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DEVELOPMENT AND EVALUATION OF BEST MANAGEMENT PRACTICES (BMPS) FOR HIGHWAY RUNOFF POLLUTION CONTROL

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DEVELOPMENT AND EVALUATION OF BEST MANAGEMENT PRACTICES (BMPS) FOR HIGHWAY RUNOFF POLLUTION CONTROL

by

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A THESIS

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DEVELOPMENT AND EVALUATION OF BEST MANAGEMENT PRACTICES (BMPS) FOR HIGHWAY RUNOFF POLLUTION CONTROL

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University of Nebraska, 2012

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As non-point source pollution, storm water runoff is one of the main contributors to stream impairment in the United States. The United States Environmental Protection Agency (USEPA) requires Municipal Separate Storm Sewer Systems (MS4s) to obtain a permit under the National Pollution Discharge Elimination System (NPDES) to manage this pollution. Many municipalities and non-traditional MS4s such as the Nebraska Department of Roads are under federal regulations that require new developments or redevelopments of a certain size to capture (and treat) runoff from all new impervious surfaces (roofs, driveways, sidewalks, and so forth) onsite, instead of allowing it to run into the sewers or nearby waterways. To do this structural Best Management Practices (BMPs) are often used to treat the first half-inch of runoff which is commonly considered to contain the majority of pollutants from those sites.

The objectives of this research were to: a) develop and test the feasibility of roadside BMPs that rely on bioretention, infiltration, and slow conveyance of storm water, b) test combinations of plants and soil media that will be sustainable in varied regions of Nebraska, and c) test the feasibility of using rubber chips as an alternative BMP medium.

Four roadside field-scale BMPs were tested: 1) check dam filters, 2) bioretention, 3) infiltration trench, and 4) filter trench. Clogging was experienced by all BMPs except the bioretention; little hard data was collected due to a dry summer.

Four bioretention test cells with different media types were monitored for plant establishment. It was found that a 50/50 mixture of compost and 47-B gravel had the best plant growth. Four types of rubber chip mediated soil mixtures were tested in lab bench-scale testing for physical properties related to plant growth and infiltration as well as storm water treatment effectiveness. It was found that a 50/50 mixture of rubber chips and sand had the best treatment, but lacked the best qualities for plant growth and may require addition of compost.

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Chapter 1 Introduction

1.1 Background

Storm water runoff from urbanized and agricultural land is a leading cause of impairment to lakes and estuaries in the United States (USEPA 1996). Municipal Separated Storm Sewers Systems (MS4s) discharges of storm water are regulated non-point source pollution. Non-point source pollution in MS4s comes from pollutants that are picked up from runoff and carried into the storm sewer system and ultimately into the nations waterways. These pollutants are from animal waste, fertilizers, cars, construction sites, etc. MS4 regulation is part of the Clean Water Act (CWA) which regulates discharges into United States navigable waters through the National Pollutant Discharge Elimination System (NPDES). MS4 regulation was implemented in two phases. Phase I was implemented in 1990 and regulates large municipalities. Phase I requires Storm Water Pollution Prevention Plans (SWPPP) to be submitted by the MS4s to the United States Environmental Protection Agency (USEPA). Phase II, implemented in 1999, regulates small municipalities. Phase II requires 6 minimum Best Management Practices (BMPs): a) public education and outreach, b) public participation and involvement, c) illicit discharge detection and elimination, d) construction site runoff control, e) post-construction runoff control, and f) pollution prevention and good house-keeping (CWA 1977a). BMPs are meant to treat storm water to the Maximum Extent Practicable (MEP), and no numerical effluent limits are placed through storm water regulations.

Currently, many municipalities and non-traditional MS4s such as the Nebraska Department of Roads (NDOR) are under federal regulations that require new developments or redevelopments of a certain size to capture (and treat) runoff from all new impervious surfaces (roofs, driveways, sidewalks, and so forth) onsite, instead of allowing it to run into the sewers or nearby waterways. Development of BMPs to manage and treat storm water before it arrives at storm sewer systems is a new challenge to these entities. The first half inch of runoff from these impervious areas is generally accepted to be the Water Quality Volume (WQV) that should be captured and treated using structural BMPs.

Two types of traditional structural BMPs are infiltration systems and bioretention. Infiltration systems can be described as natural or constructed depressions located in permeable soils that capture, store and infiltrate storm water runoff within 48 hours (MPCA 2000). Bioretention removes pollutants from the runoff via physical, chemical, and biological processes, including sedimentation, filtration, and sorption on mulch and soil layers, plant uptake, and biodegradation by soil microorganisms (Davis et al. 2001). Other examples of BMPs are constructed wetlands, fine sand filters, and detention or retention ponds. All these BMPs rely on natural means to treat storm water and mitigate storm water runoff flows. Considerable research on development of BMPs for highway storm water runoff treatment has been conducted since the 1990s (Keblin et al. 1998; U.S. EPA 1999)Ming-Han et al. 2010; (Vacha 2012; Stansbury et al. 2012). Some issues that need to be considered in roadside BMPs are driver safety, media compressibility and roadway stability. Development and modifications of structural BMPs for roadside use is a solution for the treatment of the WQV from roadways. For highway storm water runoff, heavy metals, especially copper and zinc, total suspended solids (TSS), total dissolved solids (TDS), biological oxygen demand (BOD), and chemical oxygen demand (COD) are the primary contaminants of concern from the highway runoff (Stansbury et al. 2012). The treatment processes in roadside BMPs include physical treatment by filtration, bioaccumulation in bioretention cells, and infiltration.

Many of the roadside BMPs (e.g., bioretention, infiltration, and slow conveyance of storm water) rely on engineered soil media with high percolation rates being effective to prevent ponding of surface water in these BMPs. Several challenges related to these BMPs exist:

- These BMPs (e.g., infiltration trenches and bioretention) need a 2–3 foot thick layer of porous media; the conventional media (e.g., gravel or crushed rock) are very expensive due to their high density. Finding a medium that has a low density, a long lifespan, and can recover its original volume after compression (e.g., due to car accidents or maintenance activities) is critical.
- Information is insufficient on what kinds of media are better to support plant growth in bioretention BMPs that are located different geographic regions under varied environmental conditions.
- Information is lacking on the performance and evolution of physical conditions of the BMPs and on the procedures for monitoring and operation of these BMPs.

To fulfill the knowledge gap, Nebraska Department of Roads (NDOR) funded a research project *“Feasibility of Integrating Natural and Constructed Wetlands in*

Roadway Drainage System Design" between 2009 and 2012. The project had two phases. The objectives of Phase 1 were to: 1) investigate the primary constituents in storm water runoff from interstate 80 in Omaha, Nebraska; and 2) evaluate whether an existing detention basin was effective at removing pollutants from storm water runoff of the highway. The objectives of Phase 2 were to 1) find what BMPs are most applicable to removal the pollutants of concern found in Phase I; and 2) development a fact sheet and design guide of the BMPs applicable to removal the pollutants of concern found in Phase 1. Phase 1 of the project found that the major pollutants from the site included copper, zinc, total suspended solids, total dissolved solids, biological oxygen demand, and chemical oxygen demand; the existing detention basin was found to be somewhat effective to remove these pollutants. Phase 2 of the project found that vegetated filter strips, vegetated swales, bioretention, sand filters, and horizontal filter trenches may be most applicable to highway storm water runoff treatment/management. When writing the design guide of these BMPs, several technical issues with knowledge gaps were identified, such as criteria for selection of soil media for different BMPs, relationships between soil media and plant growth, and evaluation of BMPs' performance and monitoring/maintenance procedures of BMPs. In addition, there is a need to test different BMPs in Nebraska so that the aforementioned knowledge gaps can be filled.

In light of the aforementioned analysis, this project will focus on two major issues: the soil medium and vegetative growth and use of alternative BMP media. The justifications of this focus are as follows. When a soil medium is used in these BMPs, creating a soil medium that drains at a desired rate, supports plant growth, and can treat storm water constituents are important design aspects. However, the combinations of plants and media that will be sustainable in the varied regions of Nebraska are unknown. Certain plant species have been shown to provide significant uptake of pollutants in a process called phytoremediation. This uptake is not universal for all species and all pollutants, so knowing the key species to use in a BMP could drastically improve its effectiveness.

BMP material prices can be expensive due to their density, availability, and transportation costs. Material transportation costs for BMP construction could be decreased by the use of light-weight material. Testing the feasibility of using rubber chips as the porous media in bioretention systems could prove beneficial. The use of rubber chips could be a possible medium because of they are lightweight and availability. This would be an alternative low-cost and low-weight material that could be used as filter media so that it can lower the cost of transportation of materials and ultimately the construction cost of the BMPs. Also, lightweight material from alternative sources like rubber chips can be bought at very low costs $0.25/pound (Bruckman Rubber Co., Hastings, NE, USA) and could be lower when bought in bulk quantities.

1.2 Objectives

In light of above analysis, the objectives of this research are to:

1) Test the feasibility of several types of roadside BMPs, focusing on bioretention, infiltration, and slow conveyance of storm water.

2) Test several types of bioretention soil mixtures and the plant establishment associated with those mixtures.

3) Test the feasibility of using rubber chips as an alternative BMP medium. This will be accomplished by testing four types of field-scale BMPs at two project locations in two different regions of Nebraska and testing lab bench-scale columns filled with different combinations of rubber chip mediated filter media.

1.3 Thesis Organization

There are four chapters of this thesis. Chapter 1 “Introduction” reviews the background of storm water regulations, BMPs and how these apply to roadside treatment of storm water. Chapter 2 “Design and Monitoring of Roadside BMPs” goes through the design of field-scale BMPS, materials and methods used in the field testing and monitoring of these roadside BMPs concerning their plant establishment, clogging, and general design and operation. The chapter presents the results of plant establishment in the bioretention test cells, sediment buildup problems, and general monitoring scheme and also provides recommendations for future studies. Chapter 3 “Lab Testing of Tire Chip Mediated Soil Mixtures” is a detailed description of the physical properties and storm water treatment properties of four rubber chip mediated soil mixtures; results and discussion of the best and worst medium for roadside application are presented. Chapter 4 “Conclusions and Recommendation” is a compilation of the conclusions drawn from Chapters 2 and 3 with recommendations for future research being provided.

Chapter 2 Design and Monitoring of Field-scale Roadside BMPs

2.1 Introduction

Four roadside BMP types were selected for testing at two locations with different regions and climates in Nebraska. The four types of BMPs tested were bioretention, infiltration trench, filter trench and check dam filters. To design these BMPs, soil conditions, site hydrology, and roadway design literature searches were done. Also, site constraints were evaluated before design as these constraints played a role on the type of BMPs that could be installed.

The first site selected was located at the I street on-ramp to interstate 80 in Omaha, Nebraska (Figure 2.1). At this site, four check dam filters were designed and installed. This site was chosen because it was easily accessible, had good site conditions for check dam filters, and was located in eastern Nebraska within the city of Omaha's MS4. The second site selected was located in Lincoln, Nebraska at NDOR's Salt Valley maintenance yard located near highway 77 and Warlick Ave (Figure 2.2). At this site a set of bioretention cells, infiltration trench, and filter trench were installed. The bioretention test cells were built here because a location with sufficient elevation change for under drain outlets was located where the bioretention cells could be built off-line of a ditch. The infiltration trench was installed here because a length of ditch was located on-site with a slope less than 3 percent which is required for infiltration trench structures. Lastly, a filter trench was installed at the Lincoln site because a ditch with erosion problems and a 6.5 percent slope was located on site. This was a good location because it was hoped that the BMP could mitigate the scour erosion problem, and that the higher slope of the ditch would aid in the filter trench operation.

Figure 2.1 I street site location

After the field-scale test BMPs were designed and installed, monitoring methods were established for clogging, vegetation establishment, infiltration rates, and picture logs for progression of the BMPs. Actual monitoring took place for vegetation establishment and picture logging due to small and few rain events at both sites from July to September 2012. Monitoring of the check dam filters consisted of picture logging of the sediment buildup behind each dam. The bioretention test cells were the primary focus for vegetation establishment and testing of four types of bioretention media. The infiltration trench was monitored for infiltration rates and general clogging. Finally, the filter trench is a newly developed BMP type and was tested for general feasibility, design and treatment.

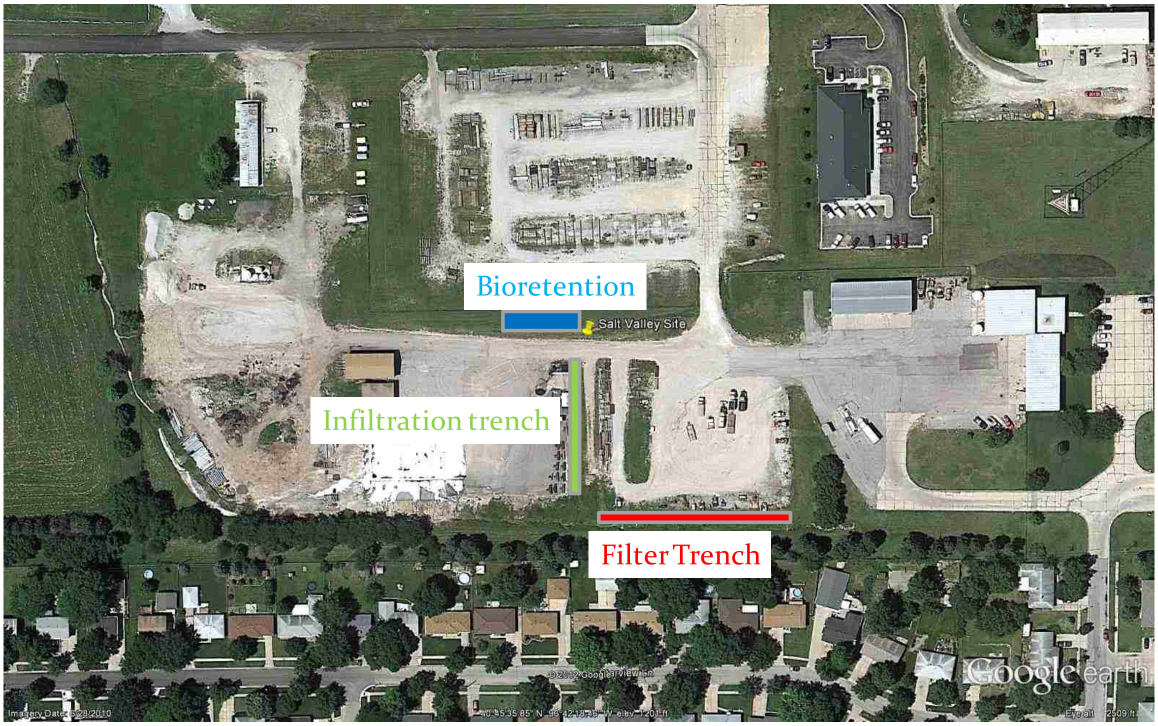


Figure 2.2 Salt valley site location

The objectives of this chapter are to 1) introduce the materials and methods used for the BMP designs, construction, and monitoring, and 2) present the results related to BMP performance and observations, and 3) provide recommendations for future studies.

2.2 Methods and Materials

2.2.1 Hydrology

The capture and treatment of the first 0.5 inches of runoff from new or redeveloped impervious areas is the motivation for the treatment of the WQV. The first 0.5 inches of runoff is known as the first flush. The first flush or WQV is used as a treatment target volume because management of the first 0.5 inches of runoff contains 81–86% of the total pollutant mass (Flint and Davis 2007). The pollutant loaded water that flows off the impervious area is considered runoff. The water that is not from the new or redeveloped impervious area is considered run on. It is beneficial to keep run on and runoff separated because if they mix the total volume must be treated. Summing the WQV from runoff with the WQV from any run-on gives the total WQV that must be treated as shown in equation 2-1:

$$WQV_{Total} = WQV_{Run\ on} + WQV_{Runoff} \tag{2-1}$$

where:

WQV_{Total}: required Water Quality Volume to treat

$WQV_{Run\ on}$: portion of the water quality volume added from pervious are and off property run off

WQV_{Runoff}: Water Quality Volume contributed from new or redeveloped impervious area

Calculating the design storm depth. The first step in the design process of the BMPs used was to calculate the design precipitation. The Natural Resource Conservation Service (NRCS) method was used to calculate the 0.5 inch runoff by using equation (2-1) (NRCS 1986):

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{2-2}$$

where:

Q: Depth of runoff over the watershed (in or cm)

P: Precipitation (in or cm)

S: Potential maximum retention of water by the soil (in or cm)

To obtain 0.5 inches of runoff from impervious areas, the precipitation (P) in equation (2-1) equals 0.75 inches (Vacha 2012). Potential maximum retention is a function of the NRCS equation (2-2) and curve numbers that are given in Table 2.2. In order to choose a curve number, first the land use must be decided from Table 2.2 and the hydraulic soil group must be chosen from Table 2.1.

$$CN = \frac{1000}{10+S} \qquad \text{2-3}$$

Table 2.1 Hydrologic soil groups (Gupta 2008)

Group	Minimum Infiltration Rate (in/hr)	Texture
A	0.3–0.45	Sand, loamy sand, or sandy loam
B	0.15–0.3	Silt loam or loam
C	0.05–0.15	Sandy clay loam
D	0–0.05	Clay loam, silty clay loam,

sandy clay, silty clay, or clay

Table 2.2 Numbers for various land uses and conditions (NRCS 1986).

Description of Land Use	**Hydrologic Soil Group**			
	A	**B**	**C**	**D**
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Cultivated (Agricultural Crop) Land:				
Without conservation treatment (no terraces)	72	81	88	91
With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land:				
Poor (<50% ground cover or heavily grazed)	68	79	86	89
Good (50–75% ground cover; not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)	30	58	71	78
Brush (good, >75% ground cover)	30	48	65	73
Woods and Forests:				
Poor (small trees/brush destroyed by over-grazing or burning)	45	66	77	83
Fair (grazing but not burned; some brush)	36	60	73	79
Good (no grazing; brush covers ground)	30	55	70	77
Open Spaces (lawns, parks, golf courses, cemeteries, etc.):				
Fair (grass covers 50–75% of area)	49	69	79	84
Good (grass covers >75% of area)	39	61	74	80
Commercial and Business Districts (85% impervious)	89	92	94	95
Industrial Districts (72% impervious)	81	88	91	93
Residential Areas:				
1/8 Acre lots, about 65% impervious	77	85	90	92
1/4 Acre lots, about 38% impervious	61	75	83	87
1/2 Acre lots, about 25% impervious	54	70	80	85
1 Acre lots, about 20% impervious	51	68	79	84

From equations (2-1) and (2-2) and Tables 2.1 and 2.2 the precipitation depth of 0.75 inches obtains the 0.5 inches of runoff depth from impervious areas. The 0.75 inch depth storm should also be used to calculate any run-on that may mix with runoff and enter the BMPs. The resulting depth found from these NRCS methods is then multiplied by each respective sub watershed area to calculate the volume of runoff or run-on.

When evaluating a mixed-use watershed, runoff and run-on, curve numbers, C values, rainfall depths, and 10-year discharges should be calculated separately for each sub-watershed and then totaled for the whole watershed. This should be done because it is more conservative compared to using a weighted/composite curve number giving larger BMP design.

Peak flow rate calculations. The peak flow rate from the 10-year return period storm was used in the design of roadside BMPs. The 10-year return period storm is the minimum design frequency commonly used for drainage of roadways recommended by the Federal Highway Administration (see Table 2.3). The rational method is widely used in storm water design and in highway drainage design. To calculate the peak flow the rational method is used based on equation 2-3 (FHWA 2009).

$$Q = CIA \qquad 2\text{-}4$$

where:

Q: Peak flow (cfs)

C: Rational Method Dimensionless runoff coefficient

I: Average rainfall intensity for a duration equal to the time of concentration, for a selected return period (in/hr)

A: Drainage area (acres)

Table 2.3 Suggested minimum design frequency and spread (FHWA 2009)

Road Classification		Design Frequency	Design Spread
High Volume or Divided or Bi-Directional	< 70 km/hr (45 mph)	10-year	Shoulder + 1 m (3 ft)
	> 70 km/hr (45 mph)	10-year	Shoulder
	Sag Point	50-year	Shoulder + 1 m (3 ft)
Collector	< 70 km/hr (45 mph)	10-year	½ Driving Lane
	> 70 km/hr (45 mph)	10-year	Shoulder
	Sag Point	10-year	½ Driving Lane
Local Streets	Low ADT	5-year	½ Driving Lane
	High ADT	10-year	½ Driving Lane
	Sag Point	10-year	½ Driving Lane

Before the rainfall intensity can be determined, the time of concentration must be calculated by using the most hydraulically remote sub-basin travel time in equation 2-5 to decide the duration of the design storm. For time of concentrations of less than 5 minutes a value for t_c equal to 5 minutes is used.

$$t_c = \frac{L}{V} \tag{2-5}$$

where:

t_c: Time of concentration (seconds)

L: Length of land use type (ft)

V: Water velocity from Figure 2.3 based on land slope (ft/s)

The C values for equation 2-3 can be found in Table 2.4, and the rainfall intensity duration curve for Omaha, NE is found in Figure 2.4.

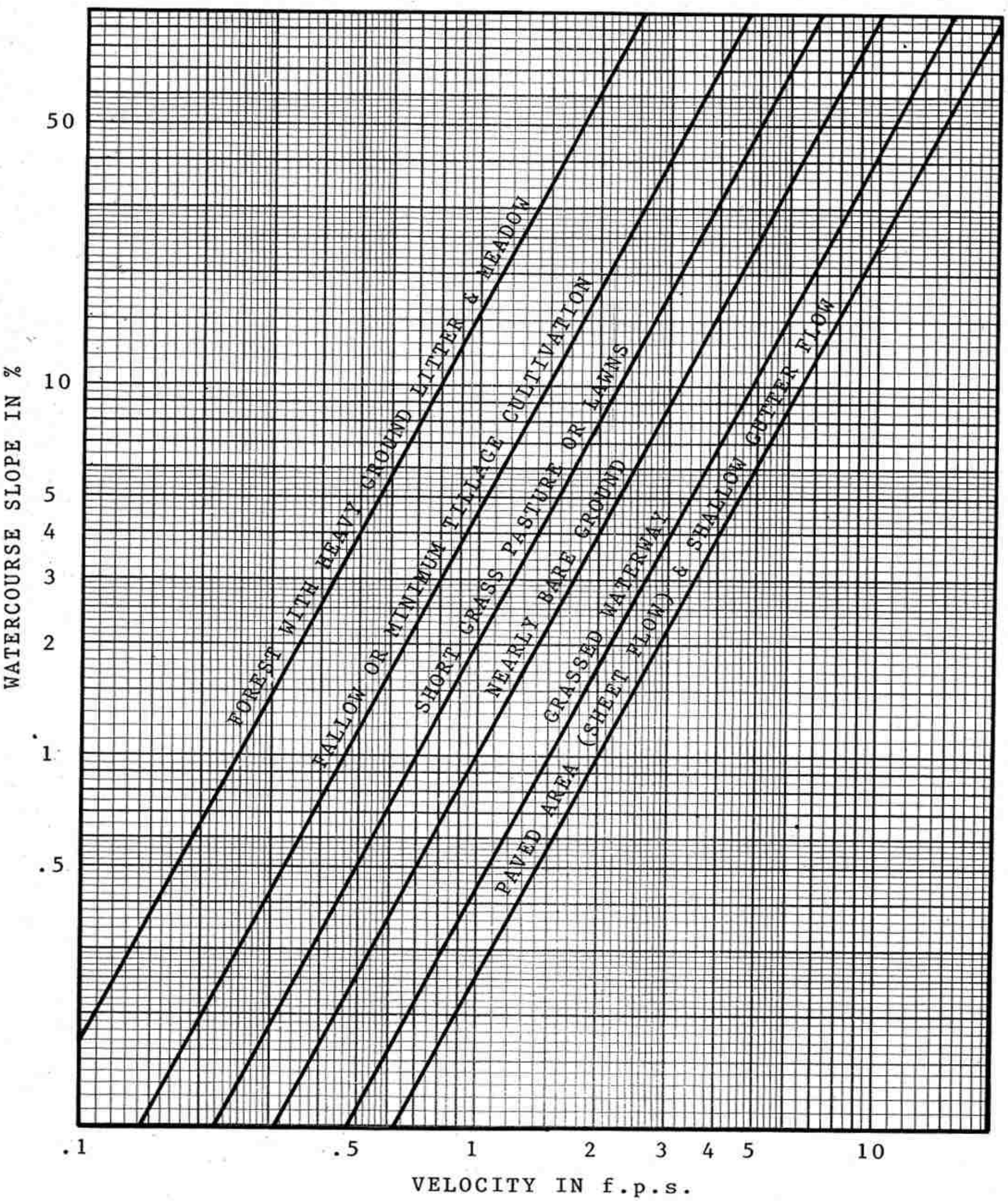


Figure 2.3 Velocities for estimating travel time (Olsson Associates 2006)

Table 2.4 Runoff coefficients for rational formula (FHWA 2009).

Type of Drainage Area	Runoff Coefficient, C[b]
Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multi-units, detached	0.40–0.60
Multi-units, attached	0.60–0.75
Suburban	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial:	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.40
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Lawns:	
Sandy soil, flat, 2%	0.05–0.10
Sandy soil, average, 2–7%	0.10–0.15
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, flat, 2%	0.13–0.17
Heavy soil, average, 2 - 7%	0.18–0.22
Heavy soil, steep, 7%	0.25–0.35
Streets:	
Asphaltic	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95

[b] Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff

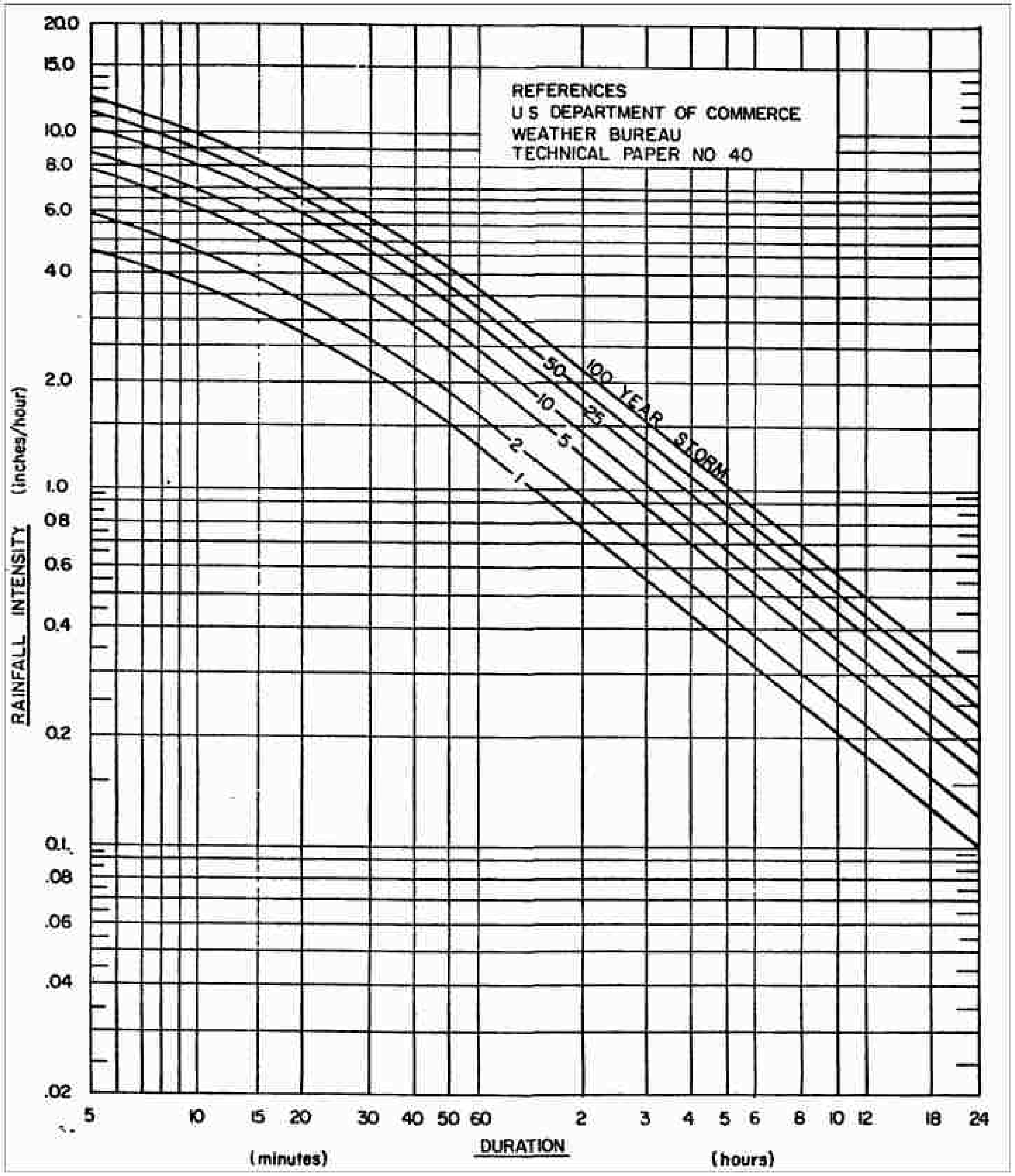


Figure 2.4 Rainfall intensity-duration – Omaha, Nebraska

Table 2.5 Example table of WQV and peak discharges

Drainage area (acres)	**0.5 inch WQV (ft^3)**	**10-yr peak discharge (cfs)**	**Drainage area (acres)**	**0.5 inch WQV (ft^3)**	**10-yr peak discharge (cfs)**
0.1	182	0.86	1.25	2269	10.69
0.2	363	1.71	1.5	2723	12.83
0.3	545	2.57	1.75	3176	14.96
0.4	726	3.42	2	3630	17.10
0.5	908	4.28	2.5	4538	21.38
0.6	1089	5.13	3	5445	25.65
0.7	1271	5.99	3.5	6353	29.93
0.8	1452	6.84	4	7260	34.20
0.9	1634	7.70	4.5	8168	38.48
1	1815	8.55	5	9075	42.75

In the above table, peak discharge is assumed to be from an all concrete watershed using the rational method and a 5 minute time of concentration

2.2.2 BMP Design

Two project sites were chosen for testing, one located at the on-ramp of interstate 80 at I street in Omaha, NE and the other located at NDOR’s Salt Valley maintenance yard in Lincoln, NE. The BMPS chosen for testing were bioretention, infiltration trench, filter trench and check dam filters. These were chosen based on roadside criteria such as implementation in the right of way, no permanent pools, low maintenance, cost effective, 80% removal of TSS, heavy metals and total extractable hydrocarbons (Vacha 2012).

Bioretention. Bioretention BMPs can be an aesthetically pleasing and versatile method of treating storm water by means of filtration, bioaccumulation, and settling of pollutants. Bioretention is applicable for roadside use because it can use a) low vegetation and soil berms for minimum hazards for vehicles, and b) short term ponding for a period of 24 to 48 hours to reduce peak flows. Bioretention can be designed for infiltration or filtration (if under drains are installed), benefiting to the stability of roadway sub grades and shoulders.

Four bioretention test cells were designed and installed at the salt valley location. The WQV for the bioretention cells was 6,044 ft^3, and the test plots with a total area of 162 ft^2 treated 20% of this volume. The peak 10-year flow-rate for the watershed was 26 cfs, which was obtained by equation 2-3 and the methods explained in section 2.2.1. Equation 2-6 was used to size the surface area of the test cells (ISMM 2009).

$$A_f = \frac{WQV * df}{[K * (hf + df) * tf]} \quad (2\text{-}6)$$

where:

A_f: surface area of ponding area (ft^2)

WQV: water quality volume (ft^3)

df: filter bed depth (ft)

K: hydraulic conductivity of filter media (ft/day)

hf: average height of water above filter bed (ft)

tf: design filter bed drain time (days)

For the bioretention at the Salt Valley site, the values below were used in equation 2-6: A_f = 162 ft^2; WQV = 1215 ft^3; df = 1.5 ft; K = 6 ft/day (for 50% sand and compost mixture)(Hartsig and Szatko 2012);

hf = 0.375 ft; and tf = 1 day.

Inflows to the bioretention cells were diverted from a grassed ditch through a 4 inch PVC pipe and were equally separated to the four test cells. The four test cells were 4.5 ft wide and 9 ft long with 18 inches of filter media depth. Each cell was under-drained with a 4 inch PVC perforated pipe installed in 10 inches of ¼” to 3/8” pea gravel. An outflow outlet weir made with a 2 inches by 12 inches board was installed to maintain a maximum ponding depth of 9 inches. Figure 2.6 shows a plan view of the bioretention test cells, and Figure 2.5 shows a cross section of the test cells.

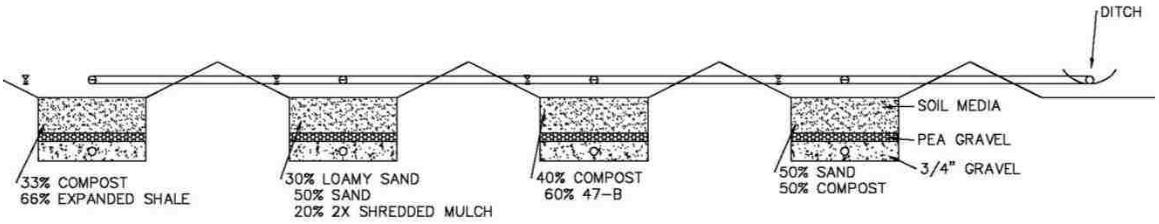


Figure 2.5 Salt valley bioretention test cells profile view

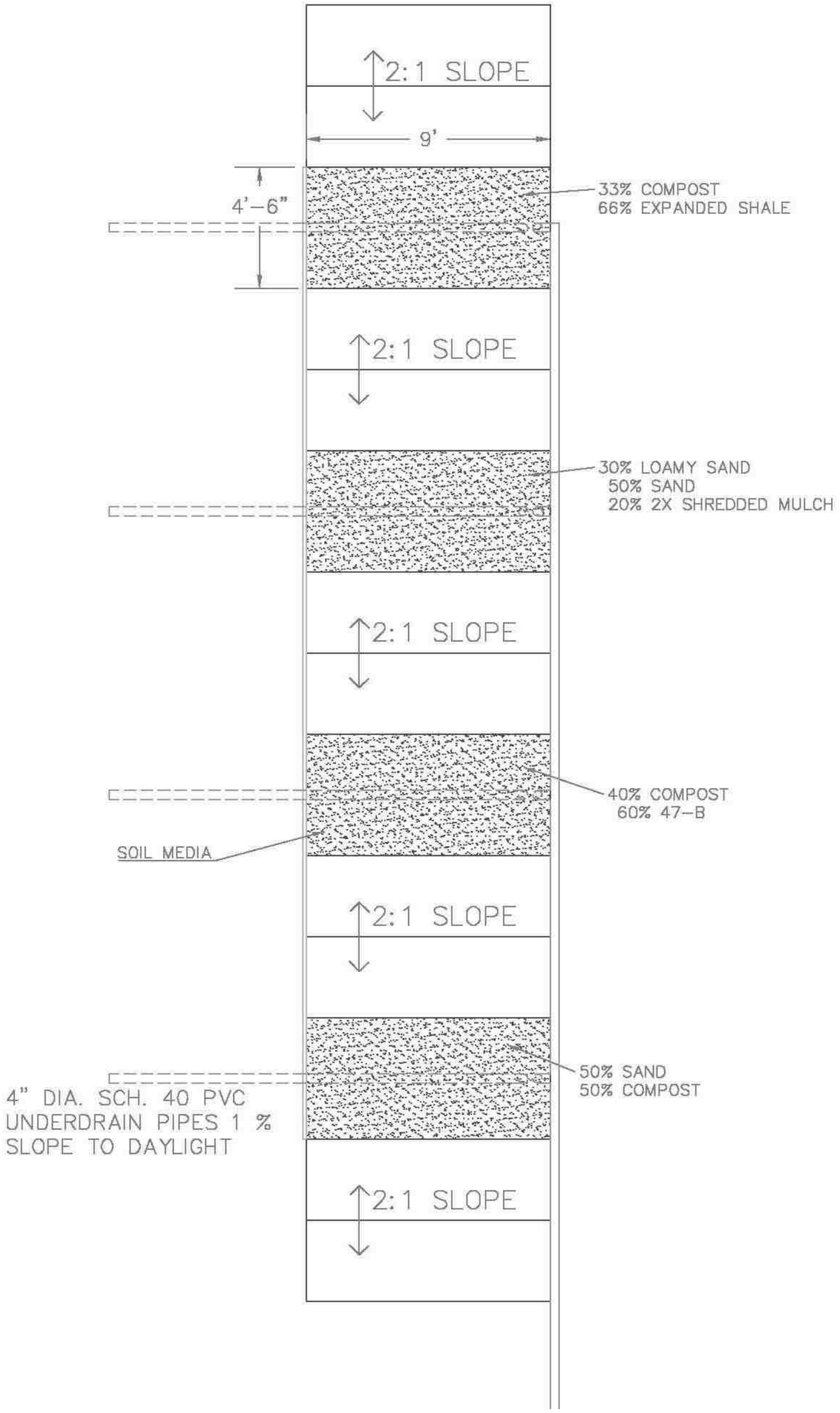
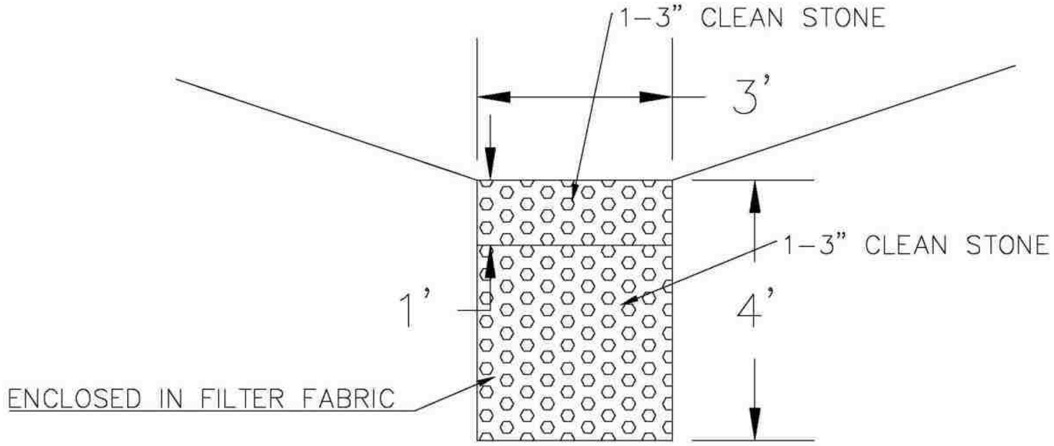


Figure 2.6 Salt valley bioretention test cells plan view

Infiltration trench An infiltration trench can be used as a roadside BMP by placing it within the bottom section of a roadside ditch. The trench can be 2 ft to 10 ft deep and up to as wide as the bottom ditch width. The trench is filled with large porous media to capture the WQV. Infiltration trenches eliminate the discharge of the WQV effectively, having 100 percent pollutant removal within the WQV because the entire WQV is captured and not allowed to run off the site (Field et al. 2006).

The infiltration trench at the Salt Valley site is located in a drainage ditch with a 2.8 percent slope. The trench is 118 ft long, 3 ft wide and 4 ft deep. As shown in Figure 2.7, the trench was filled with 1-3 inch clean stone; the bottom and side walls were wrapped in Mirafi® 170N non-woven polypropylene geotextile filter fabric. The top of the filter fabric enclosure was placed 1ft below the surface keep any sediment in the upper foot of media. The WQV for the infiltration trench is calculated by multiplying the volume of the trench by the void ratio of the media (typically 0.4). The WQV treated by the infiltration trench was 566 ft^3, which is 9 percent of the WQV for the watershed. The peak 10-year flow was 25.9 cfs, which was obtained by equation 2-3 and the methods explained in section



2.2.1.

Figure 2.7 Infiltration trench cross section

Filter trench. A filter trench is a trench filled with filter media installed along and parallel to the bottom of a roadside ditch. The storm water is filtered as the slope forces the water to pass through the treatment media. A filter trench is similar to an infiltration trench but is located on slopes not applicable for infiltration methods. Filtration is the primary treatment method although some infiltration may be possible where infiltration rates of the native soil are higher.

The filter trench at the Salt Valley site is 250 ft long and is located along the bottom of a drainage ditch with a slope of 6.5 percent. The trench is 3 ft wide and 4 ft deep with 6 inches of 3-inch armoring rock on the surface and 7 rip-rap check dams equally spaced along the trench. Two observation wells were installed to check whether the filter was working properly and water was draining. The filter media used was ¼″ to 3/8″ pea gravel with a porosity of 0.3. The WQV treated is equal to the total void volume of the filter media. The volume treated by the filter trench was 900 ft^3, which is about 25 percent of the WQV of the watershed. The peak 10-year flow for the trench was 21 cfs, which was obtained by equation 2-3 and the methods explained in section 2.2.1.

