Compacted Greenspace and Stormwater Hydrology in Burlington, Vermont:
An analysis of 3 remediation treatments for compacted soils and a comparison of stormwater from two small urban catchments.

A Thesis Presented

By

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Abstract

From May through November, 2002, I monitored experimental test plots to compare different techniques for remediating compacted soil. I completed three rounds of testing during which I simulated runoff, measured suspended sediment production, and collected runoff samples for dissolved elemental analysis. The test plots revealed that steady-state infiltration rates could be increased by as much as 10 times, from 1.5 cm/h to 15cm/h, by treating compacted soils with aeration, compost, grass seed, and isolation from further compaction. This method of remediation reduced suspended sediment production from 34 (g/m^2)/ (cm of rainfall) to less than 0.5 (g/m^2)/ (cm of rainfall).

Stormwater flow was measured and samples for chemical analysis were collected from weirs constructed at the outflow of two small drainage basins in Burlington, Vermont: Perkins Parking lot (4800 m^2) and Brookes Avenue (900 m^2). Two storm events were sampled in September, 2002: a 1 hour, 0.81cm, precipitation event on 9/11/02 and a 12 hour, 6.58cm, storm. The Perkins basin has approximately 85% impermeable cover. The Brookes Avenue basin has approximately 75% impermeable cover. Storm water discharge responded rapidly to variations in rainfall. Conductivity showed dilution over time in both basins and during both storm events. Elemental analysis of Ag, Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, P, Pb, Si, Sr, and Zn showed that at least 8 of the EPA's priority pollutants are present within runoff from the two basins. Pb was found in excess, 0.015 to 0.033 ppm, of the EPA's MCL in the runoff of both basins during the long-duration storm. The lead MCL was exceeded for 20 and 60 minutes at the Perkins and Brookes basins, respectively. Concentrations of all elements were highest in the initial samples collected during the storm events. Dissolved element loading estimates suggest that contaminant sources are different between the two drainage basins. Higher normalized loadings were seen for the short-duration storm event. Brookes Avenue had more intense loadings of K, Na, P, Pb, and Zn while Perkins Parking lot contributed more intense loading of Al, As, Ca, Cr, Cu, Fe, Mg, Ni, Si, and Sr.

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Chapter 1

Introduction

Some neighborhoods in Burlington, Vermont have lost a significant amount of greenspace within the past few decades, up to 50% between 1978 and 1999 (Nichols et. al, in press). This loss of green space is a result of landlords and tenants converting lawns into informal and formal parking areas. Replacement of permeable greenspace (lawns) by informal and formal parking areas (pavement and compacted soil) has important effects on the urban hydrologic cycle and in many cases violates Burlington zoning laws (geology.uvm.edu/morphwww/urbanhydro/paulm/urbanhydrohomepage.html).

Impermeable land cover significantly influences the urban hydrologic cycle, causing increased storm peak discharges and contaminant transport capacities (Dennison, 1996); however, water chemistry and flow characteristics from areas where urban runoff originates are not well quantified. My study attempts to understand, hydrologically, how small urban catchments respond physically and chemically during storm events. I also use experimental plot data to address ways to remediate greenspace damaged by compaction and thus improve stormwater quality and decrease stormwater runoff.

My research consists of two main components. One component involved the direct measurement of stormwater discharge and the collection of water chemistry samples from two small urban catchments in Burlington, Vermont, Brookes Avenue (920 m^2) and Perkins Parking lot (4820 m^2). These sites were sampled during two storm events in September 2002. My research reveals characteristics and differences in stormwater runoff volume and dissolved chemical loading between the two drainage basins and two sampled storm events. The second component of my research examined changes in water quality and steady state infiltration rates over three rounds of simulated rainfall testing on eleven remediation test sites on the University of Vermont campus. These test sites included three variations in remediation treatments: fencing, aeration, and aeration with composting. This research shows how different remediation methods compare in terms of suspended sediment production, steady state infiltration rates, and runoff chemistry. My two research foci are significant because they provide basic knowledge about stormwater characteristics and non-point source chemical loading in small urban source catchments and because they suggest effective ways to remediate compacted greenspace for the purpose of improving stormwater quality and reducing stormwater flow.

Literature Review

Characterizing the Urban Runoff Problem

Many professionals in the civil/environmental engineering fields have been concerned with stormwater drainage and pollutant loading in urban areas for quite some time (e.g., Helliwell, 1978). Historically, they have been asked to deal with increased storm water runoff from impervious land and the resulting problems of flooding, stream erosion, and habitat destruction. More recently, engineers and environmentalists have been dealing not only with the control of stormwater quantity, but also with stormwater quality. Urban stormwater runoff is contaminated with heavy metals, pesticides, and nutrients from sources including transportation systems, industrial activity, soil erosion, animal waste, fertilizer and pesticide application, dry fall, and urban litter (Whipple, 1983). Increased stormwater flow and contamination, associated with urban development, causes significant degradation to sensitive water bodies (Booth and Jackson, 1997). In

1977, the Clean Water Act established the Nationwide Urban Runoff Program to asses the nature and cause of urban runoff and its effects on surface and ground water (Driver and Tasker, 1990). Since that time, the USGS, EPA and academics have done much research in order to determine the extent to which urban runoff affects water quality and to provide means to control this problem.

Water Quality Issues in Burlington, VT

The Lake Champlain Basin Program maintains a web page (http://www.lcbp.org/) dedicated to education about the problem of pollution in the Lake Champlain Basin. They clearly identify the problems that I address in my research:

> As recently as 20 years ago, the Basin experienced serious water pollution and public health problems from the discharge of untreated sewage and wastes. Since then, water quality has improved as a result of required industrial waste treatment, and a large investment of state, federal, municipal and private funds for sewage treatment facilities. However, additional clean-up must also address non-point source runoff from urban and agricultural areas. Non-point source runoff can include pollutants such as nutrients, low levels of persistent toxic substances, and pathogens.

The Lake Champlain Basin Program (LCBP) also identifies Burlington Bay as one of three areas of high pollution concern within the Champlain Basin. They have identified high concentrations of lead, zinc, silver, arsenic, cadmium, chromium, nickel, and copper (all contaminants which I address in this study) within the sediments of Lake Champlain. Other contaminants of concern within the basin, which I do not address, are mercury, organic chemicals such as hydrocarbons, PCB's, and pesticides, as well as fecal coliform, and nutrients such as nitrate. All of these contaminants contribute to such negative effects as contaminated fish, toxic algal blooms, polluted beaches, and impaired drinking water quality. Stickney et al. (2001) point out the prevention and the control of non-point source toxic substances entering the lake as one of the LCBP's top priorities in the near future. Clearly, research such as mine will add to the growing knowledge about where these non-point source substances originate.

Toxic algal blooms, contaminated fish, and reduced water quality leading to Burlington beach closings have raised concern within the community of Burlington about the Bay's health for recreational use of the lake and its shore line. The School of Natural Resources, at the University of Vermont, is leading a study called the Burlington Bay Project (http://snr.uvm.edu/bbay). They are monitoring flow and water quality at several stormwater outflows (including Engelsby Brook and the College St. Drain) from Burlington into Lake Champlain. They collect data to address some of the key concerns raised by the public in recent years that have centered on impacts such as the growth of zebra mussels and the presence of toxic contaminants in the Bay's sediments and how this may affect the Bay's ecological health.

Loss of Greenspace in Burlington, VT

Several undergraduate and graduate students at the University of Vermont have worked to characterize the loss of greenspace in Burlington, Vermont. Kurfis and Bierman (2001) quantified the increase in impermeable land surfaces through time for 192 properties in Burlington's Hill Section neighborhoods. They used high-resolution, low-altitude aerial orthophotographs taken by the State of Vermont in 1978 and 1999. Using these images, they identified and mapped 5 land use categories: buildings, formal (paved) parking areas, informal (unpaved) parking areas, sidewalks, and greenspace. Their study showed that in 1978, land-use distribution of greenspace in the study area was similar (64%) to that mandated by the 1973 zoning requirements of 65% greenspace.

Despite the enactment of zoning controls in 1973, significant and ongoing losses of greenspace since 1978 reduced the overall neighborhood greenspace to 59%. Their study also pointed out that greenspace on rental parcels fell below 50% while on owner-occupied properties; greenspace remained at the mandated zoning levels. Paul Mellilo (2002) continued the work of Kurfis and Bierman in Burlington, mapping land use change for 52 properties on Buell, Lomis, and Willard Streets. This was done with aerial photographs from 1962, 1978, 1988, and 1999, digitizing, and field checking current land use characterizations. Mellilo was also the first to use the runoff simulation tests that were employed in this remediation study. He used these tests to show differences in the permeability between the types of land use found in Burlington neighborhoods.

Nichols et al. (in press) summarized greenspace loss data for Burlington neighborhoods showing that some had lost up to 50% of their permeable land. They suggested that informal and formal parking areas had nearly 100% runoff during long, intense storm events and that greenspace loss could have lead to an overall increase in stormwater flow during large events of between 20 and 30% over the last 20 years. This calculation was based upon land use changes occurring between 1978 and 1999.

Loss of greenspace is not a problem unique to Burlington. Wije, of the department of Geography at the University of Texas Austin, discusses the loss of greenspace in the city of Austin through the granting of minor variances in zoning laws, showing that in one year (1996) over 4 acres of greenspace was lost through the grant of minor variances (http://www.utexas.edu/depts/grg/ustudent/gcraft/fall96/wije/projects/zoning.html).

Stormwater flow and quality over impervious land

There is an empirical link between increases in stormwater volumes and the increase in the percentage of impervious land cover over a drainage basin. Mulvany (1851) developed the first fundamental equation for predicting runoff, the rational runoff equation, which relates runoff rate to the product of the rate of rainfall, the basin area, and the runoff coefficient (a number expressing the fraction of the rain falling which contributed to the peak flow). Since Mulvany's time, research has made many improvements to this equation. Differences in land cover have been associated with different runoff coefficients, allowing stormwater flow to be estimated in a much more reliable manner. These models, as well as deterministic studies, have shown that increases in impermeable land cover (urbanization) will result not only in increased storm peak discharges, but will also result in the generation of runoff during small hydrological events which previously did not produce runoff (Booth, 1991).

What has been less clear is how pollutant loadings vary by different land covers. There has been much research in this area, but with a seemingly unlimited number of variations in drainage basin characteristics, it is difficult to provide a general model for non-point source pollutant loading. To develop such a model, which could predict stormwater pollutant loading, deterministic studies need to be tested repeatedly, to observe how variations in land use and land cover as well as other basin variations relate to pollutant loadings. Deterministic methods, like my research, involve direct measurements of runoff volumes and water quality, relating observations back to the drainage basin's parameters. Model-based studies use the basin parameters to estimate runoff volumes and contaminant loadings based upon regression coefficients for the drainage basin attributes (Nix, 1994).

In 1990, Nancy Driver and Gary Tasker of the USGS published a water supply paper describing the development of four linear regression models for estimating storm-runoff constituent loads, storm-runoff volumes, storm-runoff mean concentrations of constituents, and mean seasonal or mean annual constituent loads from physical, land use, and climatic characteristics of urban watersheds in the United States. The data used to create this model came from many deterministic studies conducted around the country by the National Urban Runoff Program (NURP) that was started under the Clean Water Act of 1977.

Another research group, headed by Budhendra Bhaduri (2000), developed and used a Geographic Information System model for assessing watershed-scale, long-term hydrologic impacts of land use changes. They applied their model to Little Eagle Creek near Indianapolis, Indiana using three historical land use scenarios from 1973, 1984, and 1991. Their model showed that urban areas produced more metal pollution and less nutrient contamination than agricultural areas, and overall urbanization resulted in increased runoff volumes and metal loading. These types of models provide techniques for making storm-runoff volume and constituents estimates where little to no data exists; thus, they are important for urban planners and managers under budget constraints.

Urban runoff carries elevated concentrations of toxic substances including lead and other heavy metals with sources including building materials, pesticides, and transportation infrastructure (Whipple, 1983). Exact sources for specific toxins are hard to pinpoint, hence the term non-point source pollutants, but tracing can be done by conducting chemical source studies. A study in New Orleans found that lead concentrations are particularly elevated in the runoff from the roofs and walls of buildings (Steinberg, in progress). Larger-scale deterministic studies can help to determine what chemicals are of concern for a small drainage basin. One such study, by Zartman et al. (2001), assessed the variability of total and dissolved elements in urban stormwater runoff in Lubbock, Texas. They studied concentrations of elements of concern within runoff-fed playa lakes over 32 months beginning in December, 1991. Their data showed that urbanization resulted in a greater frequency of runoff events that fed these lakes and increased runoff volumes generated during precipitation events. The majority of the elements which were analyzed and considered hazardous to human health, such as As, Cd, Cr, Cu, Hg, Pb, and Zn, appeared within the stormwater-fed playas; however, the concentrations of these contaminants were relatively low.

Zartman et al. also determined that variations in some contaminant concentrations could be linked to the natural and anthropogenic processes which occur at different times of the year. They concluded that higher concentrations of Al, Mg, and Ca in the winter, spring, and summer were related to greater eolian transport of clays during those seasons as compared to the low concentrations of these elements in the fall when eolian activity is lowest in Lubbock. Also, as is associated with herbicides and Zartman noted high As concentration in the spring when herbicides are applied. Typical contaminant concentration data from this research and that from selected tables from the Results of the Nationwide Urban Runoff Program (1982) enable me to put my chemical concentration data into perspective (Tables 3.4 and 3.5).

Compacted soils, traffic, tillage, and compost

Soil compaction is a common problem in urban drainage basins. Compaction of soils contributes to the high percentage of impermeable land in urban areas, which increases stormwater flow over these drainage basins (Booth and Jackson, 1997). Heavily trafficked, compacted soil is a relatively large producer of suspended sediment; heavily used dirt roads produce 100% more suspended sediment than paved roads (Reid and Dunne, 1994). Non-urbanized areas are able to buffer increased runoff flow and suspended sediment production over small areas of compacted soils (trails and small dirt roads) because the surrounding parts of these basins are highly permeable (Harden, 1992). Urban drainage basins have very few areas of highly permeable land (greenspace) so there is little area that can buffer increased stormwater runoff volumes and the associated constituents.

Soil compaction and disturbance are well-studied processes in agriculture and water research. Reid and Dunne, (1994), noted that a heavily used dirt road produced more than 130 times the amount of suspended sediment than an abandoned dirt road; suggesting the role of traffic in causing erosion and the production of easily eroded sediment. Studies on the effect of tilling agricultural soils reveal that bulk densities are quickly reduced over tilled soils (Richard, 2001); however, recently tilled soils have a lower hydraulic conductivity than untilled soils. This is because of the destruction of pore structures (Coutadeur, 2002). Passioura (2002) noted that plant growth could be slower over highly aerated soils because root-soil contact may not be well established in excessively loose soil. However, pore spaces are quickly re-established with the settling of the soil, growth of vegetation, and movement of biota such as earthworms. Clearly the comparison in this study is not between highly compacted urban soils and tilling, but this information is useful for understanding a soil's initial response to tilling.

