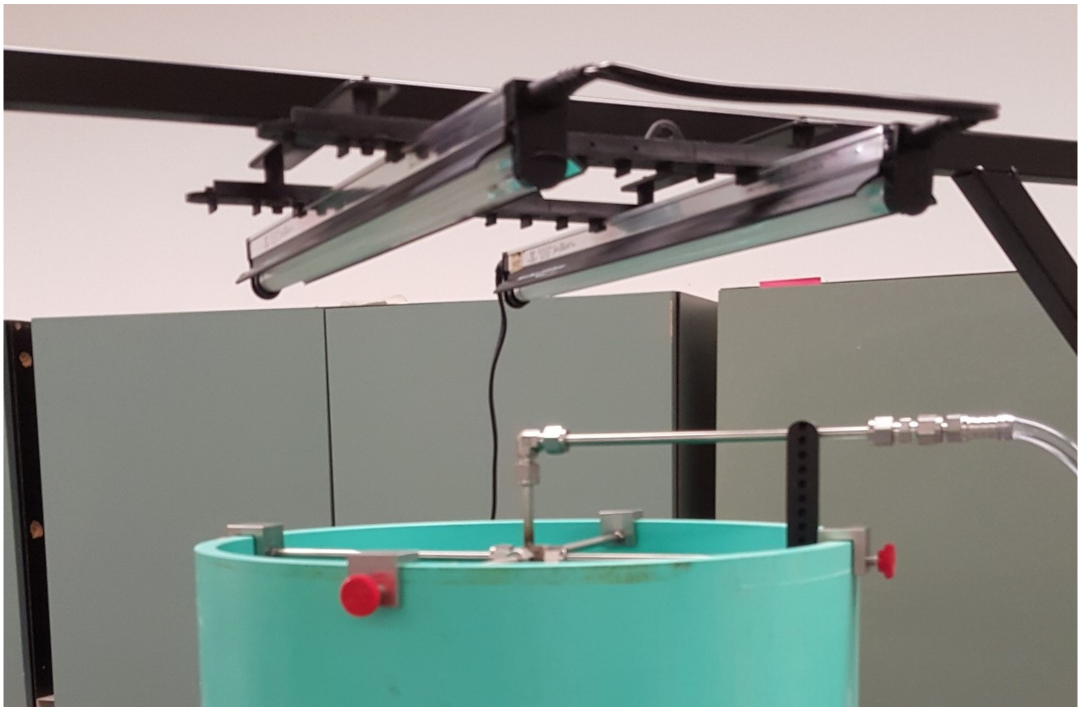


Figure 9: View of column equipped with two SunBlaster™ fluorescent lights for plant health. Taken April 12, 2016.

3.1.2 Bioretention Media Selection and Installation

All media installed in the columns was air-dried. In 2017 all four columns were filled with a 25 cm thick bottom layer of rocks. These rocks were graded appropriately so that the overlaying soil would not fall through and exfiltrate the system (i.e. a 15 cm depth of 40 mm round rock was placed and then a 10 cm depth of 7 mm washed rock was placed above). This rock layer reached the very bottom of the lowest viewing window in each column and was washed thoroughly with tap water until the water leaving the columns' effluent pipe was free of dirt and color. The selected soil medias were then placed in each column, as shown in the schematic in Figure 10. This media was placed in 10 cm lifts and gently compacted by a 10 kg bucket of sand after each lift. A detailed description and image of the media used can be found in Table 2.

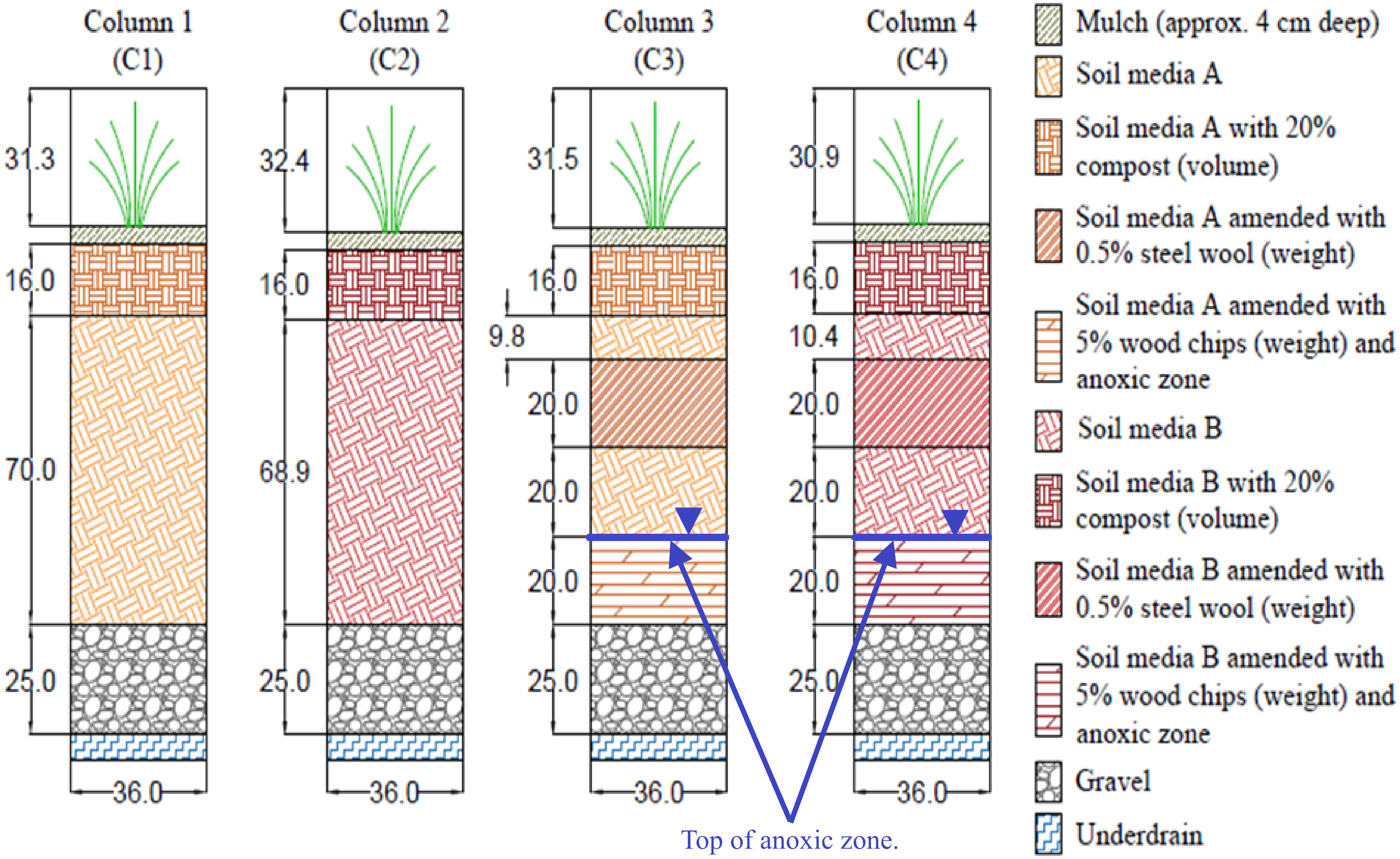


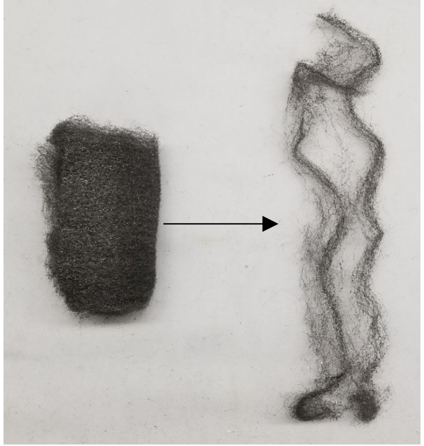
Figure 10: Schematic of bioretention column composition. Annotations are in centimeters.

Table 2: Column media composition and preparation of materials prior to installing in the columns. Details for where the materials were purchased can be found in Table 30 in Appendix A.

Media description	Image
Soil Media A: prepared by hand mixing 40% Sil 8 Sand with 60% Class B Topsoil (w/w) until visually uniform. This achieved a soil media texture of **loam** (see Figure 11) with 50.8% sand, 29.4% silt, and 19.8% clay (w/w).	
Soil Media B: prepared by hand mixing 60% Sil 8 Sand with 40% Class B Topsoil (w/w) until visually uniform. This achieved a soil media texture of **sandy loam** (see Figure 11) with 67.2% sand, 19.6% silt, and 13.2% clay (w/w).	
Compost: no preparation needed. See Appendix C for the thorough product analysis for the compost used in this study.	

Anoxic Zone Layer Woodchips: prepared by grinding and sieving surface mulch with a coffee grinder to achieve a particle size of 2-20 mm.

Steel Wool: prepared by stretching into a fine, net material, as shown to the right.



Surface Mulch: no preparation needed.

7 mm Washed Rock: no preparation needed.

40 mm Round Rock: no preparation needed.

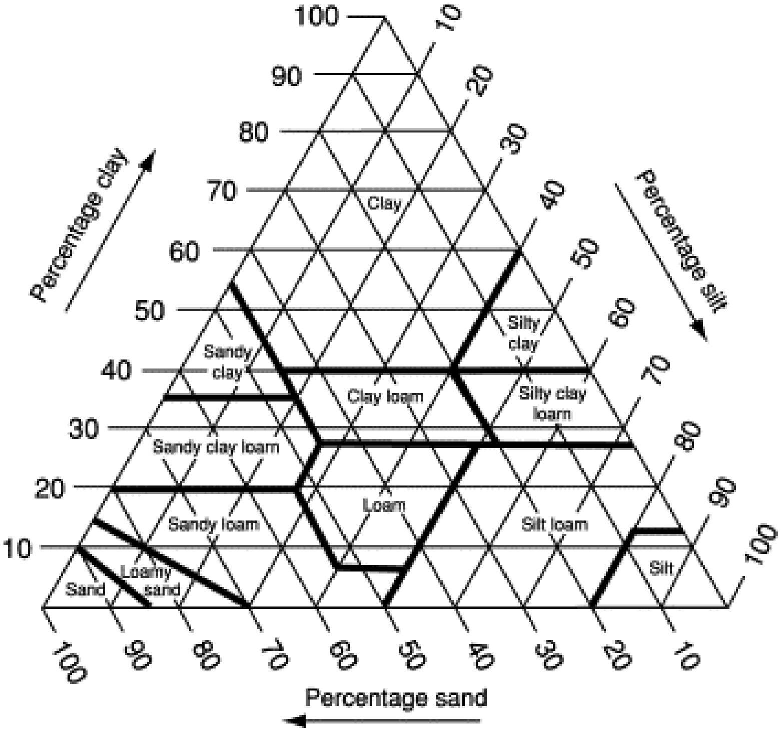


Figure 11: USDA soil textural triangle (Groenendyk et al., 2015).

Soil media A is defined as less porous (i.e. loam) soil and soil media B is defined as more porous (i.e. sandy loam) soil. Figure 12 shows the particle size distribution of the two bioretention medias used.

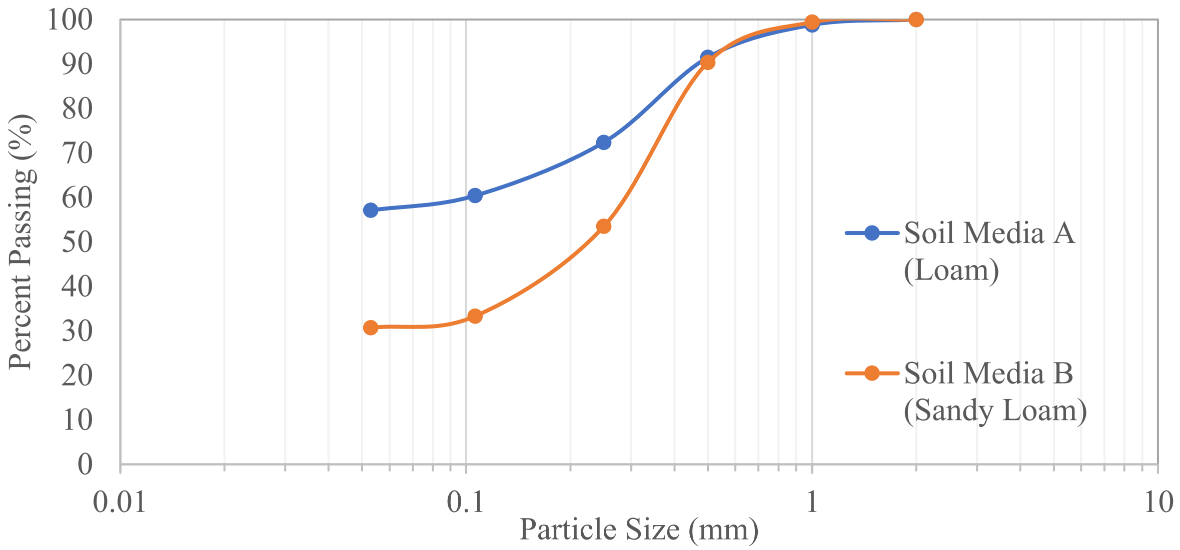


Figure 12: Particle size distribution graph for the two soil media types used.

Each column has a surface media layer mixed with 20% (v/v) compost to promote plant establishment and health. Column 1 and 3 contain soil media A (less porous) throughout and columns 2 and 4 contain soil media B (more porous) throughout. By comparing columns 1 and 2, the impact of soil permeability on hydraulic performance and water quality improvement can be determined. Columns 3 and 4 are amended with a 20 cm deep layer of 0.5% (w/w) steel wool placed randomly throughout the soil media and a 20 cm deep layer of bioretention media mixed with 5% (w/w) woodchips that is submerged during summer operation. The submerged zone is indicated by "Top of anoxic zone" in Figure 10. This means that the raised effluent drain pipe, as shown in Figure 6, was used to collect effluent during summer operation while the valve on the lowest drain pipe was closed. This caused the height of the submerged (i.e. anoxic) zone to be approximately 45 cm above the bottom of the 40 mm round drainage rock.

The steel wool is intended to increase the phosphate adsorption/precipitation capacity of the bioretention media as it rusts over time. The woodchips act as a supplemental carbon source in the submerged zone (i.e. anoxic zone) to promote denitrification. The combination of a supplemental carbon source and anoxic conditions will provide the necessary environment for denitrifying bacteria to grow and consume nitrate to produce nitrogen gas.

By comparing columns 3 and 4 with columns 1 and 2, the impact that steel wool has on phosphate removal and the impact of the denitrification layer on nitrate removal can be determined. The impact that the anoxic zone has on the hydraulic performance can also be determined.

Column 1 and column 2 were the first to be filled. Originally, column 1 was filled with 70% Sil 8 sand and 30% Class B topsoil. Column 2 was always filled with Soil media B, as indicated in Figure 10. A series of hydraulic conductivity tests were carried out on both columns 1 and 2 from April 20, 2017 to July 27, 2017. During this period, 467 L and 437 L of tap water was applied to column 1 and 2, respectively. This is close to the equivalent precipitation of what would enter these columns in 1 year in Edmonton (i.e. 417 L). The high sand mixture in column 1 had too high of an infiltration rate and was therefore emptied of all soil while leaving the base rocks in place. Once soil media B in column 2 stabilized and was determined to meet the > 10 cm/hr hydraulic conductivity criteria recommended for cold climate (Kratky et al., 2017) column 1 was refilled with a less porous media similar to what is recommended in the City of Edmonton Landscaping Design and Construction Standards (CoE, 2017) while trying to achieve between 2.5 cm/hr and 10 cm/hr hydraulic conductivity. This media was selected as the soil media A (i.e. loam) defined in Table 2.

3.1.3 Vegetation

The following three local species of vegetation (common name followed by scientific name in italics) were initially selected for planting based on their drought tolerance, size, easy care requirements, and urban pollutant and salt tolerance:

- Bulbous Oat Grass (Variegated Oat Grass) or *Arrhenatherum elatius sp.* (*Arrhenatherum elatum 'Variegatum')*
- Heavy Metal Blue Switch Grass or *Panicum virgatum 'Heavy Metal'*
- Shenandoah Reed Switch Grass or *Panicum virgatum 'Shenandoah'*

Columns 1 and 2 were planted with one of each of the above species. However, the Bulbous Oat Grass and Shanandoah Reed Switch Grass did not flourish, as seen by the withered, sparse leaves in Figure 13.

Figure 13: Visual depiction of vegetative health of the three different species planted in columns 1 and 2. Taken August 3, 2017.

Moving forward, only the Heavy Metal Blue Switch Grass species was selected for planting in all four columns. The top layer of vegetation and soil to the root depths was removed from columns 1 and 2. Eight individual plant pots, as shown in Figure 14 were purchased and first installed in 10 gallon VIVOSUN fabric pots. The fabric pots were hemmed to be the same diameter as the large column (i.e. about 0.36 m). Two Heavy Metal Blue Switch Grasses were removed from their plastic pots, the existing soil was knocked off, the roots were rolled and massaged, and the root balls were placed in the adjusted fabric pot. As the two root balls were held in place, the appropriate soil media mixed with 20% (v/v) compost was poured around the root ball and surface mulch was placed on top. This process was repeated 3 more times until 4 fabric pots planted with 2 grasses each existed. Two of the fabric pots used soil media A and two of the fabric pots used soil media B.

Figure 14: One Heavy Metal Blue Switch Grass plant in plastic pot. Taken August 19, 2017.

The vegetation was planted in fabric pots initially so that their root systems could begin growing and establishing while waiting for columns 3 and 4 to be filled with soil media and amendments. Columns 1 and 2 were installed with their grasses on September 25, 2017 after being in the fabric pots for 2 weeks. At this time, columns 3 and 4 were still empty so experiments began on columns 1 and 2 only; Figure 15 shows column 1 undergoing its first simulated storm event. Shortly after, columns 3 and 4 were finished being filled with the soil media and amendments indicated in Figure 10 and then also transplanted with the grasses from the fabric pots on October 16, 2017. To install the grasses from the fabric pots into the columns, the fabric pot was held above the column, the side and then base of the fabric was carefully cut away from the large soil ball while 2 people held the soil in place.

The large soil ball was then carefully lowered into the column. As the fabric was being cut, some loose soil fell either into the column or onto the floor. This was adjusted in the column or replaced with fresh media as required. Fresh media was then filled into an gaps around the edge of the root ball and mulch was placed on the surface as required.

Figure 15: Column 1 experiencing its first simulated storm event. Taken September 26, 2017.

3.2 Experimental Methods

3.2.1 Large Column Simulated Runoff Events

Synthetic stormwater used in all experiments in this research was made in the laboratory by adding chemicals to tap water to meet target concentrations, as shown in Table 3. Actual concentrations may have varied slightly, therefore the Results and Discussion will utilize the measured concentrations of the influent and effluent samples obtained as described in section 3.3 Analytical Methods.

Table 3: Target composition of simulated stormwater influent used in this experiment.

Parameter	Source	Unit	Concentration
TSS	Local topsoil < 0.500 mm	(mg/L)	150
COD	Glucose	(mg/L)	40
Total Nitrogen (TN)	See below	(mg/L)	4
Ammonium (NH_4^+-N)	NH_4Cl	(mg/L)	2
Nitrate (NO_3^--N)	KNO_3	(mg/L)	1.5
Nitrite (NO_2^--N)	$NaNO_2$	(mg/L)	0.5
Phosphate ($PO4^{3-}$-P)	KH_2PO_4	(mg/L)	2
Chloride (Cl^-)	NaCl	(mg/L)	15[a]
			320[b]
			1280[c]
Cadmium (Cd)	$Cd(NO_3)_2\cdot 4H_2 0$	(µg/L)	5
Copper (Cu)	$CuSO_4\cdot 5H_2 0$	(µg/L)	150
Lead (Pb)	$Pb(NO_3)_2$	(µg/L)	50
Zinc (Zn)	$ZnSO_4\cdot 7H_2 0$	(µg/L)	400

[a] During summer operation and the 1:5 and 1:10 year events

[b] During winter operation and the major melt of spring runoff event

[c] During 4x concentrated spring runoff event

Note: All contaminants except chloride remained the same concentration during all stages of operation except for during the 4x concentrated spring runoff event, in which contaminants other than COD were quadrupled.

This research carried out five stages of operation on each column which are intended to simulate an actual, typical Edmonton year of climate and precipitation volume (i.e. summer to summer) in only 10 months. The air temperatures were varied in the temperature-controlled room as shown in Figure 16. Stage 1, 4, and 5 were conducted in the room temperature laboratory; this set up is shown in Figure 17. Stage 2 and 3 were conducted in the temperature-controlled room which fits all four columns at once and can have the air temperature adjusted between -20°C and +20°C; this set up is shown in Figure 18. The detailed list of events in each stage of operation can be found in Table 4. The five stages of operation are as follows:

1. 1st summer operation: includes seventeen, weekly 1:2 year frequency events applied at room temperature from September 26, 2017 to February 7, 2018. Columns 3 and 4 both contained a submerged zone to the depth indicated in Figure 10 during this stage. On February 8, 2018, the submerged zone was drained by opening the lowest effluent valve prior to freezing the columns so that concrete frost would not form.
2. Winter operation: includes four simulated, snowmelt events applied in the temperature-controlled room from February 20, 2018 to April 16, 2018. The concentration of chloride was increased from 15 to 320 mg/L Cl^- to represent road maintenance salts applied in Edmonton's winter. Synthetic snowmelt was only ever applied when the air temperature in the room was approximately 3°C.
3. Spring runoff: includes one high concentration (i.e. 4 times the winter operation concentration), low volume event to represent the **first flush** of accumulated pollutants at the base of packed snow on May 8, 2018. This was followed by one typical winter concentration, high volume event to represent the **major melt** of packed snow from May 10, 2018 to May 12, 2018. Both events were applied at approximately 1°C.
4. 2nd summer operation: includes five, weekly 1:2 year frequency events applied at room temperature from June 14, 2018 to July 9, 2018. On June 14, 2018, the submerged zone in columns 3 and 4 was formed again to the height indicated in Figure 10 by closing the lowest effluent valve.
5. Larger events operation: includes one 1:5 year frequency event applied on July 16, 2018 and one 1:10 year frequency event applied on July 23, 2018, both conducted at room temperature.

The influent flow rates for stage 1, 4, and 5 (i.e. 1:2, 1:5, and 1:10 year events) were selected to follow a 4 hour-Chicago distribution hydrograph that was developed based on

Edmonton's historical rainfall data. The IDF curves used to create the hydrographs can be found in the City of Edmonton Drainage Design and Construction Standards (CoE, 2014b). The flow rate was determined by assuming a 100% impervious catchment area ten times the area of each bioretention column, which is within the recommendations given by the City of Edmonton LID Design Guide (CoE, 2014a). The influent hydrographs for the 1:2, 1:5, and 1:10 year frequency events are shown on the same graph in Figure 51 in Appendix A. Winter operation differed in that inflow was pumped in at a constant rate of approximately 76.7 mL/min for the duration of each event. The spring runoff events also differed in their inflow patterns: the high concentration, low volume "first flush" spring runoff event had a constant inflow rate of approximately 5.8 mL/min for the duration of the event and the high volume "major melt" spring runoff event followed the inflow pattern shown in the hydrograph in Figure 52 in Appendix A. The five stages of operation were equivalent to a typical 1.6 years of precipitation volume in Edmonton based on 778 litres (or 764.4 mm) being applied to each column in total.

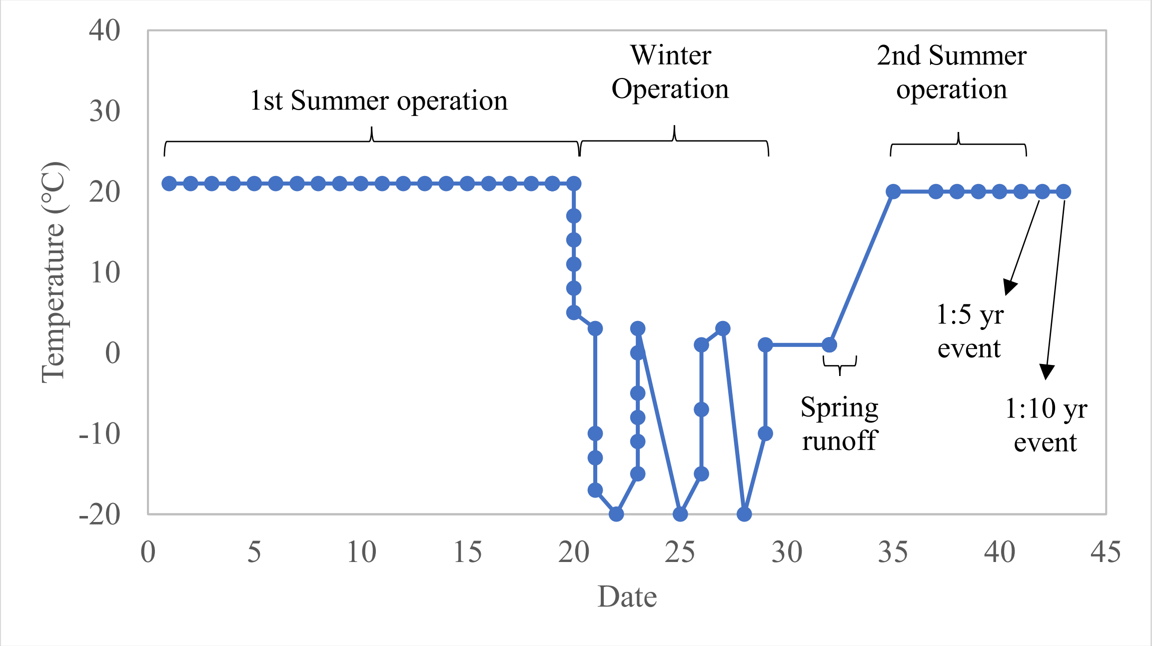


Figure 16: External air temperature fluctuation during all five stages of operation.

Figure 17: All four columns set up in the room temperature laboratory. Taken November 17, 2017.

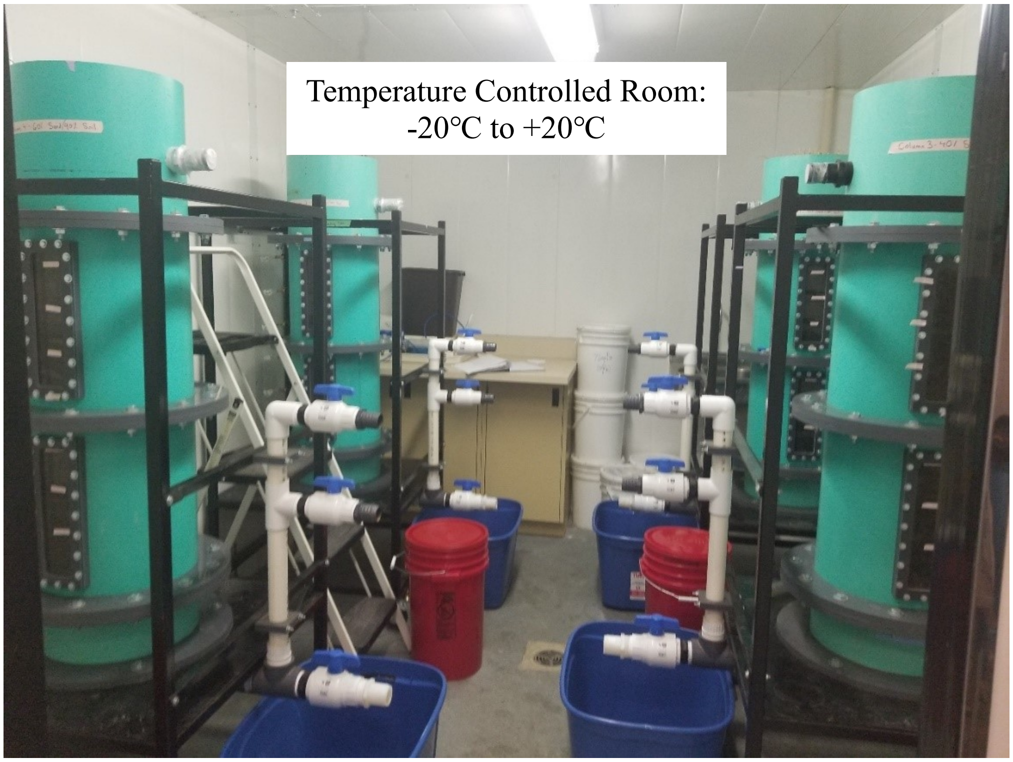


Figure 18: All four columns set up in the temperature-controlled room. Taken May 28, 2018.

Table 4: Detailed chronological list of events conducted.

Stage of operation	Week	Precipitation depth (mm)	Inflow duration (hr)	Description of event simulated and effluent sampling
1st Summer	1	22.6	4	1:2 year event on columns 1 and 2.
	2			1:2 year event on columns 1 and 2.
	3			1:2 year event on all columns.
	4			1:2 year event on all columns.
	5			1:2 year event on all columns.
	6			1:2 year event on all columns.
	7			1:2 year event on all columns.
	8			1:2 year event on all columns.
	9			1:2 year event on all columns.
	10			1:2 year event on all columns.
	11			1:2 year event on all columns.
	12			1:2 year event on all columns.
	13			1:2 year event on all columns.
	14			1:2 year event on all columns.
	15			1:2 year event on all columns.
	16			1:2 year event on all columns.
	17			1:2 year event on columns 3 and 4.
	18			1:2 year event on columns 3 and 4.
	19			1:2 year event on all columns.
Winter	21	22.6	5	Snowmelt event on all columns.
	23			Snowmelt event on all columns.
	27			Snowmelt event on all columns.
	29			Snowmelt event on all columns.
Spring Runoff (SR)	32	9.8	29	First flush of SR on all columns.
	32	39.3	48	Major melt of SR on all columns.
2nd Summer	37	22.6	4	1:2 year event on all columns.
	38			1:2 year event on all columns.
	39			1:2 year event on all columns.
	40			1:2 year event on all columns. Volume interval samples were taken.
	41			1:2 year event on all columns.
Larger Events	42	37.3	4	1:5 year event on all columns.
	43	45.2	4	1:10 year event on all columns.

Design events for 1:2, 1:5, and 1:10 year storms are Edmonton design events based on the Drainage Design and Construction Standards (CoE, 2014b).
Note: Total volume samples were collected for every event, unless indicated otherwise.

The precipitation depths used for the first flush and major melt of spring runoff were developed based on average melted snowfall depths of 107.9 mm annually in Edmonton (GoC, 2018a) and assumed a catchment area ten times the surface area of a large column. This snowfall depth was originally going to be divided between two winter events and spring runoff; however, due to inconsistencies in the response of the columns to the first two winter events applied, an additional two winter events were conducted to collect more data. The winter events used the same precipitation depth as the summer events, to be more comparable, but at a slower, constant influent rate. It was also assumed that 12.6% of the melted snowfall depth could have been lost to either sublimation or manual snow removal offsite. If the two additional winter events were not needed, then 2 x 22.6 mm (i.e. two winter events) + 9.8 mm (i.e. first flush of spring runoff) + 39.3 mm (i.e. major melt of spring runoff) equals 107.9 mm (melted snowfall depth) minus 12.6% losses. However, because an additional two winter events were required, 129% of the annual melted snowfall depth in Edmonton was applied to each column. The total spring runoff precipitation depth of 49.1 mm was calculated by assuming 48% of the snow pack (after losses) would have melted during intermittent warming periods throughout winter and 52% remained for spring runoff. The first flush was assumed to be 20% of spring runoff and the major melt accounted for the remainder.

The influent synthetic stormwater was made either the same day it was used or 1 to 3 days earlier and stored at ≤ 4°C until needed. The influent and effluent stormwater was held in 7-gallon pails. Magnetic stir plates were used to mix the water well while it was being pumped into the columns using peristaltic pumps and tubing and for sampling purposes. Throughout the operation ponding depth and influent and effluent flow rates were monitored consistently over time to analysis hydraulic performance. This data is thoroughly covered in Zhan Li's 2018 MSc thesis titled "Laboratory study on the hydraulic performance of bioretention for stormwater management in cold climates" (Li, 2018).

Influent and effluent samples were collected to measure the following water quality parameters:

- effluent TSS concentrations in triplicate

    - Note: TSS samples were not taken from the influent stormwater pails as it was visually obvious that magnetic stir plate mixing was not homogenously mixing the particles for influent TSS sufficiently; therefore, it was decided that the exact weight of influent TSS measured and influent volume used was a more accurate value. This was not an issue for effluent TSS measurements as the particles were visually much finer and could easily be well mixed by a magnetic stir plate.
- influent and effluent concentrations in duplicate for the following:
    - ammonium (NH_4^+-N),
    - COD (O_2),
    - nitrate (NO_3^--N),
    - phosphate (PO_4^{3-}-P),
    - chloride (Cl^-),
    - copper (Cu),
    - zinc (Zn),
    - cadmium (Cd),
    - lead (Pb),
    - total phosphorus (P),
    - total nitrogen (TN), and
    - nonpurgeable organic carbon (NPOC).

Two different sampling techniques were conducted depending on the event (sampling type indicated in Table 4) and are as follows:

1. <u>Total volume samples</u>:
    a. This type of sampling was completed for every event applied for all influent and effluent synthetic stormwater stored or collected into 7-gallon pails (except for the effluent water collected during week 19 as depth profile samples were taken instead).
    b. The total volume was mixed for 1 hour and then a peristaltic pump and tubing was used to pump the required volume of sample out of the 7-gallon

    pail while the tube was manually and quickly moved vertically throughout the depth of the water multiple times to ensure sample was being collected from all depths of the pail.
    c. The volume of sample extracted varied for TSS as sample was collected until it was estimated that we collected at least 2.5 mg of dried solids on the filter paper, as per the standard methods given in section 3.3. This differed based on column performance and over time.
    d. The volume of sample required for the analysis of remaining contaminants (i.e. approximately 250 mL) was extracted into centrifuge tubes and stored until analysis.
2. Volume interval samples:
    a. Volume interval samples were collected from the lowest effluent pipe for columns 1 and 2 and from the raised effluent pipe (i.e. middle effluent pipe) for columns 3 and 4 to evaluate the change of effluent contaminant concentrations over time.
    b. 200 mL was collected at each volume interval to a total of seven different interval samples. The first sample was taken as soon as effluent began flowing out of the pipe. Each consecutive sample was collected after another approximately 2000 mL had flowed out of the pipe and collected separately for total volume sampling purposes.
    c. Over half of the available volume within the columns had been emptied through the effluent pipe by the time the volume interval sampling ended. The volume that remained in the columns is slow to drain and therefore, for practicality, it was left to drain over night and contributed to the total volume sample only.

3.2.2 Small Column Phosphate Adsorption Capacity Analysis

In section 4.2, the excellent removal of orthophosphate by all four large columns will be discussed. As the steel wool has not yet appeared to make a difference in phosphate concentration reduction in the large columns 3 and 4, this small column phosphate adsorption capacity analysis was conducted to determine the adsorption capacity of soil media “A” and “B”. Holes were drilled at the base of two 50 mL polypropylene graduated cylinders (Item #RK-06135-32 from Cole Parmer); 1/8” inner diameter PVC tubing (Catalog # 14-169-7A from Fisher Scientific) was inserted into the holes and sealed with silicone gel. Class B topsoil and Sil 8 sand were dried at 50°C for 48 hours prior to the appropriate aliquots being weighed into beakers and mixed thoroughly until visually uniform. The media was then carefully scooped into the prepared graduated cylinders.

The small column filled with soil media “A” contained 60.0013 g of media (36.0009 g Class B topsoil soil and 24.0004 g Sil 8 sand). The influent water to this column contained 3.14 mg PO_4^{3-}-P /L and was pumped into the small column at an approximate flow rate of 1.56 mL/min. The other column was filled with soil media “B” and contained 60.0008 g of media (24.0002 g Class B topsoil soil and 36.0006 g Sil 8 sand). Its influent water contained 3.12 mg PO_4^{3-}-P/L and was pumped into the small column at an approximate flow rate of 1.62 mL/min. KH_2PO_4 was added to deionized water to make the influent and 1-100 RPM pumps, as described in Table 30, were used to pump the influent into the top of each column. Influent was pumped in during the day and effluent was collected and sampled at volume intervals ranging between 50 mL to 1075 mL as it drained from the bottom of the tubes. Influent and effluent samples were analyzed in duplicate for orthophosphate (PO_4^{3-}). Figure 19 shows the configuration of this experiment. This experiment ran from July 31, 2018 to August 3, 2018.

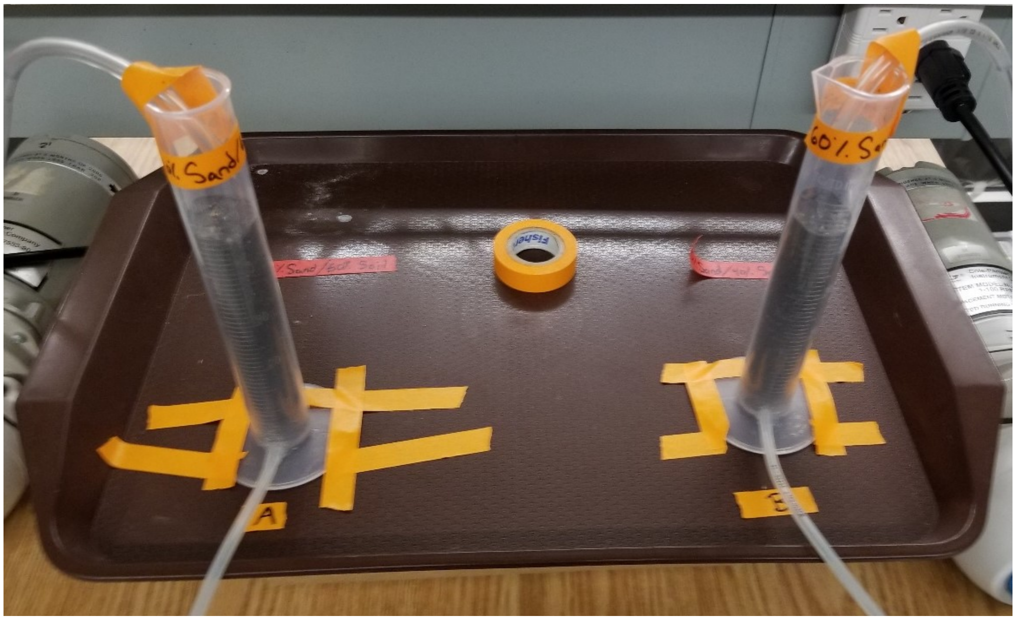


Figure 19: Set up for small columns for phosphate adsorption capacity analysis of soil media "A" and "B".

3.2.3 Soil Media and Amendment Leachate Analysis

A period of large column media maturation occurred in which certain contaminants leached considerably from the systems; this period will be discussed in section 4.8. To determine which component(s) of the columns could be contributing to this leachate, the following soil media and amendment leachate analysis was conducted from July 31, 2018 to August 7, 2018. Eight Erlenmeyer flasks were used to contain the four media types tested and 180 mL of deionized water. Soil media “A” or loam soil, soil media “B” or sandy loam soil, compost, and woodchips were the four most likely sources of the leaching contaminants and were therefore examined in this analysis. Prior to weighing the appropriate aliquots to put into each Erlenmeyer flasks, all media was dried at 50°C for 48 hours.

Each media type tested was contained in two different Erlenmeyer flasks to examine the impact that contact time has on release/leaching of contaminants from its respective media. One of the flasks for each media type had 8 hours of contact time with the deionized water prior to sampling. The remaining flask for each media type had 1 week of contact time with the deionized water prior to sampling. Figure 20 shows the set up of this experiment. After the media was place in the flask, the water was poured in and the mixture was hand stirred until all media appeared wet.

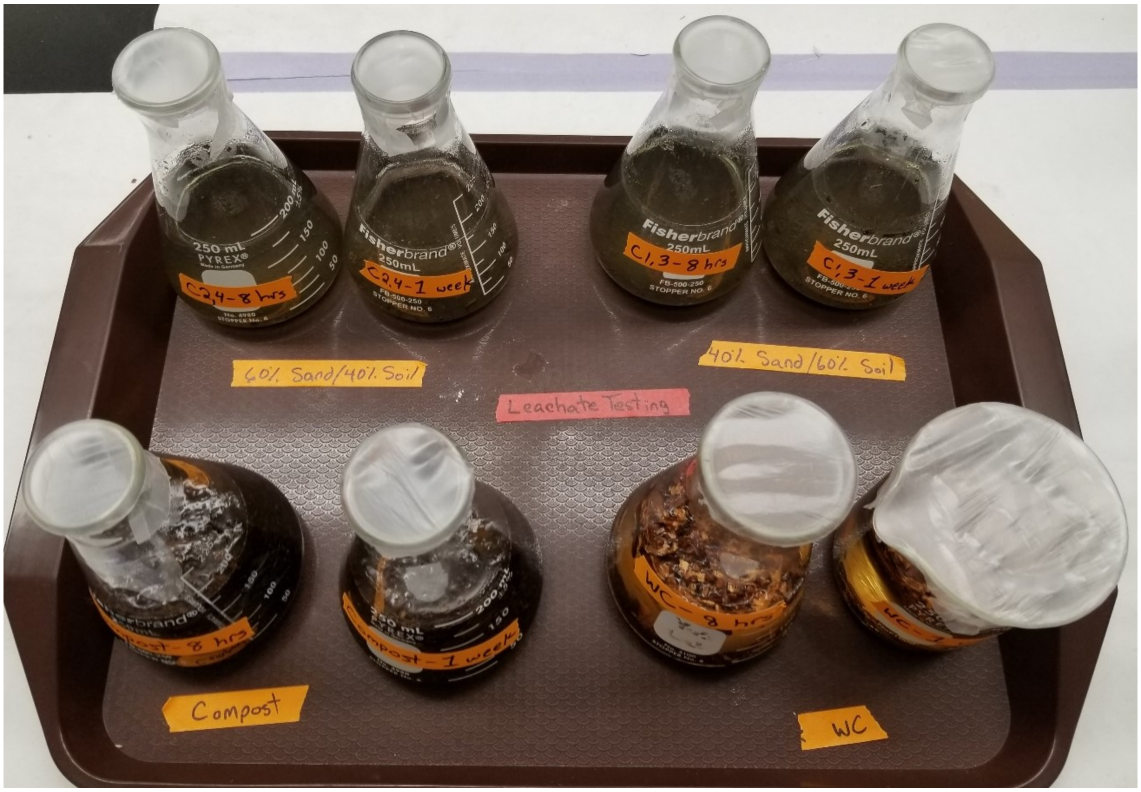


Figure 20: Arrangement of Erlenmeyer flasks for soil media and amendment leachate analysis.

Table 5 shows the weight of media added to each Erlenmeyer flask and how long it was left to soak in the 180 mL of deionized water. After the respective contact time, samples were collected, immediately filtered with a 0.2 µm syringe filter and stored at 4°C until analyzed. These samples were analyzed for the following:

- ammonium (NH_4^+-N),
- COD (O_2),
- nitrate (NO_3^--N),
- phosphate (PO_4^{3-}-P),
- chloride (Cl^-),
- copper (Cu),
- zinc (Zn),
- cadmium (Cd),
- lead (Pb),

- total phosphorus (P),
- total nitrogen (TN),
- total organic nitrogen (TON), and
- nonpurgeable organic carbon (NPOC).

The difference in values between the samples taken after 8 hours or contact time and 1 week of contact time were not considerably different so the average was taken for all parameters and will be used in the results and discussion.

Table 5: Weight of media added to each Erlenmeyer flask for leachate analysis.

Media Type	Contact Time	Weight of soil (g)	Weight of sand (g)	Weight of amendment (g)
Soil Media “A”	8 hours	5.4004	3.5999	-
	1 week	5.4004	3.5998	-
Soil Media “B”	8 hours	3.6001	5.4005	-
	1 week	3.6009	5.3998	-
Compost	8 hours	-	-	9.0003
	1 week	-	-	9.0005
Woodchips	8 hours	-	-	9.0012
	1 week	-	-	9.0025

3.3 Analytical Methods

Table 6 lists the standard methods and HACH kits used to measure the concentrations in the samples collected, as described in section 3.2. Detailed descriptions of each method can be found in Standard Methods for the Examination of Water and Wastewater (APHA, 2018) and online at www.ca.hach.com. Not every sample collected was analyzed for cations, NPOC, and total nitrogen, due to financial limitations.

Table 6: List of water quality parameters analyzed and associated methods.

Parameter		Expressed as	Analytical Method
TSS		mg/L	APHA Method 2540 D: Total Suspended Solids Dried at 103-105°C.
Anions	Chloride	mg Cl^-/L	APHA Method 4110 B: Ion Chromatography with Chemical Suppression of Eluent Conductivity. Used to test phosphate in large column experiments.
	Nitrate	mg NO_3^- -N/L	
	Orthophosphate	mg PO_4^{3-} -P/L	HACH method 10210 for Reactive Phosphorus Vial Test (0.05 – 1.50 mg PO_4^{3-} -P/L) Product #: TNT 843. This test kit is based off the principles of APHA Method 4500-P E: Ascorbic Acid Method. Used to test phosphate in small column experiment.
Ammonium		mg NH_4^+ -N/L	HACH method 10205 for Ammonia TNTplus Vial Test, ULR (0.015 – 2.00 mg NH_3-N/L) Product #: TNT830-CA. This test kit prepares samples for analysis by distillation according to APHA Method 4500-NH_3 B and is based off the principles of APHA Method 4500-NH_3 F: Phenate Method.
COD		mg O_2/L	APHA Method 5220 D: Closed Reflux, Colorimetric Method.
Cations*	Copper	mg Cu/L	APHA Method 3120 B: Inductively Coupled Plasma-Optical Emission Spectroscopy using internal standard solution containing yttrium and using nitric acid for digestion of solids.
	Zinc	mg Zn/L	
	Cadmium	mg Cd/L	
	Lead	mg Pb/L	
	Total phosphorus	mg P/L	

Table 6: List of water quality parameters analyzed and associated methods (cont'd).

Parameter	Expressed as	Analytical Method
NPOC – nonpurgeable organic carbon*	mg CO_2/L	"NPOC is measured by acidifying an aliquot of water then sparging the sample to strip off any purgeable organic and inorganic carbon. The sample is then injected into a combustion tube that contains a catalyst material. A redox reaction occurs that evolves carbon dioxide gas (CO_2) which is then detected by a non-dispersive infrared (NDIR) detector for carbon. For nitrogen analysis, the sample is combusted to NO and NO_2, then reacted with ozone to form NO_2 in an excited state. The resultant photon emission is measured by a Chemiluminescence detector. Quantitation is achieved by calibrating the TOC-V instrument with known standard materials. Instrument used was a Shimadzu TOC-V CHS/CSN Model Total Organic Carbon Analyzer, manufactured by the Shimadzu Corporation, Analytical &Measuring Instrument Division, 1, Nishinokyo-Kuwabara-cho, Nakagyo-ku, Kyoto 604-8511, Japan." (NRAL, 2012)
Total nitrogen*	mg N/L	

* Analysis completed by the Natural Resources Analytical Laboratory in the Department of Renewable Resources at the University of Alberta: 4-52 South Academic Building, Edmonton, AB.

Fresh soil samples for Class B Topsoil, Soil Media A, Soil Media B, Woodchips, and Compost were sent to Exova for analysis of various soil parameters, as shown in Table 7. Class B Topsoil was only analyzed for soil texture; Soil Media A and B were analyzed for all parameters except soil texture, and Woodchips and Compost were analyzed for all parameters except soil texture and particle size sand classification (i.e. sand gradation). Detailed descriptions of some methods can be found in Standard Methods for the Examination of Water and Wastewater (APHA, 2018).

Table 7: List of soil parameters analyzed by Exova of Edmonton and associated methods.

Parameter	Expressed as	Analytical Method and Reference
Soil texture	% sand, clay, silt	Method 55.3: Hydrometer (Kroetsch and Wang, 2008) (Modified)
Sand gradation	% weight retained on sieve size	Standard test method for materials finer than 75-µm (No. 200) sieve in mineral aggregates by washing: C117-04 (ASTM International, 2004) (Modified)
Trace metals including Al, Cd, Cu, Fe, Pb, P, Zn	mg/kg	**Digestion:** Strong acid leachable metals (SALM) (BC Ministry of Environment, 2009) (Modified) **Analysis:** APHA Method 3120 B: Inductively Coupled Plasma (Modified) **Analysis:** ICP-MS (U.S. EPA, 1994) (Modified)
Available phosphorus	mg/kg	**Extraction:** Modified Kelowna Extraction (Ashworth and Mrazek, 1995) **Phosphate analysis:** APHA Method 4500-P D: Stannous Chloride Method (Modified)
Organic matter	%	Method 3.8: Loss on ignition (McKeague, 1978) (Modified) Calculation based on Ball (1964) and Nelson and Sommers (1982)
Cation exchange capacity and cations	meq/100 g	**Extraction:** Method 3.32: CEC and exchangeable cations by NH_4OAc at pH 7 (McKeague, 1978) (Modified) **Cation analysis:** APHA Method 3120 B: Inductively Coupled Plasma (Modified) **Ammonium analysis:** APHA Method 4500-NH_3 G: Automated Phenate Method (Modified)
Available ammonium-N and nitrate-N	mg/kg	**Extraction:** Method 6.2 - NO_3-N and NH_4-N extraction with 2.0 M KCl (Maynard et al., 2008) (Modified) **Ammonium analysis:** APHA Method 4500-NH_3 G: Automated Phenate Method (Modified) **Nitrate analysis:** Method 6.3 – Determination of NO_3-N in 2.0 M KCl extracts by segmented flow analysis (cadmium reduction procedure) (Maynard et al., 2008) (Modified)

All soil analysis completed by Exova: 7217 Roper Road NW, Edmonton AB.

Chapter 4. Results and Discussion

The following results and discussion will be mainly focused on the change in concentration of TSS, nutrients, chloride, and organics due to the synthetic stormwater passing through each column during all stages of operation. For these parameters, influent and effluent samples were analyzed for nearly every event, as indicated in Table 8. For simplicity, some of the graphs show a “Target Influent” data series which shows the concentration that was being targeted for when making the synthetic stormwater. “Average Influent” is also shown in some graphs and shows the average influent concentration between the four separate columns’ influent buckets. However, all percent concentration reduction values were calculated using the actual influent and effluent concentrations measured for each individual column, except for TSS. As described in section 3.2.1, influent concentration of TSS was not measured, but rather, calculated.

Metals were also evaluated in this study, but not as thoroughly as the above-mentioned parameters due to financial constraints and because metal removal and mechanism studies have been conducted in more detail elsewhere (Muthanna et al., 2007a; Li and Davis, 2008; Blecken et al., 2009a; Blecken et al., 2011; Hatt et al., 2011; Søberg et al., 2017). Total phosphorus, metals (Cu, Zn, Cd, and Pb), total nitrogen, and NPOC were only measured for select events, as indicated in Table 8.

Table 8: Inventory of chemical analysis conducted on samples collected for each event ran.

Stage of operation	Week	Brief Event Description	TSS	Ammonium Nitrate, Phosphate, Chloride, and COD	Total Phosphorus and Metals (Cu, Zn, Cd, Pb)	Total Nitrogen and NPOC
1st Summer	1	1:2 year event	✓	✓	✓	
	2		✓	✓	✓	✓
	3		✓	✓	✓	✓
	4		✓	✓	✓	✓
	5		✓	✓	✓	✓
	6		✓	✓	✓	✓
	7		✓	✓	✓	✓
	8		✓	✓		
	9		✓	✓	✓	✓
	10		✓	✓		
	11		✓	✓		
	12		✓	✓	✓	✓
	13		✓	✓		
	14		✓	✓		
	15		✓	✓		
	16		✓	✓	✓	
	17		✓	✓		
	18		✓	✓		
	19			✓		
Winter	21	Snowmelt event	✓	✓	✓	✓
	23		✓	✓	✓	✓
	27		✓	✓		
	29		✓	✓		
Spring Runoff	32	First flush of spring runoff.	✓	✓	✓	✓
	32	Major melt of spring runoff.	✓	✓		
2nd Summer	37	1:2 year event	✓	✓		
	38		✓	✓		
	39		✓	✓		
	40		✓	✓		
	41		✓	✓		
Larger Events	42	1:5 year event	✓	✓		
	43	1:10 year event	✓	✓	✓	✓

As events were conducted weekly, very little evaporation occurred and there was therefore consistently little volume reduction through evaporation and transpiration. For this reason, mass reduction was not evaluated and only the difference between influent and effluent contaminant concentrations was analyzed. The following results and discussion will evaluate the difference in treatment capacity (i.e. change in influent to effluent concentration) between the four different column designs as well as the difference across stages of operation (i.e. seasonal changes). Columns 1 and 3 contain loam soil (i.e. less porous) and columns 2 and 4 contain sandy loam soil (i.e. more porous).

The intent of this research is to investigate whether the difference in porosity has a considerable impact on the ability of the columns to treat different parameters. Less porous media (soil media "A" in columns 1 and 3) was utilized in this research to resemble current design specifications in Edmonton (CoE, 2014a) and more porous media (soil media "B" in columns 2 and 4) was used to achieve > 10 cm/hr infiltration rate. This infiltration rate has been recommended to prevent concrete frost from forming in freezing conditions and completely clogging the soil (Kratky et al., 2017). However, increased porosity and infiltration rate may lead to decreased water quality improvement due to reduced contact time and area. This research aims to prove that even with a higher sand content (i.e. soil media "B" found in columns 2 and 4) and increased hydraulic conductivity, water quality improvement is not hindered. Refer to Zhan Li's 2018 MSc thesis titled "Laboratory study on the hydraulic performance of bioretention for stormwater management in cold climates" (Li, 2018) for the detailed hydraulic performance data.

Columns 3 and 4 have also been amended with steel wool to enhance phosphate adsorption/precipitation and a submerged (i.e. anoxic) zone and supplemental carbon (i.e. woodchips) to promote the growth of denitrifying bacteria and thus the conversion of nitrate to nitrogen gas, a process known as denitrification. By comparing columns 1 and 2, the impact of soil porosity on water quality improvement can be determined. By comparing columns 3 and 4 with columns 1 and 2, the impact that steel wool has on phosphate removal and the impact of the denitrification layer on nitrate removal can be determined. The full set of experimental data is tabulated in Appendix B (Table 31 to Table 47).

4.1 Total Suspended Solids (TSS)

TSS removal by all columns throughout all stages of operation is generally considered acceptable and holds consistent with previous research at > 94% concentration reduction (Blecken et al., 2007; Roseen et al., 2009; Blecken et al., 2010). The only exception is columns 3 and 4 during the 1st summer operation and during the major melt of spring runoff in which concentration reduction is < 94%. The average percent concentration reductions of TSS can be seen in Table 9. Graphical representations of TSS removal is shown in Figure 21. The complete data set based on event can be found in Appendix B (Figure 53, Figure 54, and Figure 55). Table 10 shows the average effluent concentration from each column during all stages of operation.

Table 9: Average TSS percent concentration reduction by all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (%)	Winter (%)	Spring Runoff – First Flush (%)	Spring Runoff – Major Melt (%)	2nd Summer (1:2 year) (%)	1:5 Year Event (%)	1:10 Year Event (%)
Column 1	97.1 ±1.1	98.3 ±0.8	98.9	98.6 ±0.6	97.0 ±0.2	98.0 ±1.2	99.0 ±0.8
Column 2	95.3 ±2.8	96.9 ±1.6	99.5	98.7 ±1.1	96.0 ±0.5	97.0 ±1.2	98.0 ±0.6
Column 3	68.3 ±10.5	96.8 ±1.8	99.3	90.1 ±2.4	96.0 ±1.2	94.0 ±0.3	97.0 ±0.4
Column 4	76.2 ±5.1	97.7 ±1.0	97.1	89.5 ±4.9	95.8 ±1.3	96.7 ±0.5	97.8 ±0.7

Table 10: Average effluent TSS concentration of all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (mg/L)	Winter (mg/L)	Spring Runoff – First Flush (mg/L)	Spring Runoff – Major Melt (mg/L)	2nd Summer (1:2 year) (mg/L)	1:5 Year Event (mg/L)	1:10 Year Event (mg/L)
Column 1	4.4 ±1.7	2.5 ±1.2	6.4	2.1 ±0.9	5.2 ±0.3	3.6 ±0.1	2.2 ±0.1
Column 2	7.0 ±4.2	4.7 ±2.5	3.1	2.0 ±1.7	5.9 ±0.7	4.4 ±0.4	2.8 ±0.2
Column 3	47.6 ±15.8	4.9 ±2.7	3.9	14.9 ±3.7	5.4 ±1.7	8.4 ±1.3	4.3 ±0.4
Column 4	35.8 ±7.7	3.5 ±1.5	17.2	15.7 ±7.4	6.3 ±1.9	5.0 ±0.3	3.3 ±0.3

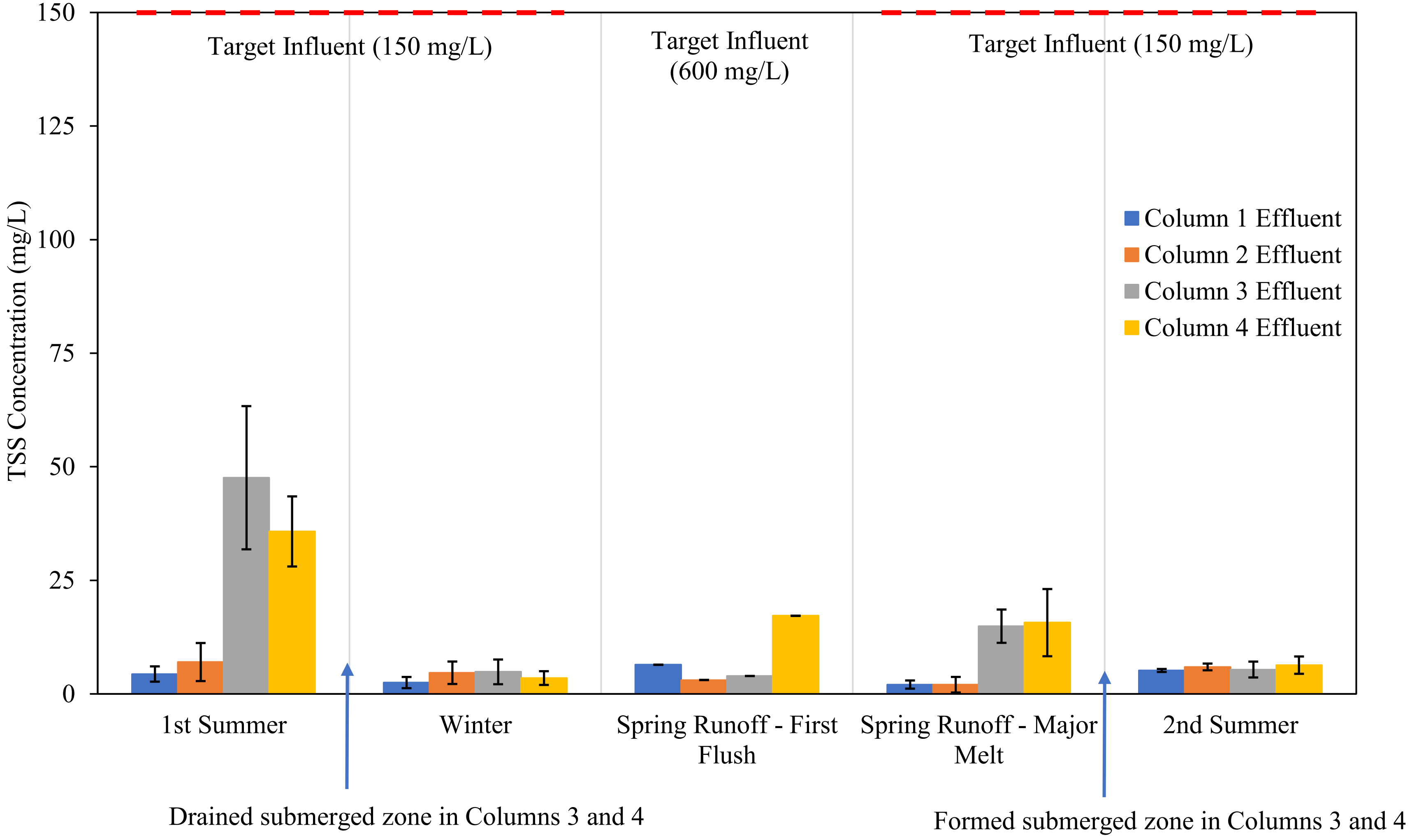


Figure 21: TSS removal during the 1st summer, winter, spring runoff, and 2nd summer operation.

By comparing TSS concentration reduction in columns 1 and 2, the difference in porosity between soil media "A" (i.e. loam) and soil media "B" (i.e. sandy loam), respectively does not hinder TSS removal as all percent reductions are considered acceptable at > 94%. Despite column 2 being washed with a years' worth of precipitation as tap water prior to being put into operation, its effluent concentration is comparable to the effluent concentration in column 1, indicating that sediment washout from the media itself is quite minimal and that fresh bioretention systems implemented in the field that follow these columns' design and construction should not expect a stabilization period of poor performance for TSS removal. As seen in Figure 53 in Appendix B, even the first 4 weeks of operation for columns 1 and 2 only had a maximum effluent TSS concentration of 9.67 mg/L (94% reduction) and 16.05 mg/L (89% reduction), respectively, which is still acceptable performance and does not imply a significant washout of media fines.

Summer (1:2 Year Events)

The anomaly occurring in columns 3 and 4 during 1st summer operation (i.e. higher effluent concentration than in columns 1 and 2 resulting in < 94% concentration reduction) was not repeated during the 2nd summer after the submerged zone is re-formed. During 2nd summer operation, the effluent TSS concentration for all the columns is quite similar with a concentration reduction of > 94%. Therefore, two phenomena are possibly contributing to the considerably higher levels of effluent TSS in columns 3 and 4 compared to columns 1 and 2 during 1st summer operation:

1. The excess fine material originated from the ground woodchips in the submerged zone of columns 3 and 4 and washout of these fines coincidentally completed after 1st summer operation.
2. The increased salinity caused by the higher concentrations of salt applied during winter and spring runoff enhanced the flocculation of suspended solids and therefore improved their chances of being captured and removed by the media.

As will be discussed in Section 4.4, influent chloride concentrations were very similar to effluent chloride concentrations in all columns and stages of operation. This implies that, due to chloride's negative charge and thus mobility throughout the soil column, which is also generally negatively charged, chloride mostly washes out of the systems and therefore would not increase their salinity. As chloride concentrations during the 2nd summer of operation were the same as the 1st summer and chloride from winter and spring runoff did not seem to remain in the system, it is not likely that a significant cause of improved TSS removal after the 1st summer was due to enhanced flocculation caused by salinity. Therefore, phenomena 1 discussed above is likely the contributing factor to the enhanced TSS removal observed after the 1st summer in columns 3 and 4.

For bioretention design considerations, if enhanced nitrate removal (i.e. via denitrification by addition of a submerged zone and woodchips for supplemental carbon) is a goal, the tradeoff will be reduced TSS removal during the first season or summer of operation until the woodchip fines washout and/or the pore spaces stabilize. Once stabilized, the highest average effluent concentration of all columns is still only 17.2 mg/L, as shown in Table 10, for column 4 during the first flush of spring runoff.

Winter and Spring Runoff

During winter and spring runoff operation, all four columns underwent multiple periods of freezing at -20°C and thawing. Events were conducted at air temperatures between 1-3°C and infiltration rates were significantly slower during these events than during room temperature operation. However, all volumes applied ultimately infiltrated through each column within a few days without any overflow forming. During these stages of operation, concentration reduction remained > 96% for all columns, except during the major melt of spring runoff for columns 3 and 4, which was closer to 90% removal, yet still acceptable. Even with influent concentrations 4 times that of typical concentrations (i.e. 600 mg/L), TSS removal was still acceptable. Therefore, the capacity for TSS removal was not hindered by the cold temperatures, which is to be expected as TSS removal is a physical treatment process.

The ability to remove filterable contaminants like TSS so shortly after being frozen is an important bioretention capability. This implies that during intermittent warming periods throughout winter and during spring runoff, bioretention cells could have capacity to filter and retain TSS if warm temperatures (1-3°C) last long enough to permit infiltration through the media. This is significant as road sediment concentrations are considerably higher in cold climates due to sanding conducted for winter road maintenance and bioretention could be a viable management technology for this source of pollution in climates such as Edmonton's, however, longer term studies are needed to evaluate how the TSS loading, the freeze thaw cycle, and vegetation growth over time will impact infiltration rates for a design period of 20 years.

1:5 Year and 1:10 Year Events

Figure 22 shows the similarity in effluent concentrations for columns 1 and 2 (i.e. soil media "A" and "B", respectively) throughout all room temperature events and for columns 3 and 4 (i.e. soil media "A" and "B", respectively, with nutrient amendments) during the 2nd summer and the 1:5 year and 1:10 year events. Without the interference of temperature or high salt concentration effects, the similarity between the effluent concentrations for columns 1 and 2 show that both soil media "A" and soil media "B" are effective at removing TSS from stormwater. The similarity between effluent concentrations for all columns during the single 1:5 year and single 1:10 year event compared with the 2nd summer operation show that larger, less frequent events are also well treated by bioretention for TSS. The ability to remove filterable contaminants like TSS from larger volumes, as in a 1:5 year and 1:10 year events, is an important bioretention capability.