Due to the possibly high velocities of water on moderately high roadside ditch slopes, scour protection may be needed for the filter media. The channel velocity of the 10-year peak flow needs to be calculated with equation 2-7 (NRCS 1986).

$$Q = \frac{k}{n} A R^{2/3} S^{1/2} \qquad 2\text{-}7$$

where:

Q: Flow from10-year storm (cfs)
S: Slope in direction of flow $\left(\frac{ft}{ft}\right)$
R: Hydraulic Radius $\left(R = \frac{A}{P_w}\right)$
A: Cross sectional area of flow (ft^2)
P_w: Wetted Perimeter (ft)
n: Manning’s coefficient
k: constant (1 for Metric Units; 1.486 for English Units)

The equations for the elements of trapezoidal cross-sections can be found in Table 2.6 with the variables being defined in Fig. 2.6. n (manning’s coefficient) for equation 2-7 is calculated for rock lined channels with equation 2-8 (FHWA 2005):

Table 2.6 Geometric elements of trapezoidal cross section

Area of flow (A) (ft^2 or m^2)	$(b+my)y$
Wetted perimeter (P_w) (ft or m)	$b+2y\sqrt{1+m^2}$
Hydraulic radius (R) (ft or m)	$\frac{(b+my)y}{b+2y\sqrt{1+m^2}}$

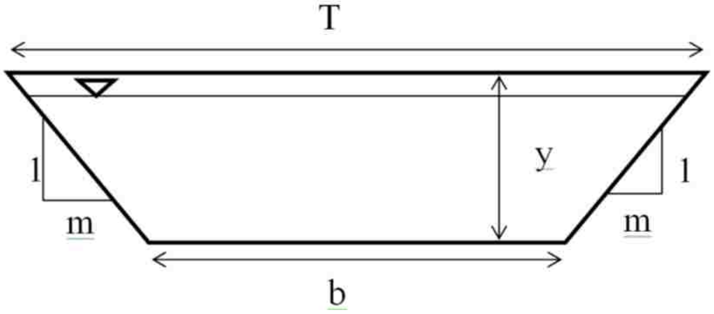


Figure 2.8 Reference shape for table 2.6

$$n = \frac{\alpha\, d_a^{\,1/6}}{2.25+5.23\log\left(\frac{d_a}{d_{50}}\right)} \qquad \text{2-8}$$

where:

n: Manning's roughness coefficient, dimensionless

d_a: average flow depth in the channel, (ft)

D_{50}: median riprap/gravel size (ft)

α: unit conversion constant 0.0262 for English units

Equation 2-8 is an iterative equation applicable for the range of conditions where $1.5 \leq d_a/D_{50} \leq 185$. Inserting the geometric elements and manning's number into the

Manning’s equation results in Equation 2-9, which is then used to solve for the depth of flow (y) by trial and error.

$$Q = \left(\frac{k}{n}\right) * (b+my)y * \left[\frac{(b+my)y}{b+2y\sqrt{1+m^2}}\right]^{2/3} * S^{1/2} \qquad (2\text{-}9)$$

The total iterative process is to find the depth by guessing a manning’s number and then calculating a new manning’s number with the new average depth; three to four iterations should be sufficient for convergence. The final flow depth for the designed filter trench was 0.82 ft with a manning’s number of 0.053 and a velocity of 4.69 ft/s by using 1– 3″ clean rock as a flexible channel lining. Figure 2.9 is a cross section of the filter trench.

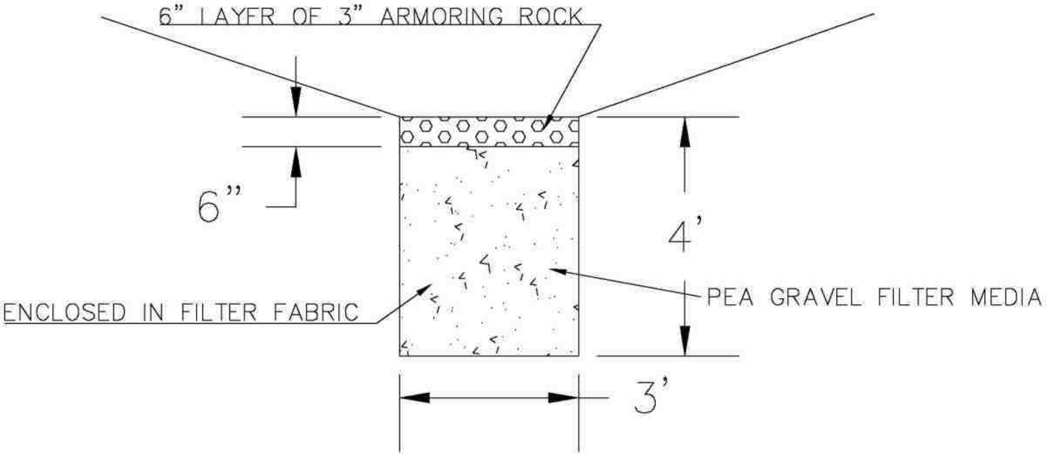
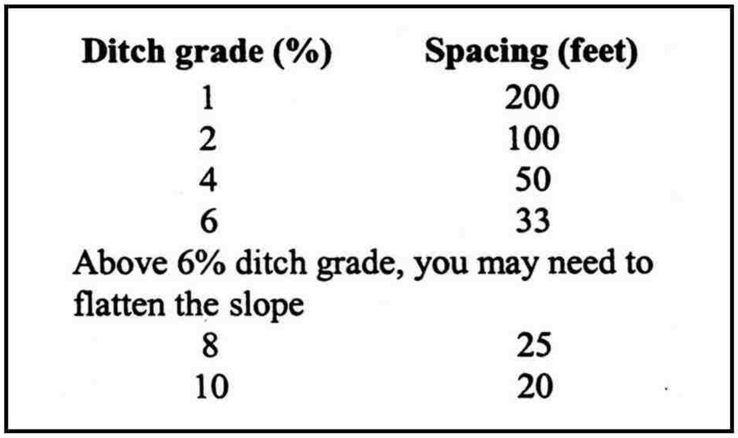


Figure 2.9 Cross section of filter trench

If rock lining is not sufficient to mitigate flow velocities, rip-rap check dams may need to be installed also. The check dams designed for the filter trench were 1.5 ft in height with 2:1 slopes. The D_{50} of the rock media was 9 inches, and seven check dams were spaced equally along the trench about 35 ft apart. Due to cost and availability at the site for rip-rap, broken concrete and used concrete core samples were placed instead of rip-rap. Table 2.7 shows some typical spacing of rip-rap check dams. Figure 2.10 shows a typical cross section.

Table 2.7 Typical spacing of riprap check dams (MPCA 2000)



Ditch grade (%)	Spacing (feet)
1	200
2	100
4	50
6	33
Above 6% ditch grade, you may need to flatten the slope	
8	25
10	20

Check Dam Filters. Check dam filters are a modification or hybrid design of filter trenches and check dams. Water is temporary impounded behind an earthen check dam within the roadside ditch and then is filtered down and underneath the dam through a pea gravel-filled trench to outlet on the downhill side of the dam. Check dam filters are optimal in ditches where check dams are already being considered for erosion control reasons. Four check dams installed in series at the I Street site are located on a 6.5 percent slope. The WQV of the watershed was 988 ft^3 and the peak 10-year flow was 10.15 cfs, which was obtained by equation 2-3 and the methods explained in section 2.2.1. The check dams are able to treat more than the WQV based on the design sizing.

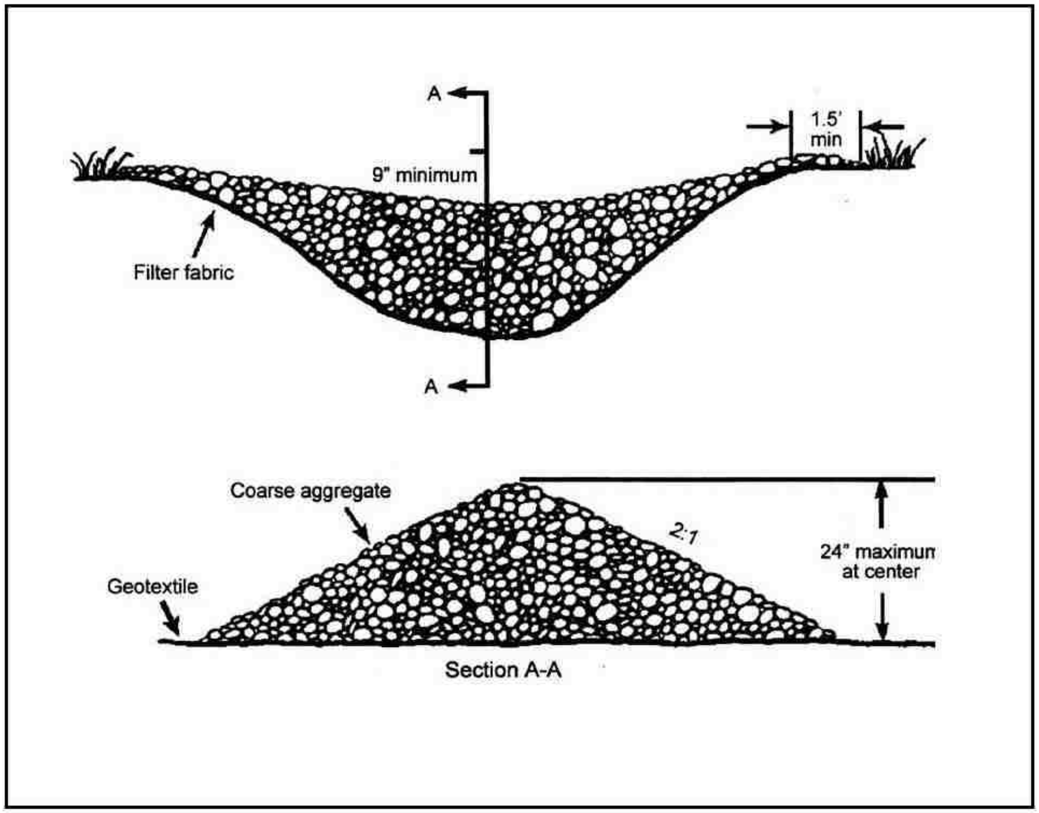


Figure 2.10 Typical riprap check dams cross and longitudinal sections (MPCA 2000)

Equation 2-10 was used to calculate the WQV that could be captured using the check dams (PSBMP 2006) and Figure 2.11 explains the variables used in equation 2-10.

$$V = 0.5 * L * D_s * (W + W_b)/2 \qquad \text{2-10}$$

Where:

V: Volume behind the check dam (ft^3)

L: Length of Swale Impoundment Area (ft)

D_s: Depth of Check Dam (ft)

W: Top Width of Check Dam (ft)

W_b: Bottom Width of Check Dam (ft)

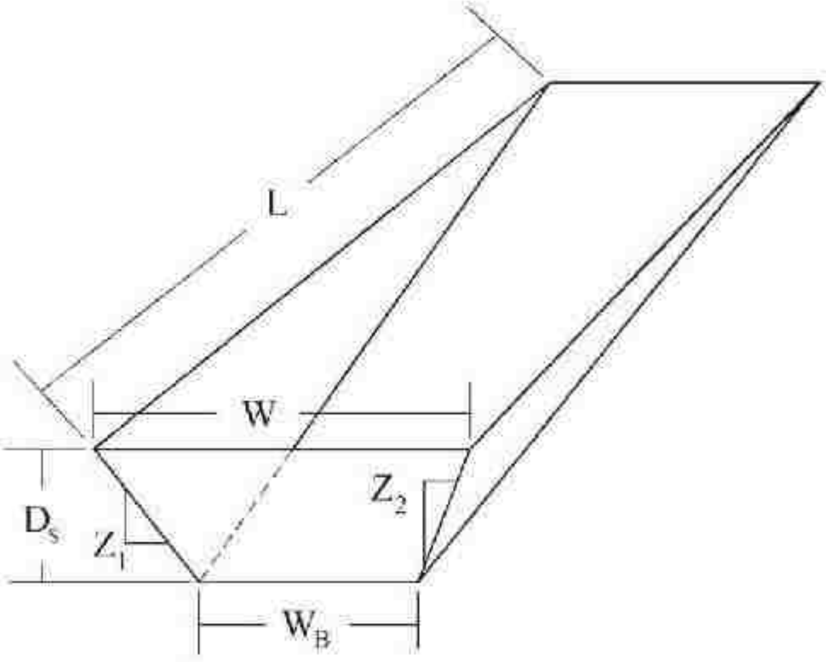


Figure 2.11 Variables used to calculate check dam volume (PSBMP 2006)

Figures 2.12, 2.13, and 2.14 are the profile view, side view, and plan view of the check dam filters. The check dam filters used in this project were installed at the I Street site located at the on ramp of interstate 80 and I street in Omaha, NE. To check the drawdown time for the media chosen in the design, Darcy's law equation (equation 2-11) was used (Gupta 2008). The flow-rate should be greater than or equal to the volume of water that can be impounded behind the check dam.

$$Q = AK\frac{\Delta h}{L} \qquad \text{2-11}$$

Where:

Q: flow-rate (ft^3/day)

A: Cross-sectional area of media (ft^2)

K: Hydraulic conductivity of the media (ft/day)

Δh: Change in elevation (ft)

L: Length of media (ft)

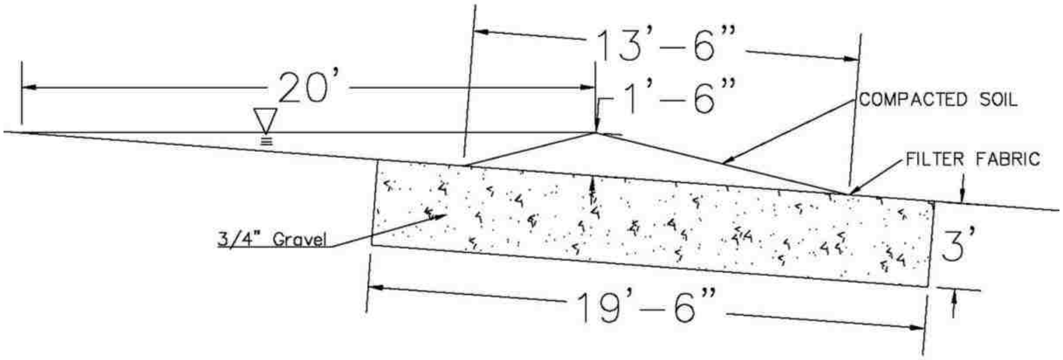


Figure 2.12 Check dam filter profile

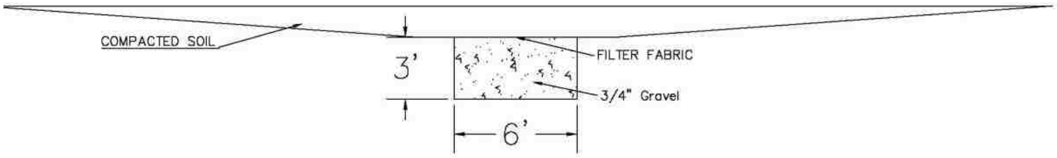


Figure 2.13 Check dam filter cross section

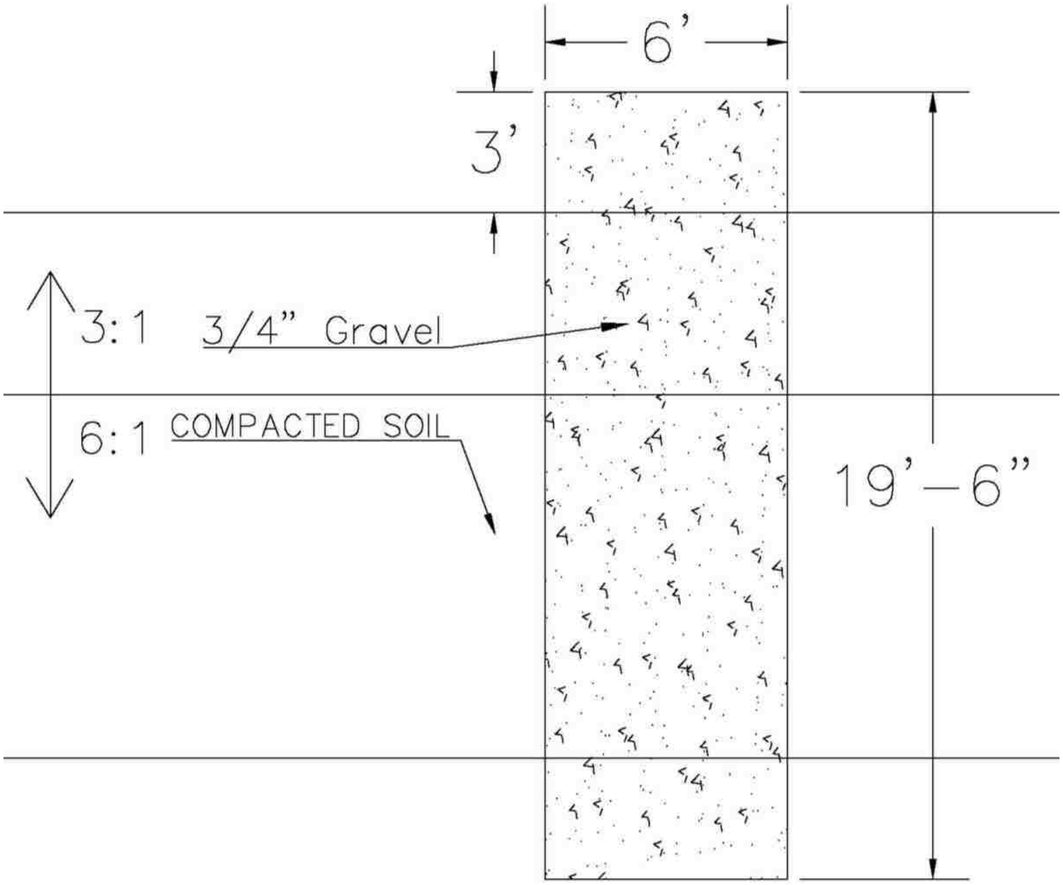
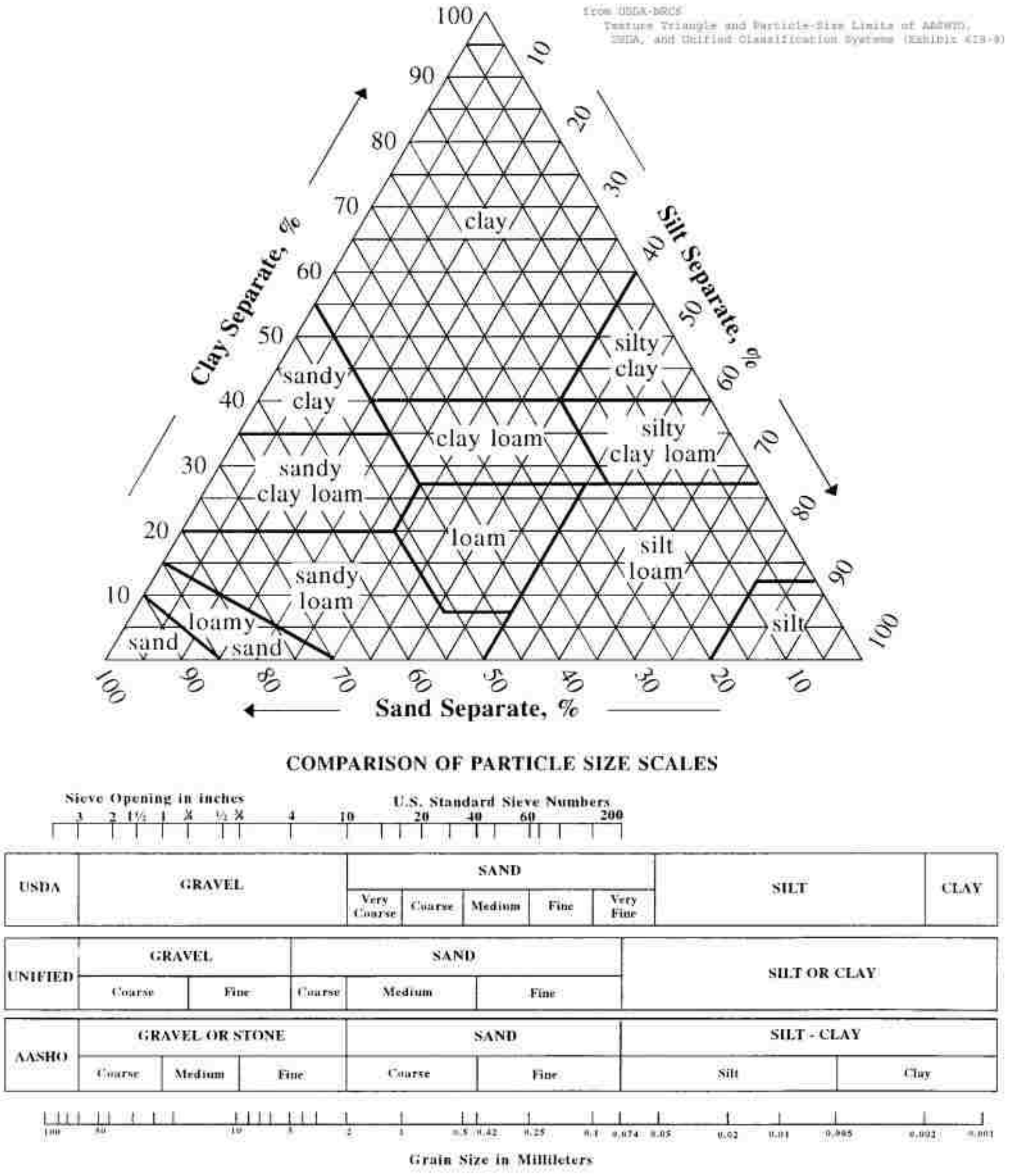


Figure 2.14 Check dam filter plan

2.2.3 BMP Materials and Soil Media

The materials and media used in BMPs can have great impacts on the final treatment efficiency of pollutants. For BMPs that rely on filtration such as bioretention, check dam filters, and filter trenches, the choice in media type and size ultimately decides the treatment efficiency for certain target pollutants. For infiltration type BMPs, the media size and type play a role in the determination of how much of the WQV can be stored in the media's pore space. In this project, similar media were chosen when applicable for both the project sites except for the bioretention test cells where four types of medium mixtures were tested.

The soil texture classification at the I-street test site was Silt Loam (NRCS 2011) which was used in lab testing in chapter 3. Silt Loam has a content range of clay (0–25%), sand (0–50%), and silt (50–80%). A soil sample from the I street site was sent to Midwest Laboratories for a texture analysis, the results were a content of 24% clay, 20% sand and 56% silt. At the Salt Valley location the most predominant soils were Silty Clay and Silty Clay Loam (NRCS 2011). Silty Clay and Silty Clay Loam have a relatively wide content range of clay (25–60%), sand (0–20%), and silt (40–70%). Because soil texture classifications have content ranges, any calculations used in the design mixtures were assumed to have sand, silt and clay content equal to the area centroid of the NRCS-USDA soil texture classification triangle shown in Figure 2.15. The minimum infiltration rates for silt loam, silty clay, and silty clay loam are 0.15–0.30, 0–0.05, and 0–0.05 in/hr, respectively (Gupta 2008). Due to these moderate to low infiltration rates, if any native soil was used as media, it had to be supplemented to improve infiltration rates. Also, because of low infiltration rates of the native soil under drains had to be installed.



from USDA-NRCS
Texture Triangle and Particle-Size Limits of AASHTO, USDA, and Unified Classification Systems (Exhibit 618-8)

Figure 2.15 USDA-NRCS soil texture triangle

Bioretention soil media Bioretention media must serve three primary purposes: have sufficient infiltration rates for acceptable drawdown times; filter sediments and pollutants; and support bioretention plant growth. Bioretention relies on physical, chemical, and biological processes, including sedimentation, filtration, and sorption on mulch and soil layers, plant uptake, and biodegradation by soil microorganisms to remove pollutants (Davis et al. 2001). Based on literature reviews and objectives of this project, four soil mixtures were field tested: 1) 50% grout sand and 50% compost; 2) 40% NDOR 47-B gravel and 60% compost; 3) 30% loam, 50% grout sand and 20% wood mulch; and (4) 33% compost and 66% expanded shale.

Sand and 47-B gravel used for bioretention should meet ASTM C33 standards for gradation (WRA Environmental Consultants 2009) and (Low Impact Development Center, Inc 2003). Tables 2.8 and 2.10 compare the Mallard Sand and Gravel used in the field testing to NDOR aggregate classes and a designed sand mixture for Contra Costa County, California. The use of easily available media and specification can aid in roadside BMP construction.

In this study, the compost called LinGro used in the bioretention cells came from the city of Lincoln, NE composting service. This compost (LinGro) was chosen because of its price and availability. Compost was added to the bioretention media to help support plant growth with nutrients and root support, and to promote infiltration of storm water as well. Table 2.9 compares the spring 2012 Midwest Laboratories LinGro compost test report values with other compost standard design values.

Table 2.8 Sieve design Specification for ASTM C33 grout sand

Sieve size	Percent passing (by weight) min-max		
Source	Bioretention sand[a]	Class D aggregate[b]	Grout Sand
1 ½”	–	–	–
3/8 inch	100–100	–	–
No. 4	90–100	100–100	100–100
No. 8	70–100	–	95–100
No. 10	–	90-100	–
No. 16	40–95	–	70–100
No. 30	15–70	39–75	40–75
No. 40	5–55	–	–
No. 50	–	–	10–35
No. 100	0–15	–	2–15
No. 200	0–5	0–6	0–5

[a] (MSG 2011); [b] (NDOR 1997); and [c] (MSG 2011).

Table 2.9 Physical and chemical properties of organic compost used in engineered soil mixtures

Property	**LinGro measured Value**	(WRA Environmental Consultants 2009; Thompson et al. 2008)	(Thompson et al. 2008) **WDNR standard**
Particle size <19 mm (0.75″)	100%	95%	>98%
Organic matter	27.76%	35% –75%	≥40%
Ash	24.6%	NA	≤60%
C:N	10.6:1	<25:1	10–20:1
pH	8.1	6.5–8	6–8
Conductivity	5.75 mS/cm	NA	≤10 mhos x 10^{-5} cm^{-1}
Moisture content	44.67%	30% –55%	35% –50%

Table 2.10 Sieve design specification for ASTM C33 47-B gravel

Sieve size	**Percent passing (by weight) min-max**		
Source	Bioretention sand[a]	Class B aggregate[b]	47-B[c]
1 ½ inch	–	–	100–100
1 inch	–	100–100	–
3/8 inch	100–100	–	–
No. 4	90–100	77–97	77–97
No. 8	70–100	–	–
No. 10	–	50–70	50–70
No. 16	40–95	–	–
No. 30	15–70	16–40	16–40
No. 40	5–55	–	–
No. 100	0–15	–	–
No. 200	0–5	0–3	0–3

[a](MSG 2011); [b](NDOR 1997); and [c](MSG 2011).

Expanded Shale was tested as a light-weight supplemental material to reduce the need for materials with a higher cost and bulk density, i.e., sand and gravel. Higher bulk density material has a small unit volume, and thus, can be more costly (due to both material and transportation costs). In this study, rubber chips were initially to be tested in the bioretention cell. However, due to unexpected circumstances, expanded shale was considered and chosen. Expanded shale is produced by heating raw shale to 2,000 ºC, which expands the clay into larger porous particles, generally 0.5 inch diameter (TNLA 2006). Expanded shale in bioretention soil mixtures can improve drainage, hold water for extended periods, making it available for plants in drier periods, and it was found to be chemically durable in municipal solid waste leachate. Therefore, storm water constituents should not be detrimental to expanded shale's integrity (Bowders et al. 1997).

Aggregates used in BMPs. The aggregates used in the test BMPs were 1–3" clean limestone aggregate and ¼–3/8" clean pea gravel (see Table 2.11 for details). All aggregate used was considered "clean" by industry terms from a conversation with an aggregate supplier *Martin and Marietta*, which means less than 5% fines passing the #200 sieve. Aggregate was clean because of the quarry or sand pits mining processes. In the design of the BMPs, all aggregate void ratios were assumed to be 0.4. The rip-rap check dams were designed for rip-rap sized to a D_{50} of 9" but broken concrete and used core samples were used due to price and availability.

Table 2.11 Aggregates used in test BMPs

BMP type	**1-3" Clean Limestone**	**¼"-3/8" clean pea gravel**
Check dam filters	Not used	Filter media
Bioretention	Not used	Under drain media
Filter trench	Armoring	Filter media
Infiltration trench	Total aggregate used	Not used

2.2.4 Monitoring Methods Used

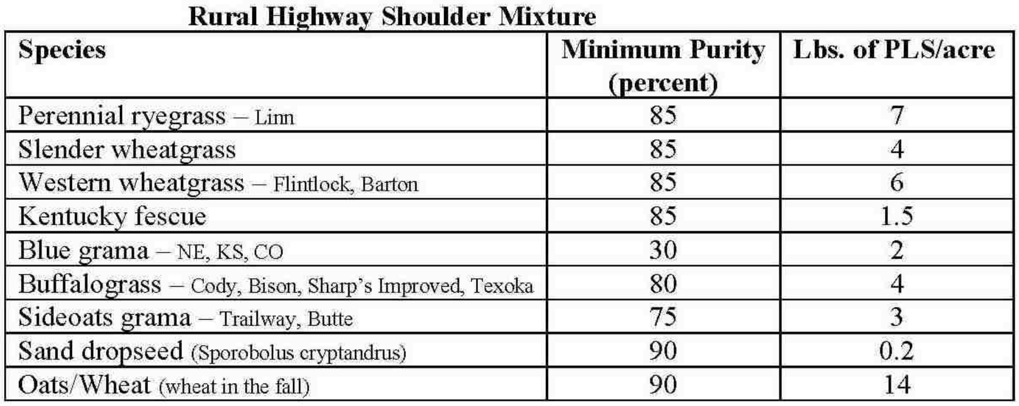
Monitoring methods were established for each of the four types of the field-scale BMPs for information on drawdown rates, clogging, and vegetation establishment. Drawdown rates, which are the speed at which an amount of storm water can infiltrate, of water in the infiltration trench, bioretention, and check dam filters, need to be checked. Drawdown rates affect plants because they can become over saturated if rates are too slow or not have enough water during dry periods if rates are too fast. Efficiency of pollutant removals based on filtration rates is also affected by drawdown rates. Finally drawdown rates affect extended period ponding which should be less than 24 or 48 hours. Clogging was monitored on all BMPs to determine the life expectancy of the BMP after which the BMP does not work with the design efficiency. Vegetation establishment was monitored on the bioretention cells to compare which soil medium supported vegetation the best.

Vegetation planted was NDOR shoulder seed mixture (see Table 2.12) for the NDOR planting region B (see Figure 2.16). For the monitoring of vegetation establishment in the four bioretention cells, digital photos were taken about every 2 weeks with a 6.2 Megapixel Nikon Coolpix L1 camera. To take the picture, a house hold, 2-step, step ladder was used to stand on and take a picture of each test cell from the south end of the cell looking north; this was done arbitrarily for convenience. Images were taken in the midday hours for better lighting except for the last test visit which was done in the dawn hours and proved to be detrimental to the results. A control check image was taken and tested from a residential lawn in good condition in Papillion, NE (appendix B).

After digital images were taken they were cropped, loaded onto a personal computer, and analyzed with Image J software. To analyze the images the thresholds of hue, saturation, and brightness were adjusted to 47-107, 0-255, and 0-255, respectively. The hue was set to 47-107 to narrow the green spectrum (Patton et al. 2005). The pixels measured with this threshold are considered green, and when divided by the total pixels in the image, results in the percent of green cover in the image (see appendix B for examples).

Minimal monitoring of the field-scale BMPs was accomplished during 2012 because, after BMP construction was completed in June, rainfall amounts were extremely low as indicated in Table 2.13. Most clogging of BMPs occurred during construction or immediately following completion due to lack of construction erosion control. Therefore, no baseline was measured, and clogging monitoring was hampered. Due to very little rainfall, infiltration rate measurements were not able to be taken. General BMP conditions were monitored through site visits and photos after each rain event.

Table 2.12 Seed mixture for Nebraska region B (NDOR 2010)



Rural Highway Shoulder Mixture

Species	**Minimum Purity (percent)**	**Lbs. of PLS/acre**
Perennial ryegrass – Linn	85	7
Slender wheatgrass	85	4
Western wheatgrass – Flintlock, Barton	85	6
Kentucky fescue	85	1.5
Blue grama – NE, KS, CO	30	2
Buffalograss – Cody, Bison, Sharp's Improved, Texoka	80	4
Sideoats grama – Trailway, Butte	75	3
Sand dropseed (Sporobolus cryptandrus)	90	0.2
Oats/Wheat (wheat in the fall)	90	14

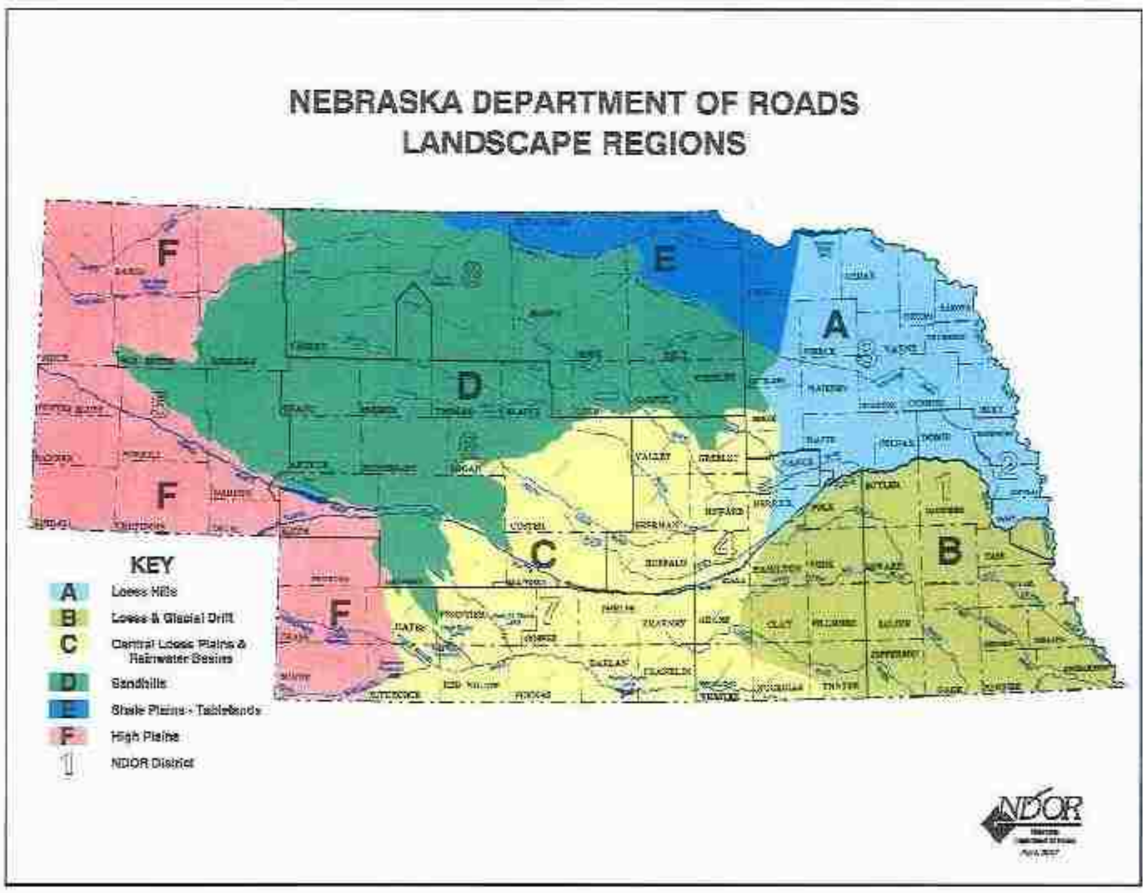


Figure 2.16 Nebraska seed mixture planting regions (NDOR 2012)

Table 2.13 Rainfall amounts for both project sites (National Climatic Data Center (NCDC) 2012)

Month	**Normal precipitation Lincoln, NE (in)**	**Actual precipitation Lincoln, NE (in)**	**Departure from normal precipitation Lincoln, NE (in)**	**Normal precipitation Omaha, NE (in)**	**Actual precipitation Omaha, NE (in)**	**Departure from normal precipitation Omaha, NE (in)**
January	0.67	0.16	-0.51	–	–	–
February	0.66	2.69	+2.03	–	–	–
March	2.21	1.14	-1.07	2.13	0.86	-1.27
April	2.9	3.67	+0.77	2.94	4.26	+1.32
May	4.23	2.98	-1.25	4.44	1.94	-2.5
June	3.51	5.03	+1.52	3.95	3.98	+0.03
July	3.54	0.12	-3.42	3.86	0.07	-3.79
August	3.35	0.69	-2.66	3.21	1.35	-1.86
September	2.92	1.87	-1.05	3.17	1.68	-1.49
Year to Date	23.99	18.35	-5.64	23.7	14.14	-9.56

2.3 Results and Discussions

Field monitoring assessed a) sediment buildup and construction period problems, b) vegetative establishment and c) the establishment of a monitoring scheme. Within the monitoring scheme only vegetative monitoring was able to be performed due to very little rainfall during the monitoring period. Detailed results and discuss are presented below.

Sediment buildup and construction period problems. Sediment buildup was experienced in all BMP types except the bioretention cells. Some of the initial buildup was from rain events that occurred during the construction period. The construction period was between the end of December 2011 and the end of June 2012 (Table 2.14). Most post construction sediment accumulation was a result of lack of erosion control measures such as erosion control blankets, silt fencing, and temporary vegetation.

Table 2.14 Estimated BMP construction time period

BMP	Start	Finish
Bioretention	April 30, 2012	June 25, 2012
Check Dam Filters	February 25, 2012	May 5, 2012
Infiltration Trench	December 27, 2011	January 6, 2012
Filter Trench	January 6, 2012	March 1, 2012

The bioretention cells did not experience this initial sediment buildup because they were built as an off-line type BMP and were constructed in midsummer when few rain events happened during construction. The rain event that did occur during the construction of the bioretention did not affect it because the diversion structure was not in place and stormwater was not diverted into the BMP (appendix B). Post construction sediment loading was minimal for the bioretention cells because there was little rainfall and because the whole watershed remained stabilized during construction.

The check dam filters were inundated with about 2 inches of sediment after the first rain event after installation (indicated in the blue circle in Figure 2.17 and the red circle in Figure 2.18). The source of the sediment was the disturbed soil from the installation of the check dams themselves (indicated by the red circle in Figure 2.17) and can be prevented by installing erosion control blanket or other soil stabilization procedures. This was the source because the contributing watershed remained stabilized throughout and after construction. Upon inspection of the amount of clogging, it was found that most of the sediment was able to be removed by shovel. After removing of sediment, the gravel used as check dam filter media was exposed (indicated by the blue circle in Figure 2.18). These results indicate that a) we need to study the methods for preventing sediment transport after BMP construction, b) how to quantify the sediment transport and their effects on BMPs, c) how to remove sediment once they clog the BMPs. For example, future projects can use photos or measurements to monitor the amount of sediment accumulation. A baseline measurement before any rain events is crucial in monitoring procedures. Depth of sediment can be measured and general area can be measured semi-quantitatively by photos.