Robert Pit and the EPA (1999) conducted a large study on the permeability of compacted urban soils and the response of these soils with amendment by aeration (30cm) and composting (12cm). The results of this study showed that aeration and composting these sites increased infiltration rates ten fold and the sites were more aesthetically pleasing with very healthy grass growth. The one negative seen from this study was an increase in the production of the nutrients nitrogen and phosphorus (5 to 10 fold) in the runoff from compost amended sites. However, concentrations of these nutrients reduced over time and the increase in nutrient concentrations was balanced by the decrease in total runoff. The authors conclude that compost clearly has a net positive remediation effect, but further research is needed to understand how much compost will maximize the benefits.

Research Setting

Municipal and Meteorological Setting

My study area included Brookes Avenue, the Perkins Parking lot, and 4 remediation sites located around the main campus of the University of Vermont in Burlington, VT (Figure 1.1). Burlington's population is nearly 40,000 people. Considering the 140,000 people living within the metropolitan area of Chittenden County, this is the most urban area within Vermont (Encyclopedia Britannica, 2003).

Prior to my first stormwater sampling event, September 11th, 2002, Burlington had been very dry. The previous precipitation event occurred two weeks prior to

September 11th, on August 29th, depositing 0.71 cm of rain in Burlington. From August 29th through September 10th, Burlington had been very warm with high temperatures ranging from 21 to 36 degrees Celsius; conditions had also been breezy during this time period with average daily wind speeds from 6 to 19 kilometers per hour. Over the entire month of August, only 2.95 cm of rain fell on the City, less than one third the monthly average (10.19 cm). My second stormwater sampling event was on September 27th, 16 days after the first. Over these 16 days it had rained 7 times totaling 7.69 cm (http://www.erh.noaa.gov/btv/html/climo2.shtml).

Brookes Avenue Drainage Basin

The Brookes Avenue weir site drains approximately 920 m^2 of land on the north side of Brookes Avenue (Figure 1.1, 1.2, and Table 1.1). To the south, it is constrained by the road crown of Brookes Avenue. Up the hill from the Brookes outflow (to the east), the drainage is constrained by the crowns of North Prospect Street and Brookes Avenue as they intersect. The north side of the basin is constrained by a ridge that closely follows the Brookes Avenue sidewalk until it reaches the second house down the hill (98 Brookes). At this point, the Brookes Avenue drainage boundary extends onto the southward facing portions of the next two houses. After the third house down the hill (92 Brookes), the basin boundary turns back toward the weir site, crossing the sidewalk and completing the basin's boundary.

The Brookes Avenue basin includes 6 plots of greenspace; three of which exist between the sidewalk and the road and three of which are portions of residents' front lawns and flower gardens. These 6 green space plots cover an area of 228 square meters, suggesting that the Brookes Avenue drainage basin is approximately 25% permeable (Figure 1.2 and Table 1.1). The remaining 75% of the Brookes Avenue drainage basin is covered by relatively impermeable driveways, sidewalk, rooftops, and roadway.

Perkins Parking Lot Drainage Basin

The Perkins Parking lot weir site receives drainage from approximately 4820 m^2 of land (Figure 1.1, 1.3 and Table 1.2). The drainage comes primarily from the south and to the west of the outflow. The eastern boundary of the basin runs south along the curbing next to the weir and then across the parking lot entrance, following the crown of the pavement, until reaching the next curb which again bounds the drainage. The drainage follows this curbing and then the east lawn of Perkins Hall until that lawn ends at the edge of the Perkins building. Drainage then is controlled by the slopes of the Perkins roof top. The eastern boundary ends as drainage comes off the roof top above the main Perkins entrance and is then controlled by a ridge near the Perkins entrance. Water that falls to the west of the ridge slopes into the parking lot from the Perkins Hall entrance.

To the south, the basin is bounded by Votey Hall, continuing around the west side of Votey to the west Votey entrance. The sidewalk leading to the west Votey entrance crowns such that water to the north flows into the Perkins drainage and water to the south does not. The crown turns north forming the western boundary of the Basin. This ridge runs through the grass between Votey and Billings Student Center and crosses two paved walking paths. It then runs over the Torrey remediation plot and over the Torrey roof top following the roof slope.

Now, back in the Perkins Parking lot, water flows with the slope of the lot to the northeast, which is in the direction of the outflow and the weir. However, there is also a lower portion of the parking lot and its entrance receives some of the parking lot's water. From the orientation of dried salt deposits, I determined the diagonal drainage line that divides water to the east, which would flow to the Perkins weir, and water to the west that would flow into the lower lot. This drainage line ends at the curbing of the entrance to the lower lot and the basin boundary follows this curbing back to the weir in the northeast corner of the lot.

Within the Perkins Parking lot there is one storm drain located directly north of the Main Perkins building. This drain receives water from 234 square meters of land, which is primarily occupied by the Perkins Building. This drainage area is not included in the weir's drainage basin. Also, within the Perkins basin, there are 10 areas of permeable greenspace totaling 734 square meters indicating that the basin is about 15% permeable. The remaining 85% of the drainage basin is covered by paved parking lot, pathways and rooftops (Figure 1.3 and Table 1.2).

I observed several other hydrologically important characteristics within the Perkins Parking Lot drainage basin. First, behind the Perkins building there is a semi-permeable (dirt and gravel) parking lot that slopes north into a large grassy area before reaching the Perkins weir outflow. Second, there are several isolated ponding areas near the south end of the Perkins Parking Lot. These puddle areas act as detention storage sites for a significant amount of the Perkins runoff. Several other areas within the Perkins drainage area are potential detention storage sites, including areas isolated behind parking lot curbing and rooftop puddles on Perkins. Another difference between the Perkins and

Brookes drainage basins is their slope. The Brookes basin has a steeper slope, approximately 0.038 (3.81 meters of vertical relief over 100 meters), than the Perkins Basin, approximately 0.033 (3.96 meters of vertical relief over 119 meters).

Campus Remediation Sites

Four campus remediation sites were identified at locations where high foot and/or university vehicle traffic had resulted in significant soil compaction: the north lawn of the Cook Physical Sciences Building and the southwest lawns of Old Mill, Fleming Museum, and Torrey Hall (Figure 1.1). The north lawn of the Cook Physical Sciences Building was severely compacted (Figure 1.4). This area slopes down and north, away from the building, to a campus bus stop. There are several paved walking paths that are adjacent to this site. The location of these walking paths and their indirect orientation to the bus stop resulted in the creation of several non-formal compacted dirt footpaths leading to the bus stop. At the bus stop, there was not enough paved waiting area for the volume of students who board the bus. Thus, many of the students were forced to wait and pace on the north lawn of Cook. When leaving the bus, at this stop, one must exit onto the green space and make a path through the greenspace to reach a formal walking path. The lack of paved walking paths from this bus stop resulted in the nearby greenspace becoming severely compacted; thus, it was selected for remediation.

I observed that the southwest lawns of Old Mill, Fleming Museum, and Torrey Hall were compacted in a similar manner and for similar reasons as the Cook site. At all three sites, compacted cut paths between walkways had resulted from a high volume of foot traffic. Furthermore, all three sites are located next to campus roadways. On several occasions at Torrey Hall, I observed university vehicles using the lawn as a parking space. On the southwest lawn of the Fleming Museum, I observed the loading and unloading of large Museum delivery trucks that must back into the loading dock. The current drive and curbing do not provide an adequate turning radius for these vehicles, so they impact the lawn. On the southwest facing lawn of Old Mill, there were tire tracks and plow cuts along the edges of the lawn.

Table 1.1
Brookes Avenue Drainage Basin Description

Feature	Perimeter (meters)	Area (Sq meters)
Brookes Drainage Basin	232	920
Green Space 1	34	45
Green Space 2	25	37
Green Space 3	58	12
Green Space 4	72	59
Green Space 5	76	59
Green Space 6	28	17

Total Area	**920**	sq meters
Greenspace Area	**228**	sq meters
Percent Greenspace	**25**	%

Footnote: Data were exported from ArcGIS, refer to Figure 1.1

Table 1.2
Perkins Drainage Basin Description

Perkins Feature	Perimeter (meters)	Area (Sq meters)
Topographic Drainage basin	334	5057
Drainage lost to the storm drain	80	237
Effective drainage basin	255	4820
Gravel Parking Lot	136	348
Green Space 1	24	28
Green Space 2	16	12
Green Space 3	59	119
Green Space 4	16	7
Green Space 5	90	215
Green Space 6	19	19
Green Space 7	33	35
Green Space 8	31	17
Green Space 9	34	58
Green Space 10	121	227

Total Area	**4820**	sq meters
Total Greenspace	**738**	sq meters
Percent Greenspace	**15**	%

Footnote: Data were exported from ArcGIS, refer to Figure 1.2

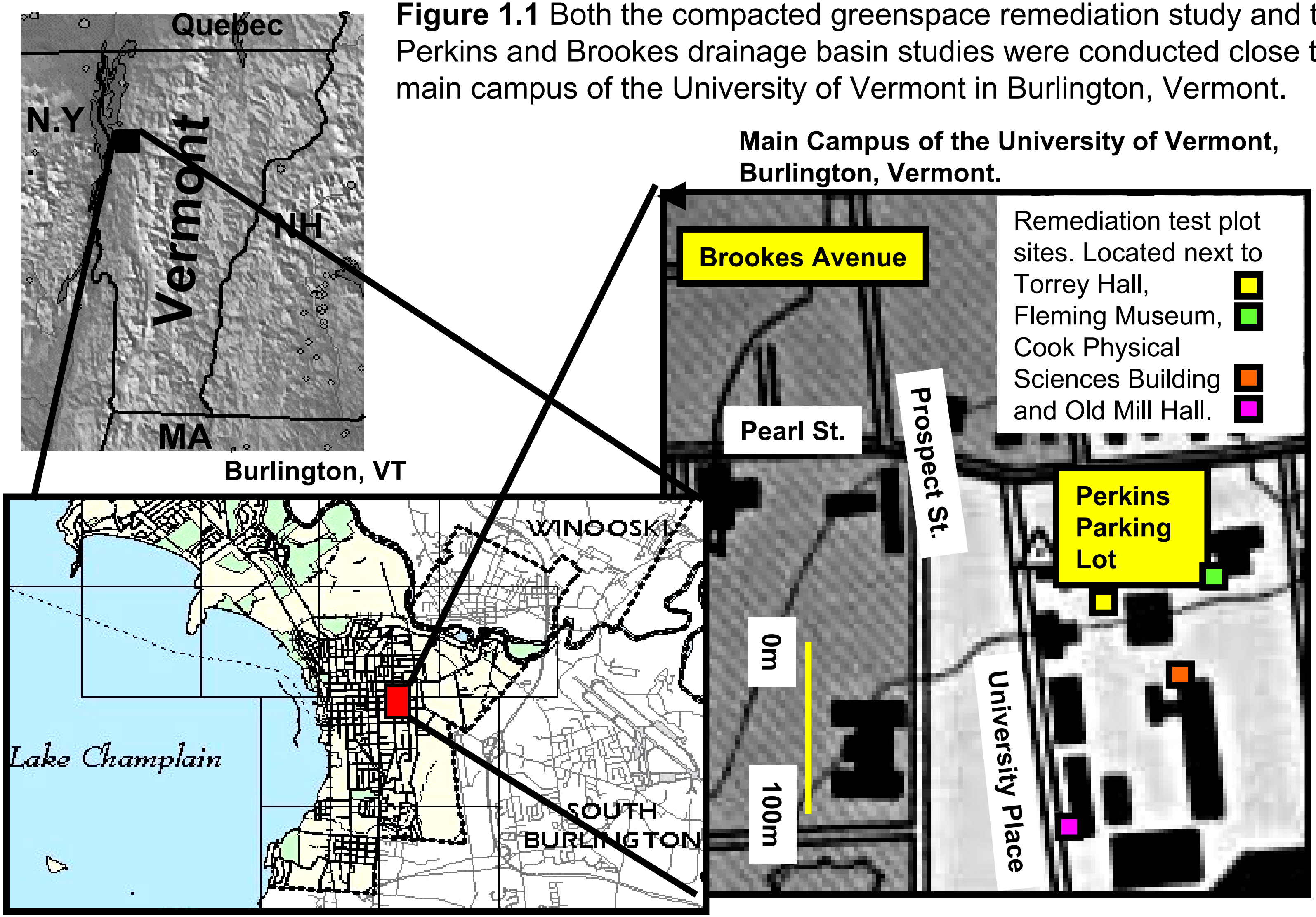


Figure 1.1 Both the compacted greenspace remediation study and the Perkins and Brookes drainage basin studies were conducted close to the main campus of the University of Vermont in Burlington, Vermont.

Figure 1.2: Brookes Avenue land cover and drainage basin delineation

Brookes Avenue Drainage Basin is 920 square meters. It is composed primarily of impermeable surfaces including the Brookes Avenue roadway, sidewalk, driveways, and portions of some buildings. There are 6 areas of greenspace covering 25% of the basin (Table 1.1).

