Growth Performance of Six Plant Species and Removal of Heavy Metal Pollutants (Cu, Cr, Pb and Zn) in a Field-Scale Bi-Phasic Rain Garden

Thesis

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By

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ABSTRACT

A field-scale, bi-phasic rain garden (three replicates) was constructed to evaluate the growth of six plant species native to Ohio and the effectiveness of the rain garden to remediate heavy metals (Cu, Cr, Pb and Zn) from simulated stormwater runoff. The first phase, an anaerobic, oxygen-poor zone contained *Eupatorium perfoliatum* (boneset), *Tradescantia ohiensis* (spiderwort) and *Veronicastrum virginicum* (culver's root). In the second, aerobic, oxygen-rich zone *Sorghastrum nutans* (Indian grass), *Echinacea purpurea* (purple coneflower) and *Eragrostis spectabilis* (purple lovegrass) were grown. The plants, 234 overall, were evaluated over six months in 2008 and four months in 2009 with regards to height, width, number of flowers and general observations. Heavy metal remediation was evaluated over three simulated storm events that were carried out over an 11-day period with each rain event five days apart. During the first two storms, heavy metal pollutants were applied and the effluent water was measured on the eleventh day. On a mass balance basis, there was greater than 99% removal efficiency for Cu, Cr and Pb. In one replication, there was only a 72% removal of Zn, whereas the removal efficiency for the other two replications was greater than 99%. Most of the plants established well. The grasses *S. nutans* and *E. spectabilis* established slowest and *E. perfoliatum* and *E. purpurea* established the fastest. After the first year, 91% of the total plants survived and re-grew in the second year. *V. virginicum* had the poorest survival with nearly a quarter of the plants not growing in the second year, the highest of any species. The suitability of this species and *E. perfoliatum*, with its leaves having been eaten by insects, is questionable in this bi-phasic rain garden. The other species were suitable under the tested conditions. Careful selection of plants, including those native to Ohio, resulted in plants that grew well in the bi-phasic rain garden and provided both effective remediation of heavy-metal contaminated storm runoff and an aesthetically pleasing urban landscape.

DEDICATION

To each of those who have stood with me when I did not think that I could stand.

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As is true with any project, it is also true of this one, many people were a part of this project and instrumental to its success. The journey of this project began with Dr. Warren Dick, who agreed to take me on as a graduate student. Hanbae Yang brought me in on his PhD project and let me run with my section of data, helping me when I needed. Dr. Parwinder Grewal, as co-adviser to Hanbae, along with Dr. Dick, was also instrumental in getting the field project in the ground and growing. Additionally, Dr. Edward McCoy has always been available to assist with the design and as a sounding board for the entire project. The author gratefully acknowledges Dr. John Cardina and Mr. Donald Beam for selecting and establishing plant species in the systems. A special thanks to Ms. Laura Bast for driving to Wooster where she assisted in measuring the plants in the first season and to Mr. Keith Diedrick for his assistance during the second season. There are many other graduate students in both Columbus and Wooster who have made these two years enjoyable. For this, and other kindnesses, I will always be thankful. And no set of acknowledgements would be complete without thanking my parents, professors from undergrad and teachers from high school, without whom I would not have the courage, the drive or the intellectual curiosity to pursue such endeavors.

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2. Florence DC, Harralson HH, Barabe JG. 2005-2006. Introduction to gel inks: chemistry and history. Journal of Forensic Document Examination. 17:33-64.

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FIELDS OF STUDY

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CHAPTER 1

INTRODUCTION TO RAIN GARDENS

The long-accepted viewpoint in conventional stormwater management has been to remove runoff from a site as quickly and efficiently as possible to a central location for processing (Coffman, 1999). This can increase runoff volume and velocity, reduce the amount of water in storage, and impair water quality (Dietz, 2007; Coffman, 1999). These negative effects often are linked to urban development, which destroys the natural landscape features and healthy ecosystem functionality (Coffman, 1999).

Bioretention areas use the physical, chemical and biological properties of soils, microbes and plants as the basis of the functions critical for the removal of pollutants from urban stormwater runoff (Winogradoff, 2002). Key processes in runoff mitigation are interception, infiltration, evapotranspiration, filtration, degradation and adsorption (Prince George's County, 2007). Typical components of bioretention areas include room for water to pond following a rain event (ideally less than 30 min), plants, a mulch layer (2 – 4 cm), soil media (60% sand and 40% clay, silt and organic matter) and an optional pea gravel underdrain (Winogradoff, 2002). Plants in the bioretention areas, which are often native species, not only add aesthetic value but support the critical functions through the uptake of pollutants, evapotranspiration, creation of infiltration pathways within the soil, and promotion of healthy soil structure and microbial growth (Winogradoff, 2002).

The low impact development (LID) philosophy was piloted in Maryland in the late 1990's as an alternative to conventional stormwater management. The principles and practices were developed to address urban expansion in Prince George's County, which borders Washington, DC (Coffman, 1999). LID advocates for greater attention to the site's initial conditions in the planning phase, with particular consideration given to preserving the functionality of the pre-development hydrology of the area (Dietz, 2007). These functionality objectives are accomplished by minimizing stormwater impact on receiving waters, dispersing runoff-storage measures throughout the landscape, routing water flow to maintain pre-development travel times and implementing public education programs (Coffman, 1999). The public involvement aspect is important to ensure that the bioretention area is properly maintained and performs to the design standards (Prince George's County, 2007). By integrating these cost-effective features of stormwater control principles throughout the urban landscape, the creation of a hydrologically functional landscape is achieved, and one that relies only on pipelines is avoided (Coffman, 1999). In addition to rain gardens, green roofs, permeable pavement and bioswales are other practices under the LID philosophy that use similar principles to enhance the pollutant removal processes.

A rain garden is one type of a bioretention area prescribed by the LID philosophy to mitigate potential negative effects of impervious surfaces on urban stormwater quality. Most early research into the effectiveness of rain gardens was carried out in the laboratory and there is little field-based information available. Both have focused on single phase (also referred to as mono-phasic) rain gardens. One form of a bi-phasic rain garden is where stormwater first enters an anaerobic (oxygen-poor) zone and then flows into an aerobic (oxygen-rich) zone. The advantages of a bi-phasic versus a mono-phasic rain garden are conditions for denitrification, higher breakdown efficiency of halogenated molecules in the anaerobic zone, potentially longer retention times and greater diversity of microbial communities.

Early laboratory studies showed that rain gardens have the potential to mitigate pollutants typically found in typical stormwater runoff. In particular, heavy metals (Cu, Pb and Zn) showed high (>90%) and consistent reduction in concentration levels (Davis et al., 2001). There was also a reduction in total Kjeldahl-nitrogen (68%), NH_3-N (79%), NO_3-N (24%) and total P (81%) at the 91 cm depth (Davis et al., 2001). These numbers did vary with depth, however, and there were several instances where there was an increase in the effluent. Similar results were shown in a later study (Davis et al., 2006). An intermediate pilot-scale study suggests that a soil profile with a water-saturated zone below an unsaturated zone aids in the removal of NO_3-N, as would including an electron-donating, substance such as newspaper, in the water saturated zone (Kim et al., 2003).

A number of field studies have also been conducted. A field study in Maryland (Davis et al., 2003) showed removal of Cu, Pb and Zn from stormwater was similar to what was measured in a previous pilot-scale study for one site but lower removals were measured for another site. Results for total Kjeldahl-nitrogen (52, 67%), and total P (65, 87%) were similar to laboratory studies, whereas NO_3-N (15, 16%) was lower (Davis et al., 2003). A study in Connecticut showed that nutrient retention was lower than the

Maryland study with regards to total Kjeldahl-nitrogen (26%), higher for NO_3-N (67%), similar for NH_3-N (82%) and there was an export of P. Most of the metal concentrations were below the detection limit (Dietz and Clausen, 2006). A third field study in North Carolina also had variable success with the nutrients (75% removal of NO_3-N, slight increase in total Kjeldahl-nitrogen and NH_3-N, large increase in total P) and a high removal level (>80%) for the heavy metals Cu, Pb and Zn (Hunt et al., 2006).

Currently, there are a number of manuals available to guide individuals and professionals in the design, construction and maintenance of a rain garden. One of these is directed towards the homeowner (Wisconsin Department of Natural Resources, 2006). Emphasized in this manual are sizing criteria, design specifications, construction, planting recommendations, maintenance and examples. A more technically-oriented manual is available through Prince George's County (2007). The topics covered are the same as in the Wisconsin manual, but at a level of detail appropriate for landscape planning professionals. A comprehensive guide about plant species habitat has been published by Shaw and Schmidt (2003) and outlines over 130 species native to the Midwestern United States with respect to water level and soil preference, flooding toleration, light requirements and other considerations. There is some technical language, but the majority of the information is accessible to homeowners and it is a useful companion to either of above mentioned bioretention manuals.

This thesis focuses on the growth performance of selected plants native to Ohio in a bi-phasic rain garden. In addition, data are provided on the ability of the bi-phasic rain garden to remove heavy metal pollutants from stormwater. Its contribution to the literature is that it is focused on a specific rain garden design for which little information is currently available.

CHAPTER 2

SIX PLANT SPECIES IN A FIELD-SCALE BI-PHASIC RAIN GARDEN ECOSYSTEM: DATA FROM TWO YEARS

INTRODUCTION

Rain gardens are becoming an increasingly popular method to reduce urban stormwater runoff and the level of urban pollutants entering the stormwater. Rain gardens are bioretention areas for stormwater that are also designed to be aesthetically pleasing. As a relatively new best management practice, there is a need for more information about rain gardens related to careful site planning and to preserving the pre-hydrology of the drainage area (Dietz, 2007).

The main components of a rain garden, from the surface downward, generally include a ponding area, a mulch layer, a soil layer, a gravel layer and, optionally, an under-drain (Winogradoff, 2002). Their construction is not just limited to large engineering firms, but accessible to homeowners. Manuals are available online that will guide a homeowner through the steps necessary to create a functional rain garden (Prince George's County, 2007; Winogradoff, 2002; Coffman, 1999; Wisconsin Department of Natural Resources, 2003). In these manuals, the plant component of the rain garden is discussed, but the majority of the information relates to the selection of a site and soil media. However, the successful implementation of the gardens is also related to appropriate plant selection as plants participate in bioremediation reactions and also provide the aesthetic value associated with rain gardens.

This study is part of a larger project to evaluate the remediation efficiency of a bi-phasic rain garden for different types of pollutants. The design, construction and hydrological evaluation of these gardens have been published elsewhere (Yang et al., 2009). This novel bi-phasic design has been patented and was developed to intercept stormwater and mitigate the pollutants found within the urban environment. Stormwater is directed into the first phase (the anaerobic or oxygen-poor zone), and then is allowed to flow into the second phase (the aerobic or oxygen-rich zone), and finally into the recharge zone underneath the system. If the recharge zone becomes fully saturated, excess water is diverted to the storm sewer. The water in the anaerobic zone is separated physically from the aerobic zone. Retention time in the anaerobic zone can be controlled by the size of the zone and through design features that only allow water to overflow into the aerobic zone when the water level is at or above a certain height. This design arrangement helps maintain the saturated, anaerobic conditions in this zone. When the overflow from the anaerobic zone enters the aerobic zone, the aerobic zone provides additional treatment to the stormwater through chemical and microbial processes complimentary to those in the anaerobic zone. Both zones are composed of a specialized soil mixture of sand, topsoil and compost designed to infiltrate stormwater quickly and eliminate runoff.

The literature contains relatively few reports on plant establishment and survival in rain gardens. Instead, most of the literature focuses on the soil component and its role in the removal of urban pollutants (Davis et al., 2001, 2006; Dietz and Clausen, 2005, 2006; Davis, 2007; Hunt et al., 2006, 2008). While there is validity to this approach, since the soil media is responsible for the majority of the pollutant removal (Sun and Davis, 2007), it is the plant component of the rain garden that the public will see and that adds aesthetic value to the landscape. In addition, some plants have the potential to accumulate high concentrations of metals (or other environmental pollutants) and either remove them from the environment or degrade them to safer components. The United States Environmental Protection Agency (EPA) is assessing the use of plant species to aid in the clean-up of brownfield and Superfund sites, since the results are effective and the cost is 50-90% less than other methods such as excavation, disposal to a landfill and incineration (EPA, 2008).

There are few studies that focus on plant health as well as the species' ability to remove pollutants from simulated stormwater. A greenhouse study under aerobic conditions compared the pollutant removal ability of 20 species, 8 monocots and 12 dicots, against unplanted soil (Read et al., 2008). Species such as *Carex appressa*, *Melaleuca ericifolia*, *Juncus amabilis* and *Juncus flavidus* were particularly effective in overall pollutant removal and all plant species reduced the effluent concentration of NO_x, total dissolved phosphorus and filterable reactive phosphorus, a measure of PO_4^{-3} (Read et al., 2008). Although there are species of *Carex* and *Juncus* native to the United States, the particular ones used in the study by Read et al. were not. They also found no evidence of plant (leaf) stress in any of the species after 22-weeks using fluorometry, but did not comment on how the rest of the plant looked. Another study carried out in Australia found similar results and additionally commented that a few species increased the level of total N in the effluent in comparison with the control (Bratieres et al., 2008). Due to these findings, the author states the importance of testing plant species to ensure the most effective species are being selected before they are planted in a rain garden or bioretention system.

Available bioretention manuals often contain long lists of plants that may be acceptable for a rain garden within a chapter on landscaping. Each of these gives varying level of detail, with the most helpful information being the soil and water optima, including tolerance to flooding frequency and duration. For the Midwestern region, Shaw and Schmidt (2003) compiled a detailed list, including plant species best suited in a bioretention system, from wetland (frequently saturated) to upland (less saturated) areas. Both the 2002 and 2007 versions of the Prince George’s County Bioretention manual also offer extensive plant lists and criteria on selecting the ones most suitable for an individual rain garden (Winogradoff, 2002; Prince George’s County, 2007). Neither version, however, offers specific results of how these plant species fared in actual rain gardens.

The current study evaluates six plant species (Table 2.1) within a bi-phasic rain garden. *Eupatorium perfoliatum* (boneset), *Tradescantia ohiensis* (spiderwort) and *Veronicastrum virginicum* (culvert’s root) were chosen for the anaerobic zone and *Sorghastrum nutans* (Indian grass), *Echinacea purpurea* (purple coneflower) and *Eragrostis spectabilis* (purple lovegrass) were chosen for the aerobic zone. A total of 234 plants were measured over six months in 2008 and four months in 2009 with regards to height, width and number of flowers. Empirical health data such as leaf color, insects present and non-planted species were also recorded.

MATERIALS AND METHODS

Site description

Construction on the novel, bi-phasic rain gardens began in the fall of 2007 and was completed the following spring at the Ohio Agricultural Research and Development Center/The Ohio State University (OARDC/OSU) in Wooster, Ohio (40°46’50”N, 81°55’38”W). Each of the three rain gardens consists of an inner anaerobic (oxygen poor) zone and outer aerobic (oxygen-rich) zone (Figure 2.1). The soil media was a commercially-prepared mixture of 60% sand, 20% compost and 20% topsoil (Kurtz Bros. Inc., Cleveland, Ohio). In May 2008, seedlings of six plant species native to Ohio were introduced. The layout of the plants within the garden is presented in Figure 2.2 and a description of each species’ height and bloom period is provided in Table 2.1. A layer of mulch, approximately 3 cm thick, was added to the surface of the entire rain garden the following month for both aesthetic reasons and because it aids in the remediation of stormwater (Dietz and Clausen, 2006).

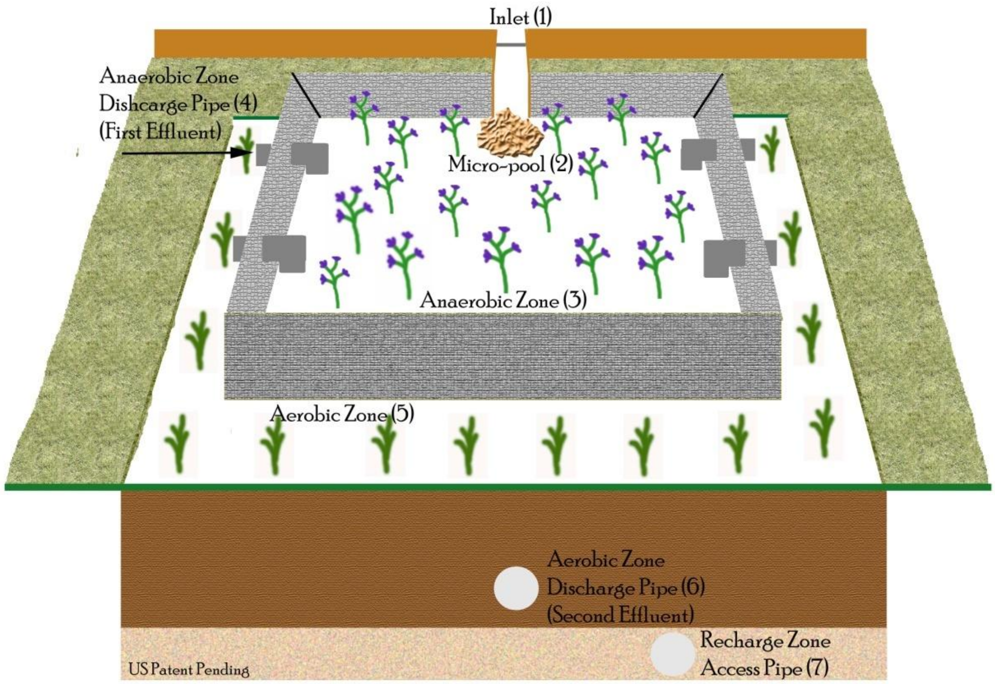

Figure 2.1: Design of the bi-phasic rain garden bioretention ecosystem. Water enters the system through the inlet (1) at the top of the figure, settles into the micro-pool (2) and fills the anaerobic zone (3). Excess water, first effluent (4), is drained from the anaerobic zone into the aerobic zone (5) using U-shaped reverse drainage pipes located at the bottom of the anaerobic zone. The water then drains by gravity into a pipe at the bottom of the aerobic zone and exits the system though the aerobic zone discharge pipe, second effluent (6). The water is returned to the environment and restores the groundwater through the recharge zone access pipe (7). The anaerobic zone is 2.6 m on each side and 1.0 m deep, whereas the aerobic zone is 0.45 m wide (from the anaerobic zone to the grass border), 3.36 m along the sides with the drainage pipes, 4.15 m along the other sides and 0.5 m deep.

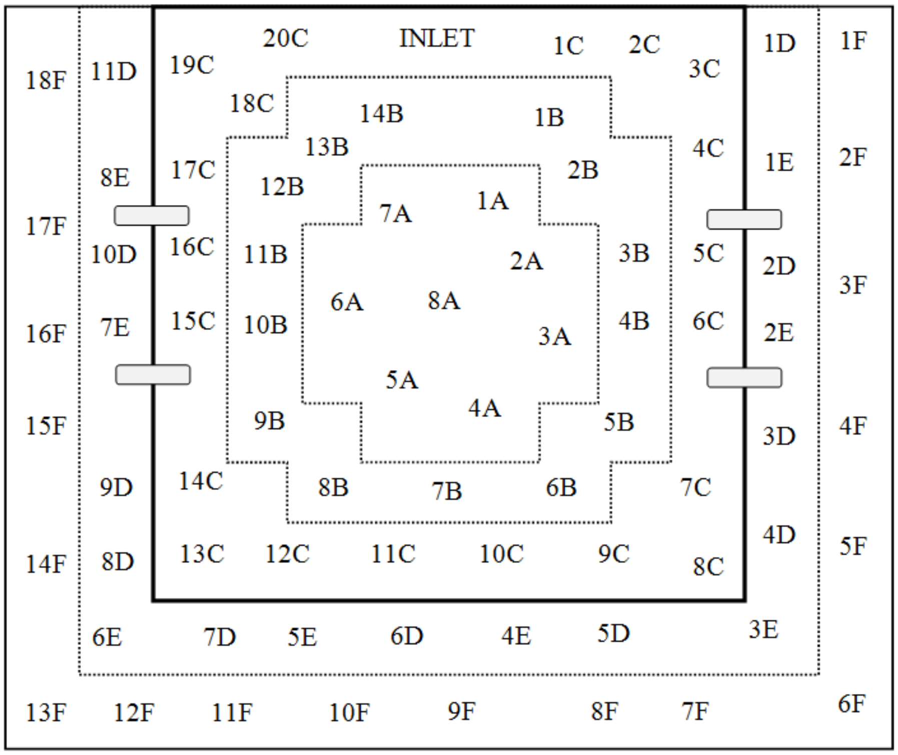

Figure 2.2: Layout of the plant species. The inlet is where runoff water enters the system. Plant species A, B and C, in the anaerobic zone, are *Eupatorium perfoliatum* (boneset), *Tradescantia ohiensis* (spiderwort) and *Veronicastrum virginicum* (culvert's root), respectively. Once the anaerobic zone is full, water drains by means of four reverse pipes (First effluent, anaerobic zone discharge (4), see Figure 1.1) into the outer zone (aerobic) and onto plant species D, E and F, which are *Sorghastrum nutans* (Indian grass), *Echinacea purpurea* (purple coneflower) and *Eragrostis spectabilis* (purple lovegrass), respectively. The water is then gravitationally drained out the aerobic zone discharge pipe opposite the inlet (below plant 9F, not shown). The rain garden sits level in the landscape. The line that the reverse pipes cross and the outer box represent physical barriers. Dotted lines are used to clarify the spatial layout of the plants.

Location	Scientific Name	Common Name	Blooms	Height
				m
Anaerobic	*Eupatorium perfoliatum*	Boneset	June – October	0.6 – 1.0
	Tradescantia ohiensis	Spiderwort	March – August	0.6 – 0.9
	Veronicastrum virginicum	Culvert's root	July – September	0.6 – 1.2
Aerobic	*Sorghastrum nutans*	Indian grass	August – October	0.9 – 2.4
	Echinacea purpurea	Purple coneflower	April – September	0.6 – 1.5
	Eragrostis spectabilis	Purple lovegrass	August – October	0.2 – 0.5

Table 2.1: Description of plant species used in the bi-phasic rain gardens including zone loacation (see Figure 2.2 for a detailed layout), scientific and common names, months during which flowers are likeliest to be present and mean height at maturity.

A member of the Asteraceae (Aster) family, *E. perfoliatum* typically grows 0.6 to 1 m tall (The University of Texas at Austin, 2007; Shaw and Schmidt, 2003). The small, white flower clusters are fuzzy (Figure 2.3) in appearance due to stalk pairs that are opposite on the stem and 90 degrees from the pair above or below (Figure 2.4). The flowers bloom between June and October (The University of Texas at Austin, 2007). Because the individual flowers are less than 1 cm across, each stalk was counted as one flower once it was distinct from the stem. Leaves are also opposite, appear to be fused at the base and covered in a fine hair. This particular species prefers moist or wet to saturated soil conditions (Shaw and Schmidt, 2003).

Figure 2.3: *Eupatorium perfoliatum* inflorescence flowers in August

Figure 2.4: Arrangement of flower clusters on stalk of *Eupatorium perfoliatum*.

Also grown in the anaerobic zone was *T. ohiensis.* A number of characteristics make this plant suitable for rain gardens. This species is tolerant to a range of soil moisture and texture conditions as well as tolerant of flooded conditions in the spring and drought in the summer (Shaw and Schmidt, 2003). The plants can grow up to 0.9 meters tall with a single 2.5 cm flower, purple or blue, that tends to only open in the morning (Figure 2.5) and shrivel into a jelly when touched (The University of Texas at Austin, 2007; Shaw and Schmidt, 2003). These tri-lobed flowers were also observed in the color white on a few plants in 2008, but not in 2009 (Figure 2.6). Flowers were counted in the morning and each open flower counted as a single flower.

Figure 2.5: Tri-lobed flowers of *Tradescantia ohiensis*.

Figure 2.6: White flowers of *Tradescantia ohiensis*. These white flowers were not observed in the second season.

The stems of *V. virginicum* can grow between 0.5 to 1.2 meters (Shaw and Schmidt, 2003). The stalk terminates with a rachis that contains spikes of densely-clustered white flowers (Figure 2.7) arranged similar to a candelabra with the center spikelet much taller than the surrounding ones (Figure 2.8). Since the number of spikelets varied from zero to six, each individual spikelet was counted as a single flower.

This species blooms from July to September (The University of Texas at Austin, 2007) and prefers moist to wet soil conditions (Shaw and Schmidt, 2003).

Figure 2.7: Densely clustered white flowers of the main spike on *Veronicastrum virginicum*.

Figure 2.8: Smaller spikelets of *Veronicastrum virginicum* surrounding taller center one on rachis.

A warm-season grass, *S. nutans* (Figure 2.9), when established, can grow to heights of 0.9 to 2.4 meters with most of the height gained later in the season prior to blooming (The University of Texas at Austin, 2007). This species can tolerate both flooded and drought conditions, although it prefers soil that is moist (The University of Texas at Austin, 2007). Additionally, the plants provide good winter cover, seed for birds, and stabilizes the soil with fibrous roots that can reach 1.2 meters deep (Shaw and Schmidt, 2003).

Figure 2.9: Grass blades of *Sorghastrum. nutans*.

A popular species due to its hardiness and long-lasting flowers, *E. purpurea* is a prairie perennial. The flowered stems of the plant can grow from 0.6 to 1.5 meters in moderately to well-drained sandy or richer soils (The University of Texas at Austin, 2007). The spiky central dome of the flower is a yellowish-brown surrounded by pink or purple petals that droop from below the dome (Figure 2.10).

Figure 2.10: Monarch butterfly (*Danaus plexippus*) on *Echinacea purpurea* in the rain garden.

At only 0.2 to 0.5 meters, *E. spectabilis* is the shortest plant in this rain garden experiment. It grows in dense tuffs and will bloom in late August through October with reddish-purple inflorescence stalks (The University of Texas at Austin, 2007). Each of these stalks was counted as one flower (Figure 2.11). This species prefers well-drained sandy soils, especially in open fields where competition for light is low (The University of Texas at Austin, 2007).

Figure 2.11: Flower stalks on *Eragrostis spectabilis.*

Methods of Data Collection

The height, width and number of flowers on each plant in each garden were recorded each month from June through October of 2008 and from May to August in 2009. Other observations about the general health of the plants, leaf color, insects and non-planted species were also noted and recorded. Data were collected, as described below, in a manner that made comparisons for each plant possible from month to month. Plant height values were recorded at the highest point of the plant as it stood in the garden. For the *T. ohiensis*, the flowers weighted down the stalk and there is an apparent decrease in the height of some plants due to this. Width measurements were an estimation of the middle value between the spread of the base of the plant and the spread of the stalks at the top of the plant. This was more of a factor in the measurements of *E. perfoliatum* and *T. ohiensis* than any of the other species. The grasses (*S. nutans* and *E. spectabilis*) and *E. purpurea* had the smallest spread difference between the base and the top of the plant. Individual mature flower groups, rather than flower clusters, were counted. These data were analyzed using ANOVA: General Linear Model in Minitab. Each rain garden was considered a replication. The plant species were considered independently from one another within each rain garden. Mean values for each plant species in each rain garden were compared.

RESULTS AND DISCUSSION

A number of comments apply to each of the rain gardens and plant species. In general, there were other weedy-type plants growing at the base of the rain garden species. Weeds were observed to be more prevalent in the first year than in the second year. Also more weeds species were observed in the aerobic zone than in the anaerobic zone. Sustained levels of saturation due to higher than normal precipitation in the spring likely helped to reduce the weeds in the anaerobic zone. Throughout the season, each species attracted a variety of insects: honey bee (*Apis mellifera*), bee (*Bombus* spp.), Monarch butterfly (*Danaus plexippus*), grasshopper (suborder Caelifera) and praying mantis (*Mantis religiosa*) (Figures 2.10, 2.12, 2.13, 2.14). A detailed data set of all the values for each plant over the 2008 growing season is located in Appendix A: Tables 1.1

through 1.6 and for 2009 in Appendix B: Tables 2.1 through 2.2. Summaries of the 2008 data, where averages (arithmetic means) by month are calculated overall and by rain garden (where statistically significant differences between the rain gardens, ANOVA at alpha = 0.05, existed), are presented in Table 2.2 for the anaerobic zone and Table 2.3 for the aerobic zone.

Figure 2.12: Bee (*Bombus* spp.) on *Echinacea purpurea*.

Figure 2.13: Grasshopper (suborder Caelifera) on *Tradescantia ohiensis*.

Figure 2.14: Praying mantis (*Mantis religiosa*) on the mulch of the anaerobic zone.

Month	Plant Species	Height		Width	Number of Flowers [a]
		cm		cm	
June	*Eupatorium perfoliatum*	61.0		26.5	0
	Tradescantia ohiensis	61.3	rg1	24.1 [a]	11.4
			rg2	22.5 [b]	
			rg3	16.7 [b]	
	Veronicastrum virginicum	56.3	rg1	28.1 [a]	0
			rg2	18.2 [b]	
			rg3	15.6 [b]	
July	*Eupatorium perfoliatum*	76.5		26.4	14.6
	Tradescantia ohiensis	61.2		16.5	0.35
	Veronicastrum virginicum	67.7		19.9	4.47
August	*Eupatorium perfoliatum*	88.5		26.0	90.4
	Tradescantia ohiensis	35.9		13.2	0
	Veronicastrum virginicum	75.9		18.6	4.86
September	*Eupatorium perfoliatum*	89.5		25.0	0
	Tradescantia ohiensis	0.00		0.00	0
	Veronicastrum virginicum	74.3	rg1	17.0 [ab]	0
			rg2	18.6 [a]	
			rg3	15.8 [b]	
October	*Eupatorium perfoliatum*	90.0		23.1	0
	Tradescantia ohiensis	0.00		0.00	0
	Veronicastrum virginicum	74.5		14.9	0

[a] See text for how flowers were counted.