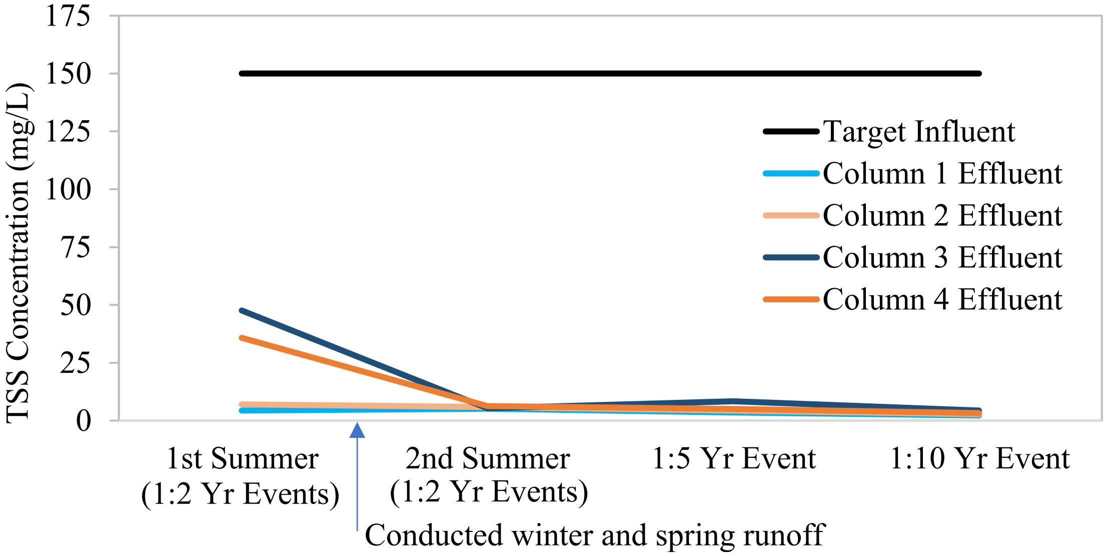


Figure 22: TSS removal during room temperature events.

Currently, bioretention is only intended to manage and treat 1:2 year storm events; however, if this exceptional treatment ability during 1:5 year and 1:10 year events could be expanded to 1:20 year or 1:50 year events, the potential for bioretention to still provide some water quality improvement during potential flooding events would be a valuable design feature. Much like spring runoff, large volume events collect most impermeable surface pollutants during the first flush, or approximately 1" of rainfall. Even if bioretention is unable to infiltrate the entire volume of a 1:20 year or 1:50 year event, if it captures the first flush volume and reduces > 94% TSS concentration, as seen in this research, this would mean considerable water quality benefits for downstream networks which may normally experience severe water quality degradation from a flood event. However, as only one 1:5 year and one 1:10 year event was conducted, more larger volume experiments, including 1:20 and 1:50 year events, should be conducted to show how longer term, high volume operation may change the infiltration rate, plant health, or contaminant wash out due to compaction, inundation, and desorption and microbial health, respectively. These factors depend greatly on not only the volume of rainfall but the speed in which it falls; in a large event such as a 1:100 year event, the flowrate may be so great that it bypasses bioretention systems entirely and therefore will not provide any water quality improvement.

This research assumed that the influent synthetic stormwater passed through some form of pretreatment prior to entering the large columns. Such pretreatment may consist of a settling basin with a weir and/or large rocks that slow influent flow rates and allow time for sedimentation of TSS before entering the bioretention facility. Pretreatment systems should prevent unnecessary amounts of sediment from entering the bioretention media and be easily and periodically shoveled out. Designing systems that incorporate some form of sediment pretreatment is vital to ensuring the extended life time of bioretention facilities by preventing premature clogging of the filter media and consequential reduction of hydraulic conductivity of the soil media. This is especially required in regions with climates such as Edmonton's due to the major road maintenance throughout winter in which an annual average of 152,000 tonnes of sand is applied (CoE, 2016). The City of Edmonton sweeps the streets in spring and recycles about 70% of the applied sand, but there is still an enormous quantity of excess sand that may enter bioretention facilities. This is not an issue in non-cold climate regions and therefore makes the design of bioretention pretreatment systems even more important in climates like Edmonton's.

Although this research shows excellent TSS reduction without a corresponding reduction in hydraulic conductivity (Li, 2018), only 1.6 years of typical, equivalent Edmonton precipitation volume was simulated. As smaller pore sizes become progressively blocked by influent TSS, flow pathways may become clogged. Vegetative root growth and the freeze and thaw cycle have the potential to reopen these blocked flow paths, but the timeline of this research cannot provide insight into this phenomenon. Long term studies on the large columns in this research would be required to determine the impact of prolonged TSS application on infiltration and therefore water quality improvement capacities.

4.2 Phosphorus

This research is focused on phosphorus in the form of reactive phosphorus (i.e. orthophosphate) as it is the bioavailable form and therefore most problematic in leading to the eutrophication of surface waters when found in excess quantities in stormwater runoff. Particulate phosphorus was also not heavily focused on in this study because stormwater is typically characterized as having an average of 45% and sometimes more than 90% of total phosphorus as dissolved phosphorus (Erickson et al., 2012); particulate phosphorus is also removed via the same mechanisms as TSS and therefore its removal can be evaluated by TSS reduction results.

Phosphate removal by all columns throughout all stages of operation is generally considered acceptable at > 85% concentration reduction and with average effluent concentrations < 0.27 mg/L, as seen in Table 11 and Table 12, respectively. These results indicate excellent performance, especially compared to other research that has experienced significant phosphate export (Denich et al., 2013). Reasons for discrepancy in performance between these two bioretention studies will be discussed below. Graphical representations of phosphate removal are shown in Figure 23 and Figure 24. The complete data set based on event can be found in Appendix B (Figure 56, Figure 57, and Figure 58).

Table 11: Average phosphate percent concentration reduction by all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (%)	Winter (%)	Spring Runoff – First Flush (%)	Spring Runoff – Major Melt (%)	2nd Summer (1:2 year) (%)	1:5 Year Event (%)	1:10 Year Event (%)
Column 1	94.5 ±4.6	95.6 ±2.2	99.1	96.7 ±0.1	92.5 ±5.4	96.3	96.5
Column 2	95.2 ±2.3	85.7 ±13.6	99.1	90.2 ±9.3	92.1 ±6.4	96.2	96.4
Column 3	92.0 ±8.7	96.4 ±0.6	99.1	88.1 ±12.4	85.2 ±23.1	96.2	96.5
Column 4	94.9 ±3.6	96.3 ±0.6	99.1	88.9 ±11.3	95.9 ±2.0	96.2	96.5

Table 12: Average effluent phosphate concentration of all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (mg/L)	Winter (mg/L)	Spring Runoff – First Flush (mg/L)	Spring Runoff – Major Melt (mg/L)	2nd Summer (1:2 year) (mg/L)	1:5 Year Event (mg/L)	1:10 Year Event (mg/L)
Column 1	0.10 ±0.09	0.09 ±0.03	0.07	0.07 ±0.00	0.17 ±0.12	0.07 ±0.00	0.07 ±0.00
Column 2	0.09 ±0.04	0.27 ±0.24	0.07	0.21 ±0.19	0.18 ±0.13	0.07 ±0.00	0.07 ±0.00
Column 3	0.15 ±0.16	0.07 ±0.00	0.07	0.25 ±0.26	0.27 ±0.39	0.07 ±0.00	0.07 ±0.00
Column 4	0.10 ±0.07	0.07 ±0.00	0.07	0.24 ±0.24	0.08 ±0.02	0.07 ±0.00	0.07 ±0.00

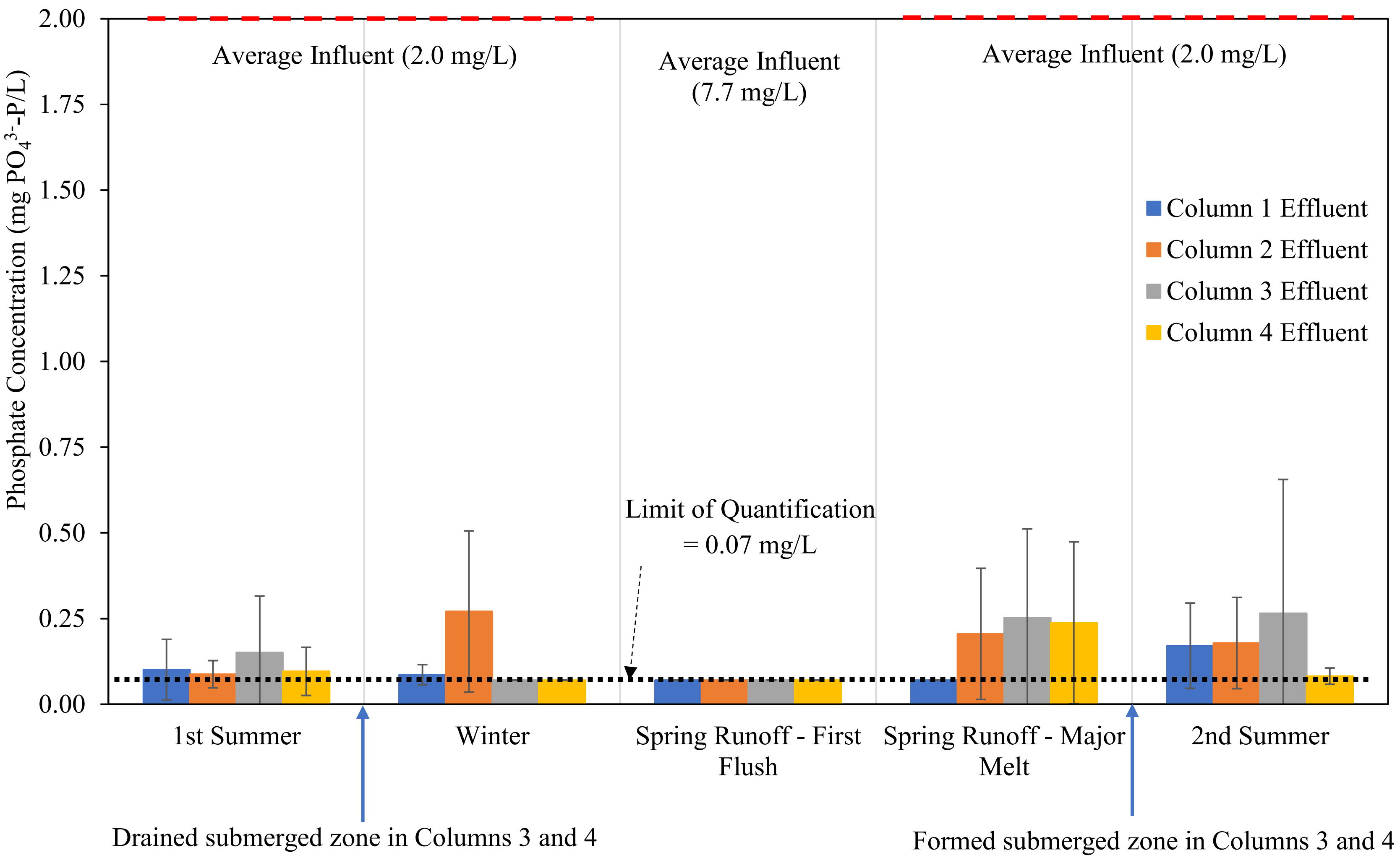


Figure 23: Phosphate removal during the 1st summer, winter, spring runoff, and 2nd summer operation.

Summer (1:2 Year Events)

By comparing effluent phosphate concentrations in columns 1 and 2 for the 1st and 2nd summer of operation, the difference in porosity between soil media "A" (i.e. loam) and soil media "B" (i.e. sandy loam), respectively does not hinder phosphate removal as effluent concentrations are considered acceptable at ≤ 0.18 mg/L. This research also shows that the vegetation used did not play an obvious factor in phosphate reduction; this is because healthy vegetation was present in each column during the 1st summer but did not grow back in the 2nd summer, yet phosphate reduction did not show a consistent increase or decrease between each column from 1st to 2nd summer. The fate of the vegetation will be discussed further in section 4.5.

Winter and Spring Runoff

During winter and spring runoff operation, all four columns underwent multiple periods of freezing at -20°C and thawing. Events were conducted at air temperatures between 1-3°C and infiltration rates were significantly slower during these events than during room temperature operation. However, all volumes applied ultimately infiltrated through each column within a few days without any overflow forming. During this period, average effluent concentrations in all columns remained similarly low as in summer temperatures at < 0.27 mg/L. This indicates that phosphate is being captured by the media via adsorption and/or precipitation mechanisms rather than biological degradation, which would likely be impacted by the cold temperatures.

Much like TSS, the ability to retain phosphate shortly after being frozen and at near freezing temperatures is a valuable feature. Bioretention systems implemented in Edmonton's climate could expect to still be functional for phosphate reduction during intermittent warming periods in winter and during spring runoff if air temperatures reach (1-3°C) and infiltration through the media is still occurring.

1:5 Year and 1:10 Year Events

The similarity between effluent concentrations for all the room temperature events is shown in Figure 24. Without the interference of temperature or high salt concentration effects, this data shows that both soil media "A" and "B", with and without a steel wool amendment are effective at removing phosphate from stormwater, even during larger volume, less frequent simulated storm events. Much like TSS, retaining phosphate during larger volume events could mean protection of downstream water quality during floods.

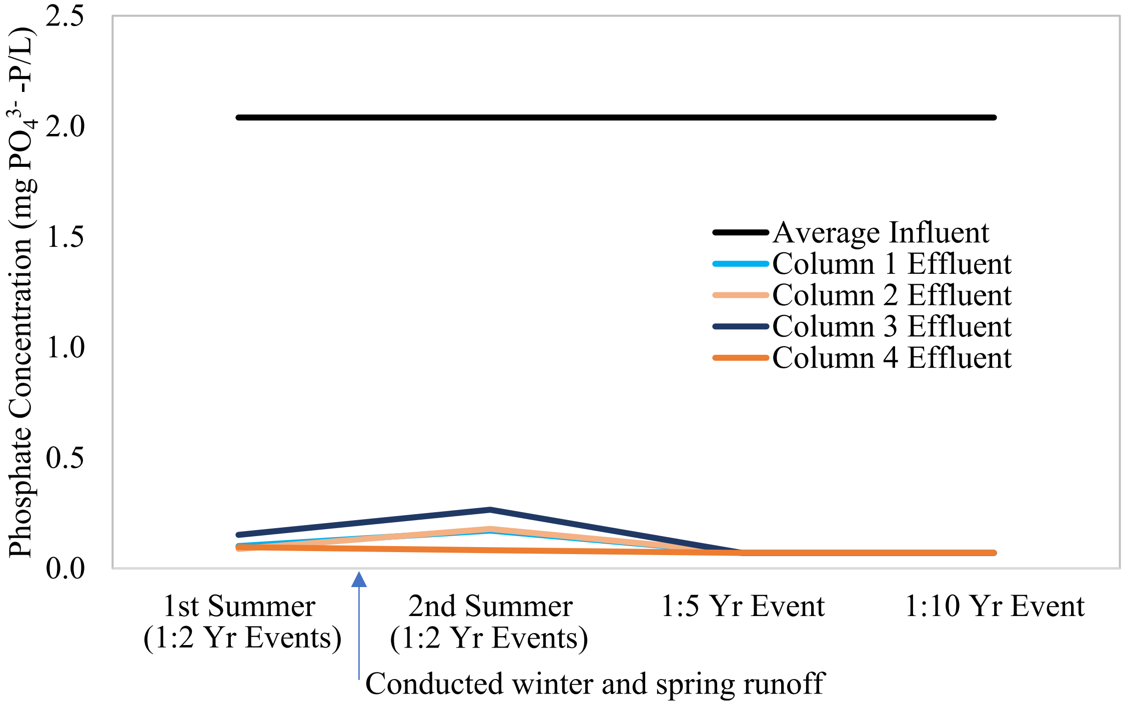


Figure 24: Phosphate removal during room temperature events.

Total phosphorus (TP) was also analyzed for select events, as seen in Figure 25. Ten events applied to columns 1 and 2 and seven events applied to columns 3 and 4 during the 1st summer were measured for TP. Columns 1 and 2 showed consistently low effluent concentrations of TP compared to influent levels, indicating acceptable TP removal. Columns 3 and 4 had slightly higher effluent concentrations, compared to columns 1 and 2, that decreased over time. The same trend does not exist in the phosphate data for this time period, as seen in Figure 56 in Appendix B. This indicates that the effluent phosphorus in columns 3 and 4 is not reactive phosphorus (orthophosphate) but is likely organic phosphorus, which could be a result of woodchips in the submerged zone releasing organic phosphorus that then has insufficient time to degrade into orthophosphate to be adsorbed or precipitated by the media.

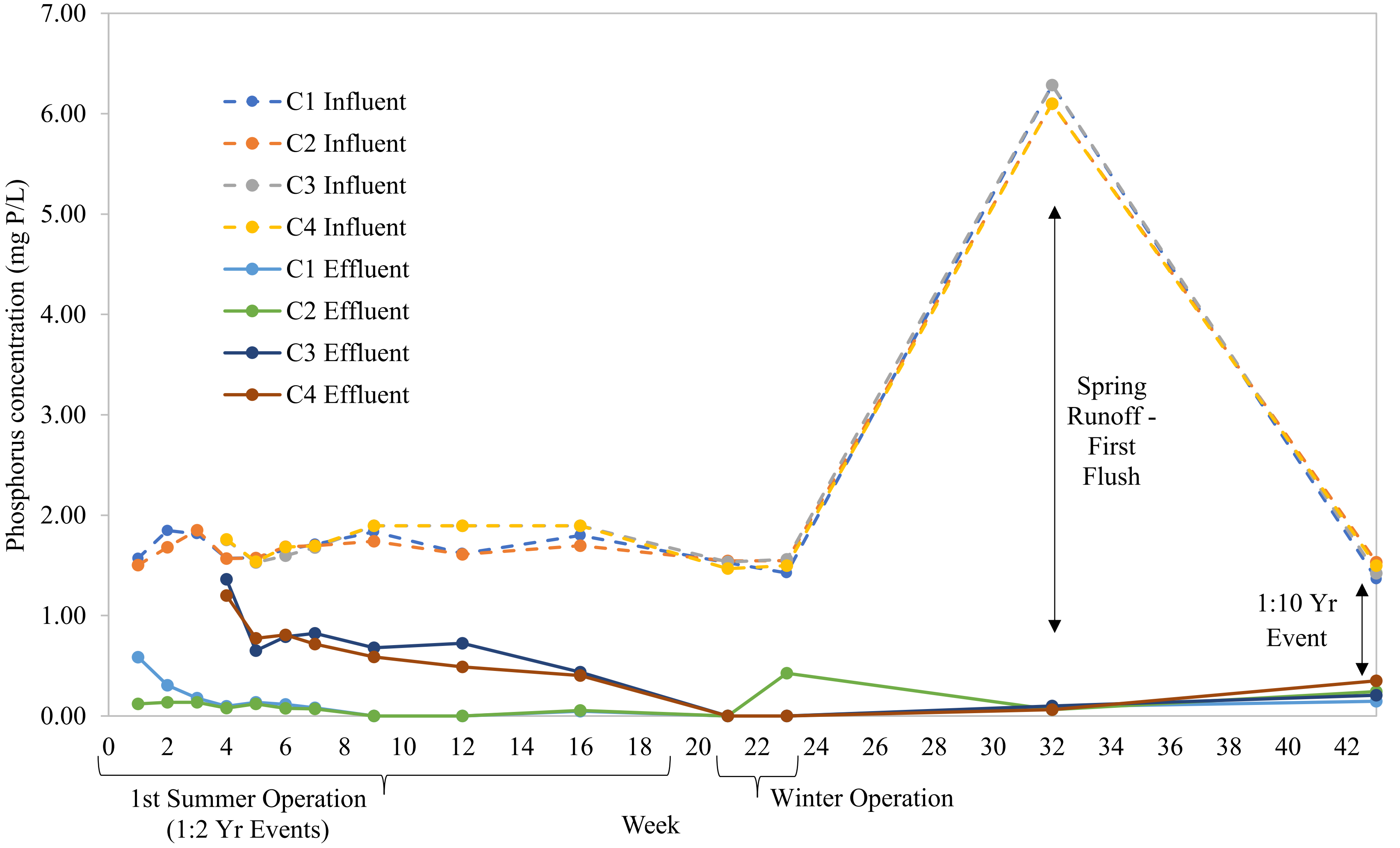


Figure 25: Total phosphorus concentration reduction during select events.

TP was also evaluated for two winter events, the spring runoff first flush event, and the 1:10 year, slightly larger event. These events showed similar TP concentrations reduced from the influent concentration for all columns, indicating acceptable phosphorus removal by all column configurations in this study. A beneficial data point to collect would have been the major melt of spring runoff to evaluate if the 4 times concentrated stormwater influent was as actually effectively reduced as indicated by the effluent concentration of the first flush spring runoff, or if there was a delay causing an elevated effluent phosphorus concentration during the major melt.

Table 13 shows the results from the leachate experiment, as described in section 3.2.3, conducted in the Erlenmeyer flasks in which the different media types were soaked in water which was then analyzed for various parameters. This data is valuable to show practically what is occurring as water infiltrates through the large columns. Table 14 shows the results from the soil analysis outsourced to Exova of Edmonton and indicates the maximum phosphorus that is in the media. From this information, the media can be ranked in terms of most likely to lead to phosphorus leaching to least likely: compost > woodchips > soil media "A" (i.e. loam) > soil media "B" (i.e. sandy loam).

Table 13: Phosphorus leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Phosphate (mg PO_4^{3-}-P/L)	0.07	0.07	33.40	7.12
Phosphate (mg PO_4^{3-}-P /kg)	1.44	1.45	667.99	142.39

Table 14: Phosphorus extracted from different media types.

Media	Soil Media "A"[a]	Soil Media "B" [a]	Compost [a]	Woodchips [a]	Media which experienced phosphorus leaching (Denich et al., 2013)
Available Phosphorus (mg P/kg)	16	14	2100	250	2235±728
Phosphorus via acid extraction (mg P/kg)	430	360	21000	520	

[a] as measured by Exova of Edmonton

Although compost has the most available phosphorus per mass of media, its placement at the top of the column allows for media below the compost layer to adsorb or precipitate phosphate and grow bacteria that will degrade organic phosphorus to orthophosphate for subsequent physical removal. This benefit of layering compost on the top of a bioretention soil column has also been observed for nitrate and phosphate removal in other research (Lei, 2018). Current LID design guidelines in Edmonton (CoE, 2014a) and numerous other cities recommend the use of compost to promote plant health or water holding capacity throughout the entire depth of the media; however, because compost acts as a fertilizer, it leaches phosphorus and nitrogen, not all of which can be taken up by plant roots. This research shows that compost placed as a surface layer only to the depth of current root growth will still have the capability of promoting plant health but will also have sufficient soil volume below the layer to capture phosphorus and nitrogen both physically and possibly, biologically. Also, by placing compost near the top of the bioretention cell, it can be more easily replenished through regular annual maintenance; thus, sparing quantities of compost can be applied to limit the potential for nutrient leaching while still ensuring vegetation has adequate access to nutrients.

Despite soil media “A”, B”, compost, and woodchips having considerable phosphorus available to leach and migrate from the bioretention columns, they also have high levels of aluminum and iron, as indicated in Table 15, which have a high affinity to precipitate phosphate. Once precipitated, the high percentage of negatively charged clay and silt particles and high cation exchange capacity (CEC), also shown in Table 15, work to adsorb the now positively charged phosphate and/or filter the newly formed particles, much like the TSS removal mechanism. This table also compares the soil characteristics in Denich et al.'s (2013) study which experienced significant phosphorus leaching from their bioretention columns. Although the aluminum, iron, and CEC values may be comparable to those of the media in this research, their media contained considerably higher levels of pre-existing phosphorus, as shown in Table 14.

Table 15: Bioretention media characteristics that act to remove phosphorus from stormwater as measured by Exova of Edmonton.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips	Media which experienced phosphorus leaching (Denich et al., 2013)
Aluminum (mg Al/kg)	5900	4370	9370	1150	5035
Iron (mg Fe/kg)	14100	7900	16300	1800	7215
Clay and Silt (% w/w)	49.2	32.8	-	-	8
CEC (meq/100 g)	16	12	25	56	21.9

The results of this research show that even phosphorus and organic matter bacterially decomposed into orthophosphate that leached from the media were well captured by the bioretention media. This research also did not show an obvious impact of the presence of steel wool in columns 3 and 4 enhancing phosphate removal, as was expected. The capacity of soil media "A", "B", compost and woodchips to retain phosphate appears to be sufficient for the time period of this research and steel wool did not appear to be needed yet. Perhaps in long term operation, once the soil media adsorption capacity is exhausted, the steel wool will extend the bioretention columns adsorption lifetime. Further experiments are required to determine the impact of steel wool. The submerged zone incorporated into the design of columns 3 and 4 may also have an unanticipated benefit in terms of phosphate capture as phosphate adsorbed to aluminum within the submerged zone is less susceptible to desorption under anoxic conditions (Palmer, 2012).

Although good removal of phosphate through all stages of operation and of total phosphorus during select events has been observed in this research, only 1.6 years of equivalent Edmonton precipitation volume was simulated. As phosphate removal is primarily a physical mechanism via adsorption and/or precipitation, there is a soil capacity that will eventually be reached. Because the large columns do not show a decline in phosphate removal over time, a small column adsorption experiment was conducted to determine the approximate phosphate removal capacity of the soil used in this study.

4.2.1 Small Column Adsorption Experiment

Two small columns were filled with soil media "A" (i.e. loam) and soil media "B" (i.e. sandy loam) to investigate their natural phosphate adsorption/precipitation capacity without the need for amendments such as steel wool or water treatment residual and without interferences from potential plant uptake or release during senescence. These amendments, used to improve phosphate removal, have been researched in detail previously (Erickson et al., 2007; Yan et al., 2017). Figure 26 shows the effluent concentration of phosphate out of each small column as a constant concentration of phosphate was pumped in at a constant flow rate.

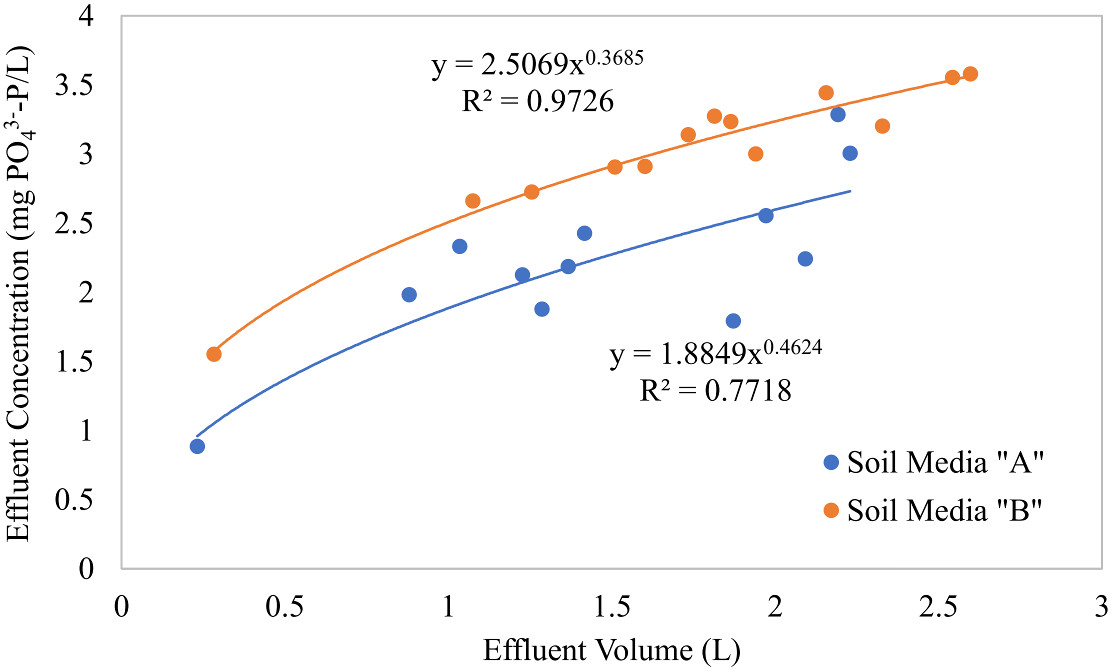


Figure 26: Phosphate adsorbed/precipitated by small soil columns.

From this data and the known influent concentrations, the adsorption capacity of each media can be calculated as follows:

Soil Media “A” Phosphate Adsorption Capacity

$$\text{Saturation point} = 3.14\ \text{mg PO}_4^{3-} - \text{P/L (influent concentration)} = 1.8849\text{x}^{0.4624}$$

$$\text{x} = 3.02\ \text{L}$$

$$\text{Amount of Phosphate Applied} = 3.14\ \text{mg PO}_4^{3-} - \text{P/L} \times 3.02\ \text{L} = 9.48\ \text{mg PO}_4^{3-} - \text{P}$$

$$\text{Amount of Phosphate in Effluent} = \int_{0\ \text{L}}^{3.02\ \text{L}} 1.8849\text{x}^{0.4624} = 6.49\ \text{mg PO}_4^{3-} - \text{P}$$

$$\text{Phosphate retained on soil} = \frac{(9.48 - 6.49)\ \text{mg PO}_4^{3-} - \text{P}}{0.0600013\ \text{kg soil}}$$

$$\text{Adsorption Capacity of } \textbf{Soil Media "A"} = \mathbf{49.83\ mg\ PO_4^{3-} - P/kg}$$

Soil Media “B” Phosphate Adsorption Capacity

$$\text{Saturation point} = 3.12\ \text{mg PO}_4^{3-} - \text{P/L (influent concentration)} = 2.5069\text{x}^{0.3685}$$

$$\text{x} = 1.81\ \text{L}$$

$$\text{Amount of Phosphate Applied} = 3.12\ \text{mg/L} \times 1.81\ \text{L} = 5.65\ \text{mg PO}_4^{3-} - \text{P}$$

$$\text{Amount of Phosphate in Effluent} = \int_{0\ \text{L}}^{1.81\ \text{L}} 2.5069\text{x}^{0.3685} = 4.13\ \text{mg PO}_4^{3-} - \text{P}$$

$$\text{Phosphate retained on soil} = \frac{(5.65 - 4.13)\ \text{mg PO}_4^{3-} - \text{P}}{0.0600008\ \text{kg soil}}$$

$$\text{Adsorption Capacity } \textbf{Soil Media "B"} = \mathbf{25.33\ mg\ PO_4^{3-} - P/kg}$$

This experiment used a power relationship to best fit the data obtained. Operation of the experiment did not continue until a plateau in the data was observed, as would be seen in a typical adsorption capacity experiment and would have been ideal. This was due to time constraints of the experiment and it was assumed that the curve would continue the same trend until a plateau was reached at the saturation point which was assumed to be when influent concentrations equal effluent concentrations. The initial period of expected near zero concentration in the effluent was also not observed due to the presence of phosphorus in the fresh media that was likely prone to leaching into the effluent.

Based on data obtained for the City of Edmonton (Yu, 2016), the highest concentration of total phosphorus found was in 2015 from roadway runoff and was 0.61 mg P/L. Using this information and the small column experiment results, the lifetime of the large columns used in this research to remove phosphate can be determined.

Assuming all of the 0.61 mg P/L is dissolved orthophosphate (which is the worst-case scenario as typically half of total phosphorus is particulate phosphorus and would be removed similarly to TSS via filtration), and assuming that Edmonton receives 0.477 m/year of precipitation, the large columns used in this research and filled with 87.5 L of only soil media "A" or only soil media "B" could last for 23.6 and 12.0 years, respectively. This estimate also assumes that the columns continue to collect runoff from 10 times the area of their surface and that the soil bulk density is 1600 kg/m^3. This estimate does not account for phosphorus uptake by plants or release of phosphorus during plant senescence or from leaching from the media itself (e.g. from compost). Both factors would have an impact on the lifetime of the soil adsorption capacity. The calculations are as follows:

$$\begin{aligned}\text{Influent} = {} & 0.61\,\text{mg PO}_4^{3-} - \text{P/L} \times 0.477\,\text{m/year} \times 10 \times \frac{\pi}{4}(0.36\text{m})^2 \times 1000\,\text{L/m}^3 \\ & = 296\,\text{mg PO}_4^{3-} - \text{P/year}\end{aligned}$$

$$\text{Mass of soil in large columns} = 1600\,\text{kg/m}^3 \times 0.86\text{m} \times \frac{\pi}{4}(0.36\text{m})^2 = 140\,\text{kg}$$

$$\text{Soil Media "A" Lifetime} = \frac{140\,\text{kg} \times 49.83\,\text{mg PO}_4^{3-} - \text{P/kg}}{296\,\text{mg PO}_4^{3-} - \text{P/year}} = 23.6\,\text{years}$$

$$\text{Soil Media "B" Lifetime} = \frac{140\,\text{kg} \times 25.33\,\text{mg PO}_4^{3-} - \text{P/kg}}{296\,\text{mg PO}_4^{3-} - \text{P/year}} = 12.0\,\text{years}$$

This same study prepared for the City of Edmonton (Yu, 2016) also estimated baseline city-wide annual total phosphorus loads, including runoff and combined sewer overflows, to be 40 tonnes/year. With this information and the small column experiment results, the area of Edmonton that would be required to have bioretention implemented to treat this annual loading of phosphorus can be calculated. The entire load will be assumed to be dissolved orthophosphate and treatment will occur in 1-meter deep bioretention systems that will last for 20 years. Thus, 0.05 meter of depth of media will be exhausted every year, assuming even distribution of stormwater infiltration into the media. The assumed area of Edmonton is 684 km^2 and the assumed soil bulk density is 1600 kg/m^3. By using soil media "A", 1.47% of Edmonton's surface area would be required to implement bioretention systems and infiltrate the total volume of rainfall; 2.89% of Edmonton's surface area would be required if soil media "B" is used. The calculations are as follows:

$$40\text{ tonnes/yr} \times \frac{1\text{x}10^9\text{ mg}}{1\text{ tonne}} = 4\text{x}10^{10}\text{ mg P/yr}$$

$$\text{Soil media "A" required to retain total mass} = \frac{4\text{x}10^{10}\text{ mg P/yr}}{49.83\text{ mg PO}_4^{3-} - \text{P/kg} \times 1600\text{ kg/m}^3}$$

$$= 501{,}706\text{ m}^3$$

$$\text{Soil media "B" required to retain total mass} = \frac{4\text{x}10^{10}\text{ mg P/yr}}{25.33\text{ mg PO}_4^{3-} - \text{P/kg} \times 1600\text{ kg/m}^3}$$

$$= 986{,}972\text{ m}^3$$

$$\text{\% of Edmonton's area requiring 1 m depth of Soil Media "A" bioretention systems}$$

$$= \frac{\frac{501{,}706\text{ m}^3}{0.05\text{ m}}}{6.84\text{x}10^8\text{ m}^2} \times 100 = \mathbf{1.47}\%$$

$$\text{\% of Edmonton's area requiring 1 m depth of Soil Media "B" bioretention systems}$$

$$= \frac{\frac{986{,}972\text{ m}^3}{0.05\text{ m}}}{6.84\text{x}10^8\text{ m}^2} \times 100 = \mathbf{2.89}\%$$

4.3 Nitrogen

This research focuses on the ammonium and nitrate species of nitrogen because ammonia is toxic to fish and nitrate is a very mobile anion through soil typically. Nitrate is also the bioavailable form of nitrogen making it problematic when in excess quantities in stormwater runoff by leading to the eutrophication of surface waters. Total nitrogen was also measured for select events.

4.3.1 Ammonium

Columns 1 and 2, which contain soil media "A" (i.e. loam) and soil media "B" (i.e. sandy loam), respectively, reduce the concentration of ammonium in all stages of operation acceptably by > 80% to effluent concentrations < 0.5 mg/L, as shown in Table 16 and Table 17. However, by only considering summer and winter operation and the 1:5 year and 1:10 year events, concentration reduction is ≥ 95%. This discrepancy was caused by the high concentrations applied during the first flush of spring runoff having an impact on ammonium reduction during the major melt phase. Ammonium was also removed through columns 3 and 4 (i.e. soil media "A" and "B", respectively, with denitrification enhancement amendment) throughout all stages of operation, but percent concentration reduction was much lower and more variable than in columns 1 and 2. Concentration reduction ranged on average from 10.6 to 88.8% for columns 3 and 4 and had average effluent concentrations as high as 1.84 mg/L.

Table 16: Average ammonium percent concentration reduction by all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (%)	Winter (%)	Spring Runoff – First Flush (%)	Spring Runoff – Major Melt (%)	2nd Summer (1:2 year) (%)	1:5 Year Event (%)	1:10 Year Event (%)
Column 1	98.3 ±3.1	95.0 ±2.3	99.4	83.2 ±2.8	95.5 ±1.8	95.4 ±0.6	96.0 ±0.5
Column 2	98.9 ±1.1	97.7 ±2.5	99.8	94.9 ±0.9	97.8 ±1.2	97.2 ±0.0	98.0 ±0.8
Column 3	72.4 ±23.4	52.7 ±20.2	84.8	21.1 ±10.5	63.5 ±12.3	41.7 ±0.9	43.0 ±3.4
Column 4	70.7 ±22.5	70.6 ±28.1	88.8	56.2 ±1.0	82.0 ±2.8	75.2 ±0.4	70.8 ±1.1

Table 17: Average effluent ammonium (as N) concentration of all columns throughout all stages of operation.

Column	1st Summer (1:2 year) (mg/L)	Winter (mg/L)	Spring Runoff – First Flush (mg/L)	Spring Runoff – Major Melt (mg/L)	2nd Summer (1:2 year) (mg/L)	1:5 Year Event (mg/L)	1:10 Year Event (mg/L)
Column 1	0.04 ±0.08	0.11 ±0.04	0.05	0.36 ±0.09	0.10 ±0.04	0.11 ±0.00	0.10 ±0.01
Column 2	0.03 ±0.03	0.05 ±0.05	0.02	0.11 ±0.02	0.05 ±0.03	0.06 ±0.00	0.05 ±0.00
Column 3	0.61 ±0.51	1.03 ±0.42	1.25	1.68 ±0.16	0.79 ±0.25	1.35 ±0.06	1.33 ±0.01
Column 4	0.63 ±0.45	0.65 ±0.68	0.94	0.95 ±0.01	0.39 ±0.05	0.62 ±0.04	0.68 ±0.00

Graphical representation of ammonium removal is shown in Figure 27. The complete data set based on event can be found in Appendix B (Figure 59, Figure 60, and Figure 61).

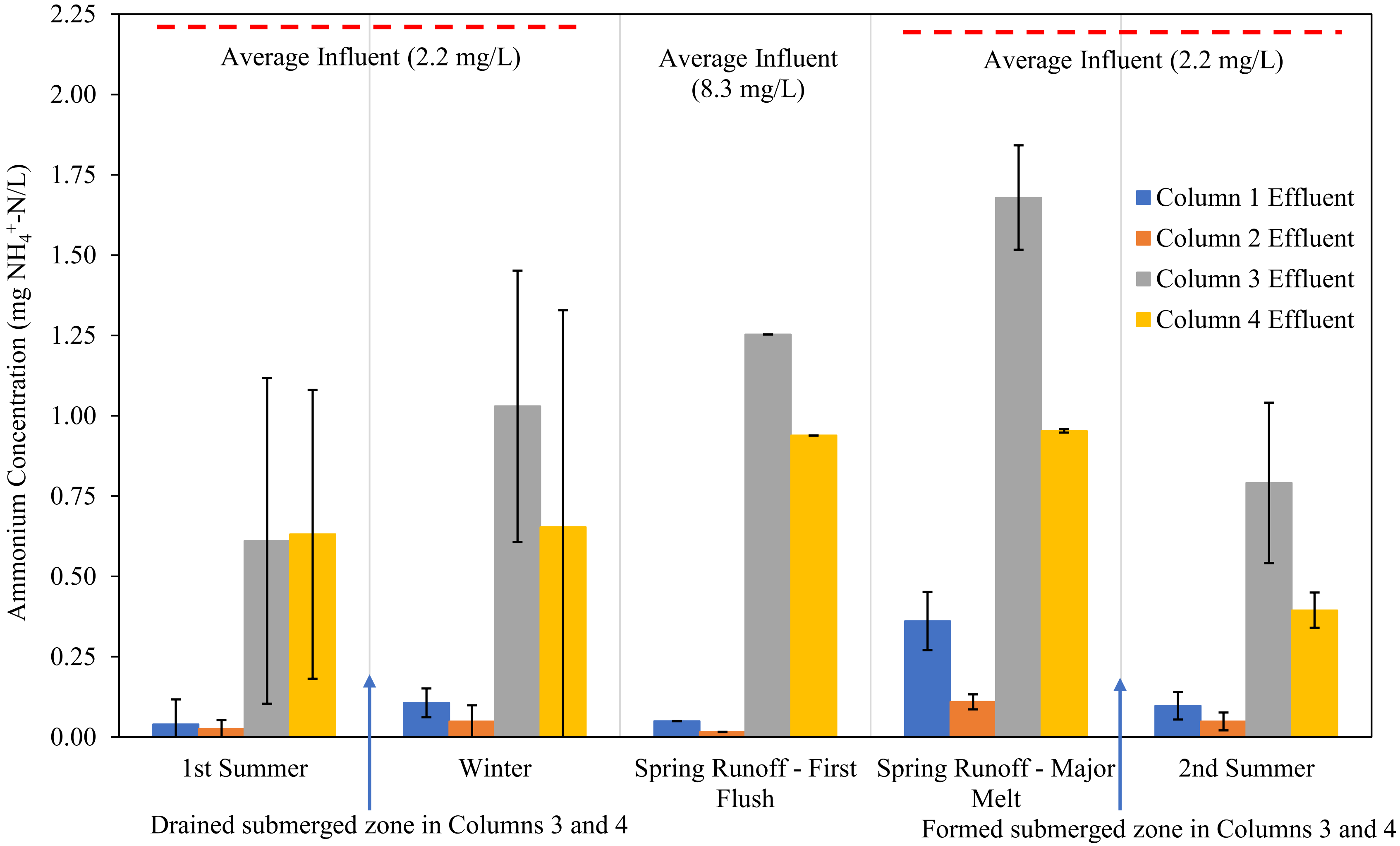


Figure 27: Ammonium removal during the 1st summer, winter, spring runoff, and 2nd summer operation.

Summer (1:2 Year Events)

By comparing effluent ammonium concentrations in columns 1 and 2 for the 1st and 2nd summer of operation, the difference in porosity between soil media "A" (i.e. loam) and soil media "B" (i.e. sandy loam), respectively does not hinder ammonium reduction as effluent concentrations are considered acceptable at ≤ 0.14 mg/L. While columns 3 and 4 still remove ammonium, their percent concentration reduction is on average 26.2% worse for column 3 and 27.9% worse for column 4 in 1st summer, and 27.9% worse for column 3 and 14.6% worse for column 4 in 2nd summer, as compared to the average removal by columns 1 and 2. The higher effluent concentration in column 3 in the 2nd summer as compared to the 1st summer may be due to an increase in infiltration rate from 1.6 to 6.1 cm/hr (likely caused by the freeze-thaw cycle expanding media pore spaces (Li, 2018)) leading to shorter contact time between the influent ammonium and soil for adsorption to occur. Conversely, the lower effluent concentration in column 4 in the 2nd summer as compared to the 1st summer may be due to a decrease in infiltration rate from 11.6 to 9.7 cm/hr (likely caused by the snowmelt compacting the pore spaces (Li, 2018)) increasing the contact time for ammonium adsorption. The higher sand content in column 4 allowed for greater compaction of the pore spaces as compared to column 3.

Winter and Spring Runoff

During winter and spring runoff operation, all four columns underwent multiple periods of freezing at -20°C and thawing. Events were conducted at air temperatures between 1-3°C and infiltration rates were significantly slower during these events than during room temperature operation. However, all volumes applied ultimately infiltrated through each column within a few days without any overflow forming. During this period, effluent concentrations in columns 1 and 2 remained similarly low as in summer temperatures at ≤ 0.14 mg/L, except for column 1 during the major melt of spring runoff, in which effluent concentrations reached as high as 0.45 mg/L. This is likely due to the higher average influent of 8.3 mg/L being applied during the first flush of spring runoff and being slightly delayed in its migration from column 1. Ammonium reduction was maintained in columns 1 and 2 to nearly the same level as in summer operation during cold temperatures (i.e. 1-

3°C) very shortly after the soil column was frozen and subsequently thawed; therefore, the dominant, short term ammonium removal mechanism is physical adsorption of positive ammonium ions to negatively charged soil particles. Biological nitrification by nitrifying bacteria of ammonium to nitrite and then nitrate is also possible as this process has been observed by other research at temperatures as low as 2°C (Blecken et al., 2010), but their columns were not frozen at -20°C only 1-5 days prior to stormwater application, as in this research. At -20°C, nitrifying bacteria will go dormant and will need time to rebound to initial performance.

Although not evidently a dominant process, nitrification may still be occurring during room temperature operation as a slower process over the intermittent drying period between events (Stefanakis et al., 2014). As will be seen in section 4.3.2, nitrate is leached (i.e. more nitrate is found in the effluent than in the influent) in all situations in which a submerged zone is not present; this may be from a number of sources, one of which being nitrification of ammonium. During the event, ammonium is quickly sorbed to the soil media; once most of the water drains or evaporates from the soil, nitrifying bacteria have access to molecular oxygen and carry out the process of consuming ammonium sorbed to the soil particles and ultimately producing nitrate; this consequentially frees ammonium adsorption sites and regenerates the media to enable further ammonium adsorption.

This process could be evident by the increased effluent ammonium concentrations in columns 3 and 4 in winter and spring runoff as compared to summer operation. Reduced nitrification caused by low temperatures during this period could be leading to less conversion of sorbed ammonium to nitrate through nitrification, thus providing more ammonium available to desorb and migrate from the soil into the effluent. The higher sodium chloride concentration applied in winter and spring runoff may also be leading to higher effluent ammonium concentrations in columns 3 and 4 in winter and spring runoff as compared to summer as the sodium acts as an ion exchanger to regenerate the media (Wasielewski et al., 2018). As this same increase in ammonium effluent concentration is not also consistently visible in columns 1 and 2 when sodium chloride concentrations increased, perhaps the greater volume of soil capable of nitrification (due to lack of an anoxic zone), allowed for more conversion of ammonium to nitrate during summer operation and thus, less available for subsequent desorption during winter. Another possible mechanism for ammonium reduction in all columns may be volatilization of ammonium to ammonia (Wang et al., 2015), however, without a nitrogen mass balance and soil coring, this would be difficult to definitively determine.

Much like TSS and phosphate, the ability to retain ammonium shortly after being frozen and at near freezing temperatures is a valuable feature as bioretention system in climates like Edmonton's could still expect to experience ammonium capture during intermittent warming periods in winter and during spring runoff if air temperatures reach (1-3°C) and infiltration through the media is still occurring.

1:5 Year and 1:10 Year Events

The similarity between column 1 and column 2 and the change in columns 3 and 4 effluent ammonium concentrations for all room temperature events are shown in Figure 28. Without the presence of the denitrification layer (i.e. anoxic zone with woodchips for supplemental carbon), the data shows that both soil media "A" and "B" are affective at capturing ammonium from influent stormwater, even during the single 1:5 year and single 1:10 year, larger volume events. This capability could potentially protect downstream waters from water quality degradation caused by the inflow of excess ammonia during floods if at least the first flush is captured and treated.

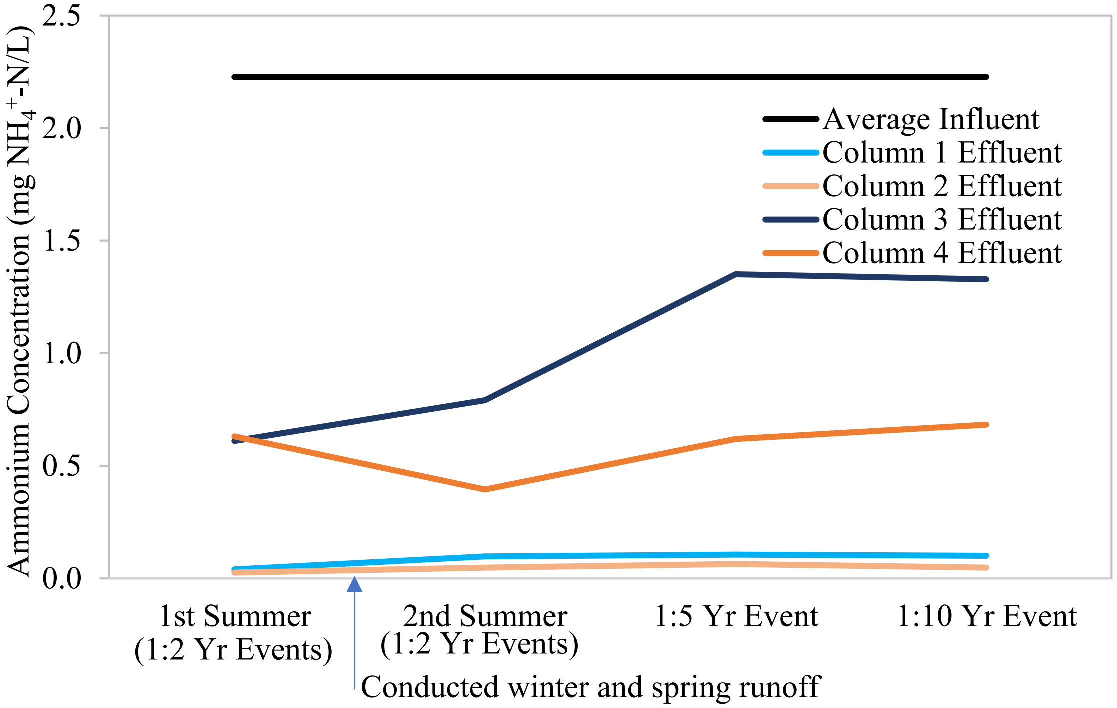


Figure 28: Ammonium removal during room temperature events.

The results for columns 3 and 4 show that if denitrification is the goal of bioretention implementation in the field and woodchips are used for the supplemental carbon source, then reduced ammonium capture is the tradeoff; this impact is worsened by larger volume events, but up to a certain level. The effluent concentrations may have increased for the larger volume events compared to the 1:2 year events, but they remained similar between the 1:5 year and 1:10 year event for columns 3 and 4.

Based on the above analysis on the difference between ammonium reduction between the columns without ground woodchips and a submerged zone (i.e. columns 1 and 2) and columns with ground woodchips and a submerged zone (i.e. columns 3 and 4), the dominating, short term ammonium reduction process is physical adsorption. Therefore, the reduced performance of columns 3 and 4 as compared to columns 1 and 2 is likely not due to the presence of the submerged zone decreasing the volume of aerobic soil available to carry out nitrification; more likely, the higher effluent concentrations in columns 3 and 4 as compared to columns 1 and 2 are due to the presence of woodchips within the submerged zone. This is also likely because draining the submerged zone for winter and spring runoff operation did not enhance ammonium removal.

Table 18 shows the results from the leachate experiment conducted in the Erlenmeyer flasks in which the different media types were soaked in water which was then analyzed for various parameters. This data is valuable to show practically what is occurring as water infiltrates through the large columns. Table 19 shows the maximum possible ammonium, nitrate, and total nitrogen available in the fresh media used in this research. Although compost has the highest nitrogen levels compared to the other media, its placement at the top of the column allows for the most contact time in the media below for physical and biological treatment. Woodchips may have the lowest levels of nitrogen available to leach, but due to their placement in the lowest soil layer (i.e. the submerged zone), any ammonia leached from woodchips may be physically adsorbed to the media but will not experience aerobic conditions for nitrification to convert the ammonium to nitrate. This is also the case for soil media "A" or "B" that are in the submerged zone and have even higher ammonia levels than in woodchips that may leach from the system. Without aerobic conditions that may regenerate the adsorption media, the soil in the submerged zone will ultimately reach its adsorption capacity and be unable to sorb more ammonium and be prone to desorption, especially in the presence of higher salt concentrations.

Table 18: Nitrogen leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Ammonium (mg NH_4^+-N/L)	0.24	0.13	0.75	0.07
Ammonium (mg NH_4^+-N/kg)	4.72	2.54	14.97	1.39
Nitrate (mg NO_3^--N/L)	2.79	2.13	218.12	0.05
Nitrate (mg NO_3^--N/kg)	55.87	42.56	4362.14	1.00
Total nitrogen (mg N/L)	4.05	3.05	193.31	1.10
Total nitrogen (mg N/kg)	80.99	61.05	3866.03	21.97

Table 19: Nitrogen in different media types as measured by Exova of Edmonton.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Ammonium (mg NH_4^+-N/kg)	5.80	2.90	42.60	9.50
Nitrate (mg NO_3^--N/kg)	53.00	23.00	3700.00	<3

Not only do woodchips and soil media "A" and "B" contain ammonium in the submerged zone that could leach from the system, but they may also contain organic nitrogen which, through biological conversion known as ammonification, organic nitrogen is converted to ammonia through hydrolysis; this process can occur in both aerobic and anaerobic conditions, such as in the submerged zone (Stefanakis et al., 2014).

4.3.2 Nitrate

An anoxic zone (i.e. submerged zone) and supplemental carbon (i.e. woodchips) are required to reduce nitrate via denitrification, as indicated by columns 1 and 2 consistently exporting nitrate and columns 3 and 4 consistently reducing nitrate when a submerged zone is present. Table 20 shows the percent concentration reduction of nitrate by columns 3 and 4 only while a submerged zone is formed (i.e. during 1st and 2nd summer and the 1:5 and 1:10 year events). Table 21 shows the effluent concentrations for all columns during the same period of operation.

Table 20:Average nitrate percent concentration reduction by columns 3 and 4 during operation in which the submerged zone is present. Omitted weeks of maturation in 1st and 2nd summer (i.e. week 4, 5, 6, 37, and 38).

Column	1st Summer (1:2 year) (%)	2nd Summer (1:2 year) (%)	1:5 Year Event (%)	1:10 Year Event (%)
Column 3	93.7 ±5.5	72.4 ±9.7	67.6	72.4
Column 4	65.2 ±44.4	81.1 ±11.8	59.8	60.8

Table 21: Average effluent nitrate (as N) concentration of all columns during operation in which the submerged zone is present. Omitted weeks of maturation in 1st and 2nd summer (i.e. weeks 1, 2, 3 (columns 1 and 2), weeks 4, 5, 6 (columns 3 and 4), and weeks 37

Column	1st Summer (1:2 year) (mg/L)	2nd Summer (1:2 year) (mg/L)	1:5 Year Event (mg/L)	1:10 Year Event (mg/L)
Column 1	4.03 ±2.03	2.64 ±0.37	2.81 ±0.24	2.57 ±0.02
Column 2	4.33 ±1.80	4.46 ±0.45	3.39 ±0.01	2.98 ±0.01
Column 3	0.11 ±0.10	0.55 ±0.23	0.68 ±0.02	0.65 ±0.01
Column 4	0.64 ±0.80	0.40 ±0.29	0.85 ±0.01	0.90 ±0.01

During the 1st summer of operation, all columns experienced a period of initial leaching in which effluent nitrate concentrations were as high as 150 mg NO_3^--N/L. After the first three events applied to each column, these high concentrations dropped and stabilized. Therefore, these first three data points were omitted from the data in Table 20 and Table 21 and the following analysis to discuss the systems once matured. Similarly, 2nd summer experienced two initial weeks of nitrate leaching in columns 3 and 4 in which time the denitrifying bacteria came out of dormancy and rebounded to almost initial performance. Therefore, these first two data points were also omitted from Table 20 and Table 21 and the following analysis.

While the columns without denitrification (i.e. columns 1 and 2) export nitrate to sometimes double the influent concentrations, columns 3 and 4 carry out denitrification and reduce concentrations by ≥ 59.8% on average while an anoxic zone is present. However, during the 1:2 year events conducted in summer operation, in which bioretention is currently designed to manage, average nitrate concentration reduction in the presence of an anoxic zone was ≥ 65.2%. Graphical representation of nitrate concentration changes is shown in Figure 29. The complete data set based on event can be found in Appendix B (Figure 62, Figure 63, Figure 64, Figure 65, and Figure 66).

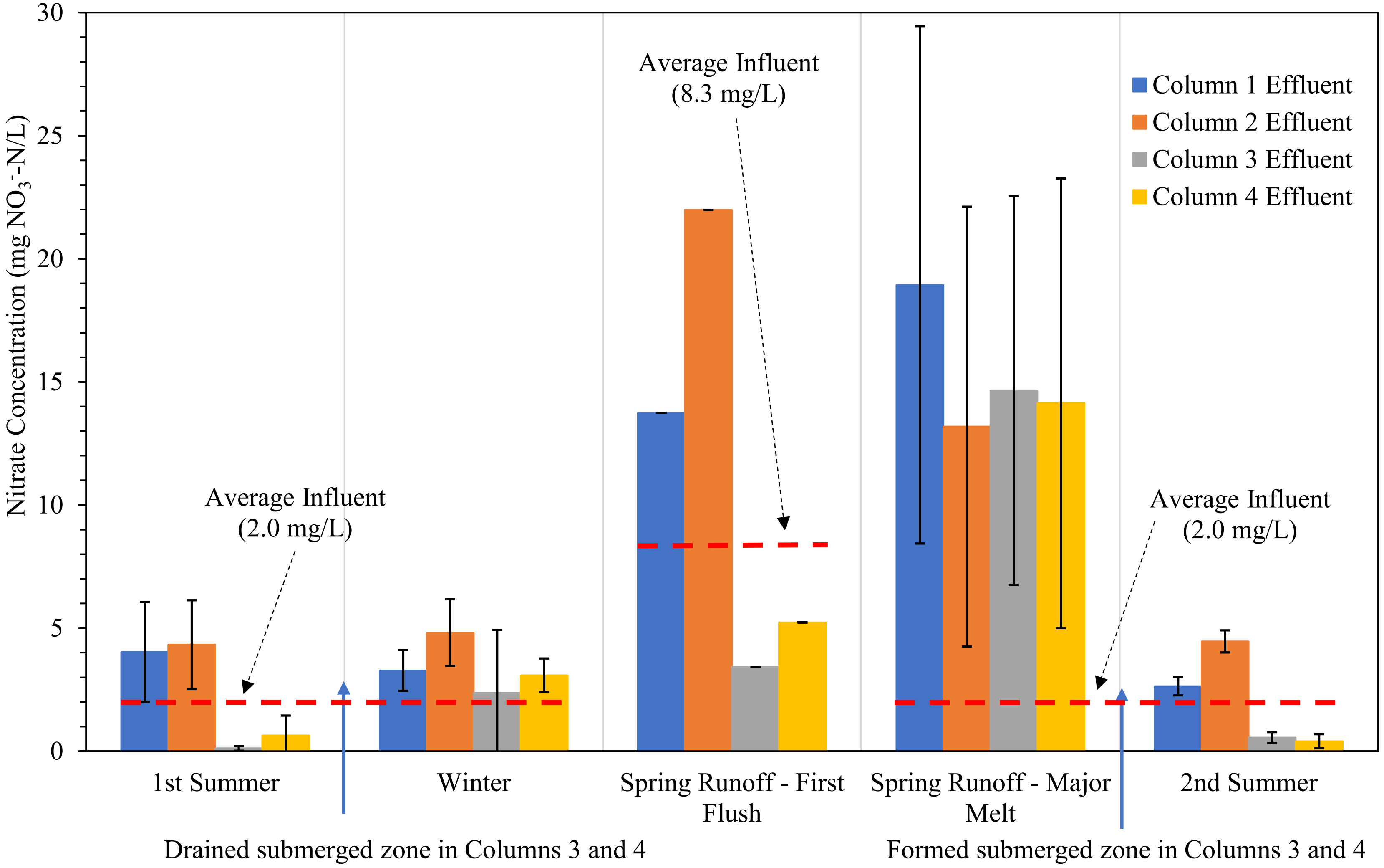


Figure 29: Nitrate removal and leaching during the 1st summer, winter, spring runoff, and 2nd summer operation.

Summer (1:2 Year Events)

Columns 1 and 2, which contain soil media “A” (i.e. loam) and soil media “B” (i.e. sandy loam), respectively, export nitrate in concentrations ranging between averages of 2.64 and 4.46 mg/L during summer operation. Columns 3 and 4 (i.e. loam and sandy loam soil, respectively, with the denitrification layer) reduce average nitrate concentrations to < 0.64 mg/L. By comparing effluent nitrate concentrations in columns 3 and 4 for the 1st and 2nd summer of operation, the difference in porosity between soil media “A” (i.e. loam) and soil media “B” (i.e. sandy loam), respectively does not hinder nitrate reduction as concentration reductions are considered acceptable at ≥ 65.2% and do not show either column 3 or 4 performing consistently better than the other.

Higher nitrate reduction of 82% has been observed in another study (Peterson et al., 2015) that used a submerged zone, hardwood woodchips (i.e. Willow Oak), and a 0.8 day retention time; this research utilized softwood woodchips (i.e. Cedar) for a supplemental carbon source and approximately 1 week retention time. Although the performance of columns 3 and 4 in this research is acceptable as most traditionally designed bioretention columns (i.e. no submerged zone) export high levels of nitrate, further analysis would be useful to determine if a different type of supplemental carbon or varying contact time could enhance nitrate reduction in the media designed for use in Edmonton bioretention systems. Regardless, this research shows that conditions that promote denitrification are a requirement to obtain nitrate reduction rather than nitrate leaching. The presence of nitrate in bioretention media is from both soil media “A”, “B”, and compost, as will be seen in section 4.8, which are unavoidable components in bioretention design. Therefore, if nitrate is of concern at a specific site, denitrification conditions must be incorporated into the design to prevent nitrate leaching into the effluent.

This research also shows that the vegetation used did not play a visible role in nitrate reduction; this is because healthy vegetation was present in each column during the 1st summer but did not grow back in the 2nd summer, yet effluent nitrate concentrations did not show a consistent increase or decrease between columns from 1st to 2nd summer operation for all four columns. The fate of the vegetation will be discussed further in section 4.5.

Winter and Spring Runoff

Before winter and spring runoff, the submerged zone of columns 3 and 4 were drained and effluent was then allowed to flow out freely through the lowest effluent pipe. After winter and spring runoff the bottom effluent pipe valve was closed and the submerged zone was reformed. During winter and spring runoff operation, all four columns underwent multiple periods of freezing at -20°C and thawing. Events were conducted at air temperatures between 1-3°C and infiltration rates were significantly slower during these events than during room temperature operation. However, all volumes applied ultimately infiltrated through each column within a few days without any overflow forming. Without denitrification occurring, nitrate leached from columns 3 and 4 at nearly the same concentrations as in columns 1 and 2 during winter operation.

In the first flush of spring operation, nitrate was reduced in columns 3 and 4 by 58.2% and 37%, respectively, but this was likely just a delayed reaction to the 4 times concentrated stormwater applied because the effluent concentrations for columns 3 and 4 during the major melt phase are approximately seven times that of the influent.

1:5 Year and 1:10 Year Events

Figure 30 shows the change in effluent concentration as compared to an average influent concentration for all columns during room temperature events. Although effluent concentrations in columns 3 and 4 increase slightly during the larger volume (a single 1:5 year and a single 1:10 year) events conducted, concentration reduction is still > 59.8% and average concentrations are < 0.9 mg/L. This slight change may be due to the decreased retention time allowed for denitrification in the submerged zone; the larger volumes applied would result in less of the influent volume remaining in the submerged zone and more influent volume leaving the column during that event, as compared to a 1:2 year event. The submerged layer holds approximately 9.5 L of water. During a 1:2 year event, that 9.5 L already in the submerged zone is pushed out the effluent and followed by another approximately 13.5 L of fresh influent being applied at that time. The remaining 9.5 L of the current influent then remains in the submerged zone and has approximately 1 week of retention time to undergo denitrification. During a 1:5 and 1:10 year event, the fresh influent volume exiting the column via the effluent pipes and following the existing submerged zone would be greater than in a 1:2 year event and would therefore have less time for denitrification and bring the effluent concentration closer to the influent concentration of 2.0 mg/L. Alternatively, effluent concentrations tend to decrease in columns 1 and 2 for the 1:5 and 1:10 year events. This is may be due to dilution caused by the higher volume of effluent similarly bringing the effluent concentration closer to 2.0 mg/L.

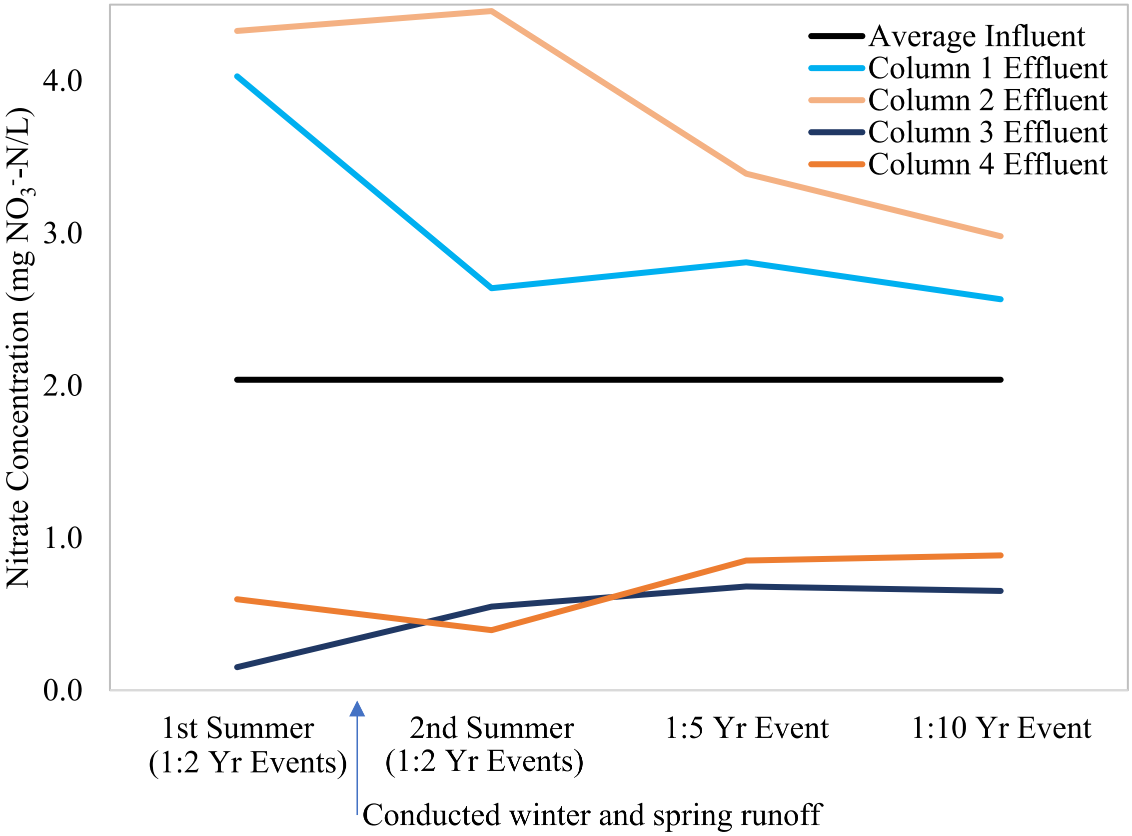


Figure 30: Nitrate removal and leaching during room temperature events.