Legend

● Storm Drain

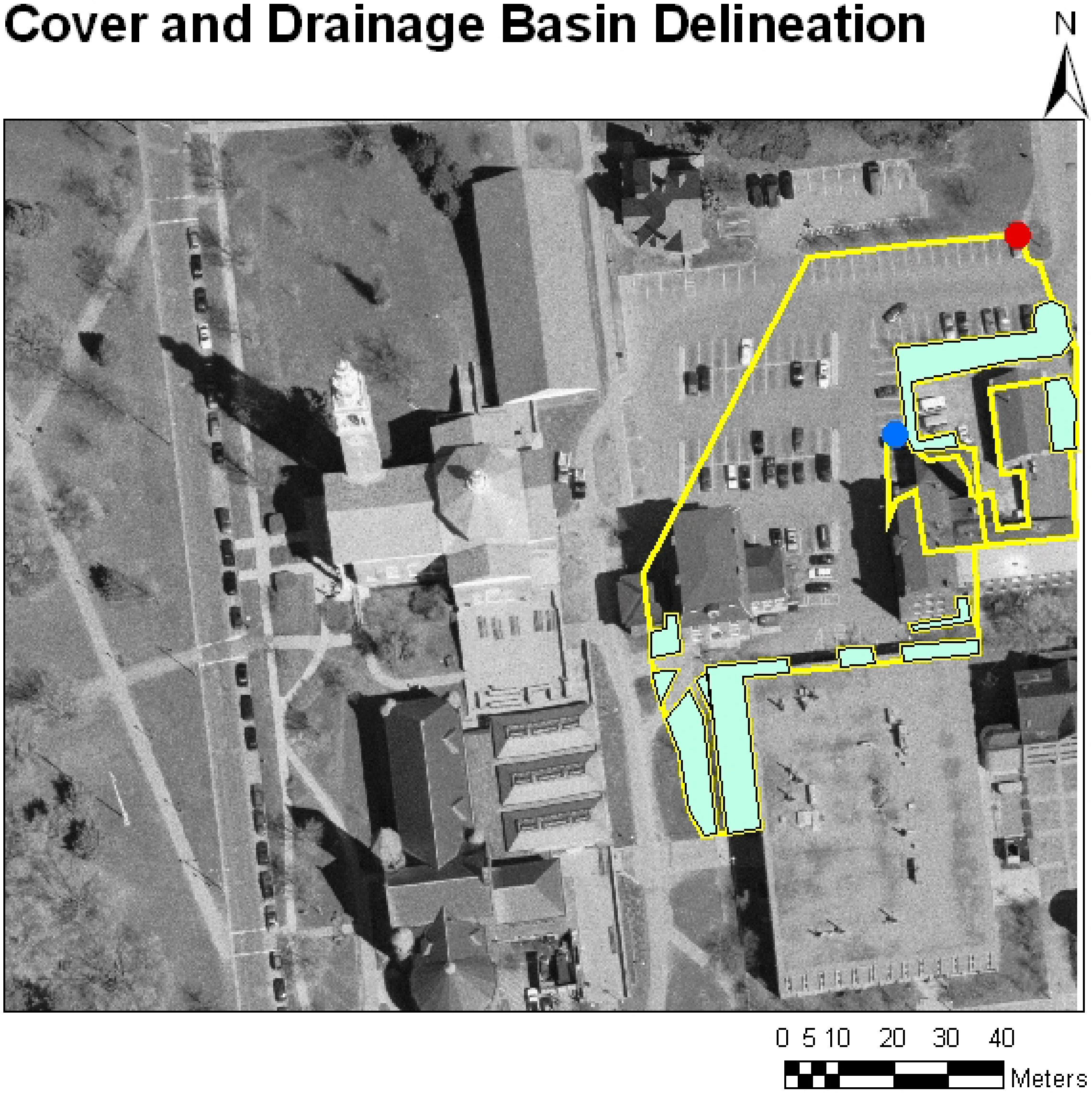
● Weir Site

▢ Basin Boundary

🟩 Greenspace

Vermont State Plane Meters (NAD83): Displayed at 1:870 Scale
Data Sources: www.vcgi.org and Vermont State Mapping Program
Created by Nathan Toké on April 22nd, 2003

Figure 1.3: Perkins Parking Lot: Land Cover and Drainage Basin Delineation



Perkins Parking Lot Drainage Basin is 4820 square meters. It is composed primarily of surfaces with little permeability including a large paved parking lot, a dirt and gravel parking lot behind Perkins Hall, several paved walking paths, and portions of the Perkins and Torrey Buildings. There are 10 areas of greenspace covering 15% of the basin (Table 1.2).

Legend

● Storm Drain

● Weir Site

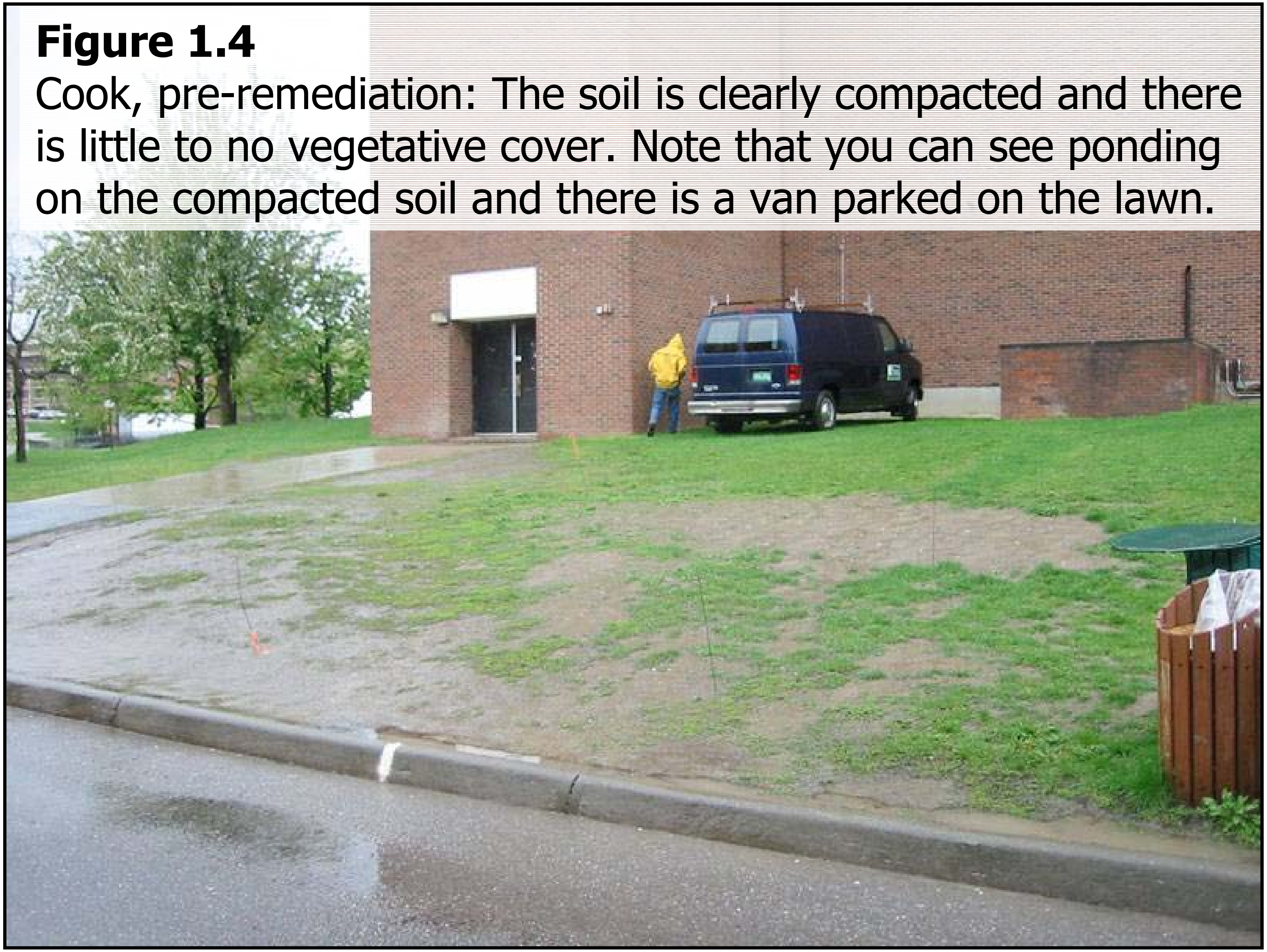
▢ Basin Boundary

▨ Greenspace

Vermont State Plane Meters (NAD83): Displayed at 1:1,324 Scale
Data Sources: www.vcgi.org and vermont state mapping program
Created by Nathan Toké on April 22nd, 2003

Figure 1.4

Cook, pre-remediation: The soil is clearly compacted and there is little to no vegetative cover. Note that you can see ponding on the compacted soil and there is a van parked on the lawn.



Chapter 2 - Methodology

Remediation of Compacted Plots on Campus

In May, 2002 Megan McGee, Jackie Hickerson, Lyman Persico, Paul Bierman and I identified 4 compacted areas of land located on the University of Vermont campus: the southwest lawn of Torrey Hall, the southwest lawn of the Fleming Museum, the southern portion of the west facing lawn of Old Mill Hall, and the north lawn of the Cook Physical Sciences Building (Figure 1.1). We selected these 4 sites as locations for the application and comparison of different remediation methods for restoring compacted land back to permeable greenspace.

During the last week of May 2002, the compacted portion of the north lawn of the Cook Physical Sciences building (Figure 1.3) was divided in to 8 small (1.5m by 2m) rectangular remediation test plots, 2 rows of 4 plots each. The southeastern plot, Cook 1 was reserved as a control plot. The other 7 plots, Cook 2 through Cook 8, were remediated using different techniques (Figure 2.1 and 2.2). Cook 2 was raked and seeded, Cook 3 was pick-axed (pick-axing decompacted soil to a depth of 12.5 cm) and seeded, Cook 4 was roto-tilled (roto-tilling decompacted soil to a depth of 25 cm) and seeded, Cook 5 was roto-tilled with light compost (about 2.5 cm of cover) and reseeded, Cook 6 was pick-axed with light compost and reseeded, Cook 7 was pick-axed with heavy compost (about 5 cm of cover) and reseeded, while Cook 8 was roto-tilled with heavy compost and reseeded (Figure 2.2). The other three sites (Fleming, Torrey, and Old Mill) were all remediated with roto-tilling, pick axing, raking, reseeding, and light composting. The grass seed we used was the University of Vermont's own grounds mix which is composed of 69.08 % Futura 2000 Perennial Ryegrass, 14.01 % Mustang tall Fescue, 9.32 % Creeping Red Fescue, 2.82 % crop, 4.71 % inert, and 0.06 % weed.

Before any remediation was conducted, each of the four compacted sites was tested for pre-remediation parameters during the third week in May 2002. Megan McGee, (2003), studied the parameters of soil density and infiltration capacity. To obtain a steady-state infiltration rate, we used the rainfall simulation method previously employed by Mellilo et al. (2002) and Persico et al. (2002). The infiltration tests involved constructing a tear-drop-shaped test area, such that the narrow part pointed down slope (Figure 2.3). Aluminum sidewalls were pushed into the ground and sealed on the outside of the structure with plaster. Three rain gauges were placed within the measured test plot area. At the test plot outflow, an aluminum collection plate was emplaced, leading to a funnel which allowed the water to flow into a collection bucket located in a previously dug hole. Rainfall was simulated using one to two backpack sprayers. Rainfall amounts were recorded in centimeters, runoff was collected and measured, and corresponding time intervals were recorded. The infiltration tests were conducted until it appeared that a steady state infiltration rate had been obtained (the same amount of runoff was produced over the same time interval).

From each of the infiltration tests, I collected all of the runoff produced. From the cumulative runoff, I obtained one 15mL water sample for each test conducted. I did this by mixing the 5-gallon water bag and then drawing the sample through a 0.2-micron filter into a 15mL sample bottle. I then added 2 drops of 5% nitric acid and stored the sample for later ICP analysis. A blank was obtained from the rainfall simulation backpacks; however, this blank was acidified without filtration rendering it unusable for dissolved load chemical subtraction from the filtered runoff samples. The cumulative runoff was transferred into 5 gallon buckets which were set aside for at least one month until the suspended sediment had settled to the bottom of each bucket. I then decanted the water to a level that left the sediment undisturbed and then I left the buckets to sit until all of the remaining water had evaporated and only the dry sediment remained. The buckets containing the sediment were then massed, cleaned, dried, and massed again, yielding a suspended sediment mass for each runoff test.

After remediation, the sites were fenced off to prevent further foot traffic and compaction. Then, during the second week of June, 2002, the first of two post-remediation infiltration tests was conducted for each of the 8 Cook remediation comparison test plots as well as Fleming, Torrey, and Old Mill. The second round of post-remediation testing was conducted during the second week in November, 2002. During each of these tests, the same methods were employed. These tests provided 1 set of pre-remediation data and 2 sets of post-remediation data; including water chemistry samples, steady state infiltration rates and total suspended sediment loads for each of the simulation tests that produced runoff. All samples were filtered (except the blanks), acidified, and placed in refrigerated storage until ICP analysis in March, 2003.

Collection of Burlington Event Sampling Data

In September of 2002, I selected two locations as sites for constructing temporary weirs which would allow me to obtain a measure of discharge and collect water samples through several storm runoff events: the outflow of Perkins Parking Lot on the UVM campus (Figure 1.2) and in front of 86 Brookes Avenue in Burlington, Vermont (Figure

1.1). These sites were selected in an attempt to obtain two contrasting drainage basins; one basin (Brookes Avenue) with a typical neighborhood mixture of permeable and impermeable land surfaces and another basin with nearly 100% impermeable land cover (Perkins Parking Lot). It was later determined that the Brookes Avenue drainage area was much less permeable than it appeared during field reconnaissance. I chose to use homemade weirs for this study because I needed to stay within a budget. Flumes would have been too expensive and difficult to install on city streets.

I constructed several temporary wooden weirs following the installation guidelines given on the v- notch (triangular) weir calculator webpage (http://www.lmnoeng.com/Weirs/vweir.htm). The guidelines were followed as closely as possible, but with several replacement weirs necessary because of destruction by angry or inconsiderate drivers; some variations in weir geometry undoubtedly occurred. Weirs were emplaced using existing curbing as the primary support along with cinder blocks, large rocks, and plaster to create a seal along the base and sides of the weir (Figure 2.3).

During the morning of September 11th, 2002, I collected my first storm event data with help from Paul Bierman. He manned the Brookes Ave. weir site throughout the entire storm event, which consisted of two rain pulses and lasted for a little over one hour, while I collected data at the Perkins Parking Lot weir, but only through the first rain pulse that lasted about 40 minutes. We collected water samples and measured the weir's hydraulic head every one to two minutes (Appendix A). Samples were collected in 15mL Falcon plastic sample tubes by a simple grab method slightly upstream of the v-notch; they were later filtered using 0.2 micron Nalgene syringe filter and transferred to new sample bottles. At this time, I measured pH and conductivity. First, each sample was transferred to a DI-cleaned testing container and conductivity was measured and recorded using a NIST Traceable Digital Conductivity Meter. Each sample was then transferred back to its corresponding sample bottle. A small portion of each sample (less than 1mL) was withdrawn with a disposable pipette and the pH of this sample was measured using a Mini Lab ISFET pH meter (model IQ125); the meter was standardized using pH 4, pH 10 and pH 7 standards and between each sample the meter was washed with DI water. After filtration, pH, and conductivity measurements were complete, the samples were acidified and stored in a refrigerator until ICP analysis.

The recorded hydraulic head was used with the v- notch (triangular) weir calculator (http://www.lmnoeng.com/Weirs/vweir.htm) to calculate a minimum discharge for each head measurement. This discharge estimate is a minimum value because during both storms, the Perkins weir was overtopped by runoff and at Brookes Avenue some runoff was lost from around the side of the weir. Rainfall during the storm events was measured via a tipping bucket rain gauge located on the 3rd floor fire escape of Perkins Hall.

On September 27th, a 12-hour storm passed through Burlington. Before this storm, I successfully installed both the Brookes Avenue and Perkins weirs. With a tremendous amount of help from Lyman Persico, I was able to obtain discharge measurements and water samples for both sites throughout the storm event at a spacing of about 20 minutes. These samples were filtered on site, pH and conductivity were later measured, and then the samples were acidified and stored. During each event, rain blanks were collected in hopes of providing a rain subtraction for the runoff sample chemistry; however, there may have been some particulates splashed into the samples because the rain was collected in a container, which sat on the ground. To compound this problem, these rain samples were not filtered before acidification.

