sources of water (groundwater, surface water, stormwater, recycled water, etc.) will be necessary to achieve basin sustainability, and as such, GSPs should be viewed as an integrated resources management plan, and their preparation and implementation should be coordinated with other integrated plans such as Integrated Regional Water Management Plans, Stormwater Resources Plans, and Integrated Watershed Plans.

Once the selected management actions and projects are implemented, GSAs will need to review the results, and will likely need to adjust their GSPs accordingly. In this sense, GSAs should include in the GSP a long-term plan for adaptive management which will help each basin reach its sustainability goals. Implementation is a long-term event that will be a challenging process for many GSAs, involving:

- Obtaining buy-in on GSP programs and actions (thereby avoiding legal challenges)
- Completing ongoing monitoring for compliance, administration of programs, and to fill data gaps
- Enforcing new rules, ordinances and programs
- Completing adaptive management and adjusting GSPs regularly to meet changing conditions

Given that GSP implementation has the ability to impact the groundwater users within each basin, GSAs must also ensure that the GSP preparation and implementation processes are conducted with stakeholder involvement. Including stakeholders in an open and transparent process will help to secure stakeholder buy-in, and reduce conflicts that may otherwise result in lawsuits or other challenges that could delay SGMA compliance. Agencies may find efficiencies in stakeholder involvement by engaging with existing stakeholder processes, such as the Integrated Regional Water Management (IRWM) framework, to reach out to established groups of stakeholders with an interest in water management. Documentation of outreach and integration processes, both during GSP preparation and implementation, will be required to demonstrate compliance with the public outreach and participation requires of Chapter 6 of the SGMA legislation.

Once a GSP has been completed, the plan must be adopted by the GSAs. The GSPs then are to be submitted to the State for review and acceptance. After State review of the initial adopted plan, the GSP will be posted to State's website for a 60-day public comment period. The State will then have two years to review the plans to evaluate the GSP's adequacy. GSPs will ultimately be deemed as either adequate, conditionally adequate, or inadequate. If deemed inadequate, the State may take control of the groundwater basin.

CONCLUSION

All in all, there will be many variables and challenges faced by GSAs to comply with the provisions of SGMA. To ensure success, agencies must take a proactive approach to acquiring funding, developing and implementing GSPs, and achieving stakeholder buy-in. As regulators in California continue to develop regulations and guidance documents that clarify how SGMA compliance will be tracked and measured, GSAs must keep abreast to these changes so that compliance can be maintained.

As GSAs near the June 30, 2017 deadline for application, many are now turning to the GSP preparation phase. One significant question that all GSAs are grappling with is how will this work be paid for? The answer, unfortunately, is not a simple one. Through the passage of Proposition 1, the *Water Quality, Supply, and Infrastructure Improvement Act of 2014*, the State has (or will shortly be), making approximately $90 million available on a statewide, competitive basis for projects that develop and implement sustainable groundwater planning and projects. However, given the amount of demand for this money, GSAs will need to consider additional funding sources. A second funding option for GSAs will be to self-fund the GSP development. Depending upon the way in which GSAs are formed and the area covered by the GSA(s), agencies can potentially share the costs associated with developing the GSP. A third funding option is to implement new funding streams via a pumping tax, replenishment fee, or other long-term funding mechanism. This third option must be implemented carefully, with agencies making sure to complete proper noticing and due diligence to ensure compliance with Propositions 26 and 218 and other legal requirements.

SGMA compliance is going to be a long-term and challenging process. While initial steps such as establishing a basin budget and sustainability goals and measurement criteria will be finite and technical in nature, proactive and regular engagement of stakeholders in the groundwater basin by GSAs will be critical to obtaining program buy-in and avoiding legal actions. There's going to be significant competition for alternative water supplies statewide, and development of a flexible water market could significantly improve on the statewide success of SGMA. Additionally, the economic, social and environmental impacts of the various management actions and programs enacted via the GSPs to achieve sustainability will also have to be considered. Long-term monitoring is going to be key in administering the GSP, documenting progress towards sustainability goals, and providing the necessary feedback for adaptive management - a critical step in successful sustainability management. GSPs are going to have to be updated and refined every five years, and success at meeting interim milestones will be key to avoiding State control in the short-term.