Table 2.2: Arithmetic mean values for height, width and flower data for the anaerobic zone in 2008. The designation of ‘rg1, rg2 and rg3’ corresponds to Rain Garden 1, Rain Garden 2 and Rain Garden 3, respectively, and indicate a statistically significant difference (according to Tukey’s pair-wise comparison, at $p < 0.05$) for that species for that month as designated by the letters that follow. If there was no statistically significant difference at alpha = 0.05, according to ANOVA, then the plant species will have only one value for height, width or number of flowers for that month, which represents the arithmetic mean across all three rain gardens for that month. Individual values for each plant are in Appendix 1.1 through 1.3.

Month	Plant Species		Height cm		Width cm	Number of Flowers [a]	
June	*Sorghastrum nutans*		13.1		4.55	0	
	Echinacea purpurea		56.8	rg1	10.3 ^{a}	0.250	3.38
				rg2	15.0 ^{b}		
				rg3	15.3 ^{b}		
	Eragrostis spectabilis		15.3	rg1	10.7 ^{a}	0	
				rg2	9.16 ^{ab}		
				rg3	8.33 ^{b}		
July	*Sorghastrum nutans*		12.8		5.38	0	
	Echinacea purpurea		67.4		16.67	3.92	0.416
	Eragrostis spectabilis		14.8	rg1	10.6 ^{a}	0	
				rg2	9.86 ^{a}		
				rg3	7.36 ^{b}		
August	*Sorghastrum nutans*		20.2		5.08	0	
	Echinacea purpurea		67.6		18.4	4.13	0
	Eragrostis spectabilis	rg1	21.3 ^{a}		9.12	0	
		rg2	21.3 ^{a}				
		rg3	16.8 ^{b}				
September	*Sorghastrum nutans*		22.45		6.06	0	
	Echinacea purpurea		66.9		15.1	0	0
	Eragrostis spectabilis	rg1	21.4 ^{a}	rg1	9.72 ^{a}	rg1	0.833 ^{a}
		rg2	20.0 ^{ab}	rg2	8.19 ^{ab}	rg2	0.444 ^{b}
		rg3	15.5 ^{b}	rg3	7.22 ^{b}	rg3	0.333 ^{b}
October	*Sorghastrum nutans*		22.2		5.83	0	
	Echinacea purpurea		65.1		14.3	0	0
	Eragrostis spectabilis	rg1	22.1 ^{a}		8.33	rg1	1.00 ^{a}
		rg2	17.9 ^{ab}			rg2	8.06 ^{b}
		rg3	14.4 ^{b}			rg3	7.36 ^{b}

[a] See text for specifics on how flowers were counted. Flower counts for *E. purpurea* are divided into two columns to represent the unopened verses open flowers.

Table 2.3: Arithmetic mean values for height, width and flowering data for the aerobic zone in 2008. The designation of 'rg1, rg2 and rg3' corresponds to Rain Garden 1, Rain Garden 2 and Rain Garden 3, respectively, and indicate a statistically significant difference (according to Tukey's pair-wise comparison, at $p < 0.05$) for that species for that month as designated by the letters that follow. If there was no statistically significant difference at alpha = 0.05, according to ANOVA, then the plant species will have only one value for height, width or number of flowers for that month, which represents the arithmetic mean across all three rain gardens for that month. Individual values for each plant are in Appendix 1.4 through 1.6.

Eupatorium perfoliatum (Boneset)

Overall, this species fared well. The height data are presented in Figure 1.15, the width data in Figure 1.16 and the flowering data in Figure 1.17. The height data follow a typical growth pattern where the plant quickly gains height in the early months of the season and levels off. At an alpha level of 0.05, ANOVA showed no statistically significant difference between rain gardens (F = 0.87). Width data do not show a clear trend within the season, but, expectedly, the values were lowest at the end of the season after the plants had died back. Analysis of variance showed no statistical differences between the rain gardens in either the width (F = 3.35) or number of flowers (F = 30.50) for any of the months. The flowers bloomed for a shorter season than published (The University of Texas at Austin, 2007), but there was consistency across the three rain gardens. The peak number of flowers occurred in August.

There are only two concerns with this plant species. The first is insects feeding on the leaves (Figure 1.18), especially in Rain Garden 2. On these plants, some of the topmost leaves were rolled in on themselves (Figure 1.19), which was not observed in unaffected plants. Rain Garden 3 was mildly affected beginning in July, whereas Rain Garden 1 was mostly unaffected. The second concern is that the lower half of the plant started to brown in August (Figure 1.20), which decreases the overall aesthetics of the rain garden, especially since it is the tallest plant in the anaerobic zone.

All of the plants in each of the gardens (24 total) survived the winter and re-emerged the second year (Figure 1.21). Each of the plants initially looked healthy, with the exception of insect feeding, most likely Colorado Potato Beetle (*Leptinotarsa* *decemlineata*), similar to that observed the previous year (Figure 1.22). By the middle of the summer, many of the plants were defoliated by greater than 70%.

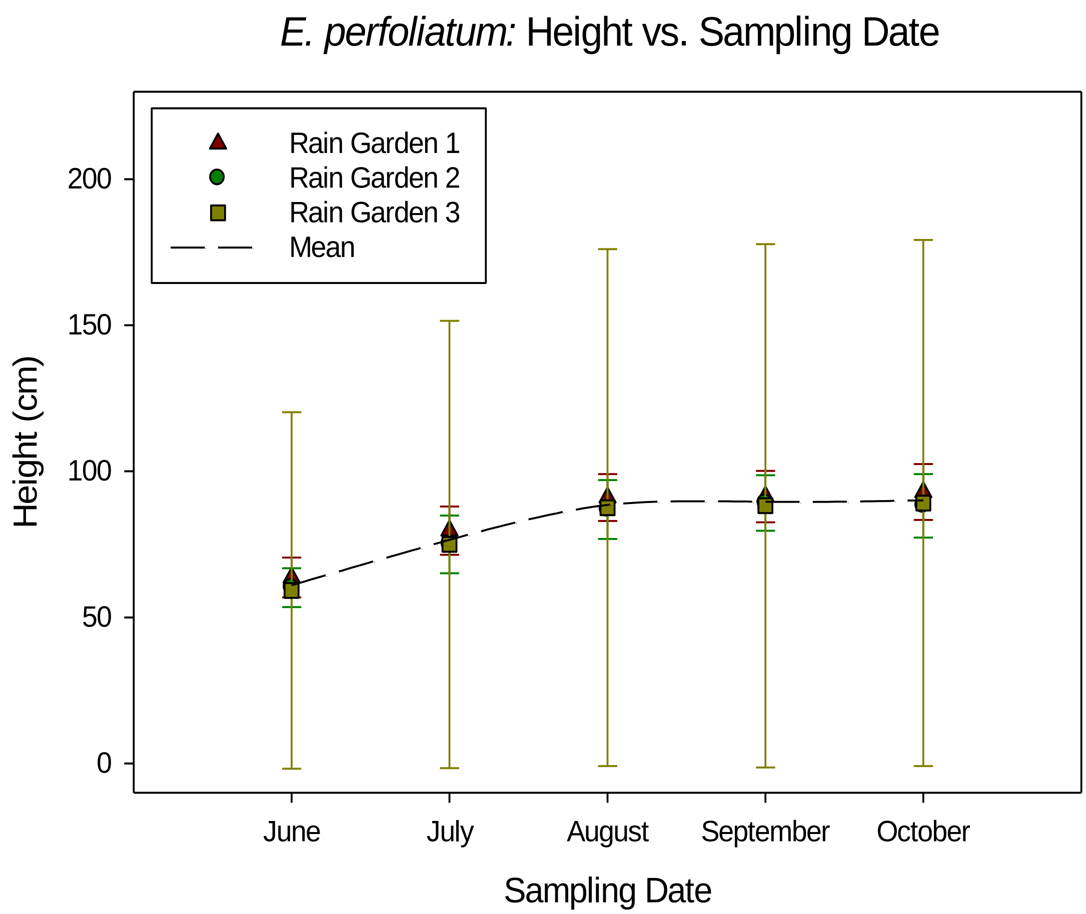

Figure 2.15: Arithmetic mean height (cm) for each month by rain garden for *Eupatorium perfoliatum*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 0.87).

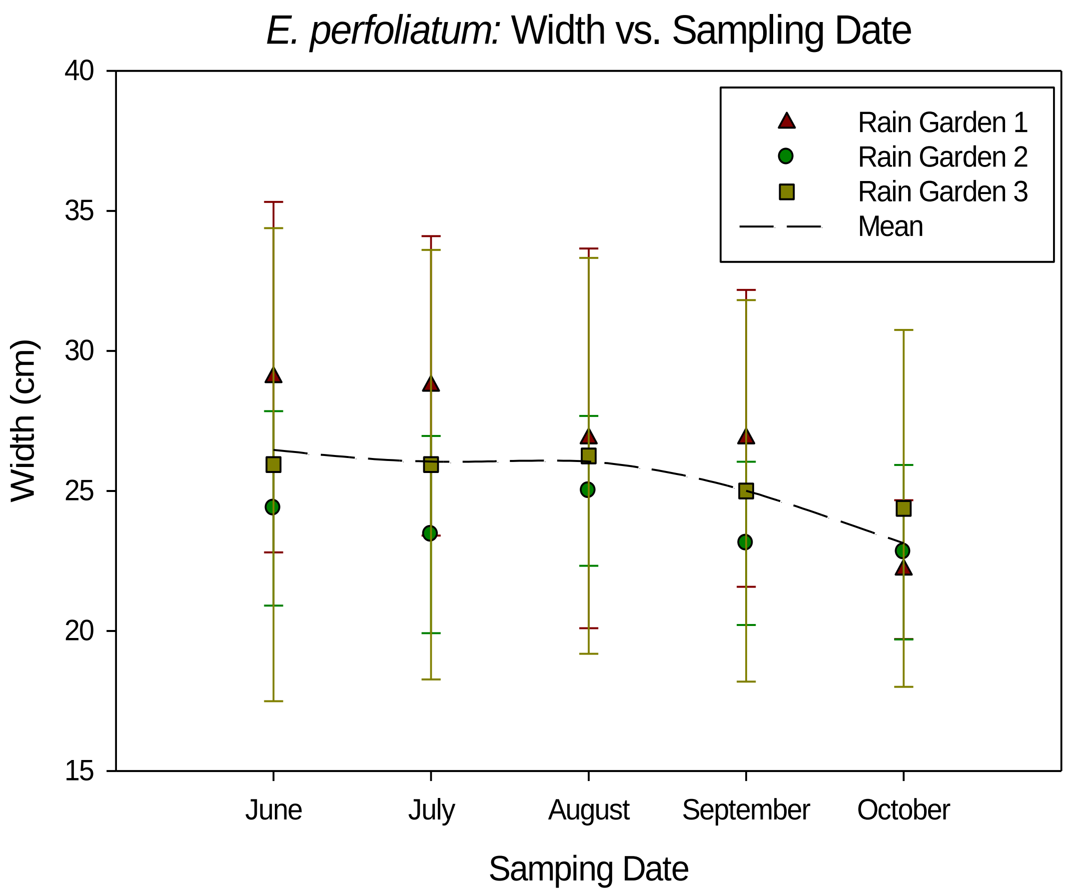

Figure 2.16: Arithmetic mean for the width (cm) for each month by rain garden for *Eupatorium perfoliatum*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 3.35).

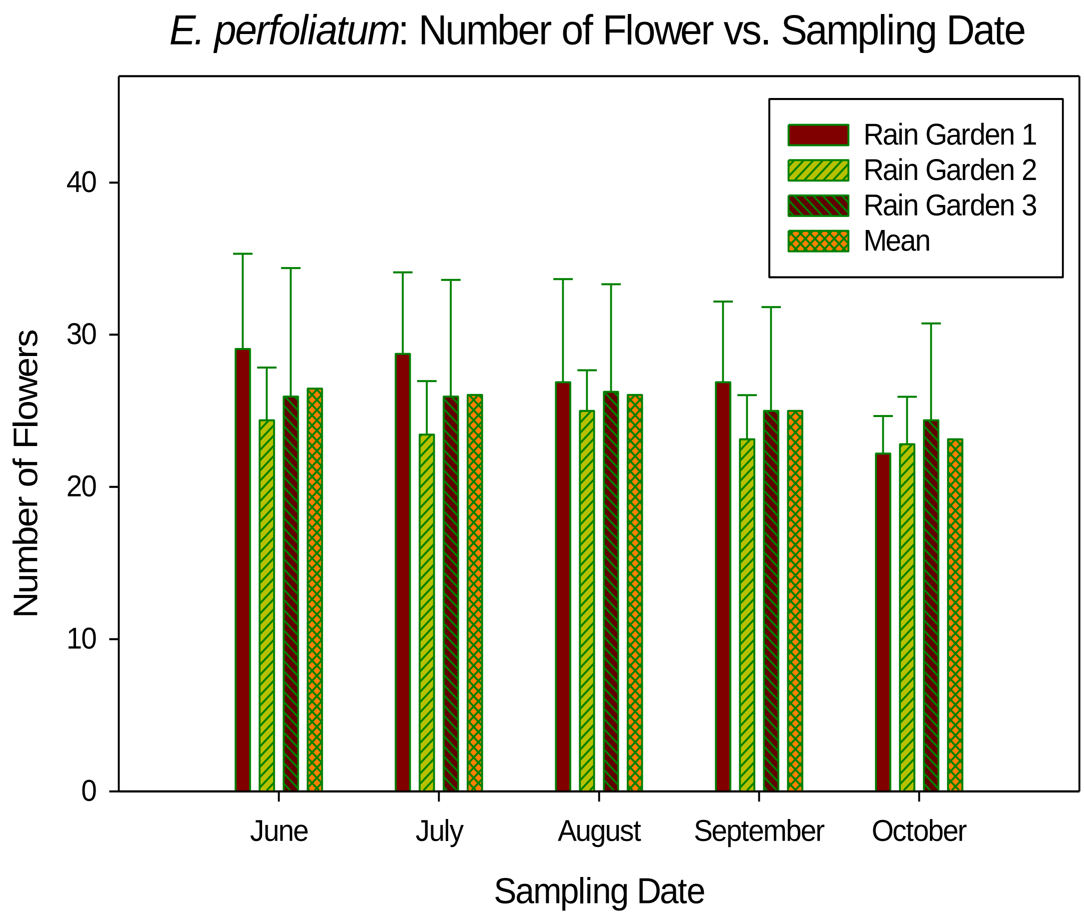

Figure 2.17: Arithmetic mean for the number of flowers for each month by rain garden for *Eupatorium perfoliatum*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 30.50).

Figure 2.18: Evidence of insect feeding on *Eupatroium perfoliatum* that persisted throughout the season.

Figure 2.19: Top leaves of *Eupatroium perfoliatum* that have rolled back on themselves.

Figure 2.20: Browning of lower half of *Eupatorium perfoliatum* plants in August.

Figure 2.21: Re-emergence of *Eupatorium perfoliatum* plants the following spring.

Figure 2.22: Insect, most likely Colorado Potato Beetle (*Leptinotarsa decemlineata*), feeding on *Eupatorium perfoliatum*. Defoliation was more extensive in 2009 than in 2008.

Tradescantia ohiensis (Spiderwort)

T. ohiensis was the first species in the rain gardens to bloom. With its cluster of slender stalks and typical monocot leaves, the plant visually appears to spread more than the other species, although the width values do not indicate that the plant had spread any more than the others in the anaerobic zone (Figure 2.23 compared with Figure 2.16 and 2.28). There was a statistically significant difference (alpha = 0.05) between the plants in Rain Gardens 1 and 3 in June (F = 7.59), but not in July or August (F = 2.28). According to ANOVA, there was no statistically significant difference in the height (F = 0.54) or number of flowers (F = 0.29) for any of the months between the rain gardens. As an earlier emerging species, the growth pattern that was seen with *E. perfoliatum* was not observed (Figure 2.24). The plants were tallest in June and became shorter as they died back. The stalks had already begun to yellow in July and nearly all the plants had died back by August. Flowering data showed a similar pattern (Figure 2.25). Other grasses took hold at the base of each plant beginning in August (Figure 2.26). In the second year, every plant re-grew and appeared healthy. If paired with a plant that blooms late season, this species would be suitable for the anaerobic zone of a rain garden.

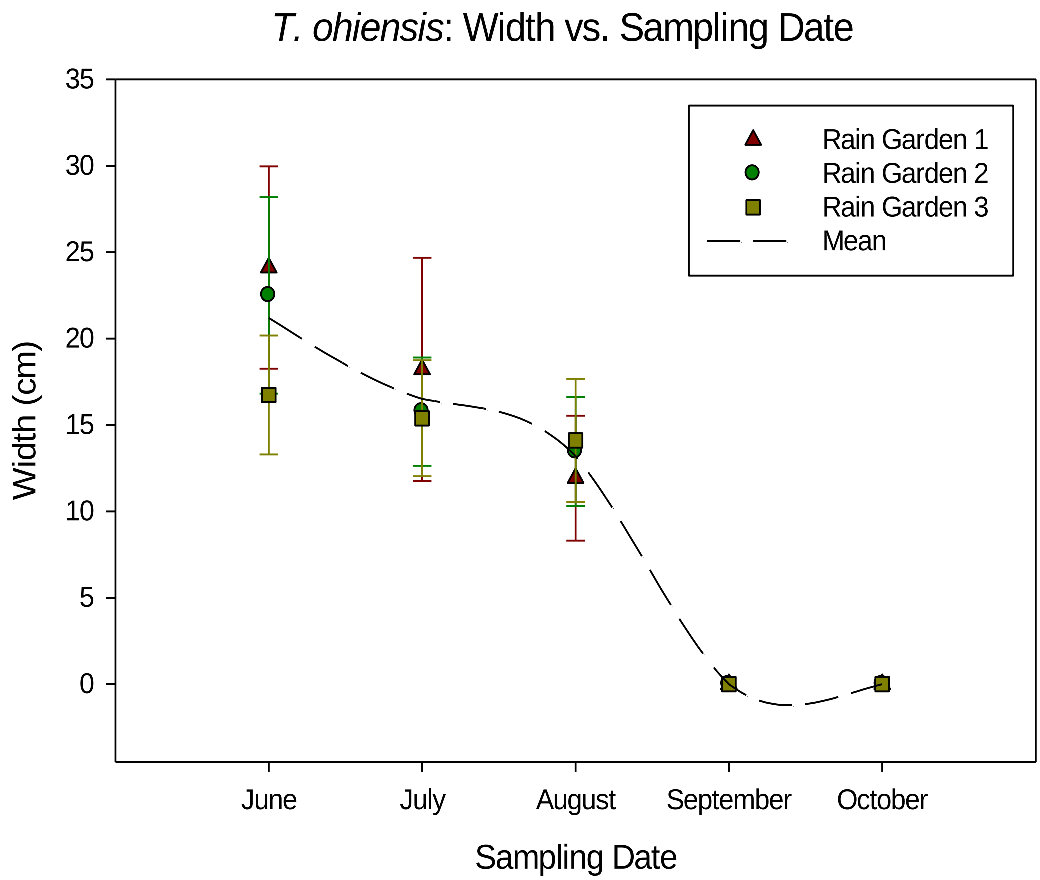

Figure 2.23: Arithmetic mean for the width (cm) for each month by rain garden for *Tradescantia ohiensis*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 0.54).

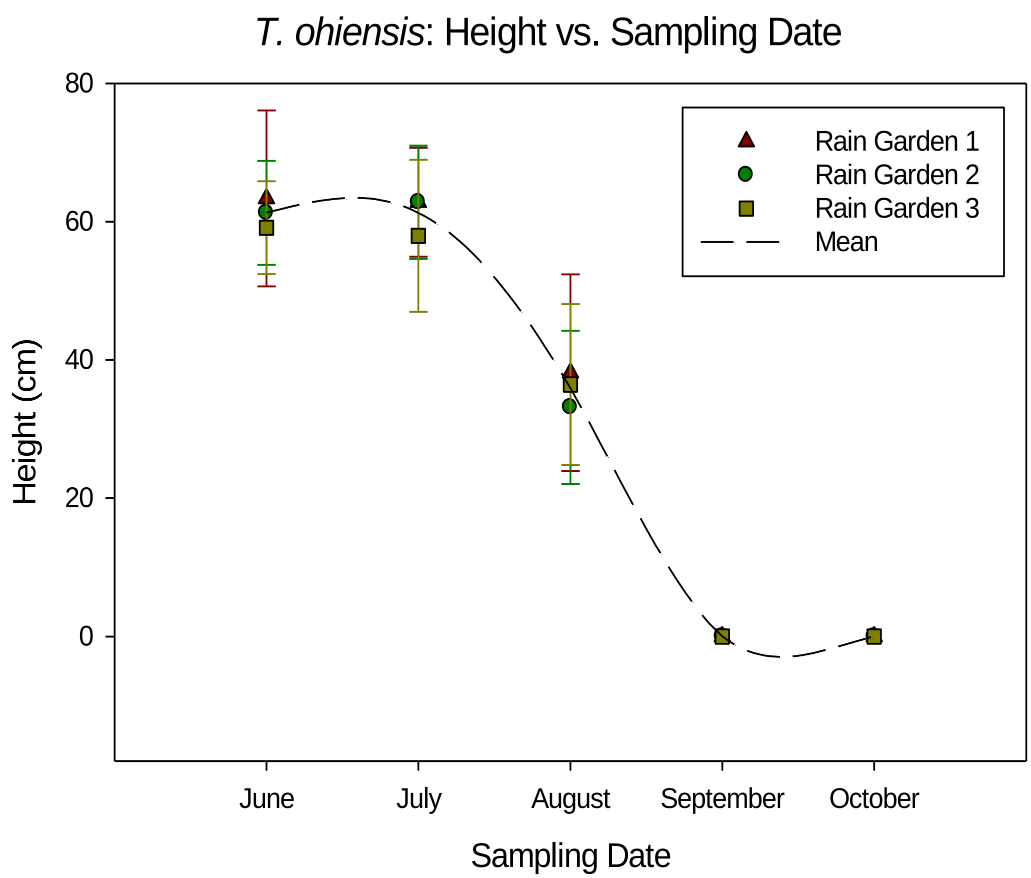

Figure 2.24: Arithmetic mean for the height (cm) for each month by rain garden for *Tradescantia ohiensis*. Using Tukey's pair-wise comparison, the only statistically significant difference was between Rain Garden 1 and 3 in June (F = 7.59).

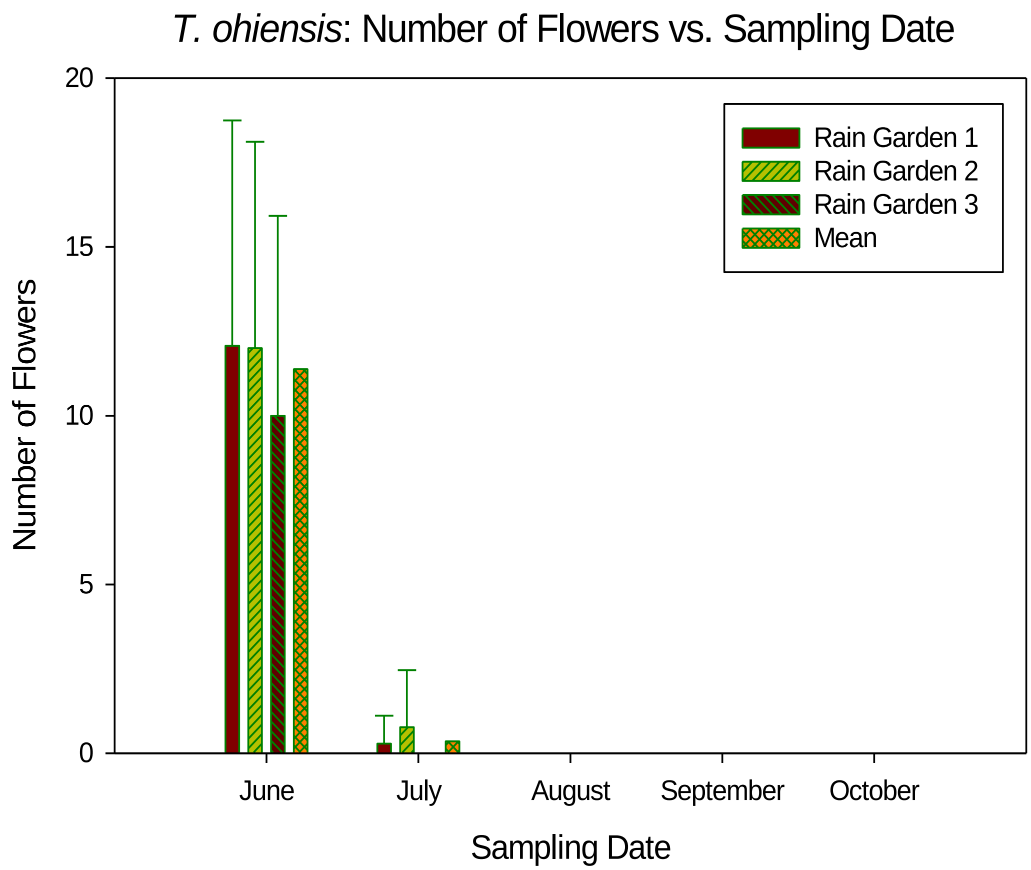

Figure 2.25: Arithmetic mean for the number of flowers for each month by rain garden for *Tradescantia ohiensis*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 2.28).

Figure 2.26: New growth at base of *Tradescantia ohiensis* after the plants had senesced.

Veronicastrum virginicum (Culvert's Root)

V. virginicum established well in the anaerobic zone of the rain garden. The height data followed a similar pattern to *E. perfoliatum* in that the plants grew quickly from June to August, and then leveled off for the rest of the season (Figure 2.27). Analysis of variance showed no statistical significant differences between the rain gardens for any of the months (F = 2.81). The trend for the average width varied by rain garden. The plants in Rain Garden 3 showed a typical response curve that mimicked the height data, whereas the plants in Rain Garden 1 showed a steady decrease and the plants in Rain Garden 2 fluctuated throughout the season (Figure 2.28). Using Tukey's pair-wise comparison, there was a statistically significant difference between Rain Gardens 1 and 3 in June (F = 5.36) and between Rain Gardens 2 and 3 in September (F = 3.51). Flowers were present in July and August (Figure 1.29) and there was no statistical significance between gardens for either month (F = 0.93). There were only a few plants with leaves that had black tips in July (Figure 2.30), when the plants began to bloom. A bacterial agent is likely responsible for the black tips since the senescence progressed down the leaf and stalk, but did not affect other stalks in the plant. The flowers began to senesce in August and some of the stalks began to turn black. In September and October, seeds were present, and the plants became dormant. ANOVA showed no statistical significant difference for the number of flowers among the rain gardens for any of the months.

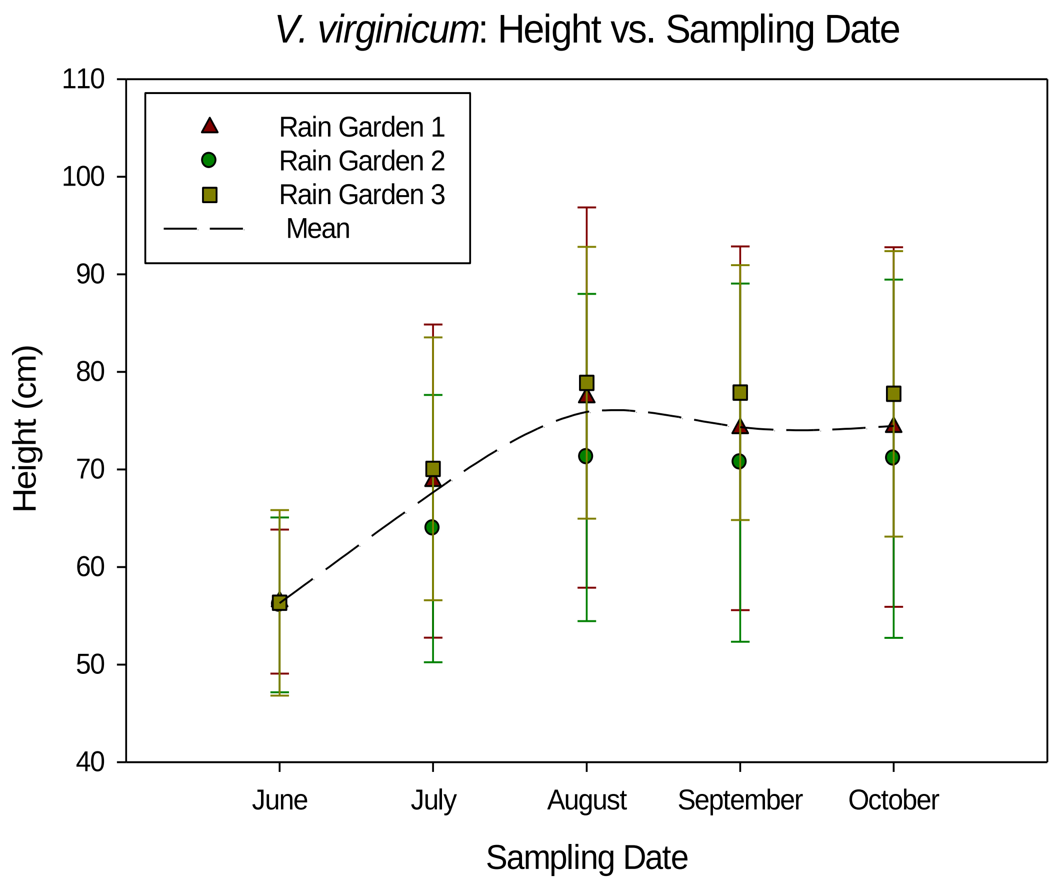

Figure 2.27: Arithmetic mean for the height (cm) for each month by rain garden for *Veronicastrum virginicum*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months ($F = 2.81$).

