

**Evaluation of Bioretention Systems for  
Stormwater Quality Improvement and Reuse:  
A Case Study of Size-Constrained Systems  
in Manly, Australia**

**Master of Science by Research**

**2011**

**Patrick James Stuart**

**School of the Environment  
Faculty of Science  
University of Technology, Sydney**

## **Certificate of Authorship/Originality**

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

---

Patrick Stuart

## **Acknowledgements**

I would like to thank my primary supervisor Dr Simon Mitrovic for his expertise and ongoing support throughout the duration of this research. Thanks to my secondary supervisor, Associate Professor Richard Lim for helpful discussions and final editing of the thesis and all the technical staff in the UTS Science Faculty, including Sue Fenech, Gemma Armstrong and Ilona Kramer, who went out of their way to make my laboratory work possible.

A special thanks to Manly Council for their financial support and accepting me into their organisation from the first day I started. In particular, Mr Lee Lau for being a great industry supervisor and Michael Galloway who used countless hours of his own time to assist my research and has continually opened doors for me into the water industry, for which I will be forever grateful. Also, many thanks to Sydney Water for funding the bacteria analysis, especially Rodney Kerr and Judith Winder for their assistance.

Thanks must also be extended to my family, friends from UTS and my many friends at Manly Council for making the experience extremely memorable.

# Table of Contents

Chapter 1. Introduction.....	11
1.1. Urban Stormwater Pollution.....	11
1.2. Bioretention Systems as a Water Quality Improvement Tool.....	11
1.3. Size Constraints on Bioretention Systems in Developed Urban Areas.....	12
1.4. Aims of this Research.....	13
Chapter 2. A Review of the Literature.....	14
2.1. Stormwater .....	14
2.1.1. Pollutants in Stormwater .....	14
2.1.2. Variability in Pollutant Concentrations in Stormwater .....	15
2.1.3. Impacts of Stormwater Pollutants on Aquatic Ecology .....	17
2.2. Bioretention Systems.....	18
2.2.1. Introduction to Bioretention Systems .....	18
2.2.2. Removal of Suspended Solids .....	20
2.2.3. Removal of Nutrients .....	21
2.2.4. Alteration of Peak Flows .....	24
2.2.5. Removal of Metals .....	25
2.2.6. Removal of Bacteria .....	27
Chapter 3. Site Description, and Materials and Methods.....	29
3.1. ‘Case Study’ Site – Manly, NSW, Australia.....	29
3.2. Bioretention System Design .....	30
3.3. Water Quality Monitoring .....	33
3.4. Flow Volume Estimation .....	35
3.5. Event Mean Concentration Calculation.....	36
Chapter 4. Removal of Suspended Solids from Stormwater by Size-Constrained Bioretention Systems.....	38
4.1. Introduction .....	38
4.2. Materials and Methods .....	40
4.3. Results.....	40
4.4. Discussion .....	47
Chapter 5. Removal of Nutrients from Stormwater by Size-Constrained Bioretention Systems .....	51
5.1. Introduction .....	51
5.2. Materials and Methods .....	54
5.3. Results.....	55

5.4. Discussion .....	63
5.4.1. Phosphorus .....	63
5.4.2. Nitrogen .....	66
Chapter 6. Removal of Metals from Stormwater by Size-Constrained Bioretention Systems .....	74
6.1. Introduction .....	74
6.2. Materials and Methods .....	76
6.3. Results.....	77
6.4. Discussion .....	83
Chapter 7. Removal of Faecal Indicator Bacteria from Stormwater by Size-Constrained Bioretention Systems .....	87
7.1. Introduction .....	87
7.2. Materials and Methods .....	89
7.3. Results.....	89
7.4. Discussion .....	95
Chapter 8. Conclusions and Recommendations .....	103
8.1. Conclusions .....	103
8.2. Recommendations for Design and Management of Bioretention Systems .....	105
8.3. Research Recommendations .....	107
Chapter 9. References.....	112
Chapter 10. Appendix.....	119
10.1. Published Bioretention Studies - Field Studies - where multiples samples were collected from multiple storms. ....	119
10.3. Results from some of the Published Bioretention Studies – Small-scale studies.....	120
10.3. Raw Data.....	121

## List of Figures

Figure 2-1: A typical first flush for a pollutant in stormwater during a rainfall event.....	16
Figure 3-1: Indicative map showing location of the studied bioretention systems in Manly Local Government Area (shaded) on the northern side of Sydney Harbour, Australia. ....	29
Figure 4-1: Inflow and outflow TSS concentrations throughout each monitored rainfall event at the Tutus St. system.....	44
Figure 4-2: Inflow and outflow TSS concentrations throughout each monitored rainfall event at the Beatty St. system. ....	45
Figure 4-3: Inflow and outflow TSS concentrations throughout each monitored rainfall event at the Jellicoe St. system. ....	46
Figure 5-1: Total phosphorus, orthophosphate, total nitrogen and inorganic nitrogen inflow and outflow concentrations, throughout the 11/8/09 rainfall event at the Tutus St. system. .	60
Figure 5-2: Total phosphorus, orthophosphate, total nitrogen and inorganic nitrogen inflow and outflow concentrations, throughout the 16/5/10 rainfall event at the Beatty St. system.	61
Figure 5-3: Total phosphorus, orthophosphate, total nitrogen and inorganic nitrogen inflow and outflow concentrations, throughout the 5/5/10 rainfall event at the Jellicoe St. system. .	62
Figure 5-4: Effect of Antecedent period on Nitrate Outflow EMCs at the Tutus St. and Beatty St. Bioretention Systems, each point is a nitrate outflow EMC for a rainfall event. ....	68
Figure 5-5: Effect of the Catchment runoff EMCs on Nitrate Outflow EMCs at the (A) Tutus St. and (B) Beatty St. Bioretention Systems. ....	69
Figure 6-1: The inflow and outflow concentrations of metals most commonly found in residential stormwater, throughout the 28/1/10 rainfall event at the Tutus St. system.....	80
Figure 6-2: The inflow and outflow concentrations of metals most commonly found in residential stormwater, throughout the 16/5/10 rainfall event at the Beatty St. system. ....	81
Figure 6-3: The inflow and outflow concentrations of metals most commonly found in residential stormwater, throughout the 5/5/10 rainfall event at the Jellicoe St. system.....	82
Figure 7-1: Faecal indicator and <i>Enterococci</i> concentrations in the Tutus St. bioretention system. ....	93
Figure 7-2: Faecal indicator and <i>Enterococci</i> concentrations in the Beatty St. bioretention system....	94
Figure 7-3: Faecal indicator and <i>Enterococci</i> concentrations in the Jellicoe St. system.....	95