These results also show that denitrification in columns 3 and 4 occur relatively quickly as the fresh influent volume (i.e. the 13.5 L mentioned above) applied during a 1:2 year event and is not retained for 1 week exits the columns in under 25 hours and still experiences nitrate reduction, as shown in Figure 31.

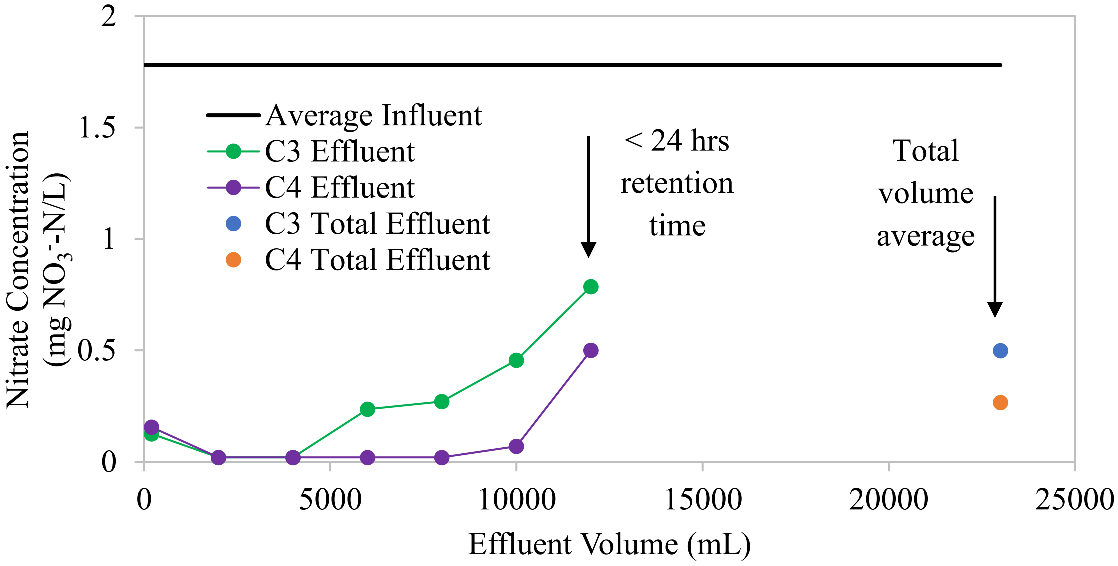


Figure 31: Volume interval sample analysis of nitrate in columns 3 and 4.

Nitrate is exported from every column when denitrifying conditions are not present. There are 3 sources of this nitrate leachate:

- Influent nitrate,
- Leached from the media itself (leachate potential can be seen in Table 22 and Table 23 (repeated from section 4.3.1)), and
- Ammonium nitrified to nitrate.

As explained in section 4.3.1, during an event, ammonium is quickly sorbed to the soil media; once most of the water drains or evaporates from the soil, nitrifying bacteria have access to molecular oxygen and carry out the process of consuming ammonium sorbed to the soil particles and ultimately producing nitrate; this consequentially frees ammonium adsorption sites and regenerates the media to enable further ammonium adsorption and subsequent nitrification.

In the absence of a submerged zone and sufficient carbon, nitrate will leach from bioretention systems designed with the media in this research, especially when designed with the use of compost; as seen in Table 22 and Table 23, compost has 77-101 times the level of nitrate available to leach compared to soil media “A” and “B”. Careful selection and placement of compost is necessary to minimize nitrate leachate in the field. This research used columns 0.36 m in diameter with an entire surface layer of compost; as the vegetation used in this research filled almost the whole diameter of the column, this amount of compost was necessary. In the field, it should be considered to put a carefully calculated quantity of compost either only on the surface (like in this research) or only in and surrounding vegetation root balls. This will heavily depend on the vegetation design.

As will be seen in section 4.5, the vegetation in this research did not survive winter and spring runoff operation; therefore, the above discussed compost application recommendation needs further experimental confirmation. However, based on the presence of phosphate and nitrate in the effluent of each column (without an anoxic zone), the lack of plant regrowth is unlikely the result of insufficient nutrients.

Table 22: Nitrate leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Nitrate ($mg\ NO_3^- - N/L$)	2.79	2.13	218.12	0.05
Nitrate ($mg\ NO_3^- - N/kg$)	55.87	42.56	4362.14	1.00

Table 23: Nitrate in different media types as measured by Exova of Edmonton.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Nitrate ($mg\ NO_3^- - N/kg$)	53.00	23.00	3700.00	<3

4.3.3 Total Nitrogen

Total nitrogen (TN) was also analyzed for select events and results can be found in Figure 32 and Figure 33. Measurements obtained for TN consisted of the following: ten events applied to columns 1 and 2 and seven events applied to columns 3 and 4 during the 1st summer, two winter events, the spring runoff first flush event, and the 1:10 year, slightly larger event.

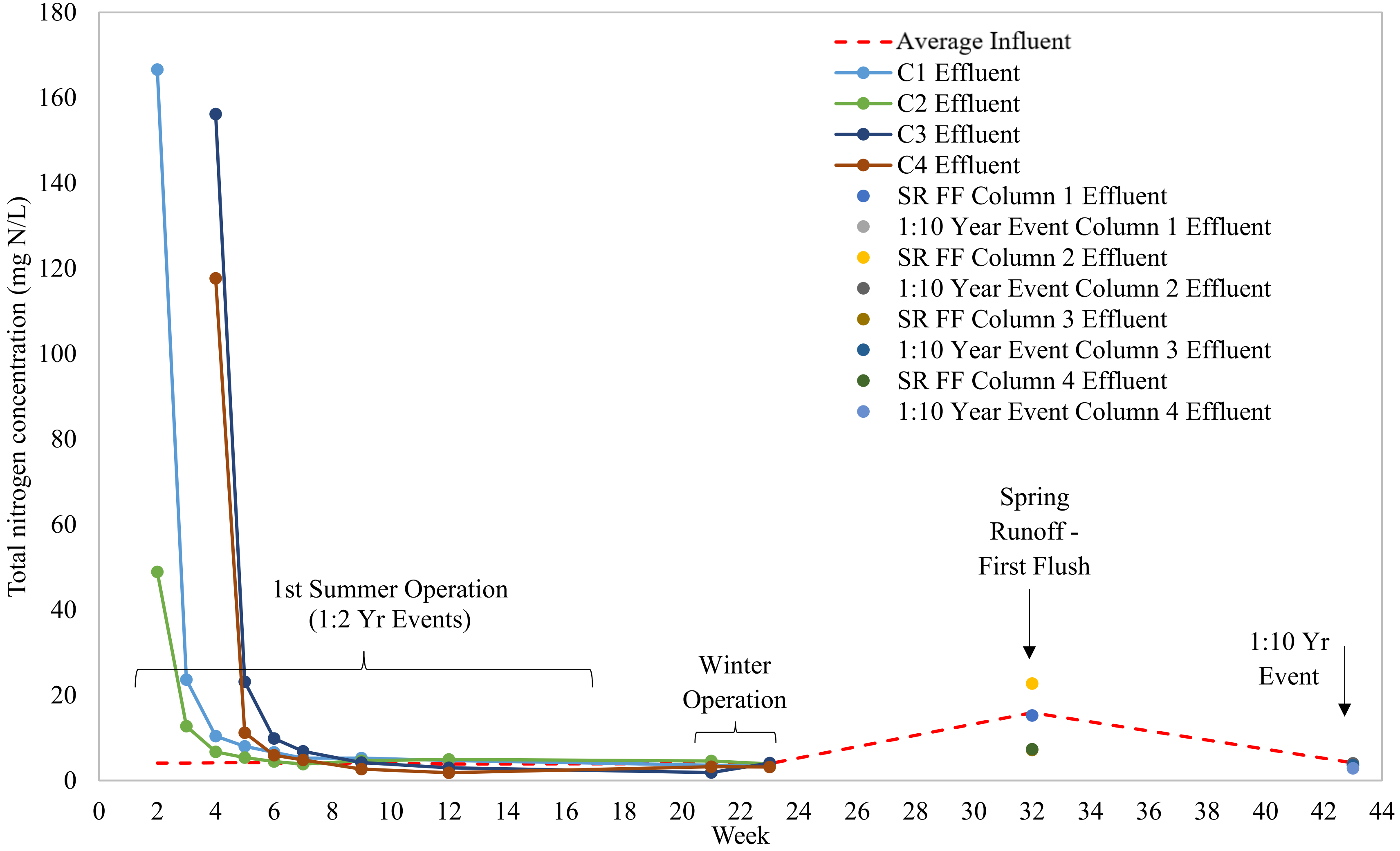


Figure 32: Total nitrogen concentration change during select events.

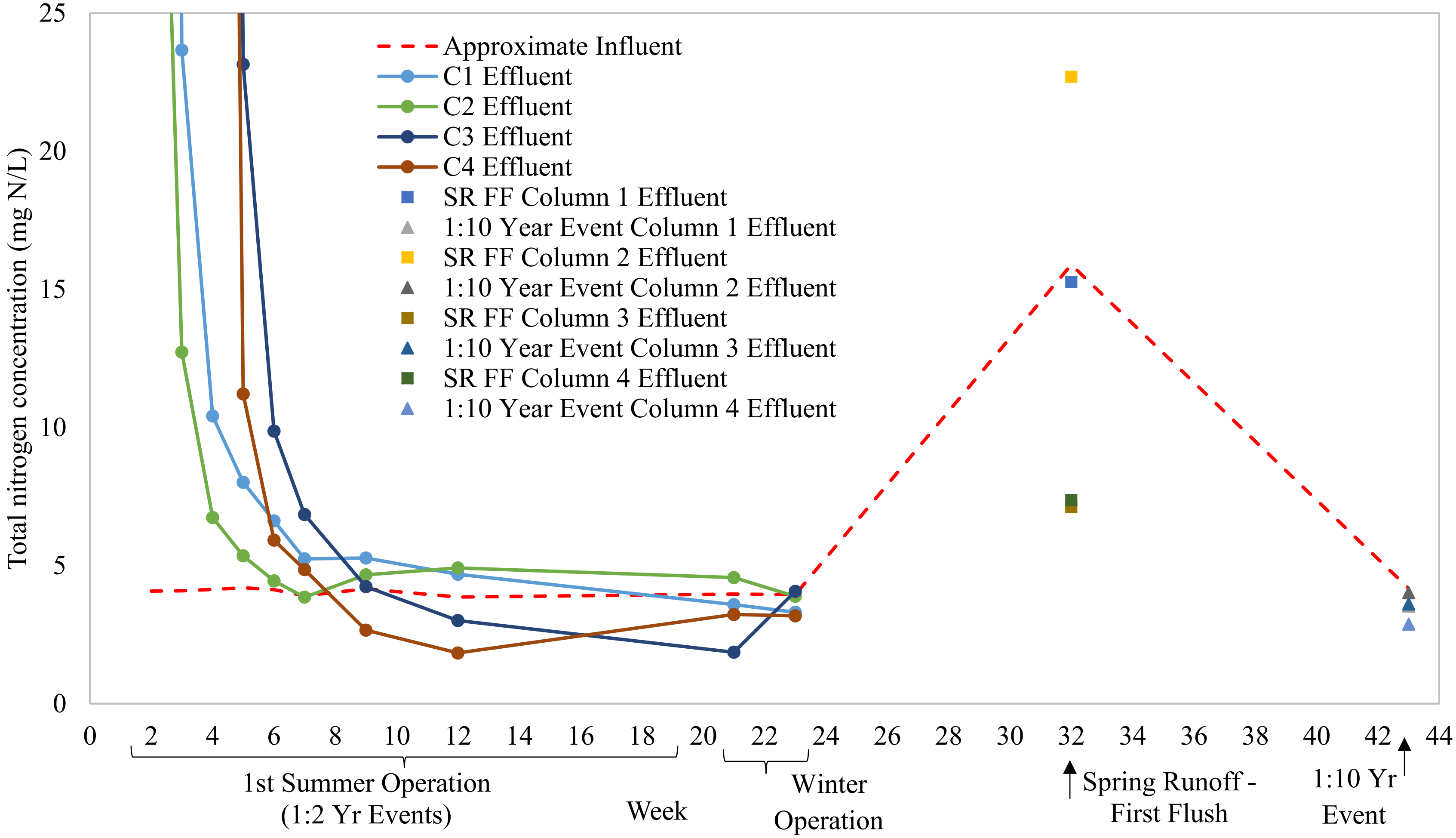


Figure 33: Total nitrogen concentration change during select events zoomed in.

Initial effluent TN concentrations (i.e. for weeks 2-3 for columns 1 and 2 and for weeks 4-5 for columns 3 and 4) show considerable leaching with concentrations ranging from 49 to 167 mg/L. The average influent concentration approximately meets the target value at 4.1 mg/L, which consists of ammonium, nitrate, and nitrite. The effluent results for TN follow the trends that exist for ammonium and nitrate such that if the ammonium and nitrate results were added together for each event, the graph would follow the patterns shown in the TN data. After the initial six weeks of TN leaching in columns 3 and 4, TN begins to be reduced by the columns; this is likely due to a combination of ammonium adsorption, subsequent nitrification, and nitrate reduction via denitrification in the anoxic zone. Alternatively, leaching or very little change from influent concentration of TN continues throughout all stages of TN measurement, despite excellent ammonium removal; this is likely due to the excessive levels of nitrate found in the compost.

4.4 Chloride

During operation other than winter and spring runoff, this research applied a similar concentration of chloride found by literature research conducted for the City of Edmonton and then validated using data collected by an Edmonton based sampling program (Yu, 2016). This chloride concentration was selected based on the average found on commercial, industrial, institutional, open space, and residential land uses (not including roadways). This is because the roadway chloride concentrations were 10-50 times higher than the other land uses, likely due to residual salts applied for winter road maintenance. A higher concentration would be accounted for in this research during winter operation and spring runoff. A high chloride concentration of 1280 mg/L was selected during spring runoff to study extreme conditions.

Spring runoff was assumed to be approximately 4 times the concentration of typical stormwater runoff. Therefore, 320 mg/L (1/4 that of spring runoff) was used during winter operation and the major melt of spring runoff as it’s unlikely that the concentration would be as low as in the summer, but it also may not be as high as in spring runoff. The spring runoff concentration used in this research is consistent with literature findings in other Canadian cold climates such as Toronto and Guelph, Ontario, where concentrations have been measured at approximately 1000 mg/L (Williams et al., 2000; Denich et al., 2013).

Ontario and Alberta may share the same two Köppen climate classifications of "Dfb" (warm-summer humid continental climate) and "Dfc" (subarctic climate) (Peel et al., 2007), however, their average temperatures and precipitation levels are slightly different.

Average low and record low temperatures in Edmonton's winter are -11℃ and -48.3℃, respectively, with an average annual snowfall of 123.5 cm (GoC, 2018a). Toronto, Ontario on the other hand, has average low and record low temperatures of -7℃ and -32.8℃, respectively, with an average annual snowfall of 121.5 cm (GoC, 2018b). As the average low temperature and amount of snowfall for Edmonton and Toronto are similar, the concentration of road maintenance salt found in the environment may be comparable, depending on each City's road maintenance strategy. However, because Edmonton is prone to more frequent, extreme low temperatures, the use of salt can be minimized compared to climates like Toronto's. This is based on the phase diagram of sodium chloride shown in Figure 34. Below temperatures of -21℃, sodium chloride becomes ineffective at melting ice. When Edmonton experiences these severe cold temperatures, road salt application should be stopped to minimize its unnecessary infiltration to surface water; alternatively, only road sand should be applied. As discussed in section 4.1, this will result in higher TSS concentrations entering bioretention facilities, but with proper sediment pretreatment and regular facility maintenance, this issue should be minimized and not lead to clogging of the bioretention filter media.

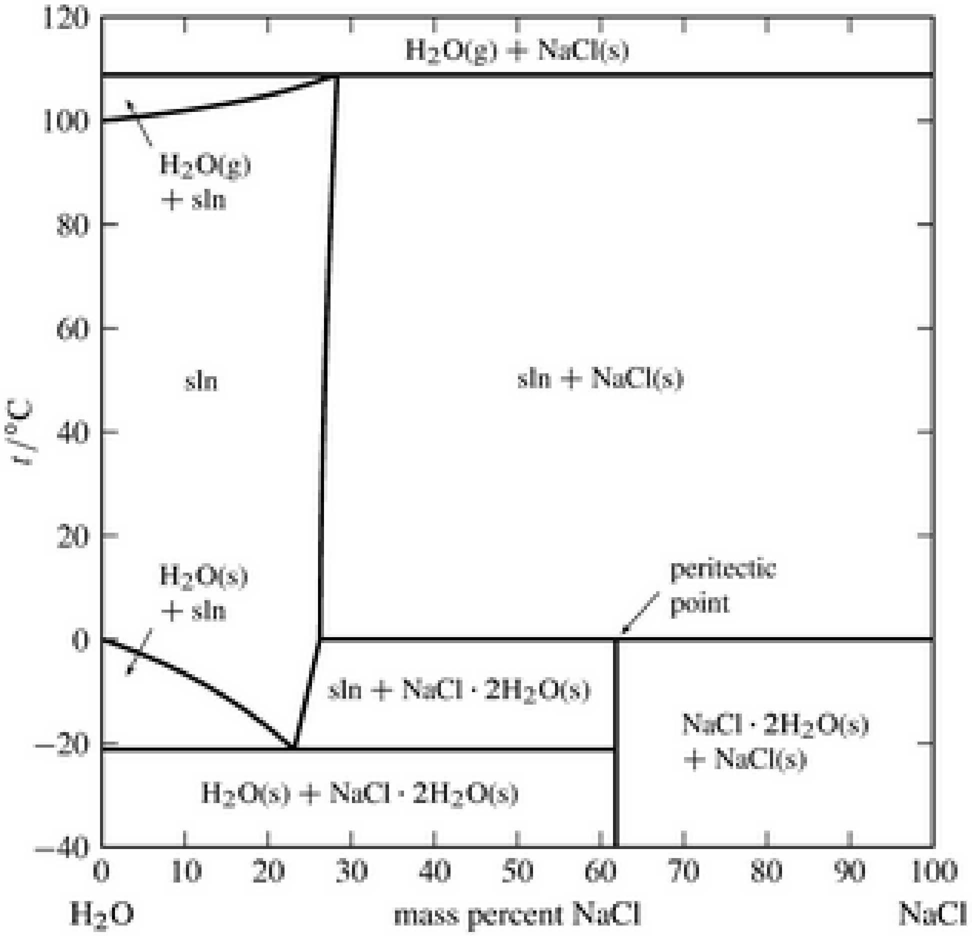


Figure 34: Sodium chloride phase diagram (DeVoe, 2017).

The City of Edmonton is currently applying a calcium chloride solution with corrosion inhibitor as a pilot project for winter 2017-2018 intended to ease snow removal and save money by needing to apply less salt (as less calcium chloride is needed as compared to sodium chloride) and traction sand (CoE, 2018). If this pilot project is successful and application continues, spring runoff samples should be collected to determine approximate concentrations that may enter bioretention facilities and column experiments should be conducted to confirm that calcium chloride moves through the soil columns designed for this study similarly to the movement of sodium chloride. The impact to the bioretention columns of the corrosion inhibitor in the brine solution being applied should also be evaluated.

This research shows that influent chloride leached from each column and experienced no retention, which was expected due to the mobility of the negatively charged chloride ion through soil. Figure 35 shows the influent and effluent chloride concentrations for each column during 1st summer and winter. From this graph, there is an initial period of chloride leaching from the media as the effluent concentrations for columns 1, 3, and 4 are considerably higher than the influent, at concentrations of 268 mg/L, 110 mg/L, and 76 mg/L, respectively. Column 2 was thoroughly washed with approximately 1 years' worth of precipitation before the 1st summer of operation and therefore did not show the same chloride leaching. Table 24 shows the chloride available to freely leach from each media used in this research based on the Erlenmeyer leachate experiment. As each column contained significantly more weight of either soil media "A" or "B" compared to compost or woodchips, all four media types would have contributed to the initial leachate period. Figure 35 also shows that the media provides a short buffer period to the higher concentration of chloride applied in winter operation; despite a target influent of 320 mg/L, the effluent of the first winter event remained approximately < 50 mg/L.

Table 24: Chloride leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Chloride (mg Cl^-/L)	3.33	1.57	36.15	18.00
Chloride (mg Cl^-/kg)	66.67	31.47	722.88	359.94

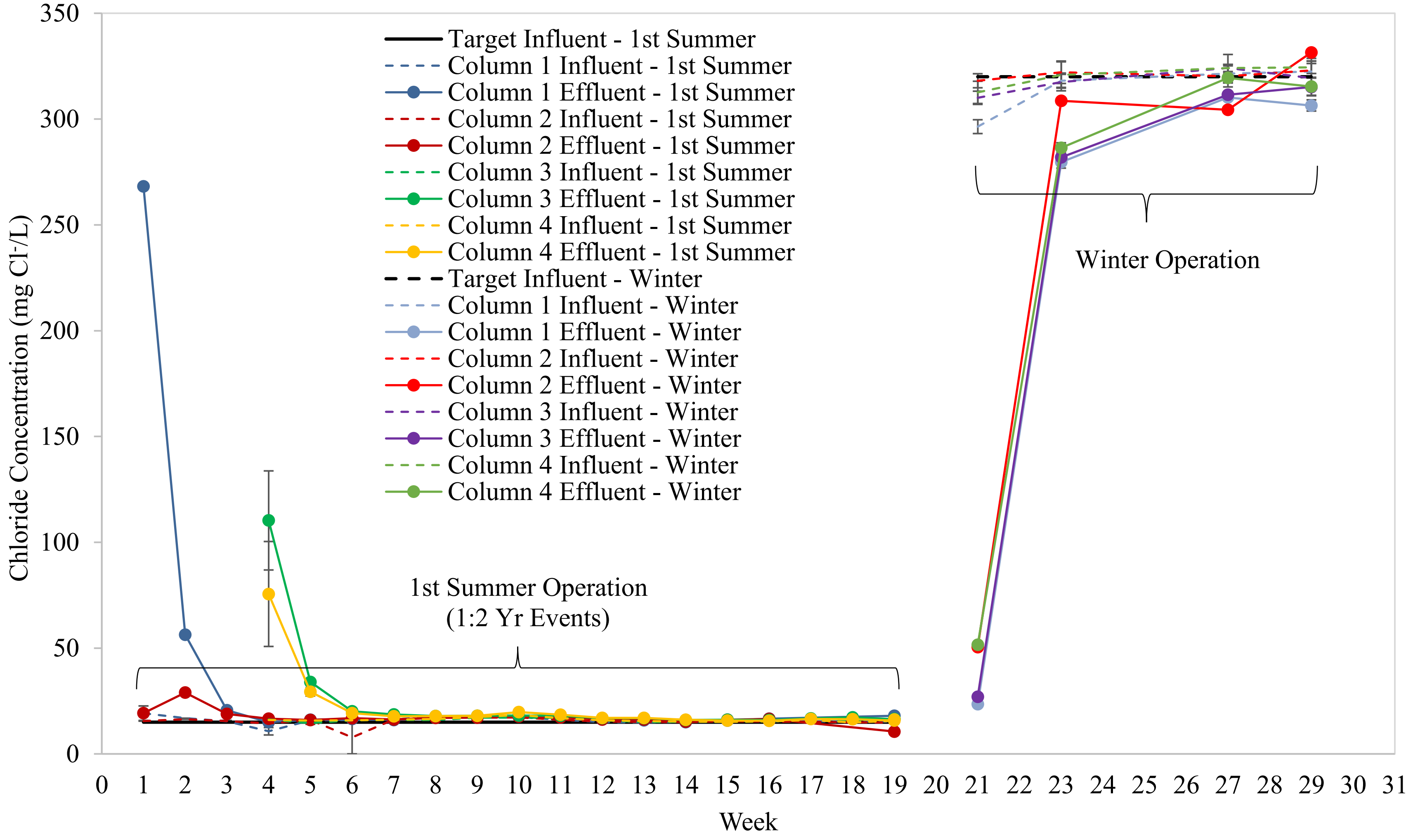


Figure 35: Chloride concentration change during 1st summer and winter operation.

Figure 36 shows the same data for 1st summer but zoomed in to show that effluent concentrations are very similar to influent concentration. Figure 37 shows the zoomed in winter operation data; from this graph, the buffer period may extend throughout all four of the winter events as the effluent concentration for all columns is consistently less than the influent, with column 2 during the fourth event being the only exception. Figure 38 shows the response of the columns to spring runoff. The concentration of first flush (i.e. approximately 1280 mg/L) was also buffered initially but was ultimately exported during the major melt period of spring runoff. Figure 39 shows the continued export of the high concentration of first flush chloride during the 2nd summer. However, by the third 2nd summer event, effluent concentrations from all columns are approximately equal to influent; this trend continues for the 1:5 year and 1:10 year event.

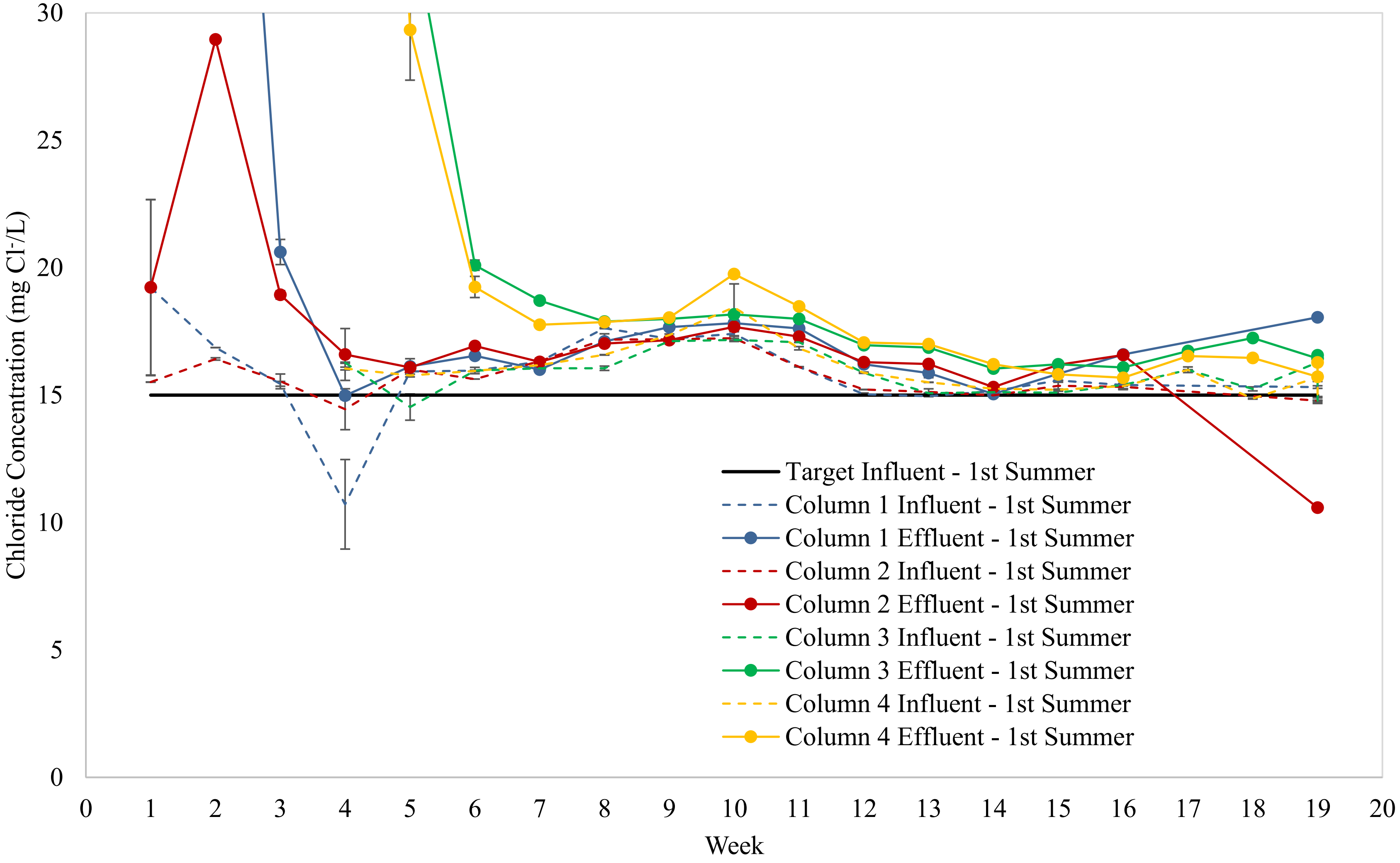


Figure 36: Chloride concentration change during 1st summer operation zoomed in.

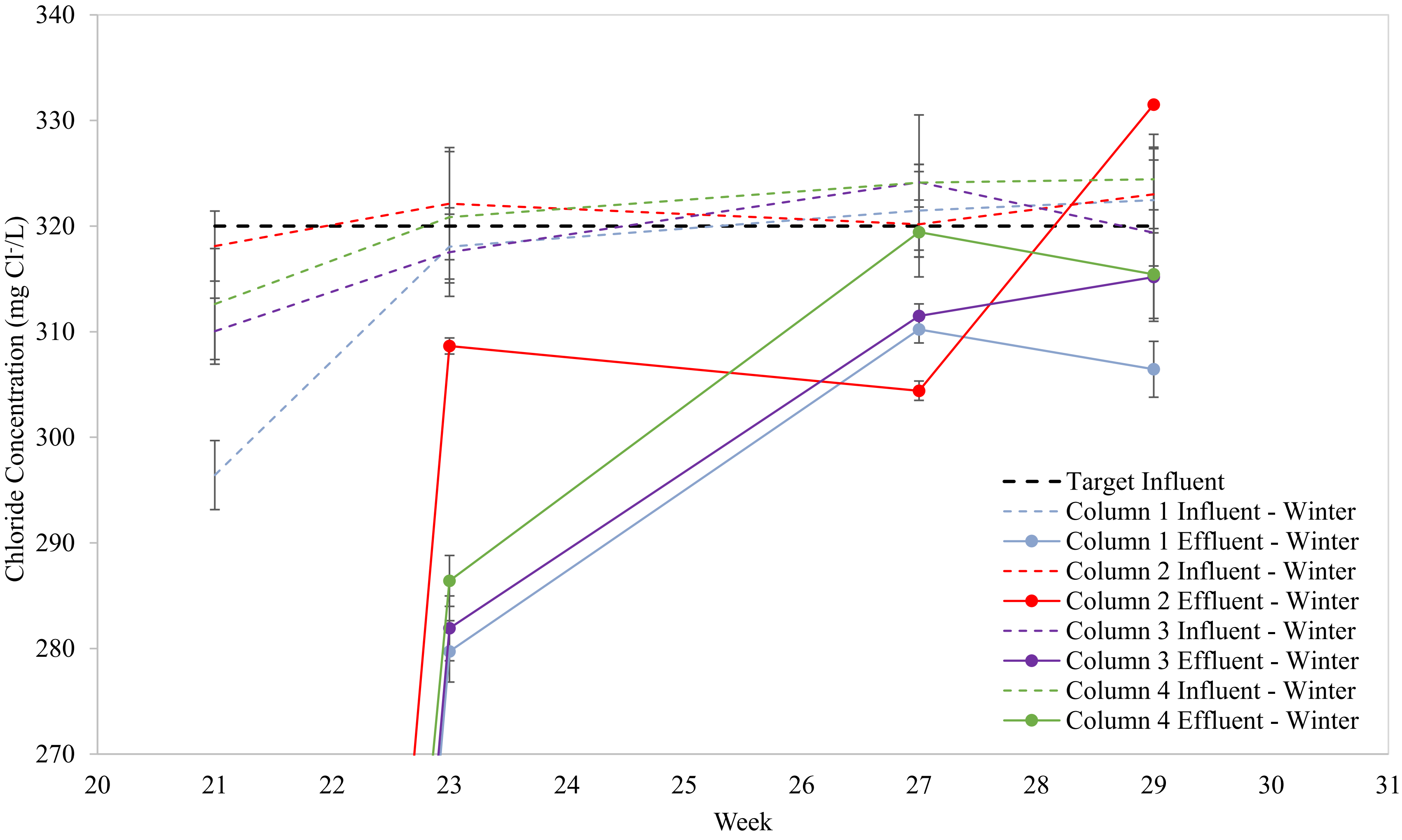


Figure 37: Chloride concentration change during winter operation zoomed in.

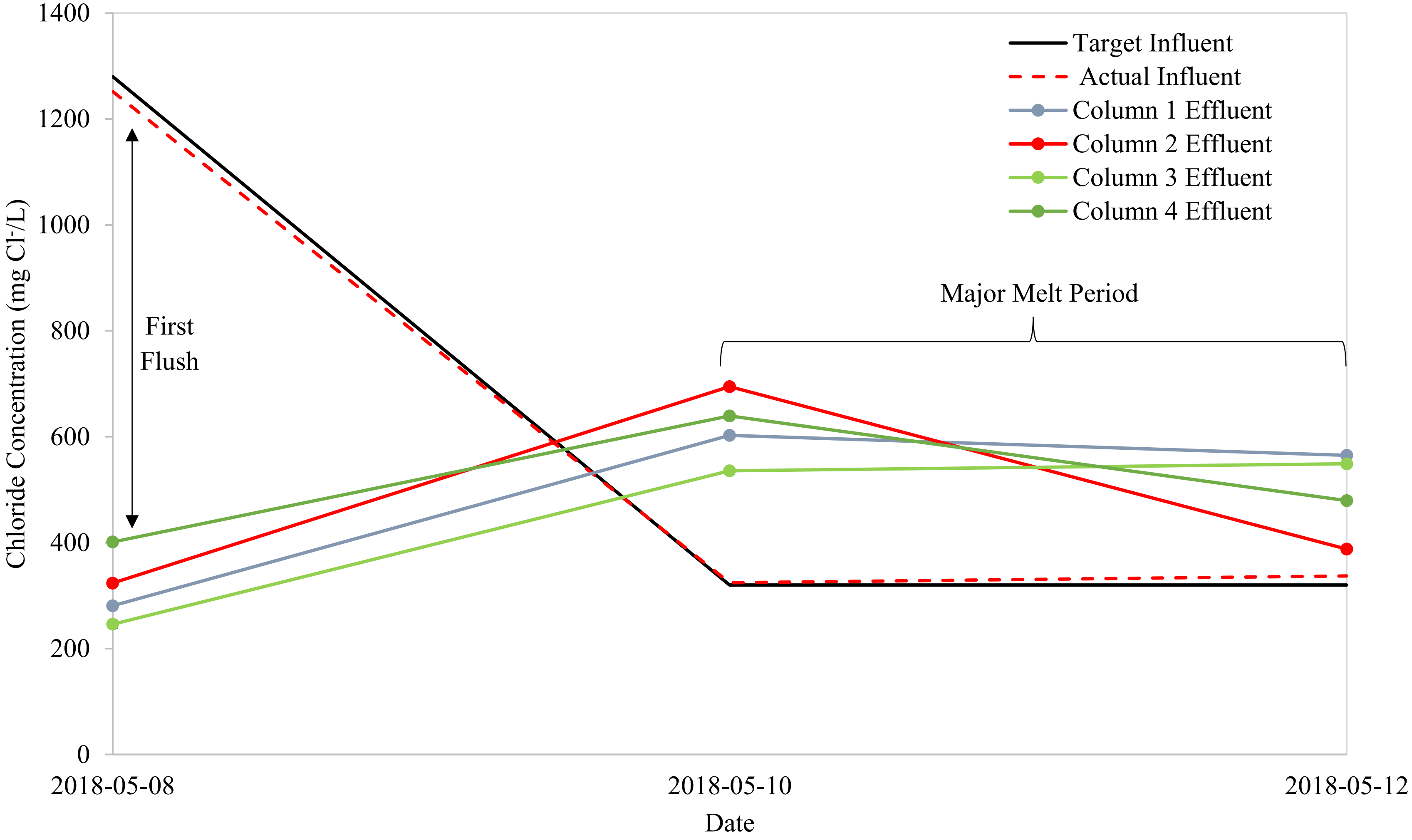


Figure 38: Chloride concentration change during spring runoff.

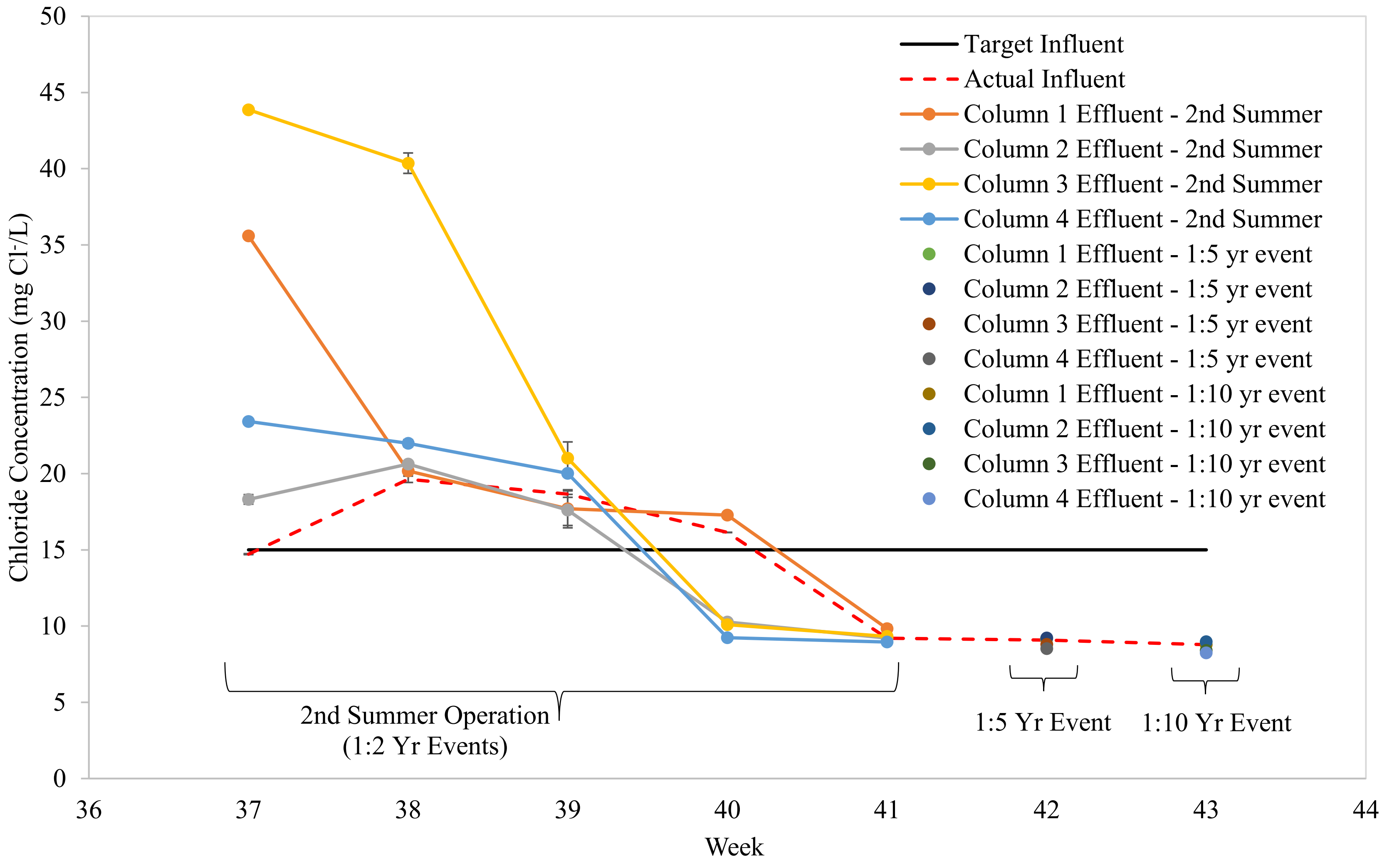


Figure 39: Chloride concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events.

The mobility of chloride shown in this research indicates that bioretention systems designed in the field without an underdrain will lead to the migration of chloride into the underlying subsoils and likely into the groundwater table. Bioretention systems designed with an underdrain will still be problematic as Edmonton's entire watershed ultimately drains to the North Saskatchewan River, thus causing surface water pollution. Typically, salts are not well treated by any stormwater management technique (Denich et al., 2013) and therefore source reduction and/or finding effective alternatives to road salts are the most viable solutions to limiting the amount of road salts migrating into fresh water systems.

Although detrimental to the environment, the high salt concentrations applied during this research may have also had a beneficial impact on the soil columns. During winter and spring runoff operation, the columns underwent multiple periods of freezing at -20°C and thawing. Although the columns were frozen solid, eventually all the applied volume infiltrated though each column. As the room and applied water temperature was between 1-3°C, the sodium chloride was in the adequate range to encourage melting of the ice within the soil columns. This likely lead to quicker thawing of the entire bioretention media which allowed for runoff to infiltrate more quickly and experience physical treatment of TSS, phosphate, and ammonium. Therefore, although ultimately a surface water pollutant and until ecofriendly winter road maintenance alternatives are discovered, road salts may provide an advantage to bioretention facilities implemented in the field by enabling them to still achieve some level of quantity and quality improvement performance during intermittent warming periods throughout winter and during spring runoff.

4.5 Vegetation

The vegetation selected for this research is a hardy, native, North American species that is drought tolerant and not susceptible to damage by environmental salts. However, none of the vegetation in any of the four columns grew back after the winter and spring runoff operation. Potential causes for this lack of regrowth is either due to the high salt concentrations applied in winter and spring runoff leading to salt stress in the plants or due to an operational error of not properly hardening the vegetation prior to undergoing freezing temperatures. Hardening is the process of exposing vegetation to low, nonfreezing temperatures to induce genetic, morphological, and physiological changes in vegetation to develop a tolerance to freezing (Gray et al., 1997). These changes are signaled by gradually decreasing temperatures and hours of sunlight. By not providing time for acclimation to freezing temperatures, intracellular ice crystals may form and are lethal (Taiz et al., 2015).

Due to the time constraints of this research and the inexperience of the researchers in maintaining vegetation, the columns and vegetation used in this research were only subjected to 8 days of gradually declining temperatures to 0°C and then frozen to -20°C in only 6 days. Hours of artificial sunlight were also not adjusted. As seen in section 4.4, influent chloride was generally equal to effluent chloride implying that chloride was not retained in significant quantities and lead to vegetative salt stress in the 2nd summer of operation. Therefore, the lack of acclimation to freezing temperatures is the most likely cause of the failure of the vegetation to regrow once subjected to warm temperatures.

Further experiments will need to be conducted to ensure the successful growth of vegetation in the media designed in this research. Specifically, the compost recommended quantity and placement (i.e. 20% (v/v) in only the plant root layer) will need to be further evaluated to determine if it will provide adequate nutrients and organic matter for the vegetation's lifetime. As bioretention is designed to capture large volumes of stormwater runoff that inherently contain nutrients and organic compounds, bioretention media should not be designed like that of a typical landscaping feature (i.e. the quantity of compost to support landscaping vegetation is unnecessary). Compost addition to bioretention systems has two purposes: enhance water holding capacity and promote plant health. As seen in this research, stormwater quantity (Li, 2018) and quality can be well managed without requiring significant quantities of compost to enhance the water holding capacity.

However, the water holding capacity of bioretention systems is also an important consideration for vegetation health that this research failed to determine. In fast draining soils like in this research, plants may experience water stress. There are three approaches to solve this issue:

1. Select hardy vegetation that is both drought and wet tolerant.

2. Design a vertical, two-tier treatment media that contains a layer of fast draining soil, like in this research, and followed by a layer with a higher clay content soil that can hold more water to support the vegetation.
3. Employ a self-watering device, such as the TreeDiaper® (Zynnovation.LLC, 2018), until plant roots are mature enough not to require it.

Therefore, the second purpose of compost application in bioretention (i.e. to promote plant health) needs to be thoroughly evaluated because its consequence is compromised effluent water quality due to potential leaching of phosphorus, nitrogen, and organic compounds. As the intent of bioretention is to enhance stormwater quality, then the main goal should be nutrient and organics release prevention rather than mitigation (i.e. minimize leachate availability by minimizing compost). A detailed analysis of typical runoff nutrients should be conducted to evaluate if their concentrations and frequency of inflow are adequate to grow plants. However, this analysis would need to be on a case by case basis. A cheaper alternative (i.e. although likely more costly than excess compost application) may be targeted fertilization as required. In areas with watersheds particularly sensitive to eutrophication, this approach may be necessary.

4.6 Organics

This research shows that organic matter, as represented by chemical oxygen demand (COD), leached from every column and experienced no retention. Figure 40 shows the influent and effluent COD concentrations for each column during 1st summer and winter. From this graph, there is an initial period of COD leaching from the media as the effluent concentrations for columns 1, 2, 3, and 4 are considerably higher than the influent, at maximum concentrations of 256 mg/L, 117 mg/L, 1067 mg/L, and 1010 mg/L, respectively. NPOC was also measured for select events and results can be found in Appendix B (Figure 67).

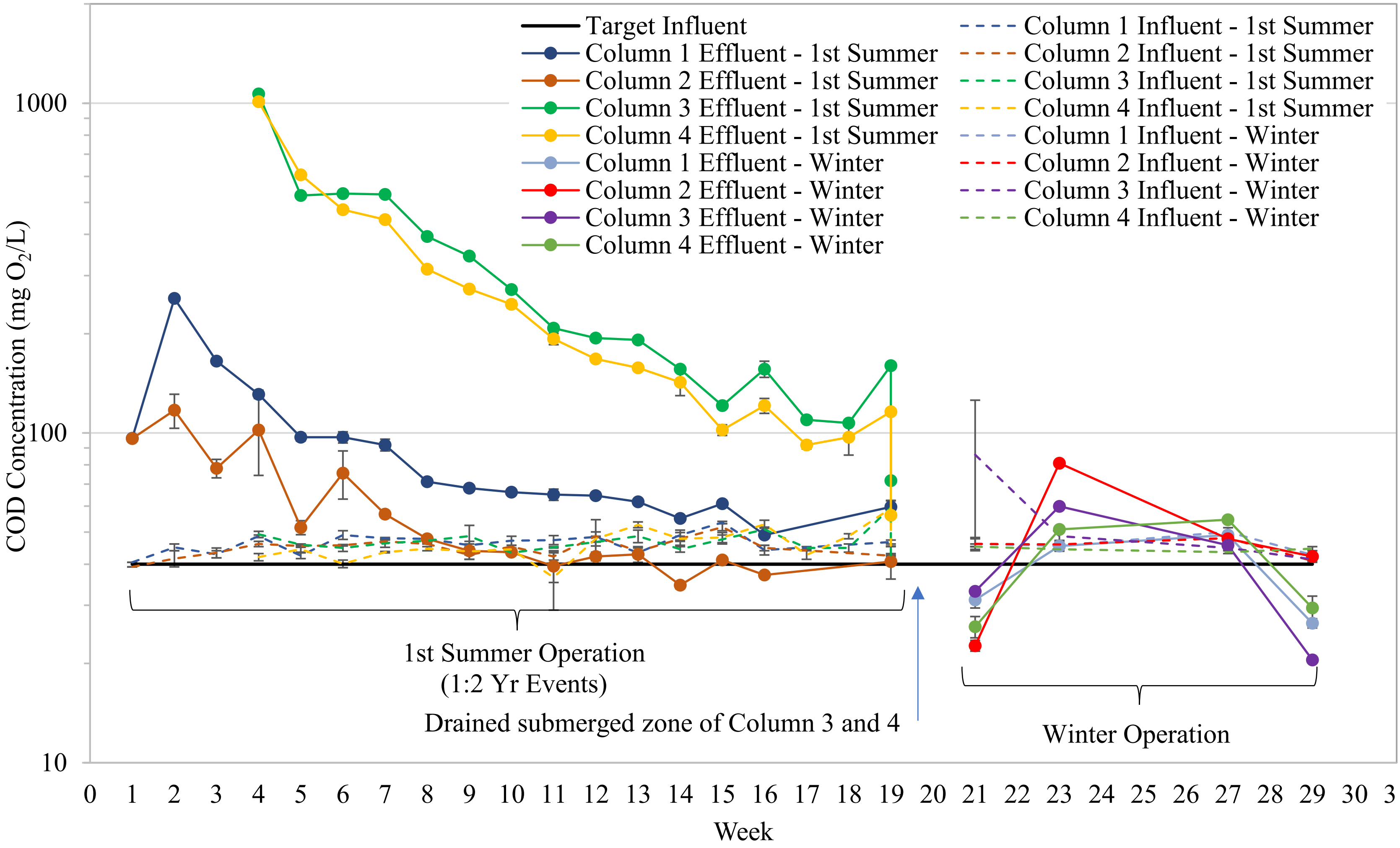


Figure 40: COD concentration change during 1st summer and winter operation.

Before the 1st summer of operation the media below the level of vegetation in column 2 was thoroughly washed with approximately 1 years' worth of precipitation, then the top layer of soil, compost, grasses, and surface mulch were added to the column. This resulted in less COD leachate appearing in column 2 than in column 1. Due to earlier leaching of COD during the washing, column 2 is seen to experience some extent of organic matter degradation beginning around week 9 of 1st summer operation.

Table 25 and Table 26 show that the media used in this research has high levels of available COD, NPOC, and organic matter which is the likely source of the high concentrations of COD found in the effluent. Woodchips and compost have the greatest available organic content that can leach from the system and therefore should be applied sparingly in bioretention facilities. However, due to the significantly greater weight of either soil media "A" or "B" contained in the large columns compared to compost or woodchips, all four media types would have contributed to the initial leachate period in this research.

Table 25: Organic compound leachate from different media types. mg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
COD (mg O_2/L)	42.00	32.97	555.51	1057.93
COD (mg O_2/kg)	840.05	659.39	11109.70	21154.18
NPOC (mg CO_2/L)	18.93	13.88	196.94	485.85
NPOC (mg CO_2/kg)	378.54	277.58	3938.52	9714.81

Table 26: Organic matter content of different media types as measured by Exova of Edmonton.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Organic Matter (%)	2.3	1.8	34.9	80.6

Columns 3 and 4 have approximately four times the concentration of initial COD leaching compared to columns 1 and 2. However, by examining the total estimated mass of COD available in in the columns, as will be shown in section 4.8, the mass of COD added by the additional woodchips is not four times that of the columns without additional woodchips (i.e. columns 1 and 2). This may indicate that there is some level of organic matter oxidation in the upper, aerobic layers of the bioretention column; because the woodchips in columns 3 and 4 are at the base of the column and under anoxic conditions the organic matter in the media in that layer leaches into the effluent and does not have the opportunity for degradation.

During winter operation and spring runoff (Figure 41), the COD leachate appears to stabilize as effluent concentrations occur less than influent concentrations almost the same number of times that they occur more than the influent concentrations. However, during 2nd summer of operation (Figure 42), all columns again show effluent concentrations consistently greater than influent, but without a clear trend. It appears that either the cold temperatures or high salt concentrations during winter and spring runoff inhibited the release of organic matter from the media, rather than the washout of organic matter coming to completion at that time. Also, column 2 no longer reduced COD concentrations in the 2nd summer as it did during the last half of the 1st summer of operation. This indicates that the freezing temperatures negatively impacted the media’s capacity to degrade organic matter by reducing the bioactivity of soil microbial populations. With a longer period of 2nd summer operation, the microbial communities may have rebounded to initial performance.

As this research only applied 1.6 years of equivalent Edmonton precipitation volume, it is difficult to predict field bioretention systems organic matter removal performance from these results. If longer term experiments were conducted on these columns, the effluent COD concentration may continue to decline as organic matter washout came to completion and microbial populations became more abundant and acclimated to the high urban pollution loads and therefore more adept at degrading influent organic compounds. Regardless, this research shows that careful selection of bioretention media is needed to select soils with low organic content to prevent leaching of organic compounds and subsequent degradation of downstream water bodies.

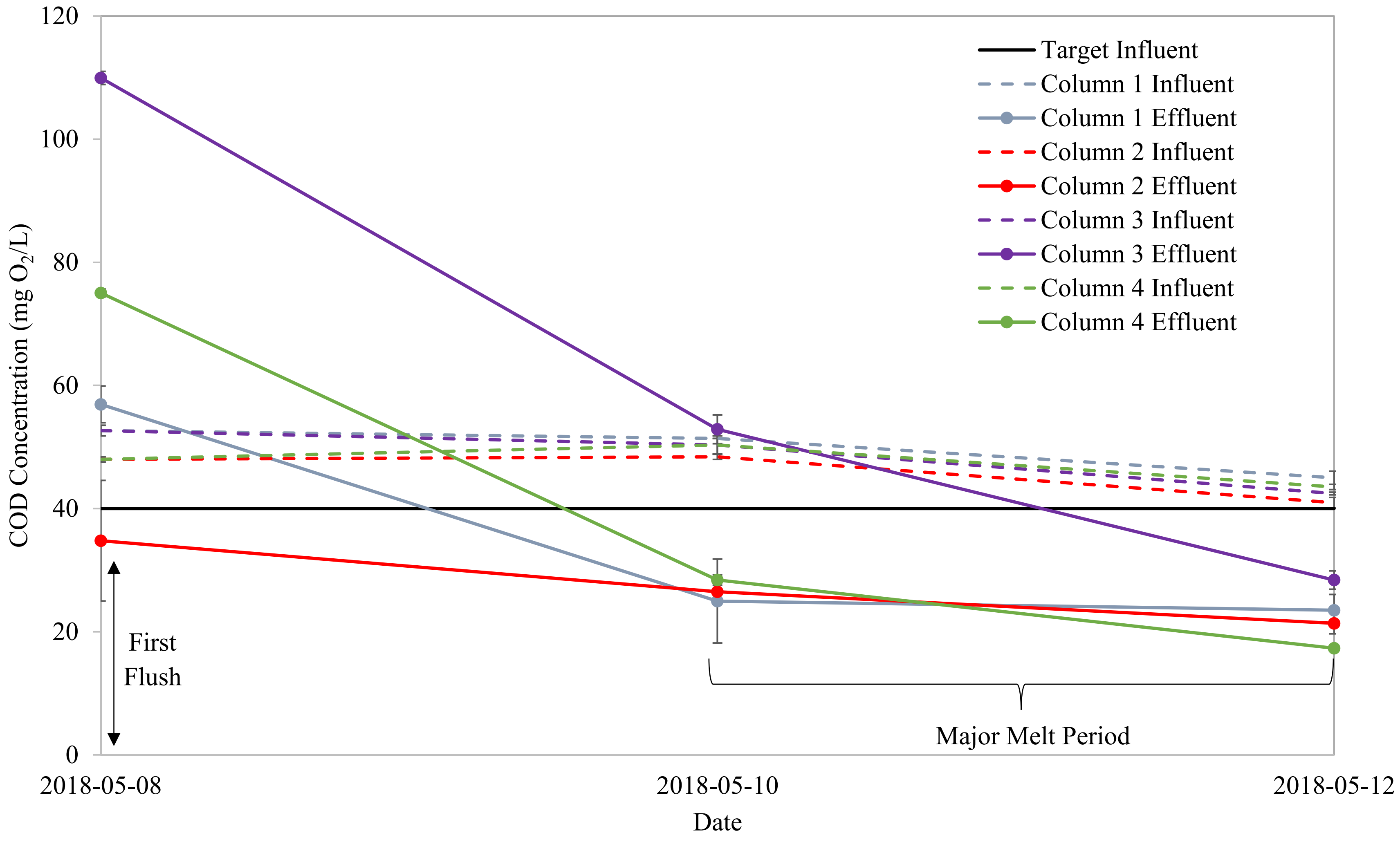


Figure 41: COD concentration change during spring runoff.

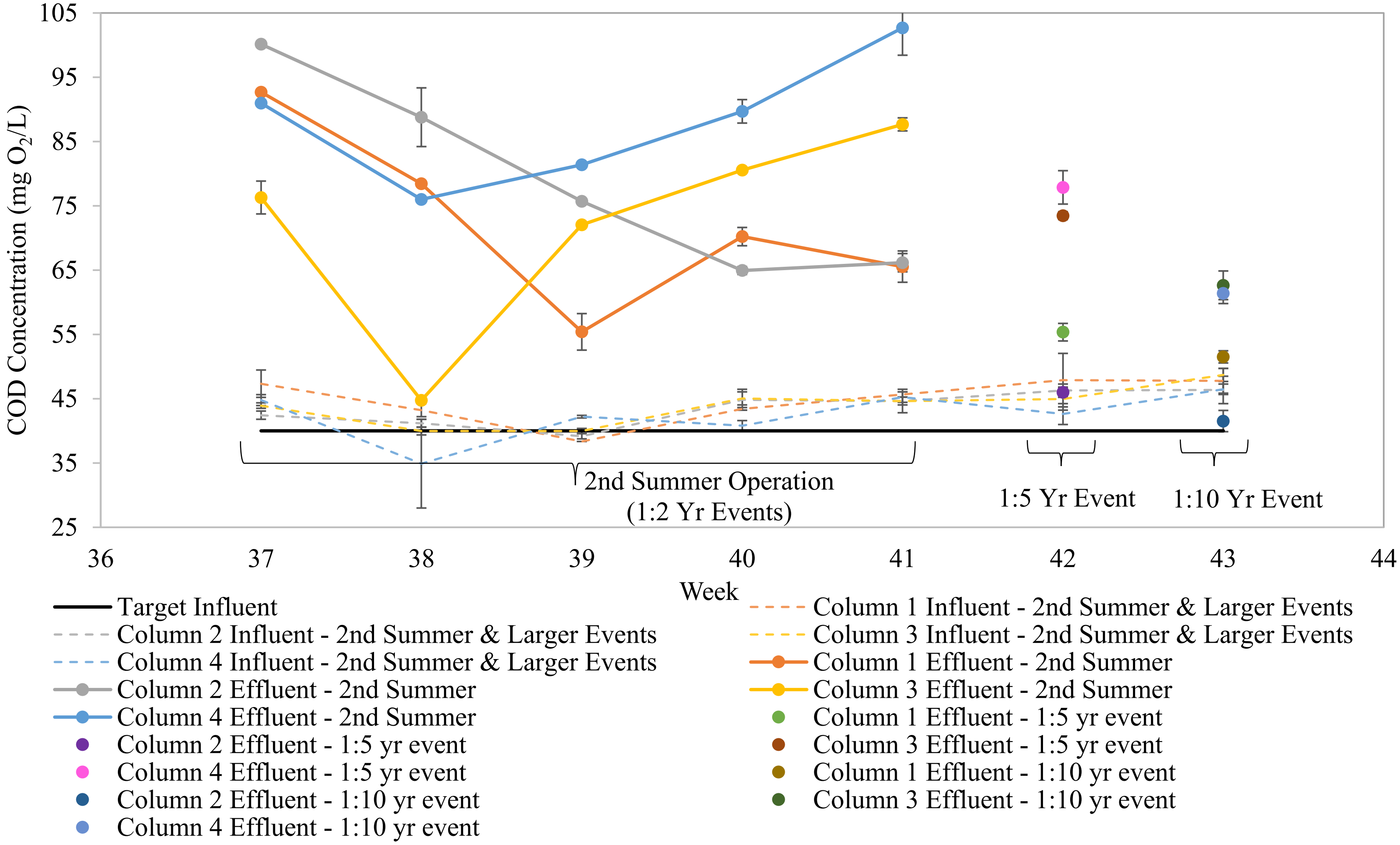


Figure 42: COD concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events.

4.7 Metals

The four heavy metals of concern in stormwater (i.e. copper, zinc, lead, and cadmium) were analyzed for select events, as seen in Figure 43, Figure 44, Figure 45, and Figure 46, respectively. Ten events applied to columns 1 and 2 and seven events applied to columns 3 and 4 during the 1st summer were measured for heavy metals. All effluent samples analyzed total metals, whereas influent samples were measured for dissolved metals up to the samples analyzed in week 12, after which, influent samples were measured for total metals. Table 27 shows the total metals available to freely leach from each media used in this research based on the Erlenmeyer leachate experiment and Table 28 shows the maximum available total metals in the media. Compost consistently has higher levels of all heavy metals tested compared to soil media "A", "B", and woodchips.

Table 27: Metals leachate from different media types. µg/L measurements utilized 180 mL of deionized water and approximately 9 g of media.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Copper (ug Cu/L)	0.00	7.92	231.50	0.00
Copper (ug Cu/kg)	0.00	158.32	4629.83	0.00
Zinc (ug Zn/L)	19.42	81.42	387.75	103.75
Zinc (ug Zn/kg)	388.32	1628.22	7754.70	2074.58
Cadmium (ug Cd/L)	1.92	5.04	4.50	2.50
Cadmium (ug Cd/kg)	38.33	100.83	90.00	49.99
Lead (ug Pb/L)	0.00	6.46	10.00	0.00
Lead (ug Pb/kg)	66.67	31.47	722.88	359.94

Table 28: Available metals in different media types as measured by Exova of Edmonton.

Media	Soil Media "A"	Soil Media "B"	Compost	Woodchips
Copper (mg Cu/kg)	8.80	6.90	337.00	5.20
Zinc (mg Zn/kg)	33.00	25.00	602.00	41.00
Cadmium (mg Cd/kg)	0.16	0.11	3.14	0.21
Lead (mg Pb/kg)	5.60	4.40	50.50	1.30

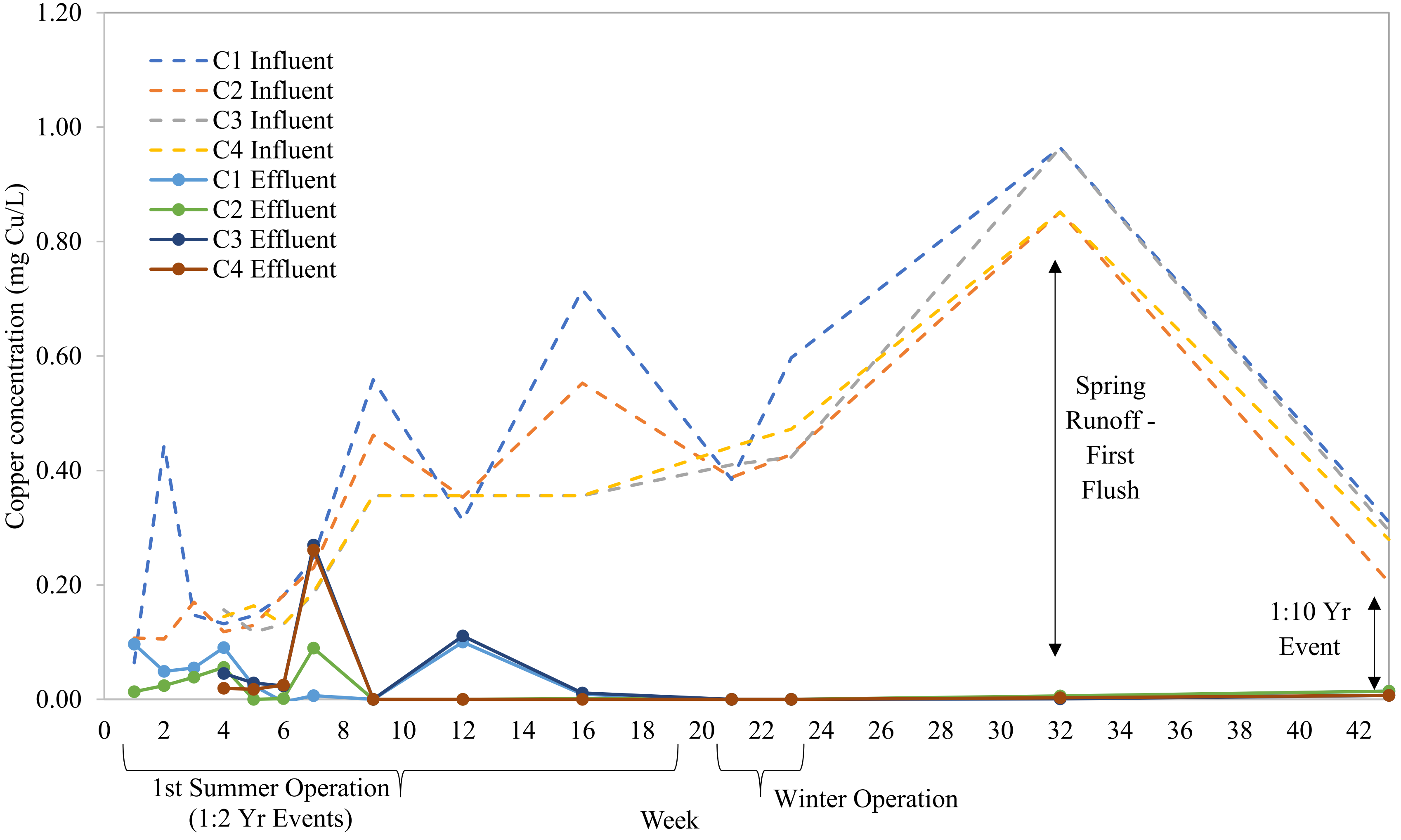


Figure 43: Copper removal during select events.