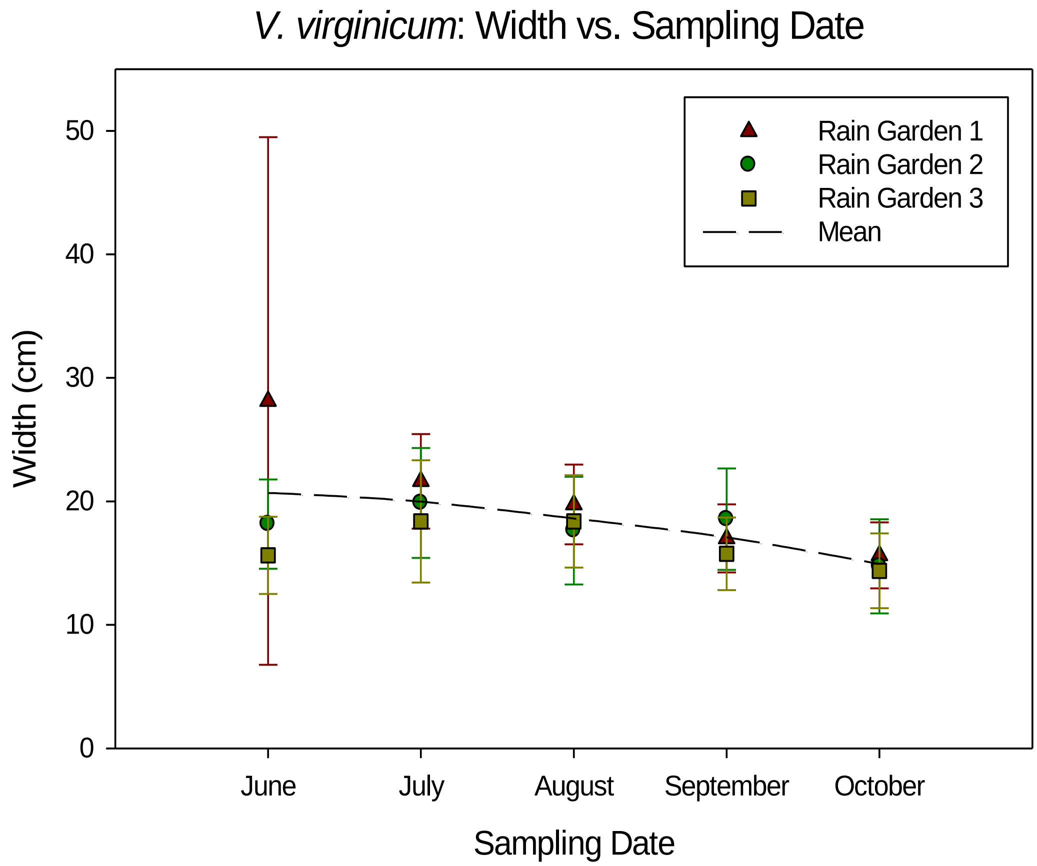

Figure 2.28: Arithmetic mean for the width (cm) for each month by rain garden for *Veronicastrum virginicum*. Using Tukey's pair-wise comparison, there was a statistically significant difference between Rain Garden 1 and 3 in June (F = 5.36) and between Rain Gardens 2 and 3 in September (F = 3.51).

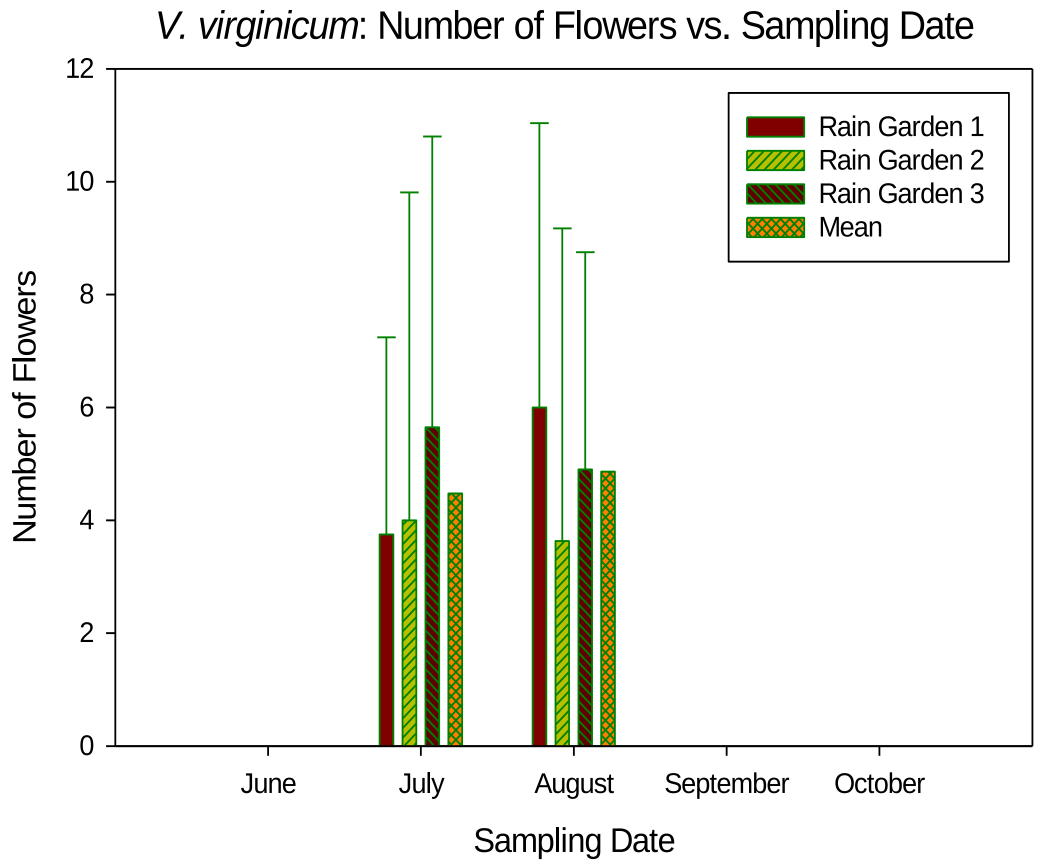

Figure 2.29: Arithmetic mean for the number of flowers for each month by rain garden for *Veronicastrum virginicum*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for July or August (F = 0.93).

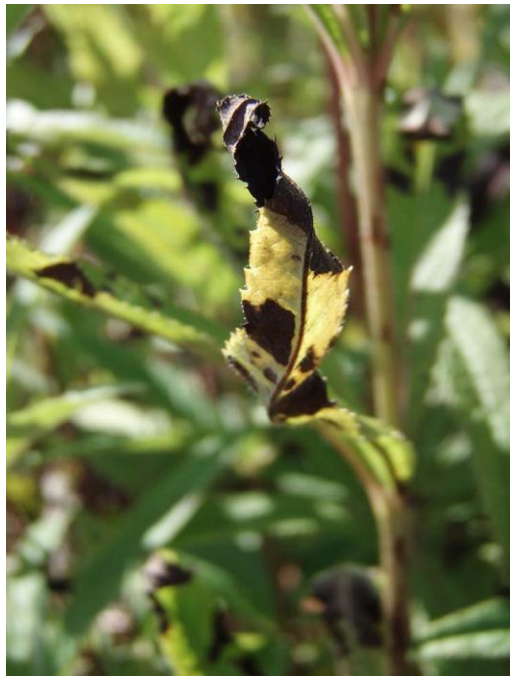

Figure 2.30: Black tips of *V eronicastrum virginicum* leaf are likely a result of a bacteria.

V. virginicum did not fare particularly well over the winter. Twenty-four percent of the 59 plants died (Figure 1.31), the most of any of the species. In Rain Garden 1, four died; in Rain Garden 2, eight died; and in Rain Garden 3, two died. With the exception of two plants in Rain Garden 2, all of these plants were located at the north end of the plots, furthest from the water inlet and potentially in the shadow of the much taller boneset, although this was not directly observed. Since the gardens sit level in the landscape, water was not observed to have ponded in or drained from this area. The flowers add a stunning visual effect to the gardens, but there is concern about their long-term suitability given the high rate of mortality between years one and two.

Figure 2.31: Rain Garden 2 where *Veronicastrum virginicum* plants were present the previous year (white arrows). The bases of last year's plants can be seen behind the white pvc pipe in the back and to the right of the *Tradescantia ohiensis* plants. Additional plants were also present in the foreground, but the bases are not visible.

Sorghastrum nutans (Indian Grass)

The *S. nutans* plants looked healthy through September, but were slow to establish. In the first year, the heights were well below published values (Figure 2.32), but generally gained steadily throughout the season (Figure 2.33). Width data also showed gains throughout the growing season, although there was more fluctuation throughout the season (Figure 2.34). The plants were brown by October, and three of 33 had died. Two were in Rain Garden 2 and one in Rain Garden 1. Three additional plants in Rain Garden 3 did not survive the winter and one that appeared to have died in Rain Garden 2 last year re-established. In Rain Garden 1 and 2, both plants were on the north side of the rain garden, and it is likely that the wall of the anaerobic zone prevented sufficient sunlight from reaching the plants. In Rain Garden 3 there was one plant on each side. A few of the plants that were closest to the anaerobic zone water drainage pipes (first effluent) appeared healthier and taller than those further away. There was no statistically significant difference between the three rain gardens for any of the months regarding height (F = 1.81) or width (F = 0.01), according to ANOVA. That the species stays green through September is aesthetically pleasing and the vertical blades of grass are visually interesting (Figure 2.35). A consideration is to plant this species in clumps, which may be closer to its native habitation.

Figure 2.32: *Sorghastrum nutans* in July of the first year.

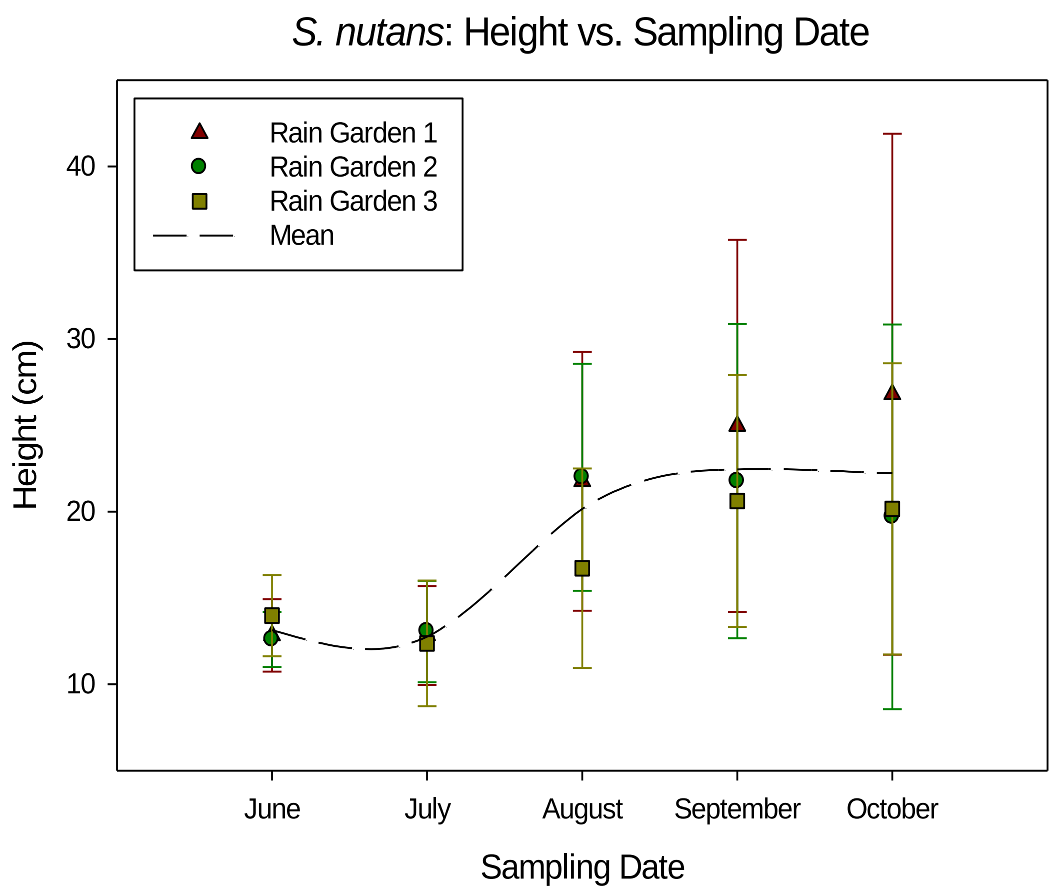

Figure 2.33: Arithmetic mean for the height (cm) for each month by rain garden for *Sorghastrum nutans*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 1.81).

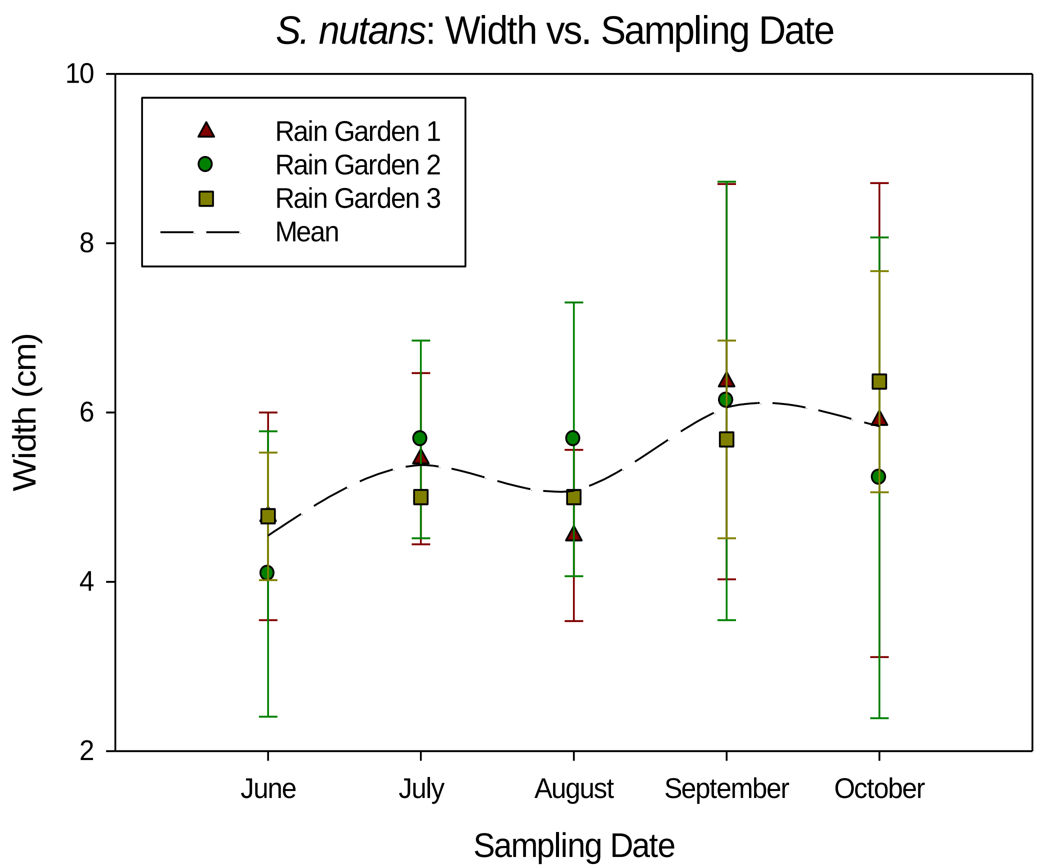

Figure 2.34: Arithmetic mean for the width (cm) for each month by rain garden for *Sorghastrum nutans*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 0.01).

Figure 2.35: *Sorghastrum nutans* in October of the first year.

Echinacea purpurea (Purple Coneflower)

E. purpurea, in the aerobic zone, was another species that flowered early. Unlike *T. ohiensis*, which was in the anaerobic zone, however, it flowered from June through August and attracted many types of insects (Figures 2.10 and 2.12). The plants grew tall rather than wide, which allowed for other plants to grow at the base. There was an initial height gain between June and July, which was then level for the rest of the season (Figure 2.36). Width data followed a more curve-linear pattern with August representing the widest plants (Figure 2.37). In June, the width of *E. purpurea* in Rain Garden 1 was statistically lower than the values for Rain Gardens 2 and 3 (F = 4.82). However, this was not the case for the following months (F = 0.07), or for height (F = 12.80) or the number of flowers (F = 0.09, unopened and F = 0.12, opened). Since there is a clear pre-flowering stage, both unopened and opened flowers were counted. The unopened flowers peaked in June (Figure 2.38) and were followed by a peak of opened flowers in July and August (Figure 2.39). A few leaves were yellow or purple tipped in June and in July there was some discoloration to the stalks (Figure 2.40). The flowers began to senesce in August and the stalks were also mostly dead by September and certainly in October. Some new leaves began to emerge at the bases of the plants in September (Figure 2.41). Stalks emerged from these the following spring. A few of the stalks appeared to have been bitten off, although there was no other indication of adverse animal activity. All the plants survived the winter, although one in Rain Garden 2 came up later than the others. There were eight plants in each garden for a total of 24 overall. This species grows well in the aerobic zone of the rain garden, is visually pleasing, attracts butterflies and can make excellent cut flowers. It is recommended for use under these and similar conditions.

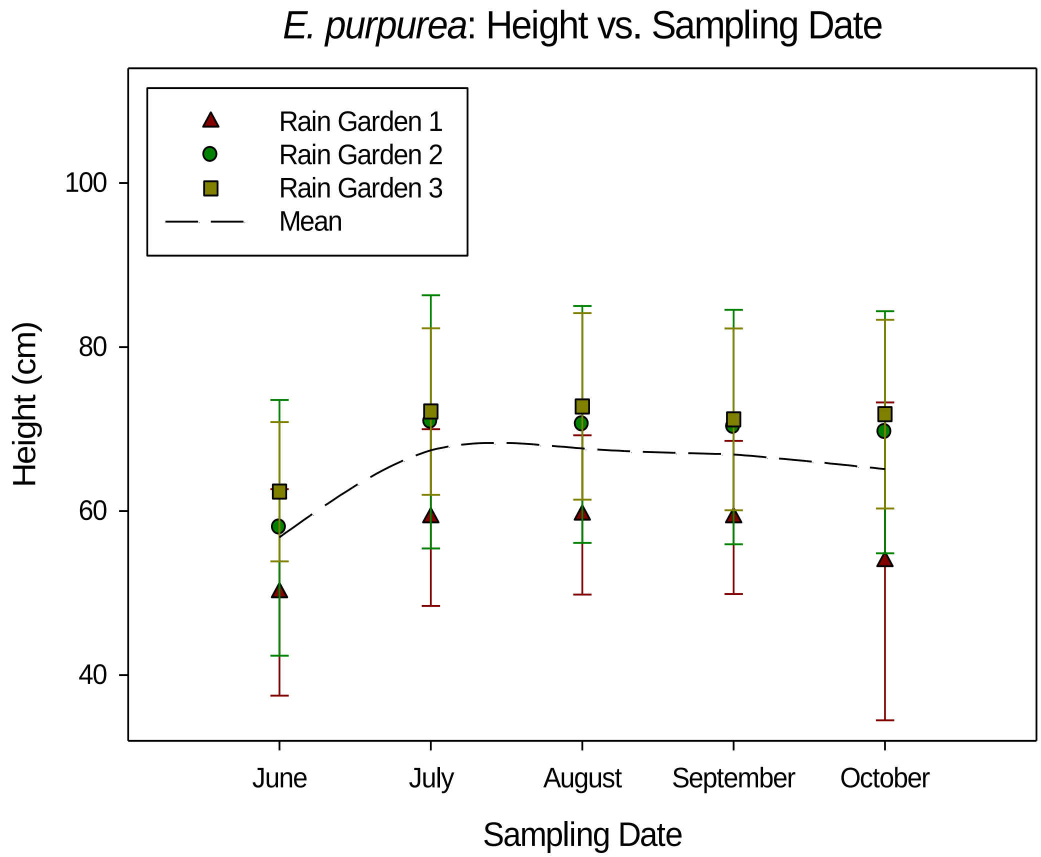

Figure 2.36: Arithmetic mean for the height (cm) for each month by rain garden for *Echinacea purpurea*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 12.80).

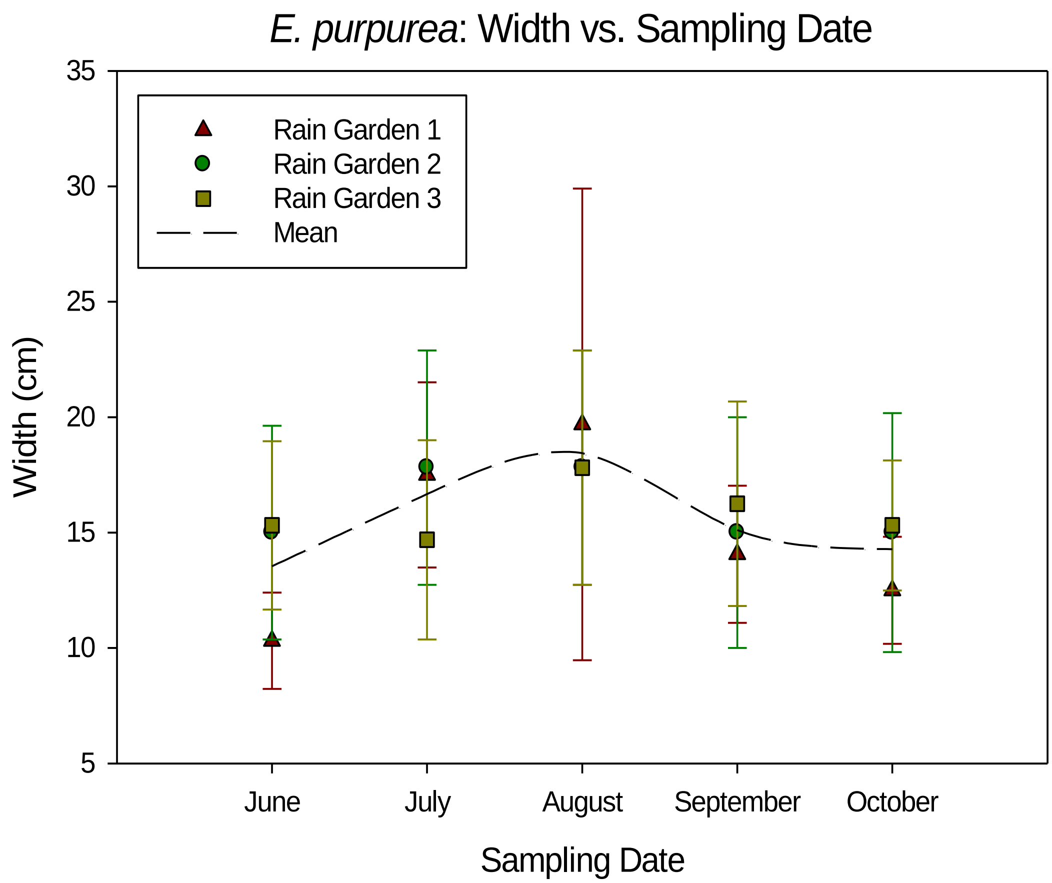

Figure 2.37: Arithmetic mean for the width (cm) for each month by rain garden for *Echinacea purpurea*. In June, the value of Rain Garden 1 is statistically lower than the values of Rain Gardens 2 and 3 ($F = 4.82$), according to a Tukey's pair-wise comparison at alpha = 0.05.

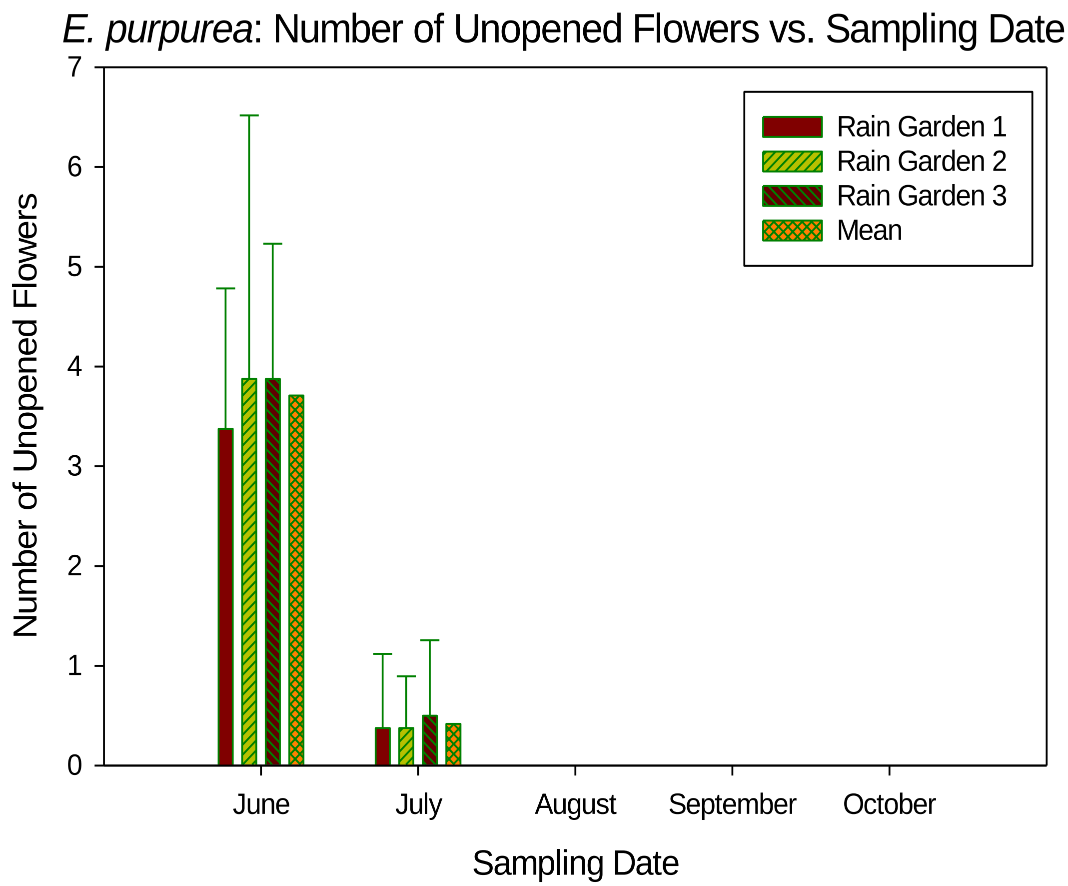

Figure 2.38: Arithmetic mean for the number of unopened flowers for each month by rain garden for *Echinacea purpurea*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 0.09).

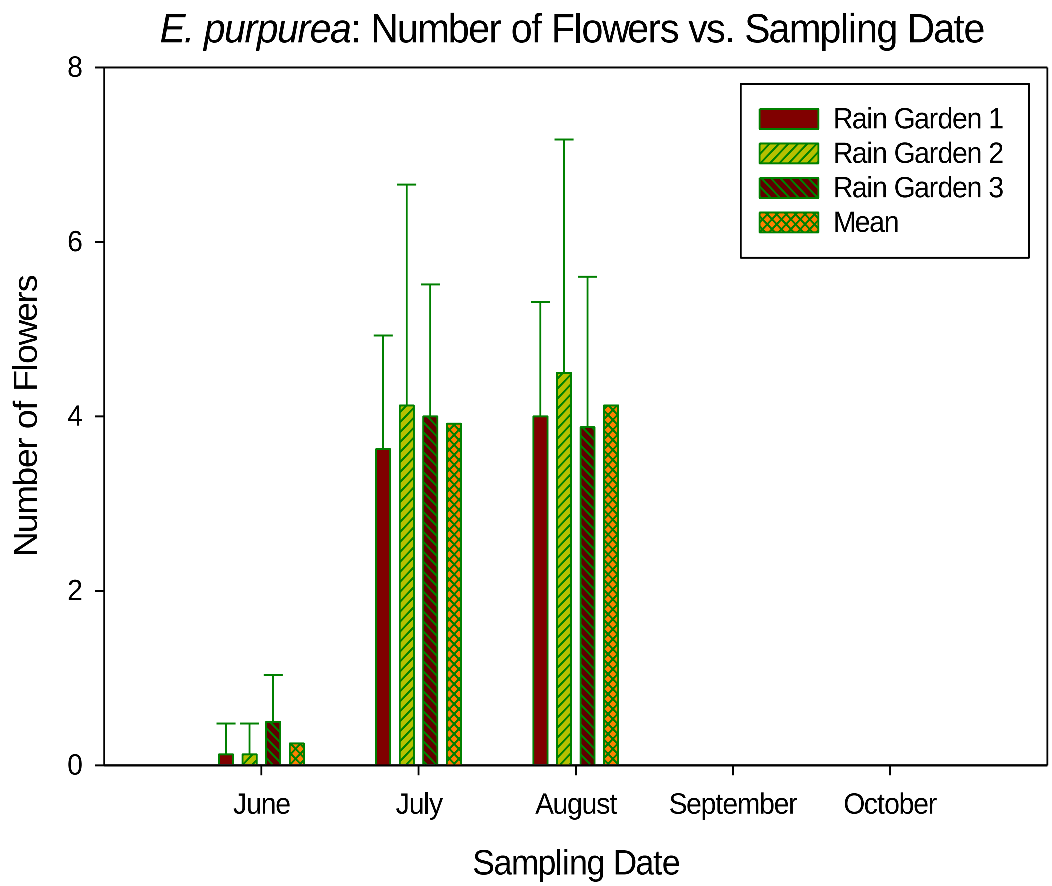

Figure 2.39: Arithmetic mean for the number of flowers for each month by rain garden for *Echinacea purpurea*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for any of the months (F = 0.12).