## List of Tables

Table 3-1: Antecedent period, sampling duration, approximate rainfall and event duration for each monitored rainfall event. ....	35
Table 4-1: TSS removal rates, EMC values and standard deviations (SD) at the inflow and outflow of each bioretention system, during each sampled rainfall event. ....	41
Table 4-2: TSS inflow and outflow load during each sampled rainfall event and average load removal rates for each bioretention system.....	42
Table 5-1: Nutrient results from some of the published bioretention <b>field</b> studies. ....	52
Table 5-2: Nutrient Results from some of the published bioretention <b>small-scale</b> studies.....	53
Table 5-3: Total phosphorus and orthophosphate removal rates, EMC values and standard deviations (SD) at the inflow and outflow of each bioretention system, during each sampled rainfall event. *This was calculated by weighting each EMC value according to total flow volume in that event. ....	57
Table 5-4: Nitrogen species' removal rates, EMC values and standard deviations (SD) at the inflow and outflow of each bioretention system, during each sampled rainfall event.....	58
Table 5-5: Inorganic nitrogen species' removal rates, EMC values and standard deviations (SD) at the inflow and outflow of each bioretention system, during each sampled rainfall event.....	59
Table 5-6: Total nitrogen and total phosphorus inflow and outflow load during each sampled rainfall event and average load removal rates for each bioretention system.....	63
Table 6-1: Flow Weighted Average Inflow Concentrations for Total and Dissolved Metals. ....	78
Table 6-2: Concentration Reductions (%) of Total and Dissolved Metals.....	78
Table 6-3: Dissolved Portion of Total Metal Concentrations (%).....	78
Table 6-4: Average Total Metal Inflow and Outflow concentrations at the bioretention systems and ANZECC/ARMCANZ (2000) total metal trigger guidelines for the protection of aquatic ecosystems.....	79
Table 7-1: Microbial results from some of the published bioretention <b>field</b> studies.....	88
Table 7-2: Microbial results from published bioretention <b>small-scale</b> studies. ....	89
Table 7-3: Faecal coliform removal rates, EMC's and standard deviations (SD) at the inflow and outflow, during each sampled rainfall event. ....	90
Table 7-4: Enterococci removal rates, EMC's and standard deviations (SD) at the inflow and outflow, during each sampled rainfall event.....	91
Table 8-1: Removal rates of stormwater pollutants by the three bioretention systems .....	104

## List of Equations

Equation 3-1: Event Mean Concentration (EMC).....	36
Equation 5-1: Inorganic Nitrogen.....	55
Equation 5.2: Organic Nitrogen.....	55



## **Abstract**

Stormwater runoff in urban areas is known to carry high concentrations of sediment, organic matter, nutrients, metals and pathogens, which can cause environmental issues in natural water bodies. Bioretention systems (also known as bio-filtration basins and rain-gardens) are a type of stormwater treatment device that attempt to remove pollutants from stormwater by harnessing natural processes. There has been limited use of bioretention systems due to the lack of sufficient space in urban areas for stormwater treatment. Size-constrained bioretention systems have a low bioretention area to catchment size ratio giving them a higher potential for more extensive use in urban areas.

The aim of this study was to evaluate the effectiveness of sized-constrained bioretention systems in removing pollutants from stormwater runoff. The studied size-constrained bioretention systems promote the horizontal sub-surface flow of stormwater through the bioretention media. This is different to the vertical flow of water seen in conventional bioretention systems. However, once established, both types of bioretention systems rely on the same pollutant removal processes, including filtration and adsorption. The three size-constrained bioretention systems that were studied are located in the Northern Beaches area of Sydney, Australia. These were closely monitored between August 2009 and December 2010, which involved collecting water samples every 10-15 minutes at the inflow and outflow of the bioretention systems during rainfall events.

The bioretention systems reduced total suspended solids concentrations by an average of 78%, while total copper, zinc and lead concentrations were reduced by an average of 66%, 58% and 61%, respectively. Nutrient and faecal indicator bacteria removal rates were more varied, with the oldest system, located at Jellicoe St. performing the worst of the three systems, leaching all forms of nitrogen and faecal indicator bacteria. The newest system located at Tutus St. performed the best of

the three systems, reducing total nitrogen by 44%, total phosphorus by 63%, faecal coliforms by 72% and *Enterococci* by 35%. Considering the small area occupied by the sized-constrained bioretention systems, they were generally found to be effective in removing pollutants from stormwater. However, size constrained bioretention systems may require greater maintenance compared to conventionally sized bioretention systems.