The goals of SGMA are achievable, but not without cost. It will be important for all groundwater users to participate in the GSP preparation and implementation processes, and for everyone to put aside differences and focus on the problem at hand. Thinking 'outside the box' will be crucial in developing solutions, and flexibility by all parties essential to the successful achievement of groundwater sustainability.

REFERENCES

Sustainable Groundwater Management Act, Senate Bill (SB) 1168, Assembly Bill (AB) 1739 and SB 1319 as Chaptered. November 2014.

California Code of Regulations, Title 23. Waters. Division 2. Department of Water Resources. Chapter 1.5. Groundwater Management. Subchapter 2. Groundwater Sustainability Plans. July 2016.

California Department of Water Resources. (2016). *Groundwater Sustainability Agencies*. As viewed at http://www.water.ca.gov/groundwater/sgm/gsa.cfm. January 19, 2017.

Evaluation of Soil Mixes in Shallow Bioretention Systems

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Abstract

Bioretention systems have become common in stormwater management. Bioretention typically requires a large footprint to accommodate required water quality volumes, which may not be feasible in high traffic areas such as ferry terminals, bridges, and other urban areas. Shallow, portable planters with sandy loam and compost were evaluated for zinc and copper retention using synthetic stormwater. The addition of vermiculite, tree bark, and plants (tufted hairgrass) were evaluated. The mass of zinc retained was consistently greater than 90% for both the vermiculite and tree bark systems, and greater than 80% for all planters in every test. Copper and zinc retention varied with each simulated storm event in the control and tufted hairgrass systems. To better understand copper and zinc distribution within the bioretention systems, simulations were conducted in Hydrus 2D. Model simulations showed copper and zinc accumulating near the surface, indicating physical processes are likely the primary mechanism of metal retention in the planters. Our results indicate that shallow bioretention systems, which have a relatively small footprint, effectively retain copper and zinc.

Introduction

Heavy metals, such as zinc and copper, are contaminants of concern in stormwater runoff, and can negatively impact aquatic ecosystems. Free copper ions are well-documented algaecides, and zinc is also known to negatively affect growth and reproduction in many aquatic organisms (EPA, 2011). Non-point sources of stormwater runoff in urban areas, such as vehicles in parking lots, highways, and roadways, contribute large concentrations of these metals in stormwater during a storm event (Davis et al., 2001). A significant source of copper and zinc in stormwater is from vehicles on roadways (Nwaneshiudu, 2004). The water quality of bridge deck runoff has been found to be statistically the same as roadway runoff (Malina et al., 2005; URS, 2010). In high traffic, impervious areas, particularly at ferry terminals where vehicles are frequently stopping and starting, these pollutants could potentially accumulate and significantly impact sensitive receiving waters.

One of the benefits of bioretention systems is the ability to treat stormwater close to the pollutant source by adsorption, precipitation, filtration, chemical reactions within the soil, and plant uptake. Bioretention systems typically require a large, centralized area, which is not practical or economical in many urban areas. Bioretention is difficult to impossible to use for paved areas with little to no adjacent land areas such as ferry terminals and bridges. Typically, little to no stormwater treatment occurs at ferry terminals and on bridges. A few ferry terminals, such as the Whidbey Island terminal in Washington, have landside treatment systems, and there are some bridges where stormwater is conveyed back to land for treatment (Winston et al, 2015). The

National Cooperative Highway Research Program (NCHRP) lists swales, dry detention basins, bioretention, and sand filters as suitable landside treatment methods, and only one effective treatment method, replacing the pavement with permeable friction course (PFC), on the bridge deck (Taylor et al., 2014). Conveying stormwater back to land areas is often very expensive and not always feasible in urban areas due to space constraints. Replacing the bridge deck pavement with PFC can also be cost prohibitive. Smaller, less expensive bioretention planters that are small enough to be installed directly on a ferry terminal or bridge is one potential solution; these systems could provide a low-cost, sustainable alternative for stormwater treatment.

The objective of this research was to investigate how retention of copper and zinc varies over multiple storm events in shallow bioretention systems using sustainable, inexpensive, and effective soil media variations. Results were used to develop model simulations in Hydrus 2D. Using four separate shallow bioretention systems with varying media, synthetic stormwater with high concentrations of zinc and copper typical of high vehicular traffic in an urban environment were applied to the units. Influent and effluent concentrations were used in Hydrus 2D simulations to better understand the effectiveness of shallow bioretention systems and the dominant mechanisms of copper and zinc retention.