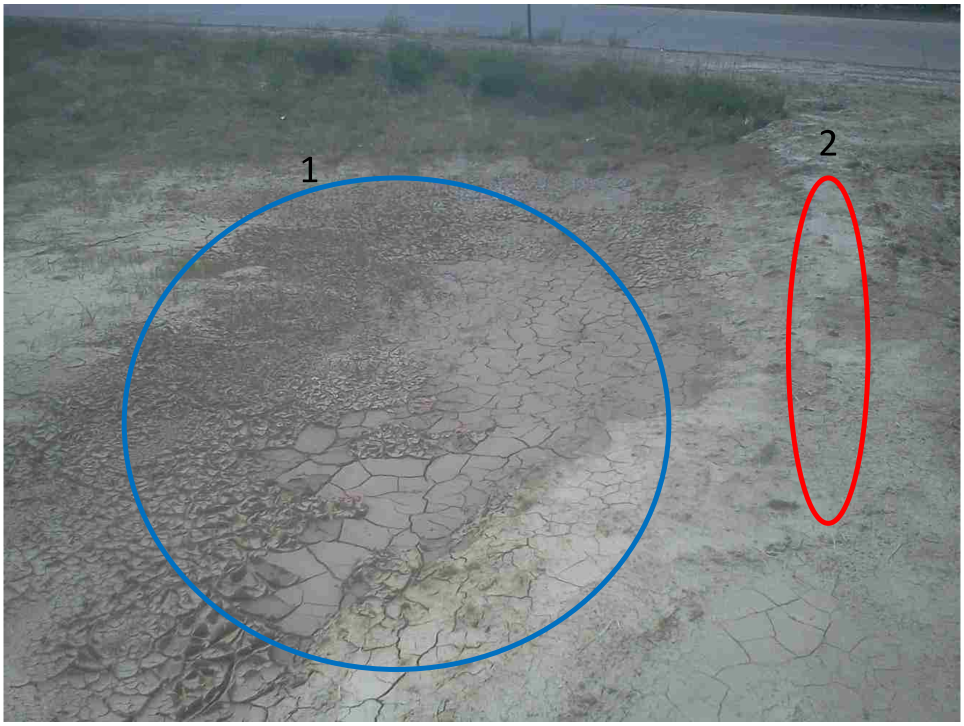


Figure 2.17 Check dam filter clogging

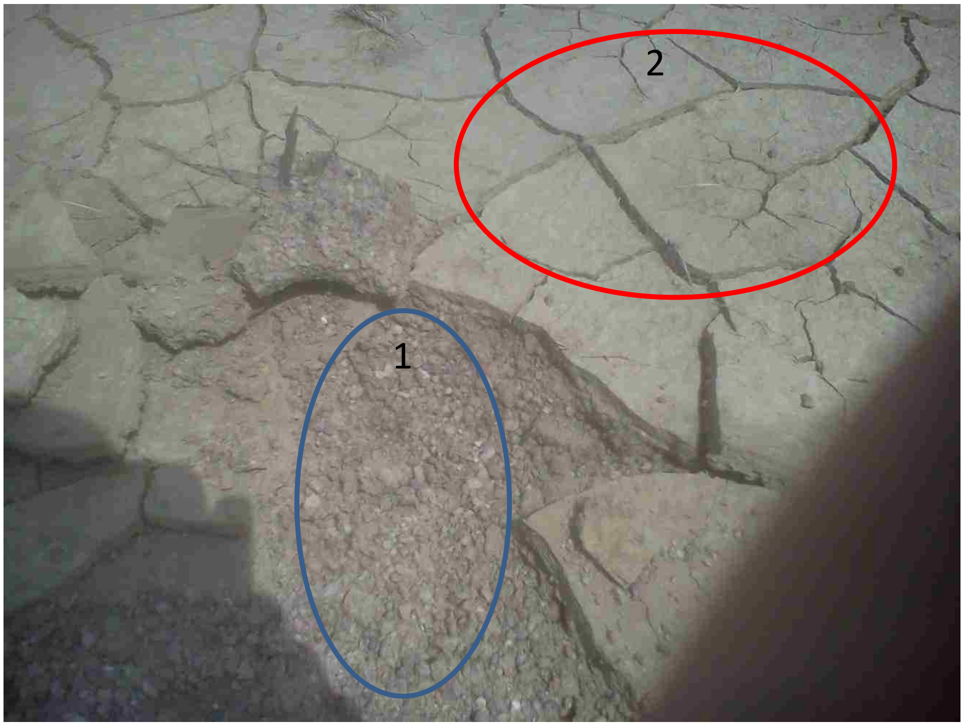


Figure 2.18 Check dam filter gravel and clogging

The infiltration trench experienced very little sediment buildup. Initial buildup was from a small area of disturbed soil near the trench as indicated by the blue circle in Figure 2.19. The contributing watershed for the infiltration trench remained stable during and after construction otherwise. Some further buildup continued to occur from the area entering the trench at the red circles indicated in Figure 2.19. The sedimentation experienced on the infiltration trench did not prove detrimental to its operation because the general size of the sediment deposited on the trench was about a 5’ by 3’ area out of the total 118’ by 3’ area of the trench shown by the green circle in Figure 2.19. The sediment buildup experienced by the infiltration trench can be prevented by stabilizing this area with erosion control blanketing and establishing permanent vegetation. Temporary erosion control can be done by placing silt fencing along the trench.

Monitoring of the clogging of infiltration trenches can be done semi-quantitatively by photos or by measuring the depth and areas of sediment deposits. One method attempted was to bury an aggregate filled bucket in the top section of trench in hopes of catching sediment then removing the bucket and analyzing the amount of sediment captured (see Appendix B for photo). It was unsuccessfully because of little rain events in this study.

Figure 2.19 Infiltration trench clogging

The filter trench experienced high amounts of clogging from the ditch side slopes Figure 2.20. The side slopes of the 250' long disturbed site were 3:1 and were not covered with erosion control blanketing and were not stabilized during construction. During construction, rain events occurred with enough precipitation to cause riling on the side slopes (Figure 2.20). This side slope erosion could have been prevented with erosion control blanketing or silt fencing installed along the bottom of the slope. Because no baseline measurement was taken, accurate monitoring of these rills was not accomplished. In the future, monitoring of rills can be done by counting the number of rills and measuring their size and length to get a volume of soil eroded, which can also linked with rain events if such measurements are done before and after the rain events.

The check dams installed on the filter trench caught some of this sediment, and so did the armoring (Figure 2.21). To prevent the buildup of sediment on the BMP, material erosion control must be done as soon as possible on any disturbed soil area within the watershed of the BMP. Just like in the monitoring of the rill erosion sediment, deposition can be monitored with measuring the depth and area of the deposits. This was impracticable for this study because a majority of the trench was clogged. Monitoring of the deposits can also be done semi-quantitatively with photo logging to acquire a general surface area of the deposit.

By the end of the observation period, weeds and plants were growing in the accumulated sediment (Figure 2.22). The amount of sediment buildup was enough to sustain root establishment in the trench. The clogging and plant growth can prevent water from being able to enter the trench. The best effort to prevent vegetative growth on the rock covering of the trench is to prevent organic matter or sediment buildup. It may be more feasible to build a BMP designed with a fast infiltrating top layer that support plant growth which would improve infiltration rates and stabilize the plant roots would BMP.

Flows in the ditch were high because evidence shows that some of the check dam material (used concrete core samples) was being washed or moved down slope (shown in the red circle in Figure 2.24). This is a good example that concrete debris (i.e. used core samples and broken concrete) is not useful as rip rap because the shape of the concrete debris is not irregular or interlocking like rock brought in from a quarry. The force of water can move this concrete debris more easily.

Some problems arouse related to the structural integrating of the filter trenches setup. Undermining occurred at the beginning of the trench, creating a hole as shown in Figure 2.23. This problem was mitigated by adding more rock material up to the top of the ditch as shown in the blue circle where the hole was located at the bottom of the blue circle Figure 2.24. The knowledge gained from this situation is that the armoring needs to extend above the beginning of the trench or the trench needs to start at the pipe outlet to the ditch. Undermining also occurred at a couple spots along the trench as shown in Figure 2.25. This is thought to be from higher than expected flow velocities within the pea gravel filter media eroding the sides of the underground trench. This could be fixed by filling the hole with 1-3 inch rock or in the design of the trench by using smaller treatment media to slow the filter flow rate.

Figure 2.20 Filter trench side slope rills

Figure 2.21 Filter trench sediment buildup on armoring and check dams

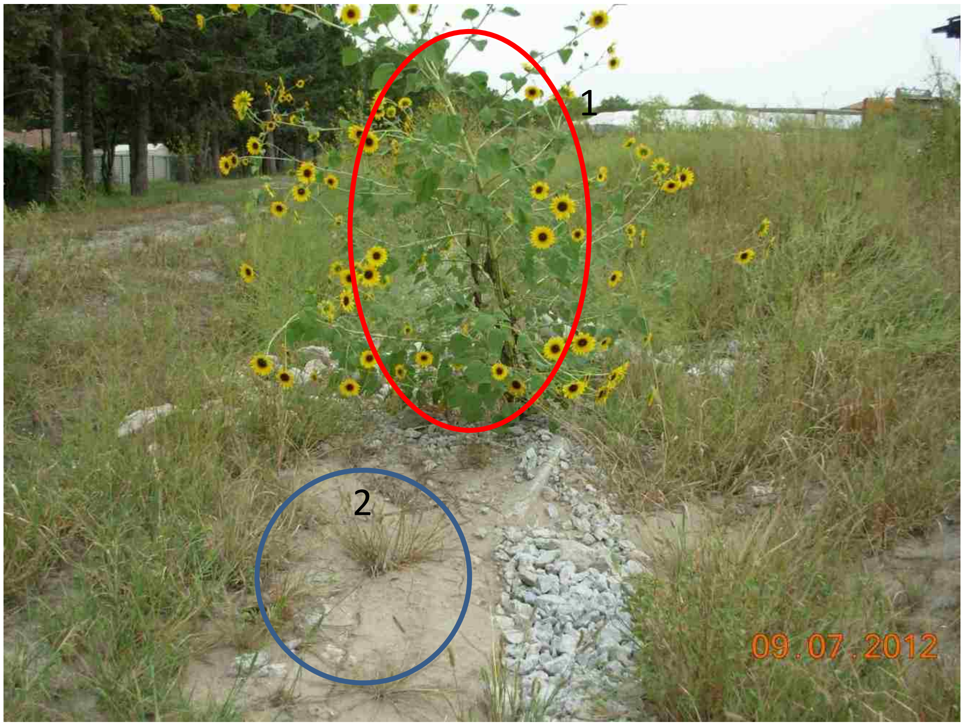


Figure 2.22 Filter trench sediment buildup and vegetative growth

Figure 2.23 Filter trench undermining at beginning of trench

Figure 2.24 Filter trench added 1-3 inch rock at beginning and check dam material migration (water flow direction: from the top to bottom of the picture)

Figure 2.25 Filter trench undermining hole along trench

Corrections to the situations encountered with sediment problems could be to maintain a tight BMP construction schedule to have constructed BMPs stabilized or built between rain events. Also, post construction and during construction erosion control measures are crucial to the initial and long term efficiency of the BMP. Some of these erosion control measures are erosion control blanketing, crimped straw, temporary or permanent vegetation, silt fencing, and straw bales.

Vegetative monitoring. Traditional monitoring is done by taking cuttings from a test area, and then drying and weighing the vegetative growth. Also color is traditionally monitored by visual inspection on a rating scale of 1–9 (Karcher and Richardson 2003).

For this research, image analysis was done using Image J software and Table 2.15 and Figure 2.29 shows the results of the vegetative monitoring.

The compost 47-B test cell had the slowest growth but the highest green growth of the four cells. These mixtures benefits may be from the wide size range and well graded 47-B that aids in conductivity of the mixture. Also the compost could be well distributed throughout the mixture with the 47-B.

The compost sand had the best initial growth and the second best peak growth percentage. The sand mixture provided good drainage and good pore spaces for root growth and, with the addition of compost for nutrients, showed the second best results from testing.

The test cell filled with loam/sand/wood mulch had moderate initial growth and the lowest total green growth. The moderate initial growth of this mixture could be from the mixture being comprised of similar local soils and supplemented with sand and mulch for drainage and nutrients. Over time this mixture may have had more settling then the other mixtures, resulting in some limitation for plant root growth.

The compost/expanded shale cell had the worst initial growth and the third best final growth percentage. This may be caused from the large amount of pore spaces provided by the expanded shale or the temperature of the media because the compost and rock could hold the heat. The heating affect of the media could have been more detrimental because of the lack of rainfall during the month of July.

All of these mixtures may have too high infiltration rates to support excellent plant growth. This is only speculation because no substantial rain events occurred during testing. Soil temperature has an influence on plant growth and any kind of mulch on the soil's surface influences soil temperatures as shown by the solid and dotted line in Figure 2.26 (Willis and Power 2012). Mulch can keep the soil cooler in the morning hours and hold the heat from the day longer into the evening helping plant growth as well as contributing moisture holding capacity and nutrients. Soil temperatures at or above 110°F to 125°F can kill weed seeds and plant seeds (Stapleton 2008). Mulch and other heat holding materials in to high of content percentages can also hurt root growth by raising soil temperatures to high from absorbing the suns heat.

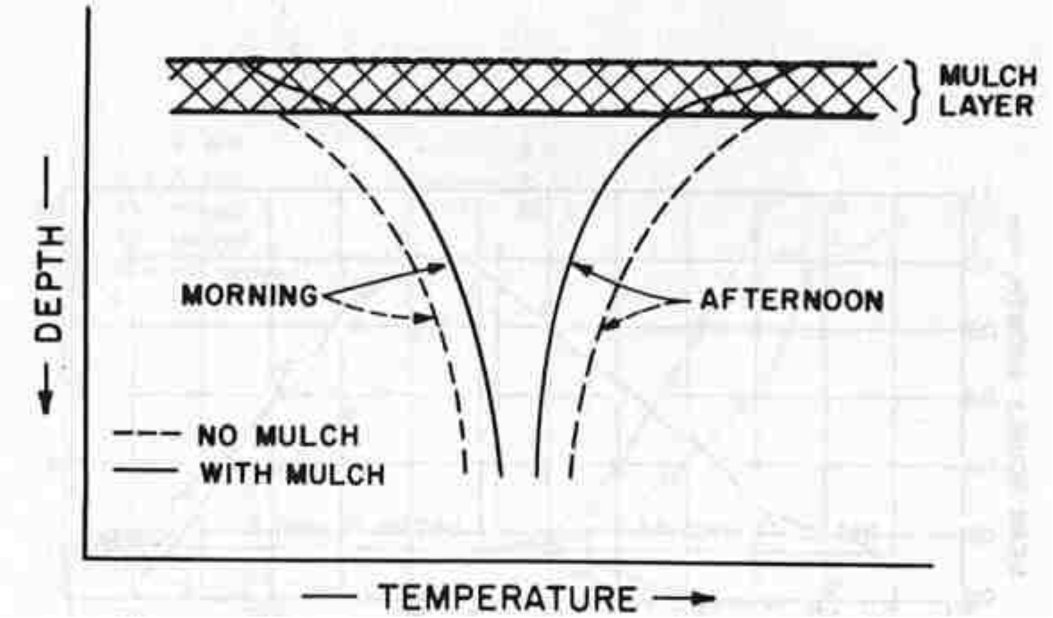
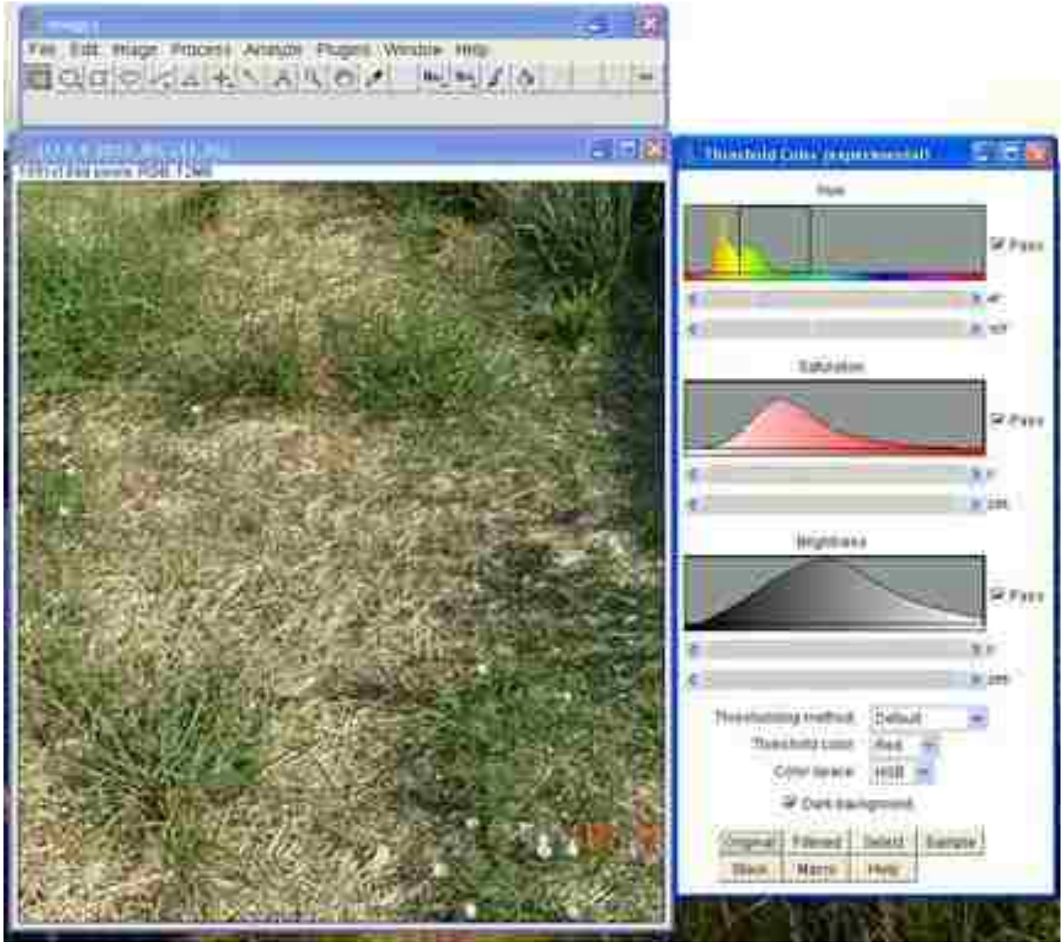


Figure 2.26 Expected soil temperature profiles with and without mulch (Willis and Power 2012)

The dip (after 8/20) on Figure 2.29 is due to the cutting of weeds by the NDOR maintenance group between measurement dates, which lowered the green in the image although only weeds were removed. Some example images of percent plant growth from testing and the control check image can be found in Appendix B (Figs. B.14–B18). The effect of removing the weeds on the amount of green vegetation in the images is one of the drawbacks to using image analysis for plant growth. The use of this image analysis is indiscriminant on what in the image is green weather it is grass, weed, or a piece of green litter. One problem that occurred in image analysis is that some creeping ground cover grew on the edges of the compost expanded shale test cells contributing to the green amount although the plant roots were not necessarily in the test cell but the plant cover was. Another aspect of this image analysis to comment on is that the green in the image was specified by a hue of 47–100 (Patton et al. 2005). This hue can be adjusted slightly to adjust what the user considers green. The benefit of a hue range is that dead plant growth or deleterious brown material is not counted and only good quality growth is. What outweighs the drawbacks of image analysis is that it is unbiased measurement compared to some traditional methods and a large area can be tested at once instead of random test plotting. The extreme slump in the last week (10/9) is explained by shadows because the images were taken in the dawn hours, indicating that light conditions may affect image analysis from shadows (Karcher and Richardson 2003).



Thresholding method: Default
Threshold color: Red
Color space: HSB
☑ Dark background

Figure 2.27 Image J screenshot before threshold selection

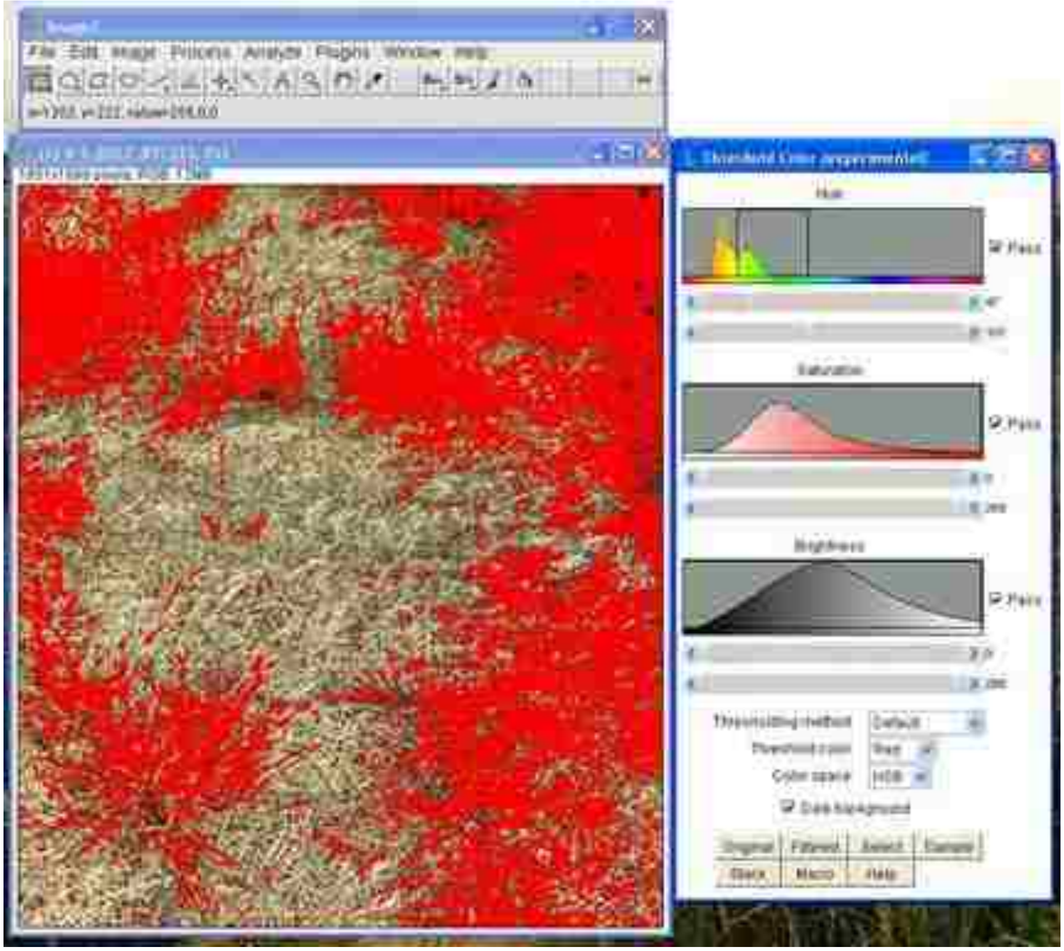


Figure 2.28 Image J screenshot after threshold selection

Table 2.15 Percent of image that is green from Image J analysis

	Date							
Test plot	**7/11**	**7/25**	**8/9**	**8/22**	**9/7**	**9/13**	**9/26**	**10/10**
Compost/sand = 50/50	7.29	20.98	44.20	31.60	53.43	57.53	63.15	21.55
Compost/47-B = 40/60	1.73	6.22	11.82	16.30	48.88	67.33	63.85	32.21
loam/sand/wood mulch = 30/50/20	2.02	12.11	39.23	17.70	39.53	46.48	49.88	20.06
compost/expanded shale 33/66	1.42	3.17	5.88	8.91	41.32	54.52	48.16	31.17

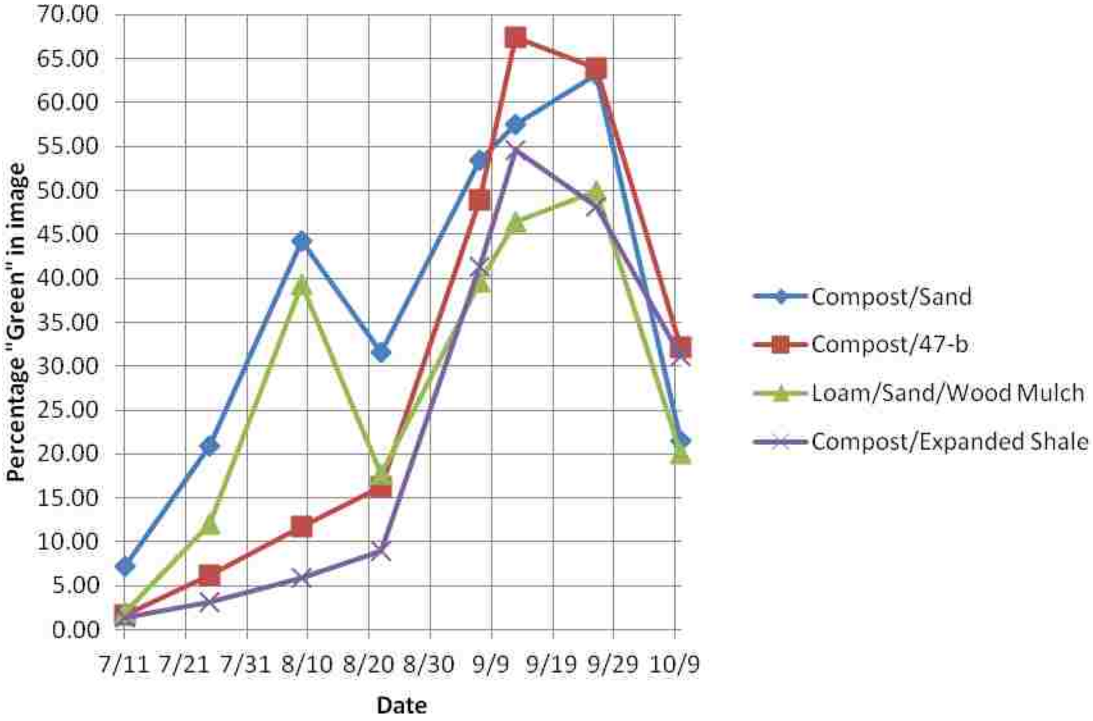


Figure 2.29 Percent of image that is green from Image J analysis

Discussion. The major recommendations that can be made from the site observations are a) erosion control measures are imperative during and after construction, b) BMPs should be build off-line whenever possible, c) stabilization of the area around the BMP and the contributing watershed with vegetation should be accomplished as soon as possible, d) specific to the filter trench armoring should extend upstream from the start of the trench about 5–10 ft and up the side slopes about 1–2 ft.

The bioretention test cells experienced little problems with sedimentation but had problems with vegetative establishment because of little rainfall. Therefore, it is important to find better soil types and vegetation to guarantee plant establishment without human help. The check dam filters experienced high amounts of clogging from the disturbed soil due to the construction process. This should be mitigated with erosion control BMPs during and after construction until the area is stabilized with vegetation. To prevent longer term clogging the use of a high infiltration top layer media that supports plant growth could be implemented. The infiltration trench had some erosion problems that should be mitigated with erosion control measures and stabilization also and long term clogging may be prevented by placing high infiltration top layer media that supports plant growth too.

The filter trench had problems with clogging and structural integrity. Clogging can be prevented with erosion control and stabilization as for all BMPs. The structural integrity issues with undermining and holes at the top and side of the trench can be mitigated on site by placing 1–3 inch rock. Also, they could be prevented by some design changes. To prevent undermining, armoring should be extended upstream from the start of the trench about 5–10 ft and up the side slopes about 1–2 ft. Furthermore, to prevent side trench undermining, smaller filter media could be used to slow the flow rate within the media; this could also increase treatment efficiencies.

Table 2.16 Four BMPs tested advantages and disadvantages

BMP	**Advantages**	**Disadvantages**
Check dam filters	Installed in ditch	Pea gravel easily clogged
Bioretention	Can be built off-line	1) complex construction 2) need elevation change for outlets
Infiltration trench	1) Installed in ditch 2) Easy to install	Can clog because of large pore spaces
Filter trench	Uses slope for treatment	Scour protection needed for high slopes

Table 2.17 General recommendations of the four BMPs.

BMP	Recommendation
Check dam filters	Place fast infiltrating plant growth media cover over gravel
Bioretention	Develop low maintenance plant growth media
Infiltration Trench	Place fast infiltrating plant growth media cover over rock
Filter Trench	1) Improve check dams with better rip-rap 2) Use smaller treatment media size

General monitoring scheme. Although vegetative monitoring was the only data results found during the monitoring of the BMPs, general monitoring methods were established for all BMPs tested. The primary things that could be monitored are vegetative growth, rill or erosion measurement, sedimentation, filter fabric clogging, infiltration rates, and site visit picture documentation. Traditional methods of vegetative monitoring rely on measuring the biomass of a randomly selected area to be tested or measuring the total biomass of the plant material by removing it from the test site. In this project, digital images were taken, and the percent area of plant matter was found using image J analysis.

Rill and erosion measurement can be performed after each rainfall event. This is done by counting and measuring the number and depth of the rills that are at least 0.5 inches deep in the area of interest. The volume of sedimentation can be estimated by measuring the depth and area of each particular deposit within the BMP. For BMPs where filter fabric is used, such as the infiltration and filter trenches, sections of filter fabric can be removed and replaced to monitoring clogging of the fabric by fine particles.

To do this, the section removed, can be weighed before and after to calculate the mass of sediments collected. Infiltration rates for the infiltration trench and bioretention cells can be monitored by site inspection within 12 or 24 hours after a rain event to record the draw-down time and depth of the water collected. General documentation by digital photos can describe the state of the BMPs such as weeds, plants, sediment deposits, and rill areas. Table 2.18 summarizes criteria and methods for these general observations and monitoring procedures.

Table 2.18 Site visit criteria and methods

Criteria	Method Description
Vegetation (%)	• A baseline digital photo is taken and at regular periods during the plant growth time being monitored. • Digital photos are analyzed with Image J software to find the percent green in each image.
Drawdown rate (in/hr)	• After a rain event and a known period of time later (i.e. 12 h) the depth of water in the observation pipes are recorded. • The change in depth divided by the change in time is the drawdown rate.
Volume of rills (ft^3)	• After each rain event rills can be counted and the width and depth recorded. • Multiplying the width, depth and number of rills can give an estimate of the volume of sediment eroded.
Volume of sediment deposits (ft^3)	• By estimating a surface area and depth of sedimentation patches, a volume of deposition can be estimated. • This can also be done semi-quantitatively by taking photos from the same position over time to monitor the general deposit size.
Mass of sediment on filter fabric (g/m^3)	• Where filter fabric is placed near the top of trenches a known section can be massed before use as a baseline. • After some deposition happens on the filter fabric it can

	be removed and massed. • The change in mass can be estimated to be the amount of particles that contributed to clogging.

2.4 Conclusions

Several conclusions can be drawn from the field monitoring of these four BMPs to treat highway runoff.

- Sedimentation within BMPs is a crucial factor that cannot be over-looked during construction and after the construction period. Construction periods should be kept as short as possible to minimize the chance of rain events during construction. After and during the construction phase, erosion control measures should be placed and maintained as soon as possible until the contributing area is stabilized with vegetation.
- From Image J analysis of the digital images taken from the test cells, the compost/47-B test cell had the best vegetative performance. In contrast the loam/sand/wood mulch test cell had the worst vegetative growth of the four test cells. All test cells had between 48 and 64 percent green in the best images.
- Although only vegetative monitoring was accomplished, a monitoring matrix is important for further methods of reporting the long term use and efficiency of these BMPs. Monitoring methods should focus primarily on clogging and treatment of solids.

Chapter 3 Lab Testing of Rubber Chip Mediated Soil Mixtures

3.1 Introduction

Bioretention BMPs and other filtration BMPs rely on engineered soil media to treat storm water via physical, chemical, and biological processes. The engineered soil (infiltration media) is commonly composed of sand, soil, and compost, and is typically covered with a mulch layer and planted in diverse vegetation (Thompson et al. 2008). Bioretention was first developed in Prince George County, Maryland in the 1980's (Ming-Han et al. 2010). Research on the engineered soil media to be placed in bioretention and other BMPs has been in continuous development since the establishment of such BMPs.

Research most commonly recommends bioretention media to be a soil with a NRCS textural classification of sandy loam or loamy sand (PGCM 2007). An alternative media that could be tested is rubber chips. Studies have shown that rubber crumb can be used as an effective filter medium achieving similar results when used as a pollution control medium on green roofs and within other storm water controls (Wanielista et al. 2008). Testing done in Florida showed that the expected concentration of rubber crumb used in the up-flow filter for discharges from a wet detention pond is much lower than the Lethal Concentration for 50% kill (LC50) or the acute toxicity (Wanielista et al. 2008). Further testing of using rubber chips as engineered media in bioretention or other BMPs needs to be done.

The objective of this chapter is to evaluate the feasibility of using rubber chips as a supplement to BMP media. Testing of the chemical and physical properties of rubber chips added to traditional BMP media, such as silty loam soil, sand, and compost, was done to evaluate the practicality and safety of using rubber chips. The primary focus in adding rubber chips was to decrease bulk density, increase infiltration rates and provide a light-weight filler material to BMPs. Chemical analysis of influent and effluent concentrations were assessed to check pollutant concentrations that may leach from the mixtures of the media tested.

3.2 Materials and Methods

Media. To test the chemical and physical properties influenced by rubber chips, eight column reactors were built and filled with 4 media mixtures in duplicate. The four mixtures used were: (1) 50% silty loam soil and 50 % rubber chips (SLR), (2) 50% sand and 50% rubber chips (SR), (3) 50% compost and 50% rubber chips (CR), and (4) 100% rubber chips (R). Silty loam soil was obtained from the project site located at the Interstate 80 I street on-ramp in Omaha, NE. The rubber chips were supplied by Bruckman Rubber Co., Hastings, NE, USA. The rubber chips were 3–4 mesh size with a porosity of 0.53. The sand used was purchased at a local home and garden store and was Quickrete® all purpose sand that meets ASTM C33 standards for gradation. The compost was purchased at a local nursery and is Oma-Gro brand produced by the City of Omaha, which is similar to the Lin-Gro brand used in the Lincoln project site BMPs. This compost is made exclusively of grass clippings, leaves, and ground wood produced from yard waste collected and composted by the city of Omaha for Oma-Gro.

Column reactors. The reactor columns were made with 3-inch diameter PVC pipe. The total height of the columns was 29 inches, 9 inches for ponding depth, 18 inches of media, and 2 inches of free drain space at the bottom. Sampling ports, effluent ports, and an overflow were located along the side of the column (Figure 3.1).

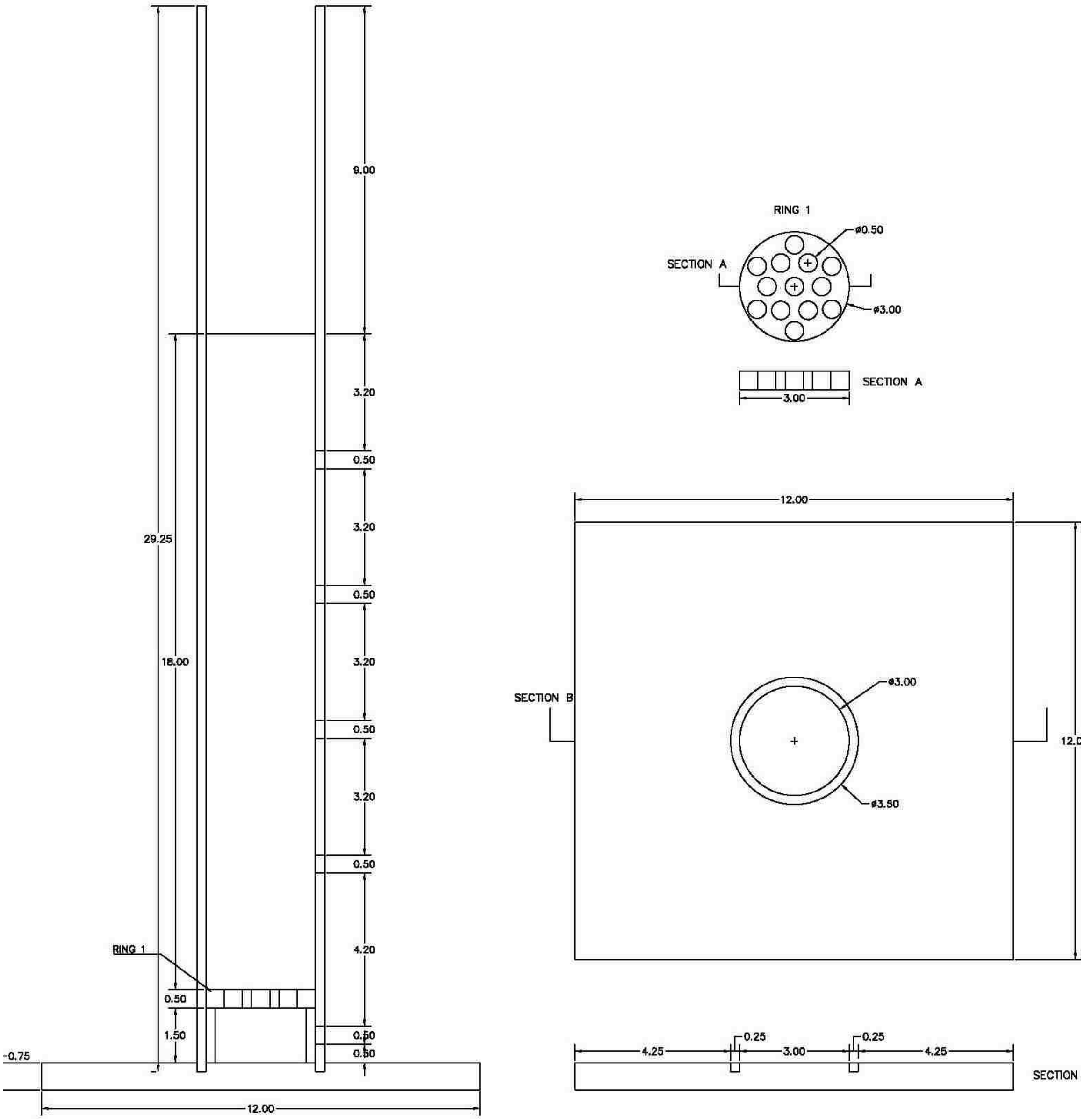


Figure 3.1 Reactor plans

Synthetic storm water. The synthetic storm water that was used in testing the reactors is described in Table 3.1. This mixture is based on literature from research done in the Austin, TX area and is modified for this project (Keblin et al.). Roadway sediment, kaolin, sodium carbonate, and sodium chloride were added to simulate the typical solids distribution of highway storm water runoff. Roadway sediment also adds any leachable storm water constituents that are present in roadway runoff. Metal nitrates (lead, copper, and zinc) were added for the source of metals and nitrate. All concentrations used are comparable to those found in highway runoff (Keblin et al. 1998).

Table 3.1 Synthetic storm water constituents and concentrations (Keblin et al. 1998)

Constituent	Concentration (mg/L)	Constituent	Concentration (mg/L)
Roadway sediment[a]	500	$Zn(NO_3)_2 \cdot 6H_2O$	0.91
Kaolin	40	Na_2CO_3	0.9
$Pb(NO_3)_2$	0.16	NaCl	200
$Cu(NO_3)_2 \cdot H_2O$	0.11		

[a] The portion used was passed through the 250 micrometer (mesh # 60) sieve of the sediment collected from a local highway storm water outfall (e.g., the I-80 detention basin near 108th Street in Omaha). The sediment was collected on 4/26/2012 and contained high amounts of sandy material most likely due to winter runoff from the roads.

Physical properties tested. The physical properties of the four types of media mixtures that were tested were: a) the initial settling, b) initial and final saturated hydraulic conductivity, c) bulk density, d) field capacity, e) wilting point, and f) available moisture. For a), after the Columns were loaded with 18 inches of media, 5 liters of tap water were ran through the reactors, 1 liter per run. After each run the depth change of the media was recorded and settling stabilized after 5 liters. For b), initial and final saturated hydraulic conductivity was measured with a method based on the ASTM D2434 standard and flow-through testing method used in *Physical and Hydraulic Properties of*

Engineered Soil Media for Bioretention Basins (Thompson et al. 2008). The saturated hydraulic conductivity procedure consisted of a consistent inflow and outflow rate with 9 inches of head about the soil media held constant. Tap water was run through a hose to the top of the reactor and ponding was allowed up to an overflow port. Once steady flow from the effluent port and overflow port were observed for a 15 to 30 minute period, effluent volumes were measured with a graduated cylinder for a given time period (i.e., 900mL for 30 seconds). Three readings were taken to check consistency.

Saturated hydraulic conductivity was calculated using equation 3-1.

$$K_{sat} = \frac{Q*L}{A*t*h} \qquad \text{3-1}$$

where:

K_{sat}: Saturated hydraulic conductivity (cm/s)

Q: Volume of water passed through column (cm^3)

L: Length of soil media (cm) = 45.72cm

A: Cross sectional area of column (cm^2) = 45.6cm^2

t: Time for Q to pass through the column (s)

h: Height of water column plus soil media (cm) = 68.58cm

After 10 consecutive weeks of loading the reactors, final saturated hydraulic conductivities were checked using the same method as the initial hydraulic conductivity test. Then the top 2.5 inches of media were removed and replaced with new media, and the saturated hydraulic conductivities were checked again with the same method to inspect the influence of clogging in the top 2.5 inches of media.

For c - f bulk density, field capacity, wilting point, and available moisture were tested by Midwest Laboratories. Field capacity was measured at 1/3 BAR only, wilting point was measured at 15 BAR and available moisture was measured with 1/3 BAR and 15 BAR limits with a membrane apparatus.