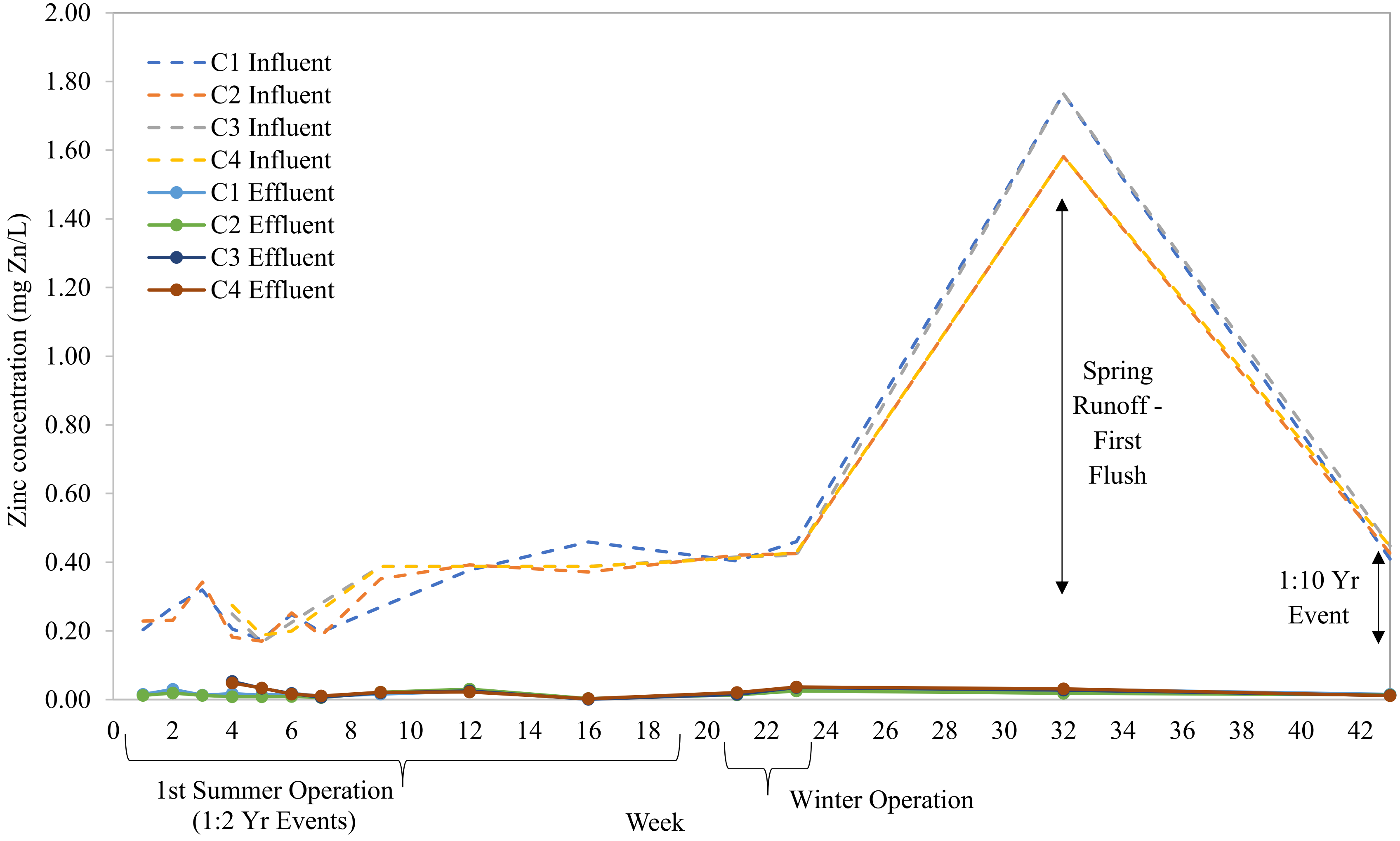


Figure 44: Zinc removal during select events.

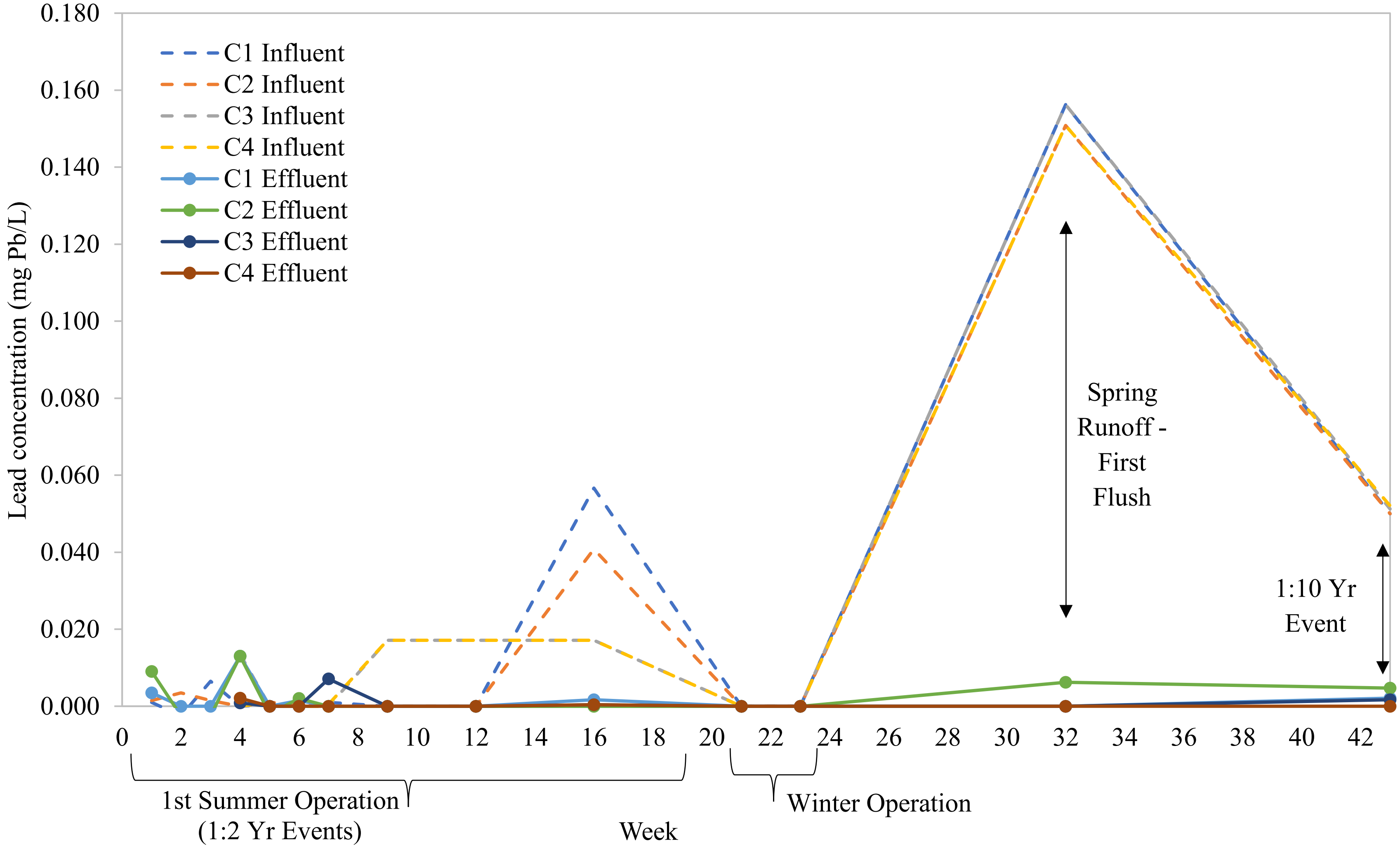


Figure 45: Lead removal during select events.

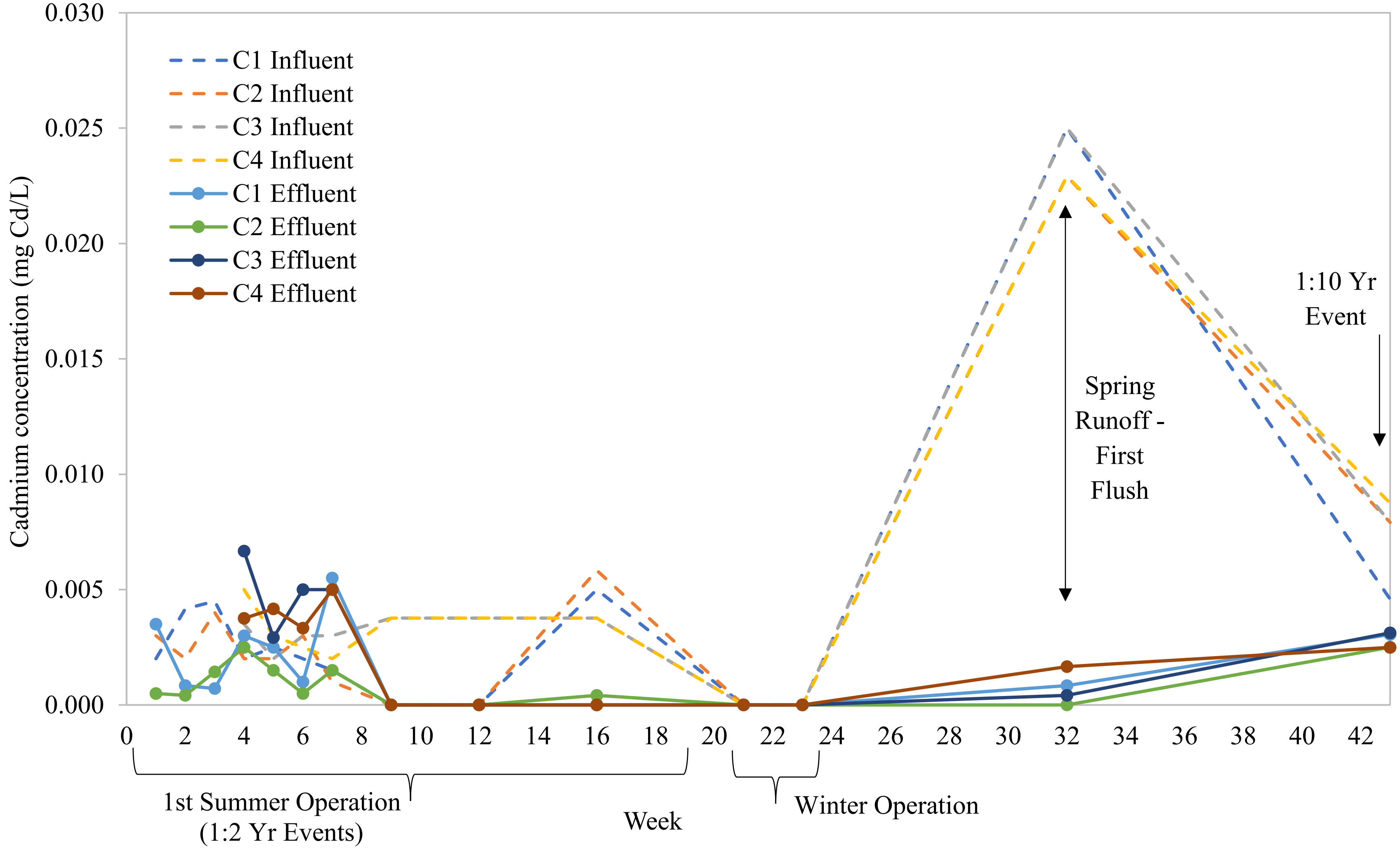


Figure 46: Cadmium removal during select events.

In evaluating the change in heavy metal concentrations, it is important to understand that results obtained from field bioretention cells may vary considerably. Heavy metals are complex and variable in stormwater runoff and their speciation between dissolved and particulate will impact their ability to be removed in the environment.

All columns generally reduced copper and zinc well in all stages of operation. Lead and cadmium reduction are more variable for all columns, especially prior to week 12, in which the sample analysis changed from measuring dissolved to total metals of the influent. Influent dissolved metals measured for lead were lower than expected, likely because lead tends to precipitate with phosphate, chloride, and sulphate (Castaldi et al., 2017), all of which are found in the synthetic stormwater. The lead sulphate precipitate has low solubility and therefore is relatively immobile in soils (Olson and Skorgerboe, 1975). The influent lead was therefore likely in particulate form resulting in low concentrations measured when samples were analyzed for dissolved metals (i.e. before week 12). Influent lead measured in week 16 was considerably higher and supports this conclusion.

The variability in influent and effluent cadmium during 1st summer is likely due to the extremely low concentrations added to the synthetic stormwater and the limitations of the analytical method. However, similarly to lead, as the influent concentration is clearly greater than the effluent concentration in week 16 when total metals were measured, precipitation of cadmium may have contributed to the variability. During winter operation, the influent lead and cadmium concentrations drop below detection limits even though total metals are measured. This may be a result of the increased sodium chloride concentrations applied during winter leading to even greater precipitation and particle size of those two metals. The larger precipitates may have settled from solution more easily and, although the synthetic stormwater was mixed well, the relatively small sample volume taken compared to the total volume may have resulted in the lead precipitates being missed during sampling and therefore not measured.

All four heavy metals analyzed during the first flush of spring runoff and the 1:10 year event, were clearly reduced well and to almost the same extent in all four columns in this study (however, to a lesser extent for cadmium during the 1:10 year event due to the already low concentrations). Data collected during the major melt of spring runoff would have been useful to collect to see if there was a delayed release of heavy metals from the high concentration of the first flush.

However, generally, heavy metals have been well removed in this research, as to be expected in media with a high organic matter content and cation exchange capacity. This research also did not experience decreased heavy metal reduction caused by the application of road salts releasing them from adsorption sites, as seen in other research (Paus et al., 2014b). Despite having considerable heavy metals existing in the fresh media used in this study, both influent and potentially leached metals were retained by the media. Other research has shown that heavy metal removal in bioretention is excellent at 80-90% and is depth dependent with the main deposits being in the top 10-15 cm of media (Li and Davis, 2008). The large columns used in this research might also have the most heavy metal deposits at the top of the soil columns where compost with high cation exchange capacity exists; however, with considerable heavy metals available in the woodchips in the submerged zone and no corresponding heavy metal leaching in the effluent, there must also be metal accumulation near the bottom of the four large columns used in this study.

As heavy metals are retained in bioretention media mostly via physical and chemical processes, there will eventually be a metal retention capacity that the media will reach. As this research only exposed the media to 1.6 years of Edmonton’s precipitation volume, heavy metals were not measured for every event, and no trend of gradually decreasing heavy metal retention exists in the data, long term performance and retention capacity are impossible to extrapolate. Further, long term studies are required to evaluate the bioretention media’s lifetime of heavy metal removal, as well as the concentrations that might exist in the media after several years of heavy metal accumulation. The possibility for heavy metals to accumulate to highly toxic levels needs to be investigated and an appropriate maintenance plan for field bioretention facilities must be established. If heavy metals are mainly accumulating in the top layer of media, periodic removal and replacement of that layer may be required. A practical and cost-efficient decontamination technique of that media will also need to be determined.

4.8 Leachate

Figure 47 and Figure 48 provide a comparison of the various contaminants of concern in stormwater runoff that can be found within the fresh bioretention media that was used in this research and act as a contaminant source. Each source of leachate and their fate during the five stages of operation in this research are discussed in more detail in the previous sections: 4.2 to 4.4 and 4.6 to 4.7. This section is intended to serve as a summarized comparison of the media types. Figure 47 expresses phosphorus, nitrogen, chloride, COD, and NPOC in terms of mg of contaminant per kg of media and Figure 48 expresses the four heavy metals of the most concern in stormwater in terms of µg of contaminant per kg of media. Figure 49 and Figure 50 show the approximate mass of stormwater contaminants that are available in the large columns used in this research that could potentially leach into the effluent of the columns. This data is based on the approximate weights of soil media, compost, and woodchips that were installed in each large column and shown in Table 29.

Table 29: Approximate mass of media prone to contaminant leaching installed in the four large columns used in this research.

Media Type	Column 1	Column 2	Column 3	Column 4
Soil Media *"A" for columns 1,3* *"B" for columns 2,4*	140 kg	140 kg	140 kg	140 kg
Compost	2.85 kg	2.85 kg	2.85 kg	2.85 kg
Woodchips *"Surface" for columns 1,2* *"Surface & ground" for columns 3,4*	1.2 kg	1.2 kg	2.4 kg	2.4 kg

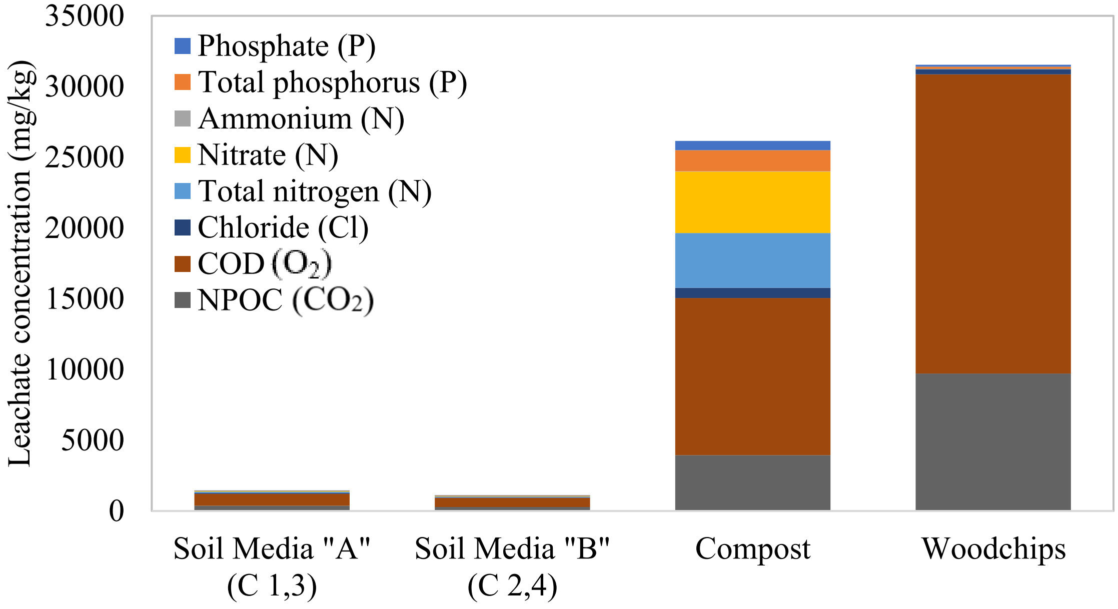


Figure 47: Leachate concentration from the different soil medias used as found in the leachate analysis.

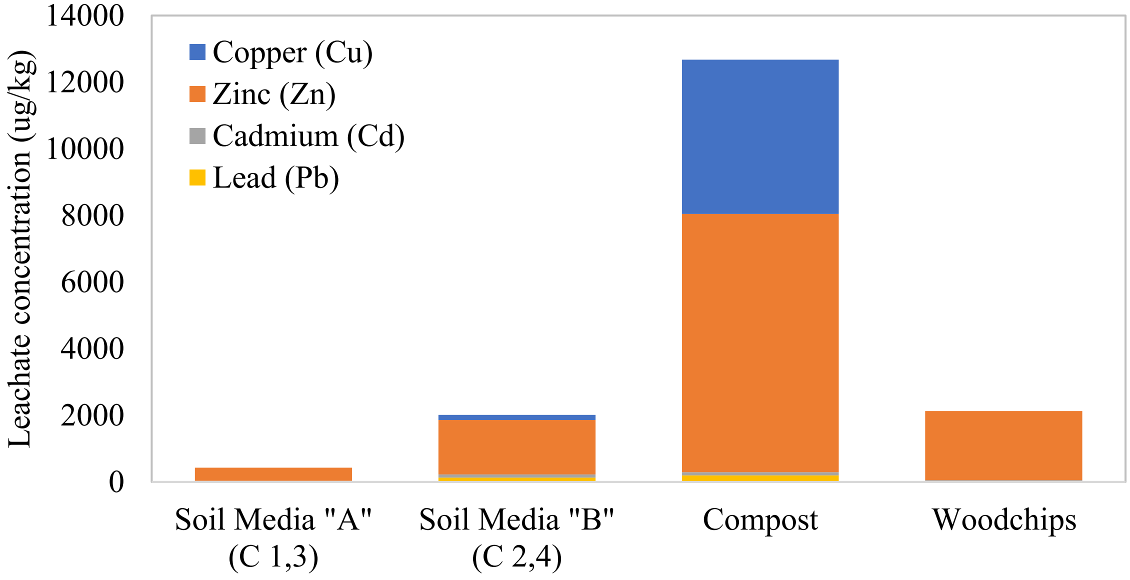


Figure 48: Leachate concentrations of metals from the different soil medias used as found in the leachate analysis.

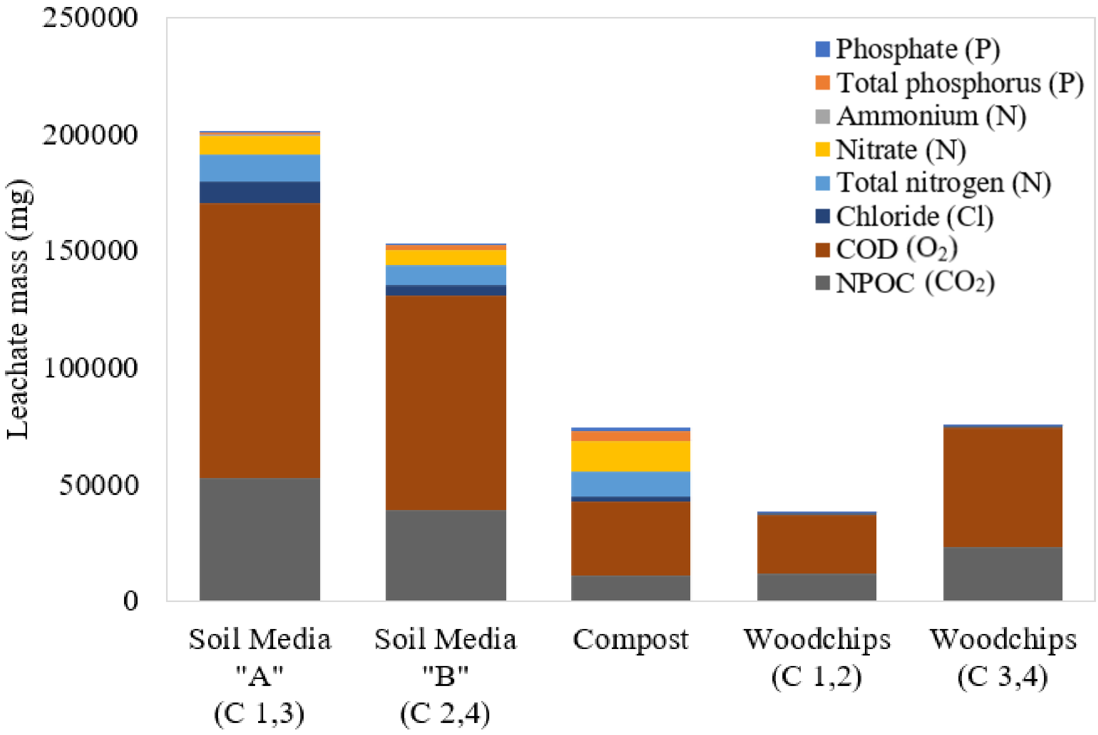


Figure 49: Approximate leachate mass available in the large columns.

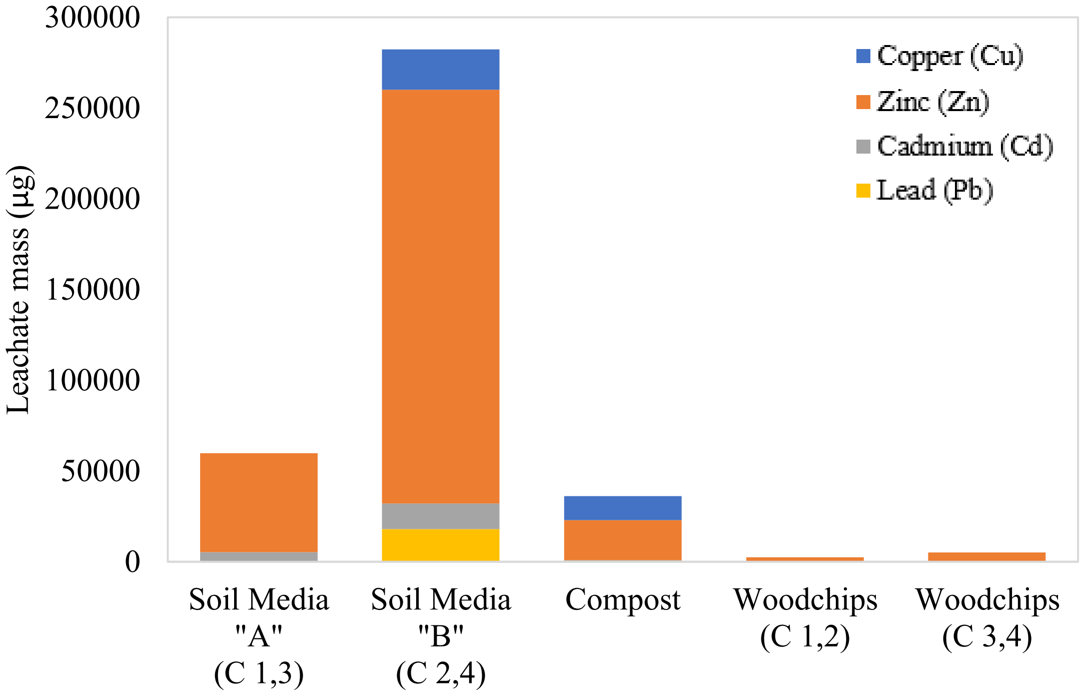


Figure 50: Approximate metals leachate mass available in the large columns.

While woodchips and compost both have much higher concentrations of overall leachate potential of nutrients, chloride, and organics combined per kg compared to soil media “A” (i.e. loam) and “B” (i.e. sandy loam), the greater mass of soil media “A” and “B” from the columns ultimately contribute the higher levels of overall leachate mass. Similarly, heavy metals have the highest concentrations per kg of compost, but due to the mass of soil media “B”, columns 2 and 4 appear to contribute more metal leachate to the effluent. Soil media “A” has considerably less metal leachate than soil media “B”. This may seem counterintuitive at first, but it may be a result of the higher organic matter in soil media “A” adsorbing and retaining more of the available heavy metals than in soil media “B”. The available leachate mass for each contaminant can be ranked from largest to smallest as: COD > NPOC > nitrogen > chloride > phosphorus > zinc > copper > lead > cadmium.

As seen in the previous sections, 4.3, 4.4, and 4.6, nitrate, total nitrogen, chloride, and organics all exhibited an initial period of leaching from the media which can be referred to as maturation. From Figure 49, the source of nitrate and total nitrogen were from soil media “A”, “B”, and compost. This figure also shows that chloride and organics leached from all medias used. Although phosphate, total phosphorus, ammonium, and metals are also present in some or all the medias used, their removal mechanisms are physical and rely most heavily on adsorption, which is immediate and does not require a stage of microbial establishment like nitrate and organic degradation would require. Soil has no chloride treatment capability, therefore any chloride existing in the media would have simply leached from the systems.

Chapter 5. Conclusions and Significance

5.1 Conclusions

Four large columns were designed for this research to determine appropriate local soils and amendments that could be utilized in bioretention systems. This research aimed to investigate the stormwater quality improvement performance of those bioretention medias for TSS, phosphorus, nitrogen, chloride, organics, and metals. Weekly, 1:2 year storm events were simulated in a laboratory to represent typical Edmonton summer operation. Then, Edmonton’s typical winter and spring runoff were simulated in a cold room to investigate their impact on performance shortly after freezing and thawing the soil media and their impact on the following summer operation of 1:2 year events. This was followed by the application of two slightly larger storm events (i.e. a single 1:5 year and a single 1:10 year event) to evaluate the impact of larger volumes on the bioretention soil media.

The four large columns were constructed with the following media:

- Column 1: Soil media "A" (i.e. loam or less porous media)
- Column 2: Soil media "B" (i.e. sandy loam or more porous media)
- Column 3: Soil media "A" with amendments to enhance nutrient removal
- Column 4: Soil media "B" with amendments to enhance nutrient removal

This research investigated whether the difference in porosity has a considerable impact on the ability of the columns to treat different water quality parameters by comparing columns 1 and 2. The nutrient removal enhancing amendments in columns 3 and 4 consisted of a submerged zone with supplemental carbon to promote nitrate reduction via denitrification and steel wool to promote phosphate reduction via adsorption/precipitation. This research investigated the effectiveness of these amendments to improve nutrient removal by comparing the performance of columns 3 and 4 with columns 1 and 2.

Summer (1:2 Year Events)

In both the first summer and second summer of simulated operation with an influent concentration of 150 mg TSS/L, 2 mg PO_4^{3-}-P/L, and 2 mg NH_4^+-N/L, each contaminant was reduced by all four media compositions and column configurations tested in this research. During this operation, the columns with soil media "A" (i.e. loam soil) and soil media "B" (i.e. sandy loam) and no nutrient removal amendment layers (i.e. columns 1 and 2, respectively) had satisfactory removal efficiency of TSS, phosphate, and ammonium, which were all $\geq$ 90% reduced.

TSS removal in columns 3 and 4 (soil media "A" (loam) and "B" (sandy loam), respectively, both with nutrient amendments) improved from the first summer to the second summer of simulated operation, likely due to:

- fines from woodchips completing washout from the media, or
- increased salt concentrations during winter and spring encouraging suspended solid flocculation and therefore removal.

Ammonia reduction in columns 3 and 4 was not as effective as in columns 1 and 2 likely due to ammonia leaching from the woodchips in the submerged zone or organic nitrogen from the woodchips and submerged zone media undergoing ammonification.

Phosphate was comparably well removed in columns 3 and 4 as in columns 1 and 2 for 1st and 2nd summer by being $\geq$ 85%. The steel wool amendment in columns 3 and 4 did not show enhanced phosphate removal during this experiment, likely due to the existing capacity of the soil media to adsorb/precipitate phosphate and the limitations to the experiment timeline; further, long term studies would be required to determine the impact of steel wool on phosphate removal.

Nitrate reduction due to denitrification was observed in the columns with an anoxic zone and supplemental carbon (i.e. columns 3 and 4) in both the first summer and second summer of simulated operation. During this stage, an influent concentration of 1.5 mg NO_3^--N/L was reduced to an average concentration $\leq$ 0.64 mg/L in both columns 3 and 4. Columns without an anoxic zone and supplemental carbon (i.e. columns 1 and 2) leached nitrate consistently (i.e. higher nitrate concentrations in the effluent than in the influent) due to the nutrient content of the fresh media and from nitrification of sorbed ammonia to nitrate during the drying period between simulated events.

Winter and spring runoff

If infiltration of snowmelt and runoff occurs during cold temperatures, physical removal of TSS, phosphate, and ammonium can still be achieved, even only days after the complete freezing (and subsequent thawing) of bioretention media at -20°C. During winter and one spring runoff event at an air temperature between 1-3°C and influent concentrations of 150 and 600 mg TSS/L, 2 and 8 mg PO_4^{3-}-P/L, and 2 and 8 mg NH_4^+-N/L, each contaminant was reduced by all four columns. All columns showed > 89.5% removal on average of TSS and > 85.7% removal on average of phosphate during winter and spring runoff. Columns

1 and 2 also showed good removal of ammonium in winter and spring runoff with > 83% removal; however, much like during summer operation, although still reduced, columns 3 and 4 exhibited worse performance of ammonium reduction due to woodchips in the anoxic zone.

Once the submerged zones in columns 3 and 4 were drained in preparation for winter operation and spring runoff, denitrification ceased and nitrate leached from the columns similarly to columns 1 and 2, that did not contain a submerged zone and supplemental carbon. However, after winter and spring runoff operation and once the submerged zone was reformed in columns 3 and 4, denitrifying bacteria rebounded within only two weeks to almost original nitrate reduction performance.

Chloride did not appear to accumulate in any column over the duration of this experiment. There was an initial period of chloride leaching from the media, but once stabilized, the effluent chloride concentration was approximately the same as the influent chloride concentration, implying that chloride is very mobile through bioretention media and therefore not likely retained.

1:5 year and 1:10 year events

During the single 1:5 year and single 1:10 year storm events, TSS, phosphate, and ammonium, were reduced by all four columns. The application of 1:5 year and 1:10 year events showed acceptable removal efficiencies of TSS, phosphate, and ammonium through all four columns, just as in the first and second summer, with ≥ 90% reduction of TSS, phosphate, and ammonium. The only exception was ammonium through columns 3 and 4 due to the woodchips in the anoxic zone causing higher leaching of ammonium from the media. Also, although nitrate was still removed, nitrate reduction through the columns with the anoxic zone and supplemental carbon (i.e. columns 3 and 4) decreased to ≥ 59.8% during the slightly larger volume events

Metals

Although metals were not the focus of this study and there was a flaw in earlier influent sample analysis, it can still be concluded that copper, zinc, lead, and cadmium were well retained by all four columns under the conditions analyzed in this study, which include some of first summer operation, the first flush of spring runoff, and the 1:10 year storm event. This retention is likely due to the high organic content and cation exchange capacity (CEC) of the media used.

5.2 Significance of these Findings

Based on the first summer and second summer of simulated operation, the difference in porosity between soil media "A" (i.e. loam) and "B" (i.e. sandy loam) does not hinder the physical removal of TSS, phosphate, and ammonium nor the biological removal of nitrate. Therefore, based on 1.6 years of equivalent Edmonton precipitation volume, both media types are viable options for application in Edmonton bioretention systems to enhance certain water quality parameters. However, long term operation is required to confirm these findings. Practically, if cost savings are the main goal of a field site, the loam soil "A" could be selected due to the lower cost for sand; conversely, if a greater infiltration rate is required, the sandy loam media "B" could be used. Also shown in the TSS results is the need for effective pretreatment design, especially in climates like Edmonton that experience heavy winter road maintenance.

These findings also show that if nitrate removal is an important goal of bioretention, then the tradeoff will be reduced efficiency of TSS removal during the first year of operation and of ammonium removal. Although TSS and ammonium are still removed, to combat this reduced efficiency, a fast flow filter could be installed in the underdrain to minimize effluent TSS and an alternative supplemental carbon source or woodchip type that leaches less ammonium and organic nitrogen could be investigated for use in place of the cedar woodchips used in this experiment.

This research also shows the potential for bioretention to have functionality in winter during intermittent warming periods that might permit infiltration into the soil. During these periods, removal of TSS, phosphate, ammonium, and metals can be achieved. Currently, bioretention is not intended to perform while freezing temperatures exist; this research shows that this assumption may be invalid and that bioretention might provide year-round stormwater management. Also, the results of this study show that high chloride concentrations applied during winter and spring runoff are mobile and therefore do not appear to be retained within bioretention media. Although road salts are still an issue for downstream surface and ground water reservoirs, this research showed little to no impact on water quality improvement through bioretention media used in this study. Therefore, bioretention could be a viable stormwater management technology for even arterial roadways if effective TSS pretreatment is present to combat the heavier sand loads entering the facility. However, as vegetation did not grow back after winter and spring runoff operation and long-term operation was not investigated, this conclusion must be validated with further experiments.

Preliminary results from the application of slightly larger volumes (i.e. the single 1:5 year and 1:10 year event) show that water quality improvement performance is not eliminated. This shows that bioretention does not necessarily only need to be designed to treat 1:2 year events but that bioretention facilities could have capacity to manage even larger volume events. Based on these water quality improvement results, if bioretention can at least still manage the first flush from a flood event, then downstream water quality degradation might be minimized. However, more frequent and larger volume events need to be applied and evaluated to determine long term impacts to the biotic and abiotic structures of bioretention.

5.3 Lessons learned

As all fresh media types used in this research contain certain concentrations of the stormwater contaminants that are intended for treatment, careful selection and placement of media and amendments must be taken. All columns exhibited a period of leaching of nitrate, organic matter as measured by COD, and chloride. Minimum amounts of compost were placed only in the top layer of the bioretention columns in this research which helped to eliminate phosphate leachate; however, the nitrate leachate could only be prevented via denitrification. This compost application technique should be implemented in the field if compost must be used. If bioretention is to be implemented in a highly sensitive watershed, perhaps different media types should be considered for use and/or the media should be thoroughly washed, and the effluent collected and treated offsite before the bioretention facility is commissioned to treat actual onsite stormwater runoff.

Due to inexperience with vegetation, the grasses used in this research did not grow back after winter and spring runoff operation. This is likely due to insufficient time provided for cold hardening and intracellular ice crystal formation killing the plants. It is unlikely that the winter salts impacted the vegetation due to chloride's high mobility through the soil; however, further study is required to determine the actual impact of winter salts on plant regrowth and soil salinity when proper vegetation care is taken.

5.4 Future Research

Although this research has filled some gaps of knowledge regarding implementation of bioretention to treat stormwater in cold climates such as Edmonton's, further study is required to confirm and improve on these findings. This research shows important findings after only 1.6 years' worth of equivalent Edmonton precipitation volume; however, as bioretention systems should be designed for a lifetime of approximately 20 years, long-term operation and investigation is required to evaluate the change in hydraulic performance, as discussed in Li's (2018) thesis, and the change in water quality improvement over extended periods of time, as well as due to variable climates caused by climate change. As the dominant removal process determined in this research is physical removal, there will likely be a removal capacity that the media will ultimately reach. Further research is required to determine this lifetime of the media and investigate whether concentrations in the media will reach toxic levels; perhaps regular maintenance of the bioretention systems (i.e. replacement of vegetation and surface media and mulch) will be sufficient to prevent concentration levels from becoming highly toxic or perhaps more intensive remediation techniques will be required. End-of-life disposal requirements have not been evaluated in depth anywhere due to the relative youth of bioretention as a best management practice for stormwater management.

The roles that vegetation and high salt concentration application during winter and spring runoff operation play on bioretention performance were also not determined in this research; research is needed to determine appropriate, local species of vegetation that not only enhance hydraulic performance due to root development and water uptake, but that also grow excellent rhizobia bacteria populations for nitrogen fixation or are hyperaccumulators of heavy metals. The impact that influent stormwater pollutants have on local vegetation was also not determined in this research but is required to enhance local bioretention vegetation selection.

The use of compost in bioretention or other low impact development technologies can be controversial. There are obvious benefits to utilizing compost as a bioretention amendment, such as enhancing plant establishment and health, improving water holding capacity, and acting as a method of municipal waste storage. However, this research has shown that even when sparingly applied to the surface layer of bioretention, compost still contributes considerably to the leachate of various stormwater contaminants. Further investigation is needed to evaluate the use of compost in bioretention and the possibility for alternative, eco-friendly sources of plant fertilizer or the cost effectiveness of a targeted fertilization program. Thorough and long-term stormwater runoff sampling and analysis at a site could give insight into the mass and frequency of influent plant fertilizers (i.e nitrogen and phosphorus in the influent runoff) to determine whether and how much compost or alternative fertilization amendments would be required in a bioretention system.

References

Amrhein C, Strong J E, and Mosher P A. 1992. Effect of deicing salts on metal and organic matter mobilization in roadside soils. *Environmental Science & Technology*, **26**(4): 703.

Antoniadis V and Alloway B J. 2001. Availability of Cd, Ni and Zn to ryegrass in sewage sludge-treated soils at different temperatures. *Water, Air, and Soil Pollution*, **132**(3): 201-214.

APHA. 2018. *Standard methods for the examination of water and wastewater, 23rd edition.* American Public Health Association, Washington, DC, United States.

Ashworth J and Mrazek K. 1995. "Modified Kelowna" test for available phosphorus and potassium in soil. *Communications in Soil Science & Plant Analysis*, **26**(5&6): 731-739.

ASTM International. 2004. ASTM C117-04 Standard test method for materials finer than 75-um (No. 200) sieve in mineral aggregates by washing. [online]. Available from <https://doi-org.login.ezproxy.library.ualberta.ca/10.1520/C0117-17> [Cited 09 November 2018].

Bäckström M and Viklander M. 2000. Integrated stormwater management in cold climates. *Journal of Environmental Science and Health, Part A*, **35**(8): 1237-1249.

Bäckström M, Karlsson S, Bäckman L, Folkeson L, and Lind B. 2004. Mobilisation of heavy metals by deicing salts in a roadside environment. *Water Research*, **38**(3): 720-732.

Ball D F. 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. *Journal of Soil Science*, **15**(1): 84-92.

Barrett M E, Limouzin M, and Lawler D F. 2013. Effects of media and plant selection on biofiltration performance. *Journal of Environmental Engineering*, **139**(4): 462-470.

Barrow N J and Shaw T C. 1975. The slow reactions between soil and anions: 2. Effect of time and temperature on the decrease in phosphate concentration in the soil solution. *Soil Science*, **119**(2): 167-177.

BC Ministry of Environment. 2009. Strong acid leachable metals (SALM) in soil, version 2.0. Contaminated Sites Regulation - Analytical Method 8. Lands and Parks, British Columbia Ministry of Environment.

Benjamin M M. 2002. *Water chemistry: Water resources and environmental engineering*. McGraw-Hill, New York, United States.

Bernhard A. 2010. The nitrogen cycle: processes, players, and human impact. *Nature Education*, **3**(10): 25.

Blecken G T, Zinger Y, Muthanna T M, Deletic A, Fletcher T D, and Viklander M. 2007. The influence of temperature on nutrient treatment efficiency in stormwater biofilter systems. *Water Science and Technology*, **56**(10): 83-91.

Blecken G T, Zinger Y, Deletic A, Fletcher T D, and Viklander M. 2009a. Impact of a submerged zone and a carbon source on heavy metal removal in stormwater biofilters. *Ecological Engineering*, **35**(5): 769-778.

Blecken G T, Zinger Y, Deletic A, Fletcher T D, and Viklander M. 2009b. Influence of intermittent wetting and drying conditions on heavy metal removal by stormwater biofilters. *Water Research*, **43**(18): 4590-4598.

Blecken G T, Zinger Y, Deletic A, Fletcher T D, Hedstrom A, and Viklander M. 2010. Laboratory study on stormwater biofiltration: nutrient and sediment removal in cold temperatures. *Journal of Hydrology*, **394**(3-4): 507-514.

Blecken G T, Marsalek J, and Viklander M. 2011. Laboratory study of stormwater biofiltration in low temperatures: total and dissolved metal removals and fates. *Water Air and Soil Pollution*, **219**(1-4): 303-317.

Bradl H B. 2004. Adsorption of heavy metal ions on soils and soils constituents. *Journal of Colloid and Interface Science*, **277**(1): 1-18.

Bratieres K, Fletcher T D, Deletic A, and Zinger Y. 2008. Nutrient and sediment removal by stormwater biofilters: a large-scale design optimisation study. *Water Research*, **42**(14): 3930-3940.

Bremer P J and Geesey G G. 1993. *Interactions of bacteria with metals in the aquatic environment*. Lewis Publishers, Boca Raton, Florida, United States: 41-63.

Brown R A and Hunt W F. 2011. Impacts of media depth on effluent water quality and hydrologic performance of undersized bioretention cells. *Journal of Irrigation and Drainage Engineering*, **137**(3): 132-143.

Brown R A and Hunt W F. 2012. Improving bioretention/biofiltration performance with restorative maintenance. *Water Science and Technology*, **65**(2): 361-367.

Calmano W, Ahlf W, and Bening J C. 1992. Chemical mobility and bioavailability of sediment-bound heavy metals influenced by salinity. *Hydrobiologia*, **235**(1): 605-610.

Castaldi P, Demurtas D, Silvetti M, Deiana S, and Garau G. 2017. Interaction of the water soluble fraction of MSW-composts with Pb(II) and Cu(II) ions. *Journal of Environmental Management*, **192**: 39-47.

Clark S and Pitt R. 2011. Filtered metals control in stormwater using engineered media. *In Proceedings of World Environmental and Water Resources Congress: Bearing Knowledge for Sustainability*. ASCE, Palm Springs, California, United States, 22-26 May 2011.

CoE (City of Edmonton). 2000. Combined sewer overflow (CSO) strategy. Asset Management and Public Works, Drainage Services, City of Edmonton, Edmonton, Alberta.

CoE (City of Edmonton). 2008. Stormwater quality control strategy and action plan. City of Edmonton, Edmonton, Alberta.

CoE (City of Edmonton). 2009. Total loadings plan (TLP). City of Edmonton, Edmonton, Alberta.

CoE (City of Edmonton). 2011. The way we green - the City of Edmonton's environmental strategic plan. City of Edmonton, Edmonton, Alberta.

CoE (City of Edmonton). 2014a. Low Impact Development Best Management Practices Design Guide. City of Edmonton, Edmonton, Alberta. Edition 1.1: 1-269.

CoE (City of Edmonton). 2014b. Drainage Design and Construction Standards. City of Edmonton, Edmonton, Alberta. Volume 3: 1-129.

CoE (City of Edmonton). 2016. Winter street sand recycling and mixing program audit. Office of the City Auditor, City of Edmonton, Edmonton, Alberta.

CoE (City of Edmonton). 2017. Landscaping Design and Construction Standards. City of Edmonton, Edmonton, Alberta. Volume 5: 1-275.

CoE (City of Edmonton). 2018. Anti-icing pilot program. City of Edmonton. [online]. Available from <https://www.edmonton.ca/transportation/on_your_streets/anti-icing-pilot-program.aspx> [Cited 09 November 2018].

Davis A and Burns M. 1999. Evaluation of lead concentration in runoff from painted structures. *Water Research*, **329**: 215-229.

Davis A P, Shokouhian M, and Shubei N. 2001. Loading estimates of lead, copper, cadmium and zinc in urban runoff from specific sources. *Chemosphere*, **44**(5): 997.

Davis A P, Shokouhian M, Sharma H, Minami C, and Winogradoff D. 2003. Water quality improvement through bioretention: Lead, copper, and zinc removal. *Water Environment Research*, **75**(1): 73-82.

Davis A P. 2008. Field performance of bioretention: hydrology impacts. *Journal of Hydrologic Engineering*, **13**(2): 90-95.

Davis A P, Hunt W F, Traver R G, and Clar M. 2009. Bioretention technology: overview of current practice and future needs. *Journal of Environmental Engineering*, **135**(3): 109-117.

Dean C M, Sansalone J J, Cartledge F K, and Pardue J H. 2005. Influence of hydrology on rainfall-runoff metal element speciation. *Journal of Environmental Engineering*, **131**(4): 632-642.

Denich C, Bradford A, and Drake J. 2013. Bioretention: assessing effects of winter salt and aggregate application on plant health, media clogging and effluent quality. *Water Quality Research Journal of Canada*, **48**(4): 387-399.

Denich C J. 2009. Assessing the performance of bioretention under cold climate conditions. Dissertation for the Master Degree (MR52218), Guelph: University of Guelph, Ontario.

DER (Department of Environmental Resources). 2007. Bioretention Manual. Department of Environmental Resources, Prince George's County, Maryland, United States.

DeVoe H. 2017. Phase diagrams: Binary systems. Chemistry LibreTexts. [online]. Available from <https://chem.libretexts.org/Textbook_Maps/Physical_and_Theoretical_Chemistry_Textbook_Maps/DeVoe%27s_%22Thermodynamics_and_Chemistry%22/13%3A_The_Phase_Rule_and_Phase_Diagrams/13.2_Phase_Diagrams%3A_Binary_Systems> [Cited 09 November 2018].

Dietz M E. 2007. Low impact development practices: a review of current research and recommendations for future directions. *Water Air and Soil Pollution*, **186**(1-4): 351-363.

Dietz M E and Clausen J C. 2005. A field evaluation of rain garden flow and pollutant treatment. *Water Air and Soil Pollution*, **167**(1-4): 123-138.

Dodds W, Bouska W, Eitzmann J, Pilger T, Pitts K, Riley A, Schloesser J, and Thornbrugh D. 2009. Eutrophication of U.S. freshwaters: analysis of potential economic damages. *Environmental Science & Technology*, **43**(1): 12-19.

EC (Environment Canada). 2004. Code of practice for environmental management of road salts. Environment Canada, Ottawa, Ontario.

EC&HC. 2001. Priority substances list assessment report: road salts. Environment Canada and Health Canada, Ottawa, Ontario.

Elizabeth F. 2012. Stormwater BMP treatment performance variability for sediment and heavy metals. *Separation and Purification Technology*, **84**: 95-103.

Endreny T, Burke D J, Burchhardt K M, Fabian M W, and Kretzer A M. 2012. Bioretention column study of bacteria community response to salt-enriched artificial stormwater. *Journal of Environmental Quality*, **41**(6): 1951-1959.

Erickson A J, Gulliver J S, and Weiss P T. 2007. Enhanced sand filtration for storm water phosphorus removal. *Journal of Environmental Engineering*, **133**(5): 485-497.

Erickson A J, Gulliver J S, and Weiss P T. 2012. Capturing phosphates with iron enhanced sand filtration. *Water Research*, **46**(9): 3032-3042.

Fletcher T, Zinger Y, Deletic A, and Bratières K. 2007. Treatment efficiency of biofilters; results of a large-scale column study. *In Proceedings of Rainwater and Urban Design*. Engineers Australia, Sydney, Australia, 21-23 August 2007.

Fritioff Å, Kautsky L, and Greger M. 2005. Influence of temperature and salinity on heavy metal uptake by submersed plants. *Environmental Pollution*, **133**(2): 265-274.

Gardner B R and Jones J P. 1973. Effects of temperature on phosphate sorption isotherms and phosphate desorption. *Communications in Soil Science & Plant Analysis*, **4**(2): 83-93.

Géhéniau N, Fuamba M, Mahaut V, Gendron M R, and Dugué M. 2015. Monitoring of a rain garden in cold climate: case study of a parking lot near Montreal. *Journal of Irrigation and Drainage Engineering*, **141**(6): 04014073.

GoC (Government of Canada). 2018a. Canadian climate normals 1981-2010 station data: Edmonton city centre a station. Government of Canada. [online]. Available from <http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnProv&lstProvince=AB&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=1867&dispBack=0> [Cited 09 November 2018].

GoC (Government of Canada). 2018b. Canadian climate normals 1981-2010 station data: Toronto station. Government of Canada. [online]. Available from <http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnProv&lstProvince=ON&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=5051&dispBack=0> [Cited 09 November 2018].

Goodison B E, Louie P Y T, and Metcalfe J R. 1986. Snowmelt acidic shock study in South Central Ontario. *Water, Air, and Soil Pollution*, **31**(1): 131-138.

Groenendyk D G, Ferré T P A, Thorp K R, and Rice AK. 2015. Hydrologic-process-based soil texture classifications for improved visualization of landscape function. *PLoS ONE*, **10**(6): e0131299.

Gray G G, Chauvin L P, Sarhan F, and Huner N P A. 1997. Cold acclimation and freezing tolerance. *Plant Physiology*, **114**(2): 467-474.

Hatt B E, Fletcher T D, and Deletic A. 2008. Hydraulic and pollutant removal performance of fine media stormwater filtration systems. *Environmental Science & Technology*, **42**(7): 2535-2541.

Hatt B E, Steinel A, Deletic A, and Fletcher T. 2011. Retention of heavy metals by stormwater filtration systems: Breakthrough analysis. *Water Science and Technology*, **64**(9): 1913-1919.

He Z X and Davis A P. 2011. Process modeling of storm-water flow in a bioretention cell. *Journal of Irrigation and Drainage Engineering*, **137**(3): 121-131.

Henderson C, Greenway M, and Phillips I. 2007. Removal of dissolved nitrogen, phosphorus and carbon from stormwater by biofiltration mesocosms. *Water Science and Technology*, **55**(4): 183-191.

Hoban A T and Kennedy K. 2012. Community perceptions of raingardens in residential streets at bellvista estate. *In Proceedings of the 7th International Conference on Water Sensitive Urban Design: Building the Water Sensitive Community*, Engineers Australia, Melbourne, Australia, 21-23 February 2012: 362-369.

Hong E Y, Seagren E A, and Davis A P. 2006. Sustainable oil and grease removal from synthetic stormwater runoff using bench-scale bioretention studies. *Water Environment Research*, **78**(2): 141-155.

Hooda P S and Alloway B J. 1993. Effects of time and temperature on the bioavailability of Cd and Pb from sludge-amended soils. *Journal of Soil Science*, **44**(1): 97-110.

House W A, Jickells T D, Edwards A C, Praska K E, and Denison F H. 1998. Reactions of phosphorus with sediments in fresh and marine waters. *Soil Use and Management*, **14**: 139-146.

Hsieh C H, Davis A P, and Needelman B A. 2007. Bioretention column studies of phosphorus removal from urban stormwater runoff. *Water Environment Research*, **79**(2): 177-184.

Hunt W F, Jarrett A R, Smith J T, and Sharkey L J. 2006. Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. *Journal of Irrigation and Drainage Engineering*, **132**(6): 600-608.

Jia H F, Yao H R, and Yu S L. 2013. Advances in LID BMPs research and practice for urban runoff control in China. *Frontiers of Environmental Science & Engineering*, **7**(5): 709-720.

Juang T C, Wang M K, Chen H J, and Tan C C. 2001. Ammonium fixation by surface soils and clays. *Soil Science*, **166**(5): 345-352.

Khan U T. 2011. Bioretention cell efficacy in cold climates. Dissertation for the Master Degree (MR75226), Calgary: University of Calgary, Alberta, Canada.

Khan U T, Valeo C, Chu A, and van Duin B. 2012a. Bioretention cell efficacy in cold climates: part 2-water quality performance. *Canadian Journal of Civil Engineering*, **39**(11): 1222-1233.

Khan U T, Valeo C, Chu A, and van Duin B. 2012b. Bioretention cell efficacy in cold climates: part 1-hydrologic performance. *Canadian Journal of Civil Engineering*, **39**(11): 1210-1221.

Kim H H, Seagren E A, and Davis A P. 2003. Engineered bioretention for removal of nitrate from stormwater runoff. *Water Environment Research*, **75**(4): 355-367.

Kottek M, Grieser J, Beck C, Rudolf B, and Rubel F. 2006. World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, **15**(3): 259-263.

Kratky H, Li Z, Chen Y, Wang C, Li X, and Yu Y. 2017. A critical literature review of bioretention research for stormwater management in cold climate and future research recommendations. *Frontiers of Environmental Science & Engineering*, **11**(4): 16 (11-15).

Kroetsch D and Wang C. 2008. Particle size distribution. Hydrometer method 55.3. In M R Carter and E G Gregorich (Eds), *Soil sampling and methods of analysis*, 2nd Edition. CRC Press, Boca Raton, Florida, United States: 713-725.

Le Coustumer S, Fletcher T D, Deletic A, and Barraud S. 2007. Hydraulic performance of biofilters for stormwater management: first lessons from both laboratory and field studies. *Water Science and Technology*, **56**(10): 93-100.

Le Coustumer S, Fletcher T D, Deletic A, Barraud S, and Poelsma P. 2012. The influence of design parameters on clogging of stormwater biofilters: a large-scale column study. *Water Research*, **46**(20): 6743-6752.

Ledin M. 2000. Accumulation of metals by microorganisms - processes and importance for soil systems. *Earth-Science Reviews*, **51**(1–4): 1-31.

LeFevre N J, Davidson J D, and Oberts G L. 2009. Bioretention of simulated snowmelt: cold climate performance and design criteria. *In Proceedings of the 14th Conference on Cold Regions Engineering 2009: Cold Regions Impact on Research, Design, and Construction*. ASCE, Duluth, Minnesota, United States, 31 August - 2 September, 2009.

Lei, L. 2018. Refining compost recommendations for stormwater control measures. ASCE World Environmental and Water Resources Congress Conference Presentation. [online]. Available from <https://www.eventscribe.com/2018/ASCE-EWRI/agenda.asp?day=6/6/2018&theday=Wednesday&h=Wednesday%20%20June%206&BCFO=P|G> [Cited 09 November 2018].

Leisenring M, Clary J, Stephenson J, Hobson P, Earles A, Quigley M, Streets B, and Strecker E. 2010. International stormwater best management practices (BMP) database pollutant category summary: nutrients. Geosyntec Consultants, Inc and Wright Water Engineers, Inc. WERF, ASCE, EWRI, APWA, FHWA, U.S. EPA.

Li H and Davis A P. 2008. Heavy metal capture and accumulation in bioretention media. *Environmental Science & Technology*, **42**(14): 5247-5253.

Li H and Davis A P. 2009. Water quality improvement through reductions of pollutant loads using bioretention. *Journal of Environmental Engineering*, **135**(8): 567-576.

Li Z. 2018. Laboratory study on the hydraulic performance of bioretention for stormwater management in cold climates. Dissertation for the Master Degree. Edmonton: University of Alberta, Alberta, Canada.

Lim H S, Lim W, Hu J Y, Ziegler A, and Ong S L. 2015. Comparison of filter media materials for heavy metal removal from urban stormwater runoff using biofiltration systems. *Journal of Environmental Management*, **147**: 24-33.

Lucas J S and Hunt W F. 2005. Hydrologic and water quality performance of four bioretention cells in central North Carolina. *In Proceedings of Managing Watersheds for Human and Natural Impacts Conference: Engineering, Ecological, and Economic Challenges*. ASCE, Williamsburg, Virginia, United States, 19-22 July 2005.

Lucas W C and Greenway M. 2008. Nutrient retention in vegetated and nonvegetated bioretention mesocosms. *Journal of Irrigation and Drainage Engineering*, **134**(5): 613-623.

Lucas W C and Greenway M. 2011a. Phosphorus retention by bioretention mesocosms using media formulated for phosphorus sorption: response to accelerated loads. *Journal of Irrigation and Drainage Engineering*, **137**(3): 144-153.

Lucas W C and Greenway M. 2011b. Hydraulic response and nitrogen retention in bioretention mesocosms with regulated outlets: part II - nitrogen retention. *Water Environment Research*, **83**(8): 703-713.

Malek E. 1992. Night-time evapotranspiration vs. daytime and 24 h evapotranspiration. *Journal of Hydrology*, **138**(1-2): 119-129.

Malhi S S and McGill W B. 1982. Nitrification in three Alberta soils: effect of temperature, moisture and substrate concentration. *Soil Biology and Biochemistry*, **14**(4): 393-399.

Marsalek J. 2003. Road salts in urban stormwater: an emerging issue in stormwater management in cold climates. *Water Science and Technology*, **48**(9): 61-70.

Marschner H. 1995. *Mineral nutrition of higher plants.* 2nd edition. Academic Press, San Diego, California, United States.

Mayer T, Snodgrass W J, and Morin D. 1999. Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments. *Water Quality Research Journal of Canada*, **34**(4): 545-574.

Maynard D G, Kalra Y P, and Crumbaugh J A. 2008. Chapter 6: Nitrate and exchangeable ammonium nitrogen. In M R Carter and E G Gregorich (Eds), *Soil sampling and methods of analysis*, 2nd Edition. CRC Press, Boca Raton, Florida, United States: 71-80.

McKeague J A. 1978. *Manual on soil sampling and methods of analysis*. 2nd edition. Canadian Society of Soil Science, Ottawa, Ontario.

Melbourne Water. 2005. *Water Sensitive Urban Design (WSUD) Engineering Procedures - Stormwater*. CSIRO Publishing, Collingwood, Australia.

Moghadas S, Gustafsson A M, Viklander P, Marsalek J, and Viklander, M. 2016. Laboratory study of infiltration into two frozen engineered (sandy) soils recommended for bioretention. *Hydrological Processes*, **30**(8): 1251-1264.

Muthanna T M. 2007. Bioretention as a sustainable stormwater management option in cold climates. Dissertation for the Doctoral Degree. Trondheim: Norwegian University of Science and Technology, Norway.

Muthanna T M, Viklander M, Gjesdahl N, and Thorolfsson S T. 2007a. Heavy metal removal in cold climate bioretention. *Water Air and Soil Pollution*, **183**(1-4): 391-402.

Muthanna T M, Viklander M, and Thorolfsson S T. 2007b. An evaluation of applying existing bioretention sizing methods to cold climates with snow storage conditions. *Water Science and Technology*, **56**(10): 73-81.

Muthanna T M, Viklander M, Blecken G, and Thorolfsson S T. 2007c. Snowmelt pollutant removal in bioretention areas. *Water Research*, **41**(18): 4061-4072.

Muthanna T M, Viklander M, and Thorolfsson S T. 2008. Seasonal climatic effects on the hydrology of a rain garden. *Hydrological Processes*, **22**(11): 1640-1649.

Nelson D W and Sommers L E. 1982. Chapter 29: Total carbon, organic carbon and organic matter. In A L Page, R H Miller, and D R Keeney (Eds), *Methods of soil analysis. Part 2. Chemical and microbiological properties*, 2nd Edition. American Society of Agronomy, Madison, Wisconsin, United States: 539-579.

Norrström A C and Bergstedt E. 2001. The impact of road de-icing salts (NaCl) on colloid dispersion and base cation pools in roadside soils. *Water, Air, and Soil Pollution*, **127**(1): 281-299.

NRAL. 2012. Total organic carbon, nitrogen method summary. University of Alberta Natural Resources Analytical Laboratory. [online]. Available from <https://nral.ualberta.ca/nral/wp-content/uploads/sites/75/2018/08/TotalOrganicCarbonNitrogenMethodSummary2012.docx> [Cited 09 November 2018].

NRCC. 2014. *Alberta Building Code* - Volume 2, Ninth Ed. NRCC (National Research Council Canada), Ottawa, Canada.

Nyle C B and Ray R W. 2008. *The nature and properties of soils*. Pearson Prentice Hall, Columbus, Ohio, United States.

O'Neill S W. 2010. Use of drinking water treatment residuals as a soil amendment for stormwater nutrient treatment. Dissertation for the Master Degree (1482504). College Park: University of Maryland, Maryland, United States.

Oberts G L. 1986. Pollutants associated with sand and salt applicated to roads in Minnesota. *Journal of the American Water Resources Association*, **22**(3): 479-483.

Oberts G L. 2003. Cold climate BMPs: solving the management puzzle. *Water Science and Technology*, **48**(9): 21-32.

Olson K W and Skorgerboe R K. 1975. Identification of soil lead compounds from automotive sources. *Environmental Science & Technology*, **9**(3): 227-230.

Palhegyi G E. 2010. Modeling and sizing bioretention using flow duration control. *Journal of Hydrologic Engineering*, **15**(6): 417-425.

Palmer E T. 2012. Nitrate and phosphate removal through an optimized bioretention system. Dissertation for the Master Degree. Pullman: Washington State University, Washington, United States.

Paus K H, Morgan J, Gulliver J S, Leiknes T and Hozalski R M. 2014a. Assessment of the hydraulic and toxic metal removal capacities of bioretention cells after 2 to 8 years of service. *Water Air and Soil Pollution,* **225**(1): 1-12.

Paus K H, Morgan J, Gulliver J S, Leiknes T, and Hozalski R M. 2014b. Effects of temperature and NaCl on toxic metal retention in bioretention media. *Journal of Environmental Engineering*, **140**(10): 04014034.

Paus K H, Morgan J, Gulliver J S, and Hozalski R M. 2014c. Effects of bioretention media compost volume fraction on toxic metals removal, hydraulic conductivity, and phosphorous release. *Journal of Environmental Engineering*, **140**(10): 04014033.

Paus K H, Muthanna T M, and Braskerud B C. 2016. The hydrological performance of bioretention cells in regions with cold climates: seasonal variation and implications for design. *Hydrology Research*, **47**(2): 291-304.

Payne E G I, Fletcher T D, Russell D G, Grace M R, Cavagnaro T R, Evrard V, Deletic A, Hatt B E, and Cook P L M. 2014. Temporary storage or permanent removal? The division of nitrogen between biotic assimilation and denitrification in stormwater biofiltration systems. *PLoS ONE*, **9**(3): 1-12.

Peel M C, Finlayson B L, and McMahon T A. 2007. Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, **11**(5): 1633-1644.

Peterson I J, Igielski S, and Davis A P. 2015. Enhanced denitrification in bioretention using woodchips as an organic carbon source. *Journal of Sustainable Water in the Built Environment*, **1**(4): 04015004.

Ping L, and Tao Y. 2011. Low impact development design for urban stormwater management - a case study in USA. *In Proceedings of the International Symposium on Water Resource and Environmental Protection (ISWREP)*. IEEE, Xi'an Shi, China, 20-22 May 2011.

Ponizovsky A A, Thakali S, Allen H E, Di Toro D M, and Ackerman A J. 2006. Effect of soil properties on copper release in soil solutions at low moisture content. *Environmental Toxicology and Chemistry*, **25**(3): 671-682.

Ramakrishna D M and Viraraghavan T. 2005. Environmental impact of chemical deicers – a review. *Water, Air, and Soil Pollution*, **166**(1): 49-63.

Read J, Fletcher, T D, Wevill T, and Deletic A. 2010. Plant traits that enhance pollutant removal from stormwater in biofiltration systems. *International Journal of Phytoremediation*, **12**(1): 34-53.

Reay D S, Nedwell D B, Priddle J, and Ellis-Evans J C. 1999. Temperature dependence of inorganic nitrogen uptake: reduced affinity for nitrate at suboptimal temperatures in both algae and bacteria. *Applied and Environmental Microbiology*, **65**(6): 2577-2584.

Rieuwerts J S, Thornton I, Farago M E, and Ashmore M R. 1998. Factors influencing metal bioavailability in soils: preliminary investigations for the development of a critical loads approach for metals. *Chemical Speciation and Bioavailability*, **10**(2): 61-75.

Roseen R M, Ballestero T P, Houle J J, Avellaneda P, Briggs J, Fowler G, and Wildey R. 2009. Seasonal performance variations for storm-water management systems in cold climate conditions. *Journal of Environmental Engineering*, **135**(3): 128-137.

Roy-Poirier A, Champagne P, and Filion Y. 2010. Bioretention processes for phosphorus pollution control. *Environmental Reviews*, **18**: 159-173.

Russell C A, Fillery I R P, Bootsma N, and McInnes K J. 2002. Effect of temperature and nitrogen source on nitrification in a sandy soil. *Communications in Soil Science and Plant Analysis*, **33**(11-12): 1975-1989.