Drainage Basin Delineation and Land Permeability Measurement

The Perkins and Brookes Avenue drainage basins were delineated using 1998 one-foot contour interval campus topographic maps (Perkins); a City of Burlington 1981 existing sewer and drainage system map with 5-foot contours, and the high resolution 2000 Vermont mapping project orthophotos. I used these maps in conjunction with field observations of road crowns, roof slopes, and small ground slope variations to determine the boundaries of the two drainage basins.

I then used ArcMap to digitize and delineate the approximate areas of the drainage basins and then determine the percent of permeable and impermeable land for each of the two basins. To do this, I created a personal geodatabase in ArcCatalog with the georeferenced TB24 coverage (www.vgs.org) and the 096220 quad of the 2000 orthophoto data. Then I used the editor function of ArcMap to add drainage basin polygons to the TB24 layer. I made the polygons by tracing over the portions of the orthophotos that corresponded to my map and field observations for the predetermined drainage basin boundaries. I then added more polygons for each of the greenspace areas at each site. Then I exported the attribute table containing these newly created polygons allowing me to create a summary table showing the total area of each drainage basin and the amount of each basin which is permeable (Tables 1.1 and 1.2).

ICAP Elemental Analysis

I spent two days using Middlebury College's IRIS 1000 DUO ICAP spectrometer, with assistance from Ray Coish and Peter Ryan, to analyze the 189 water chemistry samples obtained from the three remediation-testing rounds and the three storm sampling events. I organized the samples in an auto-sampler and had the IRIS analyze for the following elements: Ag, Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, P, Pb, Si, Sr, and Zn. (Appendix B). The ICAP was standardized at the beginning of each run and quality control (QC) checks were preformed every 7 samples; if the QC failed, then the ICAP was restandardized and the preceding samples were re-analyzed.

Data Analysis

Microsoft Excel was used to manipulate storm flow and chemical data into hydrographs and chemographs for each storm event and drainage basin. Excel was also used to compare remediation plot chemistry and suspended sediment data between testing rounds. Hydrographs were constructed by plotting the calculated discharge against elapsed storm event time and then overlaying a time interval rain bar plot to show how discharge compared to precipitation flux. Chemographs were then created by multiplying chemical concentration data by the flow discharge resulting in a minimum estimation of mass discharge, which was then plotted against elapsed storm event time. Chemical concentrations were also plotted against elapsed time and compared.

Minimum chemical loads were also calculated for each storm event by spreadsheet integration of chemical discharges and time intervals, yielding a chemical load for each of the 17 elements analyzed per site and by storm event. This estimation was a minimum because my weirs were inadequate to measure the volume of stormwater runoff produced over the Brookes and Perkins drainage basins. To compare loadings between basins I made a calculated estimation of flow for each site and storm based upon the rational runoff method. I used runoff coefficients equal to my estimations for drainage basin impermeability in order to calculate an estimated hydrograph and then integrated the chemical data in the same way as previously described to produce chemical loading data. These data were normalized by precipitation and area to compare chemical loading between sites and storms.

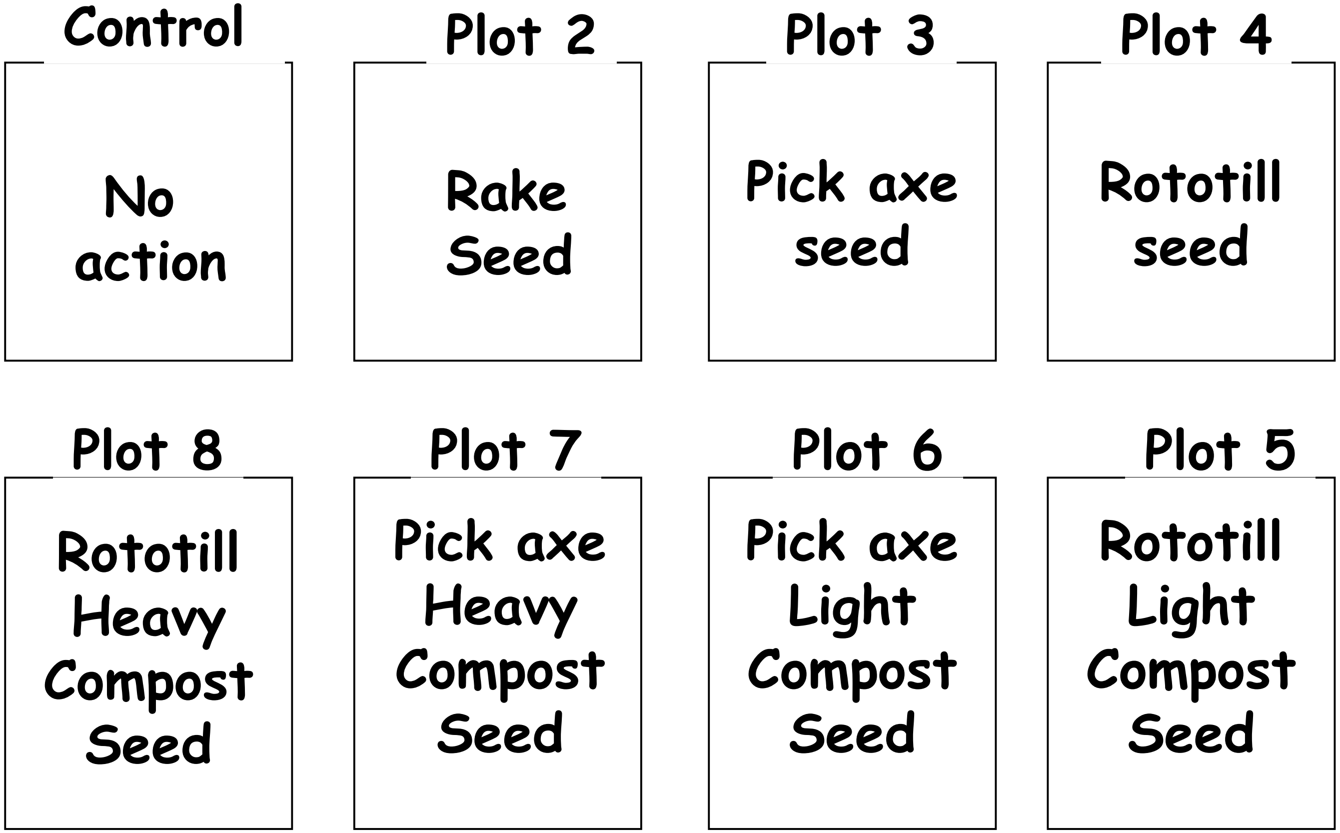
Remediation chemical data were compared by plotting the change in each element's chemical concentration at each site over time. The suspended sediment mass obtained from each plot test was normalized by total volume of simulated rainfall. The normalized data were plotted against the date of the three remediation tests showing how each plot responded in terms of erosion to the different remediation methods.

Plot data was entered into Minitab enabling a two sample t-test statistical comparison between remediation treatments and plot response for infiltration rates (McGee, 2003), normalized suspended sediment production, and chemical data. However, in order to make a statistical comparison I had to reorganize how I classified the remediation treatments between testing rounds (Figure 2.5). This reorganization resulted in n=4 pre-remediation tests. In June there were n=2 sites (Cook control and Cook 2) which received fencing as the only significant treatment, there were n=2 sites (Cook 3 and Cook 4) which only received aeration, and n=5 sites (Cook 4-8 and Fleming) which were aerated and composted. November testing had the same treatments less Fleming, which was not tested, due to snow (Figure 2.5).

Figure 2.1

The north lawn of the Cook Physical Sciences Building after remediation. Shown here are the Cook control (top left) and Cook 7 (bottom right) sites, the boundaries of which are marked by four metal pins for each plot. Notice the difference in vegetative cover between the two sites. Also shown is Cook 2 (top right) and Cook 8 (bottom left).

Figure 2.2
Cook plot remediation scheme. Cook 1 was set aside as a control plot, although all plots were fenced to prevent additional compaction. The following treatments were applied to each plot:



Control No action	**Plot 2** Rake Seed	**Plot 3** Pick axe seed	**Plot 4** Rototill seed
Plot 8 Rototill Heavy Compost Seed	**Plot 7** Pick axe Heavy Compost Seed	**Plot 6** Pick axe Light Compost Seed	**Plot 5** Rototill Light Compost Seed

Figure 2.3: Simulated rainfall test: infiltration rate analysis, runoff collection, dissolved load chemical sampling, and measurement of suspended sediment.

Construction of the tear drop
Rainfall simulation apparatus.

Area measurement

Rain gauges and
Runoff collection

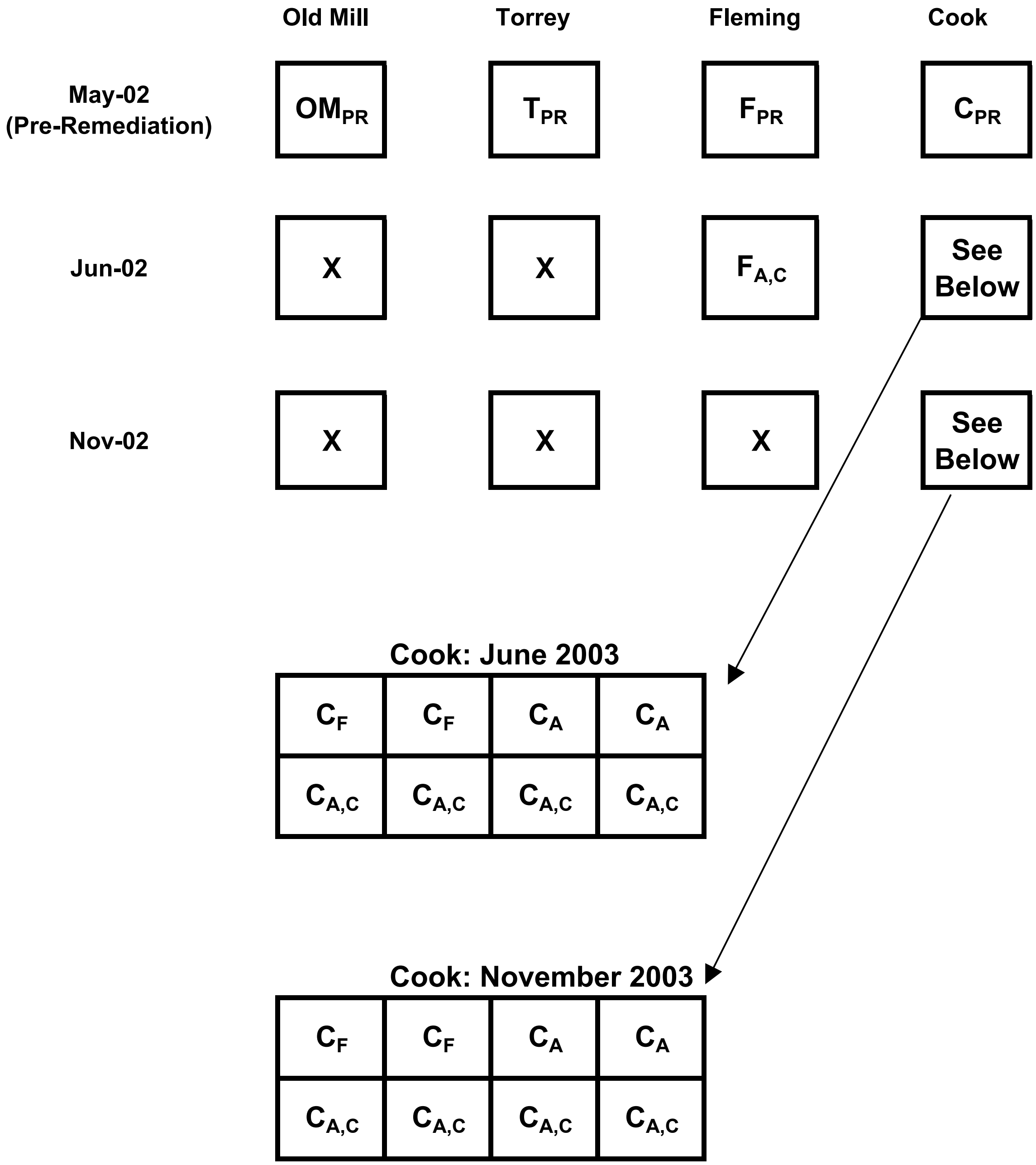
Runoff measurement

sample filtration

Figure 2.4
The Perkins Parking Lot Weir Constructed on Sept 10th, 2002. The V-notch is 90 degrees and is tapered to a shear edge. The weir is held in place with the existing curb, a plaster seal, and rocks. Note that there are clear automotive fluid stains on the pavement

Figure 2.5

Remediation plot diagram displaying remediation sites, treatments and testing dates



Footnotes:

X : not considered in statistics either because of no testing or no runoff produced

OM_{PR}, T_{PR}, F_{PR}, C_{PR} : Old Mill, Torrey, Fleming, and Cook sites (pre-remediation)

C_F : Cook sites with only the addition of fencing

C_A : Cook sites after treatment of aeration (Roto-tilling and/or Pick-axing) only

$F_{A,C}$: Fleming after treatments of aeration and compost

$C_{A,C}$: Cook sites after treatments of aeration and compost

Chapter 3 – Results

My research from the Perkins and Brookes Avenue weir sites produced stormwater flow and chemical data. The remediation test plot research produced chemical and suspended sediment data as well as infiltration and soil density data considered by McGee (2003) in a separate report. Most of the samples which were analyzed contained chemical concentrations that were below the EPA's Maximum Contaminant Limit (MCL) or other noted drinking water standards.

Vegetative recovery over the remediation test plots.

In June, one month after remediation, there was a clear difference in vegetative cover between the remediation test plots. The Cook control site had no significant vegetative cover. Cook 2, which received only raking and grass seed, had minimal grass and weed cover. All other sites all had significant grass growth.

In November, six months after remediation, differences between the vegetative cover of Cook 2 and the rest of the remediation sites were less pronounced. Cook 2 soil felt significantly harder and the site had more weed cover than the other remediation soils, which felt softer and had mainly grass cover. The Cook control site was covered by what could be described as a vine-like weed and had many small pebbles over its surface, an armor layer.

Infiltration rates from the remediation test plots

I used steady state infiltration data, provided by Mcgee (2003) to determine if remediation treatments improved the ability of the soil to infiltrate water (Table 3.1, Appendix D). This analysis showed that, after six months, sites that received aeration or aeration and composting had mean steady state infiltration rates that were greater, statistically (at the 90% confidence level), than the pre-remediation steady state infiltration rates. Sites which were only fenced showed no statistically significant improvement (P=.274) when compared to the sites prior to fencing. Sites which were aerated and composted had significantly higher mean steady-state infiltration rates than the fenced sites after one month, but no statistical difference could be seen after six months.