Procedure for leaching tests. After initial settling and hydraulic conductivity were recorded, treatment efficiencies and constituent concentrations were tested. One liter of synthetic storm water (as shown in Table 3.1) was loaded every 7 days to each of the 8 columns for a 10 week period. Loading was done every 7 days to represent a drying time between loadings based on a period greater than Antecedent Moisture Condition (AMC) type II which is 5 days (Gupta 2008). The one liter volume of loading was based on the volume required to fill the ponding depth of 9 inches (corresponding to the design ponding depth of the field tested bioretention cells) in the 3 inch diameter column. One representative influent sample was taken at the halfway point of column loading (after loading 4 liters of the 8 total liters). The effluents from each column were collected with a separate sampling bottle, which then was used to represent a composite effluent sample of that column.

Analytical methods and data analysis. Table 3.2 shows the analytical methods used and the constituents that were analyzed.

Table 3.2 Constituents, methods, and method detection limits

Constituent	Method (APHA et al. 2012)	Method Detection Limit (µg/L)
Iron	Sec. 3125 B	5.198
Nickel	Sec. 3125 B	3.373
Copper	Sec. 3125 B	2.100
Zinc	Sec. 3125 B	2.201
Lead	Sec. 3125 B	3.794
Chromium	Sec. 3125 B	12.362
Silver	Sec. 3125 B	7.436
Cadmium	Sec. 3125 B	1.228
Antimony	Sec. 3125 B	8.404
Nitrate as Nitrate	Sec. 4110 A	276
Total Suspended Solids (TSS)	Sec. 2540 D	10,000
COD	Sec. 5220 D	5,000

Metals analysis. This test follows part 3000 and section 3125 B of Standard Methods (APHA et. al. 2012). Samples were preserved with 2% (v/v) trace metal grade nitric acid (Fisher A509-212) after collection. Samples were analyzed with a 2004 Varian Inductively coupled plasma mass spectrometry (ICP-MS). Samples were preserved with nitric acid but not digested or filtered. Total metals are considered the concentration of metals determined from an unfiltered vigorously digested sample. Dissolved metals are considered metals from an unacidified sample filtered through a 0.45µm filter (APHA et.

al 2012). Our samples were preserved and unfiltered because of the analysis and preservation method and are most closely related to the definition of total metals.

Nitrate analysis. This test follows section 4110 B of Standard methods (APHA et. al. 2012). Nitrate was analyzed using 792 Basic IC Metrohm ion chromatograph instrument with an anion IC column (P/N: ANX-99-8511) and a flow rate set to 1.35 mL/min. Before measuring, samples were filtered through a 0.45-µm syringe filter. A solution of 1.8 mM sodium carbonate and 1.7 nM sodium bicarbonate was used as the eluent. The concentration of nitrate in the samples was determined against standards.

TSS analysis. This test follows Section 2540 D of Standard Methods (APHA et. al. 2012). A continuously stirred sample was filtered through a weighed standard glass-fiber 0.50µm filter and the residue retained on the filter was dried to a constant weight at 103–105ºC for 1 h. The increase in weight of the filter represents the TSS.

Chemical oxygen demand (COD) analysis. COD was tested for the last 3 weeks of reactor loadings. Samples were preserved with 2% (v/v) sulfuric acid (Fisher A300-212) and analyzed per APHA 5220 D methods colorimetric method (APHA et. al. 2012). The digestion vials used were 0-15,000ppm range CAT. 2415915. The spectrophotometer used was a Genesys 10uv from thermo scientific set to a 600nm.

Treatment efficiencies of each column were calculated using equation 3-2 and plotted for comparison. Also the influent and effluent concentrations were recorded and compared to Nebraska Department of Environmental Quality (NDEQ) stream standards (NDEQ 2006).

$$\text{Efficiency} = \left(\frac{c_{in} - c_{out}}{c_{in}}\right) * 100 \qquad \text{3-2}$$

Control checks were done for leachable nitrates and metals from the roadway sediment by mixing 0.1 g of sediment in 50 ml de-ionized water and 10 ml of trace metal grade nitric acid for 3 hours and then measuring metals and nitrates in the solution. The tap water used in making the synthetic storm water was also checked for metals and nitrates. In this case, tap water was taken from the same sink used and persevered by the same methods of all other samples of that type. The sediment and tap water metal control checks were refrigerated and did not require addition of acid because of the leaching process. Both tap water control checks did not require any acid addition and were refrigerated until analysis.

3.3 Results and Discussions

3.3.1 Initial Settling

The initial settling of the reactor media is an important aspect because one needs to know the volume of material that would be needed in the field to build BMPs without needing additional material later after settling occurs. The results in Table 3.3 show that the rubber chips have no settling after flowing 5 liters of water through the columns. In contrast, the compost rubber mixture had the greatest settling of 2.78 percent. The compost most likely had the greatest settling due to the low bulk density of compost.

Table 3.3 Initial settling of reactor media

Reactor[a]	initial depth from top of reactor (in)	final depth from top of reactor (in)	change (in)	Change (%)
R1	8.875	8.875	0	0
R2	8.75	8.75	0	0
CR1	8	8.5	0.5	2.63
CR2	9	9.5	0.5	2.78
SR1	9	9.25	0.25	1.39
SR2	7.75	8.25	0.5	2.60
SLR1	8.875	8.875	0	0
SLR2	8.5	8.75	0.25	1.35

[a] R = rubber, CR = compost/rubber, SR=sand/rubber, SLR = silty loam/rubber

3.3.2 Saturated Hydraulic Conductivities

Table 3.4 shows typical hydraulic conductivities of different filter media. The saturated hydraulic conductivity results from initial, final, and after replacing the top 2.5 inches of media are found in Tables 3.5, 3.6, and 3.8, respectively. In all saturated hydraulic conductivity testing, the reactors with only rubber chips (R) had the highest values followed by the compost rubber chip mixture (CR). The lowest conductivity values were found in the sand rubber mixture reactors (SR). In comparing the results found in testing with Table 3.4, all the media types except rubber chips (R) have a saturated hydraulic conductivity comparable to medium gravel, and the rubber chips (R) are comparable to coarse gravel. The change in conductivity after loading the reactors weekly for 10 weeks with synthetic storm water is found in Table 3.7. All columns had a decrease in conductivity except the compost rubber (CR) columns. Lower conductivity was caused most likely from continued settling of media and clogging of some pore spaces. However, in the CR columns, fine particles (presumably from the media due to the brown color on filters from TSS testing) were observed in the effluent, and this leaching of fine particles increased pore space sizes in the columns, resulting in higher conductivity after 10 week loading of synthetic storm water.

It is recommended that the top 2–5 cm of the BMP’s filter surface be scraped off every two years to prevent hydraulic failure (Hatt et al. 2008). Therefore, after final the test for conductivity, an additional test for conductivity was conducted to check the effect of surface clogging on the saturated hydraulic conductivity. The top 2.5 inches of the media was removed and then replaced with the same type but new media. Results indicate that after replacing the top 2.5 inches, the saturated hydraulic conductivity decreased in all reactors except for SLR2 show in Tables 3.8 and 3.9. The compost rubber reactors had the largest decrease between .5 to 1 cm/s and the other reactors decreased between 0.077 to 0.005 cm/s. The decrease may be from the introduction of new fine material component of the media being reintroduced after being flushed out during the 10 weeks of testing. Also the decrease may be from settling of the media from the 10 weeks of testing flows.

Table 3.4 Typical hydraulic conductivities (Gupta 2008)

Formation	Hydraulic conductivity (cm/s)
Gravel, Coarse	1.16-9.95
Gravel, Medium	0.023-1.16
Gravel, Fine	0.023-0.058
Sand, Coarse	0.00012-0.58
Sand, Medium	0.00012-0.058
Sand, Fine	0.000011-0.023
Silt, Sandy	0.0012-0.0046
Silt, Clayey	0.00023-0.0012
Till, Gravel	0.035
Till, Sandy	0.00023
Till, Clayey	0.00000012
Clay	0.00000058

Table 3.5 Initial saturated hydraulic conductivity

Reactor[a]	volume of water flowed through (ml)	time of flow through (s)	K cm/s	K in/hr
R1	960	5	2.807	3978
R2	810	4.2	2.820	3996
CR1	391	30	0.191	270
CR2	162	30	0.079	112
SR1	122	30	0.059	84
SR2	200	30	0.097	138
SLR1	476	30	0.232	329
SLR2	250	30	0.122	173

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.6 Final saturated hydraulic conductivity

Reactor[a]	volume of water flowed through (ml)	time of flow through (s)	K cm/s	K in/hr
R1	757	5.2	2.128	3017
R2	737	5	2.155	3054
CR1	950	12	1.157	1640
CR2	947	21.2	0.653	926
SR1	90	30	0.044	62
SR2	125	30	0.061	86
SLR1	508	30	0.248	351
SLR2	90	30	0.044	62

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.7 Difference in initial and final saturated hydraulic conductivity

Reactor[a]	ΔK cm/s	ΔK in/hr
R1	-0.679	-962
R2	-0.665	-942
CR1	0.967	1370
CR2	0.574	814
SR1	-0.016	-22
SR2	-0.037	-52
SLR1	0.016	22
SLR2	-0.078	-111

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.8 Saturated hydraulic conductivity after replacement of top 2.5 inches of media

Reactor[b]	volume of water flowed through (ml)	time of flow through (s)	K cm/s	K in/hr
R1	N/A[a]	N/A	N/A	N/A
R2	N/A	N/A	N/A	N/A
CR1	200	30	0.097	138
CR2	175	30	0.085	121
SR1	80	30	0.039	55
SR2	85	30	0.041	59
SLR1	350	30	0.171	242
SLR2	170	30	0.083	117

[a] N/A = not tested because apparatus wasn’t working for these reactors

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.9 Difference in saturated hydraulic conductivity after replacing the top 2.5 inches of media

Reactor[b]	ΔK cm/s	ΔK in/hr
R1	N/A	N/A
R2	N/A	N/A
CR1	-1.06	-1502
CR2	-0.568	-805
SR1	-0.005	-7
SR2	-0.019	-28
SLR1	-0.077	-109
SLR2	0.039	55

[a] N/A = not tested because apparatus wasn’t working for these reactors

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

3.3.3 Other Four Important Physical Characteristics of Media

Bulk density, field capacity, wilting point, and available moisture are all physical characteristics of the media that can affect plant growth. As shown in Table 3.10, for the materials tested in this study, the highest bulk density was found to be the expanded shale and sand mixture (ESS), and the lowest was found to be the rubber chips (R). The soil mixture that had the best moisture properties was Compost Rubber (CR). The soil mixture that had the worst ability to hold moisture available for plants was the rubber (R) only.

Table 3.10 Physical characteristics of media tested

Sample[c]	Bulk density (g/cm^3)	Field capacity 1/3 BAR %	Wilting point 15 BAR %	Available moisture %
SLR	1.5	19.77	13.32	6.45
SR	1.75	1.97	0.98	0.99
CR	1.18	44.44	38.26	6.18
R	0.04	6.84	6.44	0.4
ESS[a]	2	9.09	7.95	1.14
ESC[b]	1.3	29.92	28.47	1.45

[c] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber
[a] ESS = expanded shale sand; [b] ESC = expanded shale compost. Note: these two media were not loaded into the column for different tests, but could be used in the field BMPs, and thus, were tested here. These were tested to compare a natural porous product to rubber chips.

Bulk density can affect plant growth. Figure 3.2 shows the growth limiting bulk densities for soil types based on the NRCS soil texture triangle. The growth limiting bulk density is related to the average pore size radius of each soil class (Daddow and Warrington 1983). The growth limiting bulk density is the relative point of density where root growth starts to become inhibited by the density of the soil the roots are located in.

In testing the mixture of Silty Loam mixed with rubber chips (SLR), the measured bulk density was 1.5 g/cm^3 (Table 3.10). The addition of the rubber chips did not improve the bulk density compared to silty loam without rubber above the growth limiting bulk density based on the value of 1.45 g/cm^3 shown in Figure 3.2. Therefore, the addition of the rubber chips does not improve the physical characteristics of the bulk density of silty loams growth limiting bulk density.

Figure 3.2 is used to find the growth limiting bulk density by first locating the soils percent sand, silt, and clay on the figure and finding or interpolating its growth limiting bulk density value. For example, the silty loam used in testing was 20 percent sand, 56 percent silt and 24 percent clay. The textural point is located on the 1.45 g/cm^3 isodensity line. So the growth limiting bulk density of this soil is 1.45 g/cm^3.

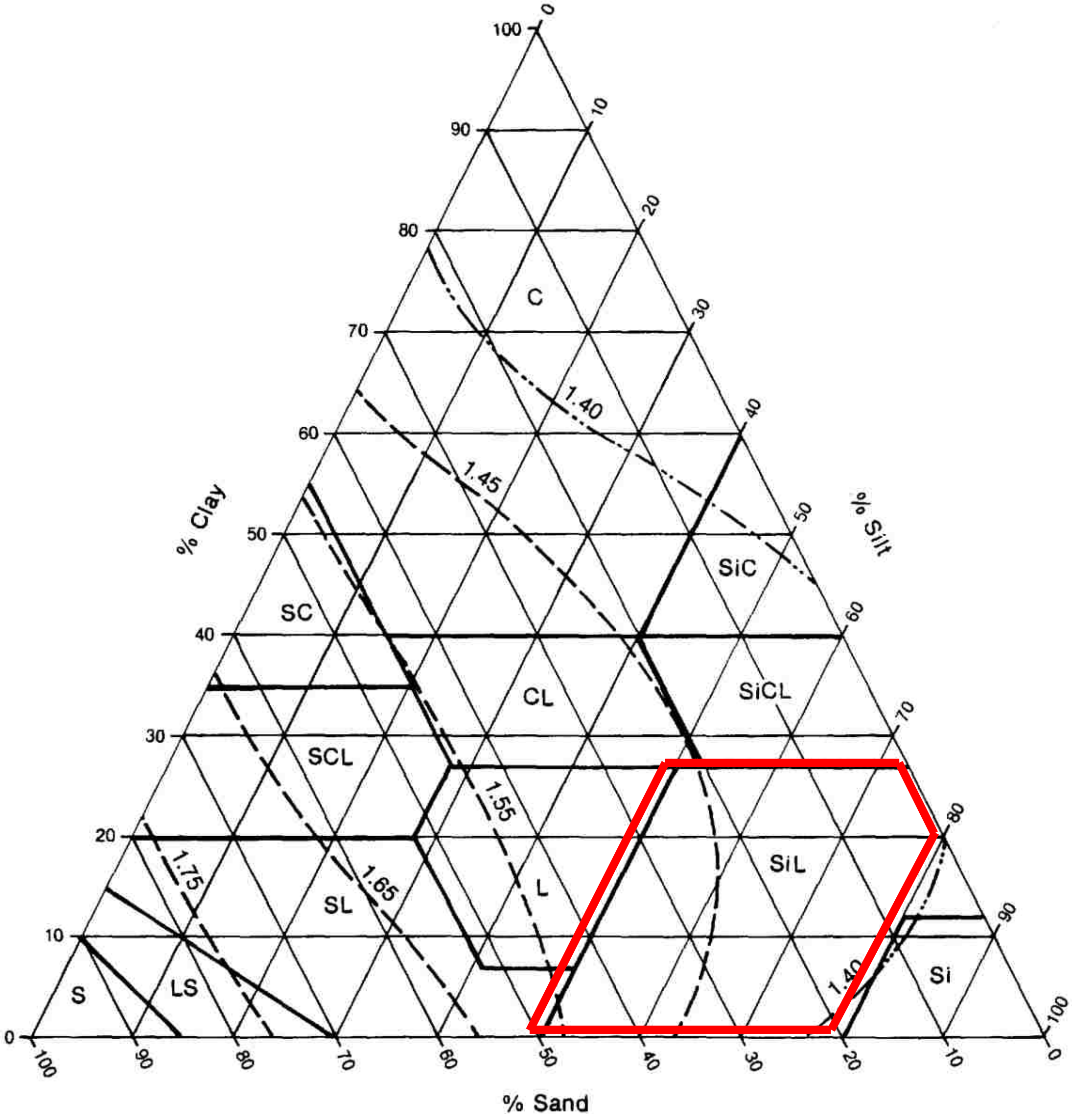


Figure 3.2 Growth-limiting bulk density textural triangle (Daddow and Warrington 1983).
*Only applicable on soils with less than 3 percent organic matter, less than 10 percent coarse fragments. For silty loam (SiL), the growth-limiting bulk density is about 1.40 to 1.50.

Bioretention soil should be within the soil texture class of loamy sand or sandy loam due to their infiltration rates ranging from 0.52 – 2.41inches/hour (PGCM 2007). However, loamy sand and sandy loam have relatively low available water properties as shown in Figure 3.3, thus it is good practice to add organic matter or other improvements to these soils for good plant growth. Figure 3.3 uses units of inches of water per foot of soil, which is a common unit for measuring moisture in soil, these units can be converted to percent moisture by dividing the inches of water by 12 and multiplying by 100. Figure 3.4 shows that increasing the organic matter of soil increases available water. Bioretention media should have 1.5 to 3 percent organic matter (ISMM 2009).

The addition of compost or other types of organic matter is important for plant growth and field capacity. For silt loam with rubber column (SLR) media, the field capacity measured was 19.77 percent or 2.37 inches of water per foot of soil, and the permanent wilting point measured was 13.32 or 1.6 inches of water per foot of soil, which are lower and higher than those shown in figure 3.3, respectively. The rubber chips added to the silty loam narrowed the range between the field capacity and permanent wilting point, decreasing the available moisture percentage. Therefore, the rubber chips did not add any moisture benefits to the media as expressed in the silty loam sample. The best media, based on moisture characteristics, were the compost rubber mixture followed by the silty loam rubber mixture. The available moisture of rubber and the sand rubber mixtures were around 6 times lower than the silty loam rubber or compost rubber mixtures. The result of the compost rubber mixture having the best moisture characteristics shows the benefits of amending soil media with compost.

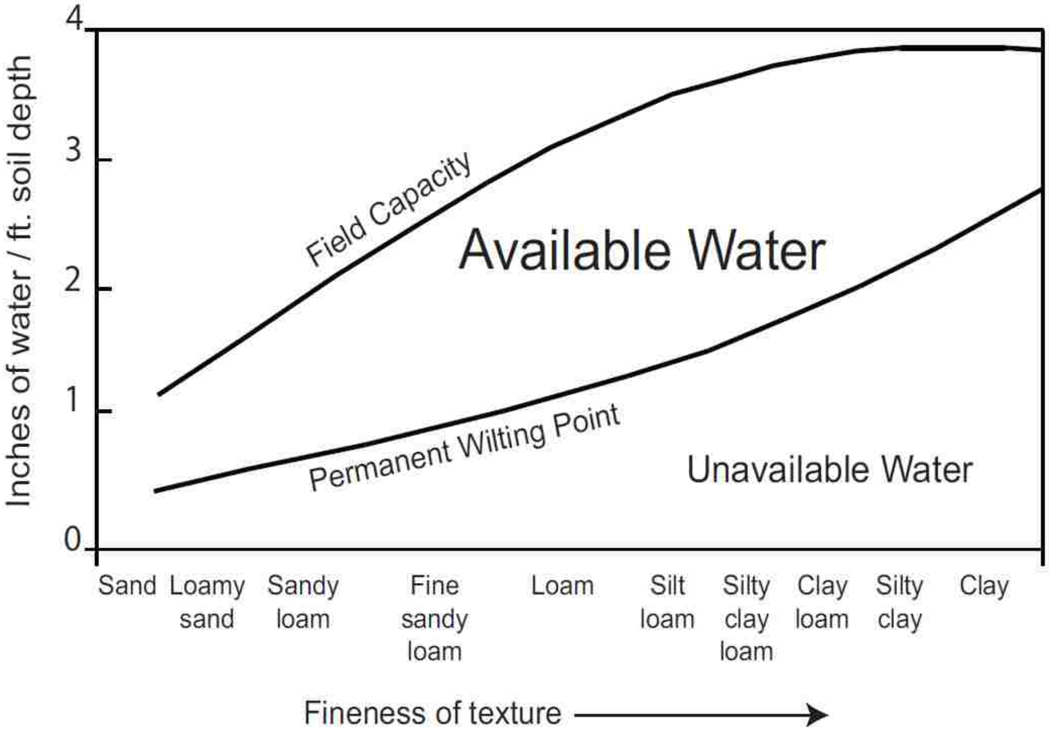


Figure 3.3 General relationship between soil moisture and texture (USDA 2008)

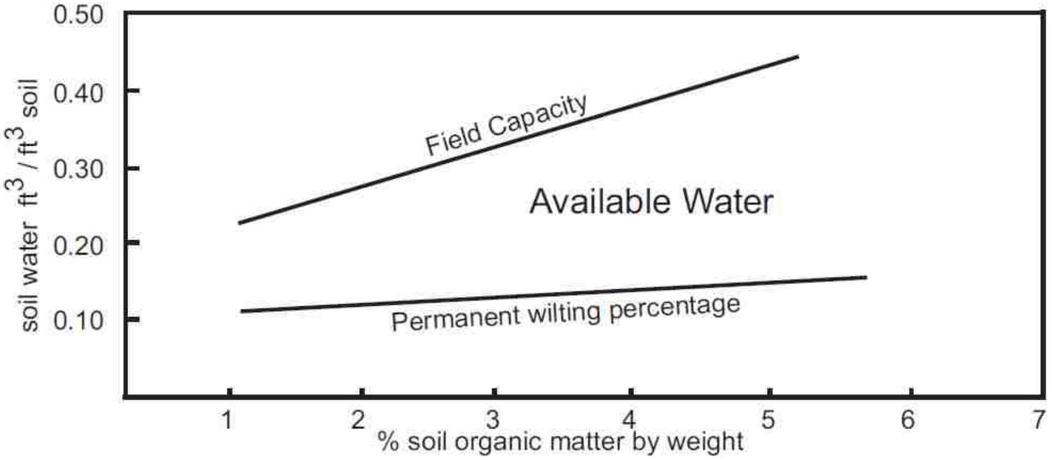


Figure 3.4 Effect of increasing organic matter on available water (USDA 2008)

3.3.4 Column Tests by Loading Synthetic Highway Storm Water Runoff

Results and analysis of the 10 weeks of reactor testing were compared against other studies and Nebraska Department of Environmental Quality (NDEQ) numerical stream standards (see table 3.11). Numerical stream standards commonly do not play a role in MS4 regulations because the use of BMPs replaces the need for numerical standards in the regulations. Comparison with the NDEQ stream standards was still done to check effluent and influent concentrations from the reactors to see if the media were improving the concentrations or adding more pollutants above stream standard concentrations. NDEQ stream standards are based on water hardness because the calculated concentration is for dissolved metals. Because of the methods used in analysis and preservation of the lab samples, the lab samples were obtained by a modified method for total metals and could be considered total metal concentrations (APHA et. al 2012).

Table 3.11 NDEQ stream standard concentrations (NDEQ 2006)

Constituent	Concentration (μg/l)[a]	Condition
Fe	1,000	chronic
Ni	842	acute
Cu	25.8	acute
Zn	211	acute
Pb	136	acute
NO_3	10,000	Drinking water standard

[a] Concentrations for metals calculated with NDEQ equations using a concentration of 200 mg/L $CaCO_3$ water hardness.

3.3.4.1 Analysis of Control Checks

The control checks done on the tap water and roadway sediment are shown in

Table 3.12. The tap water used added a trace amount (in the range of μg/L) of iron, copper, zinc, and nitrate to the influent to be used in this study. The roadway sediment also contained concentrations of iron, copper, zinc, and nitrate, most notably more than 3,000 μg/g of iron and more than 100 μg/g of zinc. Chromium and silver were found in the sediment analysis (data not shown in Table 3.12) but were not detected in the influent or effluent testing of the reactors. Table 3.13 shows some typical sources for roadway constituents such as chromium and nickel.

Table 3.12 Concentrations of constituents in tap water and roadway sediment

Constituent	Tap water (μg/l)	Roadway Sediment (μg/g)	Instrument DL (μg/l)
Cr	< DL[a]	12.148	12.362
Fe	73.122	3054.209	5.198
Ni	< DL	7.255	3.373
Cu	6.294	28.076	2.100
Zn	8.574	113.842	2.201
Ag	< DL	31.982	7.436
Cd	< DL	< DL	1.228
Sb	< DL	< DL	8.404
Pb	< DL	19.076	3.794
NO^3	589	185	276

[a] < DL = lower than detection limit.

Table 3.13 Roadway constituent sources (Stansbury et al. 2012)

Constituent	**Primary source**
Particulates	Pavement wear, vehicles, atmosphere, maintenance, snow/ice abrasives, sediment disturbance.
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer use, sediments.
Lead	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear, atmospheric fallout.
Zinc	Tire wear, motor oil, grease.
Iron	Auto body rust, steel highway structures, engine parts.
Copper	Metal plating, bearing wear, engine parts, brake lining wear, fungicides and insecticides use.
Cadmium	Tire wear, insecticide application.
Chromium	Metal plating, engine parts, brake lining wear.
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brake lining wear, asphalt paving.
Sodium, Calcium	Deicing salts, grease.
Chloride	Deicing salts.
Rubber	Tire wear

3.3.4.2 Metals Leached in Column Tests

Iron. Iron was added to the synthetic storm water via added sediment and tap water. The sand rubber reactors (SR1 and SR2) had the best treatment of iron of the four mixtures, with treatment efficiencies ranging from about 10 to 80 % (Table 3.15) in the first 9 weeks. The compost rubber reactors (CR1 and CR2) had the worst removal efficiency; they leached iron with negative efficiencies ranging from about -30 to -600 % (Table 3.15). The removal efficiency in the 10th week for reactors (SR1 and SR2) are difficult to explain, but it can be from treatment breakthrough or short circuiting of the reactors. Some of the effluent concentrations from the compost rubber reactors were above NDEQ stream standards for iron which are 1,000 µg/L chronic conditions for a 24 hr average shown in Table 3.14. Iron is not a major constituent of concern for storm water treatment so no other comparative studies were found.

Table 3.14 Iron concentrations (in µg/L) in influent and effluent of columns

Column[b]	Week									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	397	276	379	327	96	325	238	414	557	345
SLR2	412	325	279	297	105	373	309	375	391	248
SR1	212	152	149	143	103	118	136	149	142	130
SR2	233	127	137	137	112	132	161	147	126	142
CR1	**1641**[a]	**2242**	**1351**	**1083**	404	570	310	374	250	157
CR2	**2658**	**3315**	831	**1658**	995	401	485	467	340	195
R1	483	367	331	224	270	627	216	294	190	119
R2	457	305	319	290	263	668	253	254	254	152
Influent	651	722	388	226	286	382	214	230	158	119

[a] #'s in bold indicate that the sample's concentrations were above the NDEQ stream standards described.

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.15 Iron treatment efficiencies of different columns

Column[a]	Week									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	39.1	61.8	2.4	-44.5	66.4	14.9	-11.2	-80.0	-251.7	-190.1
SLR2	36.7	55.0	28.1	-31.1	63.1	2.5	-44.6	-63.1	-146.9	-108.7
SR1	67.4	78.9	61.6	36.9	64.0	69.0	36.3	35.4	10.6	-9.5
SR2	64.3	82.4	64.6	39.6	60.7	65.3	24.7	36.0	20.2	-19.6
CR1	-152.0	-210.5	-248.3	-378.1	-41.4	-49.2	-45.0	-62.4	-57.7	-32.2
CR2	-308.2	-359.2	-114.3	-632.1	-248.3	-4.9	-126.8	-102.6	-114.7	-63.8
R1	25.8	49.1	14.6	1.3	5.5	-64.1	-1.0	-27.6	-20.2	0.0
R2	29.8	57.8	17.8	-28.1	8.0	-74.8	-18.4	-10.2	-60.3	-28.1

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Nickel. Trace amounts of nickel leached from all reactors during testing. Most values for nickel were below the Method Detection Limit see appendix C for QA/QC.

The NDEQ acute stream standard for nickel is 842 µg/L at 200 mg/L $CaCO_3$ water hardness, and all values found during testing in this study were below 11 µg/L. The compost rubber reactors (CR1 and CR2) leached the most nickel and the rubber reactors (R1 and R2) leached the least (Table 3.16 and 3.17). Nickel is not a major constituent of concern for storm water treatment, so no other comparative studies were found.

Table 3.16 Nickel concentrations (in µg/L) in influent and effluent of columns

Column[b]	**week**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	4.02	*2.90*[a]	*2.70*	*2.15*	*1.78*	3.47	*2.44*	*2.98*	*2.60*	*1.54*
SLR2	4.04	*3.06*	*2.61*	*2.86*	*2.10*	3.72	*2.42*	*2.92*	*2.55*	*1.64*
SR1	4.60	*3.10*	3.91	*2.70*	*2.95*	3.69	*2.42*	3.58	*2.77*	*2.58*
SR2	5.08	*3.33*	*2.89*	*3.02*	*3.26*	3.91	*2.63*	3.58	*2.89*	*2.68*
CR1	7.28	7.69	5.67	4.45	*2.57*	*3.20*	*1.78*	*2.41*	*2.03*	*1.71*
CR2	10.96	10.02	*3.33*	7.56	5.07	4.38	*2.46*	*2.91*	*2.03*	*1.58*
R1	4.29	3.46	*2.08*	*2.17*	*1.88*	*3.36*	*1.93*	*2.33*	*2.04*	*1.77*
R2	3.72	*2.93*	*2.03*	*1.92*	*1.79*	*3.09*	*1.80*	*2.25*	*2.19*	*1.76*
Influent	3.85	3.88	*2.06*	*2.03*	*1.58*	*3.17*	*1.65*	*2.06*	*1.27*	*1.37*

[a] #’s in italics indicate concentrations below the method detection limits.
[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.17 Nickel treatment efficiencies of different columns

Column[a]	**week**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	-4.4	25.4	-30.9	-5.7	-12.9	-9.5	-47.9	-44.5	-105.3	-12.1
SLR2	-5.0	21.1	-26.6	-40.8	-33.1	-17.3	-46.7	-41.4	-101.7	-20.0
SR1	-19.5	20.2	-89.7	-32.7	-86.9	-16.5	-46.7	-73.6	-118.7	-88.1
SR2	-32.1	14.3	-40.4	-48.6	-106.6	-23.3	-59.4	-73.5	-128.2	-95.6
CR1	-89.1	-98.1	-175.2	-118.9	-62.6	-1.1	-7.6	-16.5	-60.7	-24.4
CR2	-184.8	-158.1	-61.6	-271.5	-221.2	-38.3	-49.2	-40.8	-60.2	-15.3
R1	-11.4	10.9	-1.0	-6.8	-19.2	-6.0	-16.8	-12.8	-61.1	-28.7
R2	3.4	24.7	1.4	5.4	-13.3	2.6	-9.3	-8.8	-72.8	-28.2

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Copper. Copper was added to the synthetic storm water from the roadway sediment, tap water, and as an added constituent (Table 3.1). The sand rubber reactors (SR1 and SR2) had the best treatment rates, ranging from ~72 to 92% (Table 3.19). The results from the silty loam rubber (SLR1 and SLR2) and sand rubber (SR1 and SR2) reactors are similar to other testing efficiencies, ranging from 43 to 99 % for copper removal in ten other studies (Ming-Han et al. 2010). The rubber reactors (R1 and R2) had the worst treatment efficiency, ranging from ~12 to -30%. The NDEQ acute stream standard concentration for copper is 25.8 µg/L at 200mg/L $CaCO_3$ water hardness. Influent and effluent from the rubber and compost rubber reactors were above this stream standard for a majority of the testing period.

Table 3.18 Copper concentrations (in µg/L) in influent and effluent of columns

Column[b]	**week**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	**29.64**[a]	5.73	6.90	6.98	3.13	5.07	3.97	5.58	16.14	6.28
SLR2	**31.94**	10.17	7.58	3.61	3.49	4.32	5.59	7.74	6.07	4.38
SR1	10.41	4.85	4.85	2.69	3.01	4.16	4.77	5.10	4.03	3.77
SR2	14.08	6.08	5.37	3.28	4.20	5.32	5.81	6.06	4.59	4.03
CR1	**73.13**	**37.81**	**35.80**	6.12	19.78	16.11	18.16	15.21	10.46	6.47
CR2	**82.43**	**44.69**	25.00	6.91	**32.74**	21.18	**25.97**	22.81	17.27	9.56
R1	**98.17**	**39.31**	**28.56**	**30.94**	24.50	25.71	**34.78**	**31.43**	**28.24**	16.27
R2	**99.74**	**37.86**	**28.86**	**32.25**	24.60	23.72	**38.25**	**32.57**	**33.70**	16.68
Influent	**111.67**	**47.33**	**30.82**	**33.95**	25.55	25.25	**42.31**	**31.62**	21.95	14.65

[a] #’s in bold indicate that the sample’s concentrations were above the NDEQ stream standards described.

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.19 Copper treatment efficiencies of different columns

Column[a]	week									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	73.5	87.9	77.6	79.4	87.7	79.9	90.6	82.3	26.5	57.1
SLR2	71.4	78.5	75.4	89.4	86.3	82.9	86.8	75.5	72.4	70.1
SR1	90.7	89.7	84.3	92.1	88.2	83.5	88.7	83.9	81.6	74.2
SR2	87.4	87.2	82.6	90.4	83.5	78.9	86.3	80.8	79.1	72.5
CR1	34.5	20.1	-16.2	82.0	22.6	36.2	57.1	51.9	52.4	55.8
CR2	26.2	5.6	18.9	79.6	-28.1	16.1	38.6	27.9	21.3	34.7
R1	12.1	16.9	7.4	8.9	4.1	-1.8	17.8	0.6	-28.6	-11.0
R2	10.7	20.0	6.4	5.0	3.7	6.0	9.6	-3.0	-53.6	-13.9

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Zinc. The silty loam rubber reactors (SLR1 and SLR2) had the best treatment for zinc and the rubber reactors (R1 and R2) leached the most zinc (Table 3.20). The silty loam reactors were the only reactors that had similar treatment efficiencies to other studies which showed a range of treatment from 27 to 98 % from ten other studies (Ming-Han et al. 2010). All other reactors except silty loam leached large amounts of zinc, ranging from 100 to 1,600 % of the influent concentration (Table 3.21). The acute NDEQ stream standard for zinc is 211 µg/L at 200 mg/L $CaCO_3$ water hardness. The reactor influent and silty loam reactors effluent were all below this stream standard, but all other reactor effluents were above it as shown in Table 3.20.

Table 3.20 Zinc concentrations (in µg/L) in influent and effluent of columns

Column[b]	**week**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	75	37	74	111	75	71	94	131	143	59
SLR2	113	49	73	120	108	134	140	170	163	130
SR1	**226**[a]	143	**251**	**380**	**372**	**433**	**381**	**505**	**482**	**387**
SR2	204	106	179	**342**	**294**	**340**	**344**	**398**	**371**	**281**
CR1	**611**	**641**	**452**	**373**	176	199	147	154	121	93
CR2	**909**	**1189**	**307**	**552**	**322**	**449**	209	192	123	95
R1	**623**	**512**	**286**	**405**	**372**	**563**	**441**	**456**	**351**	**310**
R2	**323**	**299**	173	**326**	**294**	**523**	**365**	**408**	**379**	**324**
Influent	164	176	34	34	35	174	158	149	121	136

[a] #'s in bold indicate that the sample's concentrations were above the NDEQ stream standards described.

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.21 Zinc treatment efficiencies of different columns

Column[a]	**week**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	54.6	79.0	-115.7	-228.6	-114.6	59.0	40.7	11.6	-17.7	56.6
SLR2	31.5	72.4	-114.4	-256.6	-205.9	22.9	11.3	-13.9	-34.3	4.3
SR1	-37.5	18.5	-633.4	-1028.0	-958.4	-149.1	-141.2	-239.6	-296.6	-184.4
SR2	-24.2	40.0	-424.0	-913.6	-735.5	-96.0	-117.7	-167.6	-205.3	-106.6
CR1	-271.7	-264.7	-1222.8	-1007.2	-400.0	-14.3	7.0	-3.7	0.5	32.0
CR2	-453.4	-576.6	-797.3	-1535.7	-816.4	-158.5	-32.3	-28.8	-1.5	30.6
R1	-279.1	-191.5	-735.7	-1099.3	-958.4	-224.4	-179.2	-206.3	-188.7	-127.6
R2	-96.6	-70.1	-407.3	-867.3	-735.5	-201.2	-131.4	-173.9	-211.7	-138.1

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Lead. The sand rubber (SR1 and SR2) reactors had the best treatment efficiencies for lead, ranging from ~97 to 100 % lead removal. In contrast, the rubber reactors (R1 and R2) had the worst treatment efficiencies, ranging from ~30 to -50 % removal (Table 3.23). The sand rubber (SR) and silty loam rubber (SLR) reactors both had treatment efficiencies similar to the one reported in the literature that showed a range of efficiencies from 54 to 95 % for ten other studies (Ming-Han et al. 2010). Some lead concentrations of the effluent from the silty loam rubber and sand rubber reactors were below method detection limits (see appendix C). This was due to the high treatment efficiencies of those reactors. The NDEQ acute stream standard for lead is 136 µg/L at 200mg/L $CaCO_3$ water hardness. For the first 5 weeks of testing the influent, rubber, and compost rubber reactors were over the NDEQ stream standard.

Table 3.22 Lead concentrations (in µg/L) in influent and effluent of columns

Column[c]	week									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	**188.76**[b]	6.12	20.70	42.38	7.07	*1.80*	*3.17*	*2.03*	21.95	10.61
SLR2	**199.66**	25.11	34.58	15.77	12.70	*2.74*	4.46	*2.56*	*3.12*	4.10
SR1	50.37	*0.00*[a]	7.55	*2.43*	5.18	*2.15*	*2.88*	*1.02*	*0.00*	*0.00*
SR2	84.25	*1.72*	5.94	*3.62*	6.82	*2.20*	*3.61*	*1.20*	*0.00*	*1.15*
CR1	**439.07**	121.08	**274.59**	**277.67**	133.10	26.95	20.80	7.34	7.36	8.28
CR2	**516.24**	**151.05**	**158.61**	**326.23**	**247.76**	43.73	37.14	15.77	16.30	17.45
R1	**536.61**	121.28	**244.07**	**252.71**	**243.88**	49.53	57.94	23.82	46.59	44.27
R2	**553.89**	120.73	**244.62**	**273.61**	**242.19**	47.52	59.52	18.01	50.54	47.74
Influent	**626.75**	**164.93**	**347.56**	**344.84**	**323.75**	50.55	69.31	15.35	32.38	51.42

[a] #'s in italic indicate concentrations below method detection limits.

[b] #'s in bold indicate that the sample's concentrations were above the NDEQ stream standards described.

[c] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.23 Lead treatment efficiencies of different columns

Column[a]	week									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SLR1	69.9	96.3	94.0	87.7	97.8	96.4	95.4	86.8	32.2	79.4
SLR2	68.1	84.8	90.1	95.4	96.1	94.6	93.6	83.3	90.4	92.0
SR1	92.0	100.0	97.8	99.3	98.4	95.7	95.8	93.3	100.0	100.0
SR2	86.6	99.0	98.3	99.0	97.9	95.6	94.8	92.2	100.0	97.8
CR1	29.9	26.6	21.0	19.5	58.9	46.7	70.0	52.2	77.3	83.9
CR2	17.6	8.4	54.4	5.4	23.5	13.5	46.4	-2.7	49.7	66.1
R1	14.4	26.5	29.8	26.7	24.7	2.0	16.4	-55.2	-43.9	13.9
R2	11.6	26.8	29.6	20.7	25.2	6.0	14.1	-17.3	-56.1	7.2

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

3.3.4.3 Other Water Quality Parameters

Nitrate. Nitrate was measured for all ten weeks but only the last five weeks of testing provide reliable data due to problems in methods used. The problems experienced in methodology were; sample preservation, sample dilution, and constituents of concern. The sample preservation issue that was experienced was that the preservation of the samples with sulfuric acid raised the sulfate concentrations in the samples and the HPLC testing. High sulfate concentration interfered with nitrate detection in the HPLC testing. Initial sample dilution was thought to be 300:1 because of the issue with preservation giving false vales of nitrate in the g/l range. Finally initial thoughts were to check for all anions detectable by the HPLC instrument, which lead to diluting samples to levels needed for accurate detection of all initial constituents of concern. At week five the conclusion was that the samples did not need acid preservation but only refrigeration and analysis within 48 hours, no dilution was required, and the only constituent of concern was nitrate.

Values for nitrate for the influent, rubber (R1 and R2), and sand rubber reactors (SR1 and SR2) were below method detection limts. The sand rubber reactors had the best treatment efficiencies for nitrate, ranging from about 11 to 40 % removal as shown in Table 3.25. Only the treatment efficiencies for sand rubber and rubber were similar to the literature which showed a treatment range of negative 5 to 95 percent removal of nitrate from ten different studies (Ming-Han et al. 2010). Nitrate leached from the silty loam rubber and compost rubber reactors, ranging from 10 to 1200 % more than the influent concentration. However, all concentrations throughout testing were below the NDEQ stream standard and drinking water standard for nitrate which is 45 mg NO_3/L (10 mg NO_3-N/L).