Søberg L C, Viklander M, and Blecken G T. 2014. The influence of temperature and salt on metal and sediment removal in stormwater biofilters. *Water Science and Technology*, **69**(11): 2295-2304.

Søberg L C, Viklander M, and Blecken G T. 2017. Do salt and low temperature impair metal treatment in stormwater bioretention cells with or without a submerged zone? *Science of the Total Environment*, **579**: 1588-1599.

Stefanakis A, Akratos C S, and Tsihrintzis V A. 2014. Chapter 5: Treatment processes in VFCWs. In *Vertical flow constructed wetlands: Eco-engineering systems for wastewater and sludge treatment.* Elsevier Science, Amsterdam, Netherlands: 57-84.

Stephens D B, Miller M, Moore S J, Umstot T, and Salvato D J. 2012. Decentralized groundwater recharge systems using roofwater and stormwater runoff. *Journal of the American Water Resources Association*, **48**(1): 134-144.

Stoeckeler J H and Weitzman S. 1960. Infiltration rates in frozen soils in northern Minnesota. *Soil Science Society America Journal*, **24**(2): 137-139.

Suarez D L, Wood J D, and Lesch S M. 2008. Infiltration into cropped soils: effect of rain and sodium adsorption ratio-impacted irrigation water. *Journal of Environmental Quality*, **37**(5_Supp): S169-S179.

Sun X. 2004. Dynamic study of heavy metal fates in bioretention systems. Dissertation for the Master Degree (1421420). College Park: University of Maryland, Maryland, United States.

Szota C, Farrell C, Livesley S J, and Fletcher T D. 2015. Salt tolerant plants increase nitrogen removal from biofiltration systems affected by saline stormwater. *Water Research*, **83**: 195-204.

Taiz L, Zeiger E, Møller I M, and Murphy A S. 2015. Plant physiology and development. Sinauer Associates, Inc., Sunderland, Massachusetts, United States.

Temminghoff E J M, van der Zee S E A T M, and Hann F A M. 1997. Copper mobility in a copper-contaminated sandy soil as affected by pH and solid and dissolved organic matter. *Environmental Science & Technology*, **31**(4): 1109-1115.

Treese D P, Clark S E, and Baker K H. 2012. Nutrient release from disturbance of infiltration system soils during construction. *Advances in Civil Engineering*, **2012**:1-7.

Tremante V J. 2005. The effects of organic soil amendments in bioretention soil mixes on the removal of total petroleum hydrocarbons. Dissertation for the Master Degree. Columbus: The Ohio State University, Ohio, United States.

Trowsdale S A and Simcock R. 2011. Urban stormwater treatment using bioretention. *Journal of Hydrology*, **397**(3-4): 167-174.

Urban Systems Ltd. 2012. River for life strategic framework. Drainage Services, Environmental Planning, City of Edmonton, Edmonton, Alberta.

U.S. EPA. 1994. Method 200.8: Determination of trace elements in waters and wastes by inductively couple plasma-mass spectrometry. Revision 5.4. United States Environmental Protection Agency. Cincinnati, Ohio, United States.

U.S. EPA. 1999. Preliminary data summary of urban storm water best management practices. United States Environmental Protection Agency. Report EPA 821-R99-012, Aug.

U.S. EPA. 2000. National water quality inventory - 1998 report to congress. Office of Water, United States Environmental Protection Agency, Washington, DC, United States.

Viklander M and Malmqvist P A. 1993. Melt water from snow deposits. *In Proceedings of the 6th International Conference on Urban Storm Drainage*. IAHR and IAWQ, Niagara Falls, Ontario, 12-17 September 1993.

Wang B, Lehmann J, Hanley K, Hestrin R, and Enders A. 2015. Adsorption of desorption of ammonium by maple wood biochar as a function of oxidation and pH. *Chemosphere*, **138**: 120-126.

Warren L A and Zimmerman A P. 1994. The influence of temperature and NaCl on cadmium, copper and zinc partitioning among suspended particulate and dissolved phases in an urban river. *Water Research*, **28**(9): 1921-1931.

Warren L A and Haack E A. 2001. Biogeochemical controls on metal behaviors in freshwater environments. *Earth-Science Reviews*, **54**(4): 261-320.

Wasielewski S, Rott E, Minke R, and Steinmetz H. 2018. Evaluation of different clinoptilolite zeolites as adsorbent for ammonium removal from highly concentrated synthetic wastewater. *Water*, **10**(5): 584.

Weiss P, LeFevre G, and Gulliver J. 2008. Contamination of soil and groundwater due to stormwater infiltration practices - A literature review. University of Minnesota Stormwater Assessment Project Report No. 515. Minnesota Pollution Control Agency, St. Paul, Minnesota, United States.

Westerlund C and Viklander M. 2006. Particles and associated metals in road runoff during snowmelt and rainfall. *Science of the Total Environment*, **362**(1–3): 143-156.

Williams D D, Williams N E, and Cao Y. 2000. Road salt contamination of groundwater in a major metropolitan area and development of a biological index to monitor its impact. *Water Research*, **34**(1): 127-138.

Yan Q, James B R, and Davis A P. 2017. Lab-scale column studies for enhanced phosphorus sorption from synthetic urban stormwater using modified bioretention media. *Journal of Environmental Engineering*, **143**(1): 1-13.

Yang H B, McCoy E L, Grewal P S, and Dick W A. 2010. Dissolved nutrients and atrazine removal by column-scale monophasic and biphasic rain garden model systems. *Chemosphere*, **80**(8): 929-934.

Yao K M, Habibian M T, and O'Melia C R. 1971. Water and waste water filtration. Concepts and applications. *Environmental Science & Technology*, **5**(11): 1105-1112.

Yin Y, Impellitteri C A, You S J, and Allen H E. 2002. The importance of organic matter distribution and extract soil:solution ratio on the desorption of heavy metals from soils. *Science of the Total Environment*, **287**(1–2): 107-119.

Yousef Y, Harper H, Wiseman L, and Bateman J. 1985. Consequential species of heavy metals in highway runoff. Tranportation Research Record, 1017, Transportation Research Board, Washington, DC, United States: 56-62.

Yu M. 2016. Discharge improvement zone study phase II - Final report: 307075-01668-1601-EN-REP-0001. Advisian Worley Parsons Group, City of Edmonton, Edmonton, Alberta.

Yuan B C, Li Z Z, Liu H, Gao M, and Zhang Y Y. 2007. Microbial biomass and activity in salt affected soils under arid conditions. *Applied Soil Ecology*, **35**(2): 319-328.

Zhang Z, Rengel Z, Liaghati T, Antoniette T, and Meney K. 2011. Influence of plant species and submerged zone with carbon addition on nutrient removal in stormwater biofilter. *Ecological Engineering*, **37**(11): 1833-1841.

Zhang Z, Rengel Z, Liaghati T, Torre A, and Meney K. 2014. Influence of plant species and submerged zone with carbon addition on the removal of metals by stormwater biofilters. *Desalination and Water Treatment*, **52**(22-24): 4282-4291.

Zynnovation LLC. 2018. TreeDiaper®. [online]. Available from <https://www.treediaper.com/index.cfm.> [Cited 10 November 2018].

Appendix A: Experimental Setup Details

Table 30: Details of products used in this research and their supplier.

Product Details	**Supplier**
Class B Topsoil (i.e. 18% sand, 49% silt, and 33% clay, therefore classified as silty clay loam as shown in Figure 11).	IWG Soil Products
Sil 8 Sand	Edmonton Sil Industrial Minerals
Second Nature Compost by the City of Edmonton	Edmonton East Burnco Landscape Centre (formerly Canar Rock Products)
Medium Wood Bark Woodchips	Edmonton East Burnco Landscape Centre (formerly Canar Rock Products)
Steel Wool Grade #00: Very Fine (product #042-9815-8)	Canadian Tire
7 mm Washed Rock (part number SW5033)	Edmonton East Burnco Landscape Centre (formerly Canar Rock Products)
40 mm Round Rock (part number SW1324)	Edmonton East Burnco Landscape Centre (formerly Canar Rock Products)
Large Columns (custom)	CME Shop, South Academic Building, University of Alberta
Water Distribution Apparatus (custom)	CME Shop, South Academic Building, University of Alberta
SunBlaster™ 18” Fluorescent 6400K, 1581 Lumens Lamps (model EDJT5-117L-NAO)	All Seasons Garden Centre
Heavy Metal Blue Switch Grass or *Panicum virgatum ‘Heavy Metal’*	Millcreek Nursery Ltd.
VIVOSUN 5-Pack 10 Gallons Heavy Duty Thickened Nonwoven Fabric Pots Grow Bags with Handles (Amazon Standard Identification Number B00VWU30PO)	Amazon.ca
MasterFlex® L/S® 6-600 RPM Peristaltic Pumps: including modular drive and pump head (product number RK-07557-00 and RK-07516-00, respectively)	Cole Parmer
MasterFlex® L/S® 1-100 RPM Peristaltic Pumps: including modular drive and pump head (product number RK-7553-80 and RK-77800-60, respectively)	Cole Parmer
Fisherbrand™ Clear PVC Influent Tubing (1/8”, 1/4”, and 3/8” inner diameter) (size depending on flow rate requirements) (product number 14-169-7A, 14-169-7C, and 14-169-7G, respectively)	Fisher Scientific
7 gallon pails and lids for influent and effluent synthetic stormwater (product number S-16969S and S-20541)	Uline
50mL Centrifuge tubes for sample collection (catalogue number 06-443-18)	Fisher Scientific

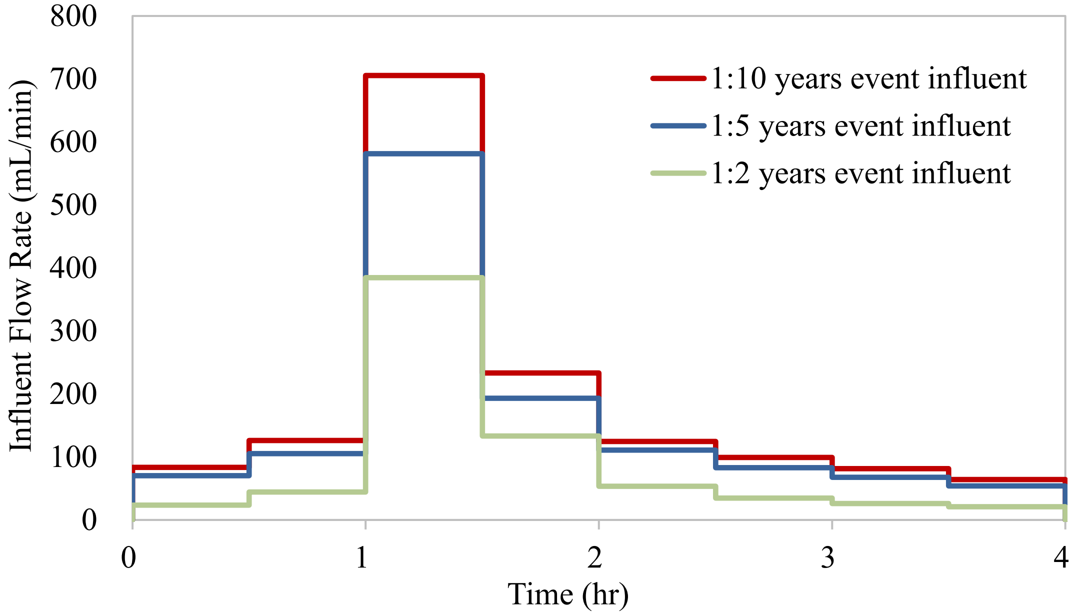


Figure 51: Influent hydrographs for the three storm frequencies used in this research.

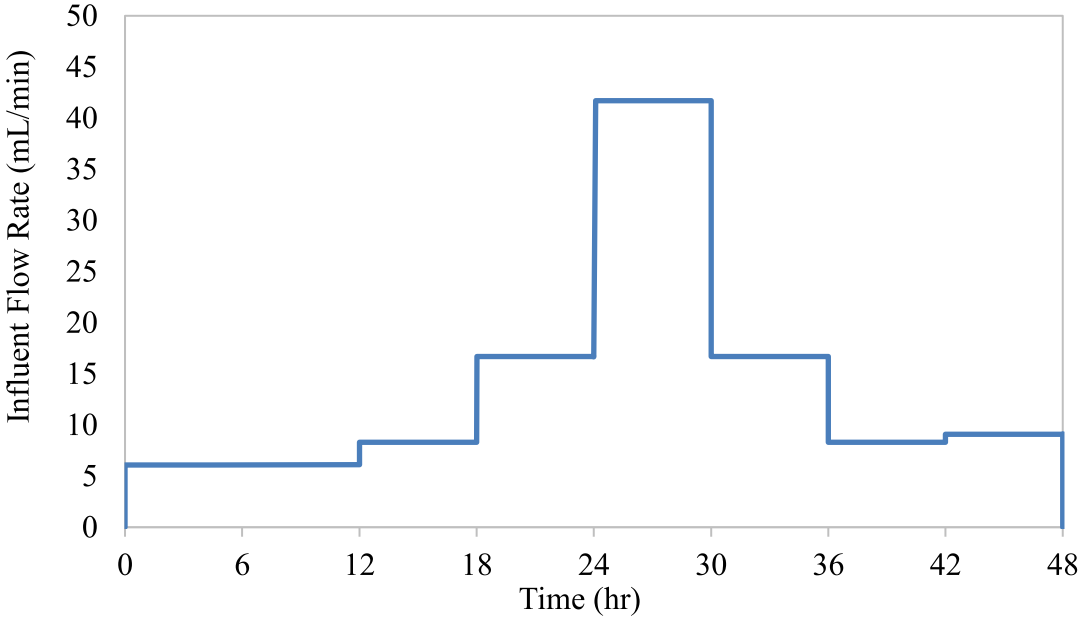


Figure 52: Influent hydrograph for the low concentration, high volume "major melt" spring runoff event.

Appendix B: Raw and Intermittent Data

This appendix contains the raw data both in tabular and graphical format. The purpose of including the data in graphical format is to help the reader to better appreciate the data and explore further details from the thesis text. The graphical format of the data may show slight trends between events but the averages over seasons or stages of operation are more valuable to analyze in terms of the practical application of bioretention systems, rather than data of one specific event. This is because bioretention systems are designed to mature and change over time, physically, chemically, and biologically. Therefore, the following information belongs to the Appendix only and any important trends seen in this data are captured and discussed in the body of this thesis.

Table 31: TSS influent and effluent concentrations and percentage concentration reduction for columns 1 and 2.

Week	Date	Column 1						Column 2					
		Description	Solids weight (g)	Volume (mL)	TSS Concentration (mg/L)	Standard Deviation	Average TSS Concentration (mg/L)	Description	Solids weight (g)	Volume (mL)	TSS Concentration (mg/L)	Standard Deviation	Average TSS Concentration (mg/L)
1	2017-09-26	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0024	200	12	1.70	9.67	Effluent	0.0086	500	17.2	1.15	16.05
			0.0018	200	9				0.0072	1000	14.9		
			0.0016	200	8				0.0077				
		Concentration Reduction	94%					Concentration Reduction	89%				
2	2017-10-10	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0026	756	3.44	0.97	4.79	Effluent	0.0088	700	12.57	0.47	13.24
			0.0036	688	5.23				0.0095	700	13.57		
			0.0042	737	5.70				0.0095	700	13.57		
		Concentration Reduction	97%					Concentration Reduction	91%				
3	2017-10-17	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0046	900	5.11	0.42	5.56	Effluent	0.0105	802	13.09	0.43	13.20
			0.0049	900	5.44				0.0109	856	12.73		
			0.0055	900	6.11				0.0095	690	13.77		
		Concentration Reduction	96%					Concentration Reduction	91%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
4	2017-10-24	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0036	1000	3.60	0.43	3.80	Effluent	0.0112	800	14	2.51	10.50
			0.0044	1000	4.40				0.0066	800	8.25		
			0.0034	1000	3.40				0.0074	800	9.25		
		Concentration Reduction	97%					Concentration Reduction	93%				
5	2017-10-30	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0055	1190	4.62	0.18	4.79	Effluent	0.0093	1000	9.30	0.42	9.18
			0.0056	1190	4.71				0.0077	800	9.63		
			0.006	1190	5.04				0.0069	800	8.62		
		Concentration Reduction	97%					Concentration Reduction	94%				
6	2017-11-06	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.005	1050	4.76	0.00	4.76	Effluent	0.0052	850	6.12	0.39	5.84
			0.005	1050	4.76				0.0052	850	6.12		
			0.005	1050	4.76				0.0045	850	5.29		
		Concentration Reduction	97%					Concentration Reduction	96%				
7	2017-11-14	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0035	1000	3.50	0.05	3.53	Effluent	0.0049	800	6.125	0.33	5.96
			0.0036	1000	3.60				0.005	800	6.25		
			0.0035	1000	3.50				0.0044	800	5.5		
		Concentration Reduction	98%					Concentration Reduction	96%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
8	2017-11-20	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0036	1000	3.60	0.21	3.63	Effluent	0.006	800	7.5	0.41	6.92
			0.0039	1000	3.90				0.0053	800	6.625		
			0.0034	1000	3.40				0.0053	800	6.625		
		Concentration Reduction	98%					Concentration Reduction	95%				
9	2017-11-27	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0037	1000	3.70	0.14	3.60	Effluent	0.0039	800	4.875	0.12	4.79
			0.0037	1000	3.70				0.0039	800	4.875		
			0.0034	1000	3.40				0.0037	800	4.625		
		Concentration Reduction	98%					Concentration Reduction	97%				
10	2017-12-04	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0026	1000	2.60	0.05	2.67	Effluent	0.0042	800	5.25	0.16	5.08
			0.0027	1000	2.70				0.0039	800	4.875		
			0.0027	1000	2.70				0.0041	800	5.125		
		Concentration Reduction	98%					Concentration Reduction	97%				
11	2017-12-11	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0029	1000	2.90	0.05	2.87	Effluent	0.0037	800	4.625	0.36	4.67
			0.0028	1000	2.80				0.0034	800	4.25		
			0.0029	1000	2.90				0.0041	800	5.125		
		Concentration Reduction	98%					Concentration Reduction	97%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
12	2017-12-18	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0056	1500	3.73	0.05	3.80	Effluent	0.0032	800	4	0.62	3.50
			0.0057	1500	3.80				0.0031	800	3.875		
			0.0058	1500	3.87				0.0021	800	2.625		
		Concentration Reduction	97%					Concentration Reduction	98%				
13	2017-12-26	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0064	1500	4.27	0.03	4.24	Effluent	0.0044	1000	4.4	0.73	3.93
			0.0064	1500	4.27				0.0045	1000	4.5		
			0.0063	1500	4.20				0.0029	1000	2.9		
		Concentration Reduction	97%					Concentration Reduction	97%				
14	2018-01-02	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0085	1500	5.67	0.11	5.62	Effluent	0.0045	1000	4.5	0.12	4.67
			0.0086	1500	5.73				0.0047	1000	4.7		
			0.0082	1500	5.47				0.0048	1000	4.8		
		Concentration Reduction	96%					Concentration Reduction	97%				
15	2018-01-08	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0036	1500	2.40	0.14	2.58	Effluent	0.0026	1000	2.6	0.12	2.47
			0.0039	1500	2.60				0.0023	1000	2.3		
			0.0041	1500	2.73				0.0025	1000	2.5		
		Concentration Reduction	98%					Concentration Reduction	98%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
16	2018-01-15	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0095	1500	6.33	1.58	4.11	Effluent	0.0027	1200	2.25	0.07	2.25
			0.0043	1500	2.87				0.0026	1200	2.17		
			0.0047	1500	3.13				0.0028	1200	2.33		
		Concentration Reduction	97%					Concentration Reduction	99%				
17	2018-01-23	Influent	-	-	0	-	0	Influent	-	-	0	-	0
		Effluent	0.0058	1500	3.87	0.08	3.96	Effluent	0.0073	1500	4.87	0.30	4.51
			0.0059	1500	3.93				0.0068	1500	4.53		
			0.0061	1500	4.07				0.0062	1500	4.13		
		Concentration Reduction	n/a					Concentration Reduction	n/a				
19	2018-02-09	Influent	-	-	0	-	0	Influent	-	-	0	-	0
		Effluent	0.0015	3000	0.50	0.00	0.50	Effluent	0.0123	1933	6.36	0.51	6.56
			0.0015	3000	0.50				0.0121	2000	6.05		
			-	-	-	-	-		0.0145	1998	7.26		
		Concentration Reduction	n/a					Concentration Reduction	n/a				
21	2018-02-20	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0058	3000	1.93	0.05	1.93	Effluent	0.0028	3000	0.93	0.09	1.00
			0.006	3000	2.00				0.0028	3000	0.93		
			0.0056	3000	1.87				0.0034	3000	1.13		
		Concentration Reduction	99%					Concentration Reduction	99%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
23	2018-03-09	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.009	2000	4.50	0.12	4.33	Effluent	0.0143	2000	7.15	1.27	5.38
			0.0085	2000	4.25				0.0085	2000	4.25		
			0.0085	2000	4.25				0.0095	2000	4.75		
		Concentration Reduction	97%					Concentration Reduction	96%				
27	2018-04-02	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0039	2000	1.95	0.09	2.02	Effluent	0.0062	1000	6.20	0.12	6.33
			0.0039	2000	1.95				0.0063	1000	6.30		
			0.0043	2000	2.15				0.0065	1000	6.50		
		Concentration Reduction	99%					Concentration Reduction	96%				
29	2018-04-16	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0046	3000	1.53	0.36	1.70	Effluent	0.0115	2000	5.75	0.12	5.92
			0.0041	3000	1.37				0.012	2000	6.00		
			0.0044	2000	2.20				0.012	2000	6.00		
		Concentration Reduction	99%					Concentration Reduction	96%				
32	2018-05-08	Influent	-	-	600	-	600	Influent	-	-	600	-	600
		Effluent	0.0122	2000	6.10	0.29	6.42	Effluent	0.0062	2000	3.10	0.04	3.05
			0.0136	2000	6.80				0.0061	2000	3.05		
			0.0127	2000	6.35				0.006	2000	3.00		
		Concentration Reduction	99%					Concentration Reduction	99%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
32	2018-05-10	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0082	3000	2.73	0.10	2.70	Effluent	0.0067	2000	3.35	0.08	3.23
			0.0064	2500	2.56				0.0064	2000	3.20		
			0.007	2500	2.80				0.0063	2000	3.15		
		Concentration Reduction	98%					Concentration Reduction	98%				
32	2018-05-12	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0044	3000	1.47	0.03	1.42	Effluent	0.0028	3000	0.93	0.13	0.81
			0.0042	3000	1.40				0.0019	3000	0.63		
			0.0049	3500	1.40				0.0026	3000	0.87		
		Concentration Reduction	99%					Concentration Reduction	99%				
37	2018-06-14	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.011	2000	5.50	0.22	5.81	Effluent	0.0102	1600	6.37	0.45	6.53
			0.009	1500	6.00				0.01	1400	7.14		
			0.0089	1500	5.93				0.0091	1500	6.07		
		Concentration Reduction	96%					Concentration Reduction	96%				
38	2018-06-21	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0107	2000	5.35	0.22	5.05	Effluent	0.0066	1000	6.60	0.08	6.70
			0.0097	2000	4.85				0.0067	1000	6.70		
			0.0084	1700	4.94				0.0068	1000	6.80		
		Concentration Reduction	97%					Concentration Reduction	96%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
39	2018-06-26	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0088	2000	4.40	0.37	4.90	Effluent	0.0088	1500	5.87	0.37	6.37
			0.01	2000	5.00				0.0108	1600	6.75		
			0.0106	2000	5.30				0.0089	1370	6.50		
		Concentration Reduction	97%					Concentration Reduction	96%				
40	2018-07-04	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0094	2000	4.70	0.24	5.03	Effluent	0.0102	2000	5.10	0.12	5.13
			0.0104	2000	5.20				0.01	2000	5.00		
			0.0104	2000	5.20				0.0106	2000	5.30		
		Concentration Reduction	97%					Concentration Reduction	97%				
41	2018-07-09	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0082	1700	4.82	0.14	5.00	Effluent	0.0097	2000	4.85	0.33	4.95
			0.0088	1700	5.18				0.0092	2000	4.60		
			0.0086	1725	4.99				0.0081	1500	5.40		
		Concentration Reduction	97%					Concentration Reduction	97%				

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
42	2018-07-16	Bucket 1 Influent	-	-	150	-	150	Bucket 1 Influent	-	-	150	-	150
		Bucket 1 Effluent	0.01	2000	5.00	0.06	5.08	Bucket 1 Effluent	0.012	2250	5.33	0.65	6.25
			0.0102	2000	5.10				0.0091	1370	6.64		
			0.0103	2000	5.15				0.009	1330	6.77		
		Concentration Reduction	97%					Concentration Reduction	96%				
		Bucket 2 Influent	-	-	150	-	150	Bucket 2 Influent	-	-	150	-	150
		Bucket 2 Effluent	0.0052	3290	1.58	0.08	1.52	Bucket 2 Effluent	0.0058	2170	2.67	0.18	2.63
			0.0042	3000	1.40				0.0061	2160	2.82		
			0.0047	3000	1.57				0.0048	2000	2.40		
		Concentration Reduction	99%					Concentration Reduction	98%				
		Effluent Bucket Average (mg/L)					3.58	Effluent Bucket Average (mg/L)					4.40
		Concentration Reduction Average					98%	Concentration Reduction Average					97%

Week	Date	Column 1						Column 2					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
43	2018-07-23	Bucket 1 Influent	-	-	150	-	150	Bucket 1 Influent	-	-	150	-	150
		Bucket 1 Effluent	0.0074	2000	3.70	0.14	3.72	Bucket 1 Effluent	0.0106	3000	3.53	0.23	3.73
			0.0078	2000	3.90				0.0081	2000	4.05		
			0.0071	2000	3.55				0.0072	2000	3.60		
		Concentration Reduction	98%					Concentration Reduction	98%				
		Bucket 2 Influent	-	-	150	-	150	Bucket 2 Influent	-	-	150	-	150
		Bucket 2 Effluent	0.0035	3000	1.17	0.04	1.18	Bucket 2 Effluent	0.0055	3000	1.83	0.25	1.88
			0.0034	3000	1.13				0.0048	3000	1.60		
			0.0037	3000	1.23				0.0066	3000	2.20		
		Concentration Reduction	99%					Concentration Reduction	99%				
		Effluent Bucket Average (mg/L)					2.24	Effluent Bucket Average (mg/L)					2.78
		Concentration Reduction Average					99%	Concentration Reduction Average					98%

Table 32: TSS influent and effluent concentrations and percentage concentration reduction for columns 3 and 4.

Week	Date	Column 3						Column 4					
		Description	Solids weight (g)	Volume (mL)	TSS Concentration (mg/L)	Standard Deviation	Average TSS Concentration (mg/L)	Description	Solids weight (g)	Volume (mL)	TSS Concentration (mg/L)	Standard Deviation	Average TSS Concentration (mg/L)
4	2017-10-24	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0057	358	15.92	3.80	21.29	Effluent	0.0059	162	36.42	1.00	36.16
			0.0085	352	24.15				0.0062	178	34.83		
			0.0085	357	23.81				0.007	188	37.23		
		Concentration Reduction	86%					Concentration Reduction	76%				
5	2017-10-30	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0031	300	10.33	0.79	10.89	Effluent	0.004	200	20.00	0.31	19.78
			0.0036	300	12.00				0.0029	150	19.33		
			0.0031	300	10.33				0.003	150	20.00		
		Concentration Reduction	93%					Concentration Reduction	87%				
6	2017-11-06	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0037	61	60.66	8.02	49.55	Effluent	0.005	150	33.33	5.72	37.70
			0.0023	50	46.00				0.0051	111.4	45.78		
			0.0021	50	42.00				0.0051	150	34.00		
		Concentration Reduction	67%					Concentration Reduction	75%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
7	2017-11-14	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0073	97	75.26	6.26	76.26	Effluent	0.005	101	49.5	3.01	46.67
			0.0108	128	84.38				0.0085	200	42.5		
			0.0056	81	69.14				0.0072	150	48		
		Concentration Reduction	49%					Concentration Reduction	69%				
8	2017-11-20	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0062	150	41.33	7.46	51.22	Effluent	0.0059	171.5	34.4	1.72	34.40
			0.0089	150	59.33				0.0062	192	32.29		
			0.0053	100	53.00				0.0073	200	36.5		
		Concentration Reduction	66%					Concentration Reduction	77%				
9	2017-11-27	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0057	106	53.77	0.58	54.59	Effluent	0.0049	150	32.67	1.09	32.67
			0.0055	100	55.00				0.0051	150	34		
			0.0055	100	55.00				0.0047	150	31.33		
		Concentration Reduction	64%					Concentration Reduction	78%				
10	2017-12-04	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0036	59	61.02	1.57	58.84	Effluent	0.0046	100	46	6.74	39.19
			0.0034	58.5	58.12				0.0048	115.5	41.56		
			0.0033	57.5	57.39				0.0045	150	30		
		Concentration Reduction	61%					Concentration Reduction	74%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
11	2017-12-11	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.009	150	60.00	1.66	58.22	Effluent	0.0053	150	35.33	1.44	37.33
			0.0084	150	56.00				0.0057	150	38		
			0.0088	150	58.67				0.0058	150	38.67		
		Concentration Reduction	61%					Concentration Reduction	75%				
12	2017-12-18	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0056	100	56.00	1.63	56.00	Effluent	0.0056	150	37.33	1.13	36.89
			0.0058	100	58.00				0.0053	150	35.33		
			0.0054	100	54.00				0.0057	150	38		
		Concentration Reduction	63%					Concentration Reduction	75%				
13	2017-12-26	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0064	100	64.00	7.85	55.33	Effluent	0.0075	150	50	6.54	42.22
			0.0045	100	45.00				0.0064	150	42.67		
			0.0057	100	57.00				0.0051	150	34		
		Concentration Reduction	63%					Concentration Reduction	72%				
14	2018-01-02	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0047	100	47.00	8.34	58.67	Effluent	0.0046	101	45.54	1.16	43.91
			0.0066	100	66.00				0.0043	100	43		
			0.0063	100	63.00				0.0054	125	43.2		
		Concentration Reduction	61%					Concentration Reduction	71%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
15	2018-01-08	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.006	154	38.96	0.27	39.34	Effluent	0.0103	397	25.94	2.98	22.39
			0.0066	167	39.52				0.0069	370	18.65		
			0.0068	172	39.53				0.0065	288	22.57		
		Concentration Reduction	74%					Concentration Reduction	85%				
16	2018-01-15	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0077	140	55.00	7.06	48.33	Effluent	0.0044	115	38.26	1.31	39.06
			0.0072	140	51.43				0.0054	132	40.91		
			0.0054	140	38.57				0.0046	121	38.02		
		Concentration Reduction	68%					Concentration Reduction	74%				
17	2018-01-23	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0043	100	43.00	3.40	47.67	Effluent	0.0082	270	30.37	0.54	30.35
			0.0051	100	51.00				0.0089	300	29.67		
			0.0049	100	49.00				0.0093	300	31.00		
		Concentration Reduction	68%					Concentration Reduction	80%				
18	2018-01-30	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0134	310	43.23	1.02	42.08	Effluent	0.0159	545	29.17	1.23	27.86
			0.0112	265	42.26				0.0148	525	28.19		
			0.0108	265	40.75				0.0156	595	26.22		
		Concentration Reduction	72%					Concentration Reduction	81%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
19	2018-02-08	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.009	238	37.82	7.11	33.13	Effluent	0.0088	205	42.93	2.73	45.61
			0.0045	195	23.08				0.009	202	44.55		
			0.0092	239	38.49				0.0115	233	49.36		
		Concentration Reduction	78%					Concentration Reduction	70%				
19	2018-02-09	Influent	-	-	0	-	0	Influent	-	-	0	-	0
		Effluent	0.0028	1000	2.80	0.45	2.20	Effluent	0.0068	1197	5.68	0.15	5.65
			0.0017	1000	1.70				0.0053	972	5.45		
			0.0021	1000	2.1				0.0056	962	5.82		
		Concentration Reduction	#DIV/0!					Concentration Reduction	#DIV/0!				
21	2018-02-20	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0034	1000	3.40	0.08	3.50	Effluent	0.0027	1000	2.70	0.09	2.57
			0.0036	1000	3.60				0.0025	1000	2.50		
			0.0035	1000	3.50				0.0025	1000	2.50		
		Concentration Reduction	98%					Concentration Reduction	98%				
23	2018-03-09	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.009	3000	3.00	0.18	3.03	Effluent	0.0052	2000	2.60	0.05	2.53
			0.0098	3000	3.27				0.005	2000	2.50		
			0.0085	3000	2.83				0.0075	3000	2.50		
		Concentration Reduction	98%					Concentration Reduction	98%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
27	2018-04-02	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0054	575	9.39	0.63	8.89	Effluent	0.0045	1300	3.46	0.24	3.13
			0.0065	700	9.29				0.0035	1200	2.92		
			0.0056	700	8.00				0.0045	1500	3.00		
		Concentration Reduction	94%					Concentration Reduction	98%				
29	2018-04-16	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0075	2000	3.75	0.21	3.98	Effluent	0.011	2000	5.50	0.15	5.72
			0.0079	2000	3.95				0.0116	2000	5.80		
			0.0085	2000	4.25				0.0117	2000	5.85		
		Concentration Reduction	97%					Concentration Reduction	96%				
32	2018-05-08	Influent	-	-	600	-	600	Influent	-	-	600	-	600
		Effluent	0.0054	1500	3.60	0.24	3.93	Effluent	0.0205	950	21.58	3.10	17.20
			0.0061	1500	4.07				0.0118	800	14.75		
			0.0062	1500	4.13				0.0107	700	15.29		
		Concentration Reduction	99%					Concentration Reduction	97%				
32	2018-05-10	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0036	200	18.00	0.41	17.50	Effluent	0.0024	100	24.00	2.24	20.92
			0.0034	200	17.00				0.002	100	20.00		
			0.0035	200	17.50				0.003	160	18.75		
		Concentration Reduction	88%					Concentration Reduction	86%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
32	2018-05-12	Influent	-	-	150	-	150	Influent	-	-	150	-	150
			0.0037	290	12.76				0.0026	280	9.29		
		Effluent	0.0037	300	12.33	0.37	12.31	Effluent	0.0029	250	11.60	0.95	10.46
			0.0032	270	11.85				0.0032	305	10.49		
		Concentration Reduction	92%					Concentration Reduction	93%				
37	2018-06-14	Influent	-	-	150	-	150	Influent	-	-	150	-	150
			0.0057	1000	5.70				0.0081	1400	5.79		
		Effluent	0.0049	1000	4.90	0.35	5.38	Effluent	0.0065	1100	5.91	0.55	6.23
			0.0072	1300	5.54				0.007	1000	7.00		
		Concentration Reduction	96%					Concentration Reduction	96%				
38	2018-06-21	Influent	-	-	150	-	150	Influent	-	-	150	-	150
			0.0053	750	7.07				0.0094	1000	9.40		
		Effluent	0.005	750	6.67	0.23	6.98	Effluent	0.0064	700	9.14	0.30	9.07
			0.0054	750	7.20				0.0052	600	8.67		
		Concentration Reduction	95%					Concentration Reduction	94%				
39	2018-06-26	Influent	-	-	150	-	150	Influent	-	-	150	-	150
			0.0051	1500	3.40				0.0041	885	4.63		
		Effluent	0.0049	1490	3.29	0.06	3.31	Effluent	0.0037	800	4.63	0.38	4.90
			0.0055	1690	3.25				0.0047	865	5.43		
		Concentration Reduction	98%					Concentration Reduction	97%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
40	2018-07-04	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0055	700	7.86	0.24	7.62	Effluent	0.0044	600	7.33	0.28	7.72
			0.0054	700	7.71				0.0043	550	7.82		
			0.0051	700	7.29				0.004	500	8.00		
		Concentration Reduction	95%					Concentration Reduction	95%				
41	2018-07-09	Influent	-	-	150	-	150	Influent	-	-	150	-	150
		Effluent	0.0048	1280	3.75	0.28	3.53	Effluent	0.0041	1000	4.10	0.44	3.74
			0.0044	1190	3.70				0.0025	800	3.12		
			0.0047	1500	3.13				0.0032	800	4.00		
		Concentration Reduction	98%					Concentration Reduction	98%				

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
42	2018-07-16	Bucket 1 Influent	-	-	150	-	150	Bucket 1 Influent	-	-	150	-	150
		Bucket 1 Effluent	0.0092	900	10.22	1.71	8.78	Bucket 1 Effluent	0.0033	800	4.12	0.35	4.37
			0.0078	800	9.75				0.0033	800	4.12		
			0.0051	800	6.37				0.0039	800	4.88		
		Concentration Reduction	94%					Concentration Reduction	97%				
		Bucket 2 Influent	-	-	150	-	150	Bucket 2 Influent	-	-	150	-	150
		Bucket 2 Effluent	0.0061	700	8.71	1.01	8.00	Bucket 2 Effluent	0.0041	700	5.86	0.13	5.76
			0.0061	700	8.71				0.0041	700	5.86		
			0.0046	700	6.57				0.0039	700	5.57		
		Concentration Reduction	95%					Concentration Reduction	96%				
		Effluent Bucket Average (mg/L)					8.38	Effluent Bucket Average (mg/L)					4.99
		Concentration Reduction Average					94%	Concentration Reduction Average					97%

Week	Date	Column 3						Column 4					
		Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)	Description	(g)	(mL)	(mg/L)	σ	Avg (mg/L)
43	2018-07-23	Bucket 1 Influent	-	-	150	-	150	Bucket 1 Influent	-	-	150	-	150
		Bucket 1 Effluent	0.003	1000	3.00	0.56	3.77	Bucket 1 Effluent	0.0024	1000	2.40	0.29	2.03
			0.0043	1000	4.30				0.002	1000	2.00		
			0.004	1000	4.00				0.0017	1000	1.70		
		Concentration Reduction	97%					Concentration Reduction	99%				
		Bucket 2 Influent	-	-	150	-	150	Bucket 2 Influent	-	-	150	-	150
		Bucket 2 Effluent	0.0046	1000	4.60	0.30	4.93	Bucket 2 Effluent	0.0035	1000	3.50	0.38	4.03
			0.0048	900	5.33				0.0033	760	4.34		
			0.0037	760	4.87				0.0034	800	4.25		
		Concentration Reduction	97%					Concentration Reduction	97%				
		Effluent Bucket Average (mg/L)					4.35	Effluent Bucket Average (mg/L)					3.26
		Concentration Reduction Average					97%	Concentration Reduction Average					98%

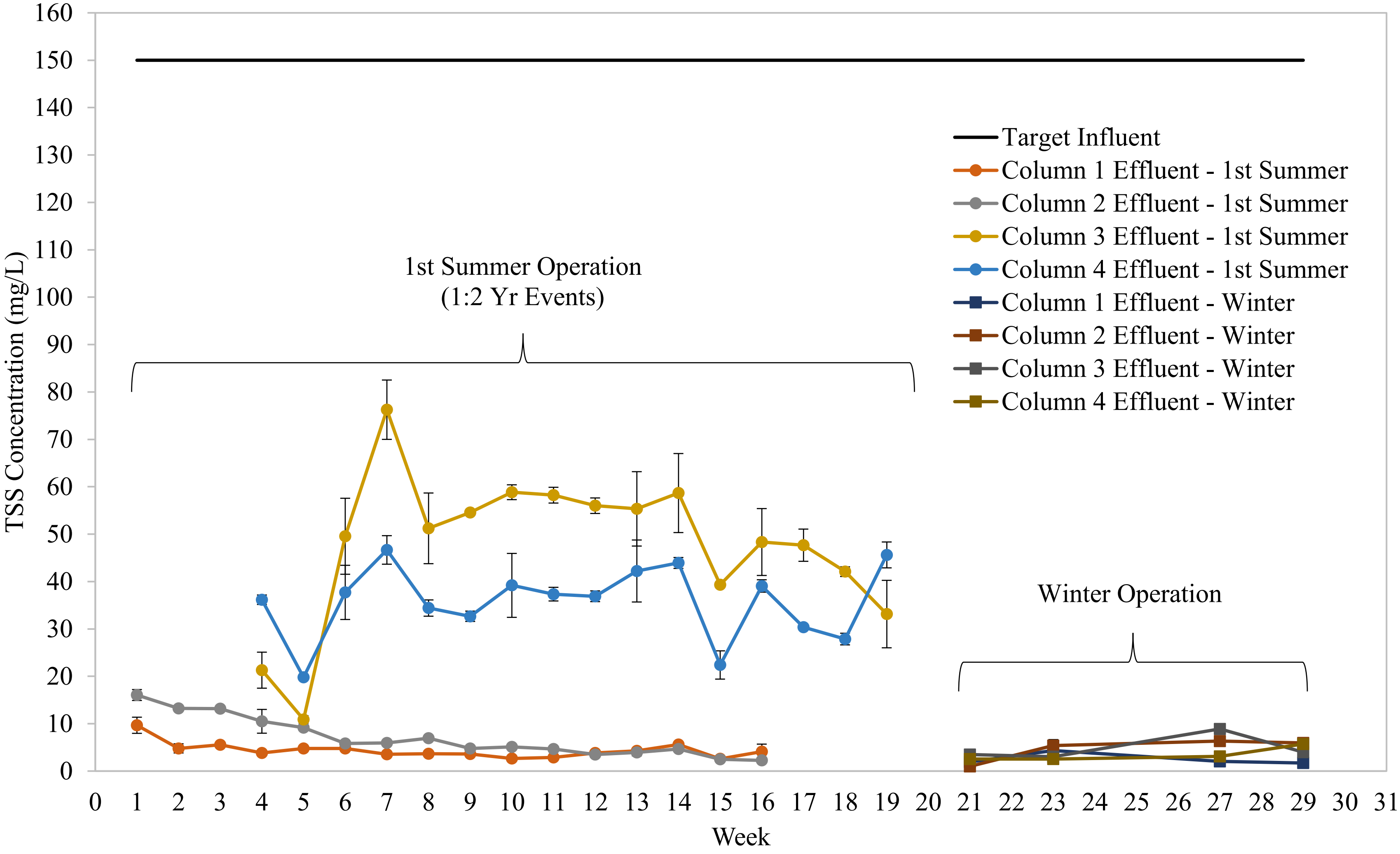


Figure 53: TSS concentration reduction during 1st summer and winter operation.

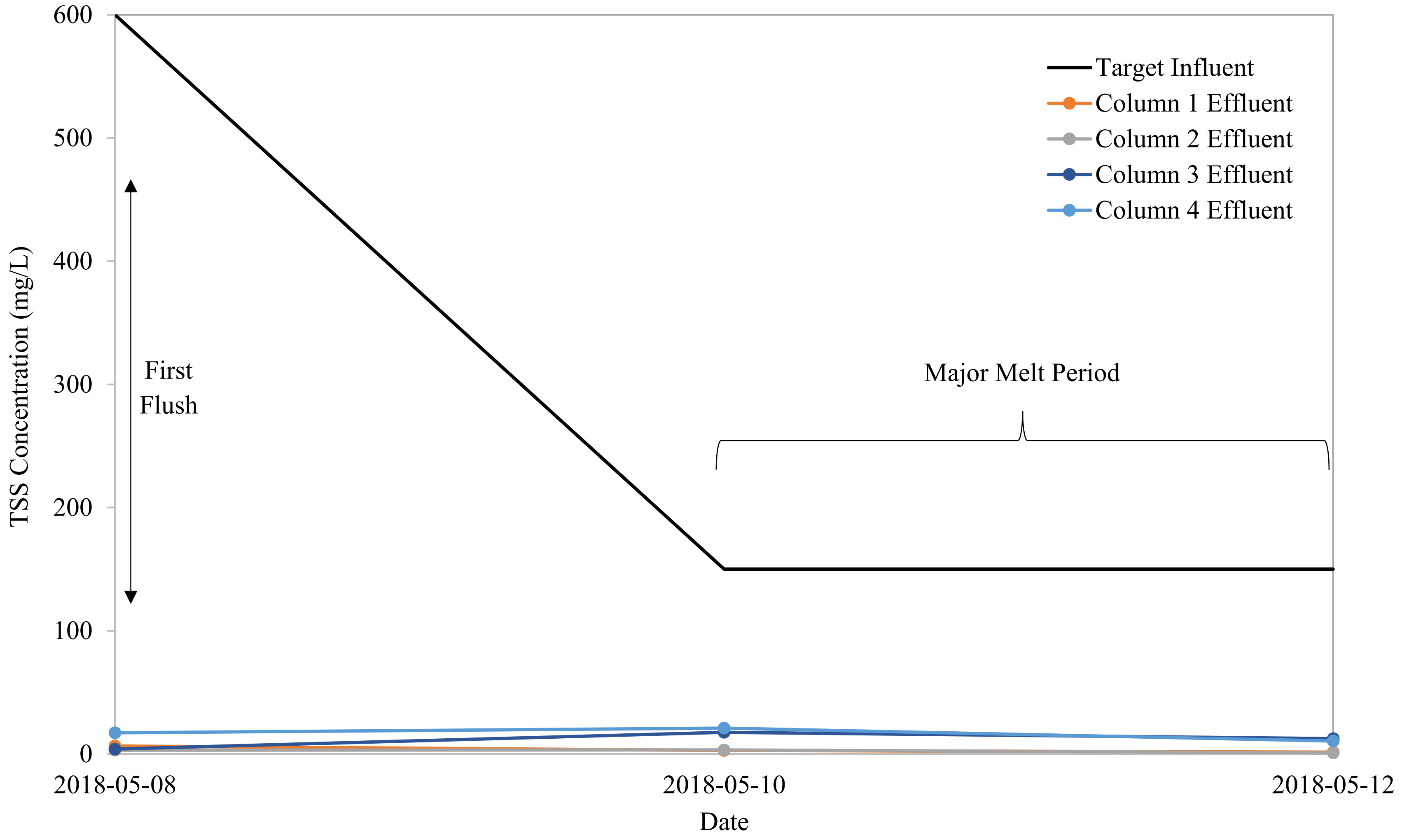


Figure 54:TSS concentration reduction during spring runoff.

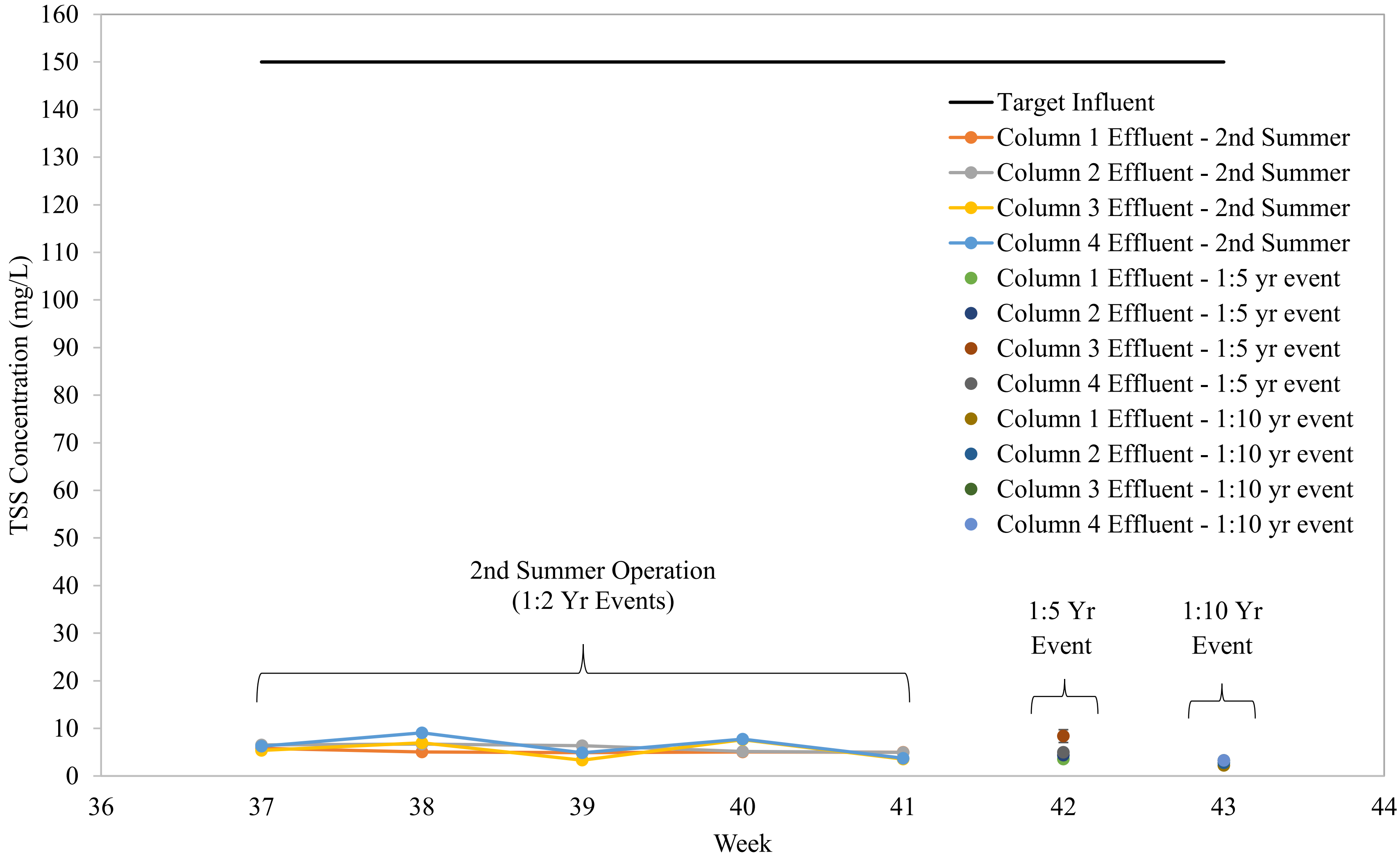


Figure 55:TSS concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events.

Table 33: Phosphate influent and effluent concentrations and percentage concentration reduction for columns 1 and 2.

Week	Date	Column 1					Column 2				
		Description	Phosphate Concentration (mg PO_4^{3-}/L)	Phosphate Concentration (mg PO_4^{3-}-P/L)	Standard Deviation	Average Phosphate Concentration (mg PO_4^{3-}-P/L)	Description	Phosphate Concentration (mg PO_4^{3-}/L)	Phosphate Concentration (mg PO_4^{3-}-P/L)	Standard Deviation	Average Phosphate Concentration (mg PO_4^{3-}-P/L)
1	2017-09-26	Influent	-	4.42	0.01	4.41	Influent	-	4.37	0.05	4.33
			-	4.40				-	4.28		
		Effluent	-	0.07[a]	n/a	0.07	Effluent	-	0.07[a]	n/a	0.07
			-	0.07[a]				-	0.07[a]		
		Concentration Reduction	98%				Concentration Reduction	98%			
2	2017-10-10	Influent	5.53	1.80	0.01	1.82	Influent	5.75	1.88	0.01	1.87
			5.60	1.83				5.72	1.87		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	0.02	0.09
			<LOQ [a]	0.07				0.31[a]	0.10		
		Concentration Reduction	96%				Concentration Reduction	95%			
3	2017-10-17	Influent	5.89[b]	1.92	0.05	1.97	Influent	5.88[b]	1.92	0.05	1.87
			6.18[b]	2.01				5.58[b]	1.82		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	0.35[a]	0.11	0.01	0.11
			<LOQ [a]	0.07				0.30[a]	0.10		
		Concentration Reduction	96%				Concentration Reduction	94%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
4	2017-10-24	Influent	4.37[b]	1.42	0.15	1.28	Influent	5.08[b]	1.66	0.09	1.75
			3.48[b]	1.13				5.64[b]	1.84		
		Effluent	0.40[b]	0.13	n/a	0.13	Effluent	0.47[b]	0.15	0.01	0.14
			n/a	n/a				0.39[b]	0.13		
		Concentration Reduction	90%				Concentration Reduction	92%			
5	2017-10-30	Influent	4.75[c]	1.55	0.01	1.56	Influent	4.81[c]	1.57	0.03	1.54
			4.82[c]	1.57				4.61[c]	1.50		
		Effluent	0.13[c]	0.04	0.00	0.04	Effluent	0.13[c]	0.04	0.00	0.05
			0.12[c]	0.04				0.16[c]	0.05		
		Concentration Reduction	97%				Concentration Reduction	97%			
6	2017-11-06	Influent	5.21[c]	1.70	0.00	1.70	Influent	5.08[c]	1.66	0.01	1.66
			5.19[c]	1.69				5.13[c]	1.67		
		Effluent	0.13[c]	0.04	0.01	0.05	Effluent	0.12[c]	0.04	0.00	0.04
			0.17[c]	0.06				0.13[c]	0.04		
		Concentration Reduction	97%				Concentration Reduction	98%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
7	2017-11-14	Influent	7.04[c]	2.30	0.04	2.33	Influent	5.36[c]	1.75	0.01	1.75
			7.26[c]	2.37				5.40[c]	1.76		
		Effluent	0.17[c]	0.06	0.00	0.06	Effluent	0.00[c]	0.00	0.00	0.04
			0.17[c]	0.06				0.11[c]	0.04		
		Concentration Reduction	98%				Concentration Reduction	98%			
8	2017-11-20	Influent	6.74	2.20	0.01	2.21	Influent	6.59	2.15	0.03	2.18
			6.82	2.23				6.79	2.21		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	0.42[a]	0.14	0.01	0.14
			<LOQ [a]	0.07				0.46[a]	0.15		
		Concentration Reduction	97%				Concentration Reduction	93%			
9	2017-11-27	Influent	6.78	2.21	0.00	2.21	Influent	6.59	2.15	0.00	2.15
			6.76	2.21				6.59	2.15		
		Effluent	0.28[a]	0.09	0.01	0.08	Effluent	0.30[a]	0.10	0.00	0.10
			<LOQ [a]	0.07				0.32[a]	0.11		
		Concentration Reduction	96%				Concentration Reduction	95%			
10	2017-12-04	Influent	6.46	2.11	0.01	2.12	Influent	6.30	2.05	0.05	2.01
			6.54	2.13				6.00	1.96		
		Effluent	1.12[a]	0.37	0.00	0.36	Effluent	0.93[a]	0.30	0.12	0.19
			1.10[a]	0.36				<LOQ [a]	0.07		
		Concentration Reduction	83%				Concentration Reduction	91%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
11	2017-12-11	Influent	5.92	1.93	0.07	1.86	Influent	5.90	1.92	0.01	1.93
			5.51	1.80				5.96	1.94		
		Effluent	0.87[a]	0.28	0.01	0.29	Effluent	0.33[a]	0.11	0.00	0.11
			0.93[a]	0.30				0.35[a]	0.11		
		Concentration Reduction	84%				Concentration Reduction	94%			
12	2017-12-18	Influent	6.60	2.15	0.02	2.17	Influent	6.68	2.18	0.01	2.16
			6.72	2.19				6.59	2.15		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			
13	2017-12-26	Influent	5.15	1.68	0.02	1.70	Influent	5.32	1.73	0.04	1.69
			5.30	1.73				5.05	1.65		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
14	2018-01-02	Influent	4.17	1.36	0.01	1.37	Influent	4.22	1.38	0.01	1.37
			4.24	1.38				4.16	1.36		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	95%				Concentration Reduction	95%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
15	2018-01-08	Influent	8.96	2.92	0.22	2.70	Influent	6.96	2.27	0.35	2.62
			7.62	2.49				9.10	2.97		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			
16	2018-01-15	Influent	4.16	1.36	0.48	0.88	Influent	3.77	1.23	0.44	0.79
			1.24	0.40				1.07	0.35		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	92%				Concentration Reduction	91%			
19	2018-02-07	Influent	5.67	1.85	0.07	1.91	Influent	6.51	2.12	0.00	2.13
			6.07	1.98				6.54	2.13		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	97%			
21	2018-02-20	Influent	6.15	2.01	0.02	2.03	Influent	6.28	2.05	0.02	2.07
			6.29	2.05				6.42	2.09		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
23	2018-03-09	Influent	6.72	2.19	0.06	2.25	Influent	6.29	2.05	0.13	2.18
			7.07	2.31				7.07	2.31		
		Effluent	0.23[a]	0.07	0.00	0.07	Effluent	1.32[a]	0.43	0.01	0.42
			0.23[a]	0.07				1.26[a]	0.41		
		Concentration Reduction	97%				Concentration Reduction	81%			
27	2018-04-02	Influent	6.85	2.23	0.09	2.14	Influent	6.41	2.09	0.00	2.09
			6.30	2.05				6.40	2.09		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			
29	2018-04-16	Influent	5.16	1.68	0.01	1.70	Influent	5.14	1.68	0.01	1.66
			5.24	1.71				5.06	1.65		
		Effluent	0.40[a]	0.13	0.00	0.13	Effluent	1.63[a]	0.53	0.01	0.52
			0.40[a]	0.13				1.56[a]	0.51		
		Concentration Reduction	92%				Concentration Reduction	59%			
32	2018-05-08	Influent	23.23[b]	7.58	0.03	7.61	Influent	23.75[b]	7.75	0.02	7.77
			23.42[b]	7.64				23.90[b]	7.80		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	99%				Concentration Reduction	99%			

Week	Date	Column 1					Column 2				
		Description	(mg PO$_4^{3-}$/L)	(mg PO$_4^{3-}$-P/L)	σ	Avg (mg PO$_4^{3-}$-P/L)	Description	(mg PO$_4^{3-}$/L)	(mg PO$_4^{3-}$-P/L)	σ	Avg (mg PO$_4^{3-}$-P/L)
32	2018-05-10	Influent	6.67 6.55	2.18 2.14	0.02	2.16	Influent	6.73 6.83	2.19 2.23	0.02	2.21
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07
		Concentration Reduction	97%				Concentration Reduction	97%			
32	2018-05-12	Influent	6.44 6.27	2.10 2.05	0.03	2.07	Influent	6.37 6.39	2.08 2.09	0.00	2.08
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	0.96[a] 1.13[a]	0.31 0.37	0.03	0.34
		Concentration Reduction	97%				Concentration Reduction	84%			
37	2018-06-14	Influent	5.69 5.33	1.86 1.74	0.06	1.80	Influent	5.75 5.21	1.88 1.70	0.09	1.79
		Effluent	0.90[a] 0.92[a]	0.29 0.30	0.00	0.30	Effluent	0.94[a] 1.21[a]	0.31 0.39	0.04	0.35
		Concentration Reduction	83%				Concentration Reduction	80%			
38	2018-06-21	Influent	9.46 9.97	3.09 3.25	0.08	3.17	Influent	10.00 10.43	3.26 3.40	0.07	3.33
		Effluent	0.88[a] 1.25[a]	0.29 0.41	0.06	0.35	Effluent	1.29[a] 0.75[a]	0.42 0.24	0.09	0.33
		Concentration Reduction	89%				Concentration Reduction	90%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
39	2018-06-26	Influent	9.09	2.96	0.06	3.03	Influent	9.55	3.11	0.15	3.27
			9.48	3.09				10.49	3.42		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	98%				Concentration Reduction	98%			
40	2018-07-04	Influent	5.02	1.64	0.03	1.66	Influent	5.04	1.64	0.01	1.65
			5.19	1.69				5.08	1.66		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
41	2018-07-09	Influent	5.76	1.88	0.01	1.87	Influent	5.81	1.90	0.00	1.90
			5.72	1.87				5.81	1.89		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
42	2018-07-16	Bucket 1 Influent	5.72	1.87	0.02	1.89	Bucket 1 Influent	5.68	1.85	0.02	1.87
			5.85	1.91				5.80	1.89		
		Bucket 1 Effluent	<LOQ [a]	0.07	n/a	0.07	Bucket 1 Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
		Bucket 2 Influent	5.62	1.83	0.04	1.87	Bucket 2 Influent	5.69	1.85	0.00	1.86
			5.85	1.91				5.70	1.86		
		Bucket 2 Effluent	<LOQ [a]	0.07	n/a	0.07	Bucket 2 Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
		Influent Bucket Average (mg PO_4^{3-}-P/L)				1.88	Influent Bucket Average (mg PO_4^{3-}-P/L)				1.86
		Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07	Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07
		Concentration Reduction Average				96%	Concentration Reduction Average				96%

Week	Date	Column 1					Column 2				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
43	2018-07-23	Influent	5.69	1.86	0.04	1.90	Influent	5.90	1.92	0.06	1.87
			5.94	1.94				5.56	1.81		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
		Influent	6.45	2.10	0.05	2.16	Influent	6.04	1.97	0.01	1.98
			6.77	2.21				6.13	2.00		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	96%			
		Influent Bucket Average (mg PO_4^{3-}-P/L)				2.03	Influent Bucket Average (mg PO_4^{3-}-P/L)				1.93
		Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07	Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07
		Concentration Reduction Average				97%	Concentration Reduction Average				96%

Data obtained using mid range calibration data of 2, 4, 6, 8, and 10 mg PO_4^{3-}/L (or 0.65 to 3.26 mg PO_4^{3-}-P/L), unless indicated otherwise.

[a] Obtained using low range calibration data of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8 mg PO_4^{3-}/L (or 0.07 to 0.59 mg PO_4^{3-}-P/L) when measurements within the low range calibration range. LOQ (limit of quantification) is therefore 0.07 mg PO_4^{3-}-P/L and any values not detected or < 0.07 mg PO_4^{3-}-P/L are considered equal to 0.07 mg PO_4^{3-}-P/L.

[b] Obtained using high range calibration data of 10, 20, 40, 100, and 200 mg PO_4^{3-}/L (or 3.26 to 65.22 mg PO_4^{3-}-P/L) when low range and mid range calibration data unavailable or measurements are within the high range calibration range.

[c] Measured by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta: 2-255 Centennial Centre for Interdisciplinary Science Building, Edmonton, AB.

Table 34: Phosphate influent and effluent concentrations and percentage concentration reduction for columns 3 and 4.