There were several notable trends in mean infiltration rates between treatments and testing dates. All remediation treatments improved (increased) infiltration as compared to pre-remediation data, and all three treatments improved in infiltration rates from June to November. In both June and November, infiltration rates were progressively greater for sites that received more aggressive remediation, i.e. compost, aeration, and fence (Table 3.1).

Suspended sediment within the runoff from the remediation test plots

Only one month after remediation, there were statistically significant improvements (decreases) in normalized suspended sediment production over sites that were composted and aerated (Table 3.3). Fenced and aerated sites showed statistically significant improvements after six months, but not after one month. No statistically significant differences were seen between treatments; however, mean suspended sediment production dropped with time for each treatment, all treatments showed an improvement in suspended sediment production compared to pre-remediation data (Figure 3.1), and there was a general drop in mean suspended sediment produced with increasing remediation rigor (Table 3.3).

Water chemistry of the remediation test plots runoff

I organized the chemical data obtained from the remediation test plots so that they could be examined from several perspectives. Raw data from the remediation test plots can be found in Appendix B. I tested for 8 metals on the EPA's priority pollutant list including: Ag, As, Cd, Cr, Ni, Pb, and Zn. All 8 were dissolved in the runoff from the remediation test plots (Table 3.4). Silver, cadmium, nickel, and lead were detected in less than 20% of the test plot runoff samples. Arsenic was detected in nearly 50% of the samples and three of these eight contaminants were detected in more than 90% of the test plot samples: Cr, Cu, and Zn. In each case when these eight contaminants were detected, they were detected at very low concentrations, always at least one order of magnitude below the EPA maximum contaminant level and usually below the median for samples from the Nationwide Urban Runoff Program (1981).

Aside from the 8 priority pollutants, dissolved concentrations of 9 other elements were measured in plot runoff: Al, Ca, Fe, K, Mg, Na, P, Si, and Sr (Table 3.5). Of these elements, calcium, sodium, potassium, magnesium, and silica were found in the highest concentrations within the test plot runoff. Iron was not found in high concentrations and in many cases it was below the detection limit of the ICP. No statistically significant relationships were seen in the changes in chemical concentrations between remediation treatments. A consistent fall in the concentration of sodium through the three rounds of testing was the only significant trend seen in the plot chemistry data. This trend transcended remediation treatments (Figure 3.2). Graphs showing changes in dissolved load concentrations for the other elements can be found in Appendix C and the dissolved load data can be found in Appendix B.

Stormwater Runoff Events

I obtained stormwater runoff data for flow, pH and conductivity, as well as chemical concentrations of 17 elements (Ag, Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, P, Pb, Si, Sr, and Zn) through three storm events on the Perkins Parking Lot and Brookes Avenue drainage basins (Appendix A and Appendix B). I have divided my data into sections on stormwater flow, pH and conductivity, and stormwater chemistry. These sections consider data from the 9/11/02 and 9/27/02 storm events.

Stormwater flow, pH and Conductivity

I collected stormwater flow and water samples from two storm events, one on 9/11/02 and the other on 9/27/02. The September 11th storm event lasted for a little over one hour depositing 0.81 cm (0.32 inches) of rain while the September 27th storm event lasted for more than 12 hours and deposited 6.58 cm (2.59 inches) of rain. The September 11th storm event consisted of two storm pulses; the September 27th storm consisted of many storm pulses. Over both the Perkins and Brookes Avenue drainage basins, discharge was seen to relate directly to these rain pulses, such that immediately after a time of increased rainfall, stormwater discharge would increase. An example of this is seen with the two rising and falling limbs of the 9/11/02 Brookes Avenue hydrograph (Figure 3.3). This relationship was also seen in the 9/27/02 storm, e.g. Perkins hydrograph (Figure 3.4).

I performed an analysis of runoff verses rainfall for both of the drainage basins and storm events. The Perkins Parking Lot weir was sampled for 42 minutes, through the first pulse of the 9/11/02 storm event. This part of the storm dropped 0.33 cm of rain over the 4820 m^2 basin or about 18,200 liters of rainfall. Integration and summation of measured stormwater discharge per time interval yielded 4,270 liters; however, the weir was overtopped throughout most of the storm event. Thus, I calculate that at least 27% of the total volume of rainfall ran off the Perkins Parking lot during this storm as a minimum limit (Table 3.6). Brookes Avenue was sampled through the entire storm event of 9/11/02, which deposited 0.81 cm of rain over the 920 m^2 drainage basins or about 7,450 liters of rainfall. Integration of Brookes Avenue flow measurements yielded only 386 liters of runoff for a runoff efficiency of 5% of the total rainfall volume. However, water was bypassing the Brookes weir around the southern wall through the entire event (Table 3.7). The September 27th, 2002 storm event deposited 6.58 cm of rain on the Perkins and Brookes Avenue drainage basins. Both stations were sampled through the entire event yielding 316,800 liters of rainfall on the Perkins Parking Lot and 60,320 liters of rainfall over Brookes Avenue. Integration of discharge at both sites yielded 26% runoff and 31 % runoff, respectively (Tables 3.8 and 3.9). However, these runoff percentages are also minimum values because there was over topping of the Perkins weir and some runoff was lost around the side of the Brookes Avenue weir.

Measurements of pH from the collected stormwater samples had similar patterns throughout the both storm events and sites. The pH measurements ranged from 6.5 to 7.6 and pH varied by no more than 0.7 through any runoff event. Early storm falls and then general rises in pH were observed over the storm events at both sites. Drops in pH during the storms were associated with increases in rainfall intensity (Appendix A and Figure 3.5). During the shorter 9/11/02 storm only one rain sample was collected, it had a pH of 4.9. During the 12-hour 9/27/02 storm, 16 rain samples were collected with pH values ranging from 5.9 to 7.3.

Conductivity measurements showed a general trend throughout all of the events. With increasing stormwater discharge, conductivity dropped (Appendix A and Figure 3.5). The range of conductivity values depended upon the storm event, since one storm produced a much greater volume of water. During the short duration storm, 9/11/02, conductivity measurements at the Brookes and Perkins sites were comparable with maximum and minimum values ranging from 0.227 to 0.048 mS and 0.229 mS to 0.063 mS, respectively. During the 9/11/02 storm, rain conductivity was 0.017 mS. During the long storm, 9/27/02, conductivity was lower. Values were also comparable between the two basins ranging from .136 to .11 mS at Brookes Avenue and .179 to .15 mS at Perkins Parking Lot. Conductivity measurements from the 9/27/02 rainfall ranged from .3 to .15 mS with conductivity starting high and decreasing.

Stormwater Chemistry

The same 17 elements that were analyzed in the filtered runoff of the remediation test plots were analyzed in the stormwater samples (Appendix B). Chemical concentrations of these elements decreased throughout the storm events, rising in concentration when stormwater discharge decreased and falling in concentration when stormwater discharge increased (Figure 3.6). It should also be recognized that element concentrations measured at a particular discharge value on the rising limb were greater than concentrations measured at the same discharge value later, on the falling limb (Figure 3.6). The general trend of dissolved chemical mass discharge was to rise and fall with stormwater discharge (Figure 3.6).

Seven of the eight priority pollutants (Ag, As, Cd, Cr, Cu, Ni, and Zn) were detected at very low concentrations throughout the storm events, typically over an order of magnitude below their respective EPA maximum contaminant levels (Tables 3.10-3.13). The three priority pollutants that had the greatest total storm loading values, Zn, Cu, and Cr, were typically detected in more than 80% of the samples.

During the 9/11/02 storm at Perkins Parking Lot, no Pb was detected (Table 3.10). At Brookes Avenue, during the same storm, Pb was detected in 13% of the samples (Table 3.11). During the 9/27/02 storm, much more lead was detected. At Perkins Parking Lot, lead was only detected in 16% of the samples (Table 3.12); however, the first sample taken had a maximum concentration of 0.033 ppm, more than two times the EPA's MCL list for lead. At Brookes Avenue, during the same storm, lead was detected in 93% of the samples (Table 3.13) and concentrations were above the MCL for the first three samples collected (Appendix B). It is important to consider that samples were taken at a rate of about 1 every 20 minutes, suggesting that lead contaminated the runoff at levels exceeding drinking water standards for as much as the first hour of the storm.

The concentrations of 9 other elements were analyzed in the runoff: Al, Ca, Fe, K, Mg, Na, P, Si, and Sr (Appendix B). Of these elements, Ca, K, Mg, Na, and Si were found in the greatest concentrations and had the greatest total loading values (Tables 3.10 through 3.13). In order to compare loading between the basins and storm events I had to account for the problem of weir over topping. Using the rational method, I calculated the amount of runoff that should have come off the two sites using basin permeability estimates as runoff coefficients. From the rational method discharge, seen on simulated hydrographs (Appendix E), I calculated loading values for both storm events and drainage basins (Appendix E) normalizing them by area and rainfall (Table 3.14).

This data suggests that the short duration 9/11/02 storm had more intense (normalized) loading for all of the elements analyzed except for silver and lead which were both detected more heavily in the long 9/27/02 storm (Table 3.14). Also, lead was loaded more heavily off the Brookes Avenue drainage basin than Perkins Parking lot. During the short storm, it appears that the Perkins Parking lot loaded Al, As, Ca, Cr, Cu, Fe, Mg, Ni, Si, and Sr more heavily than Brookes Avenue, while Brookes Avenue had more intense loadings of K, Na, P, Pb, and Zn. During the long storm, Brookes Avenue had more intense loading of Cd, Cr, Cu, Fe, K, Mg, Pb, and Zn, while Perkins loaded more Ag, Al, As, Ca, Si, and Sr (Table 3.14).

Table 3.1
A matrix displaying p-values from two-sample t-testing. P-values less than 0.10 indicate that there may be a statistically significant difference between the **mean of the steady state infiltration rates (cm/h)** compared. Comparisons can be made by greenspace remediation method and testing date.

	Pre-Remed: (OM$_{PR}$, T$_{PR}$, F$_{PR}$, C$_{PR}$)	**Jun-02, Fencing Only (C$_{F}$)**	**Nov-02, Fencing Only (C$_{F}$)**	**Jun-02, Aeration (C$_{A}$)**	**Nov-02, Aeration (C$_{A}$)**	**Jun-02, Compost and Aeration (C$_{C,A}$, F$_{C, A}$)**	**Nov-02, Compost and Aeration (C$_{C,A}$)**
	Mean = 1.5	Mean = 3.4	Mean = 8.2	Mean = 7.1	Mean = 13.5	Mean = 9.6	Mean = 15.4
	St Dev = 0.4	St Dev = 0.9	St Dev = 4.3	St Dev = 2.3	St Dev = 2.1	St Dev= 4.5	St Dev= 1.7
Pre-Remediation	X						
Jun-02 Fencing Only	0.225	X					
Nov-02 Fencing Only	0.274	0.367	X				
Jun-02 Aeration	0.185	0.285	0.804	X			
Nov-02 Aeration	0.078	0.099	0.361	0.210	X		
Jun-02 Compost and Aeration	0.016	0.042	0.754	0.378	0.201	X	
Nov-02 Compost and Aeration	0.001	0.002	0.261	0.139	0.449	0.047	X

Footnotes:
**Highlighted cells, where p-values are less than 0.1, (90% confident that means differ)*
**Refer to Figure 2.5 which displays plot configurations and testing dates*
N = number of sites with the corresponding treatment
St Dev = standard deviation

Table 3.2a: Comparison of Suspended Sediment between 3 Sampling Rounds and 8 Remediation Methods (g)

Testing Round	Date	Cook 1	Cook 2	Cook 3	Cook 4	Cook 5	Cook 6	Cook 7	Cook 8	Flemming	Old Mill	Torrey	
		fenced	fenced, rake, seed	fenced, pick axe, seed	fenced, roto-till, seed	fenced, roto-till, seed, light compost	fenced, pick axe, seed, light compost	fenced, pick axe, seed, heavy compost	fenced, roto-till, seed, heavy compost	fenced, pick-axe, rototill, seed, light compost	fenced, pick-axe, rototill, seed, light compost	fenced, pick-axe, rototill, seed, compost	**Remedition Method**
Pre-Remediation	5/20/02	146	146	146	146	146	146	146	146	43	25	236	
Round 2	6/13/02	51	16	3	30	26	13	14	11	2	NA	NA	
Round 3	11/12/02	2	3	2	0	6	1	0	2	NM	NM	NM	

(Measurements are in grams of suspended sediment)

Table 3.2b: Comparison of Suspended Sediment produced per square meter, normalized to simulated rainfall ($(g/m^2)/cm$)

Testing Round	Date	Cook 1	Cook 2	Cook 3	Cook 4	Cook 5	Cook 6	Cook 7	Cook 8	Flemming	Old Mill	Torrey	
		fenced	fenced, rake, seed	fenced, pick axe, seed	fenced, roto-till, seed	fenced, roto-till, seed, light compost	fenced, pick axe, seed, light compost	fenced, pick axe, seed, heavy compost	fenced, roto-till, seed, heavy compost	fenced, pick-axe, rototill, seed, light compost	fenced, pick-axe, rototill, seed, light compost	fenced, pick-axe, rototill, seed, light compost	**Remedition Method**
Pre-Remediation	5/20/02	34.23	34.23	34.23	34.23	34.23	34.23	34.23	34.23	19.91	6.49	61.31	
Round 2	6/13/02	8.97	5.78	0.51	6.93	6.13	1.53	1.54	3.06	0.24	NA	NA	
Round 3	11/12/02	0.90	2.18	0.32	0.00	0.91	0.18	0.00	0.48	NM	NM	NM	

(Measurements are expressed in grams of suspended sediment produced per meter per cm of rainfall)

Footnote:
NA was entered when no runoff was produced during the test; thus, there was no suspended sediment produced.
NM was entered because these sites were not measured due to snowcover
Also note that pre-remediation cook plot data is the same because a single, representative, test was conducted over the entire pre-remediation area

Table 3.3

A matrix displaying p-values from two-sample t-testing. P-values less than 0.10 indicate that there may be a statistically significant difference in the **mean normalized suspended sediment [(g/m2)/cm rain]** produced between the compared greenspace remediation methods and testing dates.