Table 3.24 Nitrate concentrations (in mg NO_3-NO_3/L) for reactors

Column[b]	**week**				
	6	**7**	**8**	**9**	**10**
SLR1	0.455	0.411	0.425	0.407	0.650
SLR2	0.307	0.354	0.342	0.514	0.620
SR1	*0.173*[a]	*0.164*	*0.097*	*0.173*	*0.227*
SR2	*0.177*	*0.163*	*0.094*	*0.173*	0.326
CR1	0.996	0.597	0.402	0.514	0.528
CR2	1.860	1.757	1.667	1.704	2.281
R1	0.336	*0.210*	*0.122*	*0.202*	0.374
R2	*0.244*	*0.208*	*0.115*	*0.207*	0.325
Influent	*0.223*	*0.214*	*0.123*	*0.235*	0.368

[a] #'s in italics indicate concentrations below reliable quantification limits.

[b] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.25 Nitrate treatment efficiencies of different columns

Column^a	week				
	6	**7**	**8**	**9**	**10**
SLR1	-104.38	-92.33	-245.23	-72.75	-76.52
SLR2	-37.78	-65.82	-177.38	-118.11	-68.47
SR1	22.34	23.04	21.60	26.68	38.24
SR2	20.44	23.74	24.11	26.33	11.39
CR1	-347.30	-179.66	-226.21	-118.46	-43.29
CR2	-735.10	-722.43	-1253.10	-623.68	-519.31
R1	-50.85	1.49	1.17	14.41	-1.64
R2	-9.47	2.76	7.06	12.17	11.76

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Total suspended solids. The sand rubber reactors (SR1 and SR2) had the best TSS removal, ranging from ~88 to 98 %. All reactors had positive removal rates except the compost rubber reactors (CR1 and CR2), which leached up to 450% of the influent concentration but improved over time to between 50 to 80% removal. Other literature showed that TSS removal can range from -170 to 60% from ten studies (Ming-Han et al. 2010).

Table 3.26 Total suspended solids concentrations (in mg/L) in influent and effluent of columns

Column[a]	week									
	1	2	3	4	5	6	7	8	9	10
SLR1	28.0	11.0	15.2	45.3	11.0	24.0	36.7	32.7	154.0	35.3
SLR2	42.3	46.5	25.0	14.0	25.5	24.0	32.7	26.7	36.0	38.0
SR1	11.8	3.8	10.3	3.3	2.7	4.3	3.0	3.5	4.3	7.0
SR2	15.0	4.5	7.3	3.5	3.5	6.5	5.0	5.7	3.3	6.2
CR1	744.0	768.0	968.0	544.0	144.0	116.0	52.0	28.0	-8.0	20.0
CR2	1344.0	1440.0	464.0	1124.0	728.0	396.0	132.0	108.0	60.0	56.0
R1	82.8	126.0	114.7	80.0	99.0	100.0	112.0	102.0	87.0	94.0
R2	59.2	86.7	105.0	86.0	94.0	113.0	111.0	99.0	119.0	127.0
Influent	132.3	261.3	176.0	168.0	172.0	140.0	137.3	134.7	132.7	102.0

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Table 3.27 Total suspended solids treatment efficiencies of different columns

Column[a]	week									
	1	2	3	4	5	6	7	8	9	10
SLR1	78.8	95.8	91.4	73.0	93.6	82.9	73.3	75.7	-16.1	65.4
SLR2	68.0	82.2	85.8	91.7	85.2	82.9	76.2	80.2	72.9	62.7
SR1	91.1	98.6	94.2	98.1	98.4	97.0	97.8	97.4	96.8	93.1
SR2	88.7	98.3	95.9	97.9	98.0	95.4	96.4	95.7	97.6	93.9
CR1	-462.2	-193.9	-450.0	-223.8	16.3	17.1	62.1	79.2	106.0	80.4
CR2	-915.6	-451.0	-163.6	-569.0	-323.3	-182.9	3.9	19.8	54.8	45.1
R1	37.4	51.8	34.8	52.4	42.4	28.6	18.4	24.3	34.4	7.8
R2	55.3	66.8	40.3	48.8	45.3	19.3	19.2	26.5	10.3	-24.5

[a] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

Chemical oxygen demand. COD was analyzed for the final 3 weeks of testing and is shown in Table 3.28. COD leached out of all reactors and in only 1 of the 3 weeks of testing COD was detected in the influent. COD in storm water is estimated to have a typical concentration of 75 mg-O/L (U.S. EPA 1999). Some sources for the leaching of COD from the reactors may be the organic matter in the compost or the silty loam materials. Also with COD testing only occurring for the last 3 weeks some accumulation may have happened during the test period. Most other storm water studies have not focused on COD.

Table 3.28 Chemical oxygen demand concentrations (in mg-O/L) in influent and effluent of columns

Column[c]	**week**		
	8	**9**	**10**
SLR 1	35	30	35
SLR 2	235	25	100
SR 1	15	20	205
SR 2	N/A[a]	N/A	80
CR 1	75	105	95
CR 2	195	155	215
R 1	65	55	55
R 2	45	60	55
IN	45	<DL[b]	<DL

[a] Bad data from boiling over of samples during digestion
[b] below method detection limits see appendix C for calibration curve
[c] R = rubber, CR = compost/rubber, SR = sand/rubber, SLR = silty loam/rubber

3.3.5 Discussion

Each media mixture tested has benefits and draw-backs. When looking at the results from the physical attributes tested, a media with less than a 24 hour drawdown time, available moisture for plant growth, and a bulk density that does not inhibit plant growth may be the most important attributes. In this study, all media tested had sufficient drawdown times to drain within 24 hr, so the media with the best treatment of storm water will over-rank the drawdown times. Available moisture may be as important as treatment efficiencies. The bench-scale columns did not include plant growth which could improve treatment efficiencies and change bulk densities and drawdown times due to root establishment. Vegetation has been found to be beneficial in nutrient removal in Porous Landscape Detention Basin (PLDB) in Colorado (Kocman et al. 2011). The two best media for available moisture in the current study were compost rubber (CR) and silty loam rubber (SLR). In addition, previous research has shown that organic matter of 1.5 to 3 percent in any BMP media adds important qualities for plant growth (ISMM 2009). Plant growth limiting bulk densities may be prevented by adding alternative materials or adding organic media such as mulch although rubber chips did not improve the growth limiting bulk density of silty loam.

From synthetic storm water testing, it was found that the sand rubber mixture (SR) provided the best treatment for iron, copper, lead, nitrate, and TSS. The silty loam reactors (SLR) were the best at treating zinc and second best at treating iron, copper, lead, and TSS. The compost rubber mixture (CR) had the worst treatment of iron, nickel, nitrate, and TSS most likely due to leaching of fine particles. The rubber reactors were tested to check for leaching from the media itself. The rubber reactors leached the most copper, lead, and zinc. No other similar research was found regarding treatment efficiencies of rubber chip mediated soils at 50 percent concentration of rubber chips.

3 to 4 mesh rubber chips may not be a good alternative media on their own for the treatment in storm water in BMPs. The rubber chip media itself is a source of lead,

copper, and zinc which may increase concentrations in the runoff instead of treating and removing constituents. In addition, rubber chips did not improve any moisture characteristics of the soil or the growth limiting bulk density of the soils tested. Other light weight or porous filler materials could be considered such as expanded shale in place of rubber chips. This research focused on testing 50 percent rubber mixture with 50 percent traditional media. Other research tested a BMP soil mixture supplemented with 8 percent shredded tires (Kocman et al. 2011). The use of 8 percent shredded tire was based on cost/availability, leaching, flow rate, and seed germination. The deciding factor for 8 percent was based on flow rate restrictions. One other major finding from (Kocman et al. 2011) is that shredded tire increased the life span of their BMP but decreased the filtering capacity for zinc.

Although the sand rubber reactors had the best treatment, it had a low available moisture and field capacity and also had high bulk density which was not the best mixture for plant growth. Without good available moisture and field capacity, good plant establishment may not be possible, which would inhibit the benefits of having biomass and plants to aid in storm water treatment. It could be suggested that BMP media be installed in layers with the top layer, or root zone (i.e. 6”), excluding the 3 inches of mulch, focusing on beneficial plant growth attributes such as good growth bulk density values, good available moisture, and good moisture holding capacity as shown by the compost rubber mixture. The remaining depth should focus on filtration and storm water constituent treatment based on treatment efficiencies tested from the added constituents shown by the sand rubber mixture. With this in mind, our results indicate that 6 inches of compost rubber could be placed on top of a depth of sand rubber to allow for a plant growth zone for roots and a storm water treatment zone below the growth layer.

3.4 Conclusions

Several conclusions can be drawn from the bench-scale testing of the four BMP soil mixtures:

- The best media mixtures based on physical properties were the silty loam rubber and compost rubber mixtures based primarily on moisture qualities and bulk densities. This is because all media types tested had sufficient drawdown times.
- The best media for storm water constituent treatment was the sand rubber mixture, and the second best was the silty loam rubber mixture. The rubber and compost rubber mixtures showed the most leaching which added storm water constituents to the effluent.
- The benefit of added a low cost alternative material for filler by using rubber chips did not outweigh the addition of lead, copper, and zinc concentrations that leached from the reactors. Also the rubber chips did not add any great physical benefit to the media.
- Because physical and chemical treatment attributes of different media are different it could be suggested that media should be layered with the top 6 inches focusing on plant establishment characteristics and the continuing depth focusing on filtration and treatment of storm water constituents.

Chapter 4 Conclusions and Recommendations

4.1 Conclusions

Several conclusions can be drawn from this research as a whole to develop and evaluate roadside BMPs to treat highway runoff.

- Sedimentation within BMPs is a crucial factor that cannot be over looked during construction and after the construction period. Construction periods should be kept as short as possible to minimize the chance of rain events during construction. After the construction phase, erosion control measures should be placed and maintained as soon as possible until the contributing watershed is stabilized with vegetation.
- From Image J analysis of the digital images taken of the test cells, the compost/47-B test cell had the best vegetative performance. In contrast the loam/sand/wood mulch test cell had the worst vegetative growth of the four test cells. All test cells had between 48 and 64 percent green in the best images.
- Although only vegetative monitoring was accomplished in this study, a monitoring matrix is important for further methods of reporting the long-term use and efficiency of these BMPs. Monitoring methods should focus primarily on clogging and treatment of Total Suspended Solids.

- All media studied have adequate drawdown times. The best media based on physical properties were the silty loam rubber and compost loam mixtures based primarily on moisture qualities and bulk densities.
- The best media for storm water constituent treatment was the sand rubber mixture and the second best was the silty loam rubber mixture. The rubber and compost rubber mixtures showed leaching which added storm water constituents to the effluent.
- The benefit of adding rubber chips as a low cost alternative material for filler did not outweigh the addition of lead copper and zinc from leaching. Also the rubber chips did not add any significant physical benefit to the media such as improving growth limiting bulk density, moisture holding capacity, or available moisture.
- Because physical and chemical treatment attributes of different media are different, it could be suggested that media should be layered with the top layer or root zone focusing on plant establishment characteristics and the continuing depth focusing on filtration and treatment of storm water constituents.

4.2 Recommendations

With the presentation of this research and conclusions, some recommendations can be made as follows:

- Because of the clogging in the field BMPs and since that clogging will eventually happen to all BMPs. Research on the best and most cost-efficient methods to unclog BMPs could be done at the site.
- More research can be done on alternative light weight materials that can reduce the cost of BMP materials. Also, some of these materials may supplement the treatment process of storm water constituents or improve qualities of the engineered media for plant growth.
- Because rubber chips are a waste material, using it in smaller amounts as a filler material to find a use for the waste material could be done. To do this the optimum percent of the BMP soil mixture that can be rubber chips should be tested. Also, different size rubber chips may have different effects on the media and the leaching of metals from the rubber chips.
- More research can be done to find optimum BMP soils for plant growth. This could prove beneficial if these media mixtures can be found and paired with plants that can bioaccumulate metals, where phytoremediation could have more of a focus. Ultimately the soil can be a loose structure for roots and vegetation like a trickling filter structure. Also, a healthy plant growth and structure could improve the longevity of the BMP.

References

APHA, AWWA, and WPCF. (2012). *Standard methods for the examination of water and wastewater.* Washington, D.C. American Public Health Association, 2012.

Bowders, J. J., Tan, J. P., and Daniel, D. E. (1997). "Expanded clay and shale aggregates for leachate collection systems." *J. Geotech. Geoenviron. Eng.*, 123(11), 1030–1034.

CWA. (1977a). "Clean Water Act of 1977." *Rep. No. 33 U.S.C § 1312*, http://www.law.cornell.edu/uscode/text/33/1312 (Accessed Nov. 2012).

Daddow, R. L., and Warrington, G. E. (1983). *Growth-limiting soil bulk densities as influenced by soil texture*. Rep. No. WSDG-TN-00005, Watershed systems development group USDA forest service, 3825 east Mulberry street Fort Collins, Colorado 80524.

Davis, A. P., Shokouhian, M., Sharma, H., and Minami, C. (2001). "Laboratory study of biological retention for urban stormwater management." *Water Environ. Res.*, 73(1), 5–14.

FHWA. (2009). *Hydraulic Engineering Circular No. 22, Third Edition : Urban Drainage Design Manual*. Rep. No. FHWA-NHI-10-009 HEC 22, Federal Highway Administration, National Highway Institute 4600 N. Fairfax Dr., Suite 800 Arlington, Virginia 22203.

FHWA. (2005). *Hydraulic Engineering Circular No. 15, Third Edition: Design of Roadside Channels with Flexible Linings*. Rep. No. FHWA-NHI-05-114 HEC 15, Federal Highway Administration, Federal Highway Administration National Highway Institute 4600 North Fairfax Drive Suite 800 Arlington, Virginia 22203.

Field, R., Tafuri, A., Muthukrishnan, S., Acquisto, B., and Selvakumar, A. (2006). *The Use of Best Management Practices (BMPs) in Urban Watersheds*. DEStech Publications, Lancaster, PA.

Flint, K. R., and Davis, A. P. (2007). "Pollutant mass flushing characterization of highway stormwater runoff from an ultra-urban area." *Journal of Environmental Engineering*, 133(6), 616–626.

Gupta, R. S. (2008). *Hydrology and Hydraulic Systems* (3rd ed.). Long Grove: Waveland Press, Inc., Long Grove, Illinois.

Hartsig, T., and Szatko, A. (2012). *Performance assessment of two stormwater best management practices for infiltration, water quality, and vegetative growth*. http://water.unl.edu/c/document_library/get_file?uuid=cbb02800-6f34-4246-8c87-6a4fb59b0fbf&groupId=468067&.pdf (Accessed Nov. 2012).

Hatt, B. E., Fletcher, T. D., and Deletic, A. (2008). "Hydraulic and pollutant removal performance of fine media stormwater filtration systems." *Environ. Sci. Technol.*, 42(7), 2535–2541.

ISMM. (2009). "*Iowa stormwater management manual*." http://www.intrans.iastate.edu/publications/_documents/handbooks-manuals/storm-water/Design/2E/2E-4%20Bioretention%20Systems.pdf (Accessed Nov.2012).

Karcher, D. E., and Richardson, M. D. (2003). "Quantifying turfgrass color using digital image analysis." *Crop Sci.*, 43(3), 943–951.

Keblin, M., Barrett, M., Malina, J., and Jr. Charbeneau, R. (1998). *The effectiveness of permanent highway runoff controls: sedimentation/filtration systems*. Rep. No. TX-00/2954-1, Center for transportation research bureau of engineering research the University of Texas at Austin, Austin, Texas.

Kocman, S. M., Guo, J. C. Y., and Ramaswami, A. (2011). "Waste-Incorporated Subbase for Porous Landscape Detention Basin Design." *J. Environ. Eng.*, 137(10), 928–936.

Low Impact Development Center, Inc. (2003). "Drainage-bioretention specification." http://www.lowimpactdevelopment.org/epa03/biospec.htm (Accessed Nov. 2012).

Ming-Han, L., Chan, Y., Sung, Myung, H., Kim, and Kung-Hui, C. (2010). "*Bioretention for Stormwater Quality Improvement in Texas: Pilot Experiments*." Texas Department of Transportation, Austin, Texas.

MPCA. (2000). *Protecting water quality in urban areas: best management practices for dealing with storm water runoff from urban, suburban, and developing areas of Minnesota*. Minnesota pollution control agency, Minneapolis.

MSG. (2011). "Mallard sand and gravel general specifications." http://mallardsand.com/id6.html (Accessed Nov. 2012).

National Climatic Data Center (NCDC). (2012). "Monthly climatological summary." http://www1.ncdc.noaa.gov/pub/orders/96364.pdf, http://www1.ncdc.noaa.gov/pub/orders/96368.pdf (Accessed Nov. 2012).

National Resource Conservation Service (NRCS). (1986). *Urban hydrology for small watersheds TR - 55.* http://www.cpesc.org/reference/tr55.pdf (Accessed Oct. 2012).

NDEQ. (2006). *Nebraska Administrative Code.* Nebraska Dept. of Environmental Quality, Lincoln, NE.

NDOR. (2010). *Seeding Handbook for Highway Maintenance*. Nebraska Department of Roads.

NDOR. (1997). *Supplemental Specifications Book*. NE Dept. of Roads.

NRCS. (2011). "Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey." http://websoilsurvey.nrcs.usda.gov/ (Accessed Nov. 2012).

Olsson Associates. (2006). *Omaha Regional Stormwater Manual*. Omaha, Nebraska.

A. Patton, Walker, K., McDuffee, D., Bigelow, C., Latin, R. and Reicher, Z. (2005). "Using Digital Image Analysis to Quantify Turfgrass Cover and Disease." http://www.agry.purdue.edu/turf/report/2005/11.pdf (Accessed Nov. 2012).

PGCM. (2007). *Bioretention Manual: Environmental Services Division Department of Environmental Resources the Prince George's County, Maryland*. Prince George county department of environmental resources.

PSBMP. (2006). *Pennsylvania Stormwater Best Management Practices Manual*. http://www.starkenvironmental.com/downloads/PADEP.pdf (Accessed Nov. 2012).

Stansbury, J., Moussavi, M., and Zhang, T. (2012). *Feasibility of integrating natural and constructed wetlands in roadway drainage system design*. NDOR Rep. No. SPR-1(09)P325. NE Dept. of Roads, Lincoln, NE.

Stapleton, J. (2008). "Soil stabilization for gardens and landscapes." http://www.ipm.ucdavis.edu/PDF/PESTNOTES/pnsoilsolarization.pdf (Accessed Nov. 2012).

Thompson, A. M., Paul, A. C., and Balster, N. J. (2008). "Physical and hydraulic properties of engineered soil media for bioretention basins." *Transactions of the Asabe,* 51(2), 499–514.

TNLA. (2006). *TNLA Green Magazine*. Texas Nursery and Landscape Association, May, 2006.

U.S. EPA. (1999). *Preliminary Data Summary of Urban Storm Water Best Management Practices.* Rep. No. EPA 821-R-99-012, U.S. Environmental Protection Agency, Office of Water, Washington D.C.

USDA. (2008). "*Soil quality indicators*." http://soils.usda.gov/sqi/assessment/files/available_water_capacity_sq_physical_indicator_sheet.pdf (Accessed Nov. 2012).

USEPA. (1996). *Managing urban runoff*. Rep. No. EPA 841-F-96-004G, U.S. Environmental Protection Agency, Washington, D.C.

Vacha, B. (2012). *Feasibility of integrating natural and constructed wetlands in roadway drainage system design volume II*. M.S. Thesis. Civil Eng. Dept., University of Nebraska-Lincoln, May 2012.

Willis, W., and Power, J. (2012) "Soil temperature and plant growth in the northern great plains."http://images.library.wisc.edu/EcoNatRes/EFacs/NAPC/NAPC04/reference/econatres.napc04.wwillis.pdf . (Accessed Oct. 2012).

WRA Environmental Consultants, I. (2009). *Appendix B: Soils, plantings, and irrigation for bioretention facilities in stormwater C.3 Guidebook* . Contra Costa Clean Water Program.

Appendix A Design Information on the Four BMP Sites with a Design Example

Table A.1 shows design information on the four BMP sites. To illustrate how to come up with Table A.1, a design example of filter trench is described below.

Site information. The aerial photo in Figure A.1 shows the total watershed that contributes to the filter trench at the Slat Valley site location in Lincoln, NE. The total impervious area is considered to be new or redeveloped, and runoff from this area needs to be treated. The total area of the watershed is 4.84 acres with 1.4 acres impervious, 2.61 acres grass, and 0.83 acres gravel. The impervious area contributes to the run off or WQV, and the gravel and grass area contributes to run on volume and flows.

Calculating runoff and run on volumes. Runoff volumes are calculated with a design precipitation of 0.75 inches which corresponds to 0.5 inches of runoff from impervious areas. Each sub-basin is calculated separately based on land use using equation 2-1. The curve numbers used are 98 for impervious, 84 for grass, and 86 for gravel based on hydraulic soil group B from Table 2.1 and curve numbers from Table 2.2. The runoff depth from each sub basin is 0.55 inches, 0.06 inches, and 0.09 inches for impervious area, grass and gravel, respectively. Multiplying the depth by the area of the sub-basin we find that impervious area, grass and gravel contribute 2,808 ft^3, 567 ft^3 and 263 ft^3 of runoff, respectively. With these numbers the total WQV is 3,639 ft^3 with the impervious area contributing 2,808 ft^3 and the run on area contributing 830 ft^3.

Calculating peak 10-year flow-rates. Runoff flow-rates are calculated using the rational method with a 10-year return period with a storm duration equal to the time of concentration. The peak flow-rates are calculated for each sub-basin then added together. The rational method coefficients used in this example are 0.95 for impervious areas, 0.35 for grass areas, and 0.45 for gravel areas. The time of concentration was found using equation 2-4 for the most hydraulically remote sub-basin and is 6.5 minutes. From Figure 2.4 the rainfall intensity to be used in the rational method equation is 8 in/hr based on the time of concentration of 6.5 minutes. From equation 2-3 the peak flows for each sub basin are 10.68 cfs, 7.31cfs, and 2.97 cfs from the impervious, grass and gravel areas, respectively. The total flow-rate for the watershed is 20.96 cfs.

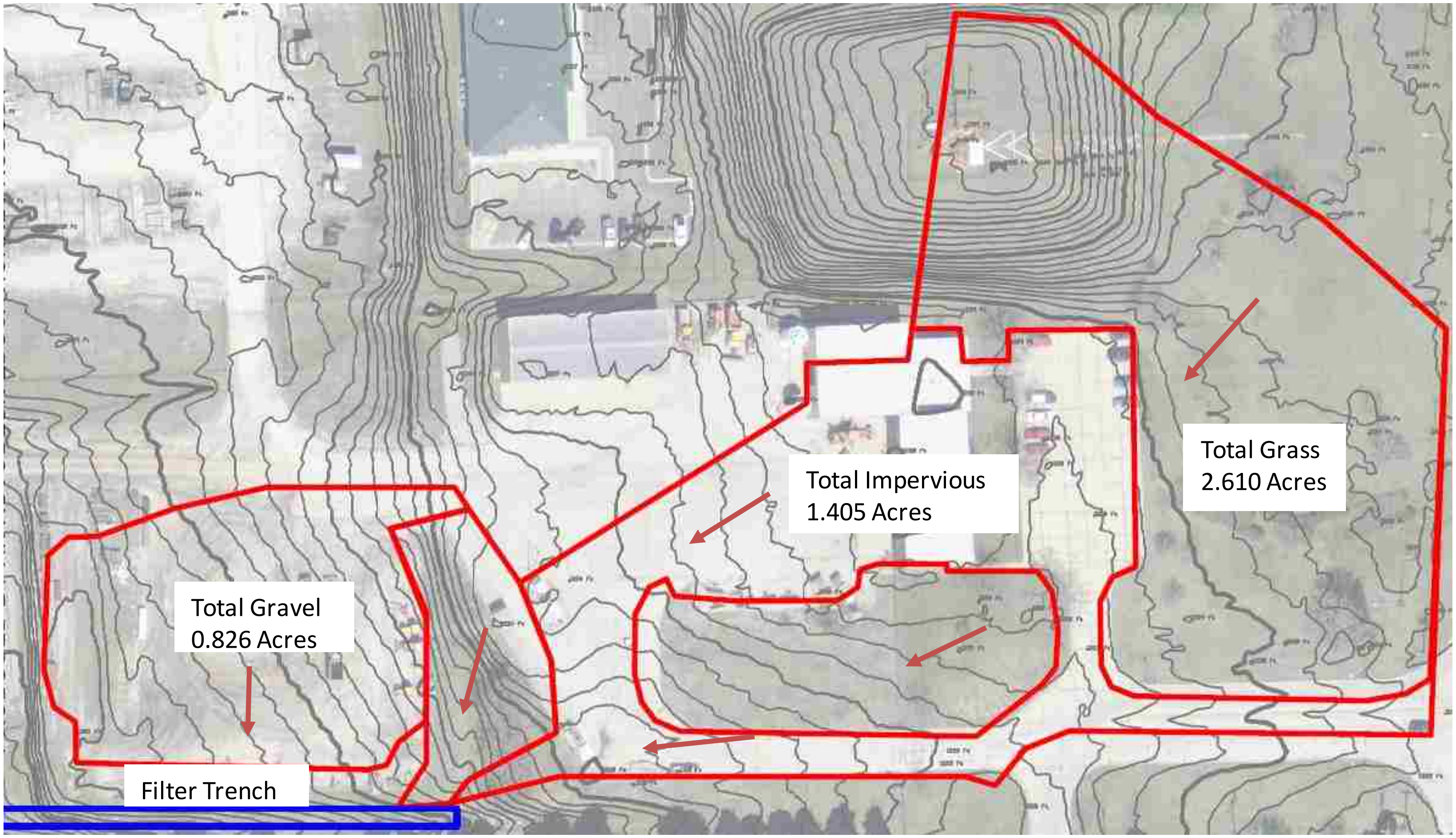


Figure A.1 Filter trench example watershed

Table A.1 BMP areas, WQV, and 10-year flows

BMP site/type	land type areas (Acres)				WQV (ft^3)				10-year flow-rates (cfs)			
	impervious	grass	gravel	total	impervious	grass	gravel	total	impervious	grass	gravel	total
I street/check dam filters	0.48	1.93	0.00	2.40	952.31	35.56	0.00	987.87	4.07	6.07	0.00	10.15
Salt Valley/Infiltration Trench	2.65	2.82	0.44	5.91	5290.64	613.60	140.07	6044.30	17.60	6.91	1.38	25.90
Salt Valley/Filter Trench	1.41	2.61	0.83	4.84	2808.94	567.50	263.09	3639.53	10.68	7.31	2.97	20.96
Salt Valley/ Bioretention	2.65	2.82	0.44	5.91	5290.64	613.60	140.07	6044.30	17.60	6.91	1.38	25.90

Appendix B Field Photos and Vegetative Monitoring

Figure B.1 Bioretention after construction

Figure B.2 Check dam filters before construction

Figure B.3 Check dam filters after construction with sediment deposition

Figure B.4 Infiltration trench before construction

Figure B.5 Infiltration trench after construction

Figure B.6 Filter trench before construction

Figure B.7 Filter trench after construction

Figure B.8 Bioretention diversion during construction

Figure B.9 Bioretention diversion after construction

Figure B.10 Small disturbed area by infiltration trench

Figure B.11 Rain event during construction of filter trench

Figure B.12 Sediment bucket in infiltration trench

Figure B.13 Filter trench outlet during rain event

Figure B.14 7/11/2012 sand compost bioretention image 7 percent green

Figure B.15 8/9/2012 sand compost bioretention image 44 percent green

Figure B.16 8/22/2012 sand compost bioretention image 32 percent green

Figure B.17 9/26/2012 sand compost bioretention image 63 percent green

Figure B.18 Control check vegetation picture from a lawn in Papillion, Ne

Appendix C QA/QC

Chemical oxygen demand (COD) analysis. COD was tested for the last 3 weeks of reactor loadings. Samples were preserved with 2% (v/v) sulfuric acid (Fisher A300-212) and analyzed per APHA 5220 D methods, colorimetric method. The digestion vials used were 0-15,000ppm range CAT. 2415915. The spectrophotometer used was a Genesys 10uv from thermo scientific set to a 600nm. The correlation coefficient for the standard cure used for COD testing was 0.9977 (Fig. C.1).

.

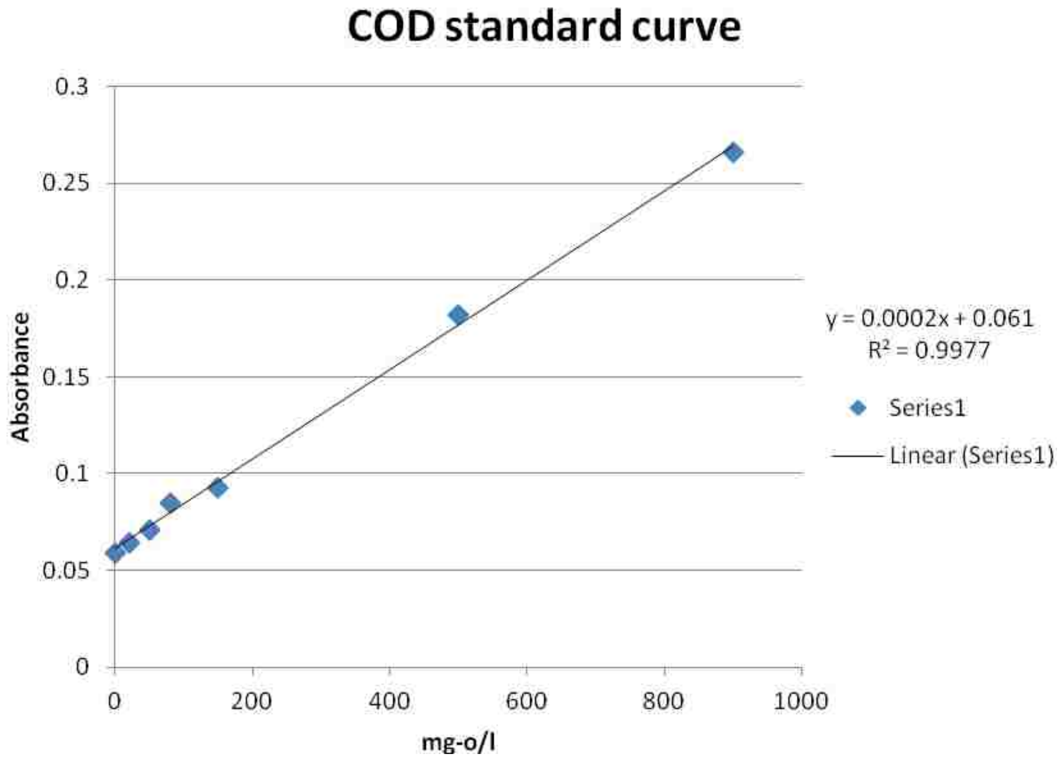


Figure C.1 COD standard curve

Nitrate analysis. This test follows section 4110 B of Standard Methods. Nitrate was analyzed using ion chromatograph instrument model 792 Basic IC Metrohm with an anion IC column (P/N: ANX-99-8511) and a flow rate set to 1.35 mL/min. Before measuring, samples were filtered through a 0.45-µm syringe filter. A solution of 1.8 mM sodium carbonate and 1.7 nM sodium bicarbonate was used as the eluent. The computer software is the same brand and model that came with the instrument. The ion chromatograph was calibrated once by a trained professional with a standard curve correlation coefficient of 0.99999. Check standards with known concentrations were run before each round of analysis was tested.

TSS analysis. This test follows Section 2540 D of Standard Methods. A continuously stirred sample was filtered through a weighed standard glass-fiber 0.50µm filter (catalog and maker's info) and the residue retained on the filter is dried to a constant weight at 103–105ºC for 1 h. The increase in weight of the filter represents the TSS.

Metals analysis. This test follows 3125 B of Standard Methods. Samples were preserved with 2% (v/v) trace metal grade nitric acid (Fisher A509-212) after collection. Samples were analyzed with an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (2004 Varian). Samples were preserved with nitric acid but not digested or filtered. Total metals are considered the concentration of metals determined from an unfiltered vigorously digested sample. Dissolved metals are considered metals from an unacidified sample filtered through a 0.45µm filter (APHA et. al 2012). Our samples were preserved and unfiltered because of the analysis and preservation method and are most closely related to the definition of total metals. All dilutions and standards used were made with de-ionized water and 2 percent trace metal grade nitric acid. A four point standard curve was used with concentrations of 0, 10, 50, and 200 ppb. All standard curves were acceptable if a correlation coefficient ≥ 0.9999 was observed. After initialization of standards the standards were run as samples to verify correctness of standards and the instrument. A continuing standard was run after every 10 sample runs and was the 50 ppb standard solution which remained within 10 percent with a goal of 5 percent. A continuous internal standard (Rhodium) was used to track instrument drift and sample viscosity. The ICP-MS was run in peak hopping mood with 5 replicates, 16 scans and a dwell time of 10 ms, and the machine flow rate was set to 0.33 ml/min.

Method detection limit. The calculation of the method detection limit was done using excel calculation of the standard curve data. Table C.2 is an example for nickel using the ICP-MS. Four points were used on the standard curve 0, 10, 50, 200 ppb with the related counts per second used by the ICP-MS. The columns from left to right are (1) ppb concentration, (2) counts per second, (3) x values, (4) y values, (5) x values squared, (6) y values squared, (7) x values multiplied by the y values, (8) the calculated y values using the best fit equation, and finally (9) the last column is the residual of each standard point which is the difference in the actual y and the calculated y.

The calculation of the S.D. Residuals, S_y is the standards of deviation of the y residual of each standard point, taking into account the degrees of freedom or n-1. The detection limit is then calculated by 3 times the S.D. Residuals, S_y. The equation of best fit and Correlation Coefficient, R is also reported in this table, which were $y = 5299.24x +7437.53$with $R = 0.99991$. The result of the t test for this example is also reported and was 4.30. In addition, the result of the “g” statistic is shown which was 0.0016 and a good value is below 0.005. The method detection limit for nickel for this example is 3.373 µg/L.

Table C.2 Calculation of the method detection limit of Nickel and statistics

	Raw Data		**Transformed Data**						
Identity	***(1)* x** ppb	***(2)* y** Instrument Signal	***(3)* $f(x)$**	***(4)* $f(y)$**	***(5)* $f(x)^2$**	***(6)* $f(y)^2$**	***(7)* $f(x) \cdot f(y)$**	***(8)* $f'(y)$**	**(9)Residuals**
Units	**ppb**	**c/s**	**ppb**	**c/s**					
First 0?	0.000	1358.800049	0	1359	0	1846338	0	7438	-6079
Expa ndabl e Regio	10.000	59545	10	59545	100	3545607025	595450	60430	-885
	50.000	281625.4063	50	281625	2500	79312869445	14081270	272400	9226
Last	200.000	1065023.25	200	1065023	40000	1134274523041	213004650	1067285	-2262
Totals			260	1407552	42600	1217134845849	227681370		

Count, n = 4

x bar = 65.000 ppb

y bar = 351888.11c/s

S_{xx} = 25700.000

S_{yy} = 721833866540.40

S_{xy} = 136190460.65

Slope, m = 5299.24c/s / c/s

Intercept, b = 7437.53c/s

S.D. Residuals, S_y = 7999.024

S.D. Slope, S_m = 49.897

S.D. Intercept, S_b = 5149.265

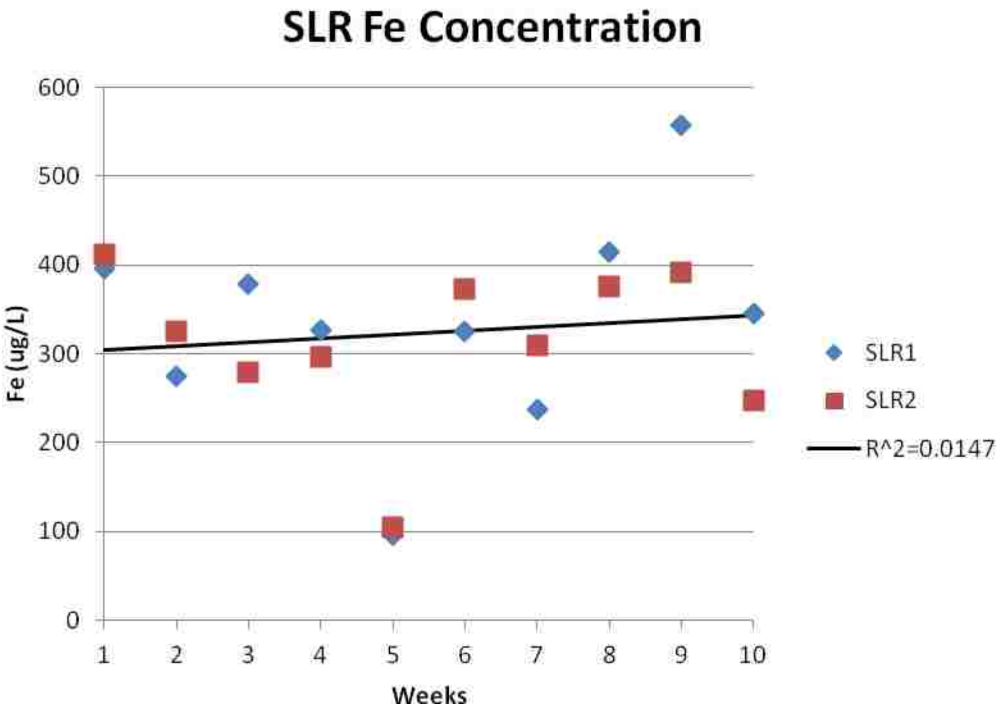
Correlation Coefficient, R = 0.99991

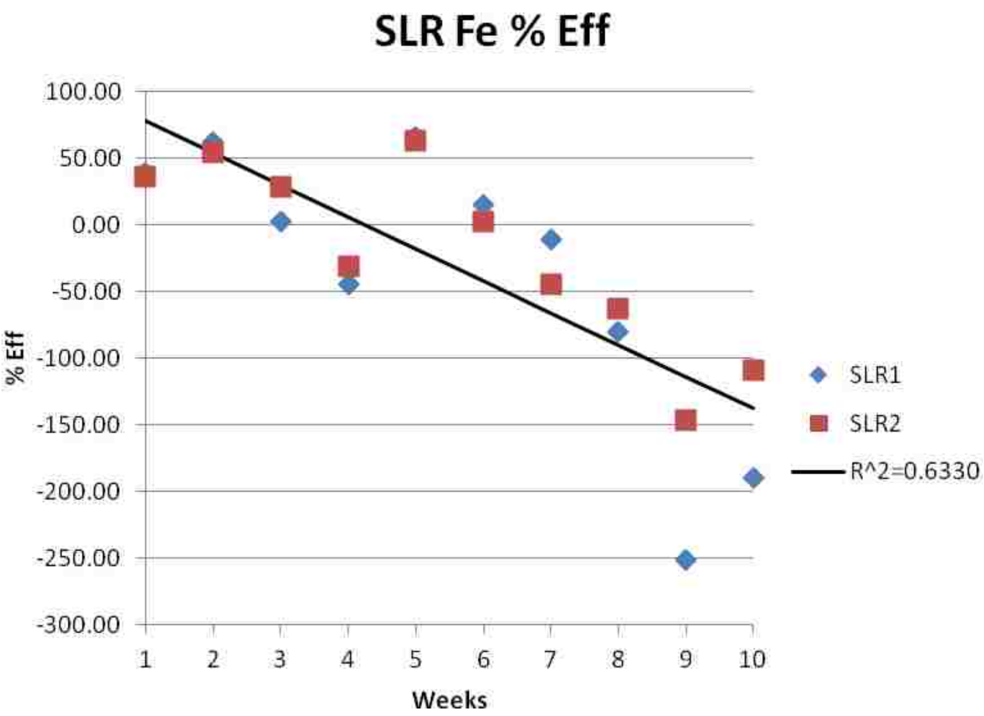
t (95%, n - 2 d.f.) = 4.30

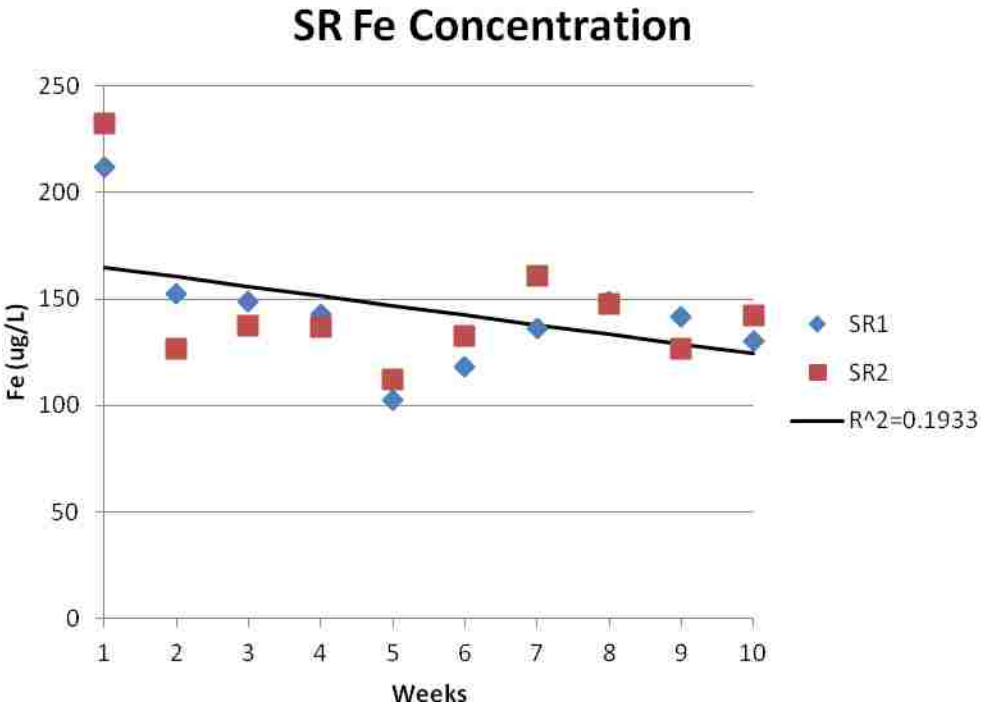
"g" Statistic, g = 0.0016

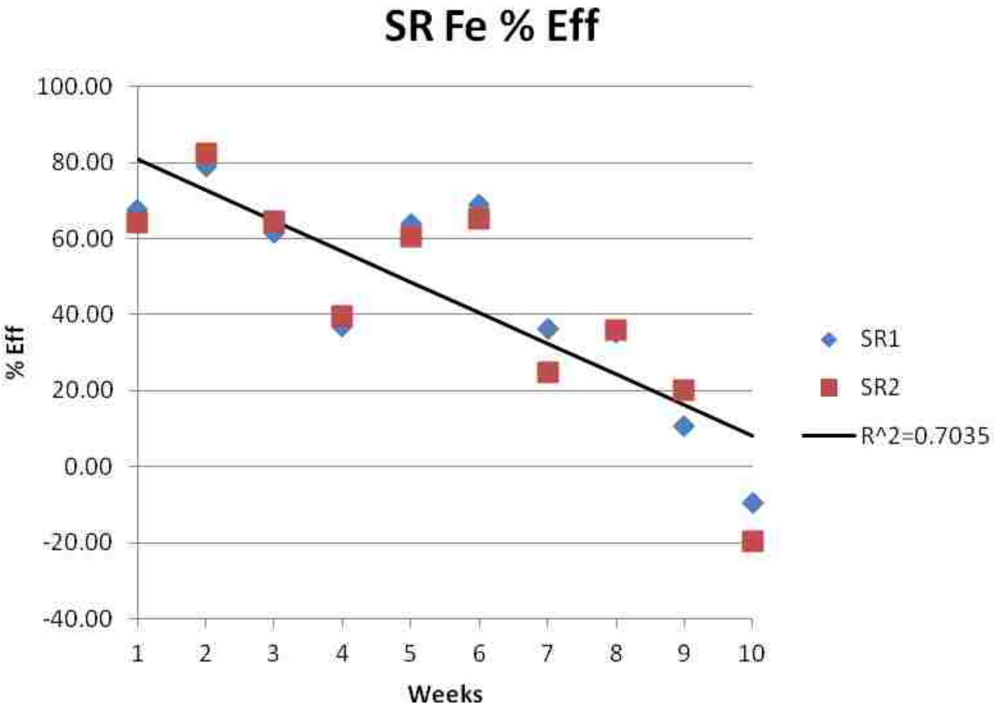
Detection Limit = Blank + 3*S_y(resid)= **3.373**