Figure 2.40: Discoloration on stem of *Echinacea purpurea* beginning in July.

Figure 2.41: New leaves at the base of *Echinacea purpurea* in October.

Eragrostis spectabilis (Purple Lovegrass)

E. spectabilis, as with *S. nutans*, was also slow to establish. Planted in the aerobic zone, this species was more prone to competition from outside plants than any of the other species, which resulted in heights that were below published values for the first year (The University of Texas at Austin, 2007). Data for both the height (Figure 2.42) and width (Figure 2.43) were variable. In Rain Garden 1, the average height increased each month, whereas there was a downward trend for Rain Gardens 2 and 3 after initial gains. This downward trend was also seen in the width data, where the final values were lower than the initial values for each of the rain gardens. Using ANOVA, these differences were often statistically significant by rain garden and month. Only the height data for June ($F = 0.60$) and July ($F = 2.13$); and the width data for August ($F = 0.60$) and October ($F = 3.13$) showed no evidence for differences between the rain gardens. In August, for height, there was no statistical differences between Rain Gardens 1 and 2, but both were statistically different from Rain Garden 3 ($F = 3.54$). In September and October, the height of the plants in Rain Garden 1 was statistically different than Rain Garden 3 ($F = 4.43$ and $F = 7.71$, respectively). The width data were statistically different for Rain Garden 1 and 3 in June ($F = 5.91$), July ($F = 10.63$) and September ($F = 4.39$). Flower (seed head) data are presented in Figure 2.44. In both September and October, there is a statistically significant difference between Rain Garden 1 with both Rain Gardens 2 and 3 ($F = 5.78$ and 7.93, respectively). There is no statistically significant difference between Rain Garden 2 and 3 for either month. These differences are summarized in Table 2.3.

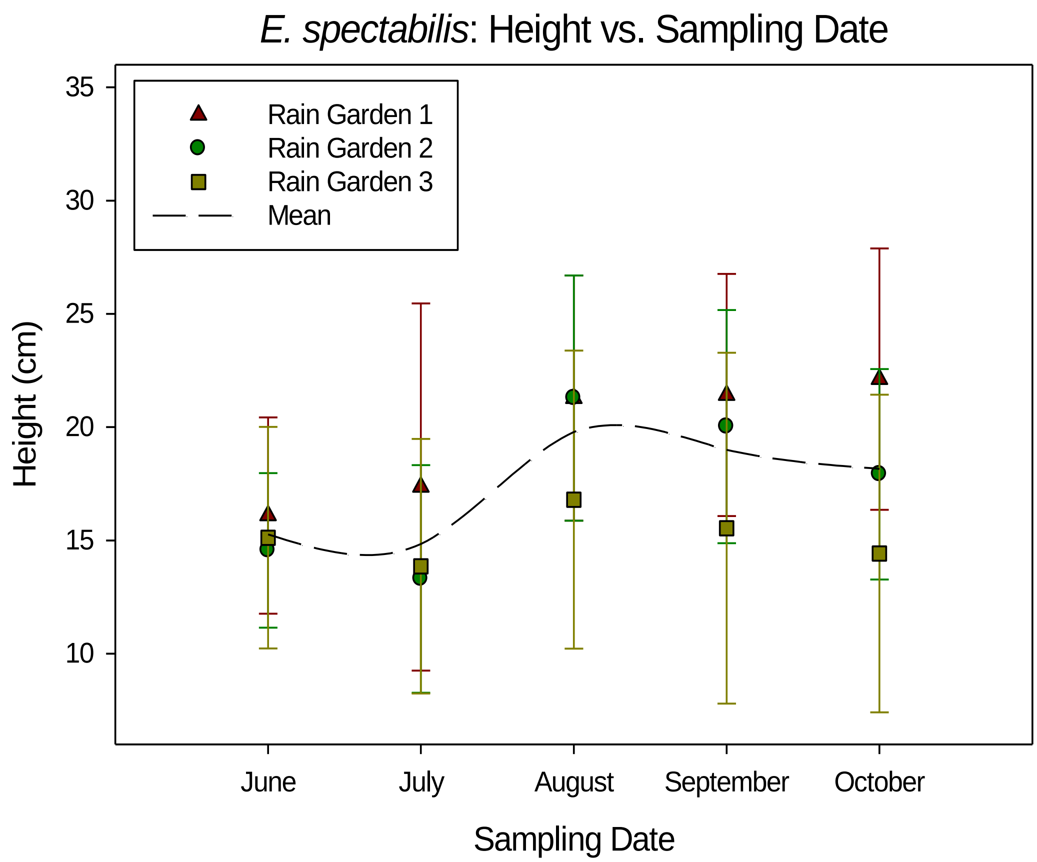

Figure 2.42: Arithmetic mean for the height (cm) for each month by rain garden for *Eragrostis spectabilis*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for June (F = 0.60) or July (F = 2.13). Using Tukey's pair-wise comparison, at the same alpha, both Rain Garden 1 and 2 are statistically difference from Rain Garden 3 in August (F = 3.54). In September and October, only Rain Garden 1 and 3 are statistically different (F = 4.43 and F = 7.71, respectively).

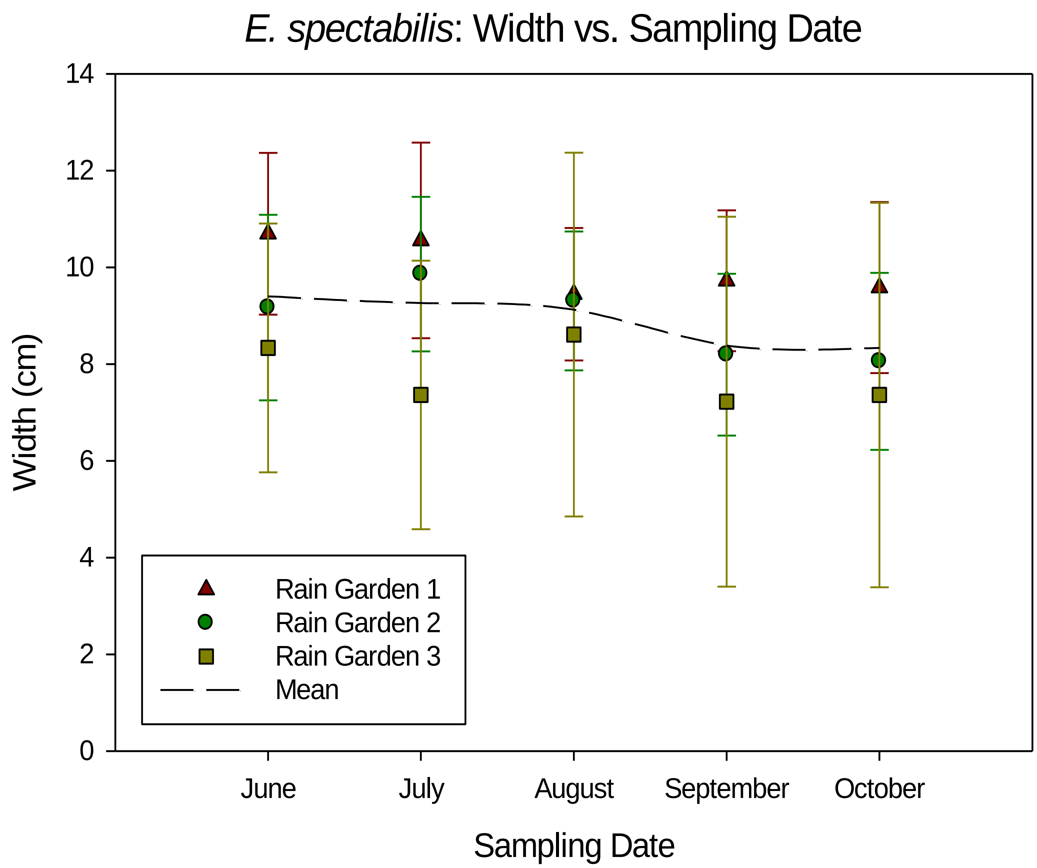

Figure 2.43: Arithmetic mean for the width (cm) for each month by rain garden for *Eragrostis spectabilis*. Using ANOVA, at alpha = 0.05, there was no statistical difference between any of the rain gardens for August (F = 0.60) and October (F = 3.13). Using Tukey's pair-wise comparison, at the same alpha, Rain Garden 1 and 3 were statistically different in June, (F = 5.91), July (F = 10.63) and September (F = 4.39).

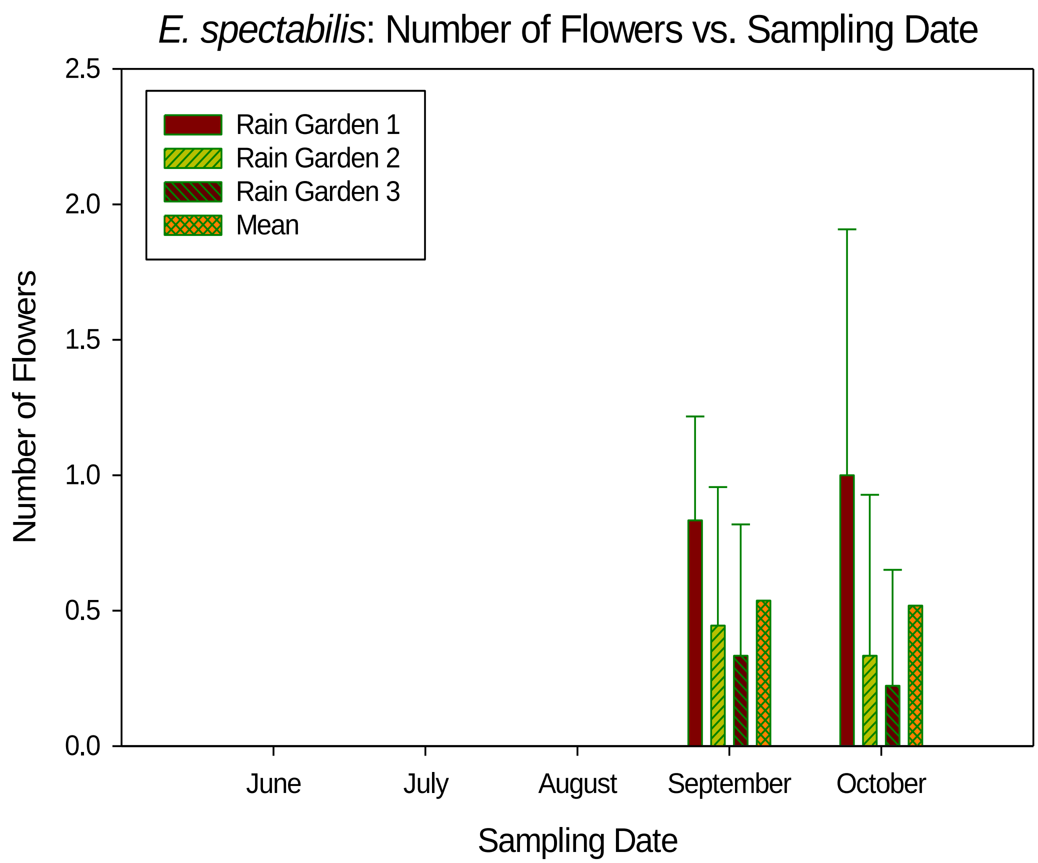

Figure 2.44: Arithmetic mean flowering (seed head) data for each month by rain garden for *Eragrostis spectabilis*. For both months, there is no statistically significant difference between Rain Gardens 2 and 3, but both are statistically difference, using Tukey's pair-wise comparison at alpha = 0.05, from Rain Garden 1 (F = 5.78 and 7.93, respectively).

Already in June, a month after planting, three plants appeared sickly and later died (Figure 2.45). Seed heads appeared in September on many of the plants. The plants were brown in October and two additional plants appeared sickly. The following May, most of the plants were still mostly brown and two additional plants had died. These were one of the sickly looking plants from late in the season that was in Rain Garden 2 and one from Rain Garden 3, where two of the three plants that had died the first season were also located. Overall, the suitability of this species is questionable. The plants mostly appear as flattened masses of grass, and compete poorly with other plants that seek to establish where they were planted.

Figure 2.45: Remnants of *Eragrostis spectabilis* in July.

Each species added a different aesthetic aspect to the rain garden. All the flowering plants attracted a variety of insects. *T. ohiensis* grew and bloomed early, providing the garden with early summer color of greens and purples. *E. purpurea* also bloomed early and the flowers lasted throughout most of the season. The white flowers of *E. perfoliatum* and *V. virginicum* contrasted in structure with *T. ohiensis* and with each other, providing for visual variety. Both plants species bloomed later in the season than *T.*

ohiensis, resulting in color throughout the summer. Both of the grass species, *S. nutans* and *E. spectabilis*, were green throughout the season and the latter had reddish-purple inflorescence stalks that added a pleasing look to this low-growing species.

Suggestions for other plants

Based on observations made in the rain gardens, both following heavy storms and between rain events, a list of suggested plants that may also perform well under these rain garden conditions are listed in Tables 2.4 and 2.5. Further research, similar to what was conducted for this thesis, is needed to provide precise recommendations. However, based on the observations made in the three rain gardens from this study and information published in the literature (mainly Shaw and Schmidt (2003), who give extensive details on the habitat, water and stress preferences of over 130 species native to the Midwest and The University of Texas at Austin (2007) that operates the Lady Bird Johnson Wildflower Center Native Plant Information Network), some additional suggestions for plant species that would be expected to perform well in a bi-phasic rain garden are made below.

Plant species were chosen that would be most likely to thrive under the relatively harsh conditions of the bi-phasic rain garden, which include: sandy, low nutrient soil, pulses of pollutants, period of both inundation and near drought (in the anaerobic zone), tolerance of unpredictable flooding frequency and duration, ornamental, provides cut flowers, green throughout the winter, or aesthetically interesting. Due to the construction and smaller size of this particular rain garden, trees were not considered. Additionally, only perennials were considered, because of their lower maintenance requirements.

Since most published rain garden information focuses on aerobic conditions and suggests plants for these conditions, the list offers more suggestions for the anaerobic zone. Table 2.7 presents a summary of plants suggested for the anaerobic zone. Though the *Amorpha fruiticose* shrub is resistant to mine spoils, drought, heat, cold, acidic or basic soils, it is sensitive to the herbicide 2,4-D and intolerant of shade (Shaw and Schmidt, 2003; The University of Texas at Austin, 2007). From June to August, purple spikes adorn the end of the branches and attract butterflies to this fast-growing plant (Shaw and Schmidt, 2003; The University of Texas at Austin, 2007). *Aster lanceolatus (simplex)* is one of the more common of the native asters and, although similar to other asters, the ray flowers are always white and 2 cm wide, which is smaller than most of the other species (Shaw and Schmidt, 2003). Mature plants will tolerate flooding duration and frequency better than many of the other asters, prefers wet to saturated conditions and will also tolerate mesic conditions (Shaw and Schmidt, 2003). The flowers of *Helenium autumnale* are similar in appearance to *E. purpurea* in that they have a central cone and dropping petals, both of these, however, are dark yellow in color and the petals have toothed edges (Shaw and Schmidt, 2003). This species also blooms later in the growing season, beginning in August and lasting through November and has a fibrous root system (Shaw and Schmidt, 2003). As with species of the *Aster* genus, there are a quite a few native in the *Juncus* genus. Three, *J. balticus, J. effuses* and *J. torreyi* have particularly desirable characteristics including a preference for wet to saturated sandy soils and a tolerance for flooding frequency, depth and duration (Shaw and Schmidt, 2003). Additionally, *J. effuses* is an evergreen plant and *J. torreyi* has a soil stabilizing rhizomatous root system (Shaw and Schmidt, 2003). Another evergreen plant, *Onoclea sensibilis* works well as ground cover in wet and saturated soils that do not dry out and are under partial sun or shade (Shaw and Schmidt, 2003). Consequently, the species can tolerate frequency and lengthy inundations of water, the latter especially in the spring (Shaw and Schmidt, 2003). *Scirpus pungens* is also tolerant of flood frequency, depth and duration, and prefers wet and saturated soils (Shaw and Schmidt, 2003). One highly desirable characteristic of this species is that it will remove metals quickly, which aids in the remediation of urban stormwater (Shaw and Schmidt, 2003). One of the tallest native grasses, *Spartina pectinata* is suitable for larger rain gardens where the rigid, upright grass can spread and form dense colonies (The University of Texas at Austin, 2007). This species also tolerates a high frequency of flooding, a moderate duration and depth, and prefers moist to saturated poor, sandy soils (Shaw and Schmidt, 2003). Both *H.autumnale* and *A. lanceolatus* produce flowers that are suitable as cut flowers and will attracts butterflies, as will *A. fruiticose* (Shaw and Schmidt, 2003).

Research from Bratieres et al. (2008) and Read et al. (2008), both Australian researchers, has indicated that the *Carex* spp. provided significant removal of NO_x and total nitrogen (TN) in biofiltration systems. Consideration to this species was given in the selection of species for Table 2.4, including *Carex bebbii, languinosa, retrorsa*, and *vulpinoidea* (commonly, bebb's, bottlebrush, wooly, retrossa and fox sedges, respectfully). Of these, only *C. bebbii* has a tolerance to the drier conditions observed in the anaerobic zone during the summer when rain was less frequent. The other three species have a preference for shallow water/saturated conditions and will tolerate mesic conditions (Shaw and Schmidt, 2003). Depending on the depth of the roots and how dry the summer is, these species may establish well enough in the spring to survive the summer and re-emerge in the autumn.

Scientific Name	Common Name	Characteristics
Amorpha fruiticose	Indigo Bush	Shrub, <0.3 m, full/partial sun, prefers sandy loam, wet to dry, high tolerance to spring floods, roots fix N
Aster lanceolatus (simplex)	Panicle aster	Perennial, 0.6-1.2 m, full/partial sun, moist to saturated soils, moderate tolerance to flooding
Helenuim autumnale	Sneezeweed	Perennial, 0.9-1.5 m, full/partial sun, moist to wet/saturated conditions, low ground of many soil types
Juncus balticus	Baltic Rush	Perennial, 0.3-0.6 m, full/partial sun, wet sandy and gravely soils, high tolerance to flooding
Juncus effuses	Soft/Common Rush	Perennial, 0.3-0.6 m, full/partial sun, tolerant of saturated soils and dryer conditions, evergreen plant
Juncus torreyi	Torrey Rush	Perennial, 0.9 m, full/partial sun, sandy and gravely soil, moderate tolerant to flooding
Onoclea sensibilis	Sensitive Fern	Perennial, 0.3-0.6 m, partial sun/shade, prefers saturated, soils, high tolerance to flooding, groundcover
Scirpus pungens	Three square Bulrush	Perennial, 0.9-1.5 m, full/partial sun, wet sand or gravel, removes metals quickly, high tolerance to flooding
Spartina pectinata	Prairie Cord Grass	Perennial, 1.5-2.1 m, full/partial sun, moist to saturated sandy and gravely soils, high tolerance to flooding

Table 2.4: Suggested plants for the anaerobic zone of a bi-phasic rain garden.

Suggestions for aerobic zone plants can be found in many readily available rain garden manuals (Coffman, 1999; Wisconsin Department of Natural Resources, 2003; Winogradoff, 2002, Prince George's County, 2007). Table 2.5 highlights a few plants species adapted to grow in oxygen-rich sandy soils. *Agastache foeniculum* is an aromatic member of the mint family with whorls of small, bright blue flowers that bloom from June through October (Shaw and Schmidt, 2003). Blooming in June and July with spikes of tiny, purple flowers, *Amorpha canescens* is a deciduous shrub that has a grayish appearance from the fine hairs that cover the leaves (The University of Texas at Austin, 2007). With preferred habitat of open prairies and a distinctive plant that has leaves reminiscent of the desert yucca, *Eryngium yuccifolium*, has 2-cm flowers are clustered into global heads, which are thistle-like in appearance and bloom from May through August (Shaw and Schmidt, 2003; The University of Texas at Austin, 2007). *Rudbeckia subtomentosa* has an appearance similar to *E. purpurea* with the central brown disk, but the long yellow petals do not droop downwards. The flowers bloom from July through September (Shaw and Schmidt, 2003).

Scientific Name	Common Name	Characteristics
Agastache foeniculum	Giant Hyssop	Perennial, 0.6-1.2 m, full/partial sun, mesic to dry loam soils, readily self-seeds
Amorpha canescens	Lead Plant	herbaceous perennial, 0.6-1.2 m, prefers well-drained, sandy soil, deep root
Eryngium yuccifolium	Rattlesnake Master	Perennial, 0.7-1 m, full/partial sun, wet to dry sandy soil in upland, fast grower, early successive plant
Rudbeckia subtomentosa	Brown-eyed Susan	Perennial, 0.6-0.9 m, full/partial sun, wet sands, will tolerate heavier soils, high tolerance to flooding

Table 2.5: Suggested plants for the aerobic zone of the bi-phasic rain garden.

CONCLUSIONS

This study provides an initial assessment of the viability of six native Ohio plant species in a field-scale bi-phasic rain garden system. Greater than 90% of the plants survived the winter between the first and second year, with the majority of this loss, 65%, resulting from the death of *V. virginicum* plants. Two species, *S. nutans* and *E. spectabilis* accounted for the other 35% of lost plants. Of the remaining three species, all the plants survived the winter. In the anaerobic zone, *E. purpurea* had a high survival rate, whereas *S. nutans* and *E. spectabilis* were slow to establish and had plants that died both in 2008 and over the winter.

Based on aesthetics and variety, each species contributed to the rain gardens. In the anaerobic zone, *E. perfoliatum* and *V. virginicum* bloomed for most of the summer, whereas *T. ohiensis* provided the rain gardens with early color. Each had a different growth habit, which provided variety and interest. In the aerobic section of the garden, *E.*

purpurea performed well both in length of flowering and growth. Both grass species, *S. nutans* and *E. spectabilis* were slow to establish, but did so with steady gains throughout the season. The plants that survived the winter came back taller and fuller the following year.

CHAPTER 3

REMOVAL OF HEAVY METAL POLLUTANTS (COPPER, CHROMIUM, LEAD AND ZINC) BY A BI-PHASIC RAIN GARDEN

INTRODUCTION

As people continue to migrate into urban areas, environmental concerns related to stormwater runoff from impervious areas have increased. Large areas devoted to roadways, parking lots, buildings and sidewalks create the need to manage the water that results from rain storms. Residential areas may consist of as little as 20% impervious surface, whereas commercial areas may have as much as 85% (Dietz and Clausen, 2005). Historically, diverting this water as quickly as possible to treatment plants by means of stormwater drains was an acceptable practice. With the increased awareness of water depletion, resulting in lower water tables, rivers that run dry and loss of habitat, this is no longer the case (Coffman, 1999).

Both point sources and non-point sources of water pollution occur. Point source pollution is often easier to mitigate because it comes from a specific, identified area such as an oil spill or discharge. Non-point source pollution, however, can originate anywhere within a watershed, and the specific source may be difficult to ascertain. As the water moves through the watershed, it picks up and carries away the pollutants present. In urban areas, impervious surfaces are a leading source of surface water pollution and can also contaminate groundwater (EPA, 2005). Over time, and depending on local land uses, certain pollutants can concentrate to unsafe levels.

In urban areas, a new development philosophy is emerging that includes low impact development. One goal is to reduce the developmental impact on the existing soils, vegetation and aquatic systems by preserving the pre-development hydrologic conditions as much as possible (Dietz, 2007). This is achieved primarily through a reduction in stormwater runoff by enhancing infiltration, evaporation and storage of rainwater to create a more functional hydrologic site (Coffman, 1999). Additional pollution prevention measures, such as those designed to increase the amount of time the stormwater spends in the landscape, are integrated into the site to protect the quality of the surface and groundwater and to reduce overall runoff.

From the low impact development philosophy, there are six main hydrologic best management practices that are commonly utilized, these are: (1) dry extended detention basins, (2) wet retention basins, (3) constructed wetlands, (4) infiltration trenches, (5) bioretention systems and (6) sand filtration (Weiss et al., 2007). The choice of which to use depends on the space available, volume of water to be treated, and existing conditions.

Rain gardens, as a relatively new best management practices approach to treat stormwater runoff, are specific types of bioretention systems that also provide an aesthetically pleasing landscape. At first glance, they appear as regular flower gardens.

However, they are specially designed to increase the water infiltration rate and to retain urban pollutants. The placement of rain gardens in well-drained depressions within the landscape enhances these functions. The main components, from the surface downward, generally include: a ponding area, a mulch layer, a soil layer, a gravel layer and, optionally, an under-drain (Winogradoff, 2002). The function of the wood mulch layer is to prevent erosion, protect the soil layer from drying and assist in the removal of heavy metals. A soil medium that is approximately 50-60% sand results in the desirable high infiltration rate. The other 40-50% is split between compost or other source of organic matter and silt or clay (Winogradoff, 2002).

Plants, often species native to the area where the rain gardens are located, promote evapotranspiration, biological activity, pollutant uptake and help maintain efficient infiltration (Davis, 2001). Trees and shrubs can be found in larger rain gardens along with the grasses and flowers common to smaller sites. There are a number of manuals that have been written to aid site planners as well as homeowners in the designing and implementing of rain gardens (Winogradoff, 2002; Coffman, 1999; Wisconsin Department of Natural Resources, 2003; EPA, 2009b).

Many recommendations related to rain garden construction and performance are based on a limited number of studies. The majority of the laboratory studies focused on the mitigation of N and P nutrients, although metal removal has also been studied. Greater than 92% reduction of Cu, Pb and Zn was achieved by laboratory rain gardens with either 61 or 91 cm of soil when synthetic stormwater runoff containing metal concentrations typical of the area was applied (Davis et al., 2001).

Field studies generally corroborate the laboratory studies and indicate high efficiency of heavy metal removal by rain gardens. Most of these field studies monitored pollutants present on-site and, as a result, there was high variation in the influent concentrations. In fact, the concentration of metals in the influent water samples was often below detection limits, as was the case for 64% of the samples collected by Dietz and Clausen (2006). Consequently, mass retentions were not calculated. Total input mass was also low for Hunt et al. (2008) and lower for Davis (2007) and, when influent concentrations of Cu and Zn were evaluated in terms of the EPA maximum contaminant levels (MCL) (EPA, 2009a), they were found to be well below the recommended limits and not in need of remediation. An earlier study (Mason et al., 1999) showed similarly low concentration of Cu, Pb and Zn in stormwater runoff from a roof in Switzerland. Studies using high levels, or worst case levels, of heavy metal pollutants are rarely conducted.

A novel bi-phasic rain garden has been designed to intercept stormwater and mitigate the pollutants found within the urban environment (Yang et al., 2009). Stormwater is directed first into the anaerobic (oxygen poor) zone, then into the aerobic (oxygen rich) zone and finally into the recharge zone underneath the system. The water in the anaerobic zone is separated from that in the aerobic zone. The retention time in the anaerobic zone can be controlled by the size of the zone and through designs whereby water overflows into the aerobic zone only when the water level in the anaerobic zone achieves a certain height. These designs help maintain a saturated, anaerobic condition, in this zone. When the overflow from the anaerobic zone enters the aerobic zone, this aerobic zone provides additional treatment to the stormwater through chemical and microbial processes complimentary to those in the anaerobic zone. Both zones are composed of specialized soil mixtures containing sand, topsoil and compost, and are designed to allow rapid infiltration of stormwater.

This study is part of a larger project to evaluate the remediation efficiency of a bi-phasic rain gardens for different types of pollutants. The design, construction and hydrological evaluation of these gardens have been published elsewhere (Yang et al., 2009). This particular study focuses on the effectiveness of field scale, bi-phasic rain gardens to remove heavy metal pollutants (i.e. Cu, Cr, Pb and Zn) at concentrations well in excess of the data collected in the National Stormwater Database (National Research Council, pg 158, 2008) over multiple rainfall events.

MATERIALS AND METHODS

Site Description

Construction of the novel, bi-phasic rain gardens began in the fall of 2007 and was completed the following spring at the Ohio Agricultural Research and Development Center/The Ohio State University (OARDC/OSU) in Wooster, Ohio (40°46’50”N, 81°55’38”W) (Yang et al., 2009). Each of the three rain gardens consisted of an inner anaerobic (oxygen poor) zone and outer aerobic (oxygen rich) zone (Figure 3.1). The soil medium was a commercial mixture of 60% sand, 20% compost and 20% topsoil (Kurtz Bros. Inc., Cleveland, Ohio). In May 2008, seedlings of six plant species native to Ohio were planted. *Eupatorium perfoliatum* (boneset), *Tradescantia ohiensis* (spiderwort) and

Veronicastrum virginicum (culvert's root) were chosen for the anaerobic zone and *Sorghastrum nutans* (Indian grass), *Echinacea purpurea* (purple coneflower) and *Eragrostis spectabilis* (purple lovegrass) were chosen for the aerobic zone. The findings associated with the suitability and performance of these plants in the bi-phasic rain gardens are reported in the previous chapter of this thesis. A layer of mulch, approximately 3 cm thick, was added to the surface the following month for both aesthetic reasons and because it aids in the remediation of stormwater (Dietz and Clausen, 2006).