Methods

The bioretention systems were designed as fiberglass boxes that can easily be installed and removed in impervious surfaces. The fiberglass boxes were 30.5 cm x 91.4 cm, which is small enough to be placed in the drains of ferry terminals, or can be installed on the side of a bridge. Four separate fiberglass boxes of equal dimensions were used; each had three equally spaced (22.9 cm apart) holes drilled through the underside of the box for adequate drainage (Figure 1). Geotextile fiber was then placed between each layer of media to prevent soil losses from the boxes. All soil media was purchased from Wittkopf Landscape Supplies located in Spokane, WA. A sandy loam bottom layer was placed in all four fiberglass boxes with a thickness of 10.2 cm. All units had a 10.2-cm top layer that consisted of:

- Control: 100% compost
- Vermiculite: 10% vermiculite, 90% compost
- Tree Bark: 10% tree bark, 90% compost
- Vegetated: 100% compost, 4 tufted hair grass plants

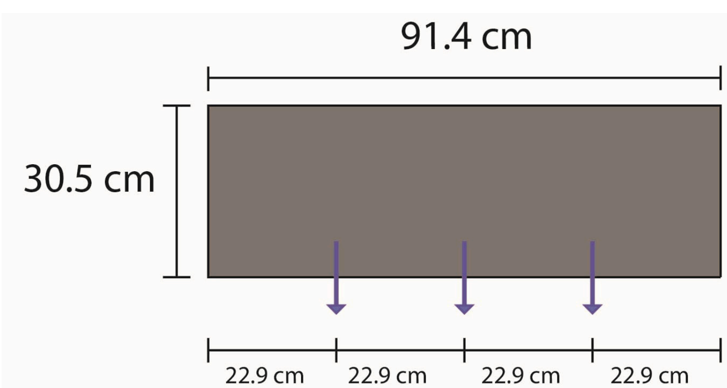

Figure 1. Profile of fiberglass boxes showing drainage locations.

Tufted hair grass is native to the Pacific Northwest region, and a common bioretention plant. The plants were planted in the unit 6 weeks prior to beginning the experiments to allow for establishment. A visual representation of the unit with 4 established tufted hair grass plants is shown in Figure 2. The other three units were constructed similarly.

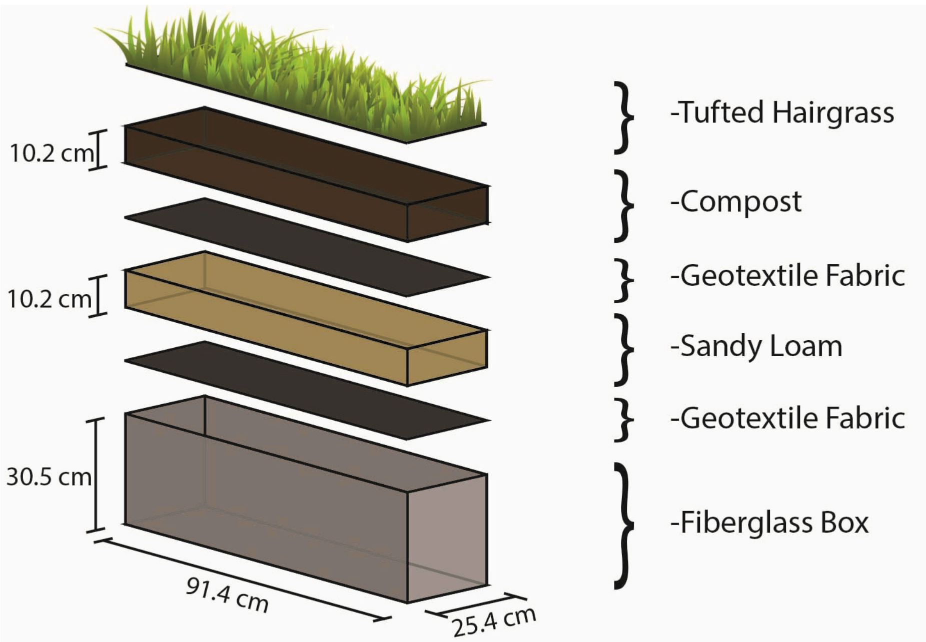

Figure 2. Diagram of Vegetated Unit Components.