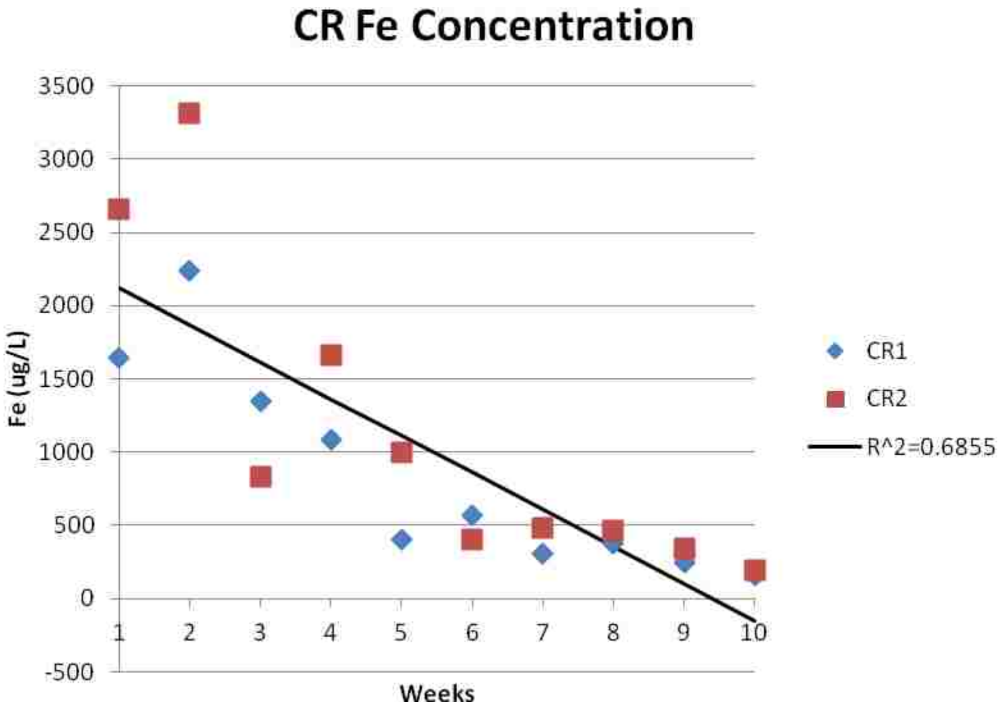
Appendix D Lab Reactor Graphs

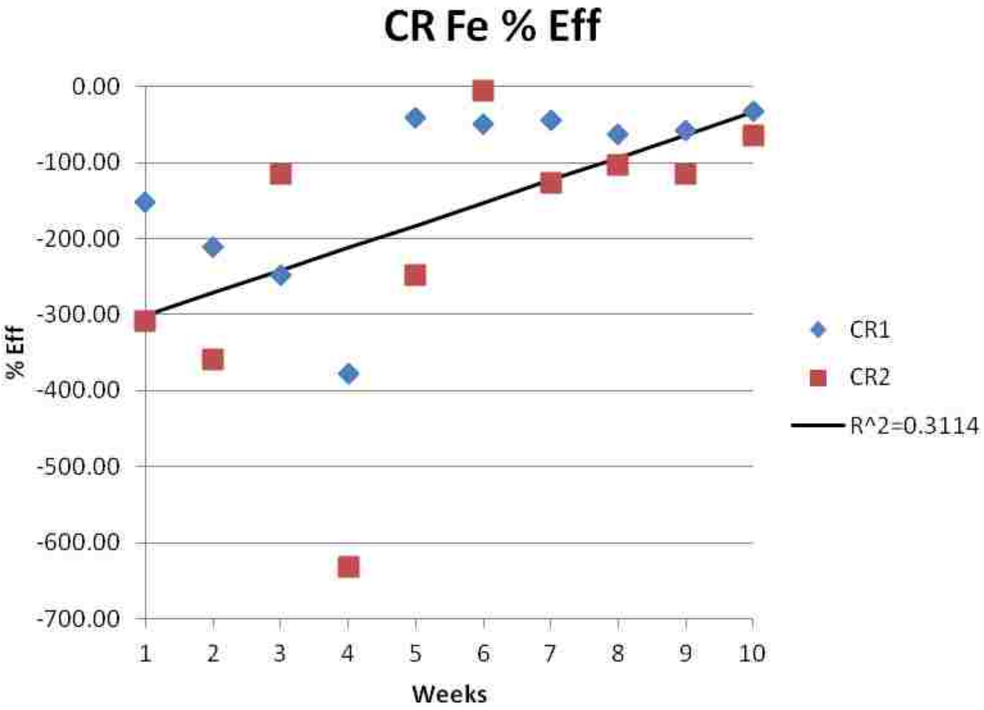


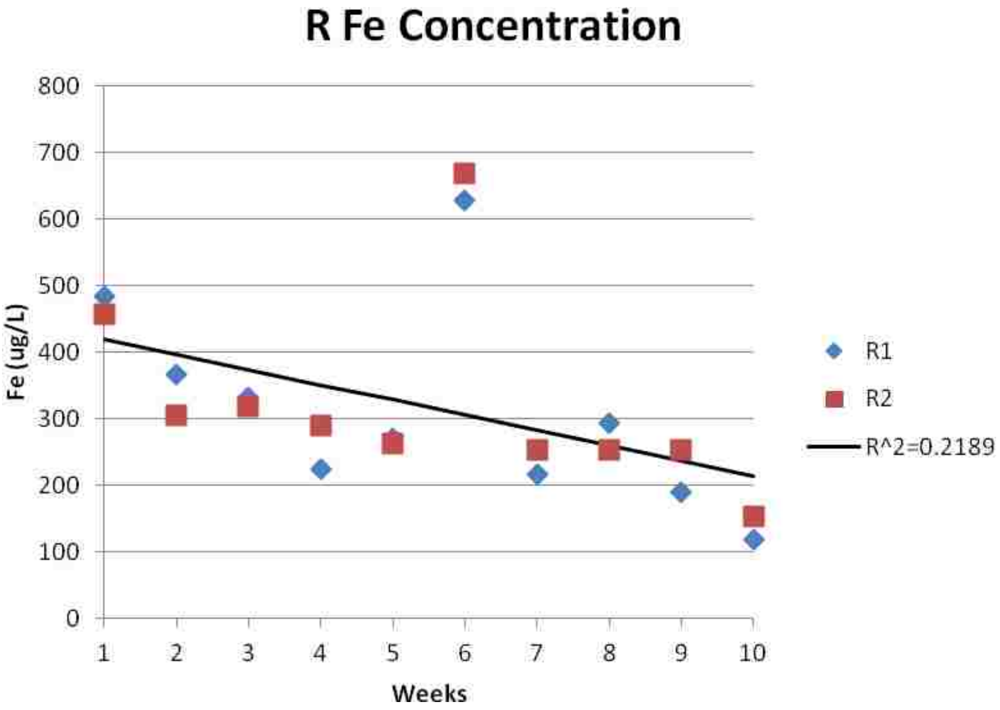

SLR Fe % Eff
100.00
50.00
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.6330

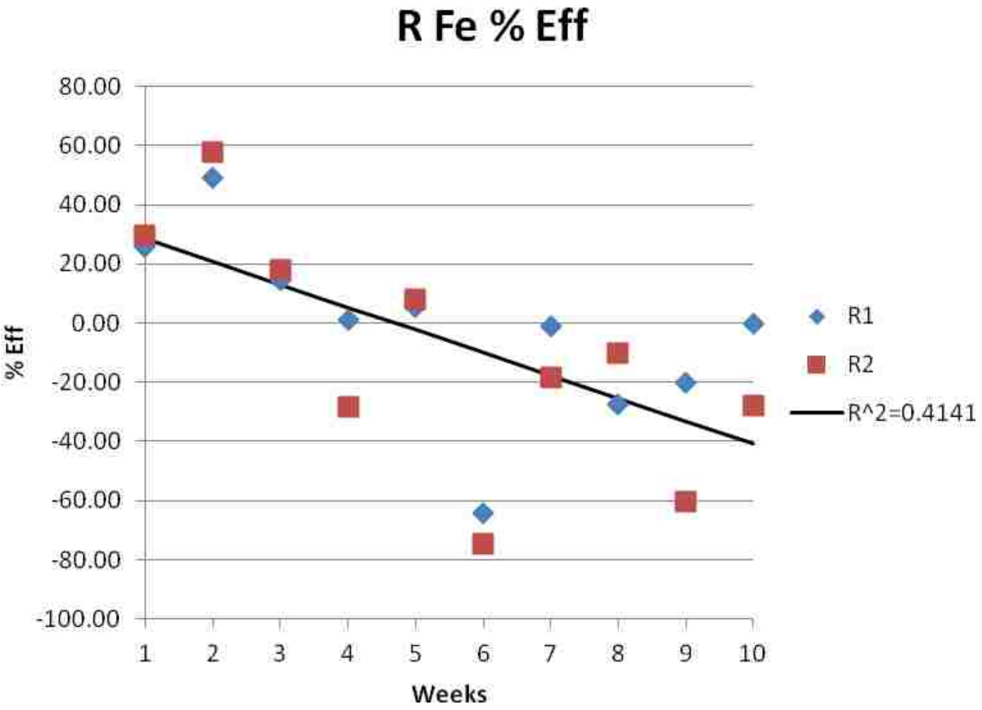

SR Fe Concentration
250
200
150
100
50
0
Fe (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.1933

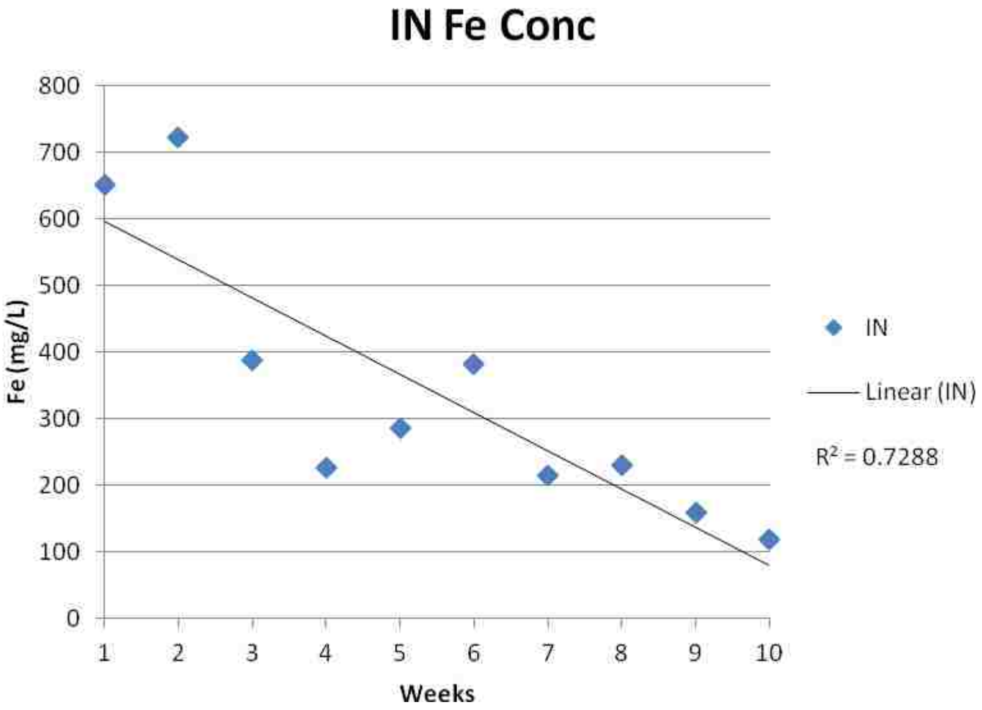

SR Fe % Eff
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.7035

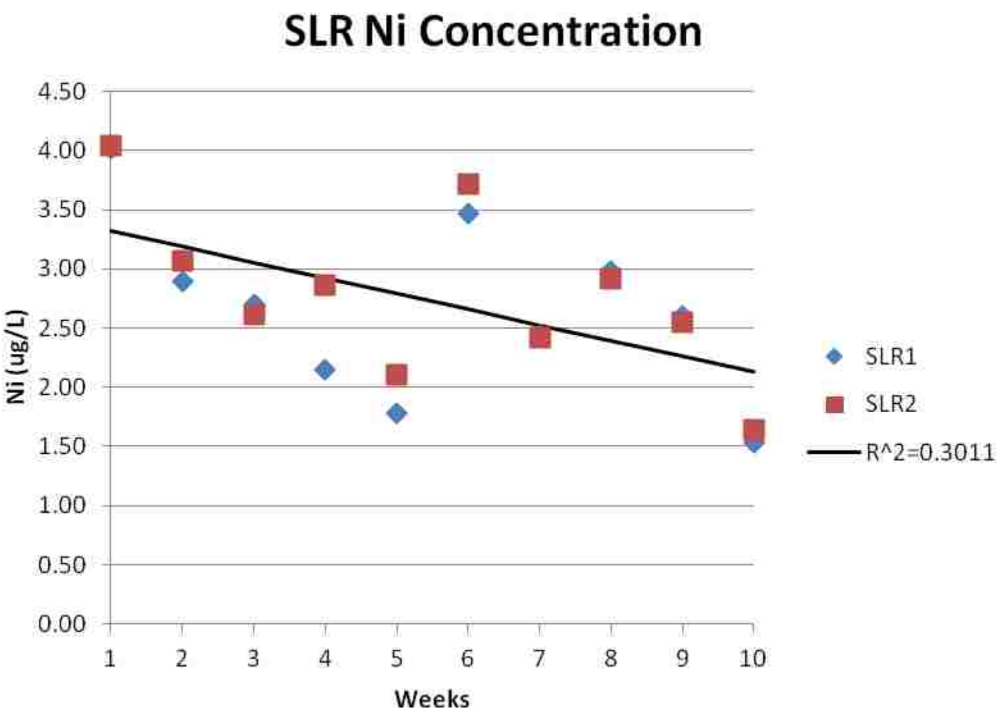

CR Fe Concentration
3500
3000
2500
2000
1500
1000
500
0
-500
Fe (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.6855

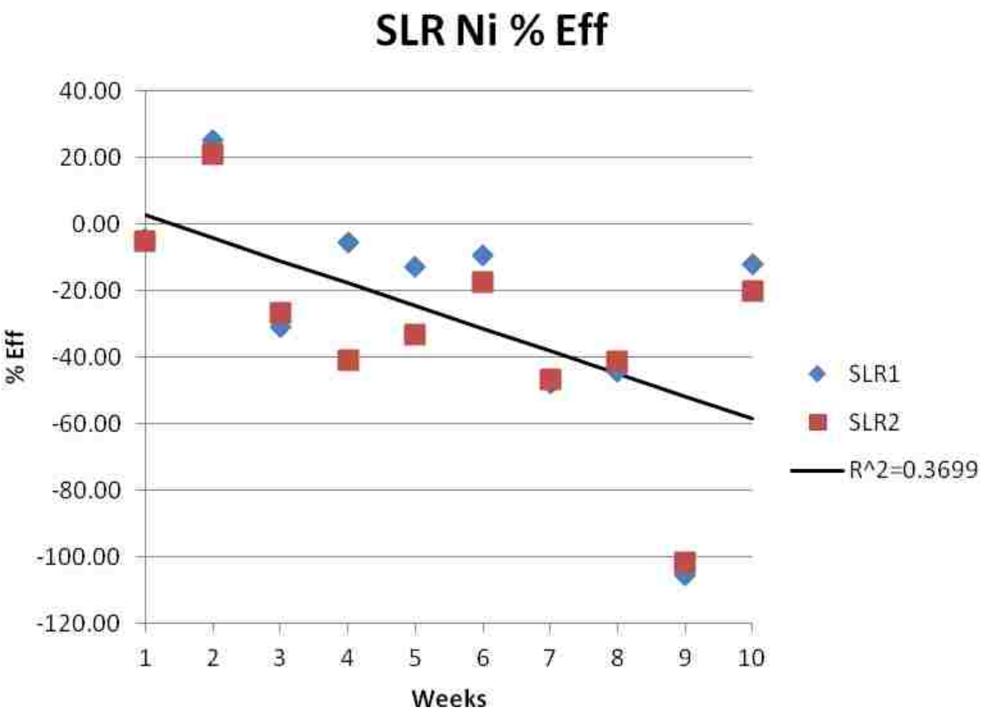

CR Fe % Eff
0.00
-100.00
-200.00
-300.00
-400.00
-500.00
-600.00
-700.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.3114

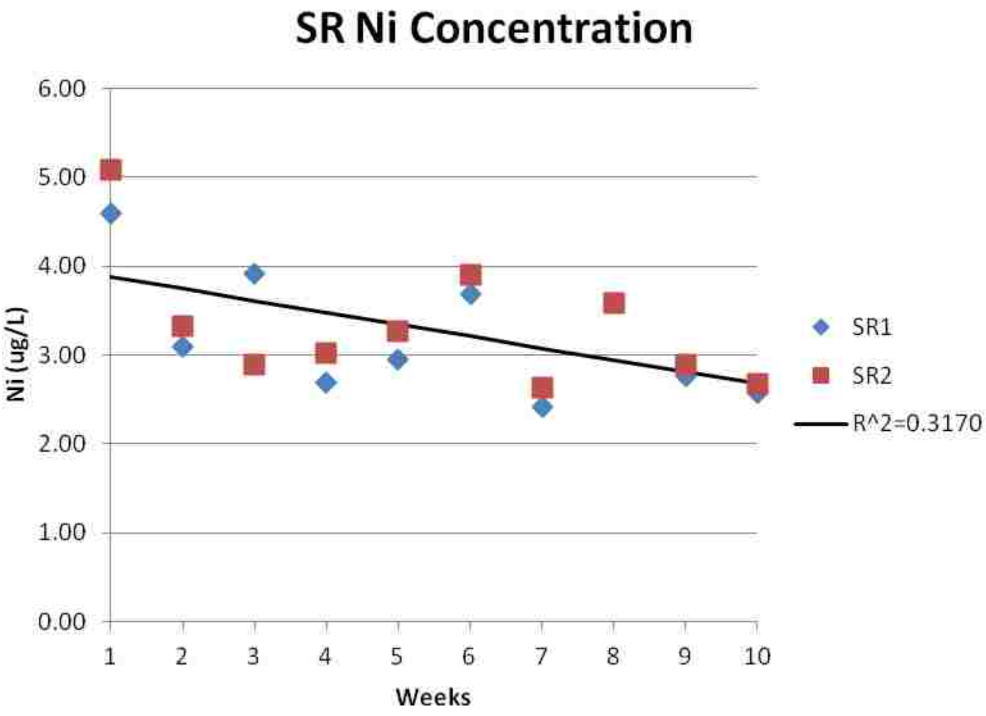

R Fe Concentration
800
700
600
500
400
300
200
100
0
Fe (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.2189

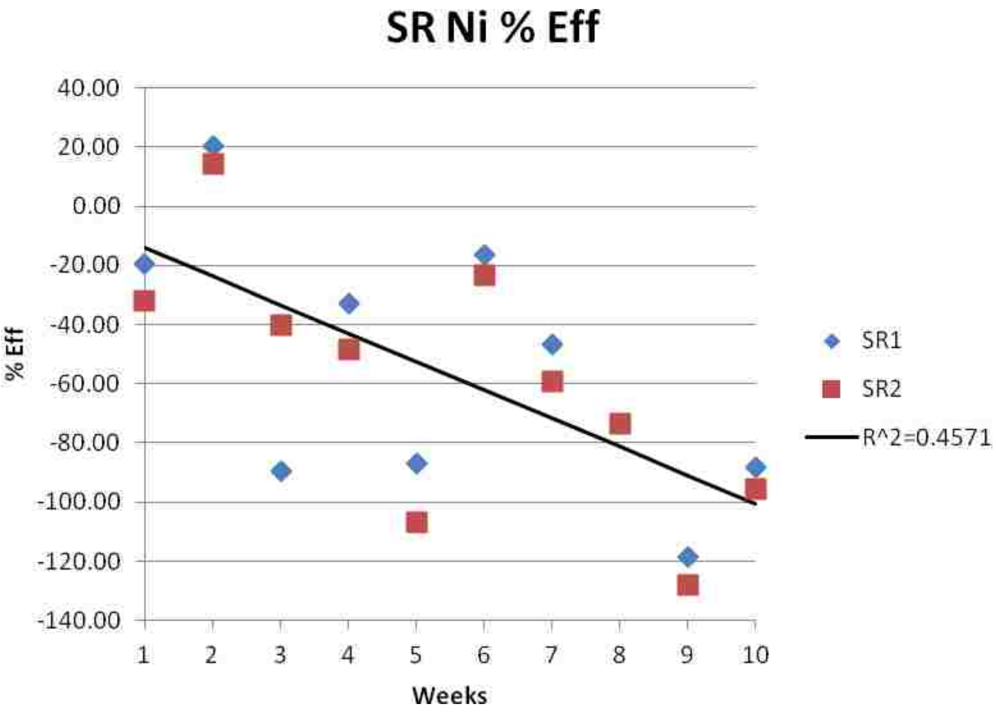

R Fe % Eff
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.4141

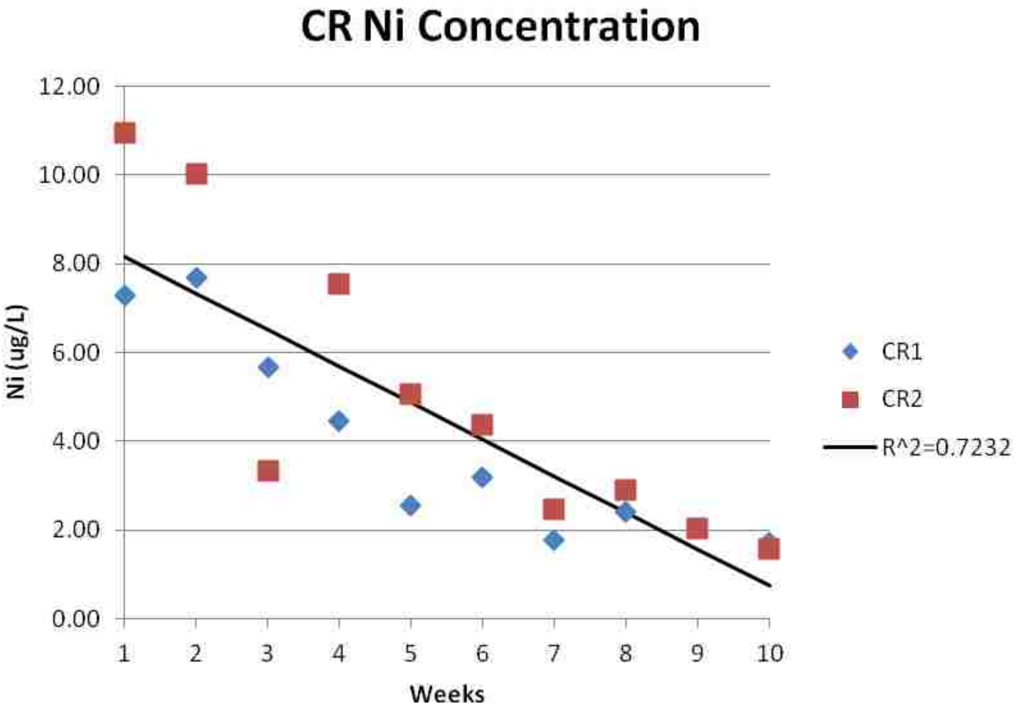

IN Fe Conc
800
700
600
500
400
300
200
100
0
Fe (mg/L)
1
2
3
4
5
6
7
8
9
10
Weeks
IN
Linear (IN)
R² = 0.7288

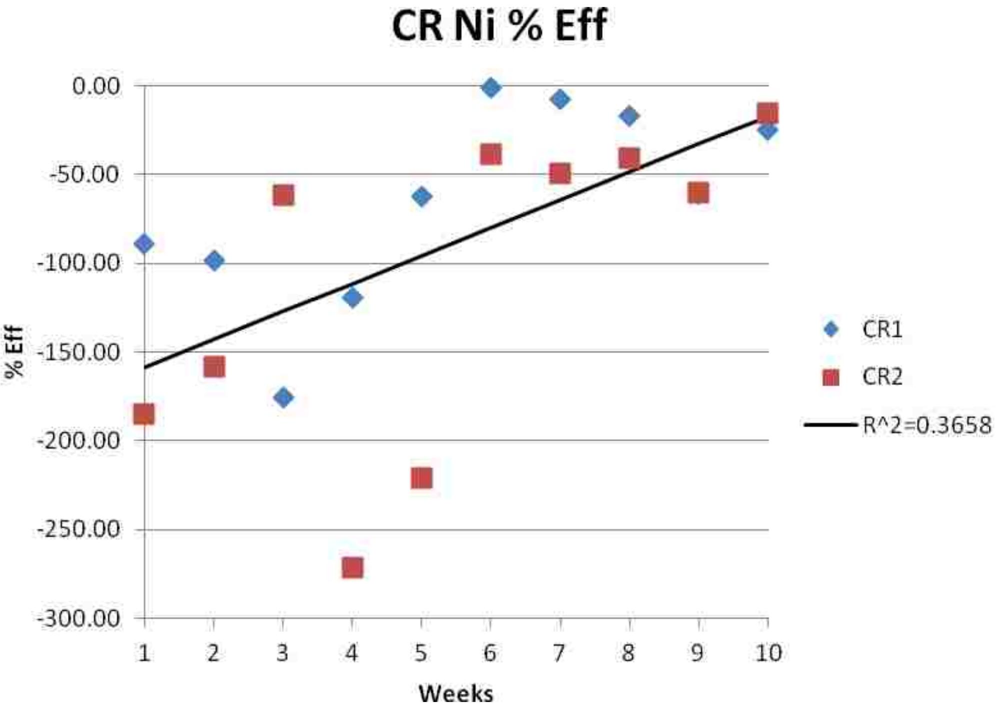

SLR Ni Concentration
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Ni (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.3011

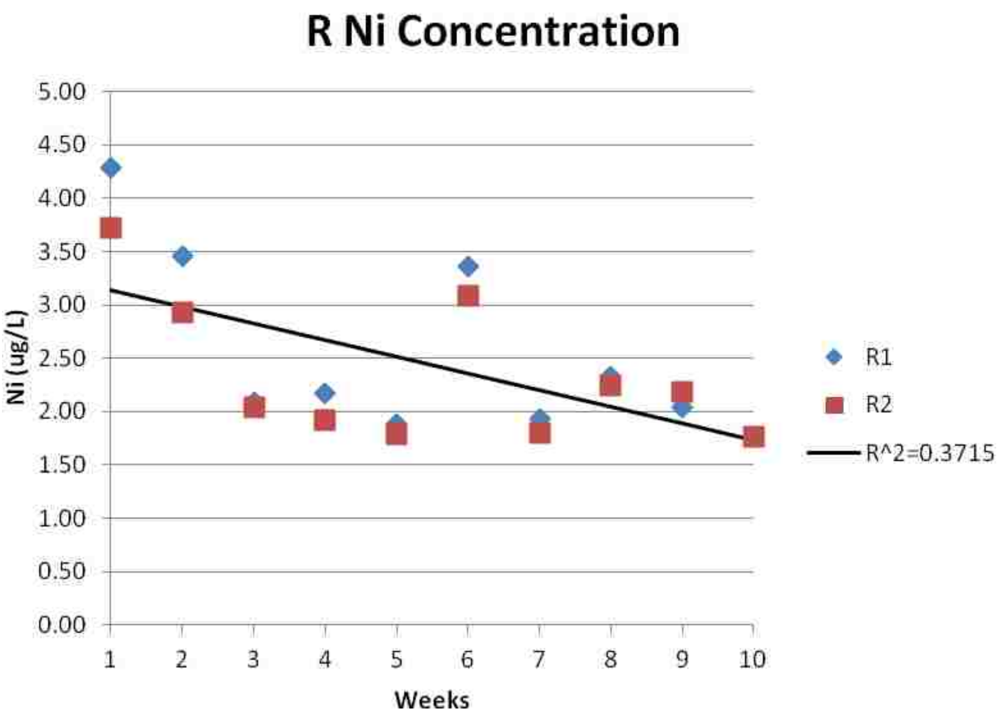

SLR Ni % Eff
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.3699

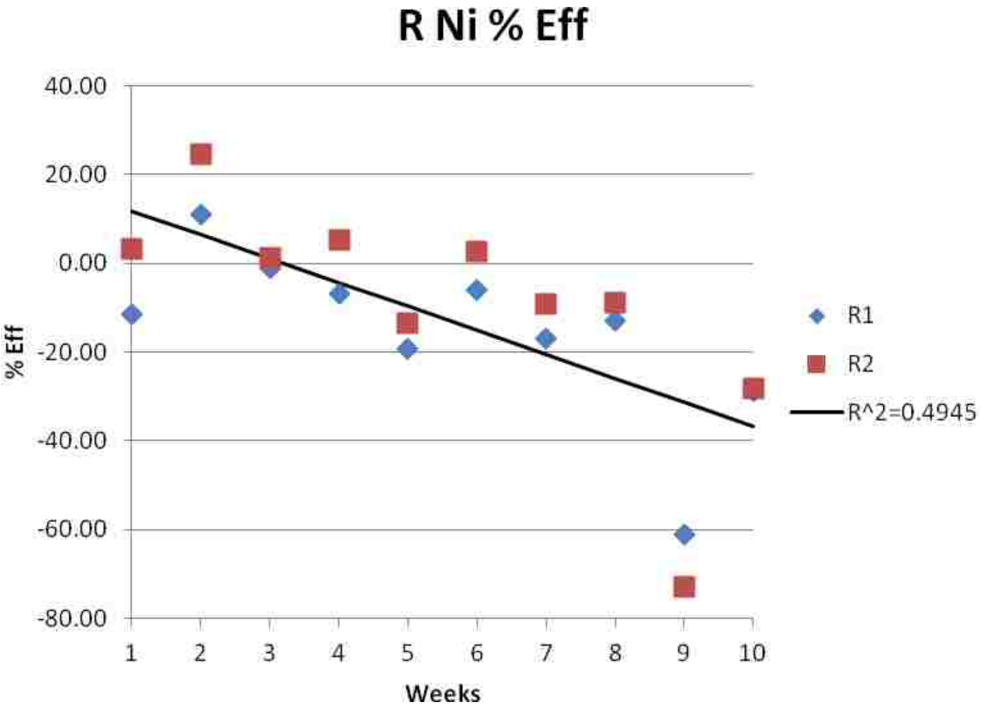

SR Ni Concentration
Ni (ug/L)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
◆ SR1
■ SR2
R^2=0.3170

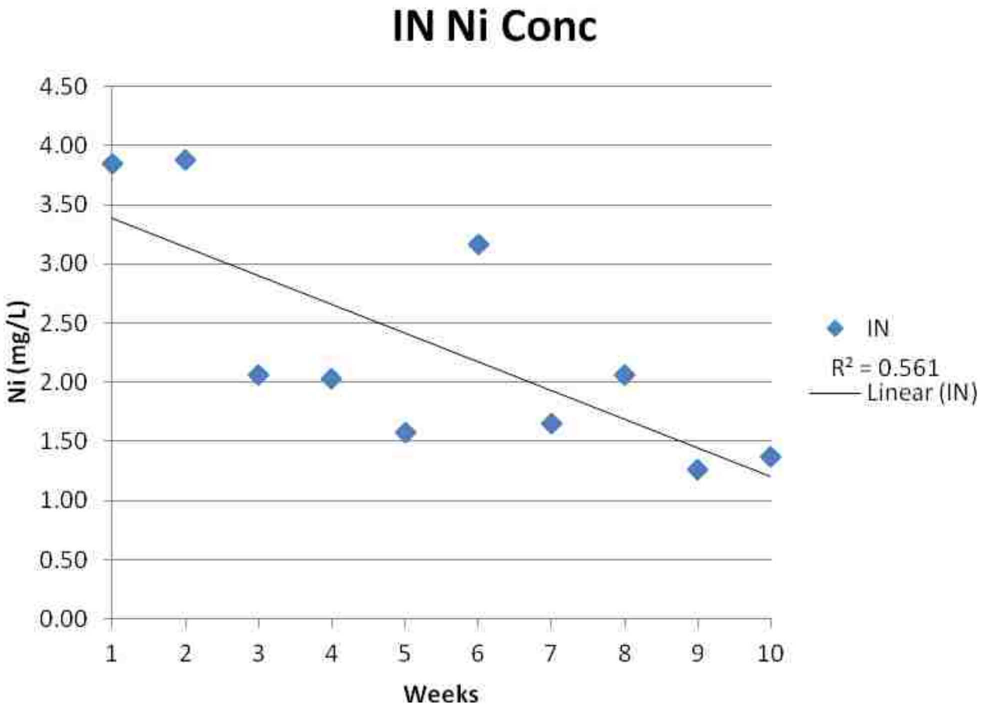

SR Ni % Eff
% Eff
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
-140.00
1
2
3
4
5
6
7
8
9
10
Weeks
◆ SR1
■ SR2
R^2=0.4571

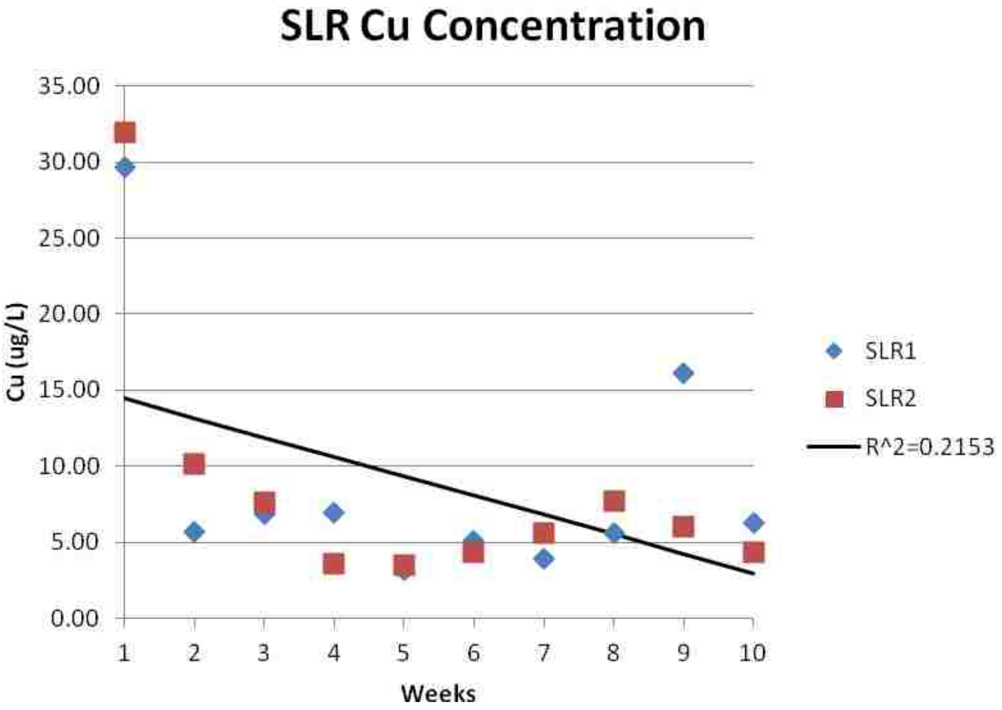

CR Ni Concentration
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Ni (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.7232