	Pre-Remed: (OM$_{PR}$, T$_{PR}$, F$_{PR}$, C$_{PR}$)	**Jun-02, Fencing Only (C$_{F}$)**	**Nov-02, Fencing Only (C$_{F}$)**	**Jun-02, Aeration (C$_{A}$)**	**Nov-02, Aeration (C$_{A}$)**	**Jun-02, Compost and Aeration (C$_{C,A}$, F$_{C,A}$)**	**Nov-02, Compost and Aeration (C$_{C,A}$)**
	N=4	N=2	N=2	N=2	N=2	N=5	N=4
	Mean = 30.5	Mean = 7.3	Mean = 1.5	Mean = 3.7	Mean = 0.2	Mean = 2.5	Mean = 0.4
	St Dev = 23.5	St Dev = 2.3	St Dev = 0.9	St Dev = 4.5	St Dev = 0.2	St Dev= 2.3	St Dev= 0.4
Pre-Remediation	X						
Jun-02 Fencing Only	0.146	X					
Nov-02 Fencing Only	0.091	0.182	X				
Jun-02 Aeration	0.115	0.494	0.626	X			
Nov-02 Aeration	0.081	0.139	0.284	0.468	X		
Jun-02 Compost and Aeration	0.098	0.235	0.467	0.779	0.084	X	
Nov-02 Compost and Aeration	0.083	0.144	0.337	0.489	0.430	0.110	X

Footnote:

**Highlighted cells, where p-values are less than 0.1 (90% confident that means differ)*

**Refer to Figure 2.5 which displays plot configurations and testing dates*

N = number of sites with the corresponding treatment

St Dev = standard deviation

Table 3.4
Priority Pollutant Concentrations (ppm) for 8 Remediation Sites and three Sampling Rounds and Percentage of Contaminant Detections Among the Remediation Tests

Site	Date	Ag	As	Cd	Cr	Cu	Ni	Pb	Zn	
		0.001	**0.004**	**0.0004**	**0.001**	**0.002**	**0.002**	**0.004**	**0.0003**	**Detection Limit**
		0.1	**0.01**	**0.005**	**0.1**	**1**	**0.1**	**0.015**	**2**	**MCL[1]**
		NA	**NA**	**NA**	**0.009**	**0.017**	**0.013**	**0.075**	**0.12**	**NURP median[2]**
		0.001	**0.006**	**0**	**0.002**	**0.009**	**NA**	**0.003**	**0.022**	**Lubbok Data[6]**
Cook 1 (Control)	**5/20**	BDL[3]	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.005	BDL	0.002	0.002	BDL	BDL	0.021	
	11/12	BDL	BDL	BDL	0.002	0.008	BDL	0.004	0.010	
Cook 2	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.004	BDL	0.002	0.003	BDL	BDL	0.044	
	11/12	BDL	0.006	BDL	0.001	0.005	BDL	BDL	0.032	
Cook 3	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.004	0.001	0.002	0.005	BDL	BDL	0.084	
	11/12	BDL	BDL	BDL	0.003	0.006	BDL	BDL	0.069	
Cook4	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.006	BDL	BDL	BDL	BDL	BDL	0.025	
	11/12	BDL	BDL	BDL	0.004	0.012	BDL	BDL	0.049	
Cook 5	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.004	BDL	0.002	BDL	BDL	BDL	0.045	
	11/12	BDL	BDL	BDL	0.005	0.005	BDL	BDL	0.129	
Cook 6	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	0.005	BDL	0.002	0.003	BDL	BDL	0.062	
	11/12	BDL	BDL	BDL	0.004	0.015	BDL	BDL	0.029	
Cook 7	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	0.002	0.016	BDL	0.003	0.045	0.004	BDL	0.139	
	11/12	BDL	BDL	BDL	0.003	0.003	BDL	BDL	0.042	
Cook 8	**5/20**	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	
	6/10	BDL	BDL	BDL	0.003	0.002	BDL	BDL	0.038	
	11/12	BDL	BDL	0.002	0.004	0.006	BDL	BDL	0.052	
Fleming	**5/16**	BDL	BDL	BDL	0.002	0.016	BDL	BDL	0.012	
	6/14	BDL	BDL	BDL	0.002	0.012	BDL	BDL	0.065	
Torrey	**5/16**	BDL	0.006	BDL	0.002	0.021	BDL	BDL	0.355	
	6/14	NA[4]	NA	NA	NA	NA	NA	NA	NA	
Old Mill	**5/17**	BDL	0.006	0.001	0.002	0.004	BDL	BDL	0.010	
	6/17	NA	NA	NA	NA	NA	NA	NA	NA	

	Ag	As	Cd	Cr	Cu	Ni	Pb	Zn
number (#) of samples	21	21	21	21	21	21	21	21
# of samples detected	1	10	3	20	19	1	1	21
% of samples dectected	**5**	**48**	**14**	**95**	**90**	**5**	**5**	**100**
NURP Detection %[5]	NA	58	38	45	91	44	93	100

1. MCL is the highest concentration of a contaminant allowed in drinking water, an EPA enforceable standard
2. NURP median = median of geometric means found for contaminants in the Nationwide Urban Runoff Program
3. BDL = below detection limit of the ICAP used in analysis
4. NA, used when no runoff was produced in the simulation; therefore, there is no water sample
5. NURP Detection % = the percentage of samples the contaminant was detected in during the NURP
6. Lubbock study (Zartman, 2001) average dissolved concentrations

Table 3.5
Other Element Concentrations (ppm) for 8 Remediation sites and Three Sampling Rounds

Sample Name	Date	Al	Ca	Fe	K	Mg	Na	P	Si	Sr	
		0.002	**0.0001**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.008**	**0.001**	**0.0002**	**Detection Limit**
		0.2	**NA**	**0.3**	**NA**	**NA**	**20**	**NA**	**NA**	**4**	**MCL[1]**
		2.86	**29.1**	**0.629**	**5.03**	**3.71**	**18**	**NA**	**NA**	**0.4**	**Lubbok Data[4]**
Cook 1	**5/20/2002**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
(control site)	**6/10/2002**	0.092	44.6	BDL[2]	2.3	4.5	16.3	0.38	0.78	0.19	
	11/12/2002	0.117	51.4	BDL	11.0	0.2	1.9	BDL	0.17	0.03	
Cook 2	**5/20/2002**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	6/10/2002	0.080	33.2	0.001	2.8	4.3	12.2	0.41	0.84	0.14	
	11/12/2002	0.106	35.0	0.003	10.7	5.0	16.0	0.85	0.89	0.21	
Cook 3	**5/20/2002**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	6/10/2002	0.106	56.5	0.018	4.3	4.8	12.1	0.45	1.22	0.23	
	11/12/2002	0.119	83.7	BDL	16.1	4.4	9.6	0.68	1.11	0.12	
Cook 4	**5/20/2002**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	6/10/2002	0.090	50.8	BDL	1.6	4.7	12.5	0.34	0.86	0.23	
	11/12/2002	0.134	254.1	BDL	16.0	4.5	9.2	0.68	1.08	0.29	
Cook 5	**05/20/02**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	06/10/02	0.104	77.0	0.006	3.7	5.0	13.4	0.39	0.86	0.29	
	11/12/02	0.119	66.3	BDL	9.3	8.8	17.2	0.59	1.26	0.89	
Cook 6	**05/20/02**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	06/10/02	0.104	96.3	0.012	14.4	5.2	14.3	1.05	0.98	0.32	
	11/12/02	0.148	78.5	0.046	25.8	4.9	12.8	0.63	0.92	0.25	
Cook 7	**05/20/02**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	06/10/02	0.248	57.7	0.365	88.3	5.9	36.1	5.56	2.53	0.17	
	11/12/02	0.119	83.8	BDL	9.6	7.6	13.7	3.20	1.71	0.23	
Cook 8	**5/20/2002**	0.090	42.4	0.001	3.2	5.2	18.6	0.35	0.76	0.16	
	6/10/2002	0.002	93.7	BDL	6.0	5.4	15.0	0.47	0.83	0.34	
	11/12/2002	0.136	73.3	0.013	11.1	4.3	8.9	1.11	0.82	0.13	
Fleming	**5/16/2002**	0.100	29.9	0.020	3.9	3.9	24.9	0.37	1.27	0.18	
	6/14/2002	0.088	105.2	0.138	35.7	5.6	24.7	3.56	1.48	0.33	
Torrey	**5/16/2002**	0.089	24.9	0.006	3.0	3.8	18.9	0.30	0.87	0.12	
	6/14/2002	NA[3]	NA	NA	NA	NA	NA	NA	NA	NA	
Old Mill	**5/17/2002**	0.108	31.8	0.010	1.9	4.3	12.7	0.25	0.72	0.16	
	6/17/2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Footnote: There is no third round for the Fleming, Torrey and Old Mill sites. This is because snow came early and data were unattainable.

1. MCl is the highest concentration of a contaminant that is allowed in drinking water, an EPA enforceable standard
2. BDL = below detection limit of the ICAP used in Analysis
3. NA is used when no runoff was produced in the simulation, therefore there is no water sample
4. Lubbock study (Zartman, 2001) average dissolved concentrations

Table 3.6: Rainfall vs Runoff Comparison
Perkins Parking Lot, September 11th, 2002

Elapsed Time	Q (gpm)	Hydraulic Head[1] (cm)	Elapsed Time (minutes)	Gallons of Runoff per time interval	Observations
0:00:00	0.2	0.0	0.0	1.8	
0:01:00	3.3	2.9	1.0	6.3	
0:02:00	9.2	4.4	2.0	12.3	
0:03:00	15.3	5.4	3.0	24.2	
0:04:00	33.2	7.4	4.0	18.1	Water flowed
0:04:30	39.0	7.9	4.5	21.1	Over curbing
0:05:00	45.4	8.4	5.0	23.4	↓
0:05:30	48.2	8.6	5.5	25.1	
0:06:00	52.4	8.9	6.0	26.6	
0:06:30	53.9	9.0	6.5	27.3	
0:07:00	55.4	9.1	7.0	55.4	
0:08:00	55.4	9.1	8.0	27.7	
0:08:30	55.4	9.1	8.5	54.6	
0:09:30	53.9	9.0	9.5	26.2	
0:10:00	51.0	8.8	10.0	50.3	
0:11:00	49.6	8.7	11.0	24.8	
0:11:30	49.6	8.7	11.5	24.4	
0:12:00	48.2	8.6	12.0	23.7	
0:12:30	46.8	8.5	12.5	46.8	
0:13:30	46.8	8.5	13.5	68.2	
0:15:00	44.1	8.3	15.0	84.4	
0:17:00	40.3	8.0	17.0	75.7	
0:19:00	35.5	7.6	19.0	63.4	
0:21:00	27.9	6.9	21.0	53.9	Water contained
0:23:00	26.0	6.7	23.0	47.5	
0:25:00	21.5	6.2	25.0	61.9	
0:28:00	19.8	6.0	28.0	53.7	
0:31:00	16.0	5.5	31.0	28.6	
0:33:00	12.6	5.0	33.0	32.1	
0:36:00	8.7	4.3	36.0	22.2	
0:39:00	6.0	3.7	39.0	16.4	
0:42:00	4.9	3.4	42.0		

Total Gallons of Runoff: **1128**

Total Rainfall in Sept 11th Storm: 0.13 inches
Total Rainfall in Sept 11th Storm: 0.33 cm
Total Area of Perkins Drainage Basin: 4820 sq meters
Volume of Rainfall on Perkins Sept 11th: 15.9 cubic meters
Volume of Rainfall on Perkins Sept 11th: **4,210** gallons

% Runoff: (Gallons of Runoff/ Gallons of Rainfall)*100

27 %

Footnotes: The wooden weir had a 90 degree v-notch which was 5.6 cm high. In the v-notch, the edges were tapered to a sharp point. Height of the v-notch was less than the called for 6 cm above the downstream side of the weir.

1: Hydraulic head = the depth of water at the stage measuring point which is above the height of the v-notch.

Table 3.7: Rainfall vs Runoff Comparison
Brookes Avenue, Sept 11th, 2002

Elapsed Time	Q (gpm)	Hydraulic head[1] (cm)	Elapsed Time (minutes)	Gallons of Runoff per time interval	Comments
0:00:00	0.0	0	0	0.2	
0:02:00	0.2	0.9	2	0.5	
0:04:00	0.3	1	4	0.4	some
0:05:00	0.5	1.3	5	1.2	water bypass
0:07:00	0.7	1.5	7	2.6	↓
0:09:00	1.9	2.3	9	4.1	
0:11:30	1.4	2	11.5	1.4	
0:12:30	1.4	2	12.5	2.6	
0:14:30	1.2	1.9	14.5	2.4	
0:16:30	1.2	1.9	16.5	1.9	
0:18:30	0.7	1.5	18.5	1.4	
0:20:30	0.7	1.5	20.5	1.3	
0:22:30	0.6	1.4	22.5	0.9	
0:24:30	0.3	1	24.5	0.2	
0:25:30	0.2	0.9	25.5	0.2	
0:26:30	0.2	0.8	26.5	0.1	
0:27:30	0.1	0.7	27.5	0.1	
0:28:30	0.1	0.6	28.5	0.1	
0:29:30	0.1	0.5	29.5	0.0	
0:30:30	0.0	0.4	30.5	0.0	
0:31:30	0.0	0.3	31.5	0.0	
0:32:30	0.0	0.2	32.5	0.0	
0:33:30	0.0	0.1	33.5	0.0	
0:34:30	0.0	0	34.5	0.0	
0:35:30	0.0	0	35.5	18.5	
0:42:30	5.3	3.5	42.5	12.6	
0:44:30	7.3	4	44.5	13.8	
0:46:30	6.5	3.8	46.5	10.7	
0:48:30	4.2	3.2	48.5	8.2	
0:50:30	3.9	3.1	50.5	6.7	
0:52:30	2.8	2.7	52.5	4.3	
0:54:30	1.5	2.1	54.5	2.6	
0:56:30	1.1	1.8	56.5	1.6	
0:58:30	0.5	1.3	58.5	0.8	
1:00:30	0.3	1.1	60.5	0.5	
1:02:30	0.1	0.7	62.5	0.2	
1:04:30	0.1	0.5	64.5	0.1	some
1:06:30	0.0	0.1	66.5	0.0	water bypass
1:08:30	0.0	0	68.5		

Total Gallons of Runoff:	**102**	
Total Rainfall in Sept 11th Storm:	0.32	inches
Total Rainfall in Sept 11th Storm:	0.81	cm
Total Area of Brookes Ave. Drainage Basin:	920	sq meters
Volume of Rainfall on Brookes Sept 11th:	7	cubic meters
Volume of Rainfall on Brookes Sept 11th:	**1,970**	gallons

% Rainfall: (Gallons of Runoff/Gallons of Rainfall)

5 %

Footnotes: The wooden weir had a 90 degree v-notch which was 3.5 cm high. In the v-notch, the edges were tapered to a sharp point. Height of the v-notch was less than the called for 6 cm above the downstream side of the weir.

1: Hydraulic head = the depth of water at the stage measuring point which is above the height of the v-notch.