Preliminary studies of the hydrological characteristics were conducted (Yang et al., 2009). In these studies, a 1-L volume of water containing Cu (as $CuSO_4$), Pb (as $PbCl_2$) and Zn (as $ZnCl_2$) was added to the pavement surface above one of the rain gardens. The other two replicate rain gardens did not receive any metal treatment. A total of 3,282 L of water from the Wooster, Ohio city water supply was then discharged onto the pavement of the treated rain garden to wash the metals into the rain garden. The hydrologic response of the rain garden was conducted along with analysis of the water samples collected at the outlet of the aerobic zone (Figure 3.1). The water samples were filtered through a 0.45 μm membrane and analyzed by ICP (inductively coupled plasma) emission spectrophotometry in the STAR (Standard Testing and Research) Laboratory of the OARDC/OSU, Wooster Campus (STAR Lab, 2008).

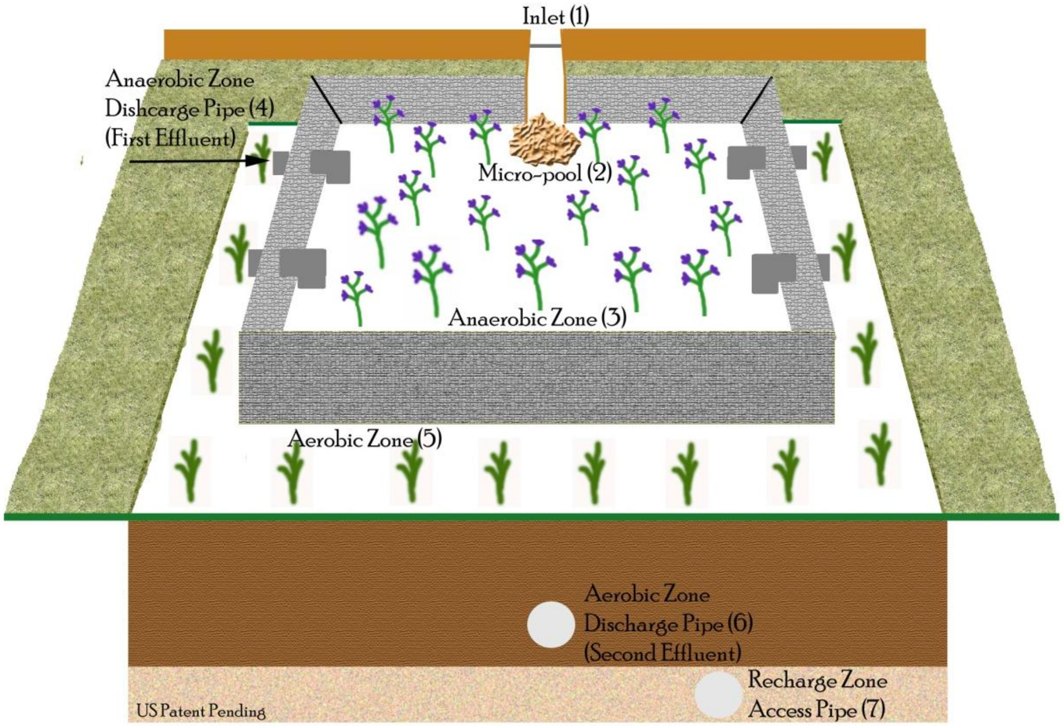

Figure 3.1: Design of the bi-phasic rain garden bioretention ecosystem. Water enters the system through the inlet (1) at the top of the figure, settles into the micro-pool (2) and fills the anaerobic zone (3). Excess water, first effluent (4), is drained from the anaerobic zone into the aerobic zone (5) using U-shaped reverse drainage pipes located at the bottom of the anaerobic zone. The water then drains by gravity into a pipe at the bottom of the aerobic zone and exits the system though the aerobic zone discharge pipe, second effluent (6). The water is returned to the environment through the recharge zone access pipe (7). The anaerobic zone is 2.6 m on each side and 1.0 m deep, whereas the aerobic zone is 0.45 m wide (from the anaerobic zone to the grass border), 3.36 m along the sides with the drainage pipes, 4.15 m along the other sides and 0.5 m deep.

Preparation of Chemicals and Experimental Setup

For this study, synthetic runoff was created containing the heavy metals Cu, Cr, Pb and Zn that are typically found in an urban environment (National Research Council, 2008, p. 158). The metals were prepared separately in 1-L of distilled water and stored at room temperature prior to use in the field. The salts for Cu, Pb and Zn used were the same as in the preliminary study; CrO_3 was used as the source of Cr. All reagents were acquired from Thermo-Fisher Scientific (Hanover Park, IL). The concentrations of the metals and the runoff volume applied at each rainfall are provided in Table 2.1. The metals were introduced into the rain garden inlet when the application of simulated rainfall began. The mass input for Cu, Cr, Pb and Zn was 8.8, 4.4, 4.4 and 17.6 g, respectively.

In order to simulate natural rainfall conditions, multiple 1-hour storm events were carried out over a 11-day period. The first two simulated storm events on days one and six were representative of a storm with a 1-year return frequency (28.4 mm/h) at Wooster, OH (NOAA, 2008). With each storm, heavy metal pollutants were introduced into the rain gardens as described above. Five days after the second simulated rainfall event, on Day 11 of the experiment, the rain gardens were flushed with a high volume of water (11,500 L) in order to evaluate removal efficiency. No heavy metals were added at this time.

Timeline	Simulated rainfall event	Total runoff volume	Influent metal concentrations			
			Cu	Cr	Pb	Zn
		L	mg L^{-1}			
Day 1	1.27 cm hr^{-1}	880	10.0	5.0	5.0	20.0
Day 6	1.27 cm hr^{-1}	880	10.0	5.0	5.0	20.0
Day 11	10.0 cm 24 hrs^{-1}	11,500	-[a]	-	-	-

[a] No metals were applied on Day 11. The amount of rainfall is designed to flush the rain garden.

Table 3.1: Composition of the simulated stormwater runoff. Each metal was dissolved in 1-L of distilled water and applied on the concrete patch just outside the inlet during the first few minutes of the simulated rain event.

Sampling

Water samples were collected during the Day 11 simulated rainfall event only. The reason for this is because the first two simulated rainfall events were designed to match the containment volume of the inner, anaerobic zone and there was not sufficient runoff to generate samples.

All sampling bottles were soaked in a 10% hydrochloric acid solution overnight, rinsed with distilled water the next day and allowed to air-dry while being inverted. Water samples were collected at 1) the interface between the anaerobic and aerobic zone (hereafter called first effluent) and 2) at the final discharge of the aerobic zone (hereafter called second effluent) throughout the 24-hour rainfall period on Day 11 (see Figure 3.1 for sample locations). The water samples were stored at $4^{o}C$ prior to ICP emission spectrophotometry analysis, after filtering at the STAR Laboratory (STAR Laboratory, 2008) and measured for concentrations of Cu, Cr, Pb and Zn.

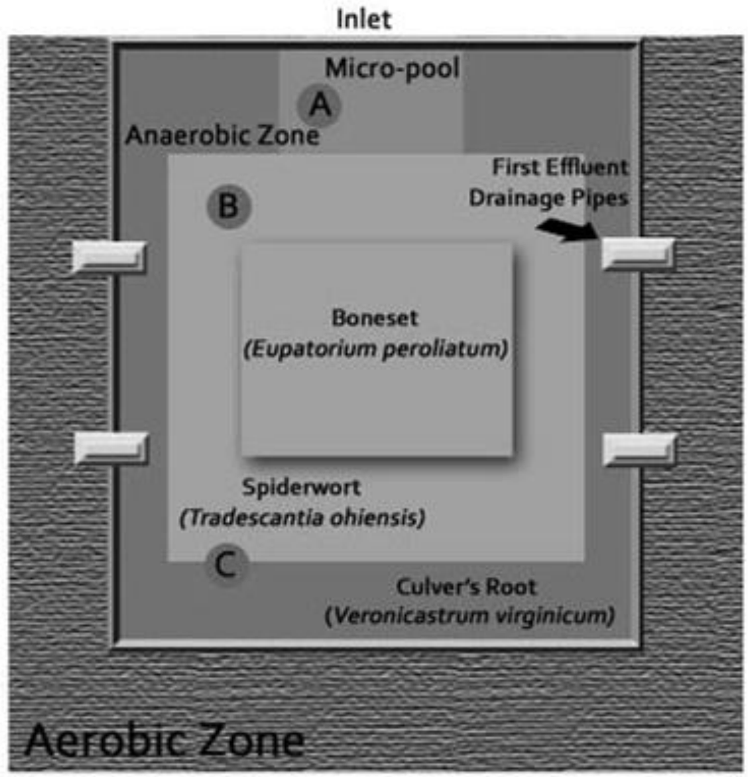

Figure 3.2: Anaerobic zone illustrating the soil sampling points (A, B and C) for each rain garden. One soil core was taken at each site and split into two segments by depth, one from 0 to 7.5 cm and the other from 7.5 to 15 cm.

In June of 2008, after the gardens had established for two months, soil samples were taken to determine initial characteristics. Three locations in the anaerobic zone of each garden were sampled to a depth of 15 cm and combined into one sample for each garden. Soil samples were also collected after the third rain storm event to determine where, in the rain garden, the heavy metals had adsorbed to the soil particles. In each garden, three sites in the anaerobic zone were sampled (Figure 3.2). Only the anaerobic zone was sampled because the volume of water input on days 1 and 6 matched the pore volume of the anaerobic zone and, thus, water did not overflow into the aerobic zone until Day 11. For the soil sample collected from the micro-pool site, the rocks were first removed. At the location of the other two sample sites, the soil was collected from the surface soil layer under the mulch. The single soil core collected at each location was split into two depths, a 0 to 7.5 cm and a 7.5 to 15 cm segment. The soil samples were air-dried and passed through a 2-mm sieve to remove plant fragments or stones. They were then analyzed by ICP microwave digestion (EPA 3051 method) at the STAR Laboratory (STAR Laboratory, 2008).

RESULTS AND DISCUSSION

Heavy Metals in Water

The heavy metal concentrations in the first and second effluent water samples of each of the three rain gardens are given in Table 3.2 and 3.3, respectively. Based on concentration, greater than 97% of the Cu, Cr, Pb and Zn was removed between the influent and the first effluent. From the influent to the second effluent, the removal efficiency is greater than 99%. All concentrations of Cu, Cr and Pb in the effluent fell below the EPA’s MCL regulation standards. Only eight water samples, out of 25 total, collected during the first and second effluents, exceeded the Zn limit defined by the National Secondary Drinking Water Regulations (EPA, 2006). All eight occurred in Rain Garden 3, which is the garden to which the heavy metals were applied in the preliminary study by Yang et al. (2009). In this study, all the metals applied were retained within the bi-phasic system.

A weighted mean was calculated to account for the difference in flow for each rain garden. A flow-weighted mean concentration (FWMC), in which the concentration is weighted by both the time and flow rate associated with the sample was chosen because it takes the perspective of the downstream waters (Heidelberg College WQL, 2005). Additional advantages of using a FWMC over either a time-weighed mean concentration or straight mean are that the data can be reduced into a single meaningful value for the entire storm event, the bias associated with volume is removed and comparisons can be more easily made (Agouridis and Edwards, 2003).

The following sample calculations for FWMC use the Cu concentration from Rain Garden 1 in Table 2.2 and the equation:

$$FWMC = \frac{{}_{1}^{n}\Sigma\,(c_i * t_i * q_i)}{{}_{1}^{n}\Sigma\,(t_i * q_i)} \quad \text{where } c_i = \text{ concentration of } i^{th} \text{ sample}, t_i = \text{ time window for } i^{th} \text{ sample}, q_i = \text{ flow for the } i^{th} \text{ sample}$$

The concentration values are given in Table 2.2 and time intervals easily calculated from the data there. The flow rate data are in Appendix C. Arranging the data based on the above equations:

[Cu]	time	flow rate	c*t*i	t*q
mg L^{-1}	min	L min^{-1}	mg	L
0.277	15	1.884	7.83	28.3
0.1420	30	6.360	27.1	191
0.0655	30	7.440	14.6	223
0.0208	120	11.760	29.4	1411
0.0144	120	13.260	22.9	1591
		summation	101.8	3445

And inserting into the above equation: Σ (c*t*i) / Σ (t*q) = 0.0304 mg L^{-1} Cu

Replicate	Time from initial rainfall event [a]	Flow rate	Concentration of metals			
			Cu	Cr	Pb	Zn
	min	L min^{-1}	mg L^{-1}			
Rain Garden 1	15	1.88	0.2770	0.0343	0.0092	0.2405
	45	6.36	0.1420	0.0160	0.0000	0.1908
	75	7.44	0.0655	0.0108	0.0000	0.1287
	195	11.8	0.0208	0.0076	0.0000	0.0757
	315	13.3	0.0144	0.0075	0.0000	0.0487
	weighted mean [b]		0.0304	$8.45e^{-3}$	$7.55e^{-5}$	0.0744
Rain Garden 2	20	0.480	0.0068	0.0069	0.0000	0.0274
	50	2.22	0.0296	0.0064	0.0000	0.0780
	80	2.88	0.0167	0.0054	0.0000	0.0236
	140	3.78	0.0107	0.0054	0.0000	0.0171
	weighted mean		0.0152	$5.61e^{-3}$	--- [c]	0.0292
Rain Garden 3	25	1.32	0.0639	0.0000	0.0063	17.68*
	55	3.42	0.0578	0.0000	0.0099	73.25*
	85	4.62	0.0560	0.0000	0.0115	85.42*
	145	6.36	0.0618	0.0000	0.0129	58.38*
	weighted mean		0.0601	--- [c]	0.0118	64.36

[a] The differences in collection times are a result of water moving through the anaerobic zone at different rates for each garden, relative to the start of applying the simulated rain. Once the water began to drain from the first effluent, collections were made at the same time intervals in each rain garden.

[b] Flow-weighted mean concentration (mg L^{-1}) calculated based on flow rate of water.

$$FWMC = \frac{\sum_1^n (c_i * t_i * q_i)}{\sum_1^n (t_i * q_i)}$$ where c_i = concentration of i^{th} sample, t_i = time window for i^{th} sample, q_i = flow for the i^{th} sample

See Heidelberg College WQL, 2005.

[c] The effluent concentrations were below the ICP detection limit (0.0013 mg L^{-1} for Pb and 0.005 mg L^{-1} for Cr), therefore a weighted mean cannot be calculate.

Table 3.2: Concentration of Cu, Cr, Pb and Zn from water collected from the anaerobic zone discharge pipe (first effluent). The Zn values marked with an asterisk (*) are in excess of the EPA's National Secondary Drinking Water Regulations, which are not legally enforceable but rather relate to aesthetic or cosmetic characteristics of the water. The EPA limit for zinc is 5.0 mg L^{-1}.

Replicate	Time from initial rainfall event [a]	Volume per sampling period	Concentration of metals			
			Cu	Cr	Pb	Zn
	min	L	µg L $^{-1}$			
Rain Garden 1	35	2.9	4.90	4.80	0.00	6.40
	65	64.4	3.60	4.40	0.00	4.80
	95	166.7	2.90	3.40	0.00	5.80
	155	257.4	0.00	3.80	0.00	3.90
	weighted mean [b]		0.844	3.64	--- [c]	4.42
Rain Garden 2	85	N/A[d]	8.00	3.50	0.00	17.8
	145	N/A	3.40	3.50	0.00	10.4
	205	N/A	2.00	3.80	0.00	4.70
	325	N/A	0.00	3.30	0.00	0.00
	weighted mean		--- [e]	--- [e]	--- [e]	--- [e]
Rain Garden 3	65	3.98	25.4	0.00	4.80	$11.4e^3$*
	95	57.7	26.5	0.00	4.30	$28.2e^3$*
	125	102.5	27.2	0.00	4.50	$31.5e^3$*
	185	152.2	29.0	0.00	3.60	$30.3e^3$*
	weighted mean		9.36	--- [c]	1.41	$9.39e^3$

[a] As with the first effluent, water moved through the systems at different times relative to the initial rainfall, but were collected at the same time intervals once water began to flow from the second effluent.
[b] Flow-weighted mean concentration (mg L^{-1}) calculated based on flow rate of water.

$$FWMC = \frac{\sum_1^n (c_i * t_i * q_i)}{\sum_1^n (t_i * q_i)}$$ where c_i = concentration of i^{th} sample, t_i = time window for i^{th} sample, q_i = flow for the i^{th} sample

See Heidelberg College WQL, 2005.
[c] The effluent concentrations were below the ICP detection limit (0.0013 mg L^{-1} for Pb and 0.005 mg L^{-1} for Cr), therefore a weighted mean cannot be calculate.
[d] Due to a leaking problem in the aerobic zone of rain garden two, accurate volume data are not available.
[e] Without flow data, FWMC cannot be calculated.

Table 3.3: Concentration of Cu, Cr, Pb and Zn from water collected from the anaerobic zone discharge pipe (second effluent). The Zn values marked with an asterisk (*) are in excess of the EPA's National Secondary Drinking Water Regulations, which are not legally enforceable but rather relate to aesthetic characteristics of the water. The EPA limit for zinc is 5.0 mg L^{-1}.

A mass balance analysis, in contrast to comparisons of metal concentrations, revealed that removal of heavy metals was greater than 99.9% for both Rain Garden 1 and 3, with the exception of Zn in Rain Garden 3, where there was a 72% removal. This lower removal number is possibly due to the previous treatment of Zn on this rain garden. Since the flow data from the first effluent of Rain Garden 2 are similar to that of Rain Gardens 1 and 3, and the concentration values are similar to those obtained for Rain Garden 1, it can be extrapolated that the overall heavy metal removal percentages are similar to those of Rain Garden 1. Values for Pb were below detection limits (0.0013 mg L^{-1}) in Rain Garden 1 and 2, and below the detection limit (0.002 mg L^{-1}) for Cr in Rain Garden 3.

Heavy Metals in Soils

Following the completion of the above remediation experiment, soil samples were again taken. Again, three samples from the anaerobic zone of each rain garden were collected. This time, however, samples were separated by location and by depth (0 to 7.5 cm and 7.5 to 15 cm). The resulting values are in Table 3.4.

ANOVA showed that there was no evidence for significant difference (at alpha = 0.05) between the rain gardens (replicate effect), the location within the rain garden or depth (Table 3.5). Since there are no data to suggest effects from these parameters, the post-experiment data were combined (arithmetic mean) into a single number for each metal in each rain garden (Table 3.6). The only evidence for statistical differences between the pre- and post-experimental total soil concentrations values was with Zn, Table 3.7.

Replication	Location [a]	Depth	Metal concentration			
			Cu	Cr	Pb	Zn
		cm	mg kg^{-1}			
Rain Garden 1	A	0-7.5	6.97	5.51	9.26	58.4
	A	7.5-15	9.20	4.60	6.18	47.5
	B	0-7.5	10.7	5.55	8.95	121
	B	7.5-15	6.10	5.07	5.70	38.9
	C	0-7.5	41.5	9.69	10.0	112
	C	7.5-15	38.2	7.22	11.1	92.0
Rain Garden 2	A	0-7.5	16.2	7.93	23.2	62.2
	A	7.5-15	7.41	6.26	7.51	46.0
	B	0-7.5	14.8	8.16	7.25	52.7
	B	7.5-15	7.61	8.97	8.01	38.7
	C	0-7.5	6.28	6.18	7.65	42.5
	C	7.5-15	10.4	9.11	9.17	53.1
Rain Garden 3	A	0-7.5	267	7.59	38.8	477
	A	7.5-15	17.4	6.93	7.63	367
	B	0-7.5	13.2	8.08	16.3	73.7
	B	7.5-15	7.35	7.76	8.34	50.4
	C	0-7.5	17.0	6.30	12.7	86.1
	C	7.5-15	10.0	7.79	6.95	57.9

[a] See Figure 2.2 to identify location for where soil samples were collected.

Table 3.4: Heavy metal data for soil post-treatment. ANOVA revealed no statistically significant differences (alpha = 0.05) between rain gardens (replication effect), locations within a rain garden, depth at these locations or an interaction between location and depth for Cu, Cr or Zn. There was a statistically significant effect due to depth with Pb, but not with any of the other above parameters. See Table 2.5 for ANOVA values.

Heavy Metal	Effect	Degrees of freedom	Sums of squares	Mean squared	f-ratio	p-value
Cu	Rain Garden	2	6821	3411	0.93	0.417
	Location [a]	2	6333	3167	0.85	0.451
	Depth [a]	1	4342	4342	1.17	0.301
	Location*Depth	2	6620	3310	0.89	0.436
Cr	Rain Garden	2	7.317	3.658	1.93	0.179
	Location	2	4.761	2.380	1.00	0.396
	Depth	2	0.090	0.090	0.04	0.849
	Location*Depth	2	2.304	1.152	0.48	0.628
Pb	Rain Garden	2	137.95	68.97	1.08	0.366
	Location	2	149.57	74.79	1.75	0.215
	Depth	1	225.30	225.30	5.28	0.040*
	Location*Depth	2	212.66	106.33	2.49	0.124
Zn	Rain Garden	2	61715	30858	2.55	0.111
	Location	2	47143	23572	1.49	0.265
	Depth	1	4818	4818	0.30	0.592
	Location*Depth	2	929	465	0.03	0.971

[a] See Figure 2.3 for specific details.

Table 3.5: ANOVA values for heavy metal for the post-treatment analysis. At alpha = 0.05, the only statistically significant difference was with Pb with depth (value marked with an asterisk).

Replicate	Sample time [a]	Total metal concentration [b]			
		Cu	Cr	Pb	Zn
		mg kg^{-1}			
Rain Garden 1	Initial	9.26	6.01	7.59	41.8
	Final	18.8	6.28	8.55	78.5
Rain Garden 2	Initial	12.2	6.60	11.8	53.1
	Final	10.5	7.78	10.5	49.2
Rain Garden 3	Initial	16.5	6.16	8.06	49.3
	Final	55.3	7.41	15.1	185

[a] Initial samples were collected in May and final samples in October. See Figure 2.2 for locations.
[b] Final values are arithmetic means calculated for each rain garden from the data in Table 2.5.

Table 3.6: Comparison of initial and final heavy metal concentrations in the soil. There were no statistically significant differences at alpha = 0.05. See Table 3.4 for ANOVA values.

Heavy Metal	Degrees of freedom	Sums of squares	Mean squared	f-ratio	p-value
Cu	1	361.6	361.6	1.24	0.327
Cr	1	1.1957	1.195	3.40	0.139
Pb	1	7.298	7.298	0.86	0.407
Zn	1	3190.0	3190	1.83	0.247

Table 3.7: ANOVA values comparing pre- and post-treatment soil samples.

CONCLUSIONS

This study provides an initial look at the removal of heavy metal pollutants by a field scale bi-phasic rain garden over multiple-rainfall events. Greater than 97% (based on concentration) and 99% (based on mass) of the Cu, Cr, and Pb that was introduced into the rain gardens was removed before the water left the rain gardens. Each of the water samples would have passed the EPA's MCL standards. Only eight out of 25 of the samples exceeded the National Secondary Drinking Water Regulations for Zn, where the removal was 72% for Rain Garden 3 and >99% for Rain Gardens 1 and 2.

Soil samples showed a non-significant change in the concentration of heavy metals in the area where stormwater runoff entered the rain gardens. In the post-treatment data, there was a statistically significant difference with Pb due to depth, but not due to rain gardens (replication effect), locations within a rain garden or an interaction between location and depth. Copper, Cr and Zn had no statistically significant differences for any of the above parameters.

Overall, the bi-phasic rain gardens performed well with a high load of heavy metal pollutants. The second effluent water samples, i.e. the water that exited the main part of the rain garden and entered the recharge zone, were within the drinking water regulations for the heavy metals. The soil showed a non-significant difference between the initial and post-experiment values. Both results indicate potential long-term efficacy of the bi-phasic rain garden as a stormwater remediation option.

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APPENDIX A: 2008: Height, width and flowering data for plant species

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
16-Jun	1	1	73.1	37.5	0	2	1	68.0	17.5	0	3	1	65.5	35.0	0
16-Jun	1	2	63.0	25.0	0	2	2	58.0	25.0	0	3	2	60.5	30.0	0
16-Jun	1	3	58.0	32.5	0	2	3	65.5	27.5	0	3	3	45.4	15.0	0
16-Jun	1	4	68.0	30.0	0	2	4	47.9	22.5	0	3	4	65.5	32.5	0
16-Jun	1	5	58.0	25.0	0	2	5	63.0	25.0	0	3	5	73.1	32.5	0
16-Jun	1	6	68.0	37.5	0	2	6	65.5	27.5	0	3	6	32.8	12.5	0
16-Jun	1	7	52.9	22.5	0	2	7	55.4	22.5	0	3	7	60.5	22.5	0
16-Jun	1	8	68.0	22.5	0	2	8	58.0	27.5	0	3	8	70.6	27.5	0

Table A.1 continued

Table A.1: Height, width and flowering data for *Eupatorium perfoliatum* (Boneset). The dates are all for 2008, ‘RG’ stands for rain garden, and ‘#fls’ for number of flowers. Each ‘Plant’ number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table A.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	93.2	35.0	13	2	1	85.7	20.0	22	3	1	78.1	30.0	18
10-Jul	1	2	80.6	27.5	3	2	2	68.0	22.5	7	3	2	73.1	22.5	18
10-Jul	1	3	88.2	32.5	34	2	3	80.6	25.0	13	3	3	52.9	15.0	2
10-Jul	1	4	79.4	30.0	10	2	4	63.0	20.0	5	3	4	85.7	35.0	21
10-Jul	1	5	68.0	25.0	8	2	5	83.2	25.0	6	3	5	88.2	32.5	17
10-Jul	1	6	79.4	35.0	33	2	6	85.7	30.0	8	3	6	55.4	15.0	1
10-Jul	1	7	70.6	20.0	5	2	7	63.0	20.0	5	3	7	75.6	30.0	17
10-Jul	1	8	78.1	25.0	14	2	8	70.6	25.0	7	3	8	90.7	27.5	65

Table A.1 continued

Table A.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
5-Aug	1	1	103	32.5	247	2	1	90.7	22.5	48	3	1	90.7	30.0	149
5-Aug	1	2	98.3	22.5	71	2	2	75.6	25.0	67	3	2	88.2	25.0	93
5-Aug	1	3	95.8	35.0	81	2	3	90.7	27.5	93	3	3	68.0	17.5	45
5-Aug	1	4	90.7	27.5	44	2	4	73.1	20.0	38	3	4	95.8	27.5	109
5-Aug	1	5	78.1	25.0	43	2	5	95.8	25.0	52	3	5	93.2	32.5	88
5-Aug	1	6	90.7	35.0	146	2	6	101	27.5	103	3	6	70.6	17.5	12
5-Aug	1	7	85.7	20.0	39	2	7	78.1	25.0	53	3	7	88.2	22.5	99
5-Aug	1	8	85.7	17.5	106	2	8	90.7	27.5	67	3	8	106	37.5	277

Table A.1 continued

Table A.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
17-Sep	1	1	103	30.0	0	2	1	90.7	20.0	0	3	1	93.2	25.0	0
17-Sep	1	2	101	22.5	0	2	2	78.1	25.0	0	3	2	88.2	27.5	0
17-Sep	1	3	98.3	20.0	0	2	3	95.8	25.0	0	3	3	68.0	17.5	0
17-Sep	1	4	90.7	32.5	0	2	4	78.1	20.0	0	3	4	95.8	25.0	0
17-Sep	1	5	78.1	30.0	0	2	5	101	20.0	0	3	5	95.8	30.0	0
17-Sep	1	6	88.2	32.5	0	2	6	101	25.0	0	3	6	73.1	17.5	0
17-Sep	1	7	83.2	27.5	0	2	7	80.6	22.5	0	3	7	83.2	20.0	0
17-Sep	1	8	88.2	20.0	0	2	8	88.2	27.5	0	3	8	108	37.5	0

Table A.1 continued

Table A.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
23-Oct	1	1	106	25.0	0	2	1	90.7	20.0	0	3	1	95.8	30.0	0
23-Oct	1	2	101	22.5	0	2	2	73.1	22.5	0	3	2	90.7	25.0	0
23-Oct	1	3	103	22.5	0	2	3	95.8	27.5	0	3	3	70.6	17.5	0
23-Oct	1	4	90.7	25.0	0	2	4	78.1	20.0	0	3	4	95.8	25.0	0
23-Oct	1	5	78.1	22.5	0	2	5	98.3	22.5	0	3	5	95.8	22.5	0
23-Oct	1	6	90.7	22.5	0	2	6	103	22.5	0	3	6	75.6	15.0	0
23-Oct	1	7	85.7	17.5	0	2	7	78.1	20.0	0	3	7	83.2	25.0	0
23-Oct	1	8	88.2	20.0	0	2	8	88.2	27.5	0	3	8	106	35.0	0

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
16-Jun	1	1	52.9	25.0	20	2	1	68.0	22.5	10	3	1	60.5	12.5	6
16-Jun	1	2	55.4	15.0	10	2	2	57.9	27.5	9	3	2	70.6	15.0	8
16-Jun	1	3	83.2	25.0	14	2	3	65.5	15.0	9	3	3	68.0	12.5	6
16-Jun	1	4	65.5	17.5	9	2	4	63.0	30.0	20	3	4	52.9	12.5	6
16-Jun	1	5	63.0	32.5	13	2	5	45.4	17.5	6	3	5	55.4	20.0	8
16-Jun	1	6	70.6	30.0	20	2	6	68.0	25.0	15	3	6	63.0	22.5	10
16-Jun	1	7	63.0	25.0	16	2	7	57.9	25.0	9	3	7	52.9	17.5	4
16-Jun	1	8	50.4	20.0	2	2	8	55.4	17.5	7	3	8	52.9	15.0	7
16-Jun	1	9	55.4	25.0	8	2	9	63.0	22.5	19	3	9	57.9	17.5	13
16-Jun	1	10	73.1	22.5	8	2	10	52.9	15.0	2	3	10	63.0	17.5	21
16-Jun	1	11	35.3	17.5	4	2	11	70.6	17.5	10	3	11	47.9	15.0	6
16-Jun	1	12	65.6	20.0	7	2	12	70.6	25.0	19	3	12	57.9	17.5	12
16-Jun	1	13	75.6	35.0	26	2	13	57.9	32.5	21	3	13	65.5	22.5	23
16-Jun	1	14	78.1	27.5	12										

Table A.2 continued

Table A.2: Height, width and flowering data for *Tradescantia ohiensis* (Spiderwort). The dates are all for 2008, ‘RG’ stands for rain garden, and ‘#fls’ for number of flowers. Each ‘Plant’ number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month. Data from September and October are not shown because all the values are zero.