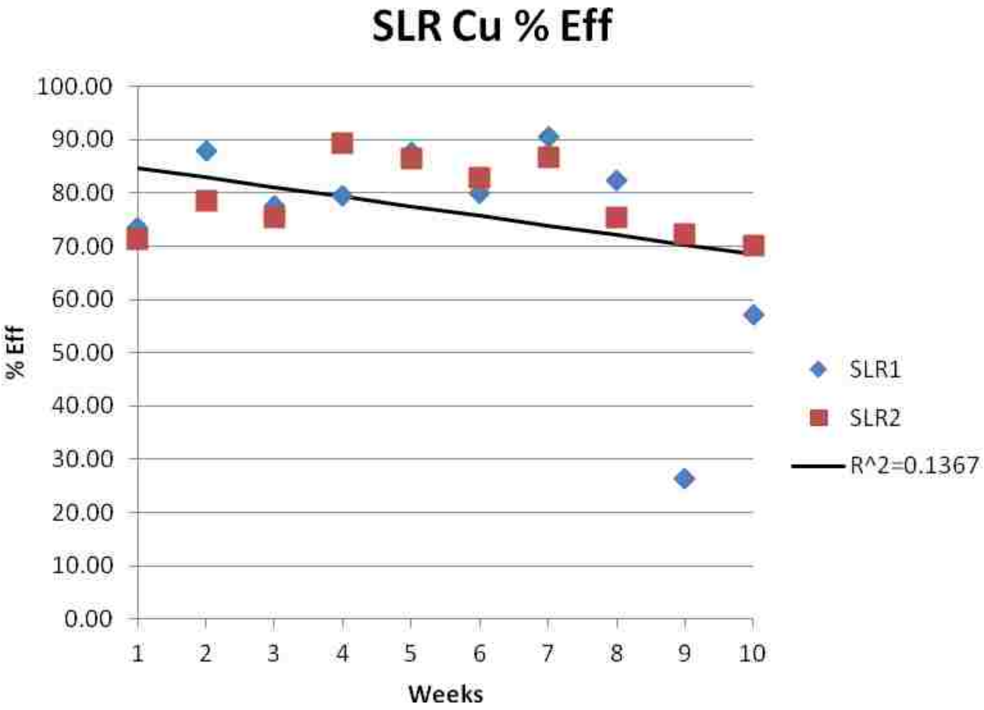

CR Ni % Eff
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.3658

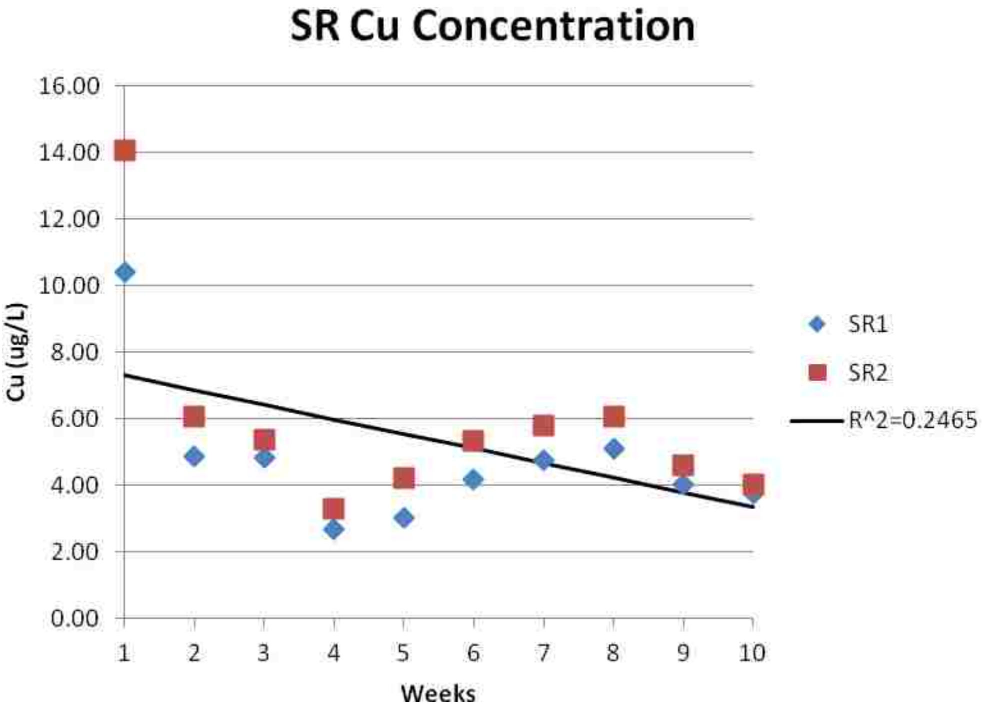

R Ni Concentration
Ni (ug/L)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.3715

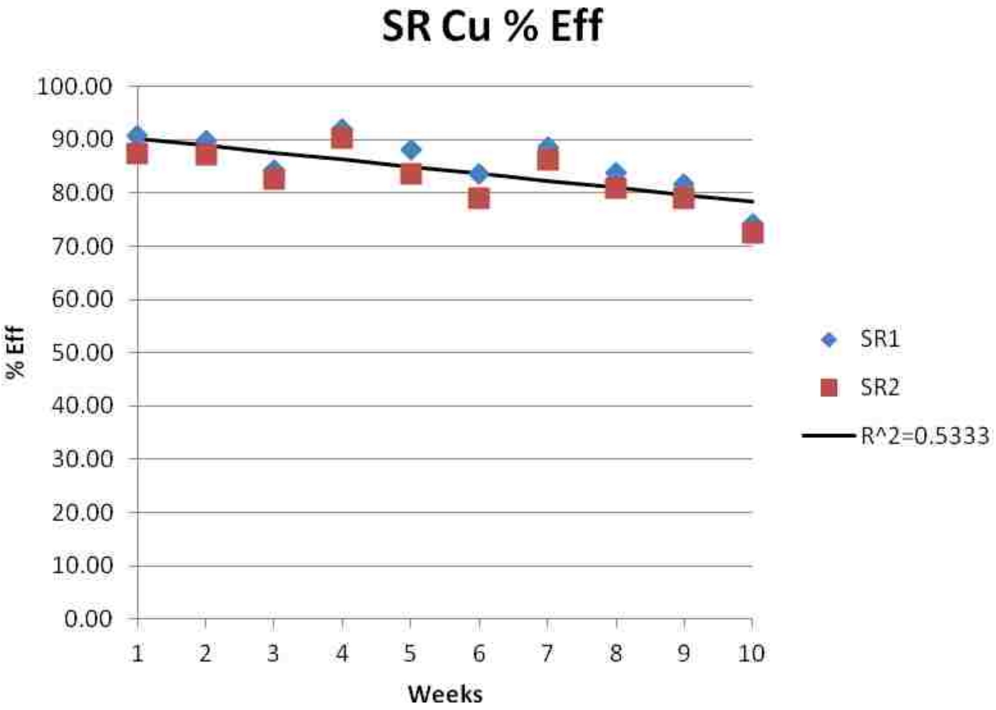

R Ni % Eff
% Eff
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.4945

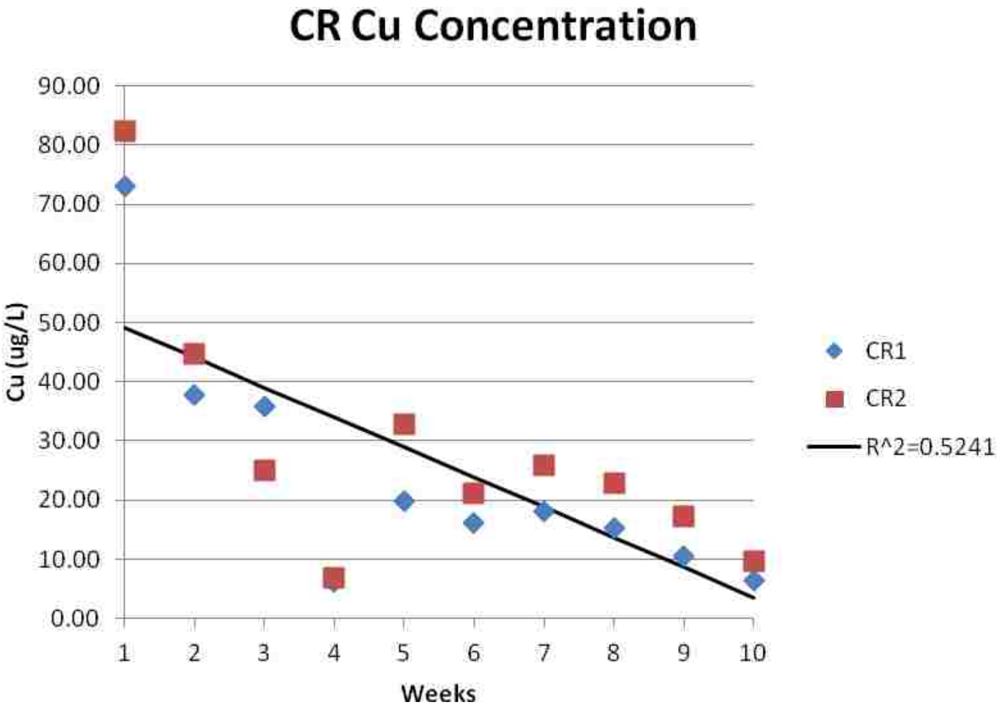

IN Ni Conc
Ni (mg/L)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
IN
R² = 0.561
Linear (IN)

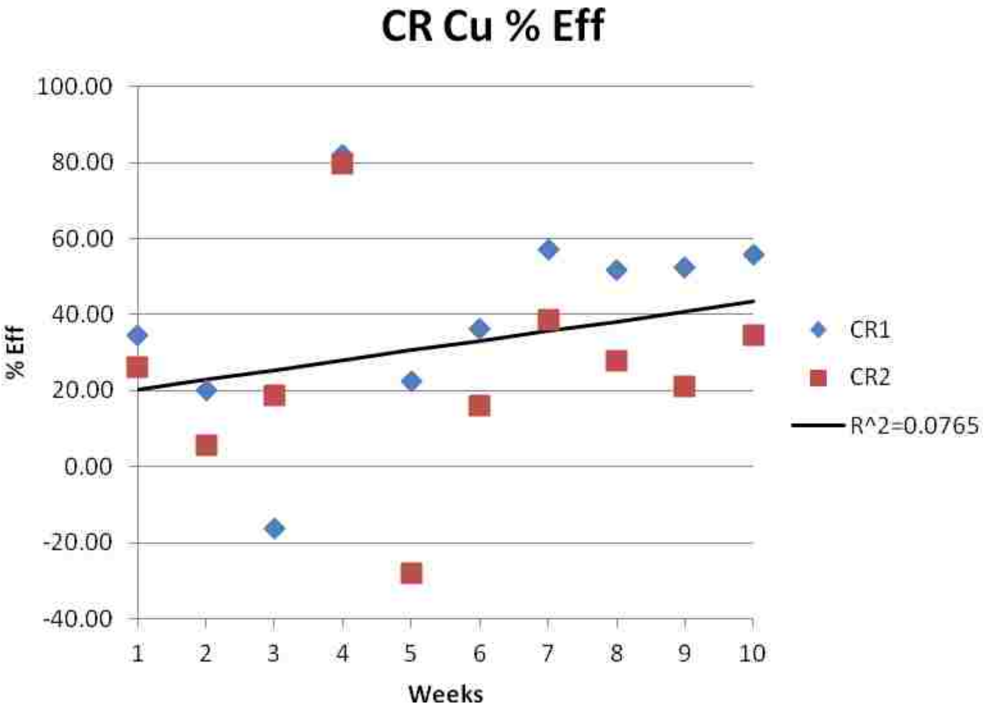

SLR Cu Concentration
Cu (ug/L)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.2153

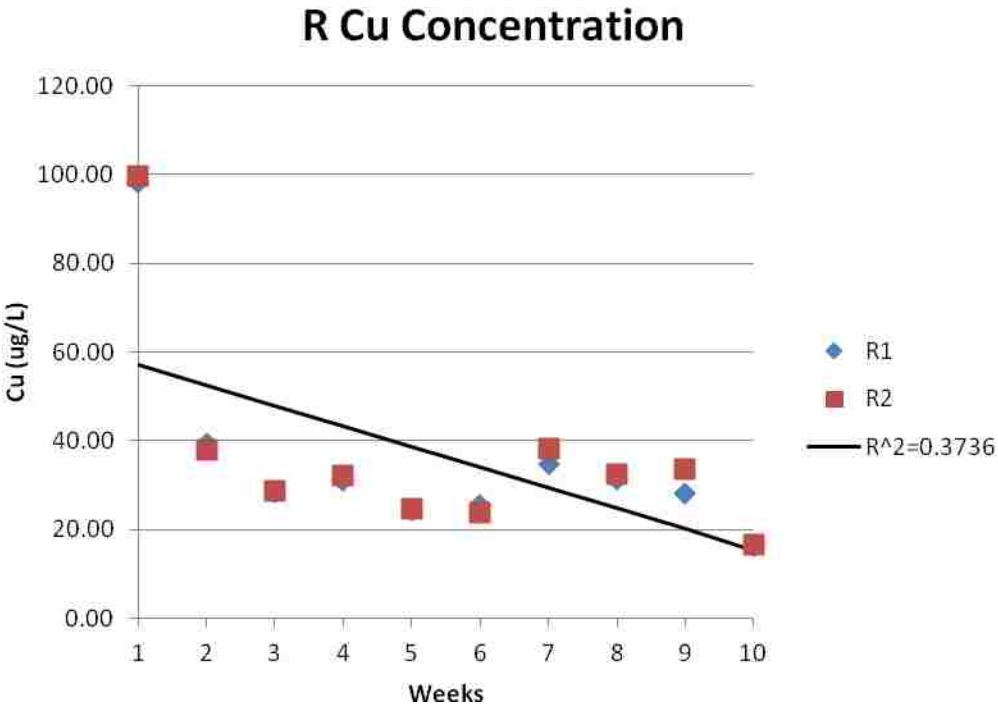

SLR Cu % Eff
% Eff
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.1367

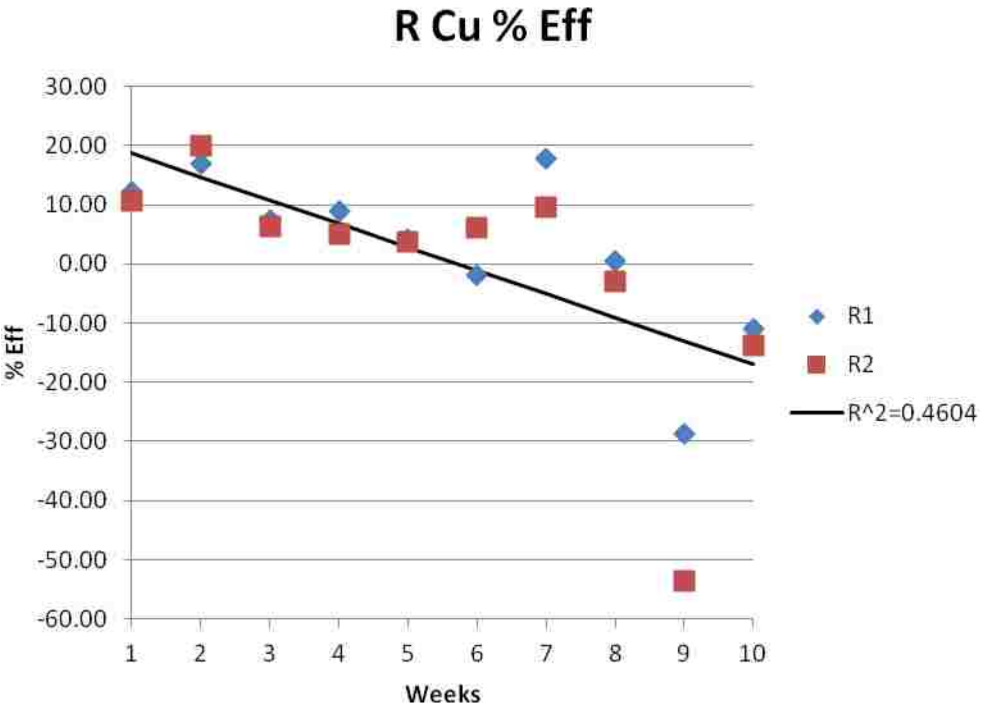

SR Cu Concentration
Cu (ug/L)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.2465

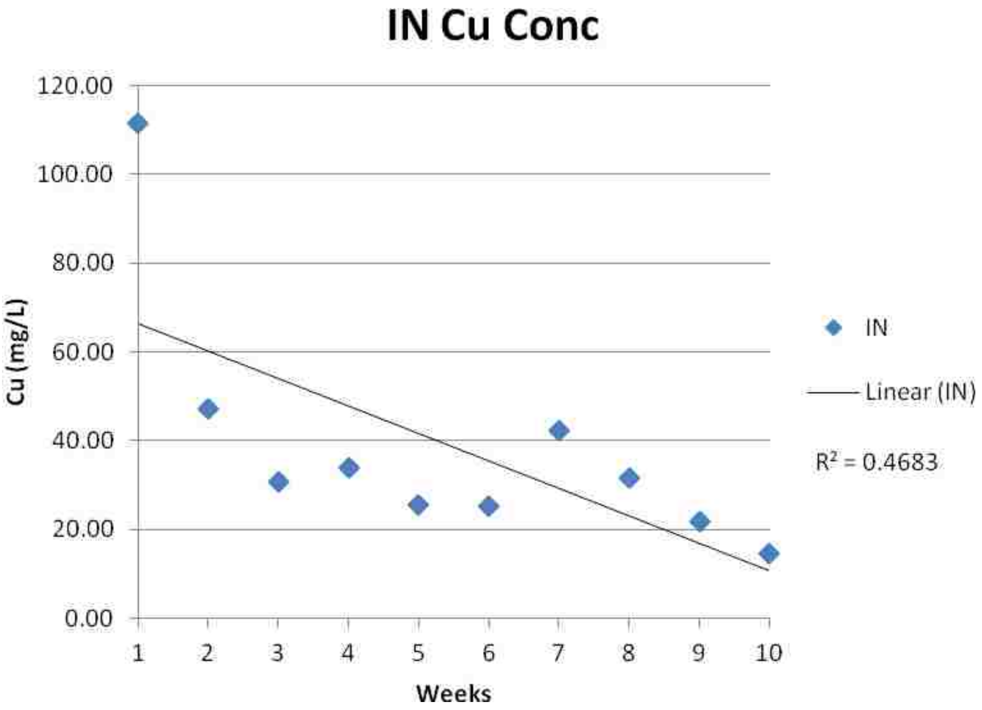

SR Cu % Eff
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.5333

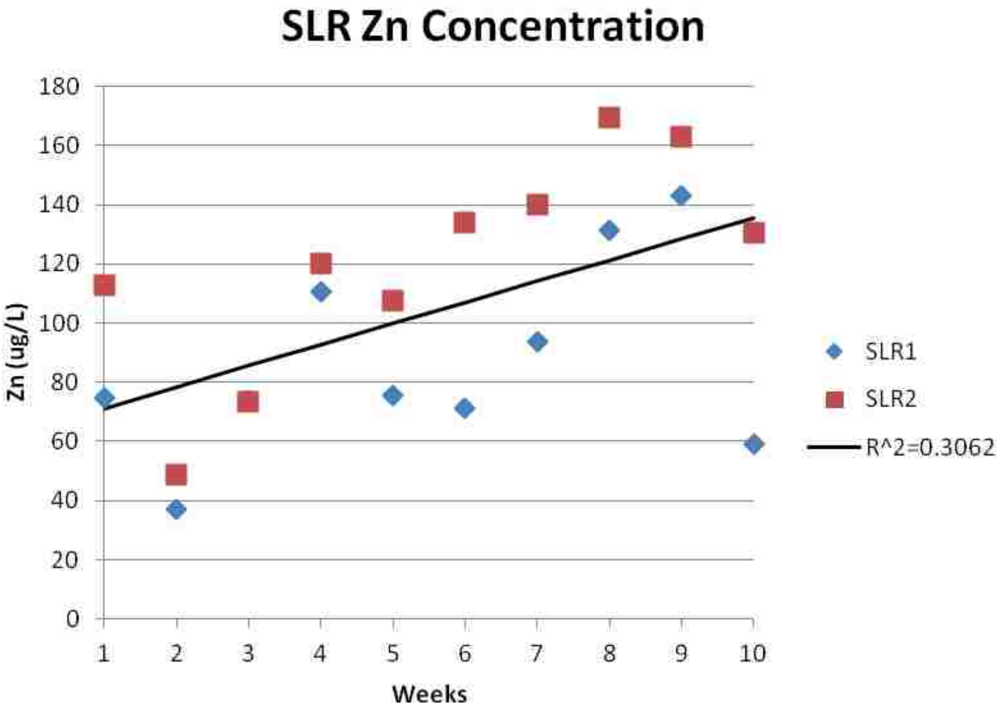

CR Cu Concentration
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Cu (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.5241

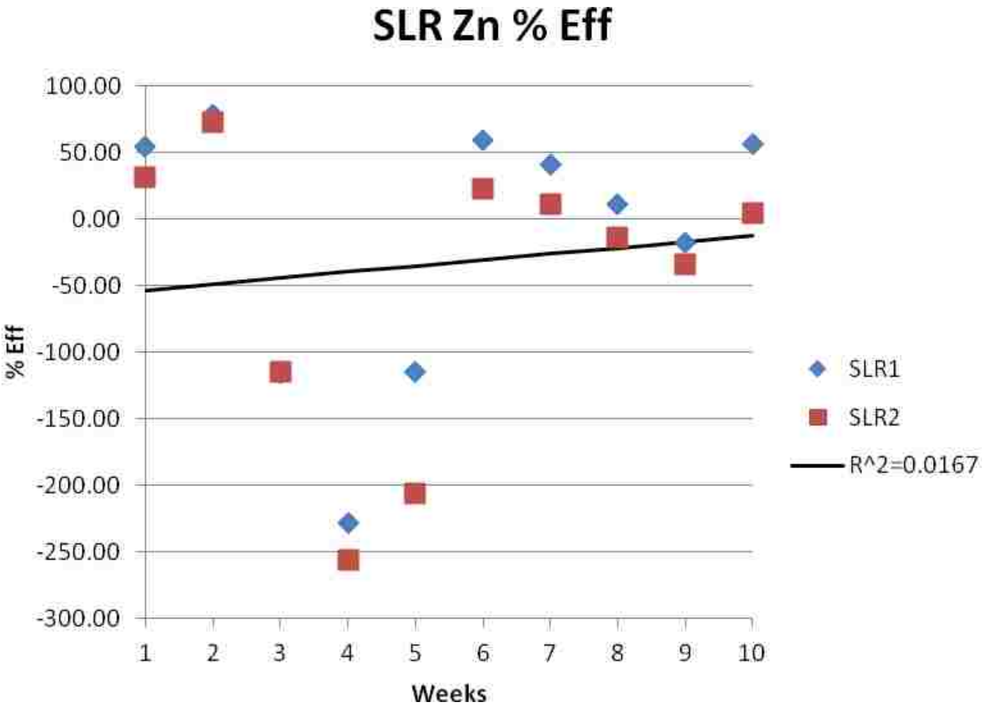

CR Cu % Eff
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.0765

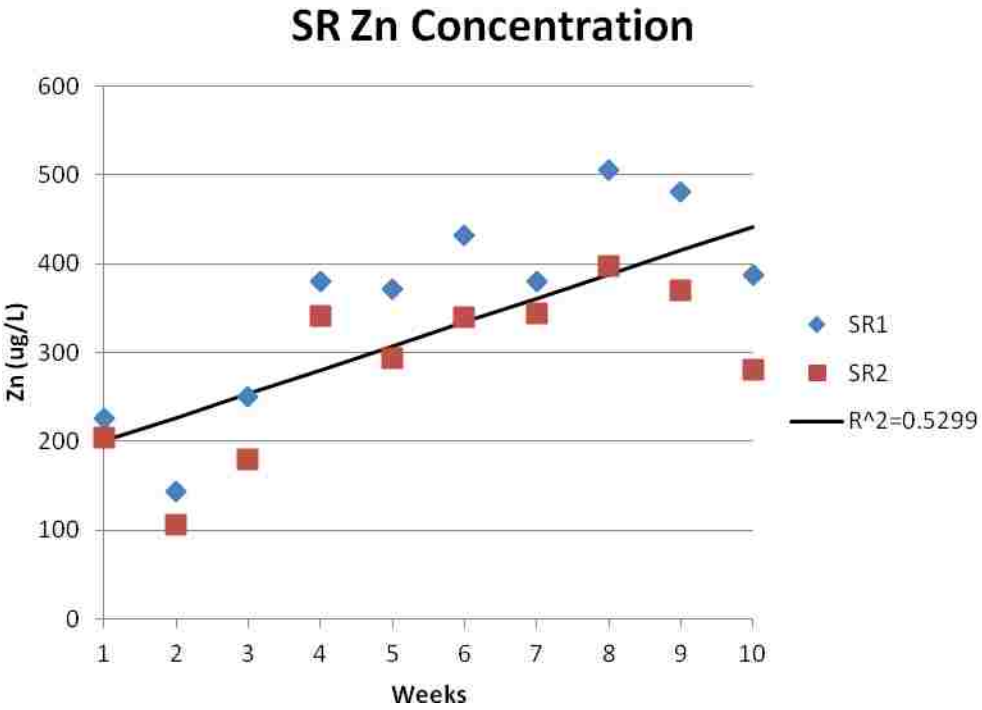

R Cu Concentration
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Cu (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.3736

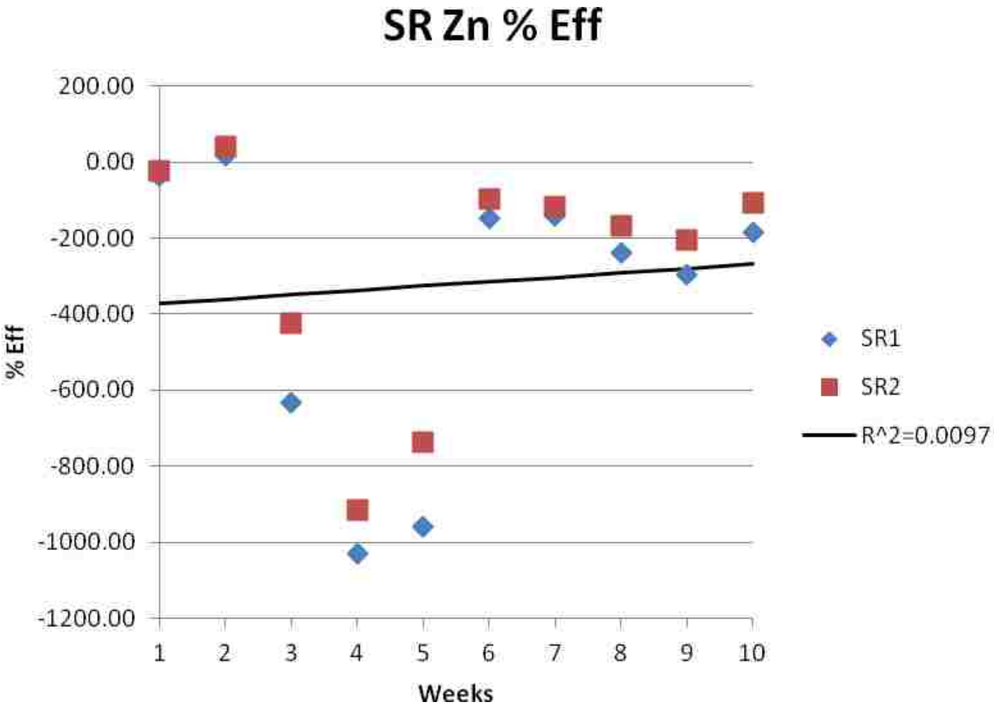

R Cu % Eff
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.4604

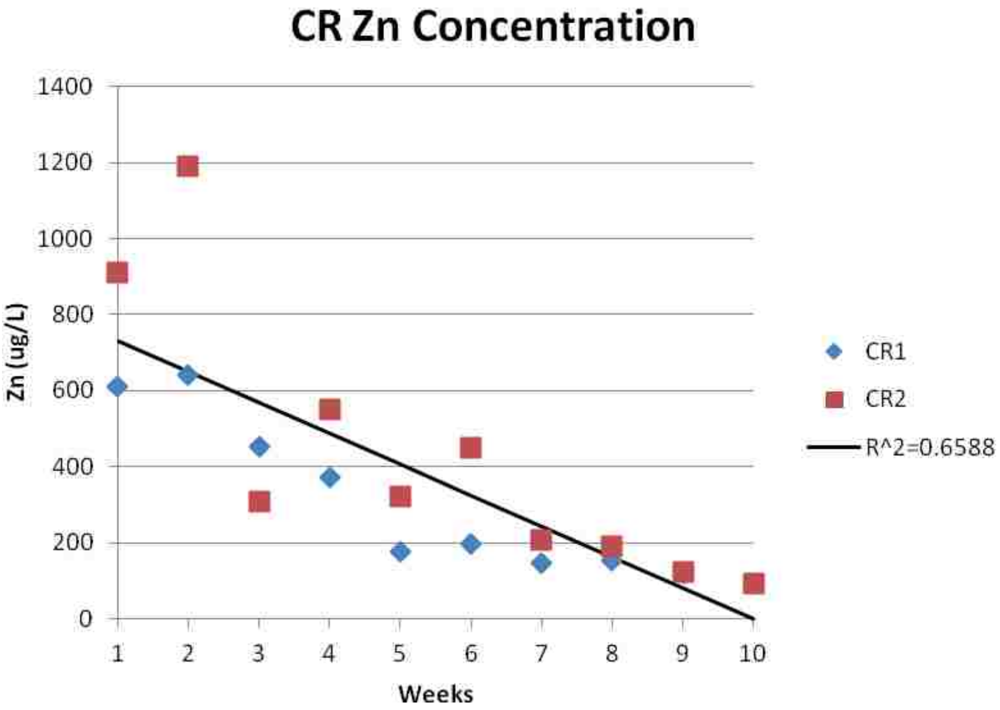

IN Cu Conc
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Cu (mg/L)
1
2
3
4
5
6
7
8
9
10
Weeks
IN
Linear (IN)
R² = 0.4683

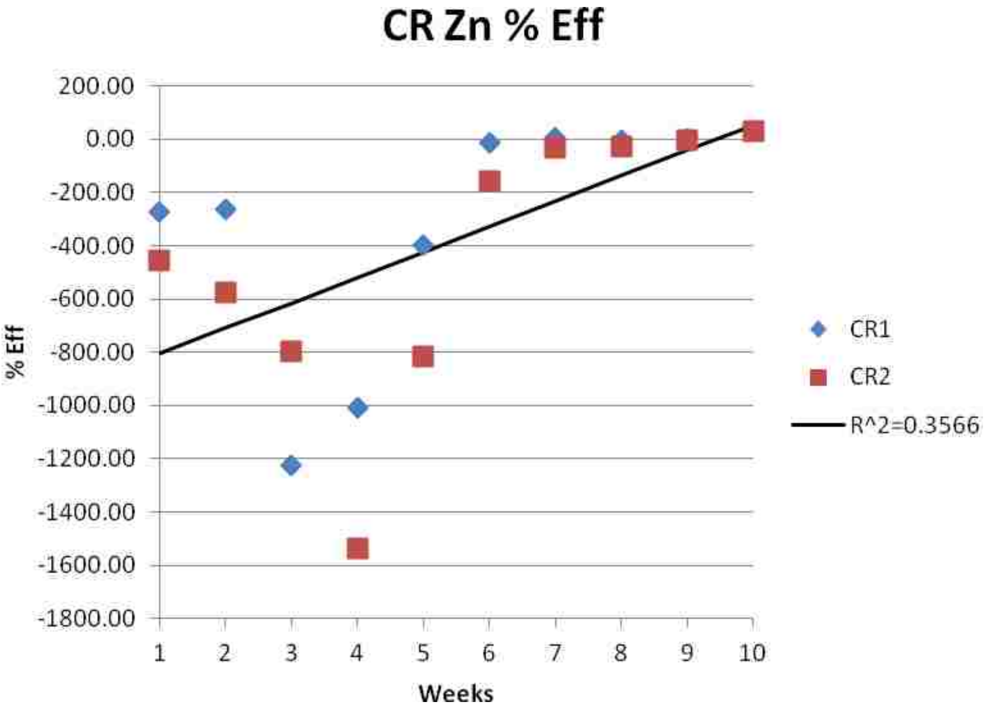

SLR Zn Concentration
Zn (ug/L)
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.3062

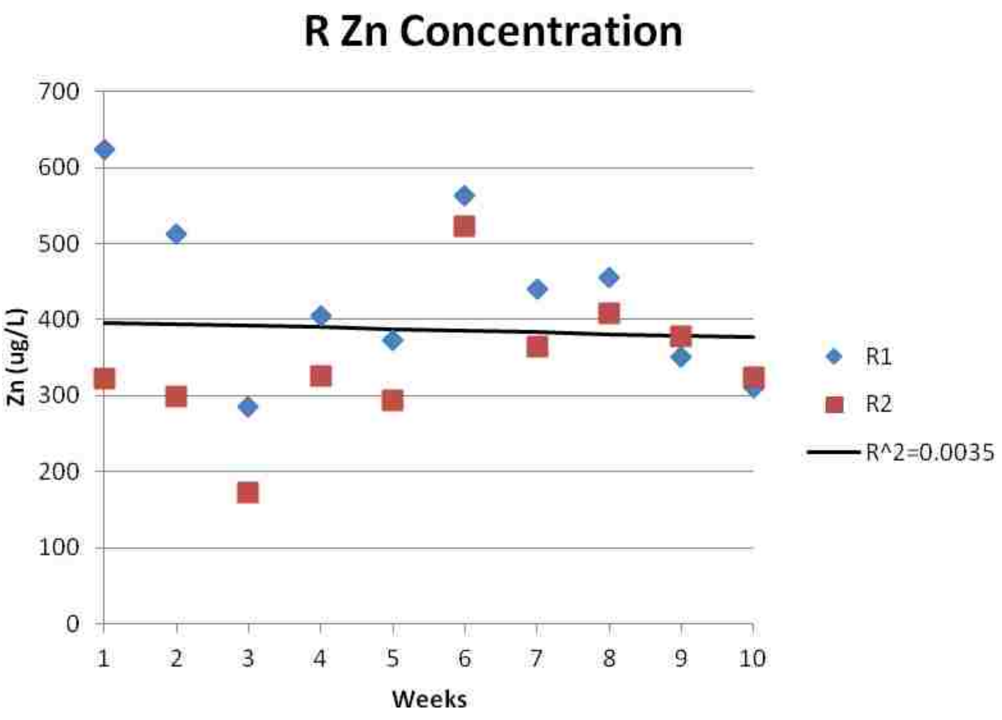

SLR Zn % Eff
% Eff
100.00
50.00
0.00
-50.00
-100.00
-150.00
-200.00
-250.00
-300.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.0167

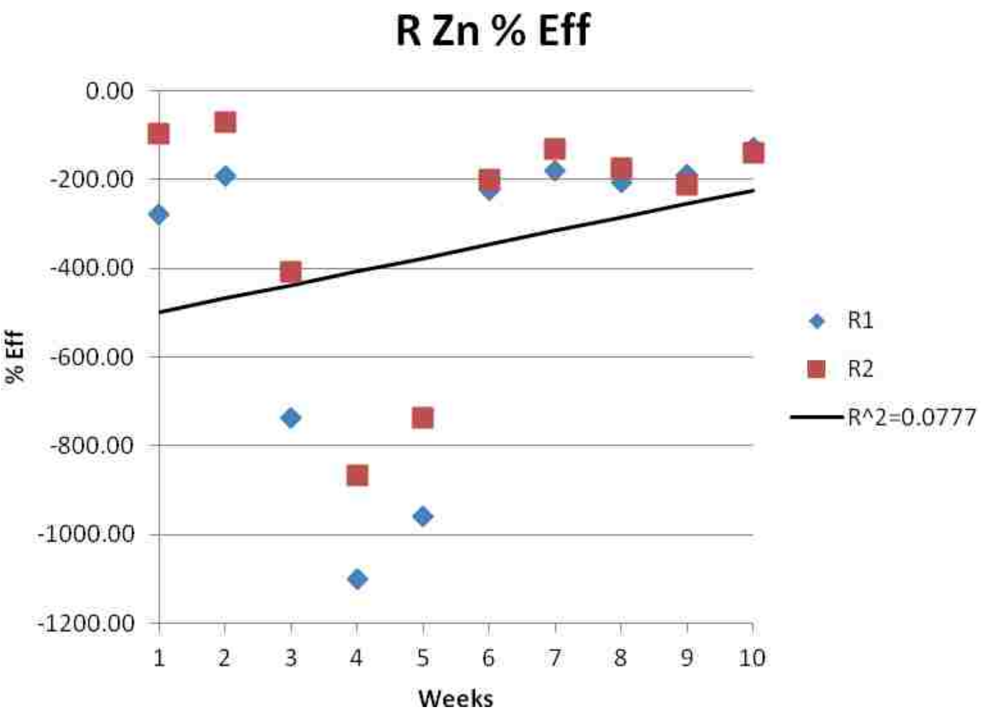

SR Zn Concentration
600
500
400
300
200
100
0
Zn (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.5299

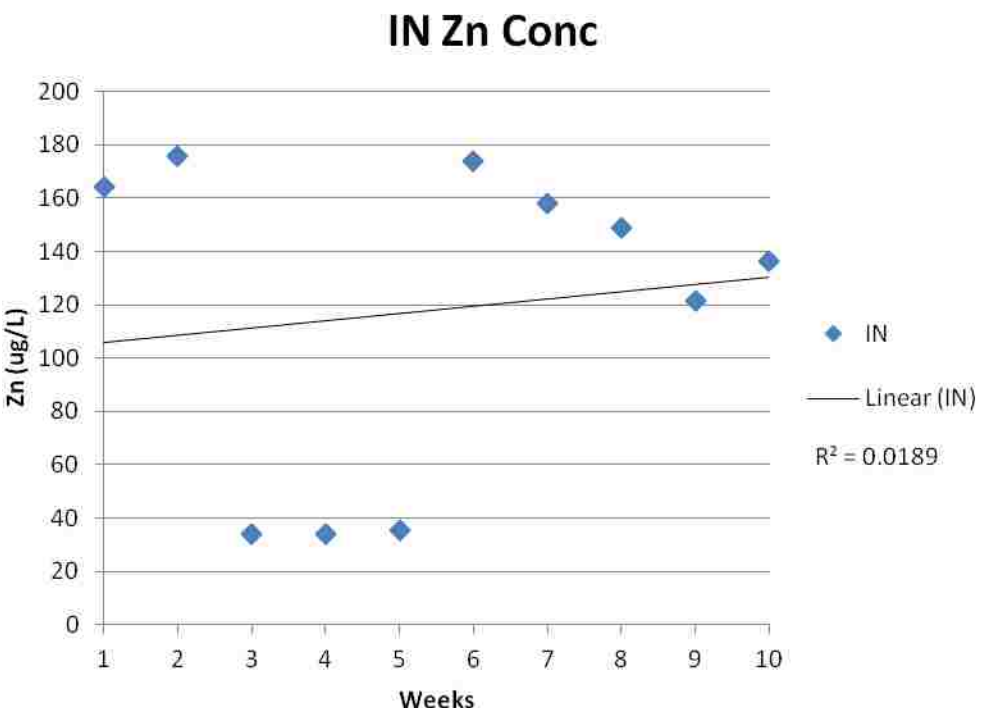

SR Zn % Eff
200.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1200.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.0097

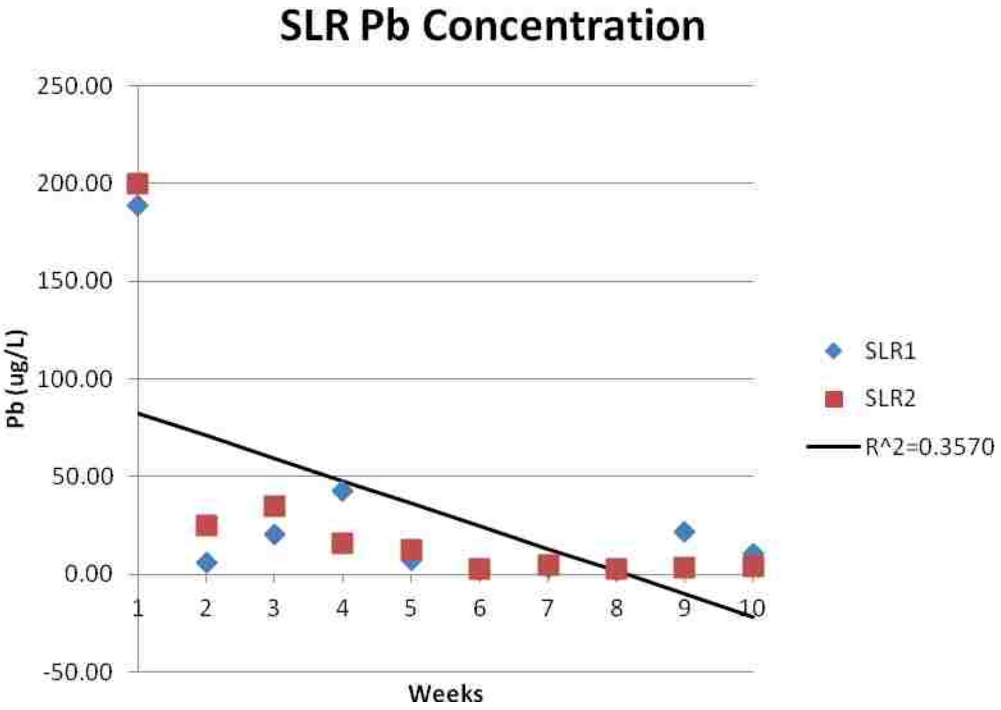

CR Zn Concentration
1400
1200
1000
800
600
400
200
0
Zn (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.6588