Units were tested with synthetic stormwater containing zinc and copper at concentrations typically observed in traffic jams, ferry terminals, and gas stations where vehicles idle and breaks are applied often (Schueler 2000). Synthetic rainwater was first made using methods similar to Thomas et al. (2015), then zinc and copper was added. The total volume of each stormwater batch was 11.375 L, with zinc and copper concentrations of 580 µg/L and 100 µg/L, respectively. The volume of water applied to the system was based on the time it took the control unit to begin ponding after water was applied at a rate of 3.78 L/min (1 gallon/min). Ponding occurred after 3 minutes, which corresponded to 11.375L (3 gallons) applied to the system. To total volume of effluent was collected from each unit.

A sample of the influent stormwater was collected before the stormwater was applied to each bioretention unit. Effluent volumes were measured at each drainage point before a composite sample was taken. This process occurred weekly for 4 weeks for all units. Due to promising results from the control and vegetated units, testing continued for these two units for an additional 6 weeks. An Agilent 7700 ICP-MS was used to analyze for zinc and copper. Using the resulting concentrations and volumes, a mass balance was performed for each simulated storm event to determine the total percentage of zinc and copper retained by mass for each simulated storm event.

Hydrus 2D software was used to simulate solute transport over time in the units during testing. Hydrus 2D is a modeling software used to analyze water flow and solute transport in unsaturated, porous media (Šimůnek et al. 2008). The observation points within the simulated bioretention unit were equally spaced vertically to understand the change in concentration of zinc and copper immediately after a storm event. Experimental application rates and influent concentrations were used as inputs to the model. Because the chemical equilibrium constants and biological reaction rates were unknown, chemical partitioning and microbial reactions were not included in the model. Although the model does not include chemical or biological reactions, model simulations can still provide insights into the physical retention mechanisms occurring in the bioretention units.

Results and Discussion

Metals Retention in Bioretention Systems. Significant retention was observed during the first few tests, but decreased with continued testing (Table 1, Figures 3 and 4). All units retained greater than 90% of the zinc initially. After the 4th test, zinc retention decreased slightly in the control and vegetated units (to a minimum of 84% in the control unit). When comparing the influent and effluent zinc concentrations for all four bioretention systems, it is clear that they are all efficient at retaining high levels of zinc.

Table 1. Influent and Effluent Copper and Zinc Concentrations and Percentage of Mass Removed.

	Influent (µg/L)		Effluent (µg/L)		% Removed	
Test	Cu	Zn	Cu	Zn	Cu	Zn
Control						
1	92	594	26	31	94.9	99.1
2	93	601	28	34	83.1	96.8
3	90	605	39	54	61.2	91.9
4	79	625	60	83	33	88.4
5	59	592	74	94	-4.6	86.9
6	36	572	74	98	-70.2	85.6
7	58	580	68	101	4.5	85.9
8	83	581	37	115	64	84
9	86	586	31	88	69.5	87.3
10	96	575	28	78	75.7	88.7
Vermiculite						
1	93.4	565	18.94	6.01	99.4	100
2	94	592	30.14	7.03	83.2	99.4
3	97	605	50.34	12.66	57.4	98.3
4	92	579	65.82	24	39	96.5
Tree Bark						
1	95	615	22.41	14.23	97.7	99.8
2	96	637	29.05	10.31	82.9	99.1
3	95	623	45.13	26.82	58.6	96.3
4	93	618	82.07	54.43	25.6	92.6
Vegetated						
1	87	576	53	21	71.1	98.3
2	88	599	73	27	39.8	96.7
3	93	622	103	58	27.6	93.9
4	91	634	134	90	3.2	90.7
5	92	603	134	84	-3.1	90.1
6	87	591	141	96	-22.5	87.8
7	82	583	54	108	53.9	87
8	82	569	48	98	54.3	86.7
9	84	569	46	92	57.8	87.7
10	83	567	42	76	64.1	89.8