Table A.2 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	55.4	30.0	0	2	1	68.0	17.5	1	3	1	70.6	12.5	0
10-Jul	1	2	63.0	20.0	0	2	2	68.0	20.0	0	3	2	60.5	12.5	0
10-Jul	1	3	75.6	17.5	0	2	3	50.4	10.0	0	3	3	68.0	15.0	0
10-Jul	1	4	68.0	12.5	0	2	4	68.0	22.5	0	3	4	45.4	12.5	0
10-Jul	1	5	70.6	30.0	0	2	5	60.5	15.0	2	3	5	50.4	20.0	0
10-Jul	1	6	63.0	17.5	0	2	6	73.1	15.0	0	3	6	63.0	12.5	0
10-Jul	1	7	57.9	15.0	3	2	7	60.5	15.0	0	3	7	35.3	15.0	0
10-Jul	1	8	55.4	20.0	0	2	8	45.4	12.5	1	3	8	50.4	10.0	0
10-Jul	1	9	47.9	7.50	0	2	9	65.5	15.0	0	3	9	68.0	17.5	0
10-Jul	1	10	52.9	15.0	1	2	10	68.0	15.0	6	3	10	60.5	15.0	0
10-Jul	1	11	65.5	15.0	0	2	11	70.6	15.0	0	3	11	55.4	20.0	0
10-Jul	1	12	65.5	12.5	0	2	12	63.0	15.0	0	3	12	73.1	17.5	0
10-Jul	1	13	68.0	17.5	0	2	13	55.4	17.5	0	3	13	52.9	20.0	0
10-Jul	1	14	70.6	25.0	0										

Table A.2 continued

Table A.2 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
5-Aug	1	1	22.7	15.0	0	2	1	32.8	15.0	0	3	1	32.8	7.50	0
5-Aug	1	2	50.4	12.5	0	2	2	30.2	15.0	0	3	2	60.5	7.50	0
5-Aug	1	3	45.4	17.5	0	2	3	17.6	12.5	0	3	3	20.2	7.50	0
5-Aug	1	4	45.4	12.5	0	2	4	55.4	17.5	0	3	4	30.2	10.0	0
5-Aug	1	5	37.8	15.0	0	2	5	37.8	10.0	0	3	5	22.7	12.5	0
5-Aug	1	6	25.2	12.5	0	2	6	40.3	12.5	0	3	6	45.4	17.5	0
5-Aug	1	7	37.8	17.5	0	2	7	20.2	12.5	0	3	7	40.3	12.5	0
5-Aug	1	8	7.56	7.5.0	0	2	8	27.7	7.50	0	3	8	35.3	10.0	0
5-Aug	1	9	35.3	15.0	0	2	9	30.2	17.5	0	3	9	47.9	10.0	0
5-Aug	1	10	57.9	12.5	0	2	10	50.4	15.0	0	3	10	22.7	17.5	0
5-Aug	1	11	22.7	12.5	0	2	11	25.2	10.0	0	3	11	42.8	15.0	0
5-Aug	1	12	42.8	10.0	0	2	12	37.8	12.5	0	3	12	30.2	12.5	0
5-Aug	1	13	52.9	15.0	0	2	13	25.2	17.5	0	3	13	42.8	15.0	0
5-Aug	1	14	50.4	22.5	0										

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
16-Jun	1	1	52.9	22.5	0	2	1	52.9	17.5	0	3	1	57.9	15.0	0
16-Jun	1	2	42.8	118	0	2	2	63.0	20.0	0	3	2	50.4	17.5	0
16-Jun	1	3	57.9	30.0	0	2	3	73.1	15.0	0	3	3	55.4	22.5	0
16-Jun	1	4	57.9	22.5	0	2	4	63.0	20.0	0	3	4	52.9	20.0	0
16-Jun	1	5	52.9	25.0	0	2	5	57.9	15.0	0	3	5	50.4	17.5	0
16-Jun	1	6	52.9	20.0	0	2	6	55.4	17.5	0	3	6	45.4	20.0	0
16-Jun	1	7	47.9	22.5	0	2	7	57.9	15.0	0	3	7	52.9	12.5	0
16-Jun	1	8	50.4	27.5	0	2	8	63.0	20.0	0	3	8	57.9	12.5	0
16-Jun	1	9	65.5	17.5	0	2	9	40.3	12.5	0	3	9	57.9	15.0	0
16-Jun	1	10	52.9	25.0	0	2	10	68.0	22.5	0	3	10	70.5	12.5	0
16-Jun	1	11	52.9	20.0	0	2	11	40.3	12.5	0	3	11	57.9	20.0	0
16-Jun	1	12	52.92	17.5	0	2	12	57.9	17.5	0	3	12	60.5	12.5	0
16-Jun	1	13	45.4	17.5	0	2	13	40.3	15.0	0	3	13	52.9	17.5	0
16-Jun	1	14	63.0	25.0	0	2	14	52.9	15.0	0	3	14	37.8	12.5	0
16-Jun	1	15	60.5	25.0	0	2	15	57.9	20.0	0	3	15	50.4	15.0	0
16-Jun	1	16	63.0	22.5	0	2	16	55.4	22.5	0	3	16	47.9	12.5	0
16-Jun	1	17	65.5	25.0	0	2	17	50.4	20.0	0	3	17	63.0	12.5	0
16-Jun	1	18	55.4	27.5	0	2	18	52.9	22.5	0	3	18	83.2	15.0	0
16-Jun	1	19	68.0	22.5	0	2	19	63.0	25.0	0	3	19	57.9	15.0	0
16-Jun	1	20	68.0	30.0	0						3	20	63.0	15.0	0

Table A.3 continued

Table A.3: Height, width and flowering data for *Veronicastrum virginicum* (Culver's Root). The dates are all for 2008, 'RG' stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table A.3 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jul	1	1	68.0	25.0	2	2	1	70.6	15.0	9	3	1	68.0	17.5	2
10-Jul	1	2	40.3	15.0	0	2	2	83.2	15.0	15	3	2	55.4	20.0	1
10-Jul	1	3	83.2	25.0	4	2	3	80.64	12.5	3	3	3	60.5	25.0	2
10-Jul	1	4	75.6	20.0	4	2	4	73.1	25.0	2	3	4	63.0	22.5	3
10-Jul	1	5	78.1	27.5	13	2	5	73.1	22.5	1	3	5	65.5	15.0	3
10-Jul	1	6	65.5	25.0	4	2	6	57.9	17.5	0	3	6	63.0	27.5	3
10-Jul	1	7	55.4	20.0	1	2	7	68.0	22.5	1	3	7	55.4	12.5	1
10-Jul	1	8	55.4	20.0	2	2	8	68.0	22.5	7	3	8	80.6	22.5	21
10-Jul	1	9	78.1	22.5	3	2	9	42.8	15.0	0	3	9	57.9	12.5	1
10-Jul	1	10	50.4	17.5	2	2	10	78.1	25.0	6	3	10	90.7	17.5	10
10-Jul	1	11	68.0	20.0	3	2	11	42.8	12.5	0	3	11	78.1	30.0	8
10-Jul	1	12	57.9	17.5	2	2	12	63	20.0	2	3	12	75.6	15.0	8
10-Jul	1	13	42.8	17.5	0	2	13	42.8	15.0	0	3	13	68.0	17.5	4
10-Jul	1	14	57.9	20.0	1	2	14	50.4	20.0	0	3	14	52.9	12.5	13
10-Jul	1	15	68.0	30.0	2	2	15	80.6	22.5	22	3	15	60.5	20.0	2
10-Jul	1	16	78.1	25.0	10	2	16	50.4	25.0	2	3	16	60.5	15.0	2
10-Jul	1	17	90.7	17.5	2	2	17	50.4	22.5	3	3	17	90.7	15.0	4
10-Jul	1	18	70.6	22.5	4	2	18	65.5	25.0	1	3	18	101	17.5	11
10-Jul	1	19	93.4	22.5	6	2	19	73.1	22.5	2	3	19	70.6	17.5	5
10-Jul	1	20	98.3	22.5	10						3	20	83.2	15.0	9

Table A.3 continued

Table A.3 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
5-Aug	1	1	80.6	17.5	5	2	1	88.2	10.0	9	3	1	88.2	25.0	10
5-Aug	1	2	40.3	17.5	1	2	2	95.8	20.0	16	3	2	70.6	20.0	3
5-Aug	1	3	101	20.0	8	2	3	83.2	12.5	0	3	3	83.2	25.0	3
5-Aug	1	4	80.6	20.0	8	2	4	78.1	22.5	4	3	4	75.6	17.5	4
5-Aug	1	5	85.7	22.5	14	2	5	78.1	20.0	2	3	5	80.6	20.0	3
5-Aug	1	6	75.6	22.5	6	2	6	57.9	15.0	0	3	6	75.6	17.5	9
5-Aug	1	7	57.9	17.5	1	2	7	75.6	17.5	3	3	7	52.9	12.5	0
5-Aug	1	8	70.6	22.5	2	2	8	78.1	15.0	8	3	8	80.6	17.5	15
5-Aug	1	9	93.2	25.0	11	2	9	42.8	15.0	0	3	9	65.5	20.0	1
5-Aug	1	10	52.9	15.0	0	2	10	88.2	20.0	1	3	10	95.8	12.5	6
5-Aug	1	11	70.6	17.5	4	2	11	45.4	10.0	0	3	11	90.7	25.0	8
5-Aug	1	12	63.0	15.0	0	2	12	65.5	17.5	1	3	12	83.2	15.0	5
5-Aug	1	13	52.9	17.5	3	2	13	42.8	12.5	0	3	13	65.5	17.5	2
5-Aug	1	14	60.5	17.5	1	2	14	52.9	20.0	0	3	14	60.5	17.5	9
5-Aug	1	15	78.1	20.0	2	2	15	90.7	22.5	19	3	15	73.1	22.5	3
5-Aug	1	16	83.2	27.5	12	2	16	83.2	25.0	1	3	16	63.0	17.5	2
5-Aug	1	17	103.3	17.5	4	2	17	65.5	20.0	2	3	17	98.3	15.0	3
5-Aug	1	18	78.1	20.0	12	2	18	60.5	17.5	1	3	18	103	17.5	0
5-Aug	1	19	108	22.5	10	2	19	80.6	22.5	2	3	19	73.1	17.5	4
5-Aug	1	20	110	20.0	16						3	20	98.3	15.0	8

Table A.3 continued

Table A.3 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
17-Sep	1	1	80.6	17.5	0	2	1	88.2	12.5	0	3	1	85.7	20.0	0
17-Sep	1	2	40.3	17.5	0	2	2	98.3	17.5	0	3	2	70.6	20.0	0
17-Sep	1	3	101	22.5	0	2	3	80.6	15.0	0	3	3	83.2	20.0	0
17-Sep	1	4	80.6	17.5	0	2	4	78.1	22.5	0	3	4	75.6	17.5	0
17-Sep	1	5	85.7	17.5	0	2	5	78.1	22.5	0	3	5	80.6	15.0	0
17-Sep	1	6	78.1	20.0	0	2	6	57.9	20.0	0	3	6	75.6	17.5	0
17-Sep	1	7	50.4	15.0	0	2	7	75.6	22.5	0	3	7	52.9	12.5	0
17-Sep	1	8	68.0	15.0	0	2	8	78.1	20.0	0	3	8	80.6	15.0	0
17-Sep	1	9	57.9	17.5	0	2	9	42.8	15.0	0	3	9	55.4	10.0	0
17-Sep	1	10	60.5	15.0	0	2	10	85.7	22.5	0	3	10	93.2	12.5	0
17-Sep	1	11	70.6	15.0	0	2	11	42.8	10.0	0	3	11	88.2	20.0	0
17-Sep	1	12	63.0	12.5	0	2	12	63.0	17.5	0	3	12	80.6	15.0	0
17-Sep	1	13	50.4	12.5	0	2	13	37.8	12.5	0	3	13	73.1	15.0	0
17-Sep	1	14	57.9	12.5	0	2	14	42.8	17.5	0	3	14	63.0	12.5	0
17-Sep	1	15	75.6	17.5	0	2	15	95.8	22.5	0	3	15	73.1	17.5	0
17-Sep	1	16	83.2	20.0	0	2	16	80.6	25.0	0	3	16	63.0	12.5	0
17-Sep	1	17	103.3	17.5	0	2	17	65.5	20.0	0	3	17	95.8	15.0	0
17-Sep	1	18	78.1	17.5	0	2	18	70.6	17.5	0	3	18	101	15.0	0
17-Sep	1	19	88.2	20.0	0	2	19	80.6	20.0	0	3	19	73.1	15.0	0
17-Sep	1	20	111	20.0	0						3	20	93.2	17.5	0

Table A.3 continued

Table A.3 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
23-Oct	1	1	80.6	17.5	0	2	1	88.2	10.0	0	3	1	88.2	15.0	0
23-Oct	1	2	40.3	12.5	0	2	2	95.8	15.0	0	3	2	73.1	17.5	0
23-Oct	1	3	98.3	15.0	0	2	3	80.6	12.5	0	3	3	80.6	17.5	0
23-Oct	1	4	80.6	17.5	0	2	4	78.1	20.0	0	3	4	73.1	12.5	0
23-Oct	1	5	85.7	15.0	0	2	5	80.6	15.0	0	3	5	80.6	17.5	0
23-Oct	1	6	78.1	20.0	0	2	6	55.4	15.0	0	3	6	75.6	17.5	0
23-Oct	1	7	47.9	15.0	0	2	7	75.6	12.5	0	3	7	50.4	10.0	0
23-Oct	1	8	70.6	17.5	0	2	8	78.1	17.5	0	3	8	80.6	15.0	0
23-Oct	1	9	57.9	17.5	0	2	9	42.8	10.0	0	3	9	50.4	15.0	0
23-Oct	1	10	63.0	12.5	0	2	10	88.2	22.5	0	3	10	98.3	12.5	0
23-Oct	1	11	70.6	12.5	0	2	11	42.8	10.0	0	3	11	90.7	17.5	0
23-Oct	1	12	65.5	12.5	0	2	12	65.5	15.0	0	3	12	80.6	10.0	0
23-Oct	1	13	50.4	15.0	0	2	13	40.3	7.50	0	3	13	70.6	12.5	0
23-Oct	1	14	57.9	12.5	0	2	14	45.4	12.5	0	3	14	60.5	10.0	0
23-Oct	1	15	75.6	17.5	0	2	15	98.3	17.5	0	3	15	73.1	15.0	0
23-Oct	1	16	83.2	20.0	0	2	16	80.6	17.5	0	3	16	63.0	10.0	0
23-Oct	1	17	103	12.5	0	2	17	60.5	15.0	0	3	17	95.8	12.5	0
23-Oct	1	18	78.1	15.0	0	2	18	70.6	17.5	0	3	18	101	20.0	0
23-Oct	1	19	88.2	15.0	0	2	19	83.2	17.5	0	3	19	73.1	15.0	0
23-Oct	1	20	111	20.0	0						3	20	95.8	15.0	0

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
16-Jun	1	1	12.60	5.00	0	2	1	10.08	7.50	0	3	1	12.60	5.00	0
16-Jun	1	2	12.60	7.50	0	2	2	12.60	2.50	0	3	2	10.08	2.50	0
16-Jun	1	3	15.12	5.00	0	2	3	12.60	5.00	0	3	3	12.60	5.00	0
16-Jun	1	4	12.60	5.00	0	2	4	10.08	5.00	0	3	4	12.60	5.00	0
16-Jun	1	5	10.08	5.00	0	2	5	12.60	2.50	0	3	5	15.12	5.00	0
16-Jun	1	6	10.08	5.00	0	2	6	12.60	2.50	0	3	6	12.60	5.00	0
16-Jun	1	7	15.12	3.75	0	2	7	12.60	5.00	0	3	7	12.60	5.00	0
16-Jun	1	8	15.12	3.75	0	2	8	15.12	2.50	0	3	8	15.12	5.00	0
16-Jun	1	9	15.12	2.50	0	2	9	12.60	5.00	0	3	9	15.12	5.00	0
16-Jun	1	10	10.08	5.00	0	2	10	12.60	2.50	0	3	10	17.64	5.00	0
16-Jun	1	11	12.60	5.00	0	2	11	15.12	5.00	0	3	11	17.64	5.00	0

Table A.4 continued

Table A.4: Height, width and flowering data for *Sorghastrum nutans* (Indian Grass). The dates are all for 2008, ‘RG’ stands for rain garden, and ‘#fls’ for number of flowers. Each ‘Plant’ number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table A.4 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jul	1	1	12.6	7.50	0	2	1	15.1	7.50	0	3	1	10.1	5.00	0
10-Jul	1	2	15.1	5.00	0	2	2	12.6	5.00	0	3	2	10.1	5.00	0
10-Jul	1	3	12.6	5.00	0	2	3	10.1	7.50	0	3	3	12.6	5.00	0
10-Jul	1	4	10.1	5.00	0	2	4	12.6	7.50	0	3	4	12.6	5.00	0
10-Jul	1	5	10.1	7.50	0	2	5	7.56	5.00	0	3	5	10.1	5.00	0
10-Jul	1	6	12.6	5.00	0	2	6	17.6	5.00	0	3	6	7.56	5.00	0
10-Jul	1	7	10.1	5.00	0	2	7	10.1	5.00	0	3	7	10.1	5.00	0
10-Jul	1	8	12.6	5.00	0	2	8	15.1	5.00	0	3	8	12.6	5.00	0
10-Jul	1	9	20.2	5.00	0	2	9	15.1	5.00	0	3	9	12.6	5.00	0
10-Jul	1	10	12.6	5.00	0	2	10	15.1	5.00	0	3	10	20.2	5.00	0
10-Jul	1	11	12.6	5.00	0	2	11	12.6	5.00	0	3	11	17.6	5.00	0

Table A.4 continued

Table A.4 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
5-Aug	1	1	15.1	5.00	0	2	1	17.6	7.50	0	3	1	10.1	5.00	0
5-Aug	1	2	25.2	5.00	0	2	2	27.7	7.50	0	3	2	17.6	5.00	0
5-Aug	1	3	17.6	5.00	0	2	3	22.7	7.50	0	3	3	15.1	5.00	0
5-Aug	1	4	17.6	5.00	0	2	4	27.7	7.50	0	3	4	17.6	5.00	0
5-Aug	1	5	15.1	2.50	0	2	5	10.1	2.50	0	3	5	10.1	5.00	0
5-Aug	1	6	20.2	5.00	0	2	6	25.2	5.00	0	3	6	12.6	5.00	0
5-Aug	1	7	12.6	2.50	0	2	7	15.1	5.00	0	3	7	10.1	5.00	0
5-Aug	1	8	27.7	5.00	0	2	8	17.6	5.00	0	3	8	20.2	5.00	0
5-Aug	1	9	32.8	5.00	0	2	9	25.2	5.00	0	3	9	20.2	5.00	0
5-Aug	1	10	35.3	5.00	0	2	10	32.8	5.00	0	3	10	22.7	5.00	0
5-Aug	1	11	20.2	5.00	0	2	11	20.2	5.00	0	3	11	27.7	5.00	0

Table A.4 continued

Table A.4 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
17-Sep	1	1	22.7	7.50	0	2	1	25.2	7.50	0	3	1	12.6	7.50	0
17-Sep	1	2	22.7	7.50	0	2	2	25.2	5.00	0	3	2	22.7	7.50	0
17-Sep	1	3	27.7	7.50	0	2	3	30.2	10.0	0	3	3	20.2	5.00	0
17-Sep	1	4	17.6	7.50	0	2	4	22.7	7.50	0	3	4	20.2	7.50	0
17-Sep	1	5	20.2	5.00	0	2	5	0.00	0.00	0	3	5	15.1	5.00	0
17-Sep	1	6	25.2	5.00	0	2	6	27.7	5.00	0	3	6	15.1	5.00	0
17-Sep	1	7	0.00	0.00	0	2	7	10.1	5.00	0	3	7	12.6	5.00	0
17-Sep	1	8	37.8	7.50	0	2	8	22.7	5.00	0	3	8	30.2	5.00	0
17-Sep	1	9	37.8	7.50	0	2	9	25.2	7.50	0	3	9	17.6	5.00	0
17-Sep	1	10	35.3	7.50	0	2	10	30.2	7.50	0	3	10	35.3	5.00	0
17-Sep	1	11	27.7	7.50	0	2	11	20.2	7.50	0	3	11	25.2	5.00	0

Table A.4 continued

Table A.4 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
23-Oct	1	1	20.2	5.00	0	2	1	25.2	7.50	0	3	1	10.1	5.00	0
23-Oct	1	2	25.2	5.00	0	2	2	17.6	7.50	0	3	2	20.2	5.00	0
23-Oct	1	3	22.7	5.00	0	2	3	35.3	7.50	0	3	3	17.6	7.50	0
23-Oct	1	4	20.2	7.50	0	2	4	22.7	7.50	0	3	4	25.2	7.50	0
23-Oct	1	5	17.6	5.00	0	2	5	0.00	0.00	0	3	5	12.6	5.00	0
23-Oct	1	6	25.2	5.00	0	2	6	30.2	5.00	0	3	6	12.6	5.00	0
23-Oct	1	7	0.00	0.00	0	2	7	0.00	0.00	0	3	7	10.1	5.00	0
23-Oct	1	8	40.3	7.50	0	2	8	17.6	5.00	0	3	8	30.2	7.50	0
23-Oct	1	9	55.4	10.0	0	2	9	25.2	7.50	0	3	9	22.7	7.50	0
23-Oct	1	10	45.4	10.0	0	2	10	25.2	5.00	0	3	10	35.3	7.50	0
23-Oct	1	11	22.7	5.00	0	2	11	17.6	5.00	0	3	11	25.2	7.50	0

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
16-Jun	1	1	63.0	10.0	0	4	2	1	63.0	17.5	0	4	3	1	73.1	12.5	0	5
16-Jun	1	2	55.4	12.5	0	5	2	2	65.5	20.0	0	6	3	2	58.0	12.5	1	5
16-Jun	1	3	60.5	12.5	0	5	2	3	68.0	10.0	0	3	3	3	60.5	20.0	1	4
16-Jun	1	4	45.4	7.5	0	3	2	4	40.3	15.0	0	1	3	4	50.4	15.0	0	5
16-Jun	1	5	30.2	10.0	0	3	2	5	65.5	10.0	0	1	3	5	63.0	17.5	0	2
16-Jun	1	6	47.9	12.5	1	4	2	6	60.5	12.5	0	4	3	6	55.4	10.0	1	3
16-Jun	1	7	63.0	7.50	0	2	2	7	73.1	22.5	1	9	3	7	75.6	20.0	0	5
16-Jun	1	8	35.3	10.0	0	1	2	8	27.7	12.5	0	3	3	8	63.0	15.0	1	2

Table A.5 continued

Table A.5: Height, width and flowering data for *Echinacea purpurea* (Purple Coneflower). The dates are all for 2008, 'RG' stands for rain garden, '#fls' for number of flowers and '#ufls' for the number of unopened flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table A5 continued

Date	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls
10-Jul	1	1	63.0	20.0	5	0	2	1	83.2	20.0	4	0	3	1	80.6	20.0	4	1
10-Jul	1	2	73.1	22.5	5	0	2	2	80.6	20.0	6	0	3	2	60.5	10.0	6	0
10-Jul	1	3	70.6	22.5	4	1	2	3	75.6	17.5	3	0	3	3	78.1	10.0	4	1
10-Jul	1	4	58.0	12.5	3	0	2	4	50.4	10.0	2	1	3	4	65.5	17.5	5	2
10-Jul	1	5	42.8	12.5	3	0	2	5	75.6	15.0	1	0	3	5	80.6	20.0	1	0
10-Jul	1	6	52.9	17.5	5	0	2	6	83.2	22.5	5	0	3	6	55.4	15.0	4	0
10-Jul	1	7	65.5	17.5	2	0	2	7	75.6	25.0	9	1	3	7	80.6	10.0	5	0
10-Jul	1	8	47.9	15.0	2	2	2	8	42.8	12.5	3	1	3	8	75.6	15.0	3	0

Date	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls
5-Aug	1	1	63.0	20.0	5	0	2	1	83.2	20.0	4	0	3	1	80.6	25.0	6	0
5-Aug	1	2	73.1	22.5	5	0	2	2	80.6	25.0	6	0	3	2	58.0	17.5	5	0
5-Aug	1	3	70.6	20.0	6	0	2	3	73.1	17.5	3	0	3	3	78.1	20.0	5	0
5-Aug	1	4	58.0	10.0	3	0	2	4	50.4	12.5	3	0	3	4	65.5	20.0	4	0
5-Aug	1	5	45.4	12.5	3	0	2	5	75.6	10.0	1	0	3	5	83.2	10.0	1	0
5-Aug	1	6	52.9	42.5	4	0	2	6	80.6	15.0	5	0	3	6	55.4	12.5	3	0
5-Aug	1	7	63.0	17.5	2	0	2	7	75.6	22.5	10	0	3	7	83.2	22.5	5	0
5-Aug	1	8	50.4	12.5	4	0	2	8	45.4	20.0	4	0	3	8	78.1	15.0	2	0

Table A.5 continued

Table A.5 continued

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
17-Sep	1	1	63.0	12.5	0	0	2	1	83.2	17.5	0	0	3	1	80.6	20.0	0	0
17-Sep	1	2	68.0	15.0	0	0	2	2	78.1	17.5	0	0	3	2	58.0	17.5	0	0
17-Sep	1	3	70.6	15.0	0	0	2	3	73.1	17.5	0	0	3	3	73.1	22.5	0	0
17-Sep	1	4	60.5	10.0	0	0	2	4	50.4	10.0	0	0	3	4	65.5	15.0	0	0
17-Sep	1	5	45.4	12.5	0	0	2	5	78.1	5.00	0	0	3	5	80.6	10.0	0	0
17-Sep	1	6	50.4	15.0	0	0	2	6	80.6	15.0	0	0	3	6	52.9	12.5	0	0
17-Sep	1	7	65.5	20.0	0	0	2	7	73.1	17.5	0	0	3	7	80.6	20.0	0	0
17-Sep	1	8	50.4	12.5	0	0	2	8	45.4	20.0	0	0	3	8	78.1	12.5	0	0

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
23-Oct	1	1	60.5	12.5	0	0	2	1	83.2	15.0	0	0	3	1	80.6	17.5	0	0
23-Oct	1	2	73.1	12.5	0	0	2	2	78.1	20.0	0	0	3	2	58.0	15.0	0	0
23-Oct	1	3	73.1	12.5	0	0	2	3	73.1	20.0	0	0	3	3	75.6	17.5	0	0
23-Oct	1	4	47.9	7.50	0	0	2	4	50.4	10.0	0	0	3	4	65.5	12.5	0	0
23-Oct	1	5	12.6	12.5	0	0	2	5	75.6	5.00	0	0	3	5	80.6	12.5	0	0
23-Oct	1	6	50.4	12.5	0	0	2	6	80.6	15.0	0	0	3	6	52.9	15.0	0	0
23-Oct	1	7	63.0	15.0	0	0	2	7	73.1	17.5	0	0	3	7	83.2	20.0	0	0
23-Oct	1	8	50.4	15.0	0	0	2	8	42.8	17.5	0	0	3	8	78.1	12.5	0	0

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
16-Jun	1	1	12.6	10.0	0	2	1	15.1	10.0	0	3	1	20.2	10.0	0
16-Jun	1	2	12.6	10.0	0	2	2	12.6	10.0	0	3	2	17.6	7.50	0
16-Jun	1	3	22.7	10.0	0	2	3	17.6	10.0	0	3	3	12.6	10.0	0
16-Jun	1	4	15.1	7.5	0	2	4	15.1	10.0	0	3	4	12.6	10.0	0
16-Jun	1	5	17.6	10.0	0	2	5	12.6	10.0	0	3	5	20.2	10.0	0
16-Jun	1	6	17.6	12.5	0	2	6	15.1	7.50	0	3	6	12.6	7.50	0
16-Jun	1	7	20.2	15.0	0	2	7	15.1	10.0	0	3	7	5.0	2.50	0
16-Jun	1	8	20.2	12.5	0	2	8	15.1	7.50	0	3	8	15.1	7.50	0
16-Jun	1	9	12.6	10.0	0	2	9	15.1	10.0	0	3	9	12.6	7.50	0
16-Jun	1	10	12.6	10.0	0	2	10	22.7	12.5	0	3	10	5.04	2.50	0
16-Jun	1	11	20.2	10.0	0	2	11	12.6	5.0	0	3	11	20.2	10.0	0
16-Jun	1	12	7.6	12.5	0	2	12	12.6	7.50	0	3	12	17.6	12.5	0
16-Jun	1	13	10.1	10.0	0	2	13	20.2	10.0	0	3	13	20.2	10.0	0
16-Jun	1	14	15.1	10.0	0	2	14	15.1	10.0	0	3	14	15.1	7.50	0
16-Jun	1	15	20.2	12.5	0	2	15	7.6	5.0	0	3	15	20.2	10.0	0
16-Jun	1	16	22.7	10.0	0	2	16	15.1	10.0	0	3	16	12.6	7.50	0
16-Jun	1	17	15.1	10.0	0	2	17	12.6	10.0	0	3	17	20.2	10.0	0
16-Jun	1	18	15.1	10.0	0	2	18	10.1	10.0	0	3	18	12.6	7.50	0