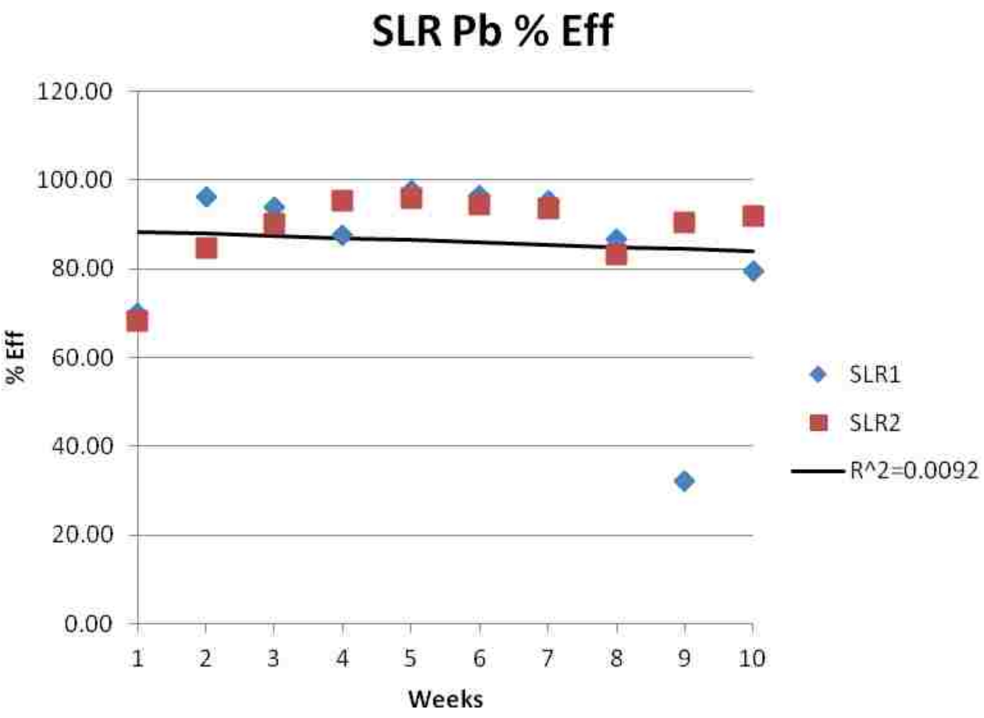

CR Zn % Eff
200.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
-1600.00
-1800.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.3566

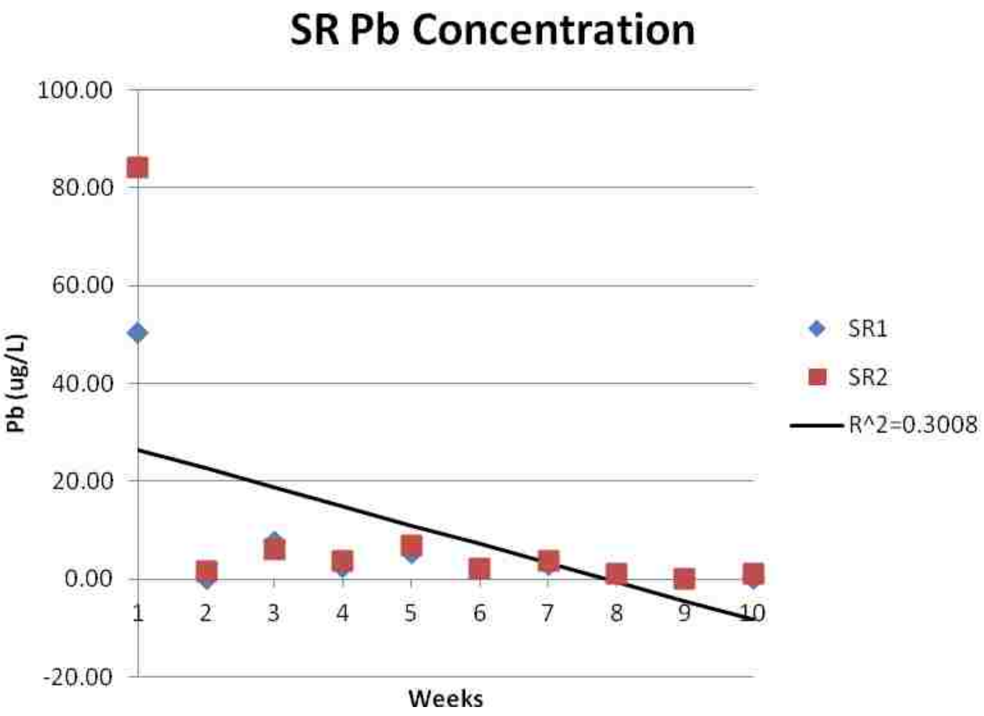

R Zn Concentration
Zn (ug/L)
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.0035

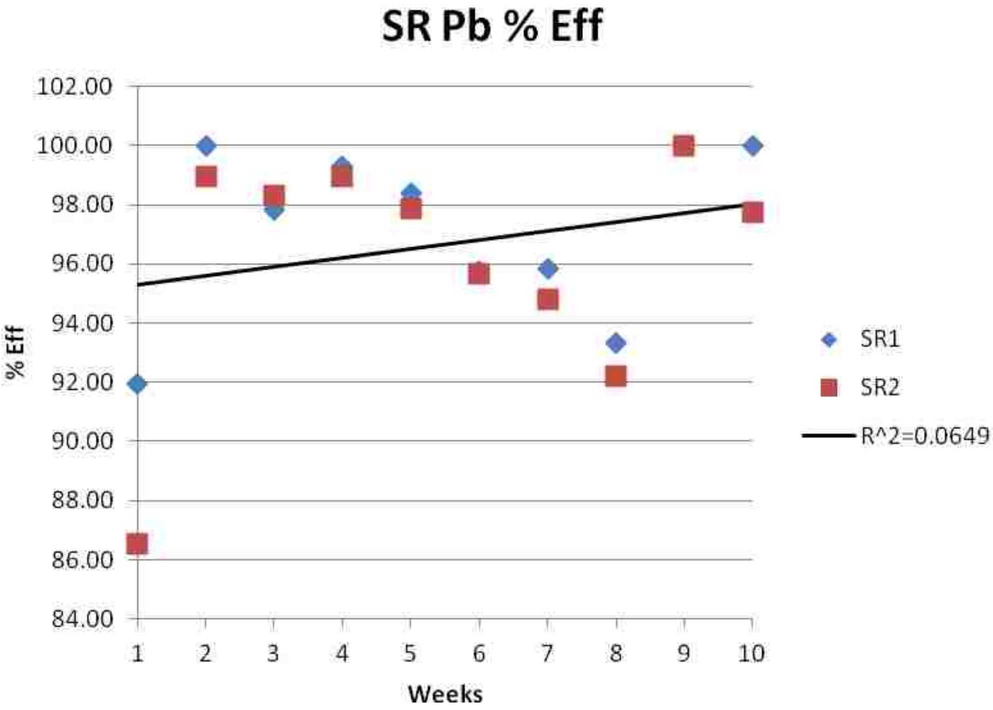

R Zn % Eff
% Eff
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1200.00
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.0777

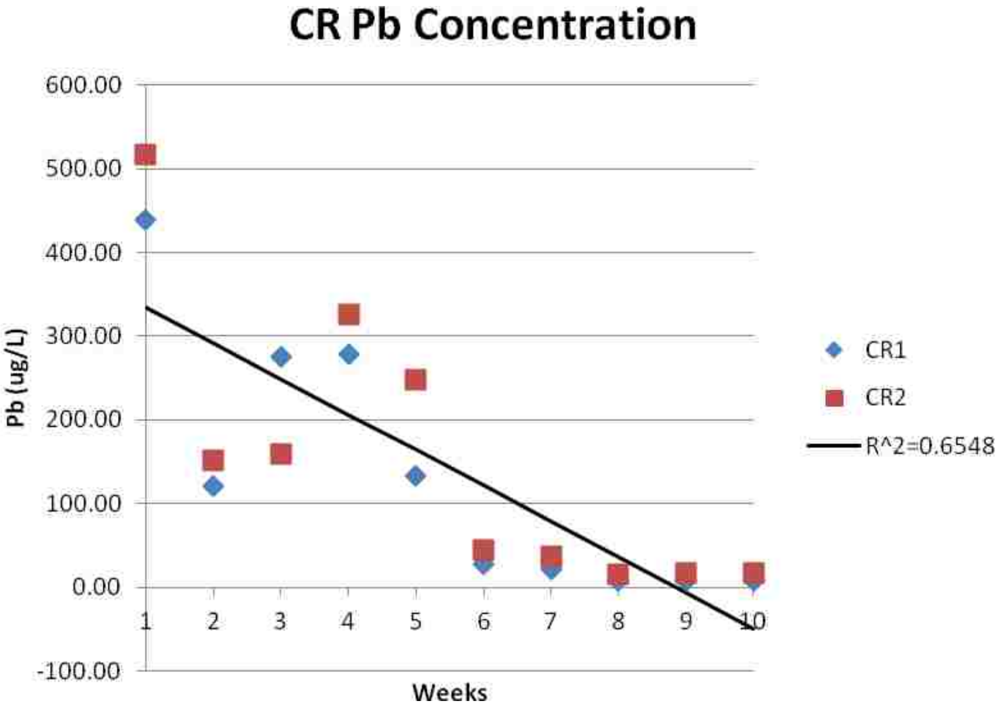

IN Zn Conc
Zn (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
Weeks
IN
Linear (IN)
R² = 0.0189

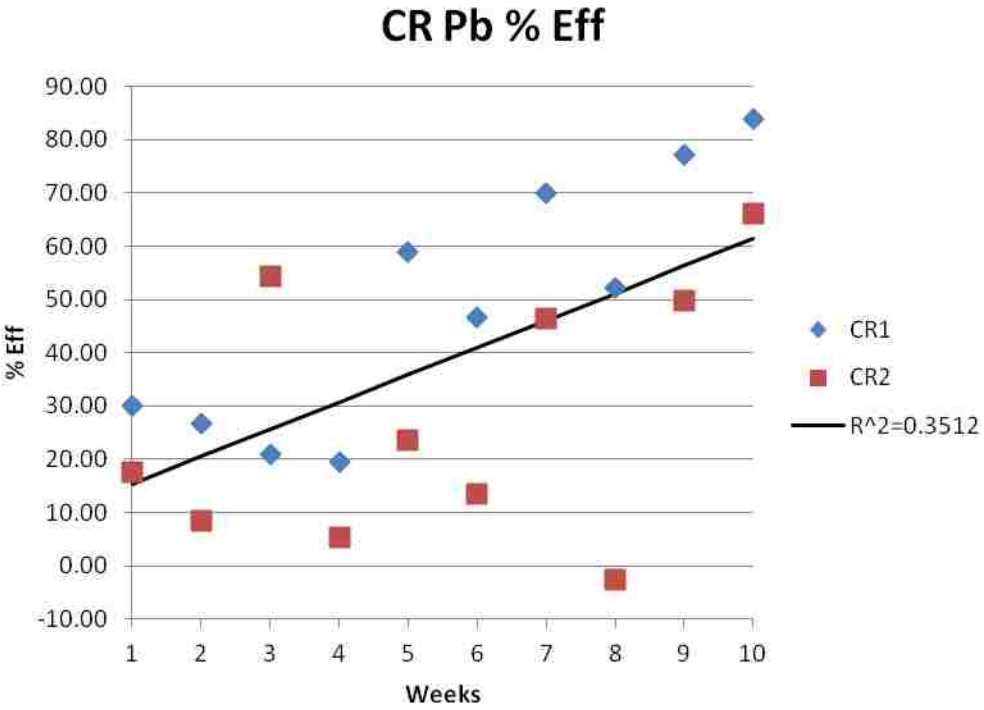

SLR Pb Concentration
Pb (ug/L)
250.00
200.00
150.00
100.00
50.00
0.00
-50.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.3570

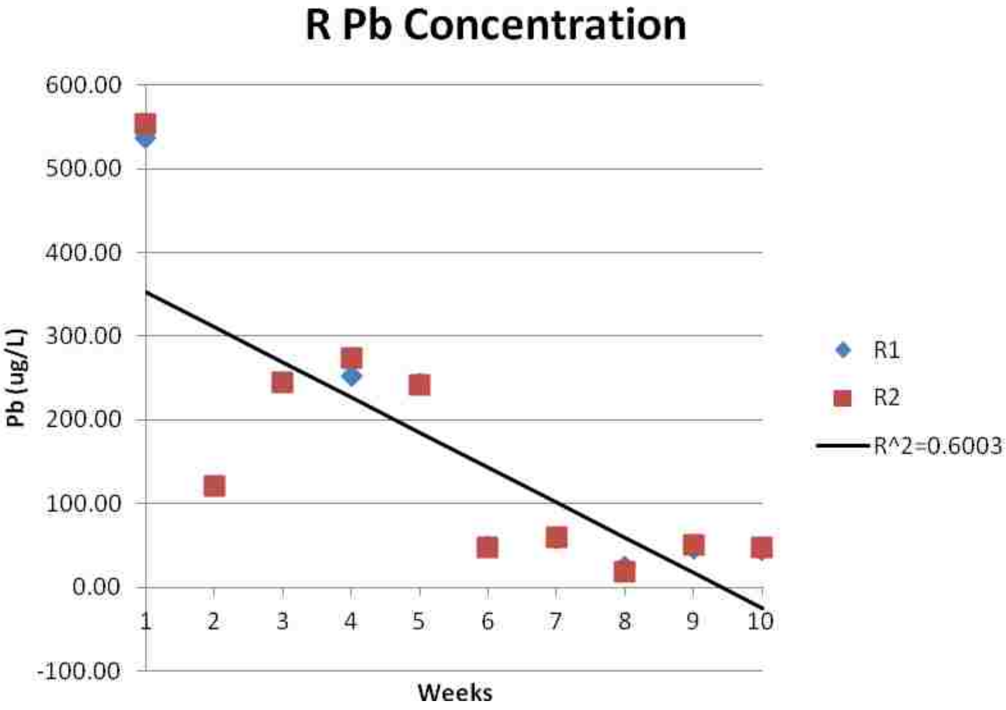

SLR Pb % Eff
120.00
100.00
80.00
60.00
40.00
20.00
0.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.0092

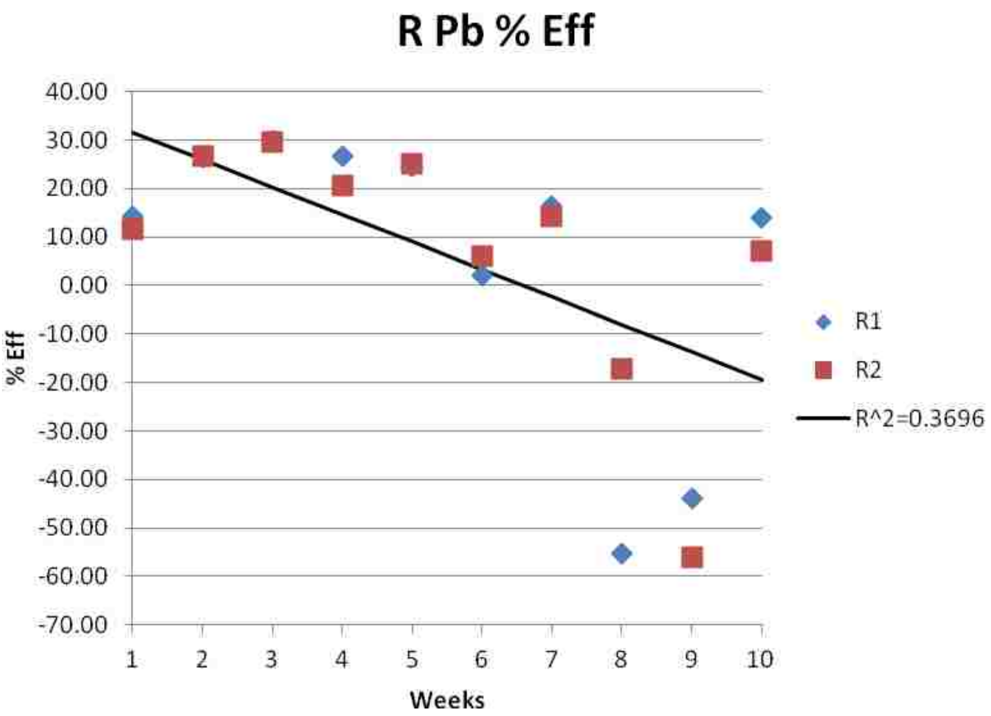

SR Pb Concentration
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
Pb (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.3008

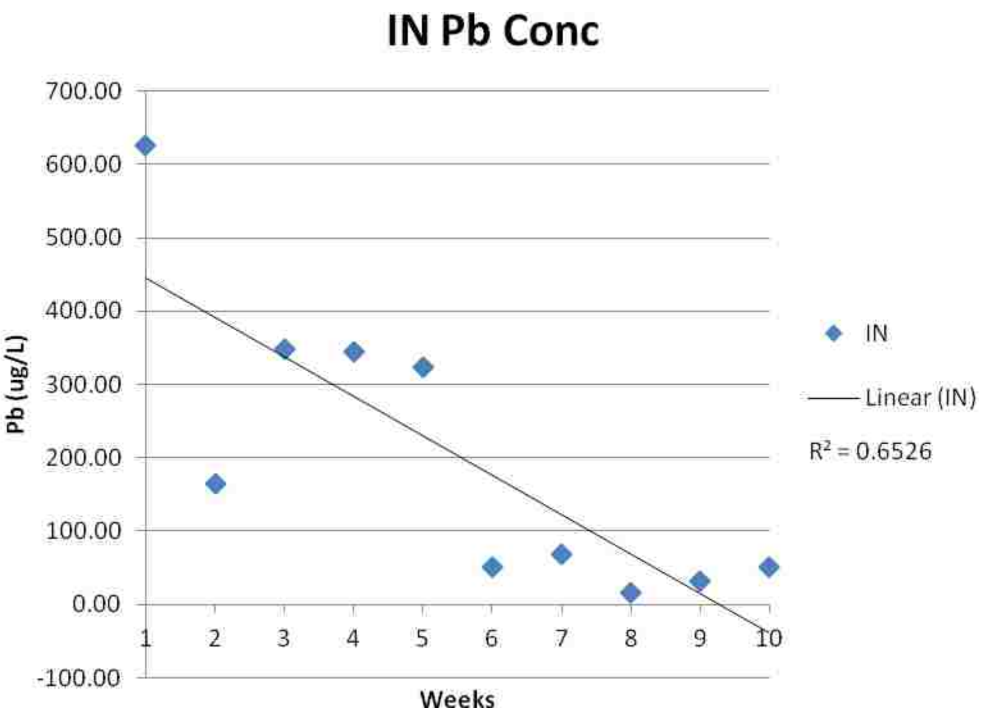

SR Pb % Eff
102.00
100.00
98.00
96.00
94.00
92.00
90.00
88.00
86.00
84.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.0649

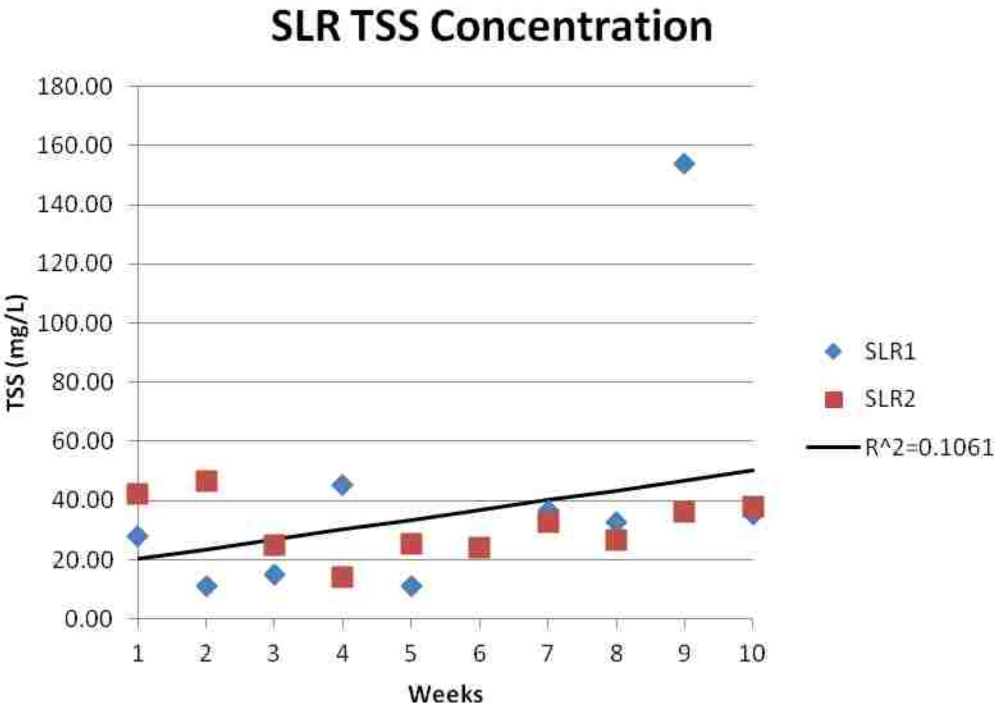

CR Pb Concentration
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
Pb (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.6548

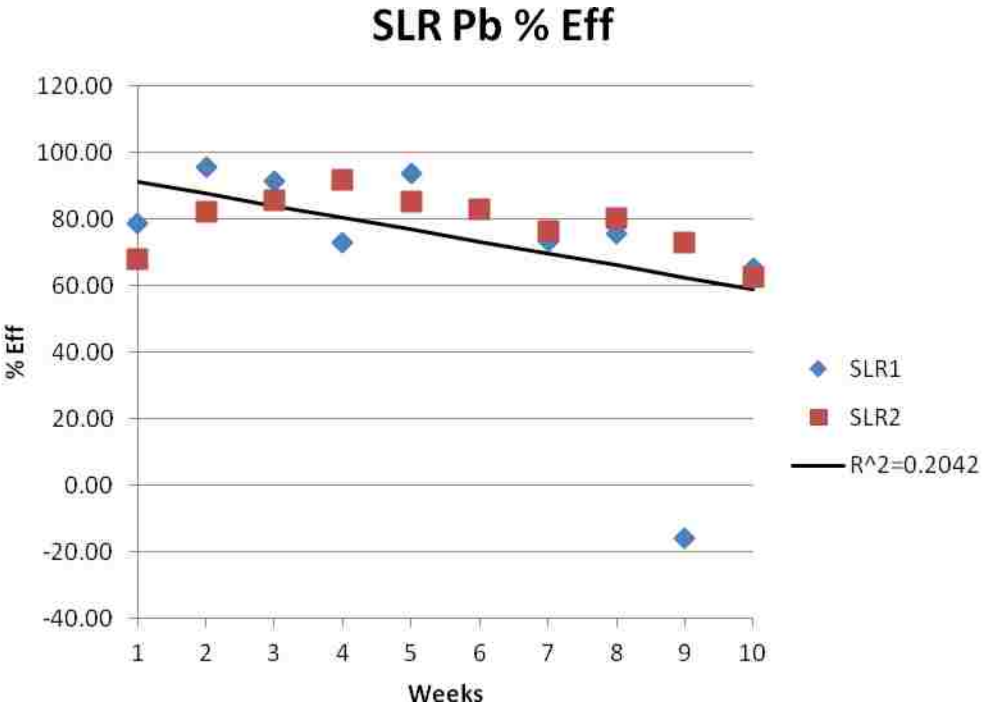

CR Pb % Eff
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.3512

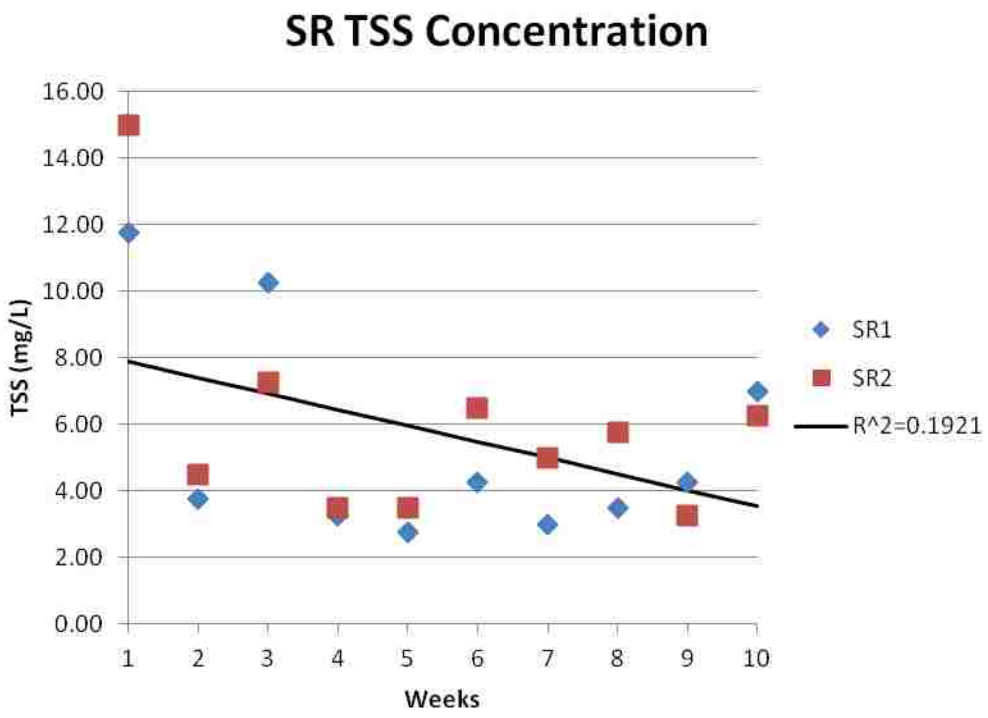

R Pb Concentration
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
Pb (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.6003

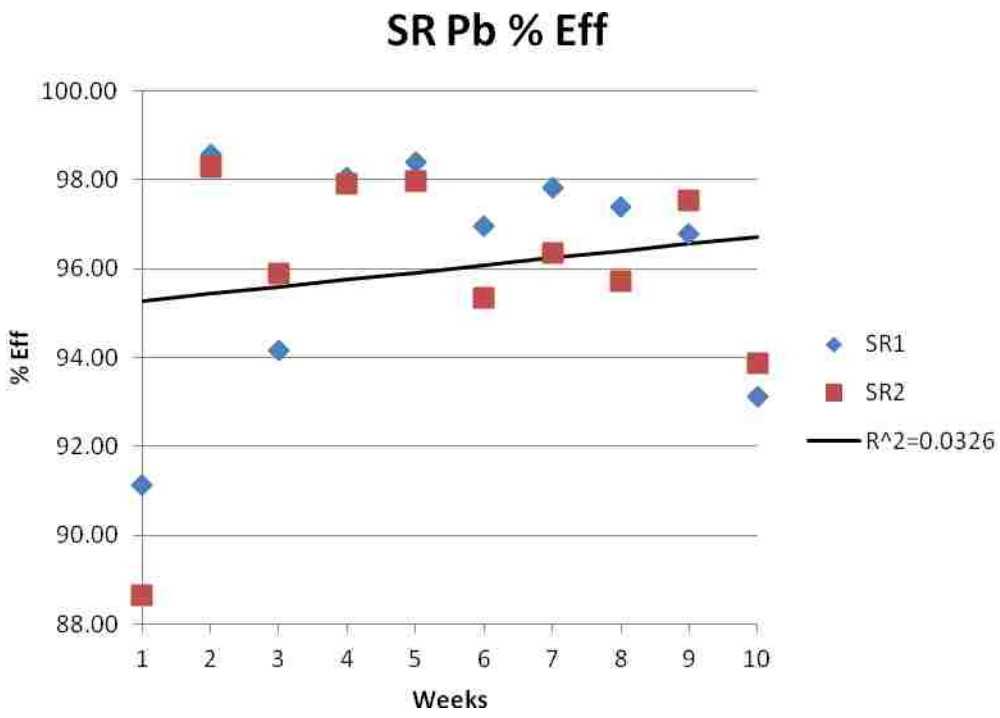

R Pb % Eff
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
% Eff
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.3696

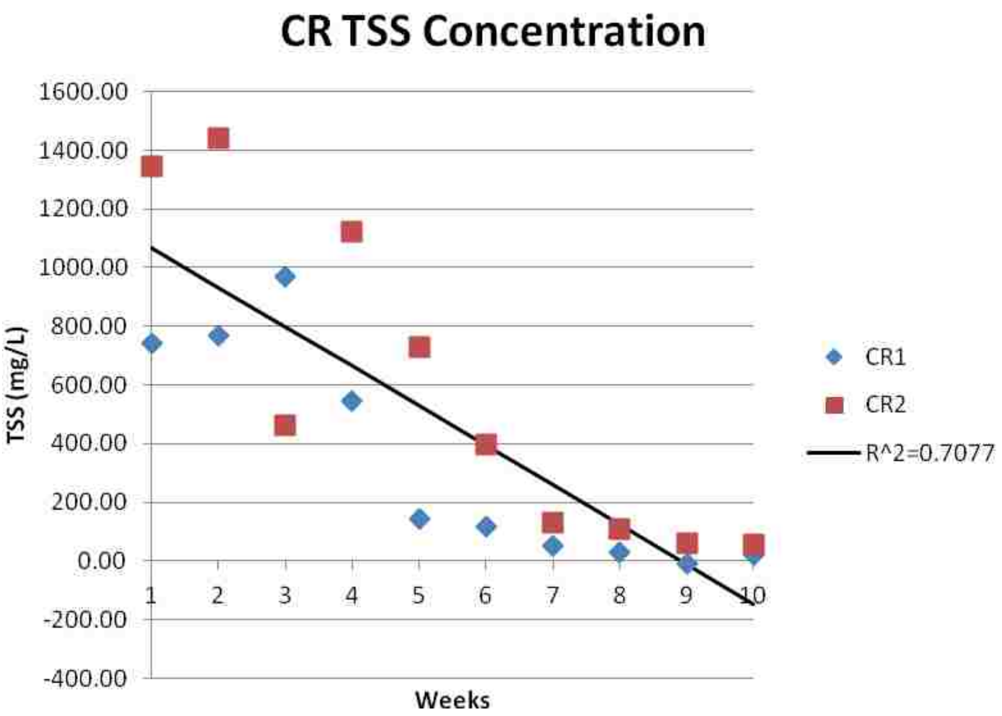

IN Pb Conc
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
Pb (ug/L)
1
2
3
4
5
6
7
8
9
10
Weeks
IN
Linear (IN)
R² = 0.6526

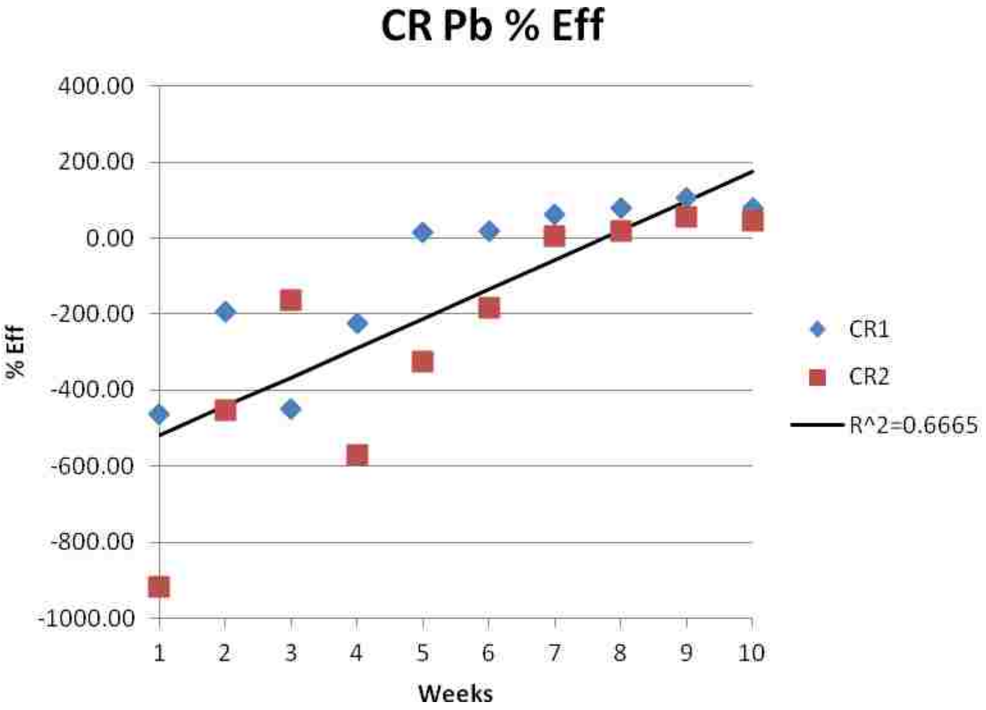

SLR TSS Concentration
TSS (mg/L)
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.1061

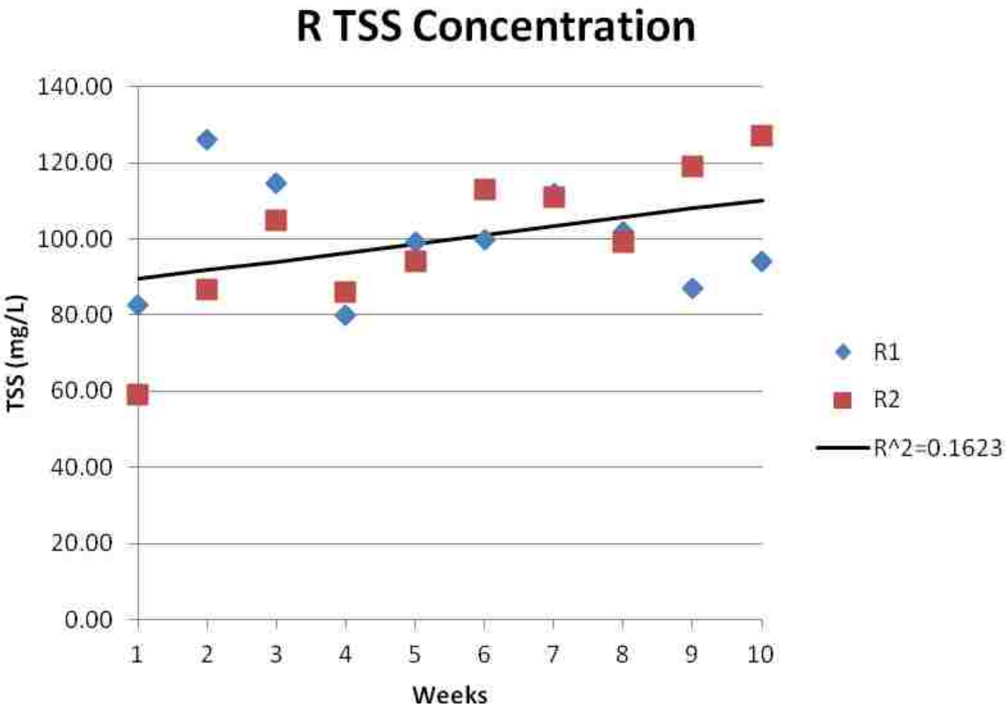

SLR Pb % Eff
% Eff
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
1
2
3
4
5
6
7
8
9
10
Weeks
SLR1
SLR2
R^2=0.2042

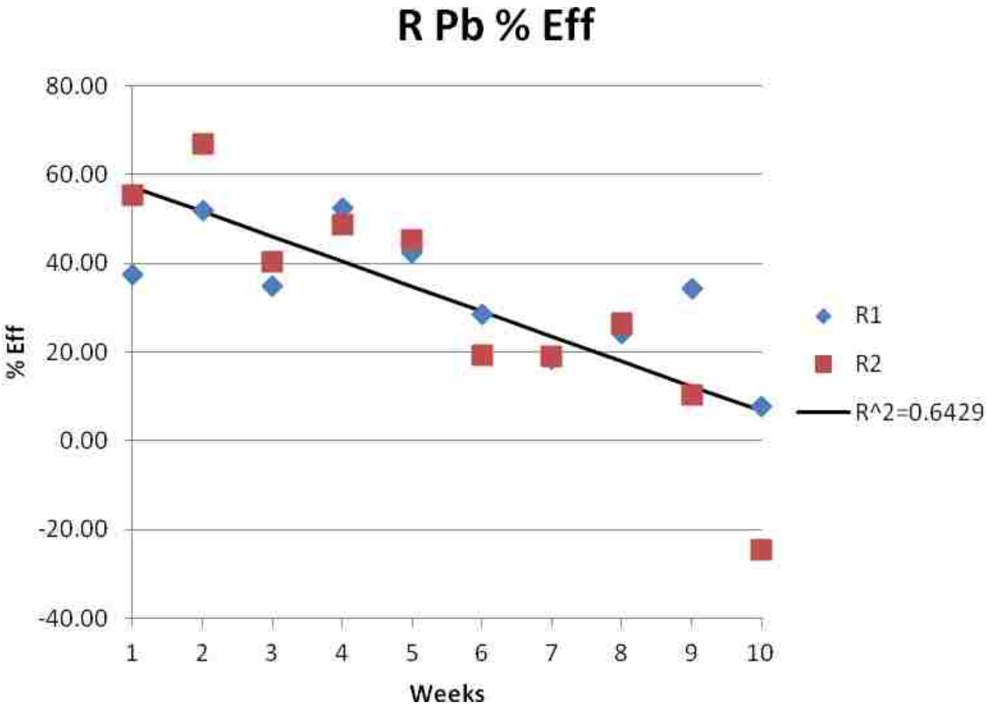

SR TSS Concentration
TSS (mg/L)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.1921

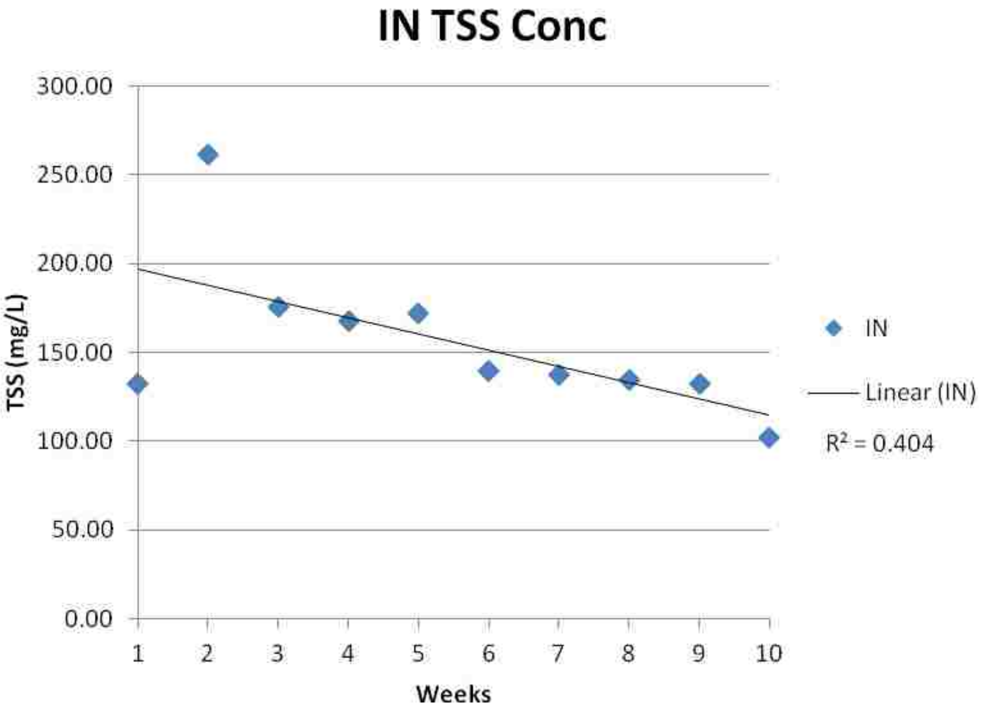

SR Pb % Eff
% Eff
100.00
98.00
96.00
94.00
92.00
90.00
88.00
1
2
3
4
5
6
7
8
9
10
Weeks
SR1
SR2
R^2=0.0326


CR TSS Concentration
TSS (mg/L)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-200.00
-400.00
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.7077


CR Pb % Eff
% Eff
400.00
200.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
1
2
3
4
5
6
7
8
9
10
Weeks
CR1
CR2
R^2=0.6665


R TSS Concentration
TSS (mg/L)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.1623


R Pb % Eff
% Eff
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
1
2
3
4
5
6
7
8
9
10
Weeks
R1
R2
R^2=0.6429


IN TSS Conc
TSS (mg/L)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1
2
3
4
5
6
7
8
9
10
Weeks
IN
Linear (IN)
R² = 0.404