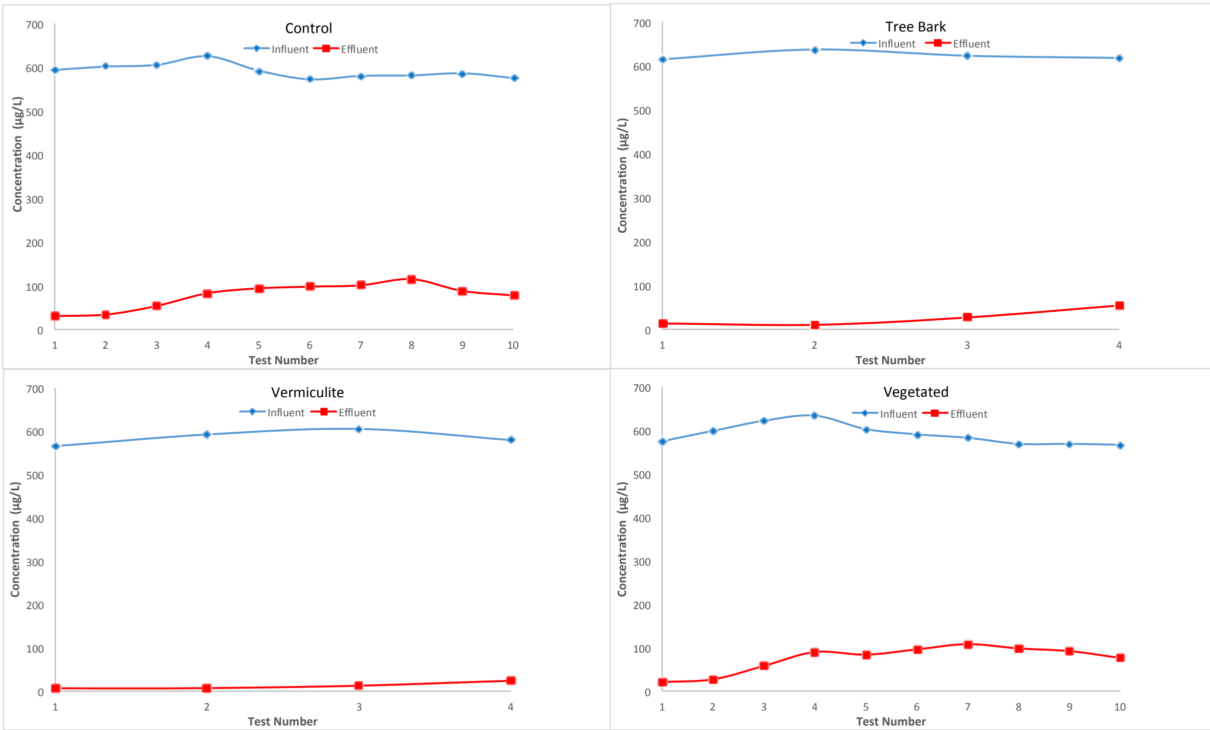

Figure 3. Influent and Effluent Zinc Concentrations for each test.