Table A.6 continued

r 2008, 'RG'

stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table A.6 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	20.2	10.0	0	2	1	15.1	10.0	0	3	1	17.6	10.0	0
10-Jul	1	2	20.2	7.50	0	2	2	10.1	10.0	0	3	2	22.7	7.50	0
10-Jul	1	3	20.2	10.0	0	2	3	15.1	10.0	0	3	3	12.6	5.00	0
10-Jul	1	4	17.6	7.50	0	2	4	25.2	12.5	0	3	4	10.1	7.50	0
10-Jul	1	5	10.1	10.0	0	2	5	10.1	10.0	0	3	5	12.6	7.50	0
10-Jul	1	6	12.6	10.0	0	2	6	12.6	10.0	0	3	6	12.6	7.50	0
10-Jul	1	7	22.7	15.0	0	2	7	20.2	12.5	0	3	7	0.0	0.00	0
10-Jul	1	8	12.6	10.0	0	2	8	10.1	7.50	0	3	8	10.1	5.00	0
10-Jul	1	9	12.6	10.0	0	2	9	10.1	10.0	0	3	9	17.6	10.0	0
10-Jul	1	10	15.1	10.0	0	2	10	10.1	10.0	0	3	10	10.1	7.50	0
10-Jul	1	11	12.6	12.5	0	2	11	17.6	7.50	0	3	11	15.1	10.0	0
10-Jul	1	12	10.1	10.0	0	2	12	12.6	7.50	0	3	12	20.2	12.5	0
10-Jul	1	13	7.6	12.5	0	2	13	10.1	12.5	0	3	13	17.6	7.50	0
10-Jul	1	14	15.1	7.50	0	2	14	10.1	10.0	0	3	14	10.1	7.50	0
10-Jul	1	15	15.1	10.0	0	2	15	10.1	10.0	0	3	15	17.6	10.00	0
10-Jul	1	16	42.8	12.5	0	2	16	22.7	10.0	0	3	16	10.1	5.00	0
10-Jul	1	17	27.7	12.5	0	2	17	10.1	7.50	0	3	17	22.7	7.50	0
10-Jul	1	18	17.6	12.5	0	2	18	7.6	10.0	0	3	18	10.1	5.00	0

Table A.6 continued

Table A.6 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
5-Aug	1	1	25.2	10.0	0	2	1	25.2	10.0	0	3	1	15.1	10.0	0
5-Aug	1	2	12.6	10.0	0	2	2	12.6	10.0	0	3	2	22.7	10.0	0
5-Aug	1	3	20.2	10.0	0	2	3	20.2	10.0	0	3	3	15.1	5.0	0
5-Aug	1	4	22.7	10.0	0	2	4	22.7	10.0	0	3	4	20.2	7.50	0
5-Aug	1	5	22.7	7.50	0	2	5	22.7	10.0	0	3	5	17.6	12.5	0
5-Aug	1	6	22.7	10.0	0	2	6	22.7	10.0	0	3	6	20.2	12.5	0
5-Aug	1	7	20.2	10.0	0	2	7	20.2	10.0	0	3	7	0.00	0.00	0
5-Aug	1	8	20.2	10.0	0	2	8	20.2	10.0	0	3	8	20.2	2.50	0
5-Aug	1	9	17.6	10.0	0	2	9	17.6	10.0	0	3	9	20.2	10.0	0
5-Aug	1	10	15.1	7.50	0	2	10	15.1	10.0	0	3	10	5.04	5.00	0
5-Aug	1	11	37.8	7.50	0	2	11	37.8	10.0	0	3	11	17.6	7.50	0
5-Aug	1	12	25.2	10.0	0	2	12	25.2	7.50	0	3	12	22.7	15.0	0
5-Aug	1	13	15.1	12.5	0	2	13	15.1	10.0	0	3	13	25.2	10.0	0
5-Aug	1	14	17.6	7.50	0	2	14	17.6	5.00	0	3	14	17.6	12.5	0
5-Aug	1	15	22.7	10.0	0	2	15	22.7	10.0	0	3	15	22.7	10.0	0
5-Aug	1	16	22.7	10.0	0	2	16	22.7	7.50	0	3	16	15.1	7.50	0
5-Aug	1	17	22.7	10.0	0	2	17	22.7	10.0	0	3	17	17.6	10.0	0
5-Aug	1	18	20.2	7.50	0	2	18	20.2	7.50	0	3	18	7.6	7.50	0

Table A.6 continued

Table A.6 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
17-Sep	1	1	15.1	7.5	1	2	1	25.2	12.5	1	3	1	15.1	7.50	0
17-Sep	1	2	22.7	10.0	1	2	2	12.6	7.50	0	3	2	20.2	10.0	0
17-Sep	1	3	20.2	7.5	1	2	3	20.2	7.50	1	3	3	22.7	7.50	0
17-Sep	1	4	17.6	10.0	1	2	4	20.2	10.0	1	3	4	10.1	2.50	0
17-Sep	1	5	15.1	10.0	0	2	5	22.7	7.50	1	3	5	22.7	15.0	1
17-Sep	1	6	22.7	10.0	1	2	6	17.6	7.50	0	3	6	22.7	10.0	1
17-Sep	1	7	30.2	10.0	1	2	7	15.1	10.0	1	3	7	0.0	0.00	0
17-Sep	1	8	17.6	10.0	1	2	8	25.2	7.50	1	3	8	10.1	2.50	1
17-Sep	1	9	17.6	7.50	0	2	9	20.2	10.0	0	3	9	15.1	7.50	0
17-Sep	1	10	15.1	12.5	1	2	10	22.7	7.50	0	3	10	0.0	0.00	0
17-Sep	1	11	30.2	12.5	1	2	11	20.2	10.0	0	3	11	15.1	7.50	0
17-Sep	1	12	25.2	10.0	1	2	12	30.2	7.50	1	3	12	22.7	10.0	0
17-Sep	1	13	32.8	10.0	1	2	13	22.7	7.50	1	3	13	25.2	10.0	1
17-Sep	1	14	20.2	10.0	0	2	14	7.56	7.50	0	3	14	15.1	7.50	0
17-Sep	1	15	22.7	10.0	1	2	15	15.1	5.00	0	3	15	25.2	10.0	1
17-Sep	1	16	22.7	7.50	1	2	16	20.2	7.50	0	3	16	15.1	7.50	1
17-Sep	1	17	17.6	10.0	1	2	17	22.7	7.50	0	3	17	15.1	7.50	0
17-Sep	1	18	20.2	10.0	1	2	18	20.2	7.50	0	3	18	7.6	7.50	0

Table A.6 continued

Table A.6 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
23-Oct	1	1	12.6	7.50	1	2	1	22.7	10.0	2	3	1	12.6	7.50	0
23-Oct	1	2	22.7	10.0	0	2	2	10.1	7.50	0	3	2	22.7	10.0	0
23-Oct	1	3	17.6	7.50	1	2	3	20.2	7.50	1	3	3	10.1	5.00	0
23-Oct	1	4	17.6	7.50	1	2	4	15.1	10.0	1	3	4	7.56	5.00	0
23-Oct	1	5	20.2	12.5	0	2	5	25.2	7.50	1	3	5	20.2	17.5	1
23-Oct	1	6	20.2	12.5	2	2	6	12.6	10.0	0	3	6	22.7	10.0	1
23-Oct	1	7	27.7	10.0	2	2	7	15.1	10.0	0	3	7	0.0	0.00	0
23-Oct	1	8	17.6	7.50	0	2	8	22.7	7.50	1	3	8	15.1	5.00	0
23-Oct	1	9	12.6	10.0	0	2	9	20.2	10.0	0	3	9	17.6	5.00	0
23-Oct	1	10	25.2	7.50	3	2	10	22.7	7.50	0	3	10	0.00	0.00	0
23-Oct	1	11	30.2	10.0	2	2	11	20.2	7.50	0	3	11	20.2	7.50	0
23-Oct	1	12	22.7	10.0	1	2	12	20.2	7.50	0	3	12	15.1	10.00	0
23-Oct	1	13	35.3	7.50	0	2	13	12.6	10.0	0	3	13	17.6	10.0	0
23-Oct	1	14	20.2	10.0	0	2	14	10.1	2.50	0	3	14	10.1	7.50	0
23-Oct	1	15	25.2	10.0	1	2	15	17.6	7.50	0	3	15	22.7	10.0	0
23-Oct	1	16	25.2	12.5	1	2	16	22.7	7.50	0	3	16	17.6	7.50	1
23-Oct	1	17	25.2	10.0	1	2	17	15.1	7.50	0	3	17	17.6	7.50	0
23-Oct	1	18	20.2	10.0	2	2	18	17.6	7.50	0	3	18	10.1	7.50	0

APPENDIX B: 2009: Height, width and flowering data for plant species

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
12-May	1	1	12.6	17.6	0	2	1	15.1	12.6	0	3	1	10.1	15.1	0
12-May	1	2	10.1	12.6	0	2	2	12.6	17.6	0	3	2	10.1	15.1	0
12-May	1	3	10.1	12.6	0	2	3	12.6	15.1	0	3	3	10.1	10.1	0
12-May	1	4	12.6	15.1	0	2	4	12.6	15.1	0	3	4	10.1	20.2	0
12-May	1	5	12.6	15.1	0	2	5	12.6	17.6	0	3	5	7.56	15.1	0
12-May	1	6	10.1	22.7	0	2	6	12.6	15.1	0	3	6	10.1	15.1	0
12-May	1	7	7.56	17.6	0	2	7	10.1	15.1	0	3	7	10.1	15.1	0
12-May	1	8	10.1	15.1	0	2	8	10.1	17.6	0	3	8	7.56	20.2	0

Table B.1 continued

Table B.1: Height, width and flowering data for *Eupatorium perfoliatum* (Boneset). The dates are all for 2009, 'RG' stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table B.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jun	1	1	32.8	25.2	0	2	1	50.4	17.6	0	3	1	27.7	22.7	0
10-Jun	1	2	17.6	15.1	0	2	2	42.8	20.2	0	3	2	25.2	20.2	0
10-Jun	1	3	17.6	22.7	0	2	3	35.3	20.2	0	3	3	17.6	12.6	0
10-Jun	1	4	25.2	22.7	0	2	4	25.2	15.1	0	3	4	27.7	22.7	0
10-Jun	1	5	25.2	15.1	0	2	5	35.3	25.2	0	3	5	22.7	25.2	0
10-Jun	1	6	25.2	30.2	0	2	6	37.8	22.7	0	3	6	22.7	12.6	0
10-Jun	1	7	25.2	22.7	0	2	7	40.3	22.7	0	3	7	25.2	17.6	0
10-Jun	1	8	22.7	20.2	0	2	8	25.2	20.2	0	3	8	32.8	30.2	0

Table B.1 continued

Table B.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	47.9	27.7	8	2	1	78.1	17.6	23	3	1	42.8	22.7	2
10-Jul	1	2	32.8	22.7	0	2	2	68.0	22.7	3	3	2	40.3	12.6	1
10-Jul	1	3	32.8	22.7	0	2	3	52.9	20.2	6	3	3	25.2	12.6	0
10-Jul	1	4	37.8	25.2	0	2	4	37.8	22.7	1	3	4	45.4	22.7	3
10-Jul	1	5	37.8	20.2	0	2	5	58.0	25.2	4	3	5	42.8	17.6	2
10-Jul	1	6	40.3	22.7	0	2	6	63.0	30.2	3	3	6	32.8	12.6	0
10-Jul	1	7	37.8	22.7	0	2	7	68.0	27.7	6	3	7	42.8	20.2	1
10-Jul	1	8	32.8	22.7	0	2	8	52.9	22.7	8	3	8	52.9	25.2	3

Table B.1 continued

Table B.1 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
7-Aug	1	1	52.9	30.2	43	2	1	88.2	20.2	117	3	1	55.4	27.7	65
7-Aug	1	2	30.2	17.6	2	2	2	78.1	25.2	78	3	2	50.4	20.2	14
7-Aug	1	3	37.8	25.2	6	2	3	65.5	25.2	67	3	3	32.8	20.2	8
7-Aug	1	4	37.8	22.7	1	2	4	45.4	42.8	17	3	4	55.4	22.7	26
7-Aug	1	5	37.8	22.7	3	2	5	65.5	22.7	45	3	5	50.4	22.7	36
7-Aug	1	6	47.9	22.7	24	2	6	78.1	22.7	73	3	6	40.3	10.1	4
7-Aug	1	7	45.4	22.7	7	2	7	80.6	20.2	73	3	7	47.9	22.7	42
7-Aug	1	8	32.8	20.2	6	2	8	63.0	25.2	62	3	8	73.1	32.8	64

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-May	1	1	30.2	10.1	0	2	1	32.8	12.6	0	3	1	32.8	10.1	0
10-May	1	2	30.2	12.6	0	2	2	32.8	12.6	0	3	2	32.8	12.6	0
10-May	1	3	35.3	12.6	0	2	3	30.2	12.6	0	3	3	27.7	10.1	0
10-May	1	4	30.2	10.1	0	2	4	30.2	12.6	0	3	4	30.2	10.1	0
10-May	1	5	30.2	10.1	0	2	5	30.2	10.1	0	3	5	27.7	10.1	0
10-May	1	6	25.2	7.56	0	2	6	25.2	10.1	0	3	6	30.2	10.1	0
10-May	1	7	32.8	10.1	0	2	7	22.7	10.1	0	3	7	27.7	10.1	0
10-May	1	8	25.2	5.04	0	2	8	27.7	7.56	0	3	8	30.2	10.1	0
10-May	1	9	27.7	10.1	0	2	9	20.2	10.1	0	3	9	30.2	10.1	0
10-May	1	10	22.7	10.1	0	2	10	30.2	12.6	0	3	10	25.2	7.56	0
10-May	1	11	30.2	10.1	0	2	11	25.2	10.1	0	3	11	35.3	12.6	0
10-May	1	12	30.2	7.56	0	2	12	30.2	12.6	0	3	12	37.8	17.6	0
10-May	1	13	32.8	15.1	0	2	13	30.2	15.1	0	3	13	32.8	12.6	0
10-May	1	14	40.3	17.6	0										

Table B.2 continued

Table B.2: Height, width and flowering data for *Tradescantia ohiensis* (Spiderwort). The dates are all for 2009, 'RG' stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table B.2 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jun	1	1	45.4	22.7	5	2	1	50.4	20.2	4	3	1	73.1	17.6	37
10-Jun	1	2	47.9	17.6	0	2	2	47.9	17.6	1	3	2	68.0	25.2	9
10-Jun	1	3	58.0	17.6	6	2	3	47.9	30.2	12	3	3	52.9	15.1	4
10-Jun	1	4	55.4	20.2	2	2	4	42.8	27.7	2	3	4	45.4	17.6	8
10-Jun	1	5	37.8	15.1	0	2	5	35.3	17.6	0	3	5	42.8	15.1	0
10-Jun	1	6	32.8	12.6	0	2	6	32.8	15.1	1	3	6	47.9	20.2	0
10-Jun	1	7	40.3	15.1	2	2	7	27.7	12.6	0	3	7	40.3	20.2	0
10-Jun	1	8	32.8	7.6	0	2	8	37.8	17.6	3	3	8	45.4	17.6	2
10-Jun	1	9	37.8	15.1	0	2	9	30.2	12.6	0	3	9	40.3	15.1	4
10-Jun	1	10	35.3	7.56	0	2	10	55.4	15.1	0	3	10	47.9	27.7	7
10-Jun	1	11	40.3	15.1	0	2	11	37.8	15.1	0	3	11	63.0	27.7	6
10-Jun	1	12	47.9	22.7	11	2	12	52.9	22.7	2	3	12	52.9	30.2	11
10-Jun	1	13	37.8	20.2	2	2	13	42.8	30.2	4	3	13	68.0	20.2	31
10-Jun	1	14	65.5	25.2	15										

Table B.2 continued

Table B.2 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	42.8	20.2	0	2	1	60.5	25.2	5	3	1	63.0	15.1	0
10-Jul	1	2	45.4	17.6	0	2	2	45.4	15.1	2	3	2	73.1	17.6	0
10-Jul	1	3	60.5	15.1	0	2	3	45.4	15.1	0	3	3	52.9	7.6	0
10-Jul	1	4	50.4	15.1	0	2	4	50.4	22.7	0	3	4	55.4	12.6	0
10-Jul	1	5	32.8	10.1	0	2	5	35.3	17.6	0	3	5	35.3	17.6	0
10-Jul	1	6	32.8	10.1	0	2	6	30.2	15.1	0	3	6	47.9	20.2	0
10-Jul	1	7	45.4	12.6	0	2	7	20.2	10.1	0	3	7	42.8	17.6	0
10-Jul	1	8	35.3	10.1	0	2	8	45.4	15.1	0	3	8	32.8	17.6	0
10-Jul	1	9	32.8	12.6	0	2	9	27.7	12.6	0	3	9	55.4	20.2	0
10-Jul	1	10	27.7	10.1	1	2	10	50.4	17.6	0	3	10	40.3	15.1	5
10-Jul	1	11	35.3	15.1	0	2	11	30.2	10.1	0	3	11	52.9	17.6	0
10-Jul	1	12	50.4	12.6	1	2	12	58.0	15.1	0	3	12	60.5	25.2	0
10-Jul	1	13	42.8	15.1	0	2	13	52.9	20.2	4	3	13	58.0	22.7	0
10-Jul	1	14	60.5	22.7	0										

Table B.2 continued

Table B.2 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
7-Aug	1	1	30.2	20.2	0	2	1	45.4	15.1	0	3	1	55.4	20.2	0
7-Aug	1	2	47.9	22.7	0	2	2	45.4	15.1	0	3	2	63.0	15.1	0
7-Aug	1	3	50.4	25.2	0	2	3	25.2	12.6	0	3	3	42.8	15.1	0
7-Aug	1	4	52.9	20.2	2	2	4	15.1	15.1	0	3	4	47.9	15.1	0
7-Aug	1	5	37.8	15.1	0	2	5	25.2	12.6	0	3	5	30.2	15.1	0
7-Aug	1	6	25.2	15.1	0	2	6	22.7	10.1	0	3	6	58.0	17.6	0
7-Aug	1	7	22.7	15.1	0	2	7	10.1	7.6	0	3	7	40.3	12.6	0
7-Aug	1	8	32.8	10.1	0	2	8	37.8	15.1	0	3	8	50.4	15.1	0
7-Aug	1	9	27.7	15.1	0	2	9	12.6	12.6	0	3	9	42.8	15.1	0
7-Aug	1	10	40.3	12.6	0	2	10	25.2	15.1	0	3	10	42.8	17.6	0
7-Aug	1	11	37.8	15.1	0	2	11	27.7	12.6	0	3	11	42.8	17.6	0
7-Aug	1	12	42.8	12.6	0	2	12	37.8	12.6	0	3	12	37.8	17.6	0
7-Aug	1	13	35.3	17.6	0	2	13	40.3	20.2	0	3	13	52.9	17.6	0
7-Aug	1	14	37.8	20.2	0										

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-May	1	1	22.7	12.6	0	2	1	15.1	7.56	0	3	1	30.2	10.1	0
10-May	1	2	12.6	7.56	0	2	2	10.1	7.56	0	3	2	12.6	10.1	0
10-May	1	3	17.6	10.1	0	2	3	0.0	0.0	0	3	3	20.2	12.6	0
10-May	1	4	15.1	10.1	0	2	4	10.1	7.56	0	3	4	20.2	12.6	0
10-May	1	5	22.7	12.6	0	2	5	0.0	0.0	0	3	5	25.2	10.1	0
10-May	1	6	12.6	10.1	0	2	6	5.0	5.0	0	3	6	20.2	10.1	0
10-May	1	7	15.1	7.56	0	2	7	20.2	10.1	0	3	7	15.1	5.0	0
10-May	1	8	12.6	7.56	0	2	8	5.0	2.54	0	3	8	7.6	7.56	0
10-May	1	9	0.0	0.0	0	2	9	0.0	0.0	0	3	9	10.1	2.54	0
10-May	1	10	0.0	0.0	0	2	10	0.0	0.0	0	3	10	0.0	0.0	0
10-May	1	11	0.0	0.0	0	2	11	0.0	0.0	0	3	11	12.6	7.56	0
10-May	1	12	0.0	0.00	0	2	12	0.0	0.0	0	3	12	17.6	10.1	0
10-May	1	13	0.0	0.0	0	2	13	0.0	0.0	0	3	13	0.0	0.0	0
10-May	1	14	0.0	0.0	0	2	14	0.0	0.0	0	3	14	12.6	7.56	0
10-May	1	15	12.6	10.1	0	2	15	17.6	5.08	0	3	15	17.6	10.1	0
10-May	1	16	17.6	10.1	0	2	16	20.2	10.1	0	3	16	15.1	10.1	0
10-May	1	17	17.6	7.56	0	2	17	20.2	10.1	0	3	17	30.2	12.6	0
10-May	1	18	10.1	7.56	0	2	18	10.1	5.08	0	3	18	20.2	7.56	0
10-May	1	19	22.7	10.1	0	2	19	17.6	7.56	0	3	19	27.7	10.1	0
10-May	1	20	25.2	12.6	0						3	20	30.2	12.6	0

Table B.3 continued

Table B.3: Height, width and flowering data for *Veronicastrum virginicum* (Culver's Root). The dates are all for 2009, 'RG' stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table B.3 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jun	1	1	32.8	15.1	0	2	1	22.7	10.1	0	3	1	50.4	25.2	0
10-Jun	1	2	25.2	12.6	0	2	2	15.1	10.1	0	3	2	22.7	17.6	0
10-Jun	1	3	25.2	12.6	0	2	3	0.00	0.00	0	3	3	32.8	20.2	0
10-Jun	1	4	27.7	12.6	0	2	4	17.6	7.56	0	3	4	30.2	17.6	0
10-Jun	1	5	37.8	12.6	0	2	5	0.00	0.00	0	3	5	47.9	15.1	0
10-Jun	1	6	25.2	10.1	0	2	6	12.6	7.56	0	3	6	32.8	15.1	0
10-Jun	1	7	22.7	10.1	0	2	7	27.7	12.6	0	3	7	20.2	7.56	0
10-Jun	1	8	22.7	12.6	0	2	8	5.04	2.5	0	3	8	15.1	5.0	0
10-Jun	1	9	5.04	2.52	0	2	9	0.00	0.00	0	3	9	20.2	2.5	0
10-Jun	1	10	0.00	0.00	0	2	10	0.00	0.00	0	3	10	0.00	0.00	0
10-Jun	1	11	2.52	2.52	0	2	11	0.00	0.00	0	3	11	15.1	7.56	0
10-Jun	1	12	0.00	0.00	0	2	12	0.00	0.00	0	3	12	30.2	10.1	0
10-Jun	1	13	0.00	0.00	0	2	13	0.00	0.00	0	3	13	0.00	0.00	0
10-Jun	1	14	0.00	0.00	0	2	14	0.00	0.00	0	3	14	22.7	7.56	0
10-Jun	1	15	20.2	10.1	0	2	15	30.2	10.1	0	3	15	27.7	10.1	0
10-Jun	1	16	30.2	15.1	0	2	16	32.8	15.1	0	3	16	27.7	10.1	0
10-Jun	1	17	27.7	10.1	0	2	17	35.3	15.1	0	3	17	45.4	15.1	0
10-Jun	1	18	20.2	7.56	0	2	18	15.12	5.0	0	3	18	32.8	10.1	0
10-Jun	1	19	35.3	15.1	0	2	19	30.2	7.56	0	3	19	42.8	17.6	0
10-Jun	1	20	45.4	20.2	0						3	20	47.9	22.7	0

Table B.3 continued

Table B.3 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
10-Jul	1	1	32.8	17.6	0	2	1	30.2	7.56	0	3	1	73.1	25.2	0
10-Jul	1	2	25.2	10.1	0	2	2	17.6	10.1	0	3	2	22.7	17.6	0
10-Jul	1	3	25.2	10.1	0	2	3	0.0	0.0	0	3	3	32.8	22.7	0
10-Jul	1	4	27.7	12.6	0	2	4	17.6	10.1	0	3	4	30.2	22.7	0
10-Jul	1	5	37.8	12.6	0	2	5	0.0	0.0	0	3	5	52.9	20.2	0
10-Jul	1	6	25.2	12.6	0	2	6	12.6	10.1	0	3	6	30.2	15.1	0
10-Jul	1	7	25.2	10.1	0	2	7	37.8	17.6	0	3	7	20.2	7.56	0
10-Jul	1	8	22.7	10.1	0	2	8	7.56	2.52	0	3	8	12.6	7.56	0
10-Jul	1	9	7.56	2.52	0	2	9	0.0	0.0	0	3	9	22.7	5.04	0
10-Jul	1	10	0.0	0.0	0	2	10	0.0	0.0	0	3	10	0.0	0.0	0
10-Jul	1	11	0.0	0.0	0	2	11	0.0	0.0	0	3	11	12.6	7.56	0
10-Jul	1	12	0.0	0.0	0	2	12	0.0	0.0	0	3	12	30.2	15.1	0
10-Jul	1	13	0.0	0.0	0	2	13	0.0	0.0	0	3	13	0.0	0.0	0
10-Jul	1	14	0.0	0.0	0	2	14	0.0	0.0	0	3	14	17.6	5.04	0
10-Jul	1	15	20.2	7.56	0	2	15	37.8	10.1	0	3	15	27.7	12.6	0
10-Jul	1	16	37.8	17.6	0	2	16	42.8	15.1	0	3	16	27.7	12.6	0
10-Jul	1	17	27.7	10.1	0	2	17	40.3	17.6	0	3	17	50.4	22.7	0
10-Jul	1	18	20.2	10.1	0	2	18	15.1	5.04	0	3	18	32.8	10.1	0
10-Jul	1	19	42.8	15.1	0	2	19	35.3	10.1	0	3	19	58.0	15.1	0
10-Jul	1	20	20.2	17.6	0						3	20	78.1	25.2	0

Table B.3 continued

Table B.3 continued

Date	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls	RG	Plant	height cm	width cm	# fls
7-Aug	1	1	32.8	20.2	0	2	1	25.2	10.1	0	3	1	78.1	17.6	2
7-Aug	1	2	25.2	10.1	0	2	2	20.2	10.1	0	3	2	22.7	15.1	0
7-Aug	1	3	25.2	12.6	0	2	3	0	0	0	3	3	30.2	17.6	0
7-Aug	1	4	27.7	15.1	0	2	4	20.2	10.1	0	3	4	32.8	17.6	0
7-Aug	1	5	40.3	17.6	0	2	5	0	0	0	3	5	50.4	17.6	0
7-Aug	1	6	25.2	12.6	0	2	6	15.1	7.56	0	3	6	32.8	15.1	0
7-Aug	1	7	22.7	10.1	0	2	7	37.8	17.6	0	3	7	20.2	5.04	0
7-Aug	1	8	25.2	15.1	0	2	8	7.56	2.52	0	3	8	15.1	5.04	0
7-Aug	1	9	7.56	2.52	0	2	9	0	0	0	3	9	20.2	2.52	0
7-Aug	1	10	0	0	0	2	10	0	0	0	3	10	0	0	0
7-Aug	1	11	0	0	0	2	11	0	0	0	3	11	15.1	5.04	0
7-Aug	1	12	0	0	0	2	12	0	0	0	3	12	32.8	12.6	0
7-Aug	1	13	0	0	0	2	13	0	0	0	3	13	0	0	0
7-Aug	1	14	0	0	0	2	14	0	0	0	3	14	0	0	0
7-Aug	1	15	20.2	10.1	0	2	15	35.3	10.08	0	3	15	27.7	12.6	0
7-Aug	1	16	35.3	17.6	0	2	16	42.8	17.6	0	3	16	32.8	15.1	0
7-Aug	1	17	27.7	12.6	0	2	17	35.3	15.1	0	3	17	50.4	17.6	0
7-Aug	1	18	20.2	12.6	0	2	18	15.1	7.56	0	3	18	60.5	22.7	0
7-Aug	1	19	40.3	12.6	0	2	19	32.8	12.6	0	3	19	32.8	10.1	1
7-Aug	1	20	45.4	17.6	0						3	20	85.7	20.2	1

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-May	1	1	7.6	7.6	0	2	1	15.1	7.6	0	3	1	0.0	0.0	0
10-May	1	2	5.0	5.0	0	2	2	12.6	2.5	0	3	2	17.6	5.0	0
10-May	1	3	15.1	5.0	0	2	3	25.2	10.1	0	3	3	0.0	0.0	0
10-May	1	4	17.6	5.0	0	2	4	15.1	7.6	0	3	4	20.2	7.6	0
10-May	1	5	0.0	0.0	0	2	5	0.0	0.0	0	3	5	5.0	2.5	0
10-May	1	6	15.1	5.04	0	2	6	5.0	2.5	0	3	6	0.0	0.0	0
10-May	1	7	0.0	0.0	0	2	7	0.0	0.0	0	3	7	2.5	2.5	0
10-May	1	8	20.2	7.56	0	2	8	0.0	0.0	0	3	8	22.7	10.1	0
10-May	1	9	20.2	10.1	0	2	9	15.1	5.0	0	3	9	0.0	0.0	0
10-May	1	10	22.7	10.1	0	2	10	0.0	0.0	0	3	10	20.2	7.6	0
10-May	1	11	25.2	7.6	0	2	11	12.6	5.0	0	3	11	17.6	7.6	0

Table B.4 continued

Table B.4: Height, width and flowering data for *Sorghastrum nutans* (Indian Grass). The dates are all for 2009, ‘RG’ stands for rain garden, and ‘#fls’ for number of flowers. Each ‘Plant’ number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table B.4 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jun	1	1	20.2	2.52	0	2	1	50.4	17.6	0	3	1	17.6	2.52	0
10-Jun	1	2	20.2	5.04	0	2	2	50.4	5.04	0	3	2	40.3	12.6	0
10-Jun	1	3	42.8	15.1	0	2	3	63.0	17.6	0	3	3	0.00	0.00	0
10-Jun	1	4	40.3	12.6	0	2	4	42.8	10.1	0	3	4	45.4	12.6	0
10-Jun	1	5	32.8	5.04	0	2	5	0.00	0.00	0	3	5	22.7	2.52	0
10-Jun	1	6	45.4	10.1	0	2	6	27.7	5.04	0	3	6	0.00	0.00	0
10-Jun	1	7	0.00	0.00	0	2	7	27.7	2.52	0	3	7	12.6	2.52	0
10-Jun	1	8	50.4	15.1	0	2	8	7.56	2.52	0	3	8	58.0	15.1	0
10-Jun	1	9	55.4	17.6	0	2	9	27.7	7.56	0	3	9	0.00	0.00	0
10-Jun	1	10	58.0	20.2	0	2	10	45.4	7.56	0	3	10	50.4	17.6	0
10-Jun	1	11	37.8	12.6	0	2	11	65.5	7.56	0	3	11	47.9	15.1	0

Table B.4 continued

Table B.4 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
7-Aug	1	1	22.7	7.6	0	2	1	78.1	22.7	0	3	1	25.2	5.0	0
7-Aug	1	2	30.2	10.1	0	2	2	68.0	12.6	0	3	2	42.8	12.6	0
7-Aug	1	3	63.0	15.1	0	2	3	85.7	22.7	0	3	3	17.6	5.0	0
7-Aug	1	4	42.8	15.1	0	2	4	42.8	12.6	0	3	4	83.2	15.1	0
7-Aug	1	5	32.8	10.1	0	2	5	0.0	0.0	0	3	5	12.6	5.0	0
7-Aug	1	6	52.9	15.1	0	2	6	25.2	7.56	0	3	6	0.0	0.0	0
7-Aug	1	7	0.0	0.0	0	2	7	45.4	7.56	0	3	7	45.4	5.0	0
7-Aug	1	8	63.0	17.6	0	2	8	15.1	5.04	0	3	8	63.0	15.1	0
7-Aug	1	9	65.5	22.7	0	2	9	32.8	7.56	0	3	9	0.0	0.0	0
7-Aug	1	10	83.2	22.7	0	2	10	58.0	12.6	0	3	10	52.9	10.1	0
7-Aug	1	11	35.3	12.6	0	2	11	90.7	10.1	0	3	11	80.6	17.6	0

Date	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls	RG	Plant	height cm	width cm	# fls	#ufls
10-May	1	1	15.1	5.0	0	0	2	1	22.7	12.6	0	0	3	1	25.2	10.1	0	0
10-May	1	2	15.1	12.6	0	0	2	2	30.2	20.16	0	1	3	2	20.2	10.1	0	0
10-May	1	3	20.2	12.6	0	0	2	3	32.8	12.6	0	0	3	3	22.7	12.6	0	0
10-May	1	4	17.6	10.1	0	0	2	4	20.2	10.08	0	0	3	4	20.2	10.1	0	0
10-May	1	5	10.1	7.6	0	0	2	5	12.6	5.0	0	0	3	5	15.1	10.1	0	0
10-May	1	6	15.1	10.08	0	0	2	6	22.7	10.08	0	0	3	6	25.2	10.1	0	0
10-May	1	7	25.2	10.1	0	1	2	7	0.0	0.0	0	0	3	7	20.2	12.6	0	0
10-May	1	8	20.2	7.56	0	0	2	8	20.2	10.08	0	0	3	8	30.2	10.1	0	0

Table B.5 continued

Table B.5: Height, width and flowering data for *Echinacea purpurea* (Purple Coneflower). The dates are all for 2009, ‘RG’ stands for rain garden, ‘#fls’ for number of flowers and ‘#ufls’ for the number of unopened flowers. Each ‘Plant’ number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month.