Table 3.8: Rainfall vs Runoff Comparison
Perkins Parking Lot, September 27th, 2002

Elapsed Time	Q (gpm)	Hydraulic Head[1] (cm)	Elapsed time (minutes)	Gallons of Runoff per time interval	Comments
0:00:00	0.0	0	0	28	
0:20:00	2.8	2.7	20	32	
0:30:00	3.6	3	30	188	
0:57:00	10.3	4.6	57	486	
1:34:00	16.0	5.5	94	299	
1:54:00	13.9	5.2	114	337	
2:14:00	19.8	6	134	331	
2:34:00	13.3	5.1	154	189	
2:54:00	5.7	3.6	174	462	
3:27:00	22.3	6.3	207	362	
3:47:00	13.9	5.2	227	351	
4:05:00	25.0	6.6	245	494	
4:24:00	27.0	6.8	264	410	
4:47:00	8.7	4.3	287	175	
5:12:00	5.2	3.2	312	286	
5:44:00	12.6	5	344	421	
6:12:00	17.4	5.7	372	1050	
6:37:00	66.6	9.8	397	1147	Overflowing[2]
6:56:00	48.2	8.6	417	1194	Overflowing
7:24:00	40.3	8	444	1688	Overflowing
7:49:00	94.7	11.3	469	2041	Overflowing
8:12:00	82.7	10.7	492	2299	Overflowing
8:49:00	41.5	8.1	529	1150	Overflowing
9:09:00	73.5	10.2	549	1304	Overflowing
9:29:00	56.9	9.2	569	1369	Overflowing
9:59:00	34.3	7.5	599	1735	Overflowing
10:39:00	52.4	8.9	639	957	Overflowing
11:04:00	24.1	6.5	664	612	
11:39:00	10.9	4.7	699	270	
12:14:00	4.6	3.3	734	101	
12:38:00	1.4	2	768		

Total Gallons of Runoff: **21770**

Total Rainfall in Sept 27 storm:		2.59	inches
Total Rainfall in Sept 27 storm:		6.58	cm
Total Area of Perkins Drainage Basin:		4820	sq meters
Volume of Rainfall on Perkins Sept 27th:	to		cubic meters
Volume of Rainfall on Perkins Sept 27th:		**83,900**	**gallons**

% Runoff: (Gallons of Runoff/Gallons of Rainfall)*100

26 %

Footnotes: The wooden weir had a 90 degree v-notch which was 4.5 cm high. In the v-notch, the edges were tapered to a sharp point. Height of the v-notch was less than the called for 6 cm above the downstream side of the weir.

1: Hydraulic head = the depth of water at the stage measuring point which is above the height of the v-notch.

2: Overflowing = the weir was overtopped and capacity for accurate flow estimation is was lost (an underestimate).

Table 3.9: Rainfall vs Runoff Comparison
Brookes Avenue September 27th, 2002

Elapsed Time	Q (gpm)	Hydraulic Head[1] (cm)	elapsed time (minutes)	Gallons of Runoff per time interval	Comments
0:00:00	0.0	0	0	0.7	
0:12:00	0.1	0.7	12	12.0	
0:35:00	0.9	1.7	35	29.8	
0:56:00	1.9	2.3	56	44.5	
1:17:00	2.3	2.5	77	34.3	
1:42:00	0.4	1.2	102	5.8	
2:09:00	0.0	0.3	129	25.9	
2:31:00	2.3	2.5	151	61.7	
2:55:00	2.8	2.7	175	56.2	
3:15:00	2.8	2.7	195	46.2	
3:38:00	1.2	1.9	218	22.1	
4:04:00	0.5	1.3	244	13.5	
4:34:00	0.4	1.2	274	96.5	
4:54:00	9.2	4.4	294	229.3	
5:24:00	6.0	3.7	324	212.5	
5:46:00	13.3	5.1	346	184.9	
6:09:00	2.8	2.7	369	234.9	
6:34:00	16.0	5.5	394	587.8	
6:59:00	31.0	7.2	419	635.6	
7:34:00	5.3	3.5	454	169.0	
7:59:00	8.2	4.2	479	669.0	
8:34:00	30.0	7.1	514	462.2	
8:56:00	12.0	4.9	536	599.6	
9:26:00	27.9	6.9	566	390.9	
9:49:00	6.0	3.7	589	93.9	
10:09:00	3.3	2.9	609	55.0	
10:34:00	1.1	1.8	634	11.5	
10:54:00	0.1	0.6	654		

Total Gallons of Runoff: **4990**

Rainfall in Sept 27th storm: 2.59 inches
Rainfall in Sept 27th storm: 6.58 cm
of Brookes Ave Drainage Basin: 917 sq meters
f Rainfall on Brookes Sept 27th: 60 cubic meters
f Rainfall on Brookes Sept 27th: **15,940** gallons

% Runoff : (Gallons of Runoff/Gallons of Rainfall)*100

31 %

Footnotes: The wooden weir had a 90 degree v-notch which was 4.3 cm high. In the v-notch, the edges were tapered to a sharp point. Height of the v-notch was less than the called for 6 cm above the downstream side of the weir.

[1]: Hydraulic head = the depth of water at the stage measuring point which is above the height of the v-notch.

Table 3.10

Contaminants, Maximum Concentration (ppm), weir calculated Loading (mg), and Percent Detection, Perkins Parking Lot, 9/11/02

Element	MCL[1]	Maximum Concentration (ppm)	Total Loading (mg)	Detection %
Ag	0.1	0.003	3	31
Al	0.2	0.13	305	100
As	0.01	0.005	4	22
Ca	NA[2]	40.0	67600	100
Cd	0.005	0.002	1	19
Cr	0.1	0.007	11	100
Cu	1	0.035	61	100
Fe	0.3	0.047	61	100
K	NA	3.9	4100	100
Mg	NA	1.8	2900	100
Na	20	11.4	12600	100
Ni	0.1	0.012	7	47
P	NA	0.059	39	72
Pb	0.015	BDL[3]	0	0
Si	NA	0.49	1040	100
Sr	4	0.11	197	100
Zn	2	0.13	197	100

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

3: BDL = below detection limit, in this case it also indicates that Pb was not detected in any of the samples.

Table 3.11

Contaminants, maximum concentration (ppm), weir calculated loading (mg), and percent detection, Brookes Avenue, 9/11/02

Element	MCL[1]	Maximum Concentration (ppm)	Total Loading (mg)	Detection %
Ag	0.1	0.004	0	54
Al	0.2	0.10	4	54
As	0.01	0.005	0	3
Ca	NA[2]	35.2	1920	97
Cd	0.005	0.002	0	13
Cr	0.1	0.005	0	85
Cu	1	0.030	3	97
Fe	0.3	0.020	5	100
K	NA	9.5	1030	97
Mg	NA	1.8	210	97
Na	20	16.6	2210	97
Ni	0.1	0.003	0	5
P	NA	0.41	41	97
Pb	0.015	0.007	0	13
Si	NA	0.37	46	97
Sr	4	0.11	7	97
Zn	2	0.18	17	97

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

Table 3.12

Contaminants, maximum concentration (ppm), weir calculated loading (mg) and percent detection, Perkins Parking Lot, 9/27/02

Element	MCL[1]	Maxium Concentration (ppm)	Total Loading (mg)	Detection %
Ag	0.1	0.008	345	68
Al	0.2	0.13	3085	100
As	0.01	0.006	64	32
Ca	NA[2]	33.2	400400	100
Cd	0.005	0.002	14	16
Cr	0.1	0.008	176	100
Cu	1	0.034	382	77
Fe	0.3	0.034	101	39
K	NA	2.7	21100	100
Mg	NA	1.2	11600	100
Na	20	9.7	44000	100
Ni	0.1	0.009	6	13
P	NA	0.11	1360	52
Pb	0.015	0.033	42	16
Si	NA	3.4	13100	100
Sr	4	0.083	1160	100
Zn	2	0.069	1280	100

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

Table 3.13

Contaminants, maximum concentration (ppm), weir measured loading (mg), and percent detection, Brookes Avenue, 9/27/02

Element	MCL[1]	Maximum Concentration (ppm)	Total Loading (mg)	Detection %
Ag	0.1	0.007	60	93
Al	0.2	0.093	461	100
As	0.01	0.005	4	7
Ca	NA[2]	18.6	50570	100
Cd	0.005	0.002	14	18
Cr	0.1	0.015	57	93
Cu	1	0.040	114	96
Fe	0.3	0.074	91	54
K	NA	2.3	8980	100
Mg	NA	1.0	3165	100
Na	20	18.3	17910	100
Ni	0.1	0.004	1	4
P	NA	0.071	147	75
Pb	0.015	0.017	84	93
Si	NA	0.51	795	100
Sr	4	0.081	186	100
Zn	2	0.10	344	100

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

Table 3.14

Comparison of total Loadings (mg/sq meter) normalized to depth of rainfall (cm) between the Brookes Avenue and Perkins Parking lot drainage basins.

(based upon a rational method calculation for discharge)

	9/11/2002	9/11/2002	9/27/2002	9/27/2002
	Brookes Avenue	Perkins Lot	Brookes Avenue	Perkins Lot
Element	Loading Normalized[1]	Loading Normalized	Loading Normalized	Loading Normalized
Ag	0.004	0.004	0.019	0.000
Al	0.170	0.597	0.199	0.270
As	0.000	0.009	0.001	0.006
Ca	53.9	140.3	28.4	37.4
Cd	0.002	0.001	0.002	0.001
Cr	0.012	0.022	0.020	0.014
Cu	0.066	0.120	0.054	0.034
Fe	0.101	0.125	0.045	0.013
K	24.7	9.0	4.3	1.8
Mg	5.04	6.07	1.50	1.07
Na	47.59	24.84	12.14	4.57
Ni	0.002	0.019	0.002	0.002
P	0.996	0.081	0.090	0.090
Pb	0.005	0.000	0.035	0.005
Si	1.003	1.975	0.461	1.417
Sr	0.178	0.405	0.090	0.103
Zn	0.415	0.399	0.146	0.123

Footnotes:

1: Loading Normalized = Total chemical loading (mg) divided by inches of rainfall and area of the basin (m2).
(mg/m2)/cm rainfall

Highlighted elements are on the EPA's priority pollutant list.

Figure 3.1
Change in normalized suspended sediment production from the Cook remediation test plots