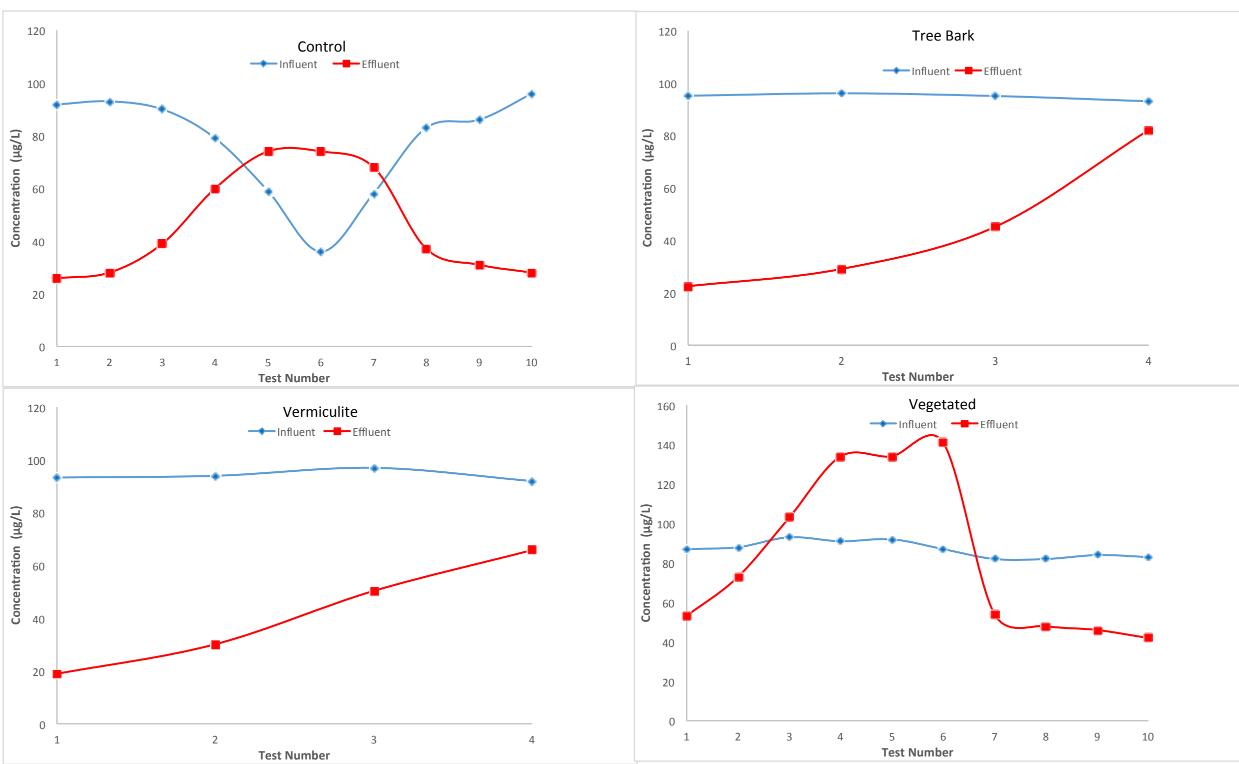

Figure 4. Influent and Effluent Copper Concentrations for each test.

Copper was also retained at high levels initially (71.1-99.4%), but decreased with subsequent testing. The vermiculite unit was the most efficient at retaining copper, and the vegetated unit was the least efficient. During the 4th test, the vermiculite system had the greatest copper retention at 39%, while the living filter system had 3.2%. Export of copper was observed during tests 5 and 6, but then increased to 76% and 64% in the control and vegetated units, respectively. The increase in copper retention after tests 5 and 6 may be due to biological processes. Particularly in the vegetated unit, as the plants become more established the microbial community also becomes more established. This may promote additional uptake and retention than a purely physical filtration process.

A mass balance was performed on the systems to account for evapotranspiration, soil saturation, and when applicable, plant uptake of water. By mass, the bioretention units retained more dissolved copper and zinc than was put into the system. The control and vegetated units consistently retained more than 84% of zinc in all 10 tests, with the vermiculite and tree bark experiments retaining greater than 90% of zinc in the four tests. While the vegetated unit did not retain copper as well as the control unit in the first 4 tests, total copper retention was greater in later tests. The vegetated unit consistently retained a greater percentage of zinc by mass after the first two tests when compared to the control unit (Table 1).

In terms of the overall effectiveness of copper and zinc retention within of all four systems during the four tests, the vermiculite unit was the most efficient. For the units tested 10 times, the vegetated unit was the most efficient at retaining zinc with retention rates consistently ≥86.7%, while the control unit had retention rates ≥84%. An export of 70.2% more copper than the influent was observed with the control unit, while the vegetated unit exported 22.5%. During tests 7-10, copper retention steadily increased in the control unit to 75.7% during the 10th test, while the living filter system exhibited a similar increase in retention to 64.1%. The vegetated unit had a lower copper retention rate by the 10th test, but the overall retention efficiency for all tests was greater than the control unit. When comparing the control unit versus the vegetated unit, the vegetated unit exhibited more efficient copper and zinc retention in later tests, which indicates vegetated systems may be a more effective choice for long-term implementation.

Further research is necessary to understand what mechanisms caused the shallow bioretention systems to start retaining copper in tests 7-10 in both the control and vegetated systems after copper export was observed during tests 5 and 6. Because copper retention in both the vegetated and control units followed the same trend, plant uptake was likely not the primary mechanism for copper uptake. Both systems contained compost, which is high in nutrients and organic carbon and essential for microbial activity. Microbial activity may explain the copper retention trend, but this would need to be verified with additional testing.