Week	Date	Column 3					Column 4				
		Description	Phosphate Concentration (mg PO$_4^{3-}$/L)	Phosphate Concentration (mg PO$_4^{3-}$-P/L)	Standard Deviation	Average Phosphate Concentration (mg PO$_4^{3-}$-P/L)	Description	Phosphate Concentration (mg PO$_4^{3-}$/L)	Phosphate Concentration (mg PO$_4^{3-}$-P/L)	Standard Deviation	Average Phosphate Concentration (mg PO$_4^{3-}$-P/L)
4	2017-10-24	Influent	6.26	2.04	0.01	2.03	Influent	6.29	2.05	0.01	2.04
			6.19	2.02				6.20	2.02		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			
5	2017-10-30	Influent	5.07[b]	1.65	0.01	1.67	Influent	4.68[b]	1.53	0.15	1.68
			5.16[b]	1.68				5.62[b]	1.83		
		Effluent	0.16[c]	0.05	0.00	0.05	Effluent	0.14[c]	0.05	0.00	0.04
			0.14[c]	0.05				0.12[c]	0.04		
		Concentration Reduction	97%				Concentration Reduction	97%			
6	2017-11-06	Influent	4.73[c]	1.54	0.03	1.57	Influent	4.89[c]	1.59	0.01	1.59
			4.92[c]	1.60				4.85[c]	1.58		
		Effluent	0.05[c]	0.02	0.01	0.02	Effluent	0.10[c]	0.03	0.00	0.03
			0.09[c]	0.03				0.07[c]	0.02		
		Concentration Reduction	99%				Concentration Reduction	98%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
7	2017-11-14	Influent	5.38[c]	1.75	0.02	1.73	Influent	5.31[c]	1.73	0.02	1.71
			5.24[c]	1.71				5.18[c]	1.69		
		Effluent	0.12[c]	0.04	0.04	0.08	Effluent	0.70[c]	0.23	0.01	0.22
			0.34[c]	0.11				0.66[c]	0.22		
		Concentration Reduction	96%				Concentration Reduction	87%			
8	2017-11-20	Influent	5.27[c]	1.72	0.03	1.75	Influent	5.59[c]	1.82	0.05	1.77
			5.45[c]	1.78				5.26[c]	1.72		
		Effluent	1.82[a]	0.59	0.01	0.53	Effluent	<LOQ [a]	0.07	n/a	0.07
			1.88[a]	0.61				<LOQ [a]	0.07		
		Concentration Reduction	69%				Concentration Reduction	96%			
9	2017-11-27	Influent	6.85	2.23	0.01	2.23	Influent	6.59	2.15	0.02	2.13
			6.81	2.22				6.47	2.11		
		Effluent	0.49[a]	0.16	0.02	0.18	Effluent	<LOQ [a]	0.07	n/a	0.07
			0.60[a]	0.19				<LOQ [a]	0.07		
		Concentration Reduction	92%				Concentration Reduction	97%			
10	2017-12-04	Influent	6.70	2.18	0.01	2.20	Influent	6.74	2.20	0.04	2.24
			6.78	2.21				6.98	2.28		
		Effluent	1.35[a]	0.44	0.03	0.41	Effluent	0.75[a]	0.25	0.02	0.27
			1.19[a]	0.39				0.90[a]	0.30		
		Concentration Reduction	81%				Concentration Reduction	88%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
11	2017-12-11	Influent	6.27	2.04	0.01	2.04	Influent	6.25	2.04	0.01	2.05
			6.23	2.03				6.34	2.07		
		Effluent	0.62[a]	0.20	0.03	0.17	Effluent	<LOQ [a]	0.07	n/a	0.07
			0.41[a]	0.14				<LOQ [a]	0.07		
		Concentration Reduction	92%				Concentration Reduction	97%			
12	2017-12-18	Influent	5.79	1.89	0.01	1.90	Influent	5.83	1.90	0.02	1.92
			5.83	1.90				5.96	1.94		
		Effluent	1.60[a]	0.52	0.02	0.50	Effluent	0.62[a]	0.20	0.03	0.23
			1.46[a]	0.48				0.77[a]	0.25		
		Concentration Reduction	74%				Concentration Reduction	88%			
13	2017-12-26	Influent	6.51	2.12	0.02	2.14	Influent	6.79	2.21	0.03	2.18
			6.60	2.15				6.60	2.15		
		Effluent	0.20[a]	0.07	0.00	0.70	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			
14	2018-01-02	Influent	5.18	1.69	0.04	1.65	Influent	5.16	1.68	0.02	1.66
			4.93	1.61				5.02	1.64		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
15	2018-01-08	Influent	3.77 4.25	1.23 1.39	0.08	1.31	Influent	4.29 3.92	1.40 1.28	0.06	1.34
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07
		Concentration Reduction	95%				Concentration Reduction	95%			
16	2018-01-15	Influent	8.51 7.73	2.78 2.52	0.13	2.65	Influent	8.05 8.94	2.62 2.91	0.15	2.77
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07
		Concentration Reduction	97%					97%			
17	2018-01-23	Influent	3.73 3.74	1.21 1.22	0.00	1.22	Influent	3.75 4.19	1.22 1.37	0.07	1.29
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07
		Concentration Reduction	94%					95%			
18	2018-01-30	Influent	10.46 10.45	3.41 3.41	0.00	3.41	Influent	10.15 10.30	3.31 3.36	0.02	3.33
		Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07	Effluent	<LOQ [a] <LOQ [a]	0.07 0.07	n/a	0.07
		Concentration Reduction	98%					98%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
19	2018-02-07	Influent	4.81	1.57	0.01	1.56	Influent	4.96	1.62	0.01	1.61
			4.75	1.55				4.90	1.60		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
19	2018-02-08	Influent	5.69	1.86	0.02	1.87	Influent	5.77	1.88	0.01	1.87
			5.80	1.89				5.71	1.86		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
21	2018-02-20	Influent	6.13	2.00	0.04	2.04	Influent	6.20	2.02	0.02	2.00
			6.36	2.07				6.06	1.98		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	96%			
23	2018-03-09	Influent	6.98	2.28	0.06	2.22	Influent	6.85	2.23	0.00	2.23
			6.62	2.16				6.83	2.23		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
27	2018-04-02	Influent	7.01	2.28	0.13	2.16	Influent	5.50	1.79	0.08	1.87
			6.21	2.03				5.99	1.95		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	96%			
29	2018-04-16	Influent	4.92	1.61	0.01	1.60	Influent	4.74	1.55	0.01	1.54
			4.86	1.58				4.71	1.53		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	95%			
32	2018-05-08	Influent	23.23[b]	7.58	0.03	7.61	Influent	23.75[b]	7.75	0.02	7.77
			23.42[b]	7.64				23.90[b]	7.80		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	99%				Concentration Reduction	99%			
32	2018-05-10	Influent	6.82	2.22	0.00	2.23	Influent	6.75	2.20	0.01	2.22
			6.84	2.23				6.84	2.23		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	97%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
32	2018-05-12	Influent	6.47	2.11	0.01	2.10	Influent	6.50	2.12	0.00	2.12
			6.43	2.10				6.50	2.12		
		Effluent	1.31[a]	0.43	0.01	0.44	Effluent	1.21[a]	0.40	0.01	0.40
			1.37[a]	0.45				1.27[a]	0.41		
		Concentration Reduction	79%				Concentration Reduction	81%			
37	2018-06-14	Influent	5.31	1.73	0.01	1.72	Influent	5.35	1.75	0.03	1.71
			5.23	1.71				5.14	1.68		
		Effluent	3.19	1.04	0.01	1.05	Effluent	0.42[a]	0.14	0.01	0.13
			3.23	1.05				0.38[a]	0.12		
		Concentration Reduction	39%				Concentration Reduction	92%			
38	2018-06-21	Influent	9.00	2.94	0.03	2.96	Influent	8.40	2.74	0.08	2.82
			9.18	2.99				8.87	2.89		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	98%				Concentration Reduction	98%			
39	2018-06-26	Influent	10.04	3.27	0.22	3.06	Influent	10.44	3.40	0.09	3.50
			8.72	2.84				11.00	3.59		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	98%				Concentration Reduction	98%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
40	2018-07-04	Influent	4.93	1.61	0.02	1.63	Influent	5.06	1.65	0.00	1.65
			5.06	1.65				-	-		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
41	2018-07-09	Influent	5.36	1.75	0.01	1.74	Influent	5.38	1.75	0.03	1.73
			5.30	1.73				5.21	1.70		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
42	2018-07-16	Bucket 1 Influent	5.74	1.87	0.01	1.86	Bucket 1 Influent	5.68	1.85	0.01	1.84
			5.70	1.86				5.60	1.82		
		Bucket 1 Effluent	<LOQ [a]	0.07	n/a	0.07	Bucket 1 Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
		Bucket 2 Influent	5.48	1.79	0.00	1.79	Bucket 2 Influent	5.63	1.84	0.02	1.82
			5.47	1.78				5.50	1.80		
		Bucket 2 Effluent	<LOQ [a]	0.07	n/a	0.07	Bucket 2 Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	96%			
		Influent Bucket Average (mg PO_4^{3-}-P/L)				1.82	Influent Bucket Average (mg PO_4^{3-}-P/L)				1.83
		Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07	Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07
		Concentration Reduction Average				96%	Concentration Reduction Average				96%

Week	Date	Column 3					Column 4				
		Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)	Description	(mg PO_4^{3-}/L)	(mg PO_4^{3-}-P/L)	σ	Avg (mg PO_4^{3-}-P/L)
43	2018-07-23	Influent	5.86	1.91	0.02	1.93	Influent	6.39	2.08	0.02	2.06
			5.99	1.95				6.25	2.04		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	96%				Concentration Reduction	97%			
		Influent	6.28	2.05	0.03	2.08	Influent	6.07	1.98	0.02	2.00
			6.49	2.12				6.17	2.01		
		Effluent	<LOQ [a]	0.07	n/a	0.07	Effluent	<LOQ [a]	0.07	n/a	0.07
			<LOQ [a]	0.07				<LOQ [a]	0.07		
		Concentration Reduction	97%				Concentration Reduction	96%			
		Influent Bucket Average (mg PO_4^{3-}-P/L)				2.01	Influent Bucket Average (mg PO_4^{3-}-P/L)				2.03
		Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07	Effluent Bucket Average (mg PO_4^{3-}-P/L)				0.07
		Concentration Reduction Average				97%	Concentration Reduction Average				97%

Data obtained using mid range calibration data of 2, 4, 6, 8, and 10 mg PO_4^{3-}/L (or 0.65 to 3.26 mg PO_4^{3-}-P/L), unless indicated otherwise.

[a] Obtained using low range calibration data of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, and 1.8 mg PO_4^{3-}/L (or 0.07 to 0.59 mg PO_4^{3-}-P/L) when measurements within the low range calibration range. LOQ (limit of quantification) is therefore 0.07 mg PO_4^{3-}-P/L and any values not detected or < 0.07 mg PO_4^{3-}-P/L are considered equal to 0.07 mg PO_4^{3-}-P/L.

[b] Obtained using high range calibration data of 10, 20, 40, 100, and 200 mg PO_4^{3-}/L (or 3.26 to 65.22 mg PO_4^{3-}-P/L) when low range and mid range calibration data unavailable or measurements are within the high range calibration range.

[c] Measured by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta: 2-255 Centennial Centre for Interdisciplinary Science Building, Edmonton, AB.

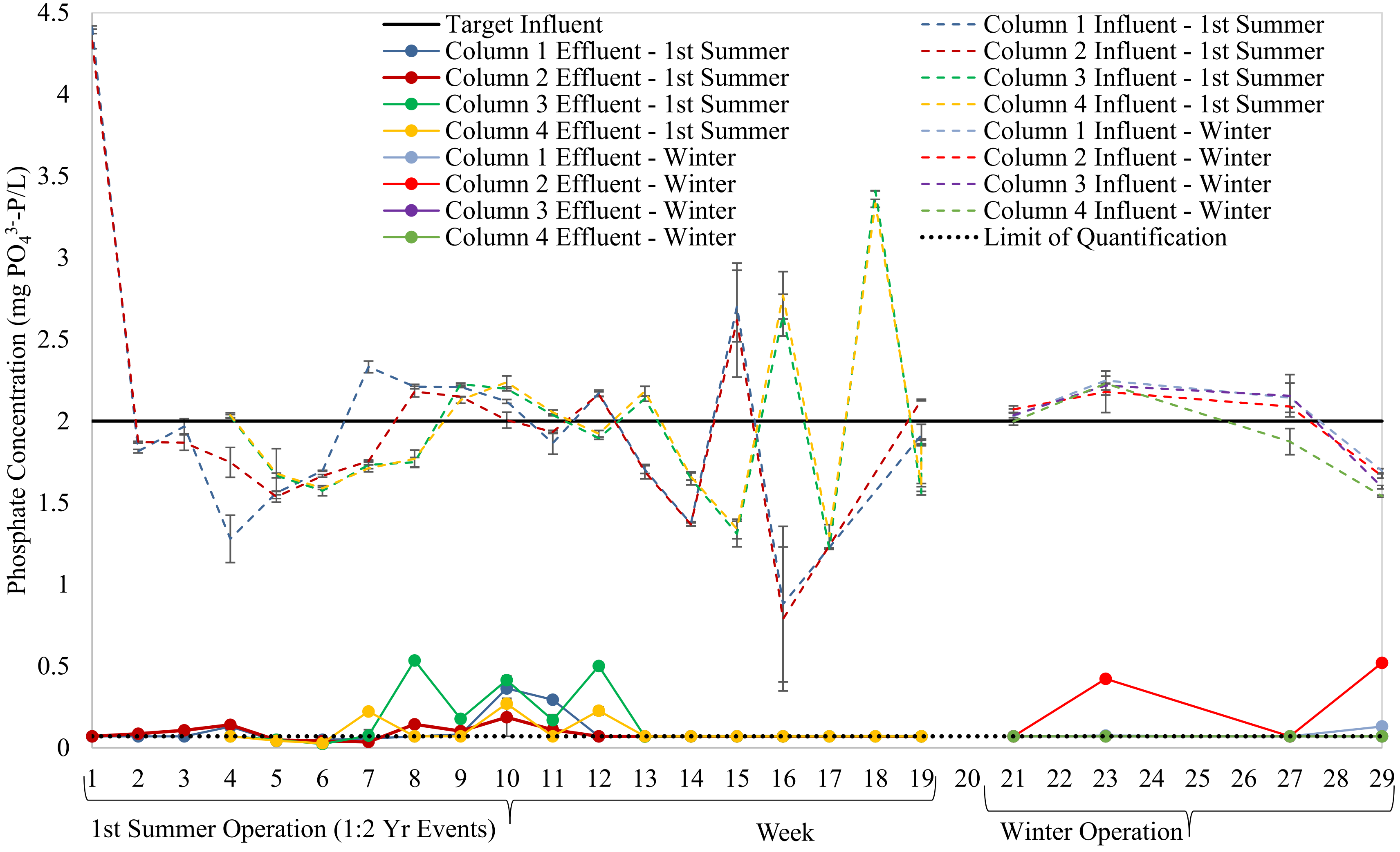


Figure 56: Phosphate concentration reduction during 1st summer and winter operation.

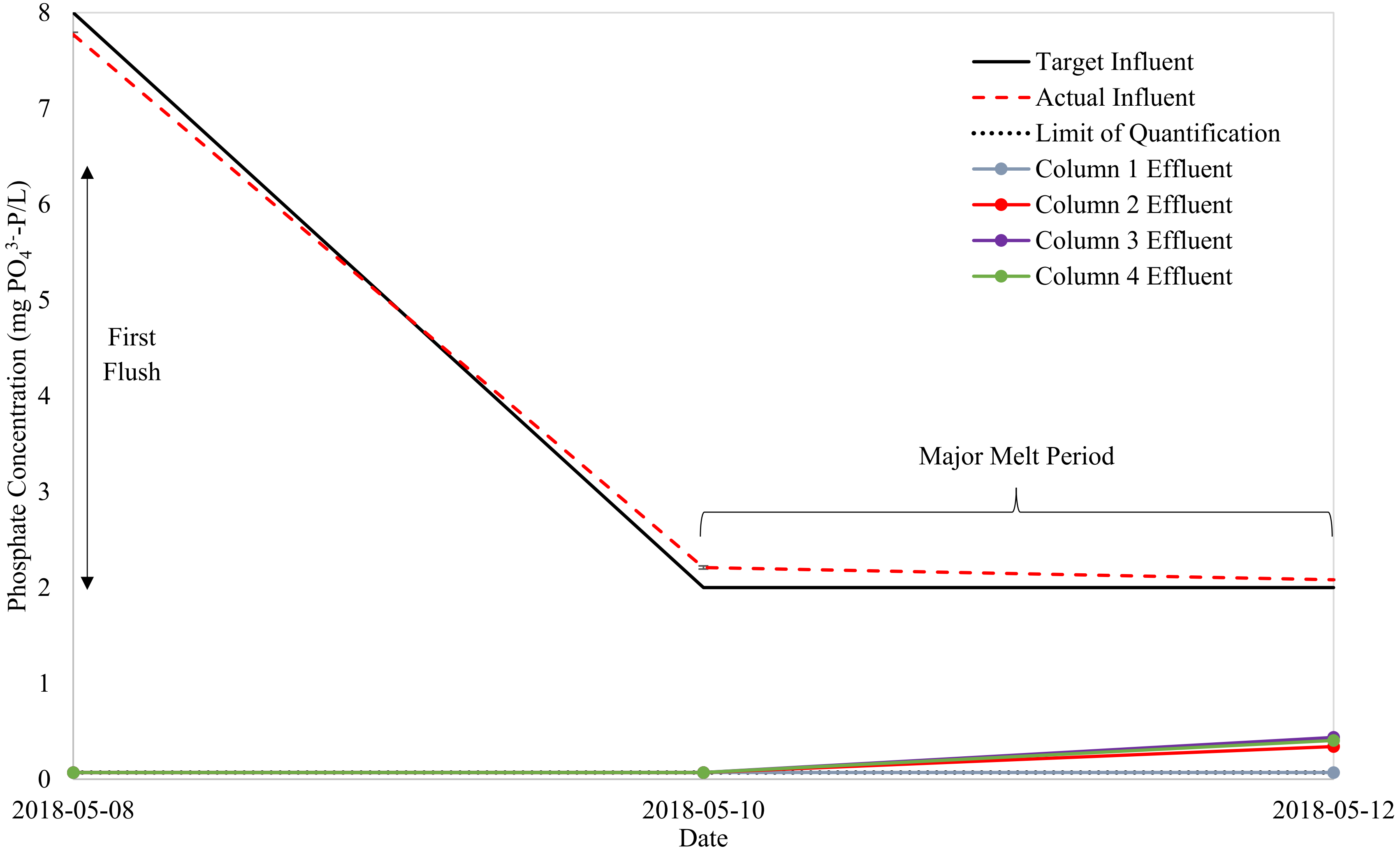


Figure 57: Phosphate concentration reduction during spring runoff.

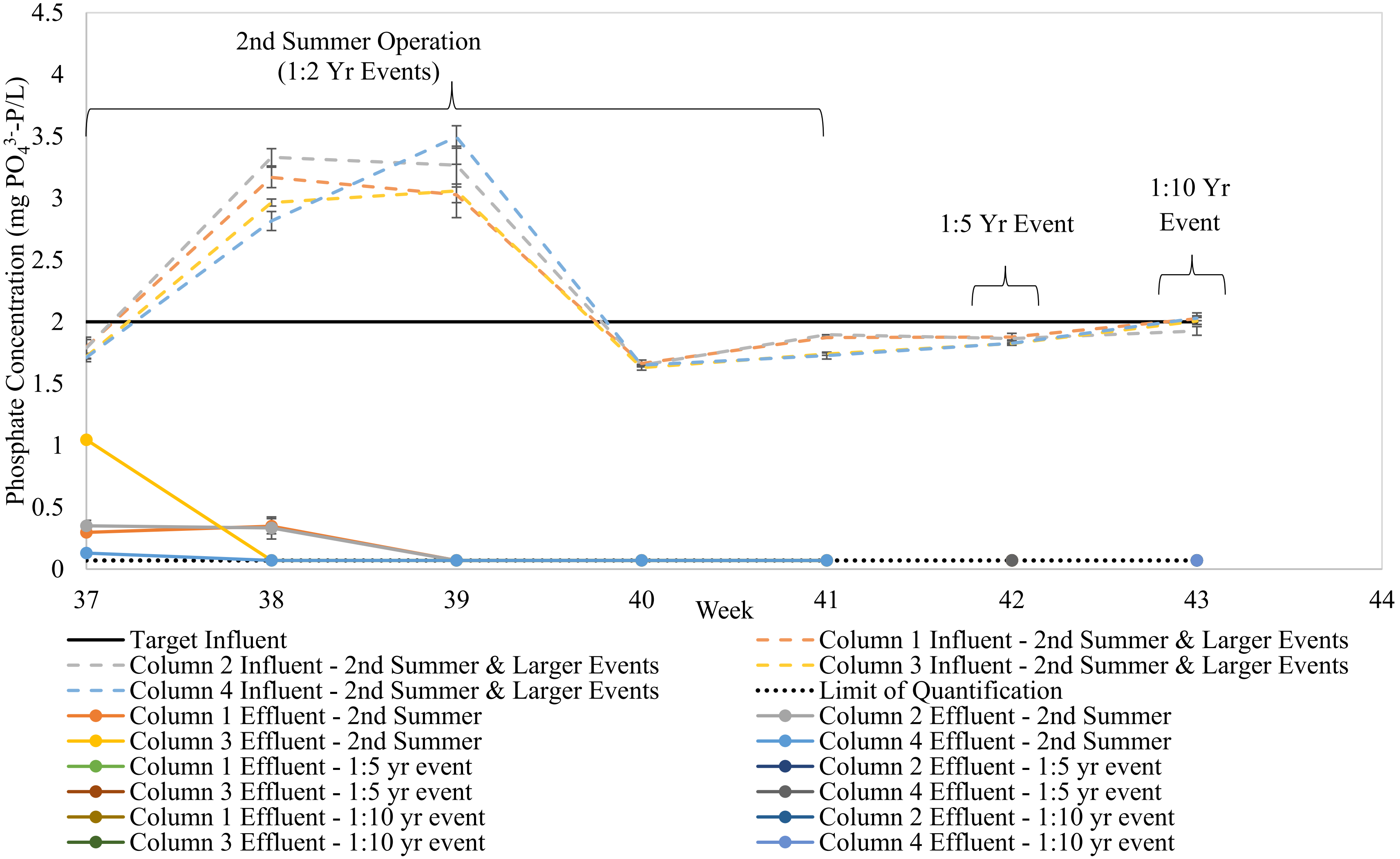


Figure 58: Phosphate concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events.

Table 35: Ammonium influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4.

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			Ammonium (mg NH_4^+-N/L)	Standard Deviation	Average NH_4^+ (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)	Standard Deviation	Average NH_4^+ (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)	Standard Deviation	Average NH_4^+ (mg NH_4^+-N/L)	Ammonium (mg NH_4^+-N/L)	Standard Deviation	Average NH_4^+ (mg NH_4^+-N/L)
1	2017-09-26	Influent	2.42 2.38	0.02	2.404	2.36 2.38	0.01	2.374						
		Effluent	0.26 0.28	0.01	0.2695	0.06 0.05	0.00	0.055						
		Concentration Reduction	89%			98%								
2	2017-10-10	Influent	2.35 2.33	0.01	2.337	2.47 2.37	0.05	2.417						
		Effluent	0.21 0.21	0.00	0.2115	0.11 0.10	0.00	0.1045						
		Concentration Reduction	91%			96%								
3	2017-10-17	Influent	2.41 2.43	0.01	2.417	2.41 2.39	0.01	2.397						
		Effluent	0.04 0.04	0.00	0.04	0.06 0.06	0.00	0.057						
		Concentration Reduction	98%			98%								

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
4	2017-10-24	Influent	2.54 2.44	0.05	2.486	2.50 2.50	0.00	2.496	2.51 2.51	0.00	2.507	2.51 2.53	0.01	2.517
		Effluent	0.04 0.04	0.00	0.037	0.02 0.03	0.00	0.0245	0 0	0.00	0	0 0	0.00	0
		Concentration Reduction	99%			99%			100%			100%		
5	2017-10-30	Influent	2.22 2.16	0.03	2.186	1.78 2.32	0.27	2.046	2.48 2.44	0.02	2.456	2.46 2.52	0.03	2.486
		Effluent	0.02 0.02	0.00	0.023	0.04 0.04	0.00	0.0385	0.13 0.15	0.01	0.143	0 0	0.00	0
		Concentration Reduction	99%			98%			94%			100%		
6	2017-11-06	Influent	2.34 2.40	0.03	2.366	2.33 2.31	0.01	2.318	1.57 1.60	0.02	1.584	2.36 2.34	0.01	2.346
		Effluent	0.01 0.02	0.00	0.0165	0.02 0.02	0.00	0.0205	0.03 0.02	0.00	0.024	0.09 0.09	0.00	0.093
		Concentration Reduction	99%			99%			98%			96%		
7	2017-11-14	Influent	2.17 2.07	0.05	2.118	2.25 2.27	0.01	2.258	2.29 2.25	0.02	2.268	2.37 2.27	0.05	2.317
		Effluent	0.00 0.01	0.00	0.002	0.02 0.02	0.00	0.0175	0.14 0.13	0.01	0.139	0.13 0.13	0.00	0.1315
		Concentration Reduction	100%			99%			94%			94%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
8	2017-11-20	Influent	2.43 2.43	0.00	2.427	2.45 2.45	0.00	2.447	2.29 2.25	0.02	2.268	2.37 2.27	0.05	2.317
		Effluent	0.02 0.02	0.00	0.02	0.04 0.04	0.00	0.041	0.28 0.30	0.01	0.289	0.34 0.33	0.00	0.33
		Concentration Reduction	99%			98%			87%			86%		
9	2017-11-27	Influent	2.38 2.38	0.00	2.381	2.40 2.40	0.00	2.401	2.55 2.53	0.01	2.537	2.51 2.53	0.01	2.517
		Effluent	0.01 0.01	0.00	0.0125	0.00 0.01	0.00	0.0045	0.33 0.38	0.02	0.358	0.47 0.48	0.01	0.4775
		Concentration Reduction	99%			100%			86%			81%		
10	2017-12-04	Influent	1.99 1.92	0.04	1.952	2.17 2.17	0.00	2.167	2.58 2.50	0.04	2.541	2.46 2.44	0.01	2.451
		Effluent	0.00 0.00	0.00	0	0 0	0.00	0	0.24 0.23	0.01	0.236	0.31 0.31	0.00	0.3085
		Concentration Reduction	100%			100%			91%			87%		
11	2017-12-11	Influent	2.18 2.20	0.01	2.189	2.26 2.32	0.03	2.289	2.37 2.27	0.05	2.317	2.31 2.31	0.00	2.307
		Effluent	0.00 0.00	0.00	0.0015	0.00 0.01	0.00	0.0035	0.42 0.44	0.01	0.4285	0.61 0.62	0.00	0.612
		Concentration Reduction	100%			100%			82%			73%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
12	2017-12-18	Influent	2.25 2.19	0.03	2.22	2.15 2.15	0.00	2.15	2.21 2.17	0.02	2.19	2.28 2.26	0.01	2.269
		Effluent	0 0	0.00	0	0.01 0.00	0.00	0.004	0.49 0.39	0.05	0.436	0.69 0.63	0.03	0.6585
		Concentration Reduction	100%			100%			80%			71%		
13	2017-12-26	Influent	2.15 2.15	0.00	2.15	2.15 2.21	0.03	2.18	2.21 2.17	0.02	2.19	2.13 2.13	0.00	2.13
		Effluent	0.01 0.01	0.00	0.008	0.03 0.02	0.01	0.023	0.80 0.80	0.00	0.803	1.05 1.03	0.01	1.039
		Concentration Reduction	100%			99%			63%			51%		
14	2018-01-02	Influent	2.01 2.09	0.04	2.052	2.07 2.07	0.00	2.072	2.27 2.31	0.02	2.287	2.30 2.30	0.00	2.299
		Effluent	0.02 0.01	0.01	0.016	0.02 0.03	0.01	0.025	0.83 0.82	0.01	0.827	1.26 1.24	0.01	1.246
		Concentration Reduction	99%			99%			64%			46%		
15	2018-01-08	Influent	2.01 1.97	0.02	1.99	1.97 1.94	0.01	1.953	2.09 2.03	0.03	2.062	2.09 2.11	0.01	2.102
		Effluent	0.02 0.02	0.00	0.0215	0.00 0.00	0.00	0.001	0.61 0.50	0.06	0.5565	0.96 0.97	0.00	0.968
		Concentration Reduction	99%			100%			73%			54%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
16	2018-01-15	Influent	2.27 2.21	0.03	2.24	2.23 2.23	0.00	2.23	2.17 2.15	0.01	2.159	2.21 2.21	0.00	2.209
		Effluent	0 0.00	0.00	0.002	0 0	0.00	0	0.68 0.80	0.06	0.739	0.61 0.55	0.03	0.578
		Concentration Reduction	100%			100%			66%			74%		
17	2018-01-23	Influent	0.30 0.29	0.00	0.29	0.31 0.30	0.00	0.308	1.93 1.96	0.02	1.945	2.09 2.05	0.02	2.07
		Effluent	0 0	0.00	0.00	0 0	0.00	0	1.12 1.16	0.02	1.142	1.05 1.01	0.02	1.033
		Concentration Reduction	100%			100%			41%			50%		
18	2018-01-30	Influent							2.21 2.17	0.02	2.186	2.27 2.23	0.02	2.246
		Effluent							1.80 1.81	0.01	1.803	1.30 1.34	0.02	1.32
		Concentration Reduction							18%			41%		
19	2018-02-07	Influent	2.25 2.25	0.00	2.25	2.27 2.23	0.02	2.25	2.45 2.27	0.09	2.356	1.72 1.67	0.02	1.692
		Effluent	0.00 0	0.00	0.001	0.03 0.02	0.01	0.021	1.32 1.29	0.02	1.302	1.23 1.26	0.02	1.247
		Concentration Reduction	100%			99%			45%			26%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
19	2018-02-08	Influent							2.25 2.25	0.00	2.25	2.25 2.25	0.00	2.25
		Effluent							1.27 1.04	0.12	1.152	0.67 0.70	0.01	0.6835
		Concentration Reduction							49%			70%		
21	2018-02-20	Influent	2.30 2.26	0.02	2.277	2.24 2.22	0.01	2.227	2.14 2.12	0.01	2.127	2.12 2.08	0.02	2.097
		Effluent	0.04 0.04	0.00	0.0395	0.02 0.01	0.00	0.0115	0.74 0.76	0.01	0.7465	0.55 0.56	0.00	0.553
		Concentration Reduction	98%			99%			65%			74%		
23	2018-03-09	Influent	1.87 1.83	0.02	1.85	2.02 2.02	0.00	2.02	2.08 2.12	0.02	2.10	1.91 1.91	0.00	1.91
		Effluent	0.13 0.13	0.00	0.13	0.12 0.12	0.00	0.12	1.36 1.32	0.02	1.34	0.26 0.27	0.00	0.26
		Concentration Reduction	93%			94%			36%			86%		
27	2018-04-02	Influent	2.34 2.32	0.01	2.33	2.32 2.32	0.00	2.32	2.36 2.34	0.01	2.35	2.34 2.34	0.00	2.34
		Effluent	0.13 0.12	0.01	0.13	0.04 0.03	0.00	0.03	0.59 0.60	0.00	0.59	1.65 1.63	0.01	1.64
		Concentration Reduction	95%			99%			75%			30%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
29	2018-04-16	Influent	2.30 2.28	0.01	2.29	2.24 2.22	0.01	2.23	2.24 2.18	0.03	2.21	2.14 2.16	0.01	2.15
		Effluent	0.13 0.12	0.01	0.13	0.04 0.02	0.01	0.03	1.47 1.41	0.03	1.44	0.17 0.16	0.01	0.16
		Concentration Reduction	94%			99%			35%			92%		
32	2018-05-08	Influent	8.30 8.20	0.05	8.25	8.35 8.40	0.02	8.38	8.30 8.20	0.05	8.25	8.35 8.40	0.02	8.38
		Effluent	0.06 0.04	0.01	0.05	0.01 0.02	0.00	0.02	1.24 1.26	0.01	1.25	0.93 0.95	0.01	0.94
		Concentration Reduction	99%			100%			85%			89%		
32	2018-05-10	Influent	1.96 2.04	0.04	2.00	2.20 2.16	0.02	2.18	2.20 2.18	0.01	2.19	2.18 2.26	0.04	2.22
		Effluent	0.29 0.30	0.01	0.30	0.13 0.12	0.01	0.13	1.62 1.50	0.06	1.56	0.91 1.01	0.05	0.96
		Concentration Reduction	85%			94%			29%			57%		
32	2018-05-12	Influent	2.29 2.23	0.03	2.26	2.09 2.09	0.00	2.09	2.09 2.07	0.01	2.08	2.15 2.11	0.02	2.13
		Effluent	0.44 0.41	0.02	0.43	0.10 0.08	0.01	0.09	1.87 1.71	0.08	1.79	0.99 0.91	0.04	0.95
		Concentration Reduction	81%			96%			14%			55%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
37	2018-06-14	Influent	2.37 2.33	0.02	2.35	2.33 2.29	0.02	2.31	2.33 2.31	0.01	2.32	2.33 2.31	0.01	2.32
		Effluent	0.18 0.18	0.00	0.18	0.10 0.10	0.00	0.10	0.47 0.46	0.01	0.47	0.37 0.35	0.01	0.36
		Concentration Reduction	92%			96%			80%			85%		
38	2018-06-21	Influent	2.13 2.05	0.04	2.09	1.99 1.93	0.03	1.96	2.09 2.01	0.04	2.05	2.11 2.11	0.00	2.11
		Effluent	0.10 0.09	0.00	0.09	0.05 0.04	0.01	0.05	0.62 0.56	0.03	0.59	0.37 0.40	0.02	0.39
		Concentration Reduction	96%			98%			71%			82%		
39	2018-06-26	Influent	2.30 2.26	0.02	2.28	2.28 2.24	0.02	2.26	2.34 2.30	0.02	2.319	2.26 2.28	0.01	2.269
		Effluent	0.07 0.06	0.01	0.07	0.03 0.03	0.00	0.03	0.81 0.74	0.04	0.77	0.38 0.38	0.00	0.38
		Concentration Reduction	97%			99%			67%			83%		
40	2018-07-04	Influent	1.85 1.83	0.01	1.84	2.13 2.13	0.00	2.13	2.15 2.07	0.04	2.112	2.15 2.17	0.01	2.162
		Effluent	0.09 0.09	0.00	0.09	0.04 0.04	0.00	0.04	0.97 0.99	0.01	0.98	0.35 0.35	0.00	0.35
		Concentration Reduction	95%			98%			54%			84%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
41	2018-07-09	Influent	2.31 2.13	0.09	2.22	2.09 2.05	0.02	2.07	2.13 2.11	0.01	2.122	2.13 2.17	0.02	2.152
		Effluent	0.07 0.06	0.00	0.06	0.02 0.02	0.00	0.02	1.17 1.13	0.02	1.15	0.52 0.48	0.02	0.50
		Concentration Reduction	97%			99%			46%			77%		
42	2018-07-16	Bucket 1 Influent	2.34 2.28	0.03	2.31	2.30 2.36	0.03	2.33	2.30 2.34	0.02	2.317	2.30 2.20	0.05	2.247
		Bucket 1 Effluent	0.10 0.09	0.00	0.10	0.07 0.06	0.00	0.06	1.42 1.32	0.05	1.37	0.67 0.59	0.04	0.63
		Concentration Reduction	96%			97%			41%			72%		
		Bucket 2 Influent	2.34 2.28	0.03	2.31	2.30 2.36	0.03	2.33	2.30 2.34	0.02	2.32	2.30 2.20	0.05	2.247
		Bucket 2 Effluent	0.12 0.12	0.00	0.12	0.07 0.06	0.00	0.06	1.39 1.27	0.06	1.33	0.65 0.57	0.04	0.61
		Concentration Reduction	95%			97%			43%			73%		
		Effluent Bucket Average	0.11 mg/L 95%			0.06 mg/L 97%			1.35 mg/L 42%			0.62 mg/L 72%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)	(mg/L)	σ	Avg (mg/L)
43	2018-07-23	Influent	2.28 2.32	0.02	2.30	2.30 2.32	0.01	2.31	2.32 2.34	0.01	2.33	2.34 2.34	0.00	2.34
		Effluent	0.10 0.08	0.01	0.09	0.07 0.07	0.00	0.07	1.43 1.39	0.02	1.41	0.72 0.71	0.01	0.72
		Concentration Reduction	96%			97%			40%			69%		
		Influent	2.28 2.32	0.02	2.30	2.30 2.32	0.01	2.31	2.32 2.34	0.01	2.33	2.34 2.34	0.00	2.34
		Effluent	0.11 0.11	0.00	0.11	0.04 0.02	0.01	0.03	1.25 1.25	0.00	1.25	0.66 0.66	0.00	0.66
		Concentration Reduction	95%			99%			46%			72%		
		Effluent Bucket Average	0.10 mg/L 96%			0.05 mg/L 98%			1.33 mg/L 43%			0.68 mg/L 71%		

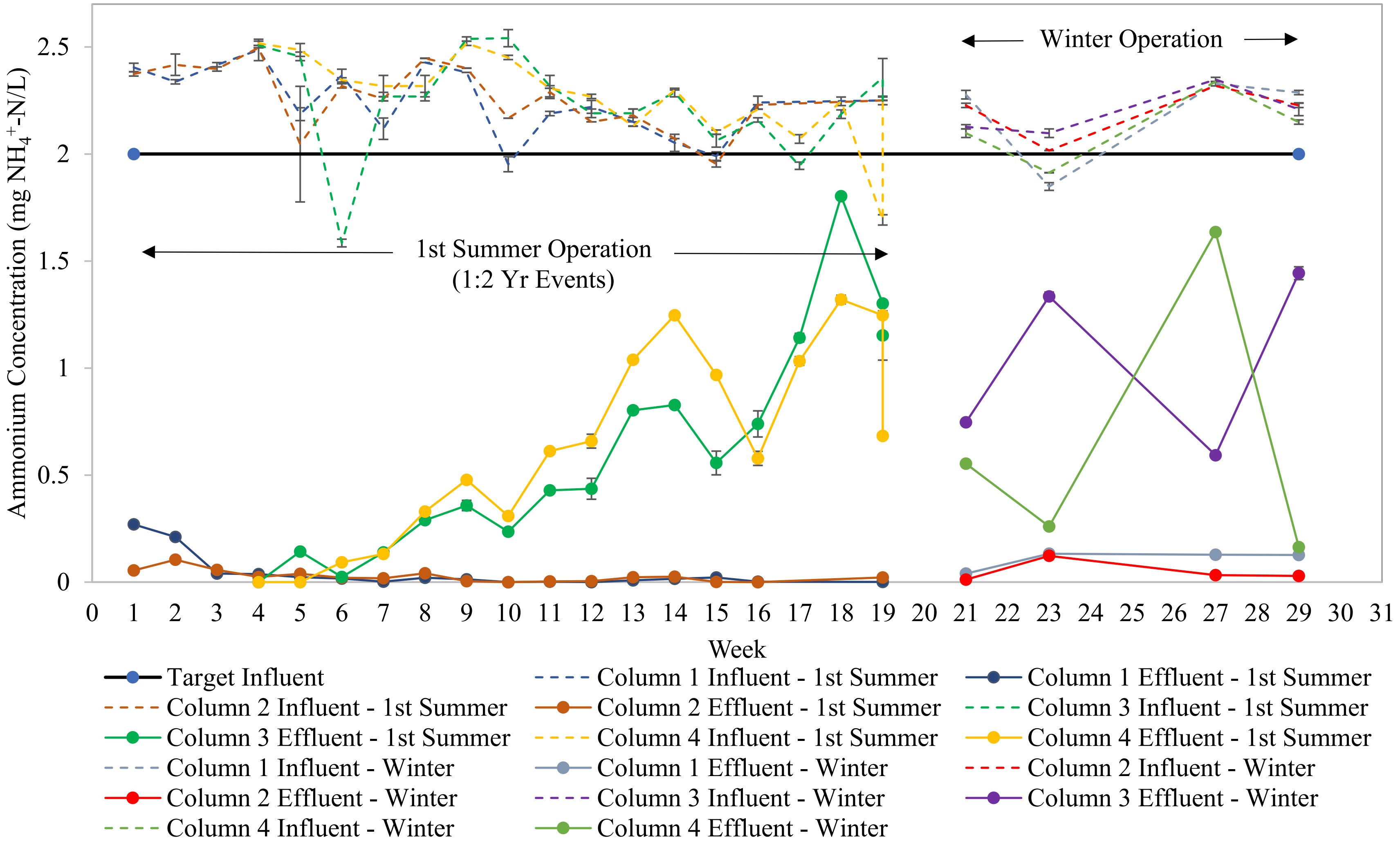


Figure 59: Ammonium concentration reduction during 1st summer and winter.

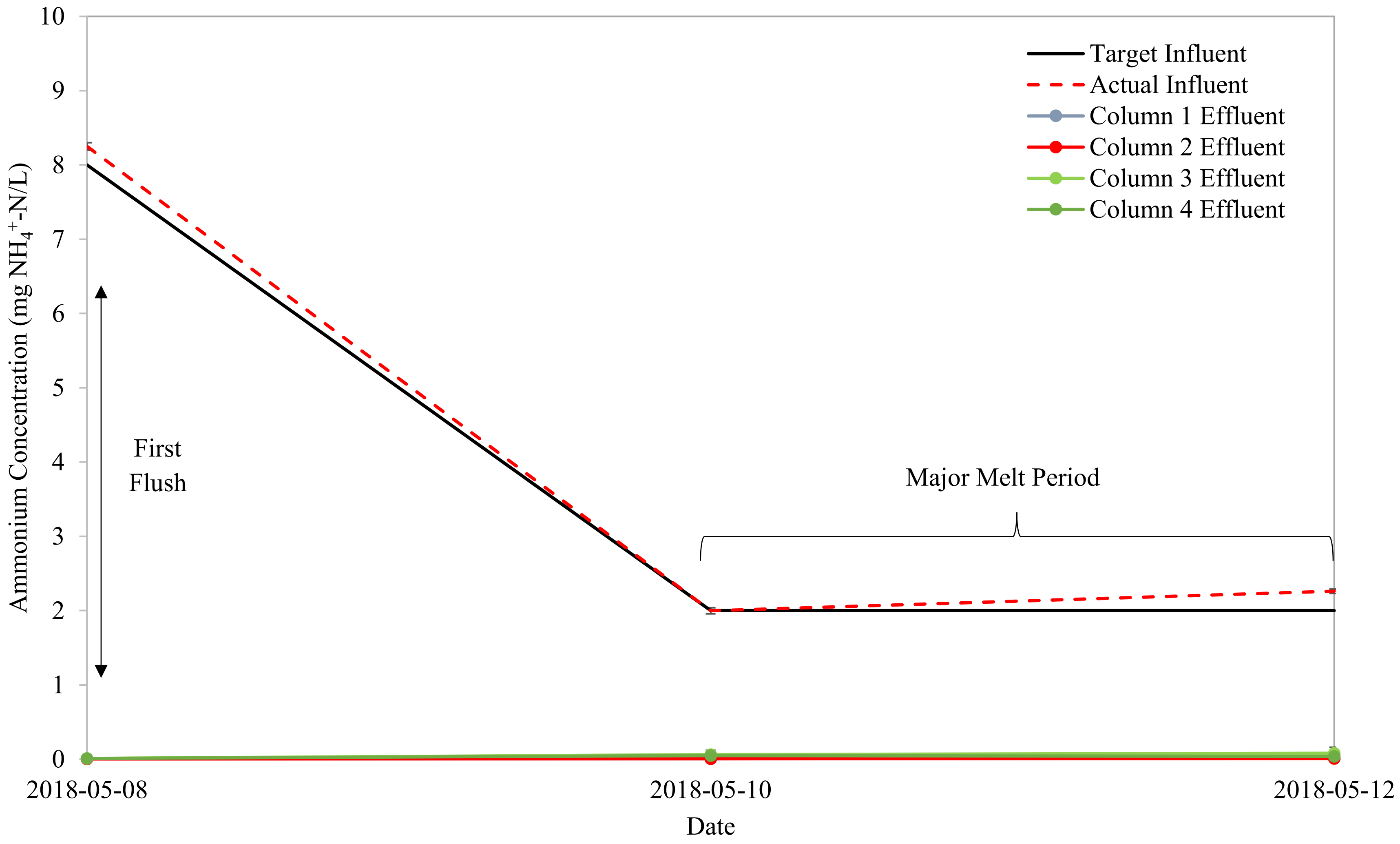


Figure 60: Ammonium concentration reduction during spring runoff.

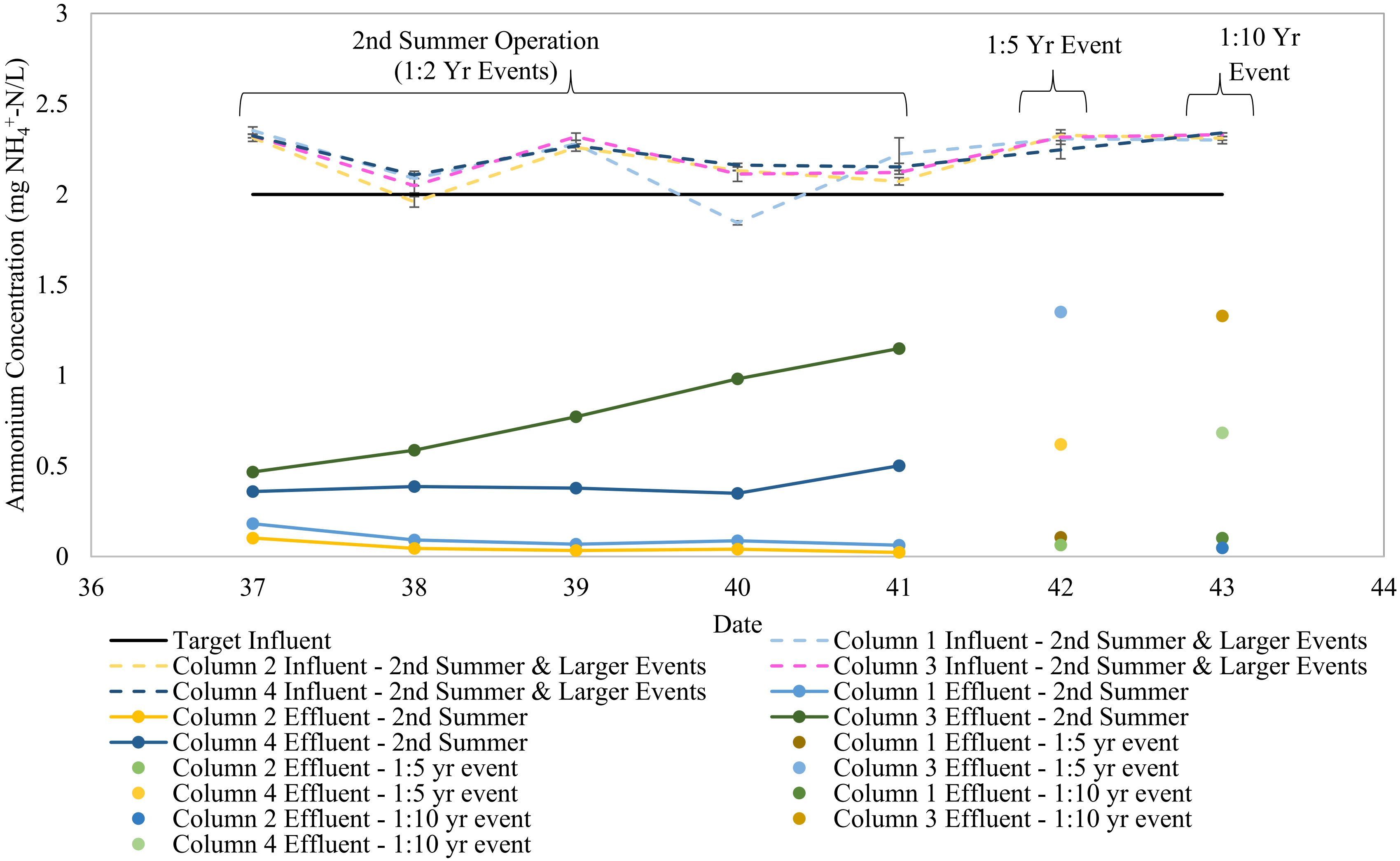


Figure 61: Ammonium concentration reduction during 2nd summer operation and 1:5 yr and 1:10 yr events.

Table 36: Nitrate influent and effluent concentrations and percentage concentration reduction for columns 1 and 2.

Week	Date	Column 1					Column 2				
		Description	Nitrate Concentration (mg NO_3^-/L)	Nitrate Concentration (mg NO_3^--N/L)	Standard Deviation	Average Nitrate Concentration (mg NO_3^--N/L)	Description	Nitrate Concentration (mg NO_3^-/L)	Nitrate Concentration (mg NO_3^--N/L)	Standard Deviation	Average Nitrate Concentration (mg NO_3^--N/L)
1	2017-09-26	Influent	- -	3.07 2.97	0.05	3.02	Influent	- -	2.80 2.96	0.08	2.88
		Effluent	- -	96.61 98.98	1.19	97.80	Effluent	- -	92.10 91.93	0.09	92.01
		Concentration Change	-3140%				Concentration Change	-3096%			
2	2017-10-10	Influent	7.25 7.45	1.64 1.68	0.02	1.66	Influent	6.92 6.90	1.56 1.56	0.00	1.56
		Effluent	536.51 511.93	121.15 115.60	2.78	118.37	Effluent	250.06 247.94	56.46 55.99	0.24	56.23
		Concentration Change	-7035%				Concentration Change	-3502%			
3	2017-10-17	Influent	7.52 7.47	1.70 1.69	0.01	1.69	Influent	7.55 7.26	1.70 1.64	0.03	1.67
		Effluent	104.90 102.84	23.69 23.22	0.23	23.45	Effluent	60.50 63.92	13.66 14.43	0.39	14.05
		Concentration Change	-1286%				Concentration Change	-740%			

Week	Date	Column 1					Column 2				
		Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)	Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)
4	2017-10-24	Influent	5.66 4.15	1.28 0.94	0.17	1.11	Influent	6.38 7.11	1.44 1.61	0.08	1.52
		Effluent	35.14 35.30	7.93 7.97	0.02	7.95	Effluent	29.64 25.98	6.69 5.87	0.41	6.28
		Concentration Change	-618%				Concentration Change	-312%			
5	2017-10-30	Influent	7.27[b] 7.27[b]	1.64 1.64	0.00	1.64	Influent	7.22[b] 7.26[b]	1.63 1.64	0.00	1.63
		Effluent	28.91[b] 28.92[b]	6.53 6.53	0.00	6.53	Effluent	21.46[b] 21.36[b]	4.85 4.82	0.01	4.83
		Concentration Change	-298%				Concentration Change	-196%			
6	2017-11-06	Influent	8.04[b] 7.91[b]	1.82 1.79	0.01	1.80	Influent	7.79[b] 8.04[b]	1.76 1.82	0.03	1.79
		Effluent	28.15[b] 28.20[b]	6.36 6.37	0.01	6.36	Effluent	20.59[b] 20.42[b]	4.65 4.61	0.02	4.63
		Concentration Change	-253%				Concentration Change	-159%			

Week	Date	Column 1					Column 2				
		Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)	Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)
7	2017-11-14	Influent	7.93[b]	1.79	0.00	1.79	Influent	8.01[b]	1.81	0.00	1.80
			7.96[b]	1.80				7.97[b]	1.80		
		Effluent	23.65[b]	5.34	0.01	5.33	Effluent	18.99[b]	4.29	0.00	4.28
			23.59[b]	5.33				18.96[b]	4.28		
		Concentration Change	-197%				Concentration Change	-137%			
8	2017-11-20	Influent	8.34	1.88	0.00	1.89	Influent	8.01	1.81	0.04	1.85
			8.36	1.89				8.39	1.89		
		Effluent	3.43[a]	0.78	0.02	0.76	Effluent	3.19[a]	0.72	0.01	0.71
			3.29[a]	0.74				3.10[a]	0.70		
		Concentration Change	60%				Concentration Change	62%			
9	2017-11-27	Influent	8.82	1.99	0.00	1.99	Influent	8.66	1.96	0.01	1.97
			8.81	1.99				8.76	1.98		
		Effluent	20.93	4.73	0.17	4.55	Effluent	19.03	4.30	0.01	4.30
			19.39	4.38				19.09	4.31		
		Concentration Change	-129%				Concentration Change	-119%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
10	2017-12-04	Influent	7.63	1.72	0.04	1.76	Influent	7.56	1.71	0.01	1.72
			7.95	1.80				7.69	1.74		
		Effluent	3.76[a]	0.85	0.00	0.85	Effluent	3.82[a]	0.86	0.06	0.80
			3.78[a]	0.85				3.27[a]	0.74		
		Concentration Change	52%				Concentration Change	54%			
11	2017-12-11	Influent	7.49	1.69	0.00	1.69	Influent	7.49	1.69	0.00	1.70
			7.48	1.69				7.53	1.70		
		Effluent	17.45	3.94	0.00	3.94	Effluent	18.88	4.26	0.01	4.25
			17.44	3.94				18.79	4.24		
		Concentration Change	-133%				Concentration Change	-151%			
12	2017-12-18	Influent	7.74	1.75	0.01	1.75	Influent	7.71	1.74	0.00	1.74
			7.80	1.76				7.70	1.74		
		Effluent	16.65	3.76	0.05	3.81	Effluent	20.21	4.56	0.01	4.57
			17.05	3.85				20.27	4.58		
		Concentration Change	-117%				Concentration Change	-163%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
13	2017-12-26	Influent	7.90	1.78	0.01	1.77	Influent	7.94	1.79	0.02	1.77
			7.82	1.77				7.77	1.75		
		Effluent	16.23	3.67	0.03	3.69	Effluent	20.25	4.57	0.02	4.55
			16.48	3.72				20.09	4.54		
		Concentration Change	-108%				Concentration Change	-157%			
14	2018-01-02	Influent	7.79	1.76	0.01	1.75	Influent	7.61	1.72	0.01	1.71
			7.68	1.73				7.56	1.71		
		Effluent	14.02	3.17	0.03	3.14	Effluent	21.43	4.84	0.01	4.85
			13.79	3.11				21.49	4.85		
		Concentration Change	-80%				Concentration Change	-183%			
15	2018-01-08	Influent	8.45	1.91	0.01	1.89	Influent	7.86	1.78	0.02	1.80
			8.32	1.88				8.06	1.82		
		Effluent	14.15	3.19	0.01	3.18	Effluent	18.25	4.12	0.05	4.17
			14.05	3.17				18.69	4.22		
		Concentration Change	-68%				Concentration Change	-132%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
16	2018-01-15	Influent	8.39 7.91	1.89 1.79	0.05	1.84	Influent	8.95 8.04	2.02 1.82	0.10	1.92
		Effluent	14.53 16.89	3.28 3.81	0.27	3.55	Effluent	20.15 19.95	4.55 4.51	0.02	4.53
		Concentration Change	-93%				Concentration Change	-136%			
19	2018-02-07	Influent	9.09 9.36	2.05 2.11	0.03	2.08	Influent	8.76 8.72	1.98 1.97	0.00	1.97
		Effluent	12.12 12.33	2.74 2.78	0.02	2.76	Effluent	34.85 34.31	7.87 7.75	0.06	7.81
		Concentration Change	-33%				Concentration Change	-296%			
19	2018-02-09	Influent	- -	- -	-	-	Influent	- -	- -	-	-
		Effluent	14.42 14.33	3.26 3.24	0.01	3.25	Effluent	18.32 18.29	4.14 4.13	0.00	4.13
		Concentration Change	n/a				Concentration Change	n/a			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
21	2018-02-20	Influent	7.77	1.76	0.00	1.75	Influent	7.85	1.77	0.00	1.78
			7.74	1.75				7.88	1.78		
		Effluent	15.03	3.39	0.01	3.41	Effluent	20.81	4.70	0.00	4.69
			15.15	3.42				20.77	4.69		
		Concentration Change	-95%				Concentration Change	-164%			
23	2018-03-09	Influent	8.71	1.97	0.01	1.97	Influent	8.59	1.94	0.02	1.96
			8.78	1.98				8.75	1.98		
		Effluent	9.88	2.23	0.01	2.25	Effluent	13.34	3.01	0.00	3.02
			10.02	2.26				13.37	3.02		
		Concentration Change	-14%				Concentration Change	-54%			
27	2018-04-02	Influent	9.23	2.08	0.03	2.06	Influent	9.04	2.04	0.01	2.04
			9.00	2.03				8.98	2.03		
		Effluent	18.72	4.23	0.03	4.26	Effluent	27.48	6.21	0.00	6.21
			19.01	4.29				27.48	6.21		
		Concentration Change	-107%				Concentration Change	-205%			
29	2018-04-16	Influent	9.06	2.04	0.00	2.05	Influent	9.04	2.04	0.01	2.05
			9.08	2.05				9.09	2.05		
		Effluent	14.20	3.21	0.00	3.20	Effluent	23.78	5.37	0.00	5.37
			14.18	3.20				23.79	5.37		
		Concentration Change	-56%				Concentration Change	-162%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
32	2018-05-08	Influent	36.20 36.40	8.17 8.22	0.02	8.20	Influent	36.72 36.83	8.29 8.32	0.01	8.30
		Effluent	61.36 60.32	13.86 13.62	0.12	13.74	Effluent	97.37 97.38	21.99 21.99	0.00	21.99
		Concentration Change	-68%				Concentration Change	-165%			
32	2018-05-10	Influent	9.33 9.26	2.11 2.09	0.01	2.10	Influent	9.29 9.32	2.10 2.11	0.00	2.10
		Effluent	114.87 118.70	25.94 26.80	0.43	26.37	Effluent	83.94 88.77	18.95 20.05	0.55	19.50
		Concentration Change	-1156%				Concentration Change	-828%			
32	2018-05-12	Influent	9.50 9.22	2.15 2.08	0.03	2.11	Influent	9.43 9.48	2.13 2.14	0.00	2.14
		Effluent	51.24 50.72	11.57 11.45	0.06	11.51	Effluent	30.33 30.51	6.85 6.89	0.02	6.87
		Concentration Change	-445%				Concentration Change	-222%			
37	2018-06-14	Influent	8.63 8.59	1.95 1.94	0.00	1.94	Influent	8.68 8.58	1.96 1.94	0.01	1.95
		Effluent	25.87 25.87	5.84 5.84	0.00	5.84	Effluent	53.76 52.43	12.14 11.84	0.15	11.99
		Concentration Change	-200%				Concentration Change	-515%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
38	2018-06-21	Influent	9.08	2.05	0.01	2.06	Influent	8.87	2.00	0.12	2.12
			9.20	2.08				9.91	2.24		
		Effluent	18.38	4.15	0.04	4.19	Effluent	29.77	6.72	0.00	6.72
			18.72	4.23				29.79	6.73		
		Concentration Change	-103%				Concentration Change	-217%			
39	2018-06-26	Influent	9.26	2.09	0.05	2.14	Influent	7.25	1.64	0.23	1.86
			9.71	2.19				9.26	2.09		
		Effluent	13.64	3.08	0.04	3.12	Effluent	18.21	4.11	0.31	4.43
			14.03	3.17				21.00	4.74		
		Concentration Change	-46%				Concentration Change	-138%			
40	2018-07-04	Influent	7.84	1.77	0.00	1.77	Influent	7.85	1.77	0.02	1.75
			7.88	1.78				7.69	1.74		
		Effluent at 200 mL	11.53	2.60	0.02	2.58	Effluent at 200 mL	8.83	1.99	0.00	2.00
			11.33	2.56				8.86	2.00		
		Effluent at 2000 mL	11.67	2.64	0.01	2.62	Effluent at 2000 mL	11.74	2.65	0.01	2.64
			11.56	2.61				11.65	2.63		
		Effluent at 4000 mL	15.62	3.53	0.00	3.53	Effluent at 4000 mL	22.70	5.13	0.00	5.13
			15.67	3.54				22.71	5.13		
		Effluent at 6000 mL	15.97	3.61	0.05	3.66	Effluent at 6000 mL	27.34	6.17	0.05	6.23
			16.44	3.71				27.80	6.28		

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
40	2018-07-04	Effluent at 8000 mL	15.99	3.61	0.01	3.60	Effluent at 8000 mL	27.40	6.19	0.01	6.18
			15.93	3.60				27.32	6.17		
		Effluent at 10,000 mL	15.65	3.53	0.01	3.53	Effluent at 10,000 mL	26.13	5.90	0.00	5.90
			15.58	3.52				26.13	5.90		
		Effluent at 12,000 mL	15.00	3.39	0.01	3.38	Effluent at 12,000 mL	23.37	5.28	0.10	5.38
			14.90	3.37				24.28	5.48		
		Total Volume Effluent	11.38	2.57	0.00	2.57	Total Volume Effluent	22.40	5.06	0.04	5.02
			11.37	2.57				22.09	4.99		
		Concentration Change	-45%				Concentration Change	-186%			
41	2018-07-09	Influent	9.02	2.04	0.01	2.03	Influent	8.88	2.00	0.02	2.02
			8.92	2.01				9.02	2.04		
		Effluent	9.86	2.23	0.00	2.22	Effluent	15.80	3.57	0.36	3.92
			9.85	2.22				18.96	4.28		
		Concentration Change	-10%				Concentration Change	-94%			

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
42	2018-07-16	Bucket 1 Influent	9.13	2.06	0.00	2.06	Bucket 1 Influent	8.98	2.03	0.07	2.10
			9.13	2.06				9.63	2.18		
		Bucket 1 Effluent	15.50	3.50	0.41	3.09	Bucket 1 Effluent	17.96	4.05	0.01	4.04
			11.90	2.69				17.87	4.03		
		Concentration Change	-50%				Concentration Change	-92%			
		Bucket 2 Influent	9.32	2.10	0.01	2.12	Bucket 2 Influent	9.28	2.10	0.02	2.12
			9.43	2.13				9.48	2.14		
		Bucket 2 Effluent	10.72	2.42	0.00	2.42	Bucket 2 Effluent	12.26	2.77	0.00	2.77
			10.70	2.42				12.25	2.77		
		Concentration Change	-14%				Concentration Change	-31%			
		Influent Bucket Average (mg NO_3^--N/L)				2.09	Influent Bucket Average (mg NO_3^--N/L)				2.11
		Effluent Bucket Average (mg NO_3^--N/L)				2.81	Effluent Bucket Average (mg NO_3^--N/L)				3.39
		Concentration Reduction Average				-34%	Concentration Reduction Average				-61%

Week	Date	Column 1					Column 2				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
43	2018-07-23	Influent	9.76	2.20	0.01	2.20	Influent	9.67	2.18	0.03	2.15
			9.71	2.19				9.37	2.12		
		Effluent	10.47	2.36	0.00	2.36	Effluent	16.57	3.74	0.01	3.73
			10.43	2.35				16.46	3.72		
		Concentration Change	-7%				Concentration Change	-74%			
		Influent	9.98	2.25	0.03	2.28	Influent	9.62	2.17	0.02	2.16
			10.25	2.31				9.48	2.14		
		Effluent	12.15	2.74	0.03	2.71	Effluent	10.06	2.27	0.00	2.27
			11.89	2.68				10.03	2.26		
		Concentration Change	-19%				Concentration Change	-5%			
		Influent Bucket Average (mg NO_3^--N/L)				2.24	Influent Bucket Average (mg NO_3^--N/L)				2.15
		Effluent Bucket Average (mg NO_3^--N/L)				2.57	Effluent Bucket Average (mg NO_3^--N/L)				2.98
		Concentration Reduction Average				-15%	Concentration Reduction Average				-38%

All data obtained using high range calibration data of 5, 10, 20, 50, and 100 mg NO_3^-/L (or 1.13 to 22.58 mg NO_3^--N/L), unless indicated otherwise. Used dilution as required.

[a] Obtained using mid range calibration data of 1, 2, 3, 4, and 5 mg NO_3^-/L (or 0.23 to 1.13 mg NO_3^--N/L) when measurements are below the high range calibration range.

[b] Measured by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta: 2-255 Centennial Centre for Interdisciplinary Science Building, Edmonton, AB.

Table 37: Nitrate influent and effluent concentrations and percentage concentration reduction for columns 3 and 4.