Table B.5 continued

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
10-Jun	1	1	63.0	15.1	4	0	2	1	60.5	25.2	4	0	3	1	60.5	17.6	6	0
10-Jun	1	2	63.0	17.6	5	0	2	2	78.1	32.76	22	1	3	2	47.9	20.2	3	0
10-Jun	1	3	52.9	17.6	2	0	2	3	60.5	20.2	7	0	3	3	50.4	17.6	5	0
10-Jun	1	4	47.9	17.6	2	0	2	4	45.4	15.12	0	0	3	4	47.9	17.6	1	0
10-Jun	1	5	22.7	12.6	0	0	2	5	47.9	10.1	1	0	3	5	32.8	12.6	1	0
10-Jun	1	6	45.4	15.12	4	0	2	6	55.4	15.12	2	0	3	6	2.5	10.1	3	0
10-Jun	1	7	83.2	17.6	5	1	2	7	20.2	10.1	0	0	3	7	50.4	20.2	4	0
10-Jun	1	8	52.9	17.64	1	0	2	8	58.0	17.64	4	0	3	8	68.0	22.7	7	0

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
10-Jul	1	1	93.2	20.2	4	0	2	1	58.0	15.1	0	0	3	1	101	25.2	5	3
10-Jul	1	2	93.2	25.2	5	5	2	2	106	35.3	22	3	3	2	70.6	17.6	5	0
10-Jul	1	3	83.2	25.2	2	2	2	3	83.2	25.2	7	0	3	3	83.2	25.2	5	0
10-Jul	1	4	83.2	17.6	2	0	2	4	68.0	20.2	0	1	3	4	83.2	17.6	1	2
10-Jul	1	5	25.2	12.6	0	0	2	5	90.7	12.6	1	1	3	5	52.9	15.1	1	0
10-Jul	1	6	70.6	20.2	4	1	2	6	88.2	17.6	4	0	3	6	55.4	12.6	3	0
10-Jul	1	7	95.8	20.2	6	2	2	7	25.2	15.1	0	0	3	7	83.2	22.7	8	3
10-Jul	1	8	88.2	20.2	3	6	2	8	90.7	22.7	4	3	3	8	98.3	22.7	7	2

Table B.5 continued

Table B.5 continued

Date	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls	RG	Plant	height	width	# fls	#ufls
			cm	cm					cm	cm					cm	cm		
7-Aug	1	1	83.2	20.2	4	0	2	1	0	0	0	0	3	1	98.3	20.2	7	0
7-Aug	1	2	95.8	27.7	8	0	2	2	106	35.3	26	0	3	2	70.6	17.6	3	0
7-Aug	1	3	83.2	17.6	3	0	2	3	83.2	22.7	7	0	3	3	83.2	17.6	5	0
7-Aug	1	4	83.2	15.1	2	0	2	4	70.6	17.6	1	0	3	4	85.7	15.1	3	0
7-Aug	1	5	22.7	12.6	0	0	2	5	93.2	12.6	2	0	3	5	55.4	10.1	1	0
7-Aug	1	6	70.6	20.2	5	0	2	6	88.2	20.2	4	0	3	6	55.4	12.6	3	0
7-Aug	1	7	98.3	17.6	2	1	2	7	20.2	12.6	0	0	3	7	88.2	22.7	9	0
7-Aug	1	8	88.2	20.2	8	0	2	8	93.2	17.6	6	1	3	8	101	22.7	8	2

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-May	1	1	7.56	10.1	0	2	1	12.6	10.1	0	3	1	12.6	7.56	0
10-May	1	2	10.1	7.56	0	2	2	7.56	7.56	0	3	2	17.6	10.1	0
10-May	1	3	10.1	10.1	0	2	3	10.1	7.56	0	3	3	12.6	7.56	0
10-May	1	4	12.6	12.6	0	2	4	15.1	7.56	0	3	4	7.56	5.04	0
10-May	1	5	12.6	15.1	0	2	5	15.1	10.1	0	3	5	12.6	10.1	0
10-May	1	6	17.6	10.1	0	2	6	12.6	7.56	0	3	6	7.56	10.1	0
10-May	1	7	15.1	12.6	0	2	7	12.6	10.1	0	3	7	0.0	0.0	0
10-May	1	8	7.56	10.1	0	2	8	15.1	7.56	0	3	8	7.6	5.04	0
10-May	1	9	10.1	10.1	0	2	9	10.1	7.56	0	3	9	0.0	0.0	0
10-May	1	10	12.6	10.1	0	2	10	12.6	7.56	0	3	10	0.0	0.0	0
10-May	1	11	12.6	12.6	0	2	11	12.6	7.56	0	3	11	10.1	7.56	0
10-May	1	12	12.6	10.1	0	2	12	12.6	7.56	0	3	12	12.6	10.1	0
10-May	1	13	12.6	12.6	0	2	13	12.6	10.1	0	3	13	12.6	10.1	0
10-May	1	14	12.6	10.1	0	2	14	0.0	0.0	0	3	14	7.56	7.56	0
10-May	1	15	12.6	12.6	0	2	15	12.6	7.56	0	3	15	10.1	7.56	0
10-May	1	16	15.1	10.1	0	2	16	17.6	10.1	0	3	16	15.1	10.1	0
10-May	1	17	12.6	10.1	0	2	17	7.56	7.56	0	3	17	7.56	5.04	0
10-May	1	18	15.1	10.1	0	2	18	12.6	7.56	0	3	18	7.56	5.04	0

Table B.6 continued

Table B.6: Height, width and flowering data for *Eragrostis spectabilis* (Purple Lovegrass). The dates are all for 2009, 'RG' stands for rain garden, and '#fls' for number of flowers. Each 'Plant' number corresponds to the layout in Figure 2.2, and makes comparisons for each plant possible from month to month

Table B.6 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jun	1	1	15.1	12.6	0	2	1	27.7	12.6	0	3	1	17.6	10.1	0
10-Jun	1	2	12.6	10.1	0	2	2	17.6	10.1	0	3	2	25.2	10.1	0
10-Jun	1	3	17.6	10.1	0	2	3	25.2	12.6	0	3	3	25.2	12.6	0
10-Jun	1	4	27.7	12.6	0	2	4	25.2	10.1	0	3	4	17.6	7.56	0
10-Jun	1	5	25.2	12.6	0	2	5	22.7	10.1	0	3	5	20.2	15.1	0
10-Jun	1	6	22.7	15.1	0	2	6	25.2	12.6	0	3	6	20.2	15.1	0
10-Jun	1	7	30.2	15.1	0	2	7	17.6	12.6	0	3	7	0.00	0.00	0
10-Jun	1	8	25.2	10.1	0	2	8	15.1	12.6	0	3	8	12.6	5.04	0
10-Jun	1	9	22.7	12.6	0	2	9	20.2	10.1	0	3	9	12.6	5.04	0
10-Jun	1	10	30.2	12.6	0	2	10	27.7	12.6	0	3	10	0.00	0.00	0
10-Jun	1	11	20.2	12.6	0	2	11	20.2	10.1	0	3	11	20.2	12.6	0
10-Jun	1	12	25.2	15.1	0	2	12	20.2	12.6	0	3	12	22.7	12.6	0
10-Jun	1	13	22.7	15.1	0	2	13	22.7	12.6	0	3	13	20.2	15.1	0
10-Jun	1	14	20.2	12.6	0	2	14	0.00	0.00	0	3	14	12.6	7.56	0
10-Jun	1	15	27.7	12.6	0	2	15	22.7	12.6	0	3	15	27.7	10.1	0
10-Jun	1	16	30.2	12.6	0	2	16	22.7	17.6	0	3	16	22.7	15.1	0
10-Jun	1	17	27.7	15.1	0	2	17	22.7	10.1	0	3	17	12.6	7.56	0
10-Jun	1	18	25.2	17.6	0	2	18	22.7	12.6	0	3	18	12.6	5.04	0

Table B.6 continued

Table B.6 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
10-Jul	1	1	22.7	15.1	0	2	1	37.8	20.2	0	3	1	25.2	12.6	0
10-Jul	1	2	20.2	15.1	0	2	2	25.2	12.6	0	3	2	27.7	12.6	0
10-Jul	1	3	30.2	17.6	0	2	3	30.2	17.6	0	3	3	25.2	10.1	0
10-Jul	1	4	32.8	15.1	0	2	4	32.8	15.1	0	3	4	27.7	7.56	0
10-Jul	1	5	27.7	15.1	0	2	5	25.2	10.1	0	3	5	25.2	12.6	0
10-Jul	1	6	37.8	27.7	0	2	6	30.2	10.1	0	3	6	25.2	10.1	0
10-Jul	1	7	32.8	25.2	0	2	7	27.7	10.1	0	3	7	0.0	0.0	0
10-Jul	1	8	30.2	12.6	0	2	8	20.2	10.1	0	3	8	22.7	5.0	0
10-Jul	1	9	32.8	17.6	0	2	9	25.2	12.6	0	3	9	22.7	7.56	0
10-Jul	1	10	27.7	20.2	0	2	10	30.2	15.1	0	3	10	0.0	0.0	0
10-Jul	1	11	30.2	22.7	0	2	11	27.7	15.1	0	3	11	20.2	15.1	0
10-Jul	1	12	30.2	20.2	0	2	12	30.2	12.6	0	3	12	25.2	15.1	0
10-Jul	1	13	30.2	20.2	0	2	13	32.8	12.6	0	3	13	22.7	15.1	0
10-Jul	1	14	30.2	22.7	0	2	14	0.0	0.0	0	3	14	12.6	7.56	0
10-Jul	1	15	32.8	20.2	0	2	15	25.2	15.1	0	3	15	17.6	12.6	0
10-Jul	1	16	30.2	17.6	0	2	16	32.8	17.6	0	3	16	22.7	15.1	0
10-Jul	1	17	32.8	15.1	0	2	17	25.2	12.6	0	3	17	25.2	7.56	0
10-Jul	1	18	35.3	20.2	0	2	18	27.7	15.1	0	3	18	15.1	7.56	0

Table B.6 continued

Table B.6 continued

Date	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls	RG	Plant	height	width	# fls
			cm	cm				cm	cm				cm	cm	
7-Aug	1	1	30.2	15.1	0	2	1	35.3	20.2	8	3	1	30.2	10.1	0
7-Aug	1	2	22.7	15.1	0	2	2	27.7	12.6	4	3	2	27.7	12.6	1
7-Aug	1	3	22.7	15.1	2	2	3	20.2	17.6	9	3	3	27.7	15.1	4
7-Aug	1	4	32.8	20.2	0	2	4	37.8	15.1	2	3	4	20.2	7.56	2
7-Aug	1	5	27.7	15.1	0	2	5	25.2	12.6	3	3	5	22.7	12.6	2
7-Aug	1	6	25.2	20.2	5	2	6	27.7	15.1	4	3	6	22.7	12.6	2
7-Aug	1	7	35.3	17.6	8	2	7	20.2	15.1	0	3	7	0.0	0.0	0
7-Aug	1	8	22.7	12.6	1	2	8	25.2	17.6	2	3	8	22.7	5.04	0
7-Aug	1	9	30.2	10.1	0	2	9	20.2	12.6	0	3	9	17.6	7.56	0
7-Aug	1	10	35.3	15.1	4	2	10	30.2	12.6	2	3	10	0.0	0.0	0
7-Aug	1	11	30.2	12.6	5	2	11	17.6	7.56	1	3	11	20.2	12.6	1
7-Aug	1	12	30.2	146.2	8	2	12	30.2	17.6	2	3	12	25.2	12.6	3
7-Aug	1	13	2.52	15.1	8	2	13	30.2	17.6	4	3	13	12.6	15.1	0
7-Aug	1	14	17.6	15.1	8	2	14	0.0	0.0	0	3	14	7.56	2.52	0
7-Aug	1	15	30.2	17.6	7	2	15	25.2	15.1	0	3	15	20.2	12.6	1
7-Aug	1	16	32.8	15.1	6	2	16	30.2	15.1	3	3	16	25.2	15.1	4
7-Aug	1	17	30.2	15.1	6	2	17	22.7	10.1	0	3	17	17.6	7.56	0
7-Aug	1	18	32.8	17.6	9	2	18	27.7	15.1	7	3	18	12.6	7.56	0

APPENDIX C: :Data from 11-day simulated storm event experiment

Water Meter	Start Time	8:35 AM	9/15/2008
	End Time	9:25 AM	9/16/2008
Time	Reading	Comments	
	gallons		
8:35	6015.5	6 gal/min	
9:40	6369.2		
11:40	7010.5		
12:35	7297.0		
13:05	7455.4	reduced to 4.0 gallon/min	
14:05	7708.8		
14:35	7836.0	reduced to 3.0 gallon/min	
15:35	8017.5		
17:35	8374.8		
18:35	8568.4	reduced to 2.0 gallon/min	
21:05	8882.3		
22:35	9033.6		
2:35	9507.9	9/15/2008	
5:05	9785.8	reduced to 1.0 gallon/min	
9:15	10005.0		
9:25	10080.0	stop	

Table C.1: Water meter readings for Rain Garden 1, which indicates the flow of water into the influent during the experiment.

Water Meter	Start Time	8:05	9/28/3008
	End Time	15:25	9/29/2008
Time	Reading	Comments	
	gallons		
8:05	32287.1	6.0 gal/min	
9:05	32644.5		
10:05	33014.5		
11:05	33385.5		
12:05	33805.9		
13:05	34225.4	reduced to 4.5 gal/min	
15:05	34754.6	reduced to 3.5 gal/min	
14:05	35363.5	reduced to 2.5 gal/min	
16:05	35688.5		
20:05	36330.3		
2:35	36650.8	9/29/2008	
4:35	36973.8		
6:35	37294.6		
15:15	38716.5	shut down	

Table C.2: Water meter readings for Rain Garden 2, which indicates the flow of water into the influent during the experiment.

Water Meter	Start Time	8:00	9/24/2008
	End Time	9:00	9/25/2008
Time	Reading	Comments	
	gallons		
800	27870.0	6.0 gallons/min	
900	28231.7		
1030	28776.5		
1200	29316.3		
1300	29698.0	reduced to 4.0 gallon/min	
1500	30211.8	reduced to 3.0 gallon/min	
1600	30398.0		
1800	30768.6	reduced to 2.0 gallon/min	
2226	31314.5	10/25/2008	
430	32021.5		
500	32079.4	reduced to 1.0 gallon/min	
730	32204.2		
900	32286.8	shut down	

Table C.3: Water meter readings for Rain Garden 3, which indicates the flow of water into the influent during the experiment.

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL (5 sec)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	mL (5 sec)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
start time [b]	8:00										
initial	8:50	77	0.2566	0.0266	0.0092	0.1881	80	0.0204	0.0077	0.0000	0.0524
0.5	9:20	275	0.0712	0.0082	0.0000	0.0995	255	0.0708	0.0078	0.0000	0.0913
1.0	9:50	350	0.0400	0.0056	0.0000	0.0792	270	0.0255	0.0052	0.0000	0.0495
1.5	10:20	400					320				
2.0	10:50	520	0.0152	0.0040	0.0000	0.0587	350	0.0056	0.0036	0.0000	0.0170
2.5	11:20	570					365				
3.0	11:50	610	0.0101	0.0036	0.0000	0.0407	370	0.0043	0.0039	0.0000	0.0080
3.5	12:20	720					380				
4.0	12:50	735					380				
4.5	13:20	750					360				
5.0	13:50	755					350				

[a] Time recorded with the reference of Eastern Daylight Savings
[b] Time at which the experiment began; water began to flow to the inlet

Table C.4 continued

Table C.4: First Effluent data for Rain Garden 1. The third runoff event (day 11 of the experiment) began on 15 September 2008. Data from Pipe A and B combined with Pipe C and D were used to calculate the flow rate from the anaerobic zone for that time interval, and subsequently, determine the flow-weighted mean concentration (FWMC) values in Tables 3.2 and 3.3. Water was collected from each pipe for 5 seconds. The volume amount recorded is a combination of the discharge from both pipes.

Table C.4 continued

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
5.5	14:20	785					370				
6.0	14:50	745					370				
7.0	15:50	730					365				
8.0	16:50	690					360				
9.0	17:50	640					380				
10.0	18:50	620					390				
12.0	20:50	505					350				
14.0	22:50	425					300				
16.0	0:50 [c]	370					265				
18.0	2:50	355					245				
20.0	4:50	330					245				
22.0	6:50	235					195				
24.0	8:50	195					170				

[c] Measurements were taken on the following day, 16 September 2008

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
start time [b]	8:05										
initial	8:25	10	0.0022	0.0038	0.0000	0.0104	30	0.0046	0.0031	0.0000	0.017
0.5	8:55	95	0.0225	0.0027	0.0000	0.0684	90	0.0071	0.0037	0.0000	0.0096
1.0	9:25	105	0.0123	0.0027	0.0000	0.0152	135	0.0044	0.0027	0.0000	0.0084
1.5	9:55	110					155				
2.0	10:25	130	0.0087	0.0024	0.0000	0.0103	185	0.002	0.003	0.0000	0.0068
2.5	10:55	145					205				
3.0	11:25	160					245				
3.5	11:55	190					315				
4.0	12:25	250					290				
4.5	12:55	265					325				
5.0	13:25	255					335				

[a] Time recorded with the reference of Eastern Daylight Savings
[b] Time at which the experiment began; water began to flow to the inlet

Table C.5 continued

Table C.5: First Effluent data for Rain Garden 2. The third runoff event (day 11 of the experiment) began on 28 September 2008. Data from Pipe A and B combined with Pipe C and D were used to calculate the flow rate from the anaerobic zone for that time interval, and subsequently, determine the flow-weighted mean concentration (FWMC) values in Tables 3.2 and 3.3. Water was collected from each pipe for 5 seconds. The volume amount recorded is a combination of the discharge from both pipes.

Table C.5 continued

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	mL (5 sec)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
5.5	13:55	245					325				
6.0	14:25	245					310				
7.0	15:25	250					530				
8.0	16:25	195					325				
9.0	17:25	195					325				
10.0	18:25	195					295				
12.0	20:25	135					200				
14.0	22:25	110					195				
16.0	24:25	85					155				
18.0	2:25 [c]	70					140				
20.0	4:25	65					115				
22.0	6:25	50					110				
24.0	8:25	50					120				
26 hr	10:25	50					140				
31 hr	15:25	60					150				

[c] Measurements were taken on the following day, 29 September 2008

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL $(5\ sec)^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	mL $(5\ sec)^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
start time [b]	8:00										
initial	8:25	70	0.0328	0.0000	0.003	10.1321	40	0.0311	0.0000	0.0033	7.5504
0.5	8:55	165	0.0281	0.0000	0.0051	54.6684	120	0.0297	0.0000	0.0048	18.5867
1.0	9:25	215	0.0269	0.0000	0.0056	48.7045	170	0.0291	0.0000	0.0059	36.718
1.5	9:55	270					190				
2.0	10:25	300	0.0297	0.0000	0.0059	37.6073	230	0.0321	0.0000	0.007	20.7741
2.5	10:55	340					250				
3.0	11:25	340					280				
3.5	11:55	370					345				
4.0	12:25	375					350				
4.5	12:55	270					525				
5.0	13:25	250					505				

[a] Time recorded with the reference of Eastern Daylight Savings
[b] Time at which the experiment began; water began to flow to the inlet

Table C.6 continued

Table C.6: First Effluent data for Rain Garden 3. The third runoff event (day 11 of the experiment) began on 24 September 2008. Data from Pipe A and B combined with Pipe C and D were used to calculate the flow rate from the anaerobic zone for that time interval, and subsequently, determine the flow-weighted mean concentration (FWMC) values in Tables 3.2 and 3.3. Water was collected from each pipe for 5 seconds. The volume amount recorded is a combination of the discharge from both pipes.

Table C.6 continued

From start	Actual time [a]	Pipe A and B	Effluent metal concentration for Pipe A and B				Pipe C and D	Effluent metal concentration for Pipe C and D			
			Cu	Cr	Pb	Zn		Cu	Cr	Pb	Zn
hr		mL $(5\ sec)^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	mL $(5\ sec)^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
5.5	13:55	210					545				
6.0	14:25	230					555				
7.0	15:25	235					580				
8.0	16:25	210					580				
9.0	17:25	220					590				
10.0	18:25	215					560				
12.0	20:25	215					490				
14.0	22:25	185					460				
16.0	24:25	170					445				
18.0	2:25 [c]	145					400				
20.0	4:25	125					405				
22.0	6:25	75					340				
24.0	8:25	95					245				

[c] Measurements were taken on the following day, 25 September 2008

Table C.7 continued

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
start time [c]	8:35					
initial [d]	9:10		0.0049	0.0048	0.0000	0.0064
0.5	9:40	67.3	0.0036	0.0044	0.0000	0.0048
1.0	10:10	166.7	0.0029	0.0034	0.0000	0.0058
1.5	10:40	225.2				
2.0	11:10	257.4	0.0000	0.0038	0.0000	0.0039
2.5	11:40	284.7				
3.0	12:10	307.1	0.0000	0.0032	0.0000	0.0043
3.5	12:40	325.7				
4.0	13:10	339.3				
4.5	13:40	370.5				
5.0	14:10	375.4				

[a] Time recorded with the reference of Eastern Daylight Savings
[b] As determined by a calibrated tipping bucket (CR3000 data logger).
[c] Time at which the experiment began; water began to flow to the inlet
[d] There is no volume data for the initial sample because it represents the first flush and no tipping bucket data was recorded before this time.

Table C.7: Second Effluent data for Rain Garden 1. The third runoff event (day 11 of the experiment) began on 15 September 2008. Effluent volumes were constantly recorded through the use of a calibrated tipping bucket and a CR3000 Data Logger System (Campbell Scientific, Logan, UT).

Table C.7 continued

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
5.5	14:40	385.1				
6.0	15:10	377.3				
7.0	16:10	758.6				
8.0	17:10	694.2				
9.0	18:10	638.6				
10.0	19:10	613.3				
12.0	21:10	1063.7				
14.0	23:10	887.3				
16.0	1:10 [e]	779.0				
18.0	3:10	718.6				
20.0	5:10	687.4				
22.0	7:10	586.0				
24.0	9:10	449.5				

[e] Measurements were taken on the following day, 16 September 2008

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
start time [c]	8:05					
initial	9:30		0.00800	0.00350	0.0000	0.01780
1.0	10:30		0.00340	0.00350	0.0000	0.01040
2.0	11:30		0.00200	0.00380	0.0000	0.00470
3.0	12:30					
4.0	13:30		0.0000	0.00330	0.0000	0.0000
5.0	14:30					
6.0	15:30					
7.0	16:30					
8.0	17:30					
9.0	18:30					
11.0	20:30					
13.0	22:30					

[a] Time recorded with the reference of Eastern Daylight Savings
[b] Due to a slow leak in the aerobic zone, accurate data are not available
[c] Time at which the experiment began; water began to flow to the inlet
[d] There is no volume data for the initial sample because it represents the first flush and no tipping bucket data was recorded before this time.

Table C.8 continued

Table C.8: Second Effluent data for Rain Garden 2. The third runoff event (day 11 of the experiment) began on 28 September 2008. Accurate effluent volumes were unable to be obtained due to a slow leak in the aerobic zone.

Table C.8 continued

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
15.0	0:30 [d]					
17.0	2:30					
19.0	4:30					
21.0	6:30					
23.0	8:30					
25.0	10:30					

[e] Measurements were taken on the following day, 29 September 2008

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}	μg mL^{-1}
start time [c]	8:00					
initial [d]	9:05		0.02540	0.0000	0.00480	11.38600
0.5	9:35	61.7	0.02650	0.0000	0.00430	28.24750
1.0	10:05	102.5	0.02720	0.0000	0.00450	31.48090
1.5	10:35	130.3				
2.0	11:05	152.2	0.02900	0.0000	0.00360	30.25810
2.5	11:35	173.1				
3.0	12:05	206.0				
3.5	12:35	236.8				
4.0	13:05	293.5				
4.5	13:35	260.7				
5.0	14:05	265.7				

[a] Time recorded with the reference of Eastern Daylight Savings
[b] As determined by a calibrated tipping bucket (CR3000 data logger).
[c] Time at which the experiment began; water began to flow to the inlet
[d] There is no volume data for the initial sample because it represents the first flush and no tipping bucket data was recorded before this time.

Table C.9 continued

Table C.9: Second Effluent data for Rain Garden 1. The third runoff event (day 11 of the experiment) began on 24 September 2008. Effluent volumes were constantly recorded through the use of a calibrated tipping bucket and a CR3000 Data Logger System (Campbell Scientific, Logan, UT).

Table C.9 continued

From start	Actual time [a]	Effluent Volume [b]	Effluent metal concentration for Pipe A and B			
			Cu	Cr	Pb	Zn
hr		mL (time period)$^{-1}$	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}	µg mL^{-1}
5.5	14:35	249.7				
6.0	15:05	255.7				
7.0	16:05	546.3				
8.0	17:05	507.5				
9.0	18:05	488.5				
10.0	19:05	477.6				
12.0	21:05	879.6				
14.0	23:05	791.0				
16.0	1:05 [e]	723.4				
18.0	3:05	676.6				
20.0	5:05	648.7				
22.0	7:05	555.2				
24.0	9:05	417.9				

[e] Measurements were taken on the following day, 25 September 2008