Other studies have found bioretention systems retained 54%-97% copper influent, and 62%-99% zinc influent (Davis, 2007; Glass and Bissouma, 2005; Hunt et al., 2008; Sun and Davis, 2007). While the parameters of the bioretention units of previous studies varied, retention in the four shallow bioretention units investigated in this study were within this range. Copper retention in the current study was in the upper range of expected values during most tests. The percentage of zinc retention in all four systems was in the upper range of expected values, and remained so even after 10 storm events.

Hydrus 2D Modeling. Model simulations show that the highest concentration of metals was retained in the uppermost layer of the bioretention unit (Figure 5). As the simulated stormwater was consistently applied for 3 minutes, an increase in the concentration of metals was transported toward the outlets of the systems. The first 3 minutes show the most significant changes of zinc and copper concentrations in the system. The concentration of metals between the first and third hour do not vary much, and the highest concentration of metals is retained in the uppermost section of the bioretention unit. Modeling results provide an indication of where and how copper and zinc was retained in the units. Most of the copper and zinc was retained in the top layers. This could simplify bioretention maintenance; the top layers could be replaced periodically instead of the entire bioretention basin.

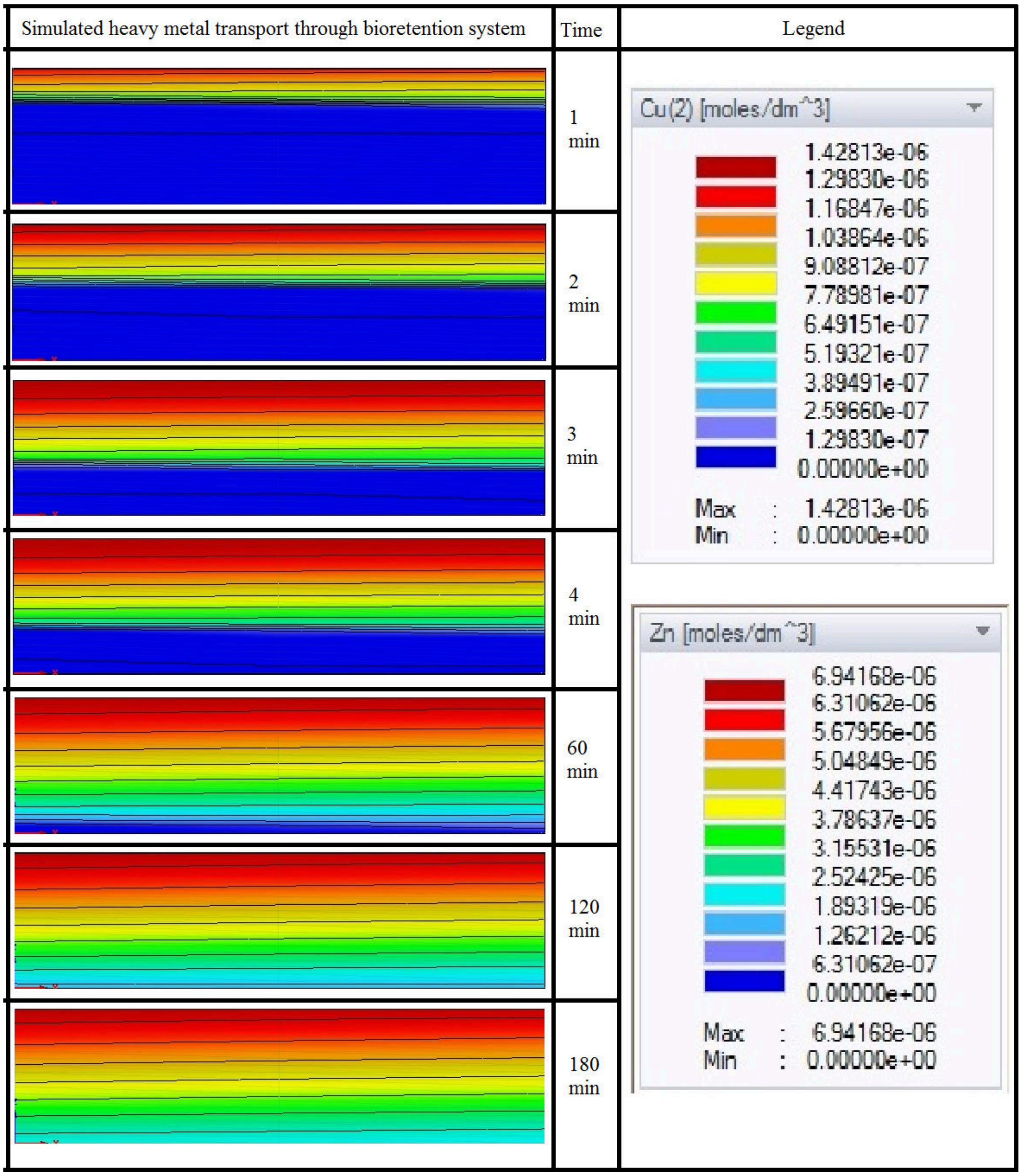