Week	Date	Column 3					Column 4				
		Description	Nitrate Concentration (mg NO_3^-/L)	Nitrate Concentration (mg NO_3^--N/L)	Standard Deviation	Average Nitrate Concentration (mg NO_3^--N/L)	Description	Nitrate Concentration (mg NO_3^-/L)	Nitrate Concentration (mg NO_3^--N/L)	Standard Deviation	Average Nitrate Concentration (mg NO_3^--N/L)
4	2017-10-24	Influent	7.46 7.40	1.68 1.67	0.01	1.68	Influent	7.43 7.36	1.68 1.66	0.01	1.67
		Effluent	783.10 518.37	176.83 117.05	29.89	146.94	Effluent	279.64 555.96	63.14 125.54	31.20	94.34
		Concentration Change	-8658%				Concentration Change	-5549%			
5	2017-10-30	Influent	6.97 6.53	1.57 1.47	0.05	1.52	Influent	6.90 7.24	1.56 1.64	0.04	1.60
		Effluent	63.73[c] 63.82[c]	14.39 14.41	0.01	14.40	Effluent	38.27[c] 38.26[c]	8.64 8.64	0.00	8.64
		Concentration Change	-845%				Concentration Change	-441%			
6	2017-11-06	Influent	7.22[c] 7.22[c]	1.63 1.63	0.00	1.63	Influent	7.21[c] 7.20[c]	1.63 1.63	0.00	1.63
		Effluent	7.38[c] 7.54[c]	1.67 1.70	0.02	1.68	Effluent	2.24[c] 2.26[c]	0.51 0.51	0.00	0.51
		Concentration Change	-3%				Concentration Change	69%			

Week	Date	Column 3					Column 4				
		Des.	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)	Des.	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)
7	2017-11-14	Influent	8.02[c] 8.04[c]	1.81 1.82	0.00	1.81	Influent	8.02[c] 8.00[c]	1.81 1.81	0.00	1.81
		Effluent	0.14[c] 0.12[c]	0.03 0.03	0.00	0.03	Effluent	15.09[c] 14.44[c]	3.41 3.26	0.07	3.33
		Concentration Change	98%				Concentration Change	-84%			
8	2017-11-20	Influent	7.83[c] n/a[c]	1.77 0.00	0.00	1.77	Influent	7.87[c] 7.78[c]	1.78 1.76	0.00	1.78
		Effluent	1.53[b] 1.76[b]	0.35 0.40	0.03	0.37	Effluent	1.04[a] 1.05[a]	0.23 0.24	0.00	0.24
		Concentration Change	79%				Concentration Change	87%			
9	2017-11-27	Influent	8.34 8.32	1.88 1.88	0.00	1.88	Influent	7.92 8.24	1.79 1.86	0.04	1.83
		Effluent	0.27[a] 1.27[a]	0.06 0.29	0.11	0.17	Effluent	3.03[b] 3.10[b]	0.68 0.70	0.01	0.69
		Concentration Change	91%				Concentration Change	62%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
10	2017-12-04	Influent	8.85 8.92	2.00 2.01	0.01	2.01	Influent	8.68 9.39	1.96 2.12	0.08	2.04
		Effluent	0.80[a] 0.53[a]	0.18 0.12	0.03	0.15	Effluent	0.84[a] 0.46[a]	0.19 0.10	0.04	0.15
		Concentration Change	92%				Concentration Change	93%			
11	2017-12-11	Influent	8.02 7.61	1.81 1.72	0.05	1.76	Influent	7.50 7.68	1.69 1.73	0.02	1.71
		Effluent	0.55[a] 0.57[a]	0.13 0.13	0.00	0.13	Effluent	0.92[a] 0.70[a]	0.21 0.16	0.03	0.18
		Concentration Change	93%				Concentration Change	89%			
12	2017-12-18	Influent	7.42 7.44	1.68 1.68	0.00	1.68	Influent	7.46 7.54	1.68 1.70	0.01	1.69
		Effluent	0.72[a] 0.98[a]	0.16 0.22	0.03	0.19	Effluent	1.67[b] 1.83[b]	0.38 0.41	0.02	0.39
		Concentration Change	89%				Concentration Change	77%			

Week	Date	Column 3					Column 4				
		Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)	Description	(mg NO$_3^-$/L)	(mg NO$_3^-$-N/L)	σ	Avg (mg NO$_3^-$-N/L)
13	2017-12-26	Influent	7.80 7.75	1.76 1.75	0.00	1.76	Influent	8.25 7.86	1.86 1.78	0.04	1.82
		Effluent	0.39[a] 0.15[a]	0.09 0.03	0.03	0.06	Effluent	2.15[b] 2.39[b]	0.49 0.54	0.03	0.51
		Concentration Change	97%				Concentration Change	72%			
14	2018-01-02	Influent	7.67 7.93	1.73 1.79	0.03	1.76	Influent	7.75 7.90	1.75 1.78	0.02	1.77
		Effluent	<LOQ[a] <LOQ[a]	0.02 0.02	n/a	0.02	Effluent	1.69[b] 1.39[b]	0.38 0.31	0.03	0.35
		Concentration Change	99%				Concentration Change	80%			
15	2018-01-08	Influent	7.75 7.57	1.75 1.71	0.02	1.73	Influent	7.85 7.82	1.77 1.77	0.00	1.77
		Effluent	0.16[a] 0.28[a]	0.04 0.06	0.01	0.05	Effluent	2.49[b] 2.86[b]	0.56 0.65	0.04	0.60
		Concentration Change	97%				Concentration Change	66%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
16	2018-01-15	Influent	8.39	1.89	0.03	1.87	Influent	8.18	1.85	0.03	1.88
			8.17	1.84				8.48	1.91		
		Effluent	1.57[b]	0.35	0.15	0.21	Effluent	2.37[b]	0.53	0.09	0.63
			0.25[a]	0.06				3.20[b]	0.72		
		Concentration Change	89%				Concentration Change	67%			
17	2018-01-23	Influent	9.21	2.08	0.00	2.08	Influent	8.64	1.95	0.07	2.03
			9.19	2.08				9.31	2.10		
		Effluent	0.36[a]	0.08	0.00	0.08	Effluent	3.39[b]	0.77	0.01	0.75
			0.39[a]	0.09				3.29[b]	0.74		
		Concentration Change	96%				Concentration Change	63%			
18	2018-01-30	Influent	8.43	1.90	0.00	1.91	Influent	8.59	1.94	0.01	1.95
			8.45	1.91				8.67	1.96		
		Effluent	0.32[a]	0.07	0.00	0.08	Effluent	2.32[b]	0.52	0.02	0.50
			0.35[a]	0.08				2.11[b]	0.48		
		Concentration Change	96%				Concentration Change	74%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
19	2018-02-07	Influent	8.72	1.97	0.06	2.03	Influent	9.54	2.15	0.03	2.13
			9.25	2.09				9.28	2.10		
		Effluent	<LOQ[a]	0.02	n/a	0.02	Effluent	0.45[a]	0.10	0.00	0.10
			<LOQ[a]	0.02				0.42[a]	0.09		
		Concentration Change	99%				Concentration Change	95%			
19	2018-02-08	Influent	9.00	2.03	0.01	2.02	Influent	8.94	2.02	0.01	2.03
			8.93	2.02				9.06	2.05		
		Effluent	0.23[a]	0.05	0.01	0.05	Effluent	2.16[b]	0.49	0.08	0.57
			0.18[a]	0.04				2.86[b]	0.65		
		Concentration Change	98%				Concentration Change	72%			
21	2018-02-20	Influent	7.76	1.75	0.01	1.77	Influent	7.92	1.79	0.00	1.79
			7.88	1.78				7.89	1.78		
		Effluent	1.04[b]	0.24	0.00	0.24	Effluent	13.19	2.98	0.02	3.00
			1.06[b]	0.24				13.37	3.02		
		Concentration Change	87%				Concentration Change	-68%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
23	2018-03-09	Influent	8.66 9.19	1.96 2.08	0.06	2.02	Influent	8.59 8.59	1.94 1.94	0.00	1.94
		Effluent	5.55 5.63	1.25 1.27	0.01	1.26	Effluent	9.48 9.62	2.14 2.17	0.02	2.16
		Concentration Change	37%				Concentration Change	-11%			
27	2018-04-02	Influent	9.05 8.99	2.04 2.03	0.01	2.04	Influent	9.00 9.05	2.03 2.04	0.00	2.04
		Effluent	26.17 27.45	5.91 6.20	0.14	6.05	Effluent	15.84 15.59	3.58 3.52	0.03	3.55
		Concentration Change	-197%				Concentration Change	-74%			
29	2018-04-16	Influent	9.14 9.09	2.06 2.05	0.01	2.06	Influent	9.06 9.06	2.05 2.05	0.00	2.05
		Effluent	8.53 8.57	1.93 1.93	0.00	1.93	Effluent	16.31 15.90	3.68 3.59	0.05	3.64
		Concentration Change	6%				Concentration Change	-78%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
32	2018-05-08	Influent	36.20 36.40	8.17 8.22	0.02	8.20	Influent	36.72 36.83	8.29 8.32	0.01	8.30
		Effluent	15.23 15.08	3.44 3.41	0.02	3.42	Effluent	23.45 22.87	5.29 5.16	0.07	5.23
		Concentration Change	58%				Concentration Change	37%			
32	2018-05-10	Influent	9.35 9.35	2.11 2.11	0.00	2.11	Influent	9.31 9.26	2.10 2.09	0.01	2.10
		Effluent	88.83 90.40	20.06 20.41	0.18	20.24	Effluent	91.31 91.05	20.62 20.56	0.03	20.59
		Concentration Change	-858%				Concentration Change	-882%			
32	2018-05-12	Influent	9.45 9.40	2.13 2.12	0.01	2.13	Influent	9.45 9.47	2.13 2.14	0.00	2.14
		Effluent	40.28 40.05	9.09 9.04	0.03	9.07	Effluent	34.17 33.81	7.72 7.63	0.04	7.68
		Concentration Change	-326%				Concentration Change	-259%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
37	2018-06-14	Influent	8.69	1.96	0.02	1.94	Influent	8.47	1.91	0.02	1.90
			8.54	1.93				8.34	1.88		
		Effluent	25.17	5.68	0.02	5.67	Effluent	19.83	4.48	0.00	4.48
			25.02	5.65				19.86	4.48		
		Concentration Change	-191%				Concentration Change	-136%			
38	2018-06-21	Influent	9.59	2.17	0.01	2.18	Influent	8.77	1.98	0.09	2.07
			9.70	2.19				9.56	2.16		
		Effluent	13.02	2.94	0.13	2.81	Effluent	9.86	2.23	0.15	2.08
			11.89	2.69				8.57	1.93		
		Concentration Change	-29%				Concentration Change	0%			
39	2018-06-26	Influent	9.80	2.21	0.05	2.17	Influent	10.13	2.29	0.00	2.28
			9.38	2.12				10.10	2.28		
		Effluent	3.90[b]	0.88	0.03	0.85	Effluent	3.59[b]	0.81	0.01	0.80
			3.60[b]	0.81				3.52[b]	0.79		
		Concentration Change	61%				Concentration Change	65%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
40	2018-07-04	Influent	7.82	1.77	0.01	1.75	Influent	7.70	1.74	0.11	1.84
			7.70	1.74				8.64	1.95		
		Effluent at 200 mL	0.65[a]	0.15	0.02	0.13	Effluent at 200 mL	0.70[a]	0.16	0.00	0.16
			0.47[a]	0.11				0.68[a]	0.15		
		Effluent at 2000 mL	<LOQ[a]	0.02	n/a	0.02	Effluent at 2000 mL	<LOQ[a]	0.02	n/a	0.02
			<LOQ[a]	0.02				<LOQ[a]	0.02		
		Effluent at 4000 mL	<LOQ[a]	0.02	n/a	0.02	Effluent at 4000 mL	<LOQ[a]	0.02	n/a	0.02
			<LOQ[a]	0.02				<LOQ[a]	0.02		
		Effluent at 6000 mL	1.04[b]	0.23	0.00	0.24	Effluent at 6000 mL	<LOQ[a]	0.02	n/a	0.02
			1.05[b]	0.24				<LOQ[a]	0.02		
		Effluent at 8000 mL	1.20[b]	0.27	0.00	0.27	Effluent at 8000 mL	<LOQ[a]	0.02	n/a	0.02
			1.19[b]	0.27				<LOQ[a]	0.02		
		Effluent at 10,000 mL	2.02[b]	0.46	0.00	0.46	Effluent at 10,000 mL	0.24[b]	0.05	0.00	0.05
			2.01[b]	0.45				0.24[b]	0.05		
		Effluent at 12,000 mL	3.48[b]	0.79	0.00	0.79	Effluent at 12,000 mL	2.22[b]	0.50	0.00	0.50
			3.48[b]	0.79				2.20[b]	0.50		
		Total Volume Effluent	2.21[b]	0.50	0.00	0.50	Total Volume Effluent	1.18[b]	0.27	0.00	0.27
			2.20[b]	0.50				1.18[b]	0.27		
		Concentration Change	72%				Concentration Change	86%			

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
41	2018-07-09	Influent	8.69	1.96	0.00	1.96	Influent	8.93	2.02	0.00	2.01
			8.68	1.96				8.90	2.01		
		Effluent	1.33^b	0.30	0.00	0.30	Effluent	0.65^a	0.15	0.01	0.15
			1.32^b	0.30				0.64^a	0.14		
		Concentration Change	85%				Concentration Change	93%			
42	2018-07-16	Bucket 1 Influent	9.26	2.09	0.02	2.11	Bucket 1 Influent	9.41	2.13	0.01	2.12
			9.44	2.13				9.37	2.11		
		Bucket 1 Effluent	1.13^b	0.25	0.00	0.26	Bucket 1 Effluent	1.19^b	0.27	0.01	0.28
			1.15^b	0.26				1.27^b	0.29		
		Concentration Change	88%				Concentration Change	87%			
		Bucket 2 Influent	9.20	2.08	0.01	2.09	Bucket 2 Influent	9.51	2.15	0.03	2.11
			9.30	2.10				9.22	2.08		
		Bucket 2 Effluent	4.89^b	1.10	0.03	1.07	Bucket 2 Effluent	7.08	1.60	0.02	1.58
			4.62^b	1.04				6.91	1.56		
		Concentration Change	49%				Concentration Change	25%			
		Influent Bucket Average (mg NO_3^--N/L)				2.10	Influent Bucket Average (mg NO_3^--N/L)				2.12
		Effluent Bucket Average (mg NO_3^--N/L)				0.68	Effluent Bucket Average (mg NO_3^--N/L)				0.85
		Concentration Reduction Average				68%	Concentration Reduction Average				60%

Week	Date	Column 3					Column 4				
		Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)	Description	(mg NO_3^-/L)	(mg NO_3^--N/L)	σ	Avg (mg NO_3^--N/L)
43	2018-07-23	Bucket 1 Influent	9.56	2.16	0.11	2.27	Bucket 1 Influent	10.25	2.31	0.00	2.31
			10.57	2.39				10.24	2.31		
		Bucket 1 Effluent	1.79[b]	0.41	0.01	0.40	Bucket 1 Effluent	1.12[b]	0.25	0.00	0.25
			1.71[b]	0.39				1.08[b]	0.24		
		Concentration Change	83%				Concentration Change	89%			
		Bucket 2 Influent	11.59	2.62	0.17	2.44	Bucket 2 Influent	10.14	2.29	0.01	2.28
			10.05	2.27				10.03	2.27		
		Bucket 2 Effluent	4.10[b]	0.93	0.02	0.91	Bucket 2 Effluent	5.83	1.32	0.01	1.31
			3.95[b]	0.89				5.76	1.30		
		Concentration Change	63%				Concentration Change	43%			
		Influent Bucket Average (mg NO_3^--N/L)				2.36	Influent Bucket Average (mg NO_3^--N/L)				2.30
		Effluent Bucket Average (mg NO_3^--N/L)				0.65	Effluent Bucket Average (mg NO_3^--N/L)				0.89
		Concentration Reduction Average				72%	Concentration Reduction Average				61%

Data obtained using high range calibration data of 5, 10, 20, 50, and 100 mg NO_3^-/L (or 1.13 to 22.58 mg NO_3^--N/L), unless indicated otherwise. Used dilution as required.

[a] Obtained using low range calibration data of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 mg NO_3^-/L (or 0.02 to 0.20 mg NO_3^--N/L) when measurements within the low range calibration range. LOQ (limit of quantification) is therefore 0.02 mg NO_3^--N/L and any values not detected or < 0.02 mg NO_3^--N/L are considered equal to 0.02 mg NO_3^--N/L.

[b] Obtained using mid range calibration data of 1, 2, 3, 4, and 5 mg NO_3^-/L (or 0.23 to 1.13 mg NO_3^--N/L) when measurements are within the high range calibration range.

[c] Measured by the Biogeochemical Analytical Service Laboratory (BASL) at the University of Alberta: 2-255 Centennial Centre for Interdisciplinary Science Building, Edmonton, AB.

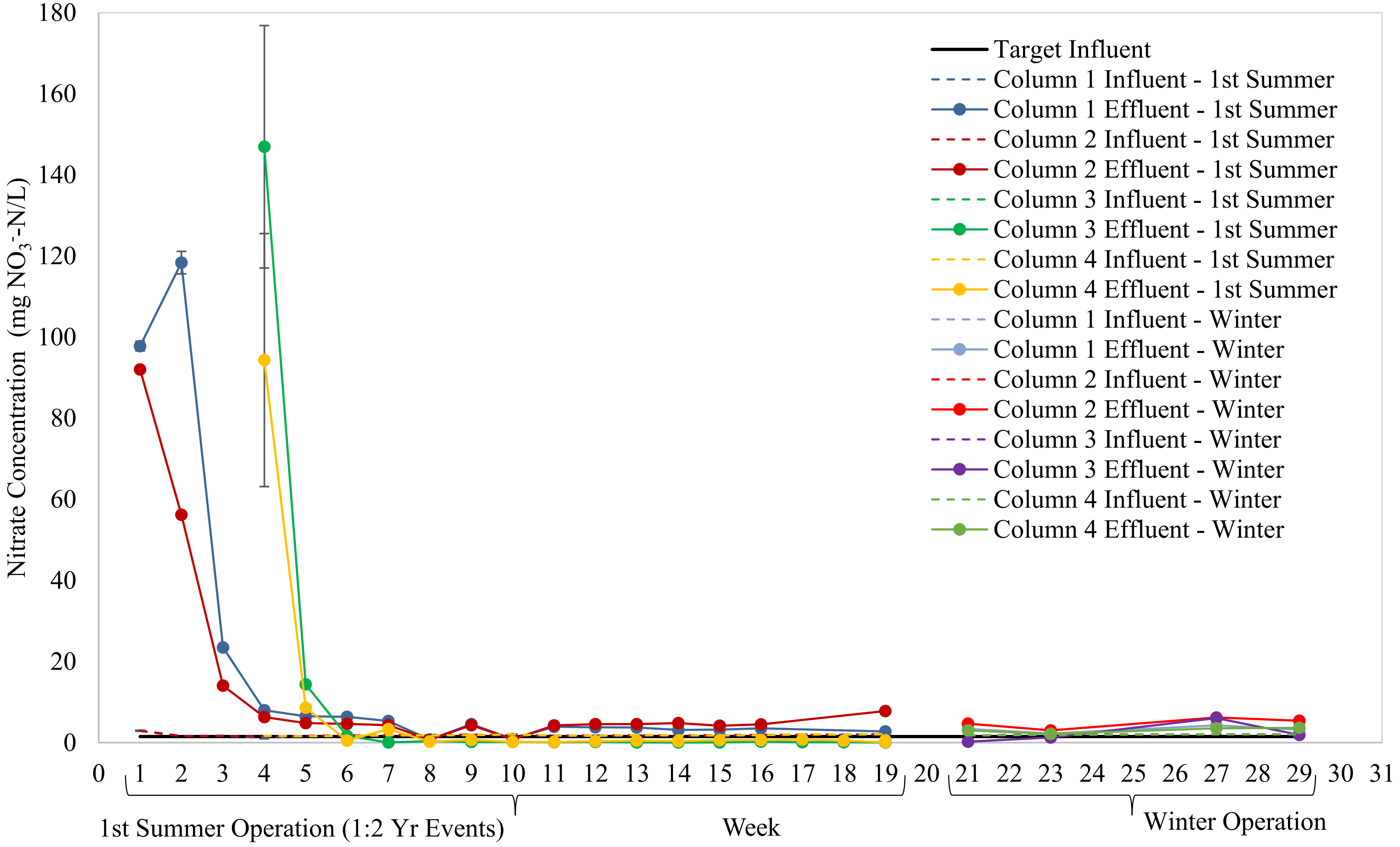


Figure 62: Nitrate concentration change during 1st summer and winter operation.

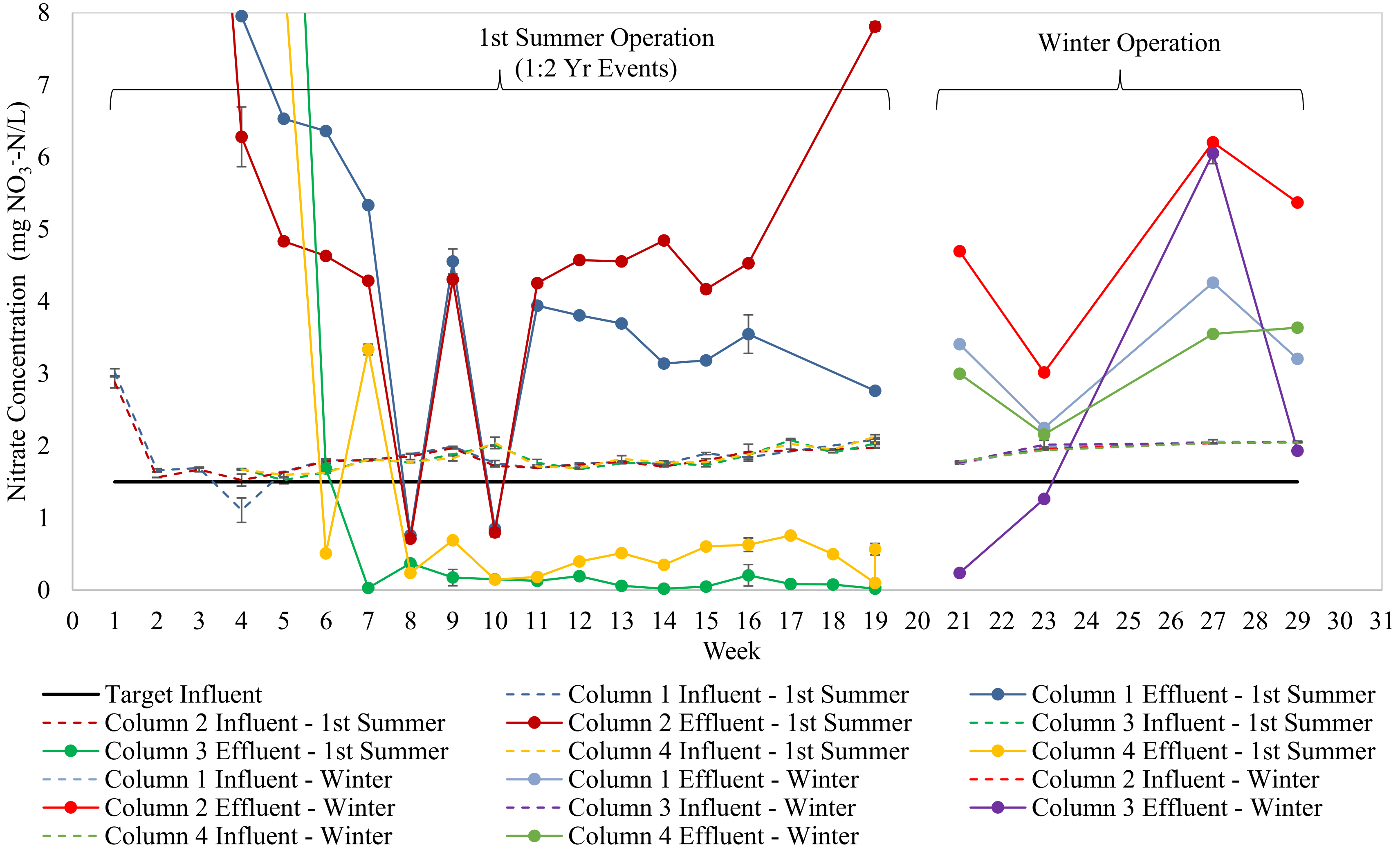


Figure 63: Nitrate concentration change during 1st summer and winter operation zoomed in.

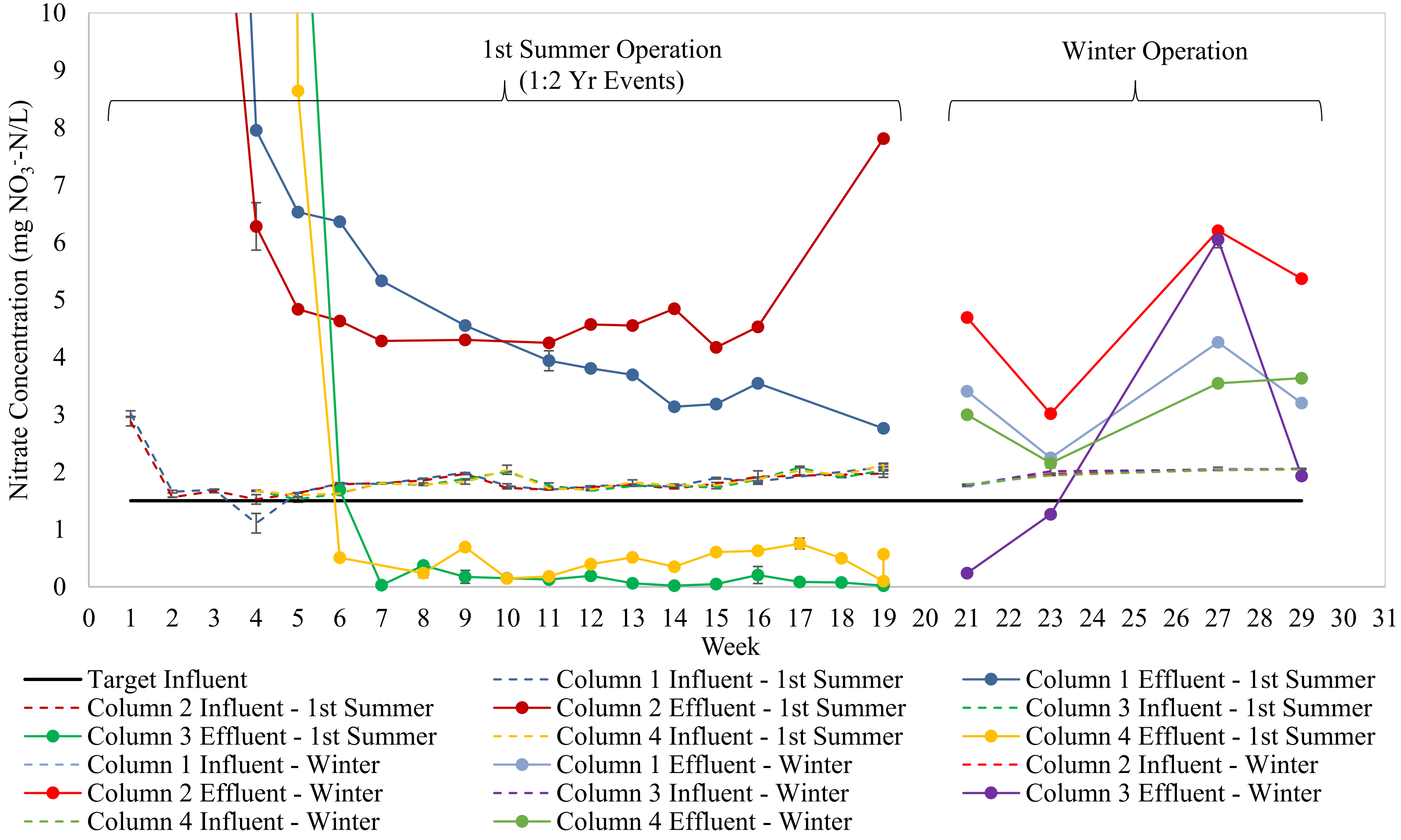


Figure 64: Nitrate concentration change during 1st summer and winter operation with effluent outliers omitted (week 8 and 10 from columns 1 and 2 and week 7 from column 4).

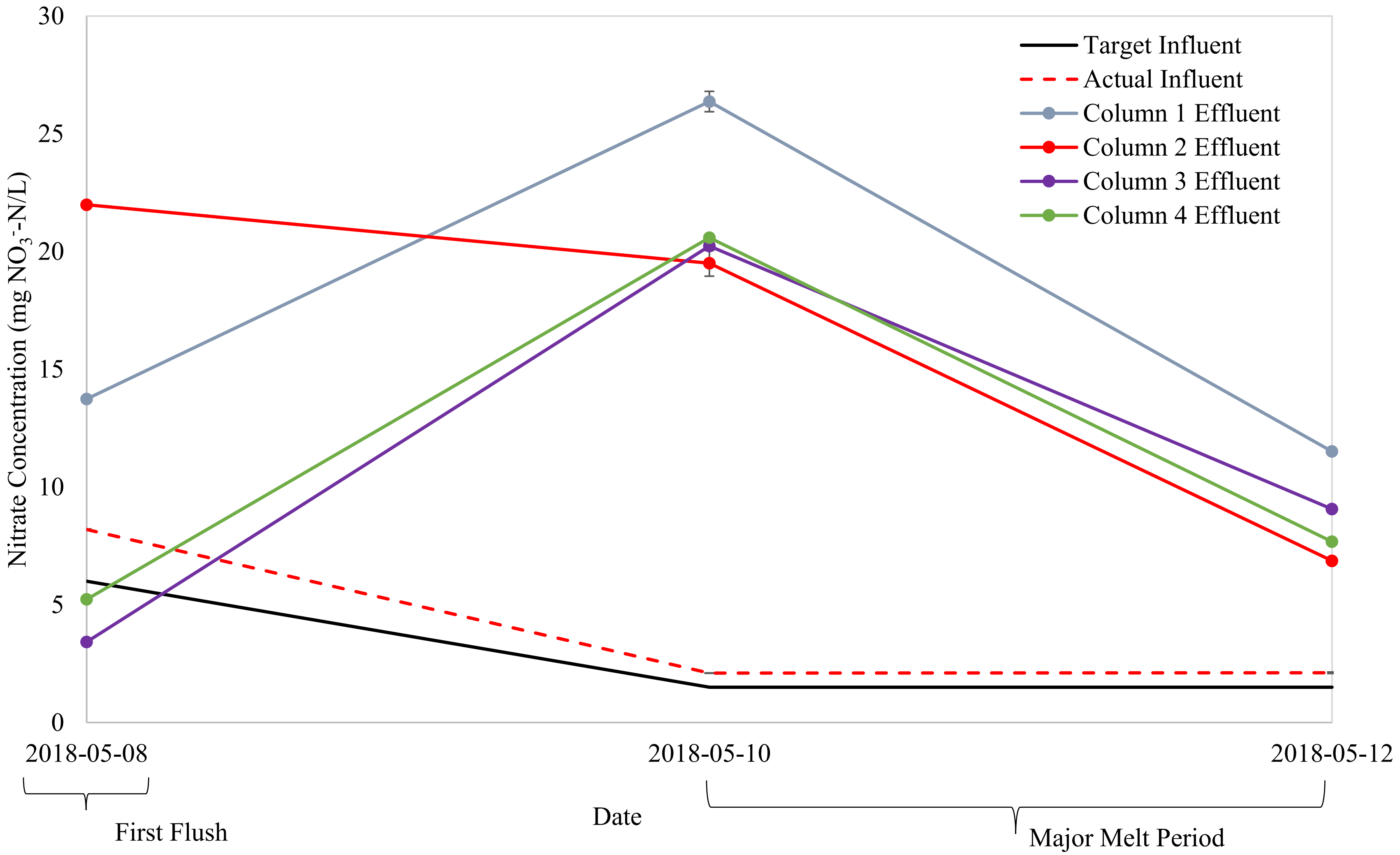


Figure 65: Nitrate concentration change during spring runoff.

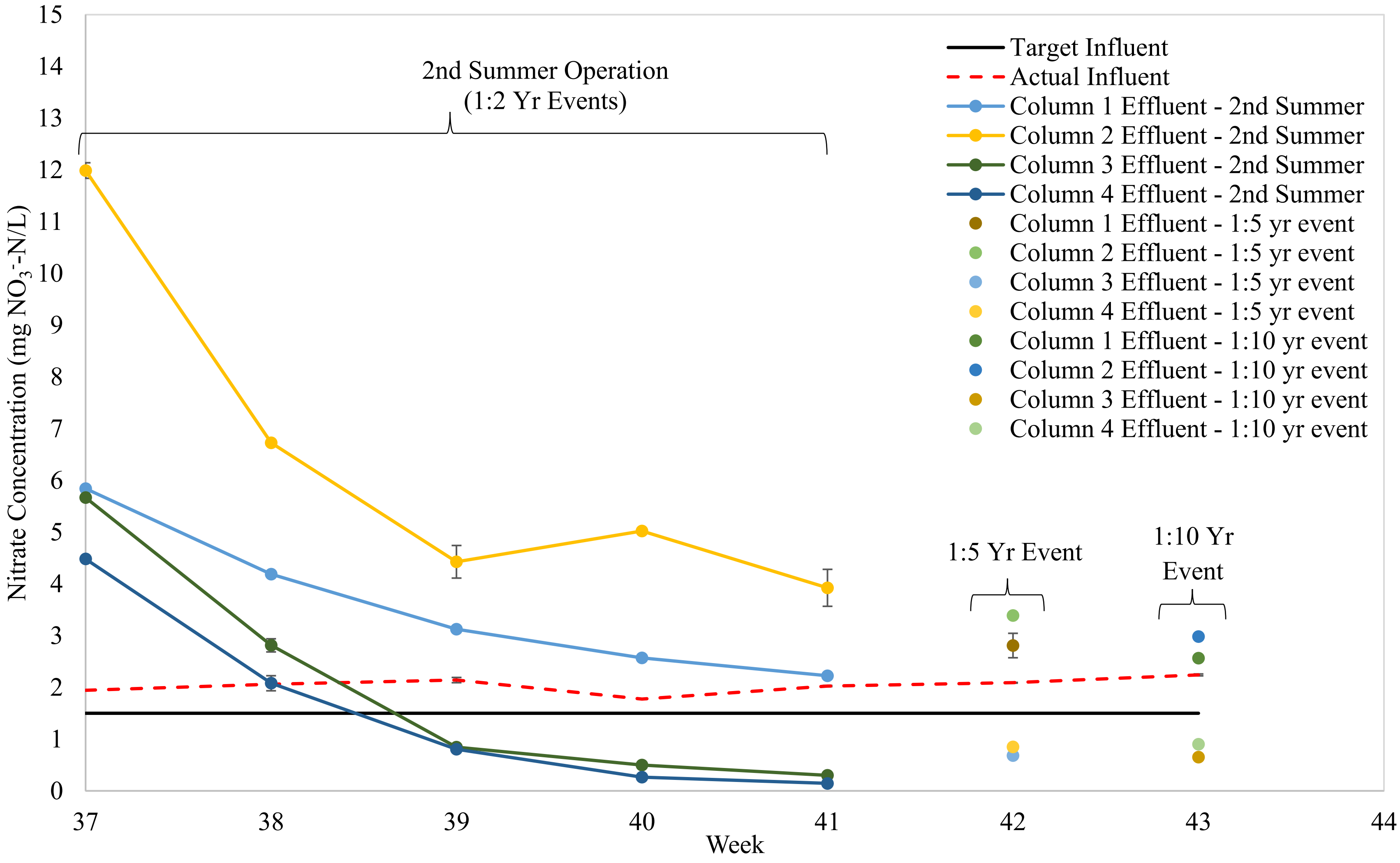


Figure 66: Nitrate concentration change during 2nd summer operation and 1:5 yr and 1:10 yr events.

Table 38: Chloride influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4.

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			Chloride Concentration (mg Cl^-/L)	Standard Deviation	Average Chloride Concentration (mg Cl^-/L)	Chloride Concentration (mg Cl^-/L)	Standard Deviation	Average Chloride Concentration (mg Cl^-/L)	Chloride Concentration (mg Cl^-/L)	Standard Deviation	Average Chloride Concentration (mg Cl^-/L)	Chloride Concentration (mg Cl^-/L)	Standard Deviation	Average Chloride Concentration (mg Cl^-/L)
1	2017-09-26	Influent	22.67 15.77	3.45	19.22	15.51 15.51	0.00	15.51						
		Effluent	268.50 267.94	0.28	268.22	22.68 15.79	3.44	19.23						
		Concentration Change	-1296%			-24%								
2	2017-10-10	Influent	16.86 16.87	0.00	16.87	16.47 16.37	0.05	16.42						
		Effluent	56.25 56.47	0.11	56.36	28.95 28.97	0.01	28.96						
		Concentration Change	-234%			-76%								
3	2017-10-17	Influent	15.54 15.35	0.09	15.44	15.83 15.25	0.29	15.54						
		Effluent	20.12 21.11	0.49	20.62	19.10 18.77	0.16	18.93						
		Concentration Change	-33%			-22%								

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
4	2017-10-24	Influent	12.47 8.96	1.76	10.72	13.64 15.25	0.80	14.45	16.29 16.25	0.02	16.27	16.10 15.99	0.05	16.04
		Effluent	14.83 15.14	0.15	14.98	17.61 15.58	1.02	16.60	133.74 86.92	23.41	110.33	50.79 100.38	24.80	75.58
		Concentration Change	-40%			-15%			-578%			-371%		
5	2017-10-30	Influent	15.93 15.93	0.00	15.93	15.96 16.05	0.04	16.01	15.05 14.02	0.52	14.53	15.71 15.83	0.06	15.77
		Effluent	15.82 16.43	0.31	16.13	16.06 16.11	0.03	16.09	33.86 34.04	0.09	33.95	31.31 27.36	1.98	29.34
		Concentration Change	-1%			0%			-134%			-86%		
6	2017-11-06	Influent	16.09 15.84	0.13	15.97	15.63 -	0.00	15.63	15.93 15.98	0.03	15.96	15.97 15.92	0.03	15.95
		Effluent	16.56 16.53	0.01	16.55	16.99 16.87	0.06	16.93	19.90 20.30	0.20	20.10	19.66 18.83	0.42	19.25
		Concentration Change	-4%			-8%			-26%			-21%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
7	2017-11-14	Influent	16.45 16.18	0.14	16.32	16.31 16.36	0.03	16.34	16.08 16.03	0.02	16.06	16.19 16.17	0.01	16.18
		Effluent	16.00 16.00	0.00	16.00	16.28 16.33	0.02	16.31	18.67 18.74	0.03	18.71	17.76 17.76	0.00	17.76
		Concentration Change	2%			0%			-17%			-10%		
8	2017-11-20	Influent	17.61 17.64	0.02	17.63	16.95 17.41	0.23	17.18	15.97 16.14	0.09	16.06	16.59 16.57	0.01	16.58
		Effluent	17.03 17.19	0.08	17.11	17.02 17.02	0.00	17.02	17.83 17.94	0.06	17.89	17.86 17.87	0.00	17.86
		Concentration Change	3%			1%			-11%			-8%		
9	2017-11-27	Influent	17.18 17.25	0.04	17.21	17.16 17.23	0.03	17.19	17.14 17.09	0.02	17.12	17.31 17.40	0.05	17.35
		Effluent	17.61 17.73	0.06	17.67	17.16 17.15	0.00	17.15	17.90 18.09	0.09	18.00	18.12 17.96	0.08	18.04
		Concentration Change	-3%			0%			-5%			-4%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
10	2017-12-04	Influent	17.49 17.33	0.08	17.41	17.31 17.16	0.08	17.23	17.10 17.23	0.06	17.17	19.37 17.53	0.92	18.45
		Effluent	17.82 17.82	0.00	17.82	17.71 17.65	0.03	17.68	18.26 18.08	0.09	18.17	19.76 19.75	0.01	19.76
		Concentration Change	-2%			-3%			-6%			-7%		
11	2017-12-11	Influent	16.11 16.11	0.00	16.11	16.11 16.10	0.00	16.11	17.08 17.07	0.01	17.07	16.78 16.90	0.06	16.84
		Effluent	17.62 17.62	0.00	17.62	17.28 17.31	0.02	17.30	18.05 17.93	0.06	17.99	18.50 18.47	0.01	18.49
		Concentration Change	-9%			-7%			-5%			-10%		
12	2017-12-18	Influent	14.98 15.08	0.05	15.03	15.21 15.23	0.01	15.22	15.87 15.87	0.00	15.87	15.85 15.91	0.03	15.88
		Effluent	16.15 16.28	0.07	16.21	16.28 16.30	0.01	16.29	16.99 16.92	0.03	16.96	17.07 17.05	0.01	17.06
		Concentration Change	-8%			-7%			-7%			-7%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)
13	2017-12-26	Influent	14.94 14.97	0.02	14.96	15.00 15.25	0.12	15.12	15.05 15.09	0.02	15.07	15.50 15.51	0.01	15.50
		Effluent	15.68 16.04	0.18	15.86	16.33 16.12	0.11	16.23	16.86 16.88	0.01	16.87	16.99 17.02	0.01	17.00
		Concentration Change	-6%			-7%			-12%			-10%		
14	2018-01-02	Influent	15.21 15.12	0.05	15.16	15.02 14.97	0.02	14.99	15.04 15.20	0.08	15.12	15.32 15.19	0.07	15.26
		Effluent	15.02 15.08	0.03	15.05	15.27 15.36	0.04	15.32	16.09 15.99	0.05	16.04	16.15 16.27	0.06	16.21
		Concentration Change	1%			-2%			-6%			-6%		
15	2018-01-08	Influent	15.58 15.57	0.01	15.58	15.23 15.51	0.14	15.37	15.15 15.05	0.05	15.10	15.18 15.23	0.03	15.21
		Effluent	15.89 15.77	0.06	15.83	16.04 16.33	0.15	16.18	16.27 16.15	0.06	16.21	15.81 15.82	0.00	15.82
		Concentration Change	-2%			-5%			-7%			-4%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^- /L)	σ	Avg (mg Cl^- /L)	(mg Cl^- /L)	σ	Avg (mg Cl^- /L)	(mg Cl^- /L)	σ	Avg (mg Cl^- /L)	(mg Cl^- /L)	σ	Avg (mg Cl^- /L)
16	2018-01-15	Influent	15.43 15.35	0.04	15.39	15.44 15.21	0.11	15.33	15.54 15.25	0.15	15.39	15.25 15.45	0.10	15.35
		Effluent	16.60 16.59	0.00	16.59	16.66 16.50	0.08	16.58	16.07 16.09	0.01	16.08	15.70 15.67	0.02	15.68
		Concentration Change	-8%			-8%			-4%			-2%		
17	2018-01-23	Influent	5.62 5.69	0.04	5.65	5.82 5.78	0.02	5.80	16.00 15.99	0.00	15.99	15.89 16.11	0.11	16.00
		Effluent	17.96 16.65	0.65	17.31	14.95 14.80	0.07	14.87	16.73 16.73	0.00	16.73	16.52 16.55	0.02	16.53
		Concentration Change	-206%			-156%			-5%			-3%		
18	2018-01-30	Influent							15.32 15.17	0.08	15.24	14.88 14.84	0.02	14.86
		Effluent							17.37 17.11	0.13	17.24	16.34 16.57	0.12	16.46
		Concentration Change							-13%			-11%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
19	2018-02-07	Influent	15.27 15.37	0.05	15.32	14.78 14.80	0.01	14.79	16.37 16.18	0.09	16.28	15.86 15.53	0.16	15.70
		Effluent	17.99 18.12	0.06	18.05	10.59 10.58	0.00	10.59	16.36 16.53	0.08	16.44	15.71 15.72	0.00	15.72
		Concentration Change	-18%			28%			-1%			0%		
19	2018-02-08	Influent							14.73 14.67	0.03	14.70	14.89 14.95	0.03	14.92
		Effluent							16.63 16.50	0.07	16.56	16.30 16.26	0.02	16.28
		Concentration Change							-13%			-9%		
21	2018-02-20	Influent	299.69 293.15	3.27	296.42	314.79 321.42	3.32	318.11	313.17 306.92	3.12	310.05	307.36 317.87	5.25	312.62
		Effluent	23.50 23.63	0.06	23.57	50.64 50.31	0.16	50.48	27.00 27.01	0.01	27.01	51.59 51.53	0.03	51.56
		Concentration Change	92%			84%			91%			84%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
23	2018-03-09	Influent	321.13 314.98	3.07	318.05	327.44 316.82	5.31	322.13	321.73 313.35	4.19	317.54	327.05 314.62	6.22	320.84
		Effluent	276.82 282.63	2.91	279.73	309.41 307.88	0.76	308.64	278.84 284.98	3.07	281.91	283.99 288.81	2.41	286.40
		Concentration Change	12%			4%			11%			11%		
27	2018-04-02	Influent	325.84 317.08	4.38	321.46	325.16 315.19	4.99	320.17	322.47 325.84	1.68	324.15	330.52 317.72	6.40	324.12
		Effluent	311.49 308.93	1.28	310.21	305.33 303.49	0.92	304.41	310.32 312.63	1.16	311.47	317.06 321.80	2.37	319.43
		Concentration Change	4%			5%			4%			1%		
29	2018-04-16	Influent	328.69 316.22	6.23	322.46	326.26 319.76	3.25	323.01	327.47 311.26	8.11	319.36	327.33 321.54	2.89	324.43
		Effluent	309.08 303.79	2.65	306.44	331.60 331.42	0.09	331.51	319.36 310.98	4.19	315.17	315.70 315.14	0.28	315.42
		Concentration Change	5%			-3%			1%			3%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl$^-$/L)	σ	Avg (mg Cl$^-$/L)	(mg Cl$^-$/L)	σ	Avg (mg Cl$^-$/L)	(mg Cl$^-$/L)	σ	Avg (mg Cl$^-$/L)	(mg Cl$^-$/L)	σ	Avg (mg Cl$^-$/L)
32	2018-05-08	Influent	1239.48 1264.09	12.30	1251.78	1324.33 1236.96	43.69	1280.64	1239.48 1264.09	12.30	1251.78	1324.33 1236.96	43.69	1280.64
		Effluent	281.84 279.78	1.03	280.81	327.85 319.54	4.16	323.70	238.68 253.09	7.20	245.89	401.50 400.97	0.27	401.23
		Concentration Change	78%			75%			80%			69%		
32	2018-05-10	Influent	329.13 319.44	4.85	324.29	328.14 323.29	2.43	325.71	338.07 328.49	4.79	333.28	327.99 317.85	5.07	322.92
		Effluent	607.49 597.61	4.94	602.55	700.88 688.39	6.24	694.64	539.72 531.92	3.90	535.82	642.48 636.15	3.16	639.31
		Concentration Change	-86%			-113%			-61%			-98%		
32	2018-05-12	Influent	344.35 329.55	7.40	336.95	317.93 325.68	3.87	321.81	333.19 325.22	3.99	329.20	301.88 303.73	0.92	302.80
		Effluent	568.23 561.03	3.60	564.63	389.77 385.47	2.15	387.62	551.37 546.51	2.43	548.94	481.63 477.10	2.26	479.37
		Concentration Change	-68%			-20%			-67%			-58%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)	(mg Cl$^-$ /L)	σ	Avg (mg Cl$^-$ /L)
37	2018-06-14	Influent	14.75 14.69	0.03	14.72	14.96 15.11	0.07	15.03	14.71 14.67	0.02	14.69	14.72 14.77	0.03	14.75
		Effluent	35.58 35.60	0.01	35.59	18.62 18.00	0.31	18.31	43.88 43.86	0.01	43.87	23.40 23.45	0.03	23.42
		Concentration Change	-142%			-22%			-199%			-59%		
38	2018-06-21	Influent	19.42 19.84	0.21	19.63	18.52 20.11	0.79	19.32	19.36 19.43	0.03	19.39	18.41 19.43	0.51	18.92
		Effluent	20.07 20.29	0.11	20.18	20.61 20.64	0.01	20.63	39.69 41.03	0.67	40.36	22.23 21.76	0.23	21.99
		Concentration Change	-3%			-7%			-108%			-16%		
39	2018-06-26	Influent	18.87 18.45	0.21	18.66	14.63 18.19	1.78	16.41	18.44 17.67	0.38	18.05	19.13 18.63	0.25	18.88
		Effluent	16.45 18.94	1.25	17.69	16.60 18.64	1.02	17.62	22.08 19.95	1.06	21.02	20.12 19.92	0.10	20.02
		Concentration Change	5%			-7%			-16%			-6%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
40	2018-07-04	Influent	16.14 16.15	0.01	16.14	15.57 15.55	0.01	15.56	15.56 15.56	0.00	15.56	15.67 15.71	0.02	15.69
		Effluent	17.19 17.36	0.09	17.28	10.30 10.25	0.03	10.28	10.14 10.06	0.04	10.10	9.36 9.12	0.12	9.24
		Concentration Change	-7%			34%			35%			41%		
41	2018-07-09	Influent	8.99 9.42	0.22	9.20	9.42 9.56	0.07	9.49	9.35 9.15	0.10	9.25	9.25 9.38	0.06	9.32
		Effluent	10.08 9.59	0.24	9.84	9.15 9.27	0.06	9.21	9.39 9.26	0.06	9.32	8.96 8.95	0.01	8.95
		Concentration Change	-7%			3%			-1%			4%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
42	2018-07-16	Bucket 1 Influent	9.15 8.67	0.24	8.91	9.08 8.64	0.22	8.86	8.55 8.75	0.10	8.65	8.83 8.59	0.12	8.71
		Bucket 1 Effluent	9.22 9.14	0.04	9.18	9.37 9.09	0.14	9.23	9.06 8.81	0.13	8.93	8.56 8.56	0.00	8.56
		Concentration Change	-3%			-4%			-3%			2%		
		Bucket 2 Influent	9.42 9.10	0.16	9.26	8.47 8.67	0.10	8.57	8.46 8.51	0.03	8.48	8.95 8.73	0.11	8.84
		Bucket 2 Effluent	9.32 8.86	0.23	9.09	9.28 9.11	0.09	9.20	8.55 8.79	0.12	8.67	8.37 8.59	0.11	8.48
		Concentration Change	2%			-7%			-2%			4%		
		Influent Bucket Average (mg/L)			9.08	8.71			8.57			8.77		
		Effluent Bucket Average (mg/L)			9.14	9.21			8.80			8.53		
		Concentration Change	-1%			-6%			-3%			3%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)	(mg Cl^-/L)	σ	Avg (mg Cl^-/L)
43	2018-07-23	Influent	8.77 8.98	0.10	8.87	8.82 8.93	0.06	8.87	8.81 9.37	0.28	9.09	8.87 9.11	0.12	8.99
		Effluent	8.69 8.61	0.04	8.65	8.83 8.57	0.13	8.70	8.20 8.60	0.20	8.40	8.44 8.40	0.02	8.42
		Concentration Change	3%			2%			8%			6%		
		Influent	8.76 8.62	0.07	8.69	8.93 8.72	0.11	8.83	8.66 9.12	0.23	8.89	8.58 8.95	0.18	8.77
		Effluent	8.90 8.85	0.03	8.88	9.34 9.17	0.09	9.25	8.62 8.21	0.21	8.41	8.27 8.00	0.14	8.14
		Concentration Change	-2%			-5%			5%			7%		
		Influent Bucket Average (mg/L)			8.78	8.85			8.99			8.88		
		Effluent Bucket Average (mg/L)			8.78	8.98			8.41			8.88		
		Concentration Change	0%			-1%			6%			7%		

Table 39: COD influent and effluent concentrations and percentage concentration reduction for columns 1, 2, 3, and 4.

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			Corrected COD Concentration (mg O_2/L)	Standard Deviation	Average COD Concentration (mg O_2/L)	Corrected COD Concentration (mg O_2/L)	Standard Deviation	Average COD Concentration (mg O_2/L)	Corrected COD Concentration (mg O_2/L)	Standard Deviation	Average COD Concentration (mg O_2/L)	Corrected COD Concentration (mg O_2/L)	Standard Deviation	Average COD Concentration (mg O_2/L)
1	2017-09-26	Influent	40.53 -	0.00	40.53	- 39.25	0.00	39.25						
		Effluent	96.31 96.31	0.00	96.31	94.61 97.59	1.49	96.10						
		Concentration Change	-138%			-145%								
2	2017-10-10	Influent	46.06 43.93	1.06	45.00	43.93 39.25	2.34	41.59						
		Effluent	259.51 251.95	3.78	255.73	103.31 131.02	13.86	117.16						
		Concentration Change	-4.68			-1.82								

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
3	2017-10-17	Influent	43.93 41.80	1.06	42.87	41.80 44.78	1.49	43.29						
		Effluent	166.29 163.77	1.26	165.03	73.08 83.15	5.04	78.12						
		Concentration Change	-285%			-80%								
4	2017-10-24	Influent	49.04 48.19	0.43	48.62	46.91 45.21	0.85	46.06	48.19 50.32	1.06	49.26	43.08 40.95	1.06	42.02
		Effluent	134.80 127.24	3.78	131.02	129.76 74.34	27.71	102.05	1066.94 1066.94	0.00	1066.94	1006.48 1014.04	3.78	1010.26
		Concentration Change	-170%			-122%			-2066%			-2304%		
5	2017-10-30	Influent	43.29 41.59	0.85	42.44	45.85 45.00	0.43	45.42	46.06 45.64	0.21	45.85	45.21 43.51	0.85	44.36
		Effluent	99.53 94.49	2.52	97.01	54.18 49.14	2.52	51.66	525.29 525.29	0.00	525.29	603.39 608.43	2.52	605.91
		Concentration Change	-129%			-14%			-1046%			-1266%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
6	2017-11-06	Influent	50.53 47.55	1.49	49.04	45.42 45.85	0.21	45.64	45.85 43.72	1.06	44.78	39.03 41.16	1.06	40.10
		Effluent	93.23 100.79	3.78	97.01	63.00 88.19	12.60	75.60	534.11 529.07	2.52	531.59	478.68 471.13	3.78	474.91
		Concentration Change	-98%			-66%			-1087%			-1084%		
7	2017-11-14	Influent	48.19 47.76	0.21	47.98	47.34 46.49	0.43	46.91	47.55 45.00	1.28	46.27	43.29 43.72	0.21	43.51
		Effluent	88.19 95.75	3.78	91.97	57.96 55.44	1.26	56.70	526.55 531.59	2.52	529.07	438.38 448.45	5.04	443.41
		Concentration Change	-92%			-21%			-1043%			-919%		
8	2017-11-20	Influent	- 47.76	0.00	47.76	46.06 -	0.00	46.06	46.49 47.76	0.64	47.13	43.93 45.21	0.64	44.57
		Effluent	70.76 71.61	0.43	71.19	47.34 48.19	0.43	47.76	389.25 399.33	5.04	394.29	313.67 313.67	0.00	313.67
		Concentration Change	-49%			-4%			-737%			-604%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
9	2017-11-27	Influent	46.91 44.36	1.28	45.64	43.93 41.38	1.28	42.65	44.78 52.45	3.83	48.62	46.06 41.38	2.34	43.72
		Effluent	69.48 66.50	1.49	67.99	45.21 42.65	1.28	43.93	340.12 347.68	3.78	343.90	269.58 277.14	3.78	273.36
		Concentration Change	-49%			-3%			-607%			-525%		
10	2017-12-04	Influent	48.62 45.64	1.49	47.13	45.64 44.78	0.43	45.21	43.93 42.65	0.64	43.29	45.64 43.08	1.28	44.36
		Effluent	64.80 67.35	1.28	66.08	43.51 43.51	0.00	43.51	274.62 269.58	2.52	272.10	239.35 251.95	6.30	245.65
		Concentration Change	-40%			4%			-529%			-454%		
11	2017-12-11	Influent	48.83 45.85	1.49	47.34	43.29 41.16	1.06	42.23	45.21 44.78	0.21	45.00	29.03 43.93	7.45	36.48
		Effluent	62.46 67.57	2.56	65.01	35.20 43.72	4.26	39.46	210.38 205.34	2.52	207.86	185.19 200.30	7.56	192.74
		Concentration Change	-37%			7%			-362%			-428%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
12	2017-12-18	Influent	48.19 48.62	0.21	48.40	54.58 42.65	5.96	48.62	46.70 46.70	0.00	46.70	50.11 45.42	2.34	47.76
		Effluent	66.08 63.10	1.49	64.59	43.51 40.95	1.28	42.23	192.74 195.26	1.26	194.00	170.07 165.03	2.52	167.55
		Concentration Change	-33%			13%			-315%			-251%		
13	2017-12-26	Influent	44.78 41.80	1.49	43.29	43.51 43.93	0.21	43.72	46.49 50.75	2.13	48.62	53.73 51.60	1.06	52.66
		Effluent	61.82 -	0.00	61.82	45.21 40.53	2.34	42.87	192.74 190.22	1.26	191.48	159.99 154.95	2.52	157.47
		Concentration Change	-43%			2%			-294%			-199%		
14	2018-01-02	Influent	50.75 47.34	1.70	49.04	49.89 45.64	2.13	47.76	45.21 43.51	0.85	44.36	46.91 48.62	0.85	47.76
		Effluent	55.86 54.15	0.85	55.00	33.71 35.41	0.85	34.56	157.47 154.95	1.26	156.21	129.76 154.95	12.60	142.36
		Concentration Change	-12%			28%			-252%			-198%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
15	2018-01-08	Influent	53.94 53.09	0.43	53.51	50.53 53.09	1.28	51.81	49.04 46.06	1.49	47.55	49.89 46.49	1.70	48.19
		Effluent	59.48 62.46	1.49	60.97	42.02 40.31	0.85	41.16	118.42 123.46	2.52	120.94	105.83 98.27	3.78	102.05
		Concentration Change	-14%			21%			-154%			-112%		
16	2018-01-15	Influent	45.64 42.65	1.49	44.14	45.64 43.93	0.85	44.78	51.81 50.11	0.85	50.96	54.37 51.38	1.49	52.87
		Effluent	49.89 48.19	0.85	49.04	37.12 37.12	0.00	37.12	165.03 147.40	8.82	156.21	127.24 114.65	6.30	120.94
		Concentration Change	-11%			17%			-207%			-129%		
17	2018-01-23	Influent	- -	-	-	- -	-	-	44.36 45.21	0.43	44.78	43.93 41.38	1.28	42.65
		Effluent	61.39 58.84	1.28	60.11	32.01 31.58	0.21	31.80	109.61 109.61	0.00	109.61	94.49 89.45	2.52	91.97
		Concentration Change							-145%			-116%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
18	2018-01-30	Influent							46.06 43.51	1.28	44.78	47.76 49.47	0.85	48.62
		Effluent							108.35 105.83	1.26	107.09	108.35 85.67	11.34	97.01
		Concentration Change							-139%			-100%		
19	2018-02-07	Influent	47.34 46.06	0.64	46.70	42.23 42.65	0.21	42.44	56.71 62.24	2.77	59.48	58.41 59.69	0.64	59.05
		Effluent	62.46 56.92	2.77	59.69	45.42 36.05	4.68	40.74	163.77 156.21	3.78	159.99	113.39 118.42	2.52	115.91
		Concentration Change	-28%			4%			-169%			-96%		
19	2018-02-08	Influent							40.10 40.95	0.43	40.53	43.08 45.21	1.06	44.14
		Effluent							72.46 70.76	0.85	71.61	57.13 55.43	0.85	56.28
		Concentration Change							-77%			-27%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
21	2018-02-20	Influent	48.19 43.93	2.13	46.06	47.76 44.36	1.70	46.06	46.06 -	0.00	46.06	45.21 -	0.00	45.21
		Effluent	29.45 32.86	1.70	31.16	23.49 21.79	0.85	22.64	33.29 32.86	0.21	33.07	27.75 23.92	1.92	25.83
		Concentration Change	32%			51%			28%			43%		
23	2018-03-09	Influent	45.92 45.07 -	0.43 -	45.49 -	44.64 47.20 -	1.28 -	45.92 -	50.18 47.20 -	1.49 -	48.69 -	45.07 43.79 -	0.64 -	44.43 -
		Effluent	46.91 43.93 -	1.49 -	45.42 -	82.26 79.70 -	1.28 -	80.98 -	60.11 59.69 -	0.21 -	59.90 -	52.02 49.89 -	1.06 -	50.96 -
		Concentration Change	0%			-76%			-23%			-15%		
27	2018-04-02	Influent	48.62 51.60	1.49	50.11	48.62 47.34	0.64	47.98	45.64 43.93	0.85	44.78	43.93 43.08	0.43	43.51
		Effluent	48.19 49.89	0.85	49.04	49.04 46.49	1.28	47.76	46.91 44.36	1.28	45.64	54.58 54.58	0.00	54.58
		Concentration Change	2%			0%			-2%			-25%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
29	2018-04-16	Influent	- 42.65	-	42.65	40.95 40.95	0.00	40.95	41.80 40.95	0.43	41.38	45.21 43.93	0.64	44.57
		Effluent	27.32 25.62	0.85	26.47	40.53 43.93	1.70	42.23	20.08 20.94	0.43	20.51	32.01 26.90	2.56	29.45
		Concentration Change	38%			-3%			50%			34%		
32	2018-05-08	Influent	53.51 51.81	0.85	52.66	47.55 48.40	0.43	47.98	53.51 51.81	0.85	52.66	47.55 48.40	0.43	47.98
		Effluent	53.94 59.90	2.98	56.92	44.57 24.98	9.79	34.78	111.00 108.87	1.06	109.94	75.66 74.38	0.64	75.02
		Concentration Change	-8%			28%			-109%			-56%		
32	2018-05-10	Influent	51.38 51.38	0.00	51.38	47.98 48.83	0.43	48.40	51.81 48.83	1.49	50.32	51.81 48.83	1.49	50.32
		Effluent	18.17 31.80	6.81	24.98	24.56 28.39	1.92	26.47	55.22 50.53	2.34	52.87	29.24 27.54	0.85	28.39
		Concentration Change	51%			45%			-5%			44%		
32	2018-05-12	Influent	46.06 43.93	1.06	45.00	41.80 40.10	0.85	40.95	42.65 42.23	0.21	42.44	43.93 43.08	0.43	43.51
		Effluent	26.05 20.94	2.56	23.49	23.07 19.66	1.70	21.36	29.88 26.90	1.49	28.39	17.53 17.10	0.21	17.32
		Concentration Change	48%			48%			33%			60%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
37	2018-06-14	Influent	49.47 45.21	2.13	47.34	43.08 41.80	0.64	42.44	44.36 43.51	0.43	43.93	45.64 43.93	0.85	44.78
		Effluent	92.90 92.48	0.21	92.69	100.57 99.72	0.43	100.14	73.74 78.85	2.56	76.30	90.78 91.20	0.21	90.99
		Concentration Change	-96%			-136%			-74%			-103%		
38	2018-06-21	Influent	44.24 42.21	1.01	43.22	41.80 40.58	0.61	41.19	40.58 39.37	0.61	39.97	41.80 28.00	6.90	34.90
		Effluent	78.74 78.13	0.30	78.43	93.35 84.22	4.57	88.79	45.05 44.44	0.30	44.74	76.30 75.69	0.30	76.00
		Concentration Change	-81%			-116%			-12%			-118%		
39	2018-06-26	Influent	38.35 38.35	0.00	38.35	39.57 38.76	0.41	39.16	40.38 39.57	0.41	39.97	42.00 42.41	0.20	42.21
		Effluent	52.56 58.24	2.84	55.40	76.10 75.29	0.41	75.69	72.04 72.04	0.00	72.04	81.78 80.97	0.41	81.38
		Concentration Change	-44%			-93%			-80%			-93%		
40	2018-07-04	Influent	43.22 43.63	0.20	43.42	46.47 43.22	1.62	44.85	46.06 44.03	1.01	45.05	41.60 39.97	0.81	40.79
		Effluent	68.79 71.64	1.42	70.22	64.33 65.55	0.61	64.94	80.97 80.16	0.41	80.57	87.87 91.53	1.83	89.70
		Concentration Change	-62%			-45%			-79%			-120%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
41	2018-07-09	Influent	45.25 46.06	0.41	45.66	46.47 42.82	1.83	44.64	45.25 44.03	0.61	44.64	46.06 44.44	0.81	45.25
		Effluent	63.11 67.98	2.44	65.55	64.74 67.58	1.42	66.16	86.65 88.68	1.01	87.67	98.43 106.95	4.26	102.69
		Concentration Change	-44%			-48%			-96%			-127%		
42	2018-07-16	Bucket 1 Influent	53.78 47.08	3.35	50.43	45.25 49.11	1.93	47.18	42.82 47.89	2.54	45.35	39.97 43.02	1.52	41.50
		Bucket 1 Effluent	59.46 56.21	1.62	57.83	49.72 46.87	1.42	48.30	83.81 84.63	0.41	84.22	91.93 85.84	3.04	88.89
		Concentration Change	-15%			-2%			-86%			-114%		
		Bucket 2 Influent	40.38 50.32	4.97	45.35	45.25 45.45	0.10	45.35	43.63 45.45	0.91	44.54	42.00 45.45	1.73	43.73
		Bucket 2 Effluent	52.96 50.93	1.01	51.95	44.03 43.63	0.20	43.83	64.33 62.71	0.81	63.52	65.95 61.89	2.03	63.92
		Concentration Change	-15%			3%			-43%			-46%		
		Influent Bucket Average (mg/L)			47.80	46.27			44.95			42.61		
		Effluent Bucket Average (mg/L)			55.35	46.01			73.84			77.87		
		Concentration Change	-16%			1%			-63%			-83%		

Week	Date	Description	Column 1			Column 2			Column 3			Column 4		
			(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)	(mg O_2/L)	σ	Avg (mg O_2/L)
43	2018-07-23	Influent	51.14 45.45	2.84	48.30	49.51 47.48	1.01	48.50	48.30 49.11	0.41	48.70	46.67 45.05	0.81	45.86
		Effluent	53.17 57.43	2.13	55.30	43.83 44.85	0.51	44.34	73.46 74.48	0.51	73.97	74.27 80.97	3.35	77.62
		Concentration Change	-14%			9%			-52%			-69%		
		Influent	46.27 48.30	1.01	47.28	40.99 47.48	3.25	44.24	50.32 47.08	1.62	48.70	47.89 46.27	0.81	47.08
		Effluent	48.70 48.90	0.10	48.80	36.12 41.60	2.74	38.86	55.20 47.28	3.96	51.24	50.73 51.75	0.51	51.24
		Concentration Change	-3%			12%			-5%			-9%		
		Influent Bucket Average (mg/L)			47.79	46.37			48.70			46.47		
		Effluent Bucket Average (mg/L)			51.51	41.53			62.64			61.40		
		Concentration Change	-8%			10%			-29%			-32%		

Table 40: Influent and effluent concentrations and concentration percent change for heavy metals for column 1.

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
1	2017-09-26	Influent	0.0620	0.2080	0.0010	0.0020	0.0640	0.2030	0.0010	0.0020
			0.0660	0.1980	0.0010	0.0020				
		Effluent	0.1040	0.0130	0.0000	0.0030	0.0965	0.0155	0.0035	0.0035
			0.0890	0.0180	0.0070	0.0040				
		Concentration Change					-51%	92%	-250%	-75%
2	2017-10-10	Influent	0.5133	0.3192	-0.0025	0.0050	0.4438	0.2696	0.0000	0.0042
			0.3742	0.2200	-0.0025	0.0033				
		Effluent	0.0442	0.0225	-0.0025	0.0008	0.0492	0.0296	0.0000	0.0008
			0.0542	0.0367	-0.0025	0.0008				
		Concentration Change					89%	89%	n/a	80%
3	2017-10-17	Influent	0.1960	0.3310	0.0130	0.0050	0.1475	0.3195	0.0065	0.0045
			0.0990	0.3080	0.0000	0.0040				
		Effluent	0.0621	0.0121	-0.0025	0.0000	0.0550	0.0132	0.0000	0.0007
			0.0479	0.0143	-0.0025	0.0014				
		Concentration Change					63%	96%	100%	84%
4	2017-10-24	Influent	0.1290	0.2060	-0.0010	0.0020	0.1320	0.2060	0.0000	0.0020
			0.1350	0.2060	0.0000	0.0020				
		Effluent	0.1160	0.0210	0.0120	0.0040	0.0905	0.0175	0.0130	0.0030
			0.0650	0.0140	0.0140	0.0020				
		Concentration Change					31%	92%	n/a	-50%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
5	2017-10-30	Influent	0.1490	0.1820	0.0010	0.0030	0.1465	0.1745	0.0005	0.0025
			0.1440	0.1670	0.0000	0.0020				
		Effluent	0.0230	0.0140	-0.0090	0.0020	0.0240	0.0130	0.0000	0.0025
			0.0250	0.0120	-0.0060	0.0030				
		Concentration Change					84%	93%	100%	0%
6	2017-11-06	Influent	0.1770	0.2430	-0.0010	0.0020	0.1810	0.2480	0.0000	0.0020
			0.1850	0.2530	0.0000	0.0020				
		Effluent	0.0060	0.0220	-0.0140	0.0000	0.0000	0.0180	0.0015	0.0010
			-0.0150	0.0140	0.0170	0.0020				
		Concentration Change					100%	93%	n/a	50%
7	2017-11-14	Influent	0.2730	0.2000	-0.0030	0.0020	0.2480	0.1965	0.0010	0.0015
			0.2230	0.1930	0.0050	0.0010				
		Effluent	0.0060	0.0110	-0.0030	0.0050	0.0065	0.0095	0.0000	0.0055
			0.0070	0.0080	0.0030	0.0060				
		Concentration Change					97%	95%	100%	-267%
9	2017-11-27	Influent	0.5320	0.2660	<DL	<DL	0.5585	0.2690	0.0000	0.0000
			0.5850	0.2720	<DL	<DL				
		Effluent	<DL	0.0180	<DL	<DL	0.0000	0.0160	0.0000	0.0000
			<DL	0.0140	<DL	<DL				
		Concentration Change					100%	94%	n/a	n/a

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
12	2017-12-18	Influent	0.3125	0.3758	<DL	<DL	0.3125	0.3767	0.0000	0.0000
			0.3125	0.3775	<DL	<DL				
		Effluent	0.1000	0.0250	<DL	<DL	0.1000	0.0245	0.0000	0.0000
			<DL	0.0240	<DL	<DL				
		Concentration Change					68%	93%	n/a	n/a
16	2018-01-15	Influent	0.7158	0.4592	0.0567	0.0050	0.7158	0.4592	0.0567	0.0050
			0.7158	0.4592	0.0567	0.0050				
		Effluent	0.0175	0.0033	0.0000	0.0000	0.0088	0.0029	0.0017	0.0000
			0.0000	0.0025	0.0033	0.0000				
		Concentration Change					99%	99%	97%	100%
21	2018-02-20	Influent	0.3760	0.4020	<DL	<DL	0.3840	0.4035	0.0000	0.0000
			0.3920	0.4050	<DL	<DL				
		Effluent	<DL	0.0160	<DL	<DL	0.0000	0.0135	0.0000	0.0000
			<DL	0.0110	<DL	<DL				
		Concentration Change					100%	97%	n/a	n/a
23	2018-03-09	Influent	0.5920	0.4580	<DL	<DL	0.5970	0.4600	0.0000	0.0000
			0.6020	0.4620	<DL	<DL				
		Effluent	<DL	0.0270	<DL	<DL	0.0000	0.0265	0.0000	0.0000
			<DL	0.0260	<DL	<DL				
		Concentration Change					100%	94%	n/a	n/a

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
32	2018-05-08	Influent	0.9700	1.7850	0.1600	0.0267	0.9642	1.7642	0.1563	0.0250
			0.9583	1.7433	0.1525	0.0233				
		Effluent	0.0100	0.0342	0.0000	0.0008	0.0050	0.0300	0.0000	0.0008
			0.0000	0.0258	0.0000	0.0008				
		Concentration Change					99%	98%	100%	97%
43	2018-07-23	Influent	0.3733	0.4092	0.0492	0.0042	0.3096	0.4092	0.0500	0.0046
			0.2458	0.4092	0.0508	0.0050				
		Effluent	0.0208	0.0167	0.0000	0.0025	0.0150	0.0154	0.0021	0.0021
			0.0092	0.0142	0.0042	0.0017				
		Concentration Change					95%	96%	96%	55%
		Influent	0.3733	0.4092	0.0492	0.0042	0.3096	0.4092	0.0500	0.0046
			0.2458	0.4092	0.0508	0.0050				
		Effluent	0.0167	0.0175	0.0042	0.0050	0.0142	0.0150	0.0021	0.0038
			0.0117	0.0125	0.0000	0.0025				
		Concentration Change					95%	96%	96%	18%
		Influent Bucket Average (mg/L)					0.3096	0.4092	0.0500	0.0046
		Effluent Bucket Average (mg/L)					0.0145	0.0152	0.0021	0.0031
		Concentration Change					95%	96%	96%	33%

Red text signifies data unavailable due to negative readings or division by zero.