Figure 5. Simulated Heavy Metal Transport Through Bioretention System Over Time Using Hydrus 2D.

The concentration of zinc and copper was tracked over time as the stormwater drained past each node (Figures 6 and 7). The average concentration of zinc and copper at the uppermost nodes remained relatively consistent and did not vary much compared to the initial loading of approximately 500 µg/L for zinc and 100 µg/L for copper. The nodes closer to the outlet exhibited higher variation in concentration over time and were much lower than the initial loading. An average effluent concentration of 62.5 µg/L for zinc was observed in the model, which is similar to effluent concentrations measured during the 3rd and 4th tests. The total zinc retention was approximately 84.5% in the model. All zinc retention rates from the shallow bioretention units were greater than 84.5%, with the exception of the 8th test in the control unit. Copper retention in the model was approximately 83.1%, which corresponds to retention in three of the four bioretention units during the 2nd test. An average effluent concentration of 13.5 µg/L for copper was observed in the model, yet no effluent concentrations in the experiment were found to be that low. Although model results are within the range of experimental results, the model simulated a higher percentage of copper retention and lower percentage of zinc retention than the tests.

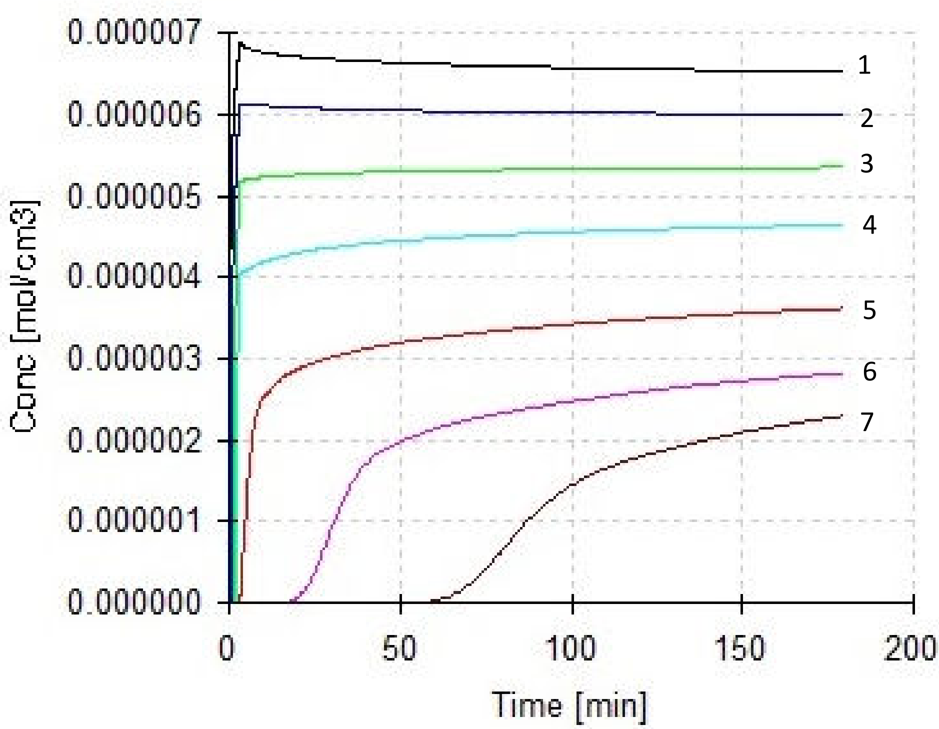

Figure 6. Modeled Zinc Concentrations at Individual Nodes Over Time. Nodes 1 through 7 are equally spaced through the depth of the bioretention system.