Table 41: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 1.

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
1	2017-09-26	Influent	1.57		4.46	1.57	-	4.61
			1.57		4.76			
		Effluent	0.55		97.20	0.59	-	97.20
			0.62		-			
		Concentration Change				63%	-	-2010%
2	2017-10-10	Influent	1.88	22.69	4.22	1.85	21.44	4.20
			1.81	20.19	4.19			
		Effluent	0.32	95.04	166.10	0.31	94.84	166.60
			0.29	94.64	167.10			
		Concentration Change				83%	-342%	-3863%
3	2017-10-17	Influent	1.81	21.88	4.05	1.82	20.65	4.04
			1.82	19.41	4.03			
		Effluent	0.17	63.59	23.41	0.18	63.87	23.67
			0.19	64.14	23.92			
		Concentration Change				90%	-209%	-485%
4	2017-10-24	Influent	1.56	20.14	4.12	1.57	20.54	4.10
			1.59	20.93	4.09			
		Effluent	0.12	50.51	10.35	0.10	50.99	10.42
			0.07	51.47	10.48			
		Concentration Change				94%	-148%	-154%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
5	2017-10-30	Influent	1.57	21.39	4.20	1.58	21.14	4.20
			1.58	20.88	4.20			
		Effluent	0.14	22.16	8.02	0.14	21.61	8.01
			0.13	21.05	8.01			
		Concentration Change				91%	-2%	-91%
6	2017-11-06	Influent	1.64	22.96	4.16	1.66	23.35	4.15
			1.67	23.73	4.15			
		Effluent	0.13	40.38	6.63	0.12	39.64	6.62
			0.10	38.90	6.60			
		Concentration Change				93%	-70%	-59%
7	2017-11-14	Influent	1.73	21.27	3.91	1.71	20.57	3.87
			1.69	19.86	3.84			
		Effluent	0.08	37.04	5.25	0.08	36.51	5.24
			0.09	35.98	5.22			
		Concentration Change				95%	-78%	-35%
9	2017-11-27	Influent	1.77	19.90	4.22	1.84	20.37	4.19
			1.90	20.83	4.17			
		Effluent	<DL	31.22	5.21	0.00	31.27	5.27
			<DL	31.31	5.32			
		Concentration Change				100%	-54%	-26%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
12	2017-12-18	Influent	1.62 1.62	21.67 20.92	3.92 3.80	1.62	21.30	3.86
		Effluent	<DL <DL	30.01 36.04	4.76 4.61	0.00	33.03	4.69
		Concentration Change				100%	-55%	-21%
16	2018-01-15	Influent	1.799 1.799			1.80		
		Effluent	0.050 0.044			0.05		
		Concentration Change				97%		
21	2018-02-20	Influent	1.522 1.53	22.65 22.05	3.87 3.89	1.53	22.35	3.88
		Effluent	<DL <DL	20.96 20.96	3.63 3.55	0.00	20.96	3.59
		Concentration Change				100%	6%	8%
23	2018-03-09	Influent	1.407 1.444	21.22 20.85	3.89 3.91	1.43	21.04	3.90
		Effluent	<DL <DL	13.04 13.74	3.29 3.32	0.00	13.39	3.31
		Concentration Change				100%	36%	15%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
32	2018-05-08	Influent	6.33	14.01	15.56	6.28	14.05	15.57
			6.24	14.08	15.58			
		Effluent	0.09	30.1	15.34	0.09	29.99	15.27
			0.10	29.88	15.2			
		Concentration Change				99%	-114%	2%
43	2018-07-23	Influent	1.28	24.98	4.116	1.37	25.00	4.11
			1.45	25.02	4.106			
		Effluent	0.16	34.07	3.772	0.15	35.01	3.80
			0.14	35.94	3.832			
		Concentration Change				89%	-40%	8%
		Influent	1.28	24.98	4.116	1.37	25.00	4.11
			1.45	25.02	4.106			
		Effluent	0.15	28.85	3.346	0.14	28.79	3.33
			0.14	28.73	3.312			
		Concentration Change				90%	-15%	19%
		Influent Bucket Average (mg/L)				1.37	25.00	4.11
		Effluent Bucket Average (mg/L)				0.15	31.38	3.53
		Concentration Change				89%	-26%	14%

Table 42: Influent and effluent concentrations and concentration percent change for heavy metals for column 2.

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
1	2017-09-26	Influent	0.1070	0.2310	0.0010	0.0030	0.1070	0.2285	0.0015	0.0030
			0.1070	0.2260	0.0020	0.0030				
		Effluent	0.0150	0.0140	0.0090	0.0010	0.0135	0.0120	0.0090	0.0005
			0.0120	0.0100	0.0090	0.0000				
		Concentration Change					87%	95%	-500%	83%
2	2017-10-10	Influent	0.0760	0.2300	0.0000	0.0020	0.1055	0.2310	0.0035	0.0020
			0.1350	0.2320	0.0070	0.0020				
		Effluent	0.0217	0.0183	-0.0025	0.0000	0.0242	0.0192	0.0000	0.0004
			0.0267	0.0200	-0.0025	0.0008				
		Concentration Change					77%	92%	100%	79%
3	2017-10-17	Influent	0.1950	0.3460	0.0000	0.0040	0.1700	0.3420	0.0015	0.0040
			0.1450	0.3380	0.0030	0.0040				
		Effluent	0.0336	0.0114	-0.0025	0.0007	0.0386	0.0118	0.0000	0.0014
			0.0436	0.0121	-0.0025	0.0021				
		Concentration Change					77%	97%	100%	64%
4	2017-10-24	Influent	0.1180	0.1810	0.0000	0.0020	0.1180	0.1815	0.0000	0.0020
			0.1180	0.1820	0.0000	0.0020				
		Effluent	0.0600	0.0110	0.0130	0.0040	0.0560	0.0085	0.0130	0.0025
			0.0520	0.0060	0.0130	0.0010				
		Concentration Change					53%	95%	n/a	-25%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
5	2017-10-30	Influent	0.1270	0.1700	0.0010	0.0020	0.1295	0.1700	0.0010	0.0020
			0.1320	0.1700	0.0010	0.0020				
		Effluent	-0.0100	0.0100	-0.0090	0.0010	0.0000	0.0080	0.0000	0.0015
			-0.0040	0.0060	0.0050	0.0020				
		Concentration Change					100%	95%	100%	25%
6	2017-11-06	Influent	0.1890	0.2610	0.0000	0.0030	0.1820	0.2525	0.0005	0.0030
			0.1750	0.2440	0.0010	0.0030				
		Effluent	-0.0070	0.0120	-0.0050	0.0000	0.0015	0.0090	0.0000	0.0005
			0.0100	0.0060	0.0090	0.0010				
		Concentration Change					99%	96%	100%	83%
7	2017-11-14	Influent	0.2110	0.1850	-0.0120	0.0010	0.2300	0.1855	0.0000	0.0010
			0.2490	0.1860	-0.0050	0.0010				
		Effluent	0.0630	0.0060	-0.0060	0.0010	0.0895	0.0060	0.0000	0.0015
			0.1160	0.0060	-0.0010	0.0020				
		Concentration Change					61%	97%	n/a	-50%
9	2017-11-27	Influent	0.4720	0.3630	<DL	<DL	0.4615	0.3515	0.0000	0.0000
			0.4510	0.3400	<DL	<DL				
		Effluent	<DL	0.0230	<DL	<DL	0.0000	0.0210	0.0000	0.0000
			<DL	0.0190	<DL	<DL				
		Concentration Change					100%	94%	n/a	n/a

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
12	2017-12-18	Influent	0.3333	0.3908	<DL	<DL	0.3533	0.3925	0.0000	0.0000
			0.3733	0.3942	<DL	<DL				
		Effluent	<DL	0.0200	<DL	<DL	0.0000	0.0305	0.0000	0.0000
			<DL	0.0410	<DL	<DL				
		Concentration Change					100%	92%	n/a	n/a
16	2018-01-15	Influent	0.5525	0.3717	0.0408	0.0058	0.5525	0.3717	0.0408	0.0058
			0.5525	0.3717	0.0408	0.0058				
		Effluent	0.0025	0.0017	0.0000	0.0008	0.0013	0.0029	0.0000	0.0004
			0.0000	0.0042	0.0000	0.0000				
		Concentration Change					100%	99%	100%	93%
21	2018-02-20	Influent	0.3880	0.4240	<DL	<DL	0.3880	0.4205	0.0000	0.0000
			0.3880	0.4170	<DL	<DL				
		Effluent	<DL	0.0140	<DL	<DL	0.0000	0.0140	0.0000	0.0000
			<DL	<DL	<DL	<DL				
		Concentration Change					100%	97%	n/a	n/a
23	2018-03-09	Influent	0.4480	0.4350	<DL	<DL	0.4280	0.4255	0.0000	0.0000
			0.4080	0.4160	<DL	<DL				
		Effluent	<DL	0.0260	<DL	<DL	0.0000	0.0250	0.0000	0.0000
			<DL	0.0240	<DL	<DL				
		Concentration Change					100%	94%	n/a	n/a

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
32	2018-05-08	Influent	0.8567	1.5650	0.1575	0.0242	0.8517	1.5813	0.1508	0.0229
			0.8467	1.5975	0.1442	0.0217				
		Effluent	0.0042	0.0217	0.0000	0.0000	0.0058	0.0183	0.0063	0.0000
			0.0075	0.0150	0.0125	0.0000				
		Concentration Change					99%	99%	96%	100%
43	2018-07-23	Influent	0.2025	0.4183	0.0492	0.0075	0.2046	0.4258	0.0500	0.0079
			0.2067	0.4333	0.0508	0.0083				
		Effluent	0.0117	0.0183	0.0017	0.0017	0.0058	0.0146	0.0008	0.0025
			0.0000	0.0108	0.0000	0.0033				
		Concentration Change					97%	97%	98%	68%
		Influent	0.2025	0.4183	0.0492	0.0075	0.2046	0.4258	0.0500	0.0079
			0.2067	0.4333	0.0508	0.0083				
		Effluent	0.0183	0.0142	0.0042	0.0033	0.0225	0.0133	0.0083	0.0025
			0.0267	0.0125	0.0125	0.0017				
		Concentration Change					89%	97%	83%	68%
		Influent Bucket Average (mg/L)					0.20	0.43	0.05	0.01
		Effluent Bucket Average (mg/L)					0.01	0.01	0.00	0.00
		Concentration Change					93%	97%	91%	68%

Red text signifies data unavailable due to negative readings or division by zero.

Table 43: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 2.

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
1	2017-09-26	Influent	1.57		4.33	1.50		4.22
			1.43		4.11			
		Effluent	0.13		939.11	0.12		960.02
			0.12		980.94			
		Concentration Change				92%		-22661%
2	2017-10-10	Influent	1.69	21.16	4.10	1.68	20.60	4.08
			1.67	20.03	4.06			
		Effluent	0.15	35.09	49.07	0.14	34.71	48.89
			0.12	34.32	48.71			
		Concentration Change				92%	-69%	-1098%
3	2017-10-17	Influent	1.85	18.98	4.08	1.85	19.56	4.09
			1.85	20.13	4.09			
		Effluent	0.15	30.49	12.93	0.14	30.81	12.73
			0.12	31.12	12.52			
		Concentration Change				93%	-58%	-211%
4	2017-10-24	Influent	1.57	19.62	4.14	1.57	20.07	4.13
			1.57	20.51	4.13			
		Effluent	0.09	25.81	6.71	0.08	25.97	6.74
			0.07	26.13	6.77			
		Concentration Change				95%	-29%	-63%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
5	2017-10-30	Influent	1.56	19.81	4.21	1.57	20.34	4.19
			1.59	20.87	4.17			
		Effluent	0.13	24.48	5.33	0.12	24.06	5.35
			0.11	23.63	5.37			
		Concentration Change				92%	-18%	-28%
6	2017-11-06	Influent	1.69	27.59	4.14	1.69	25.14	4.13
			1.68	22.69	4.12			
		Effluent	0.08	23.23	4.57	0.08	23.14	4.45
			0.07	23.04	4.33			
		Concentration Change				96%	8%	-8%
7	2017-11-14	Influent	1.71	25.04	3.88	1.70	23.65	3.91
			1.69	22.26	3.94			
		Effluent	0.08	22.83	3.85	0.07	23.06	3.85
			0.07	23.28	3.85			
		Concentration Change				96%	3%	1%
9	2017-11-27	Influent	1.72	19.42	4.15	1.74	19.42	4.16
			1.76	19.41	4.17			
		Effluent	<DL	21.35	4.64	0.00	21.05	4.66
			<DL	20.74	4.68			
		Concentration Change				100%	-8%	-12%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
12	2017-12-18	Influent	1.60	21.21	3.87	1.61	20.88	3.86
			1.62	20.54	3.85			
		Effluent	<DL	23.37	4.88	0.00	23.12	4.92
			<DL	22.86	4.95			
		Concentration Change				100%	-11%	-27%
16	2018-01-15	Influent	1.698			1.70		
			1.698					
		Effluent	0.053			0.06		
			0.058					
		Concentration Change				97%		
21	2018-02-20	Influent	1.562	22.39	4.00	1.55	22.31	3.97
			1.528	22.22	3.94			
		Effluent	<DL	13.75	4.57	0.00	13.91	4.56
			<DL	14.06	4.55			
		Concentration Change				100%	38%	-15%
23	2018-03-09	Influent	1.539	20.89	3.94	1.55	20.93	3.94
			1.556	20.96	3.95			
		Effluent	0.421	16.22	3.90	0.43	16.08	3.88
			0.431	15.94	3.87			
		Concentration Change				72%	23%	1%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
32	2018-05-08	Influent	6.17	23.62	15.91	6.10	24.05	15.89
			6.03	24.47	15.87			
		Effluent	0.07	22.92	22.69	0.06	22.82	22.70
			0.06	22.71	22.71			
		Concentration Change				99%	5%	-43%
43	2018-07-23	Influent	1.51	25.61	4.182	1.53	25.20	4.18
			1.56	24.79	4.172			
		Effluent	0.24	28.1	4.966	0.23	28.84	4.93
			0.23	29.58	4.884			
		Concentration Change				85%	-14%	-18%
		Influent	1.51	25.61	4.182	1.53	25.20	4.18
			1.56	24.79	4.172			
		Effluent	0.25	21.56	3.129	0.25	21.18	3.15
			0.25	20.79	3.173			
		Concentration Change				84%	16%	25%
		Influent Bucket Average (mg/L)				1.53	25.20	4.18
		Effluent Bucket Average (mg/L)				0.24	24.91	4.02
		Concentration Change				84%	1%	4%

Table 44: Influent and effluent concentrations and concentration percent change for heavy metals for column 3.

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
4	2017-10-24	Influent	0.1450	0.2490	0.0140	0.0030	0.1565	0.2495	0.0135	0.0035
			0.1680	0.2500	0.0130	0.0040				
		Effluent	0.0350	0.0558	0.0033	0.0092	0.0454	0.0529	0.0008	0.0067
			0.0558	0.0500	-0.0017	0.0042				
		Concentration Change					71%	79%	94%	-90%
5	2017-10-30	Influent	0.1170	0.1710	0.0000	0.0020	0.1175	0.1670	0.0000	0.0020
			0.1180	0.1630	0.0000	0.0020				
		Effluent	0.0300	0.0342	0.0033	0.0033	0.0288	0.0329	0.0000	0.0029
			0.0275	0.0317	-0.0033	0.0025				
		Concentration Change					76%	80%	n/a	-46%
6	2017-11-06	Influent	0.1250	0.2220	0.0000	0.0030	0.1315	0.2245	0.0000	0.0030
			0.1380	0.2270	0.0000	0.0030				
		Effluent	0.0183	0.0192	-0.0083	0.0050	0.0233	0.0175	0.0000	0.0050
			0.0283	0.0158	-0.0142	0.0050				
		Concentration Change					82%	92%	n/a	-67%
7	2017-11-14	Influent	0.1940	0.2860	0.0000	0.0030	0.1845	0.2805	0.0000	0.0030
			0.1750	0.2750	0.0000	0.0030				
		Effluent	0.2250	0.0083	0.0033	0.0042	0.2696	0.0071	0.0071	0.0050
			0.3142	0.0058	0.0108	0.0058				
		Concentration Change					-46%	97%	n/a	-67%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
8	2017-11-14	Influent	0.1780	0.1990	0.0010	0.0060	0.1970	0.2030	0.0005	0.0070
			0.2160	0.2070	0.0000	0.0080				
9	2017-11-27	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	<DL	0.0170	<DL	<DL	0.0000	0.0195	0.0000	0.0000
			<DL	0.0220	<DL	<DL				
		Concentration Change					100%	95%	100%	100%
10	2017-12-04	Influent	0.5120	0.2860	<DL	<DL	0.5045	0.2720	0.0000	0.0000
			0.4970	0.2580	<DL	<DL				
12	2017-12-18	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	<DL	0.0280	<DL	<DL	0.1110	0.0255	0.0000	0.0000
			0.1110	0.0230	<DL	<DL				
		Concentration Change					69%	93%	100%	100%
13	2017-12-26	Influent	0.3508	0.3758	<DL	<DL	0.3475	0.3833	0.0000	0.0000
			0.3442	0.3908	<DL	<DL				
16	2018-01-15	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	0.0000	0.0008	0.0008	0.0000	0.0113	0.0008	0.0004	0.0000
			0.0225	0.0008	0.0000	0.0000				
		Concentration Change					97%	100%	98%	100%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
17	2018-01-23	Influent	0.5358	0.3258	0.0325	0.0033	0.5358	0.3258	0.0325	0.0033
			0.5358	0.3258	0.0325	0.0033				
21	2018-02-20	Influent	0.4250	0.4200	<DL	<DL	0.4100	0.4150	0.0000	0.0000
			0.3950	0.4100	<DL	<DL				
		Effluent	<DL	0.0170	<DL	<DL	0.0000	0.0155	0.0000	0.0000
			<DL	0.0140	<DL	<DL				
		Concentration Change					100%	96%	n/a	n/a
23	2018-03-09	Influent	0.4220	0.4240	<DL	<DL	0.4235	0.4210	0.0000	0.0000
			0.4250	0.4180	<DL	<DL				
		Effluent	<DL	0.0370	<DL	<DL	0.0000	0.0350	0.0000	0.0000
			<DL	0.0330	<DL	<DL				
		Concentration Change					100%	92%	n/a	n/a
32	2018-05-08	Influent	0.9700	1.7850	0.1600	0.0267	0.9642	1.7642	0.1563	0.0250
			0.9583	1.7433	0.1525	0.0233				
		Effluent	0.0000	0.0300	0.0000	0.0008	0.0008	0.0271	0.0000	0.0004
			0.0017	0.0242	0.0000	0.0000				
		Concentration Change					100%	98%	100%	98%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
43	2018-07-23	Influent	0.2817	0.4467	0.0433	0.0092	0.2946	0.4479	0.0513	0.0079
			0.3075	0.4492	0.0592	0.0067				
		Effluent	0.0075	0.0142	0.0000	0.0025	0.0038	0.0121	0.0017	0.0029
			0.0000	0.0100	0.0033	0.0033				
		Concentration Change					99%	97%	97%	63%
		Influent	0.2817	0.4467	0.0433	0.0092	0.2946	0.4479	0.0513	0.0079
			0.3075	0.4492	0.0592	0.0067				
		Effluent	0.0150	0.0142	0.0000	0.0033	0.0104	0.0117	0.0017	0.0033
			0.0058	0.0092	0.0033	0.0033				
		Concentration Change					96%	97%	97%	58%
		Influent Bucket Average (mg/L)					0.29	0.45	0.05	0.01
		Effluent Bucket Average (mg/L)					0.01	0.01	0.00	0.00
		Concentration Change					98%	97%	97%	61%

Red text signifies data unavailable due to negative readings or division by zero.

Blue text signifies influent concentrations averaged for each parameter over every event due to lack of measurements taken for that event.

Table 45: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 3.

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
4	2017-10-24	Influent	1.76	20.23	4.32	1.75	20.37	4.26
			1.75	20.50	4.19			
		Effluent	1.34	303.70	162.20	1.36	305.90	156.15
			1.38	308.10	150.10			
		Concentration Change				22%	-1402%	-3570%
5	2017-10-30	Influent	1.51	20.62	4.13	1.53	21.05	4.14
			1.55	21.47	4.15			
		Effluent	0.65	165.60	22.54	0.65	167.35	23.14
			0.65	169.10	23.74			
		Concentration Change				57%	-695%	-459%
6	2017-11-06	Influent	1.61	21.01	4.12	1.60	31.60	4.13
			1.58	42.19	4.15			
		Effluent	0.79	160.00	9.94	0.79	159.50	9.86
			0.79	159.00	9.79			
		Concentration Change				50%	-405%	-139%
7	2017-11-14	Influent	1.68	21.01	4.16	1.68	21.20	4.16
			1.68	21.38	4.15			
		Effluent	0.83	187.30	6.89	0.82	187.85	6.85
			0.82	188.40	6.81			
		Concentration Change				51%	-786%	-65%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
8	2017-11-20	Influent	1.72 1.67	19.81 20.71	3.89 3.90	1.69	20.26	3.89
9	2017-11-27	Influent	- -	- -	- -	1.89	21.53	4.80
		Effluent	0.66 0.70	96.95 105.00	4.10 4.38	0.68	100.98	4.24
		Concentration Change				64%	-369%	12%
10	2017-12-04	Influent	1.71 1.55	20.61 20.94	4.27 4.16	1.63	20.78	4.22
12	2017-12-18	Influent	- -	- -	- -	1.89	21.53	4.80
		Effluent	0.705 0.741	64.66 67.51	3.02 3.01	0.72	66.09	3.01
		Concentration Change				62%	-207%	37%
13	2017-12-26	Influent	1.596 1.594	20.97 21.41	3.84 3.87	1.60	21.19	3.86
16	2018-01-15	Influent	- -	- -	- -	1.89	21.53	4.80
		Effluent	0.409 0.466			0.44		
		Concentration Change				77%		

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
17	2018-01-23	Influent	1.645			1.65		
			1.645					
21	2018-02-20	Influent	1.538	21.98	3.91	1.53	21.81	3.90
			1.529	21.64	3.89			
		Effluent	<DL	17.55	1.86	0.00	17.50	1.86
			<DL	17.44	1.85			
		Concentration Change				100%	20%	52%
23	2018-03-09	Influent	1.554	20.41	3.90	1.56	20.67	3.89
			1.567	20.93	3.88			
		Effluent	<DL	15.77	4.09	0.00	15.40	4.06
			<DL	15.02	4.04			
		Concentration Change				100%	26%	-4%
32	2018-05-08	Influent	6.33	14.01	15.56	6.28	14.05	15.57
			6.24	14.08	15.58			
		Effluent	0.09	40.48	7.14	0.10	41.32	7.13
			0.11	42.16	7.112			
		Concentration Change				98%	-194%	54%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
43	2018-07-23	Influent	1.43	24.69	4.167	1.42	24.98	4.21
			1.41	25.26	4.246			
		Effluent	0.20	44.45	3.406	0.21	45.32	3.39
			0.22	46.19	3.371			
		Concentration Change				85%	-81%	19%
		Influent	1.43	24.69	4.167	1.42	24.98	4.21
			1.41	25.26	4.246			
		Effluent	0.20	34.76	3.804	0.20	34.21	3.83
			0.20	33.65	3.849			
		Concentration Change				86%	-37%	9%
		Influent Bucket Average (mg/L)				1.42	24.98	4.21
		Effluent Bucket Average (mg/L)				0.21	39.78	3.61
		Concentration Change				85%	-59%	14%

Blue text signifies influent concentrations averaged for each parameter over every event due to lack of measurements taken for that event.

Table 46: Influent and effluent concentrations and concentration percent change for heavy metals for column 4.

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
4	2017-10-24	Influent	0.1720	0.2820	0.0000	0.0060	0.1445	0.2750	0.0000	0.0050
			0.1170	0.2680	0.0000	0.0040				
		Effluent	0.0350	0.0475	-0.0025	0.0058	0.0192	0.0483	0.0021	0.0038
			0.0033	0.0492	0.0067	0.0017				
		Concentration Change					87%	82%	n/a	25%
5	2017-10-30	Influent	0.1600	0.1880	0.0010	0.0030	0.1635	0.1875	0.0010	0.0030
			0.1670	0.1870	0.0010	0.0030				
		Effluent	0.0158	0.0292	0.0067	0.0017	0.0175	0.0333	0.0000	0.0042
			0.0192	0.0375	-0.0183	0.0067				
		Concentration Change					89%	82%	100%	-39%
6	2017-11-06	Influent	0.1340	0.2030	-0.0020	0.0030	0.1310	0.1995	0.0000	0.0025
			0.1280	0.1960	-0.0010	0.0020				
		Effluent	0.0217	0.0167	-0.0108	0.0033	0.0250	0.0163	0.0000	0.0033
			0.0283	0.0158	-0.0133	0.0033				
		Concentration Change					81%	92%	n/a	-33%
7	2017-11-14	Influent	0.1930	0.2620	0.0010	0.0020	0.1875	0.2615	0.0005	0.0020
			0.1820	0.2610	0.0000	0.0020				
		Effluent	0.2933	0.0100	-0.0092	0.0042	0.2608	0.0108	0.0000	0.0050
			0.2283	0.0117	-0.0042	0.0058				
		Concentration Change					-39%	96%	100%	-150%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
8	2017-11-14	Influent	0.2090	0.2060	-0.0060	0.0080	0.2045	0.2030	0.0000	0.0065
			0.2000	0.2000	0.0030	0.0050				
9	2017-11-27	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	<DL	0.0260	<DL	<DL	0.0000	0.0215	0.0000	0.0000
			<DL	0.0170	<DL	<DL				
		Concentration Change					100%	94%	100%	100%
10	2017-12-04	Influent	0.5370	0.2970	<DL	<DL	0.5250	0.2870	0.0000	0.0000
			0.5130	0.2770	<DL	<DL				
12	2017-12-18	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	<DL	0.0260	<DL	<DL	0.0000	0.0220	0.0000	0.0000
			<DL	0.0180	<DL	<DL				
		Concentration Change					100%	94%	100%	100%
13	2017-12-26	Influent	0.3942	0.3900	<DL	<DL	0.4158	0.3983	0.0000	0.0000
			0.4375	0.4067	<DL	<DL				
16	2018-01-15	Influent	-	-	-	-	0.3559	0.3877	0.0171	0.0038
			-	-	-	-				
		Effluent	0.0000	0.0025	0.0000	0.0000	0.0000	0.0025	0.0004	0.0000
			0.0000	0.0025	0.0008	0.0000				
		Concentration Change					100%	99%	98%	100%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
17	2018-01-23	Influent	0.6650	0.4392	0.0600	0.0058	0.6650	0.4392	0.0600	0.0058
			0.6650	0.4392	0.0600	0.0058				
21	2018-02-20	Influent	0.4620	0.4190	<DL	<DL	0.4415	0.4120	0.0000	0.0000
			0.4210	0.4050	<DL	<DL				
		Effluent	<DL	0.0230	<DL	<DL	0.0000	0.0205	0.0000	0.0000
			<DL	0.0180	<DL	<DL				
		Concentration Change					100%	95%	n/a	n/a
23	2018-03-09	Influent	0.4580	0.4290	<DL	<DL	0.4725	0.4280	0.0000	0.0000
			0.4870	0.4270	<DL	<DL				
		Effluent	<DL	0.0370	<DL	<DL	0.0000	0.0365	0.0000	0.0000
			<DL	0.0360	<DL	<DL				
		Concentration Change					100%	91%	n/a	n/a
32	2018-05-08	Influent	0.8567	1.5650	0.1575	0.0242	0.8517	1.5813	0.1508	0.0229
			0.8467	1.5975	0.1442	0.0217				
		Effluent	0.0000	0.0333	0.0000	0.0008	0.0029	0.0313	0.0000	0.0017
			0.0058	0.0292	0.0000	0.0025				
		Concentration Change					100%	98%	100%	93%

Week	Date	Description	[Copper] (mg/L)	[Zinc] (mg/L)	[Lead] (mg/L)	[Cadmium] (mg/L)	Average [Copper] (mg/L)	Average [Zinc] (mg/L)	Average [Lead] (mg/L)	Average [Cadmium] (mg/L)
43	2018-07-23	Influent	0.2725	0.4392	0.0517	0.0083	0.2792	0.4463	0.0521	0.0088
			0.2858	0.4533	0.0525	0.0092				
		Effluent	0.0167	0.0117	0.0000	0.0025	0.0175	0.0117	0.0000	0.0025
			0.0183	0.0117	0.0000	0.0025				
		Concentration Change					94%	97%	100%	71%
		Influent	0.2725	0.4392	0.0517	0.0083	0.2792	0.4463	0.0521	0.0088
			0.2858	0.4533	0.0525	0.0092				
		Effluent	0.0000	0.0108	0.0000	0.0008	0.0000	0.0108	0.0000	0.0025
			0.0000	0.0108	0.0000	0.0042				
		Concentration Change					100%	98%	100%	71%
		Influent Bucket Average (mg/L)					0.28	0.45	0.05	0.01
		Effluent Bucket Average (mg/L)					0.01	0.01	0.00	0.00
		Concentration Change					98%	98%	100%	71%

Red text signifies data unavailable due to negative readings or division by zero.

Blue text signifies influent concentrations averaged for each parameter over every event due to lack of measurements taken for that event.

Table 47: Influent and effluent concentrations and concentration percent change for phosphorus, NPOC, and TN for column 4

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
4	2017-10-24	Influent	1.77 1.74	20.70 21.48	4.13 4.11	1.76	21.09	4.12
		Effluent	1.19 1.21	303.20 310.00	121.10 114.30	1.20	306.60	117.70
		Concentration Change				32%	-1354%	-2757%
5	2017-10-30	Influent	1.53 1.55	20.69 20.38	4.16 4.16	1.54	20.54	4.16
		Effluent	0.78 0.77	153.10 153.30	11.44 10.99	0.77	153.20	11.22
		Concentration Change				50%	-646%	-169%
6	2017-11-06	Influent	1.60 1.77	43.19 22.23	4.14 4.15	1.68	32.71	4.15
		Effluent	0.82 0.80	141.00 141.50	5.93 5.92	0.81	141.25	5.92
		Concentration Change				52%	-332%	-43%
7	2017-11-14	Influent	1.70 1.69	24.75 22.42	4.13 4.12	1.69	23.59	4.12
		Effluent	0.73 0.70	151.60 151.40	4.81 4.89	0.72	151.50	4.85
		Concentration Change				58%	-542%	-18%
8	2017-11-20	Influent	1.69 1.65	20.27 19.91	3.88 3.83	1.67	20.09	3.86

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
9	2017-11-27	Influent	-	-	-	1.89	21.53	4.80
			-	-	-			
		Effluent	0.59	74.75	2.63	0.59	75.20	2.66
			0.59	75.65	2.70			
		Concentration Change				69%	-249%	45%
10	2017-12-04	Influent	1.69	20.61	4.15	1.62	20.26	4.18
			1.55	19.90	4.22			
12	2017-12-18	Influent	-	-	-	1.89	21.53	4.80
			-	-	-			
		Effluent	0.482	41.81	1.81	0.49	42.63	1.84
			0.497	43.45	1.86			
		Concentration Change				74%	-98%	62%
13	2017-12-26	Influent	1.553	21.85	3.89	1.56	21.69	3.87
			1.567	21.53	3.85			
16	2018-01-15	Influent	-	-	-	1.89	21.53	4.80
			-	-	-			
		Effluent	0.393			0.40		
			0.413					
		Concentration Change				79%		
17	2018-01-23	Influent	1.724			1.72		
			1.724					

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
21	2018-02-20	Influent	1.46	21.70	4.00	1.47	21.87	4.00
			1.476	22.03	4.00			
		Effluent	<DL	13.83	3.23	0.00	13.51	3.23
			<DL	13.19	3.24			
		Concentration Change				100%	38%	19%
23	2018-03-09	Influent	1.495	18.34	3.89	1.50	20.23	3.87
			1.498	22.12	3.85			
		Effluent	<DL	11.47	3.19	0.00	11.42	3.18
			<DL	11.37	3.17			
		Concentration Change				100%	44%	18%
32	2018-05-08	Influent	6.17	23.62	15.91	6.10	24.05	15.89
			6.03	24.47	15.87			
		Effluent	0.08	29.96	7.358	0.06	29.66	7.36
			0.05	29.35	7.369			
		Concentration Change				99%	-23%	54%

Week	Date	Description	[Phosphorus] (mg/L)	[NPOC] (mg/L)	[Total Nitrogen] (mg/L)	Average [Phosphorus] (mg/L)	Average [NPOC] (mg/L)	Average [Total Nitrogen] (mg/L)
43	2018-07-23	Influent	1.47	26.41	4.25	1.50	25.19	4.22
			1.53	23.97	4.183			
		Effluent	0.45	42.78	2.298	0.44	41.78	2.29
			0.44	40.77	2.285			
		Concentration Change				71%	-66%	46%
		Influent	1.47	26.41	4.25	1.50	25.19	4.22
			1.53	23.97	4.183			
		Effluent	0.28	28.56	3.267	0.29	28.70	3.25
			0.30	28.83	3.228			
		Concentration Change				81%	-14%	23%
		Influent Bucket Average (mg/L)				1.50	25.19	4.22
		Effluent Bucket Average (mg/L)				0.35	33.73	2.88
		Concentration Change				77%	-34%	32%

Blue text signifies influent concentrations averaged for each parameter over every event due to lack of measurements taken for that event.

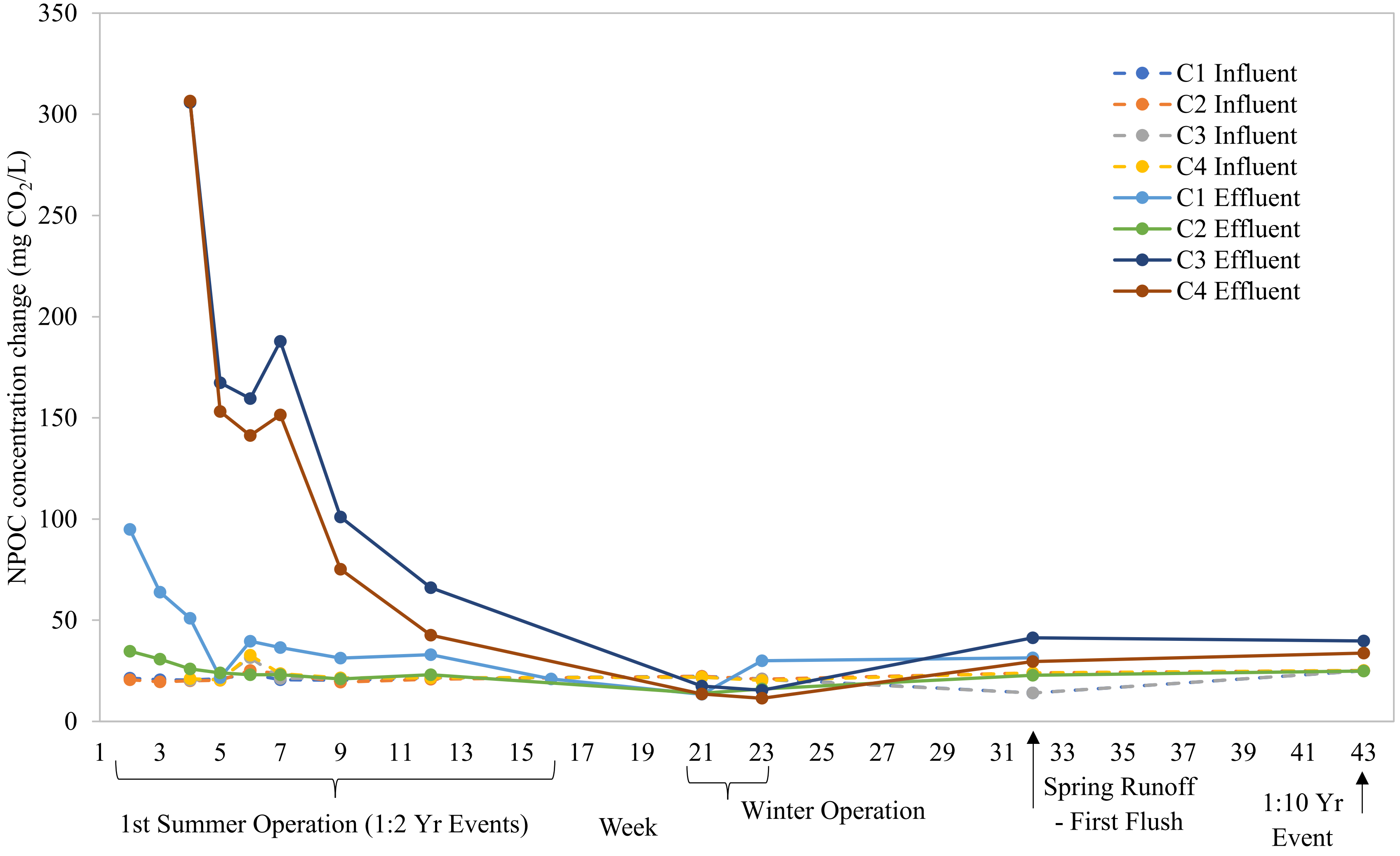


Figure 67: NPOC concentration change during select events.

Appendix C: Second Nature Compost Final Analytical Report

Report Number: C17045-10023
Account Number: 00896

A & L Canada Laboratories Inc.

2136 Jetstream Road, London, Ontario, N5V 3P5
Telephone: (519) 457-2575 Fax: (519) 457-2664

C17045-10023

To: CITY OF EDMONTON
13111 MERIDIAN STREET
SITE 310
EDMONTON, AB T6S 1G9
Attn: TERRY HENDERSON
780-496-5668

For: RE16-HORT-09

Reported Date: 2017-02-16
Printed Date: Feb 24, 2017

COMPOST REPORT

Page: 1 / 1

Sample Number	Lab Number	pH	Lime Index	Available Organic Matter %	Phosphorus P ppm	Potassium K ppm	Magnesium Mg ppm	Calcium Ca ppm
RE16-HORT-09	**42595**	**5.6**	**5.8**	**31.2**	**2163**	**1371**	**2121**	**6753**

Sulfur S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Sodium Na ppm	Nitrate-N NO3-N ppm	Soluble Salt ms/cm	Nitrogen (Total) (%)	Moisture %
2263	**119.5**	**53**	**261**	**9.7**	**6.0**	**348**	**865**	**6.6**	**2.23**	

INTERPRETATION

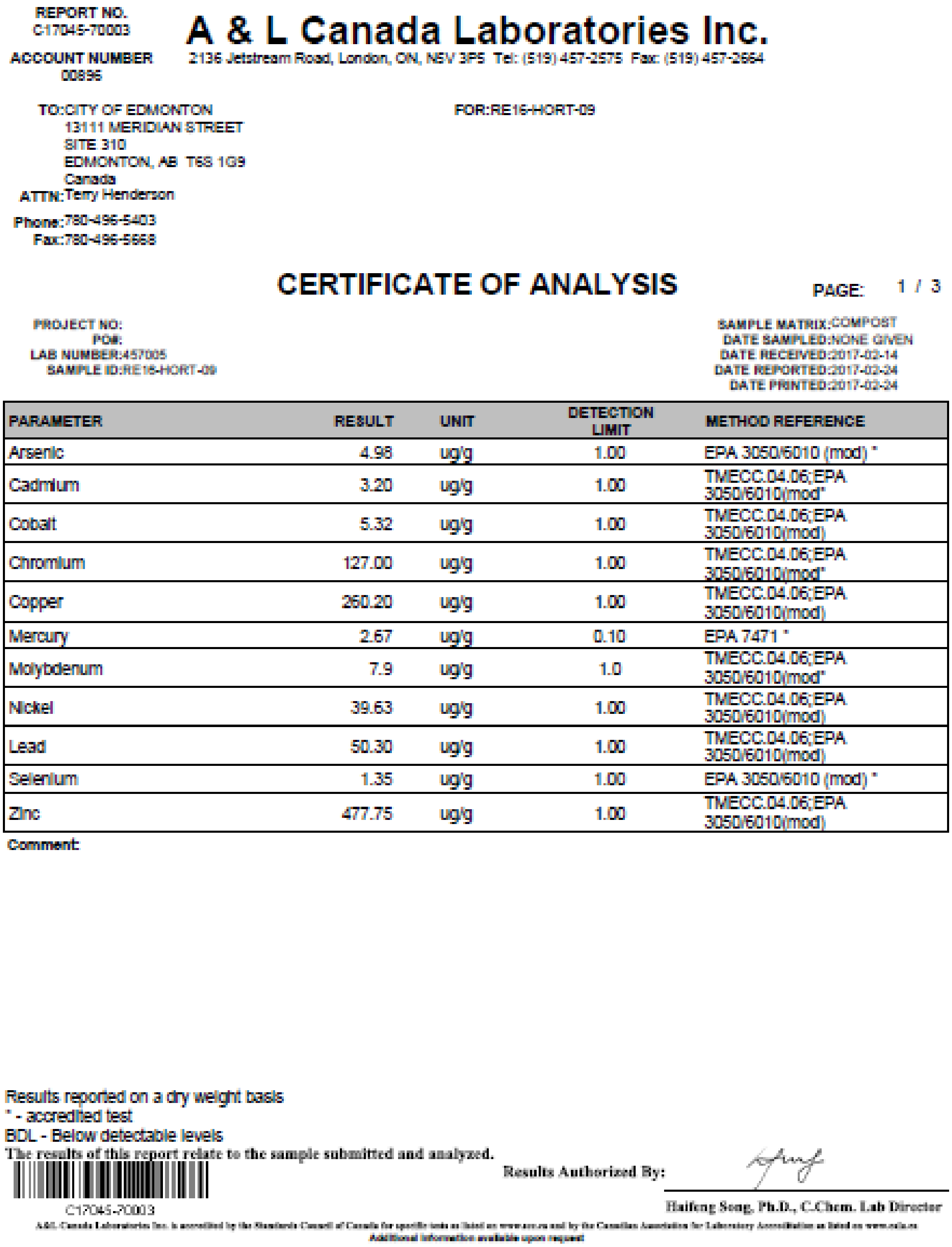
CEC		Percent Base Saturation				Proportional Equivalents (meq)				Cation Ratio		C/N Ratio
meq/100g	% BS	% K	% Mg	% Ca	% Na	K	Mg	Ca	Na	Mg/K	Ca/Mg	
59.4	**94.6**	**5.91**	**29.35**	**56.81**	**2.55**	**3.52**	**17.44**	**33.77**	**1.51**	**5:1**	**2:1**	
Optimum Range:		3 - 5	8 - 20	60 - 80		0.5 - 1.3				7:1	5:1	

CQA

* Results reported on a dry weight basis.
The results of this report relate to the sample submitted and analyzed.
* Crop yield is influenced by a number of factors in addition to soil fertility.
No guarantee or warranty concerning crop performance is made by A & L.

Results Authorized By: **Ian McLachlin, Vice President**

A&L Canada Laboratories Inc. is accredited by the Standards Council of Canada for specific tests as listed on www.scc.ca and by the Canadian Association for Laboratory Accreditation as listed on www.cala.ca
Additional information available upon request



REPORT NO.
C17045-70003

ACCOUNT NUMBER
00896

A & L Canada Laboratories Inc.

2136 Jetstream Road, London, ON, N5V 3P5 Tel: (519) 457-2575 Fax: (519) 457-2664

TO:CITY OF EDMONTON
13111 MERIDIAN STREET
SITE 310
EDMONTON, AB T6S 1G9
Canada
ATTN:Terry Henderson

Phone:780-496-5403
Fax:780-496-5668

FOR:RE16-HORT-09

CERTIFICATE OF ANALYSIS

PAGE: 1 / 3

PROJECT NO:
PO#:
LAB NUMBER:457005
SAMPLE ID:RE16-HORT-09

SAMPLE MATRIX:COMPOST
DATE SAMPLED:NONE GIVEN
DATE RECEIVED:2017-02-14
DATE REPORTED:2017-02-24
DATE PRINTED:2017-02-24

PARAMETER	RESULT	UNIT	DETECTION LIMIT	METHOD REFERENCE
Arsenic	4.98	ug/g	1.00	EPA 3050/6010 (mod) *
Cadmium	3.20	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)*
Cobalt	5.32	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)
Chromium	127.00	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)*
Copper	260.20	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)
Mercury	2.67	ug/g	0.10	EPA 7471 *
Molybdenum	7.9	ug/g	1.0	TMECC.04.06;EPA 3050/6010(mod)*
Nickel	39.63	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)
Lead	50.30	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)
Selenium	1.35	ug/g	1.00	EPA 3050/6010 (mod) *
Zinc	477.75	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)

Comment:

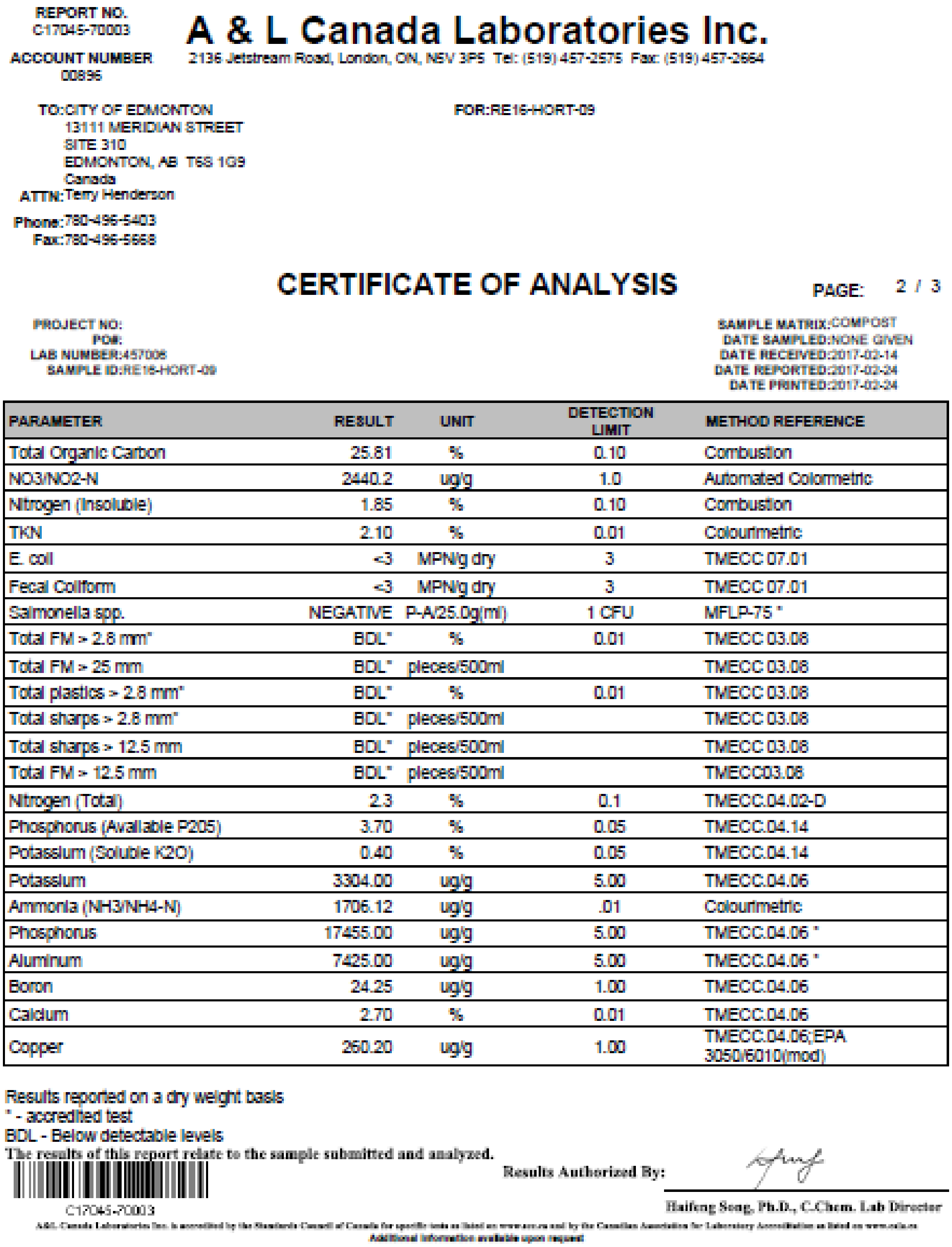
Results reported on a dry weight basis
* - accredited test
BDL - Below detectable levels
The results of this report relate to the sample submitted and analyzed.

C17045-70003

Results Authorized By:

Haifeng Song, Ph.D., C.Chem. Lab Director

A&L Canada Laboratories Inc. is accredited by the Standards Council of Canada for specific tests as listed on www.scc.ca and by the Canadian Association for Laboratory Accreditation as listed on www.cala.ca
Additional information available upon request



REPORT NO.
C17045-70003

ACCOUNT NUMBER
00896

A & L Canada Laboratories Inc.

2136 Jetstream Road, London, ON, N5V 3P5 Tel: (519) 457-2575 Fax: (519) 457-2664

TO: CITY OF EDMONTON
13111 MERIDIAN STREET
SITE 310
EDMONTON, AB T6S 1G9
Canada
ATTN: Terry Henderson

Phone: 780-496-5403
Fax: 780-496-5668

FOR: RE16-HORT-09

CERTIFICATE OF ANALYSIS

PAGE: 2 / 3

PROJECT NO:
PO#:
LAB NUMBER: 457006
SAMPLE ID: RE16-HORT-09

SAMPLE MATRIX: COMPOST
DATE SAMPLED: NONE GIVEN
DATE RECEIVED: 2017-02-14
DATE REPORTED: 2017-02-24
DATE PRINTED: 2017-02-24

PARAMETER	RESULT	UNIT	DETECTION LIMIT	METHOD REFERENCE
Total Organic Carbon	25.81	%	0.10	Combustion
NO3/NO2-N	2440.2	ug/g	1.0	Automated Colormetric
Nitrogen (Insoluble)	1.85	%	0.10	Combustion
TKN	2.10	%	0.01	Colourimetric
E. coli	<3	MPN/g dry	3	TMECC 07.01
Fecal Coliform	<3	MPN/g dry	3	TMECC 07.01
Salmonella spp.	NEGATIVE	P-A/25.0g(ml)	1 CFU	MFLP-75 *
Total FM > 2.8 mm*	BDL*	%	0.01	TMECC 03.08
Total FM > 25 mm	BDL*	pieces/500ml		TMECC 03.08
Total plastics > 2.8 mm*	BDL*	%	0.01	TMECC 03.08
Total sharps > 2.8 mm*	BDL*	pieces/500ml		TMECC 03.08
Total sharps > 12.5 mm	BDL*	pieces/500ml		TMECC 03.08
Total FM > 12.5 mm	BDL*	pieces/500ml		TMECC03.08
Nitrogen (Total)	2.3	%	0.1	TMECC.04.02-D
Phosphorus (Available P205)	3.70	%	0.05	TMECC.04.14
Potassium (Soluble K2O)	0.40	%	0.05	TMECC.04.14
Potassium	3304.00	ug/g	5.00	TMECC.04.06
Ammonia (NH3/NH4-N)	1706.12	ug/g	.01	Colourimetric
Phosphorus	17455.00	ug/g	5.00	TMECC.04.06 *
Aluminum	7425.00	ug/g	5.00	TMECC.04.06 *
Boron	24.25	ug/g	1.00	TMECC.04.06
Calcium	2.70	%	0.01	TMECC.04.06
Copper	260.20	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)

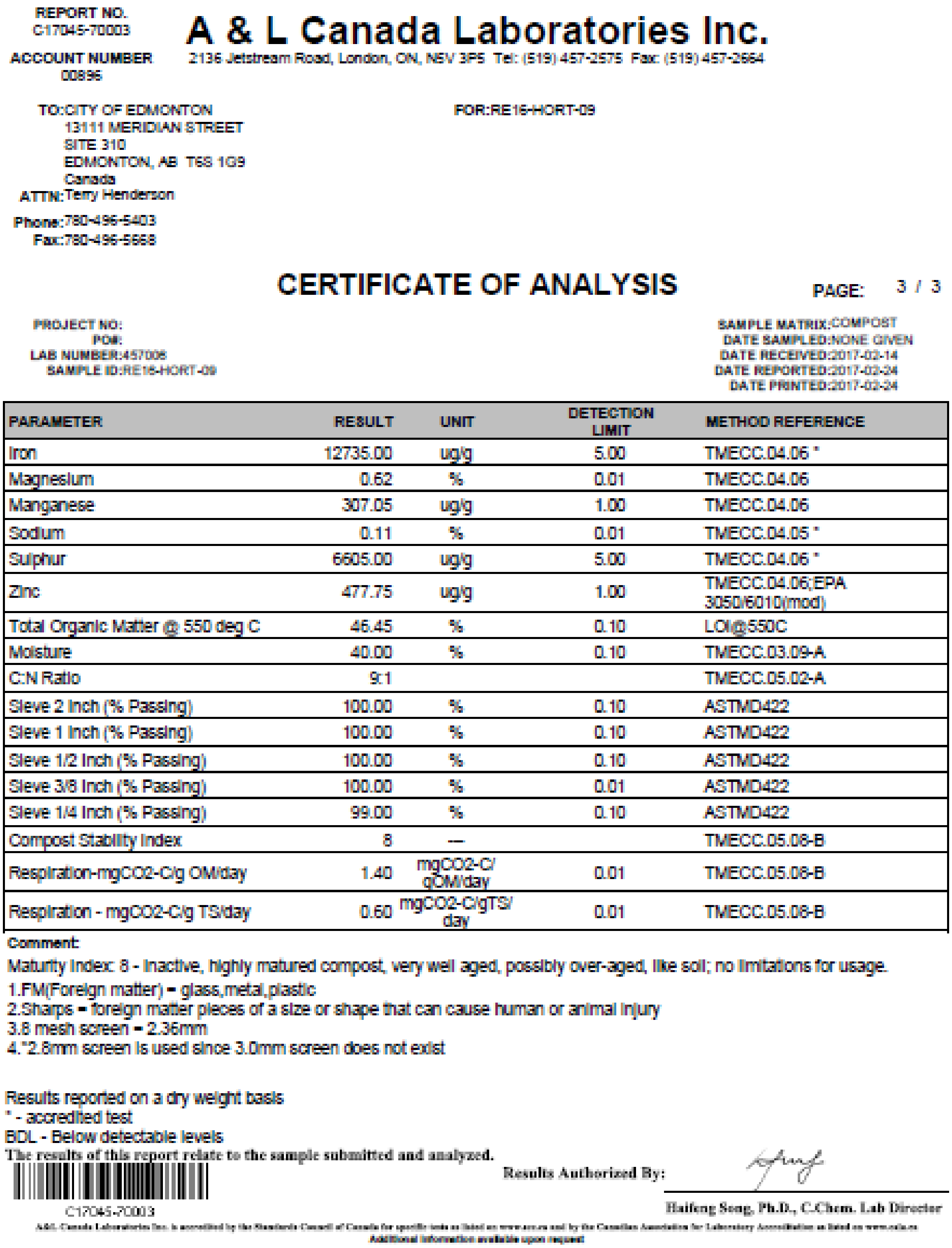
Results reported on a dry weight basis
* - accredited test
BDL - Below detectable levels
The results of this report relate to the sample submitted and analyzed.

C17045-70003

Results Authorized By:

Haifeng Song, Ph.D., C.Chem. Lab Director

A&L Canada Laboratories Inc. is accredited by the Standards Council of Canada for specific tests as listed on www.scc.ca and by the Canadian Association for Laboratory Accreditation as listed on www.cala.ca
Additional information available upon request



REPORT NO.
C17045-70003

ACCOUNT NUMBER
00896

A & L Canada Laboratories Inc.

2136 Jetstream Road, London, ON, N5V 3P5 Tel: (519) 457-2575 Fax: (519) 457-2664

TO:CITY OF EDMONTON
13111 MERIDIAN STREET
SITE 310
EDMONTON, AB T6S 1G9
Canada
ATTN: Terry Henderson

Phone:780-496-5403
Fax:780-496-5668

FOR:RE16-HORT-09

CERTIFICATE OF ANALYSIS

PAGE: 3 / 3

PROJECT NO:
PO#:
LAB NUMBER:457006
SAMPLE ID:RE16-HORT-09

SAMPLE MATRIX:COMPOST
DATE SAMPLED:NONE GIVEN
DATE RECEIVED:2017-02-14
DATE REPORTED:2017-02-24
DATE PRINTED:2017-02-24

PARAMETER	RESULT	UNIT	DETECTION LIMIT	METHOD REFERENCE
Iron	12735.00	ug/g	5.00	TMECC.04.06 *
Magnesium	0.62	%	0.01	TMECC.04.06
Manganese	307.05	ug/g	1.00	TMECC.04.06
Sodium	0.11	%	0.01	TMECC.04.05 *
Sulphur	6605.00	ug/g	5.00	TMECC.04.06 *
Zinc	477.75	ug/g	1.00	TMECC.04.06;EPA 3050/6010(mod)
Total Organic Matter @ 550 deg C	46.45	%	0.10	LOI@550C
Moisture	40.00	%	0.10	TMECC.03.09-A
C:N Ratio	9:1			TMECC.05.02-A
Sieve 2 Inch (% Passing)	100.00	%	0.10	ASTMD422
Sieve 1 Inch (% Passing)	100.00	%	0.10	ASTMD422
Sieve 1/2 Inch (% Passing)	100.00	%	0.10	ASTMD422
Sieve 3/8 Inch (% Passing)	100.00	%	0.01	ASTMD422
Sieve 1/4 Inch (% Passing)	99.00	%	0.10	ASTMD422
Compost Stability Index	8	---		TMECC.05.08-B
Respiration-mgCO2-C/g OM/day	1.40	mgCO2-C/ gOM/day	0.01	TMECC.05.08-B
Respiration - mgCO2-C/g TS/day	0.60	mgCO2-C/gTS/ day	0.01	TMECC.05.08-B

Comment:

Maturity Index: 8 - Inactive, highly matured compost, very well aged, possibly over-aged, like soil; no limitations for usage.

1.FM(Foreign matter) = glass,metal,plastic
2.Sharps = foreign matter pieces of a size or shape that can cause human or animal injury
3.8 mesh screen = 2.36mm
4."2.8mm screen is used since 3.0mm screen does not exist

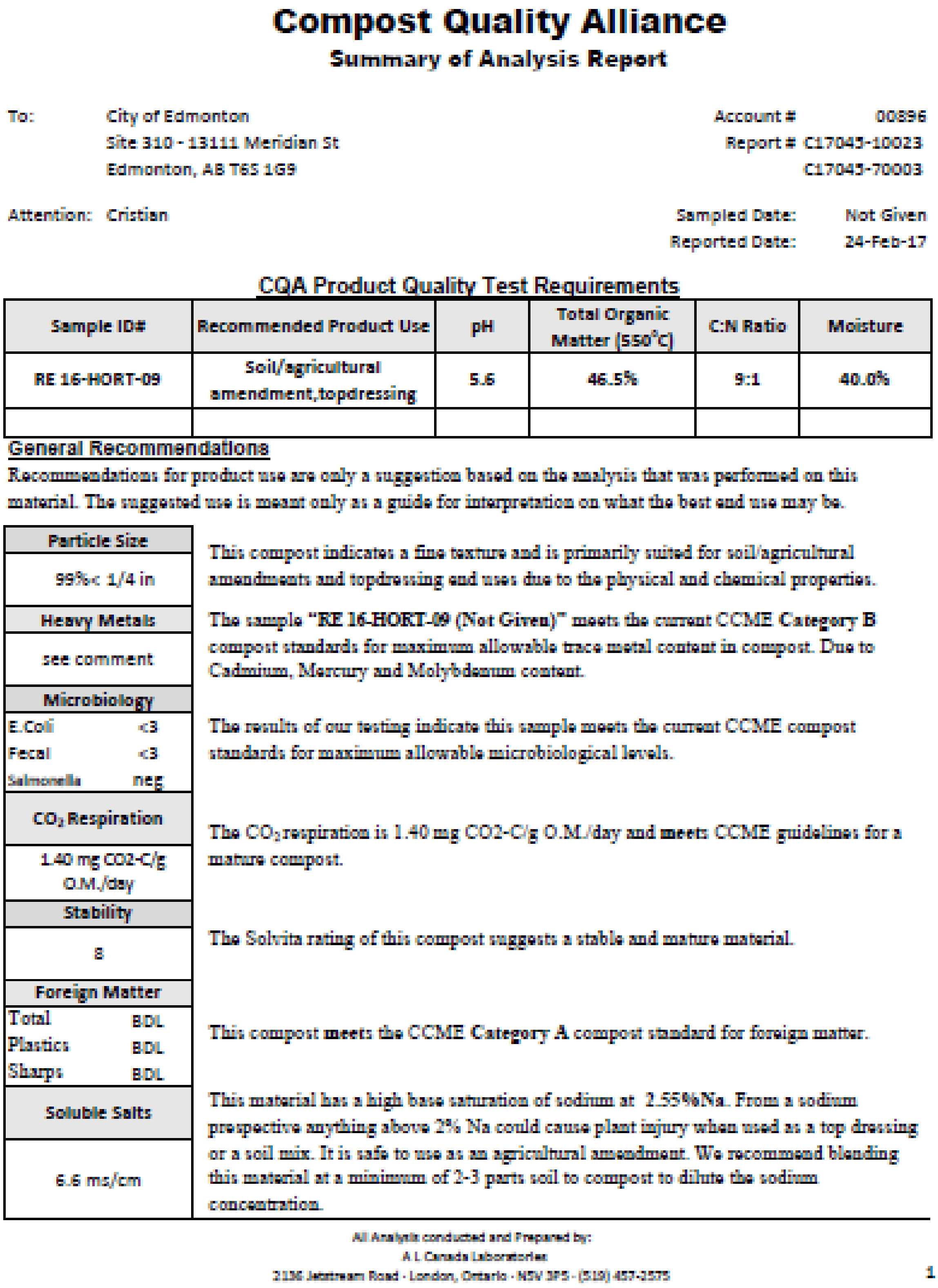
Results reported on a dry weight basis
* - accredited test
BDL - Below detectable levels
The results of this report relate to the sample submitted and analyzed.

Results Authorized By:

C17045-70003

Haifeng Song, Ph.D., C.Chem. Lab Director

Additional information available upon request



Compost Quality Alliance

Summary of Analysis Report

To:	City of Edmonton Site 310 - 13111 Meridian St Edmonton, AB T6S 1G9	Account #	00896
		Report #	C17043-10023 C17043-70003
Attention:	Cristian	Sampled Date:	Not Given
		Reported Date:	24-Feb-17

CQA Product Quality Test Requirements

Sample ID#	Recommended Product Use	pH	Total Organic Matter (550°C)	C:N Ratio	Moisture
RE 16-HORT-09	Soil/agricultural amendment,topdressing	5.6	46.5%	9:1	40.0%

General Recommendations

Recommendations for product use are only a suggestion based on the analysis that was performed on this material. The suggested use is meant only as a guide for interpretation on what the best end use may be.

Particle Size 99%< 1/4 in	This compost indicates a fine texture and is primarily suited for soil/agricultural amendments and topdressing end uses due to the physical and chemical properties.
Heavy Metals see comment	The sample "RE 16-HORT-09 (Not Given)" meets the current CCME Category B compost standards for maximum allowable trace metal content in compost. Due to Cadmium, Mercury and Molybdenum content.
Microbiology E.Coli <3 Fecal <3 Salmonella neg	The results of our testing indicate this sample meets the current CCME compost standards for maximum allowable microbiological levels.
CO_2 Respiration 1.40 mg CO2-C/g O.M./day	The CO_2 respiration is 1.40 mg CO2-C/g O.M./day and meets CCME guidelines for a mature compost.
Stability 8	The Solvita rating of this compost suggests a stable and mature material.
Foreign Matter Total BDL Plastics BDL Sharps BDL	This compost meets the CCME Category A compost standard for foreign matter.
Soluble Salts 6.6 ms/cm	This material has a high base saturation of sodium at 2.55%Na. From a sodium prespective anything above 2% Na could cause plant injury when used as a top dressing or a soil mix. It is safe to use as an agricultural amendment. We recommend blending this material at a minimum of 2-3 parts soil to compost to dilute the sodium concentration.

All Analysis conducted and Prepared by:
A L Canada Laboratories
2136 Jetstream Road - London, Ontario - N5V 3P5 - (519) 457-2575