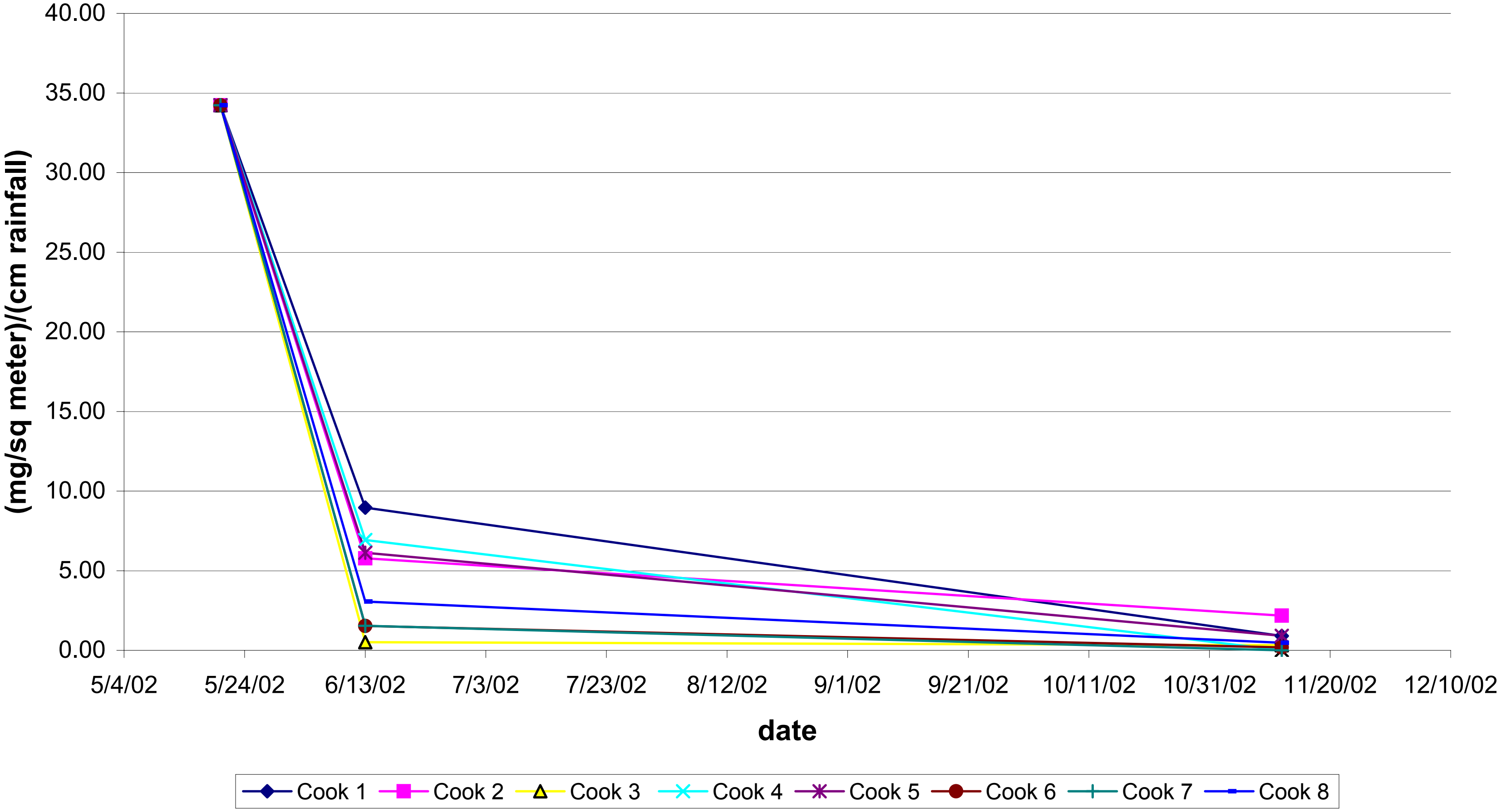


Figure 3.2

Change in sodium concentration in runoff from the Cook remediation test plots

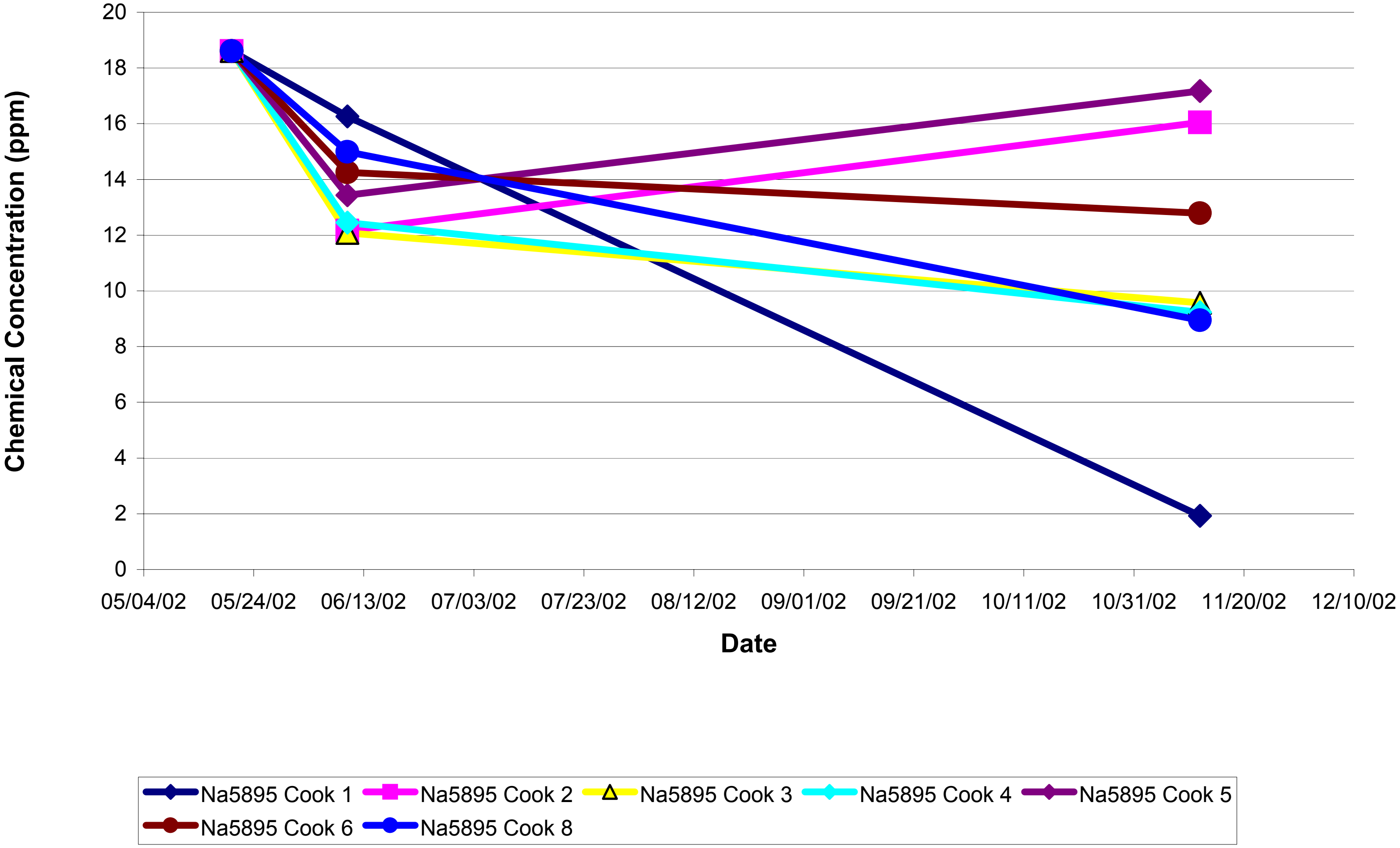


Figure 3.3

Discharge and Precipitation, Brookes Avenue 9/11/02. As a precipitation pulse occurs, it is immediately followed by a surge in stormwater discharge. Note that there are two rain pulses and two rising and falling limbs of this hydrograph.

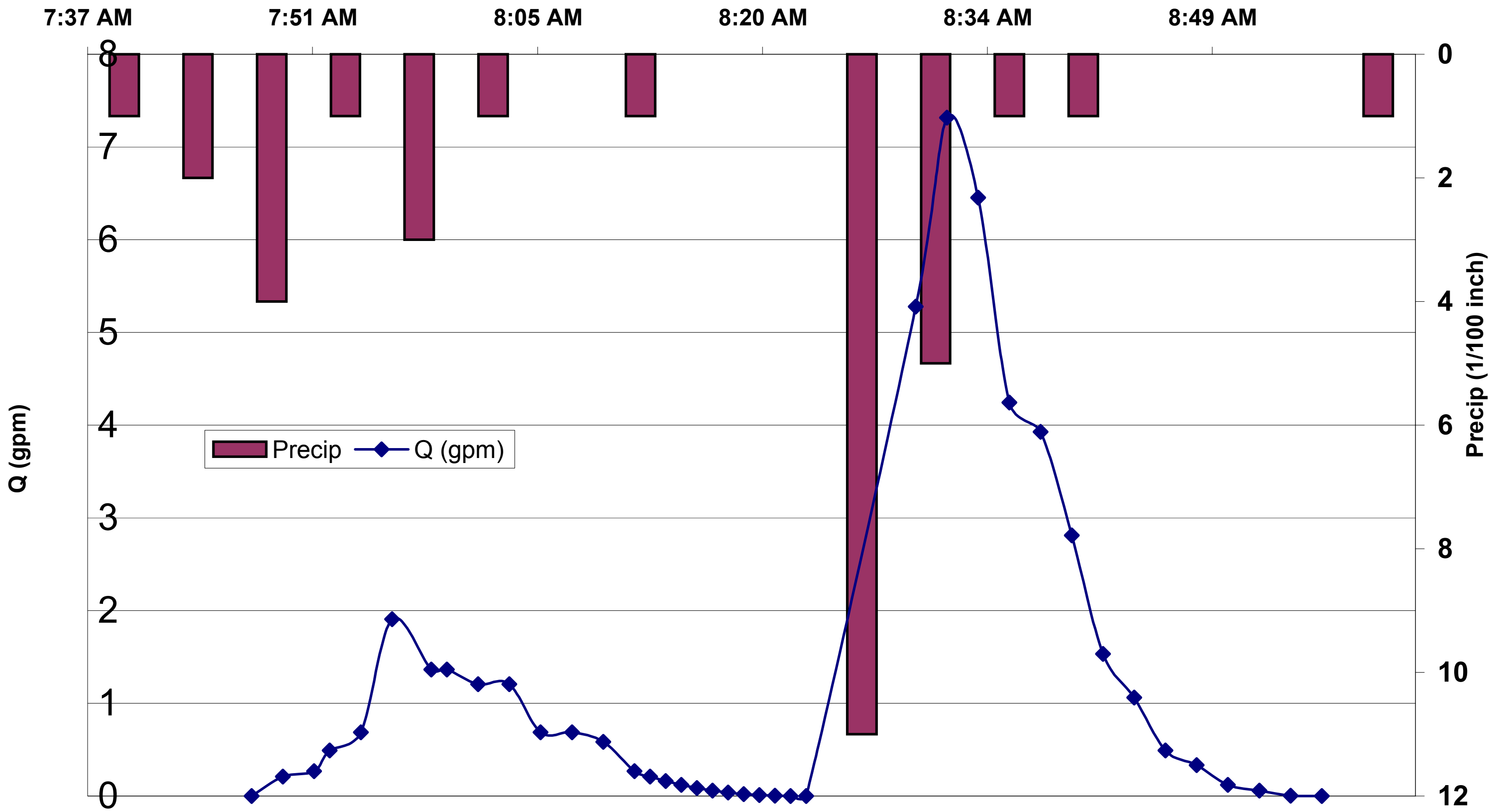


Figure 3.4

Discharge and Precipitation, Perkins Lot, 9/27/02.

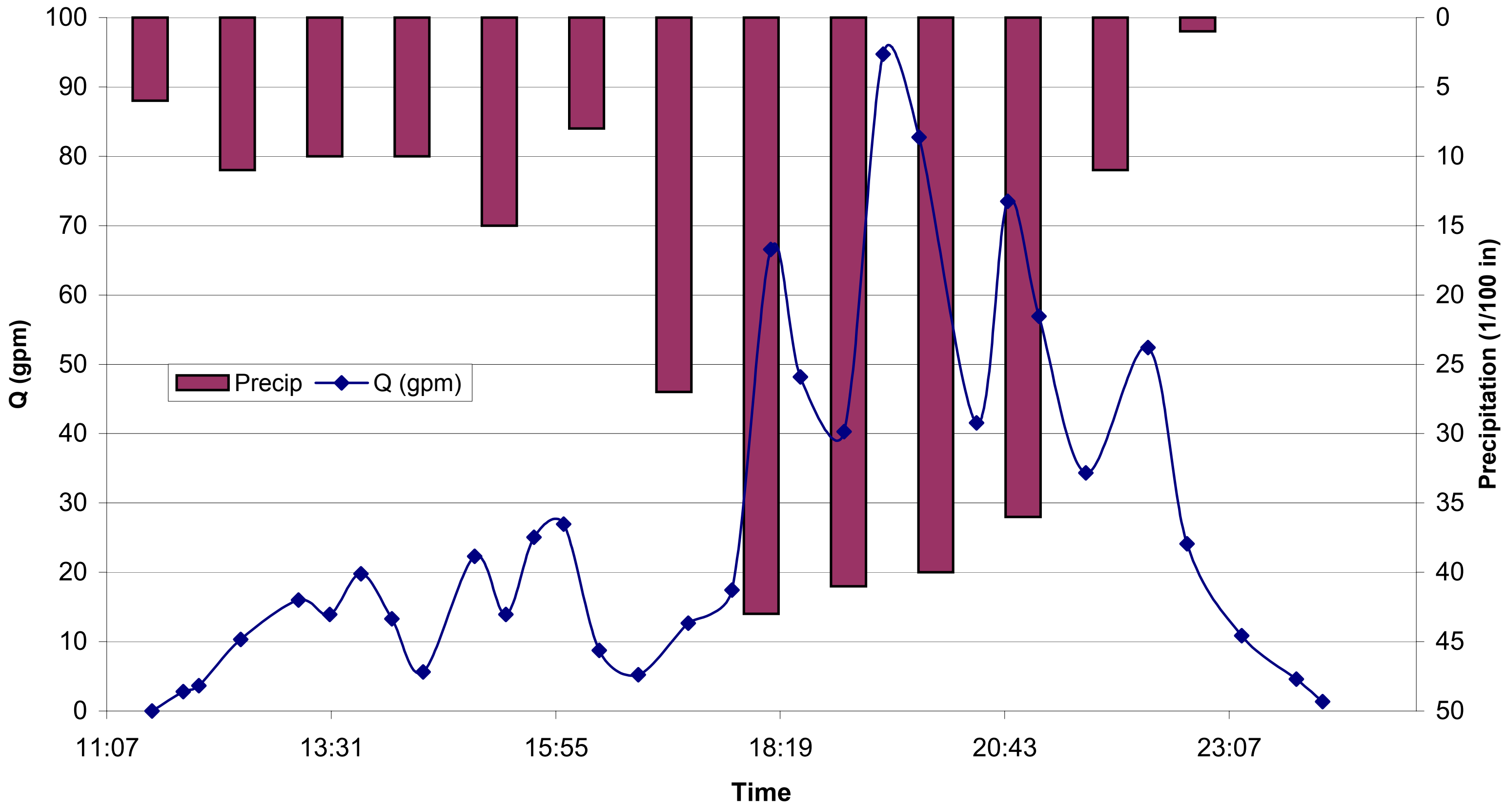


Figure 3.5
Discharge, pH, and Conductivity throughout the 9/11/02 Storm, Brookes Avenue

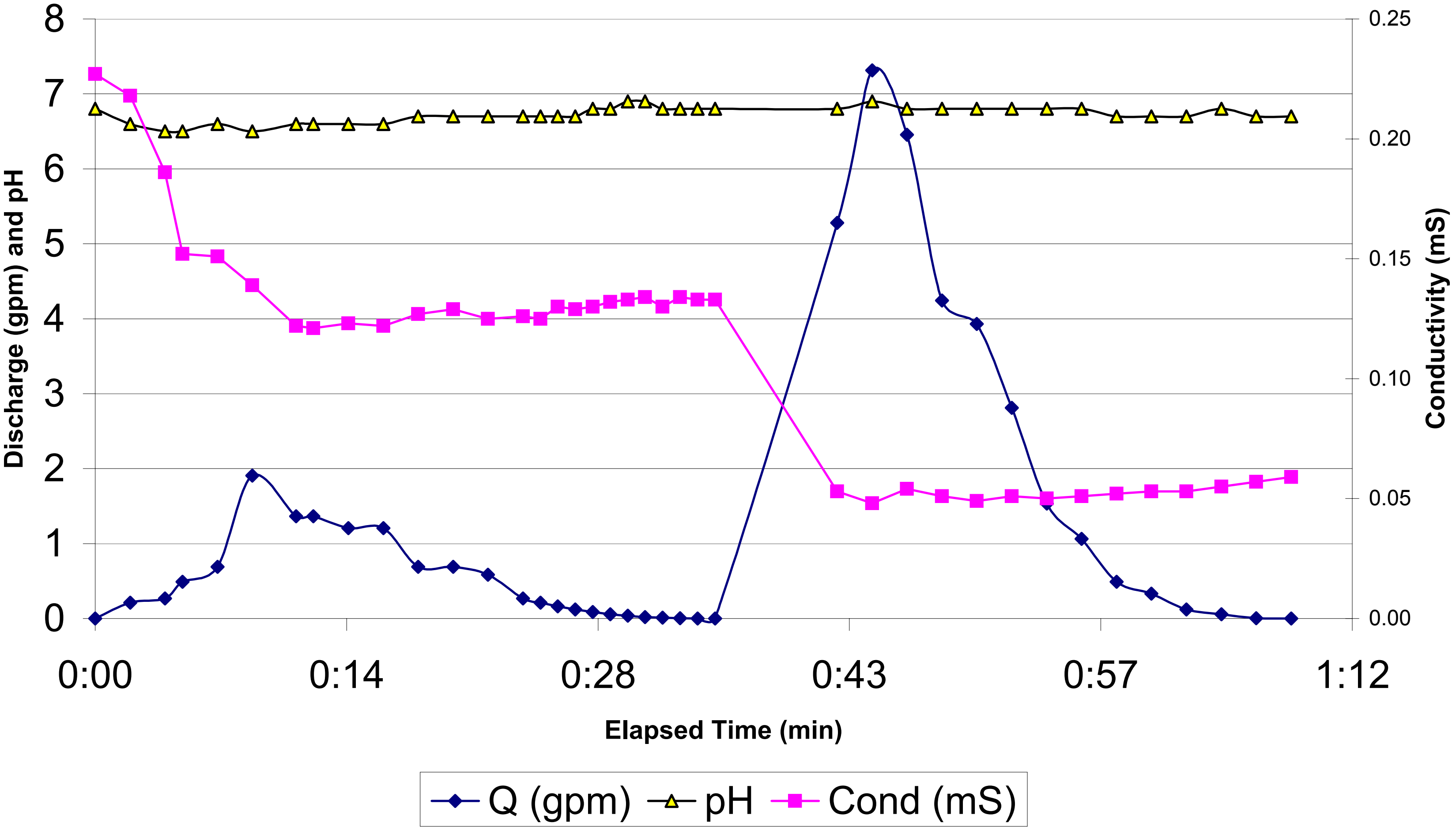
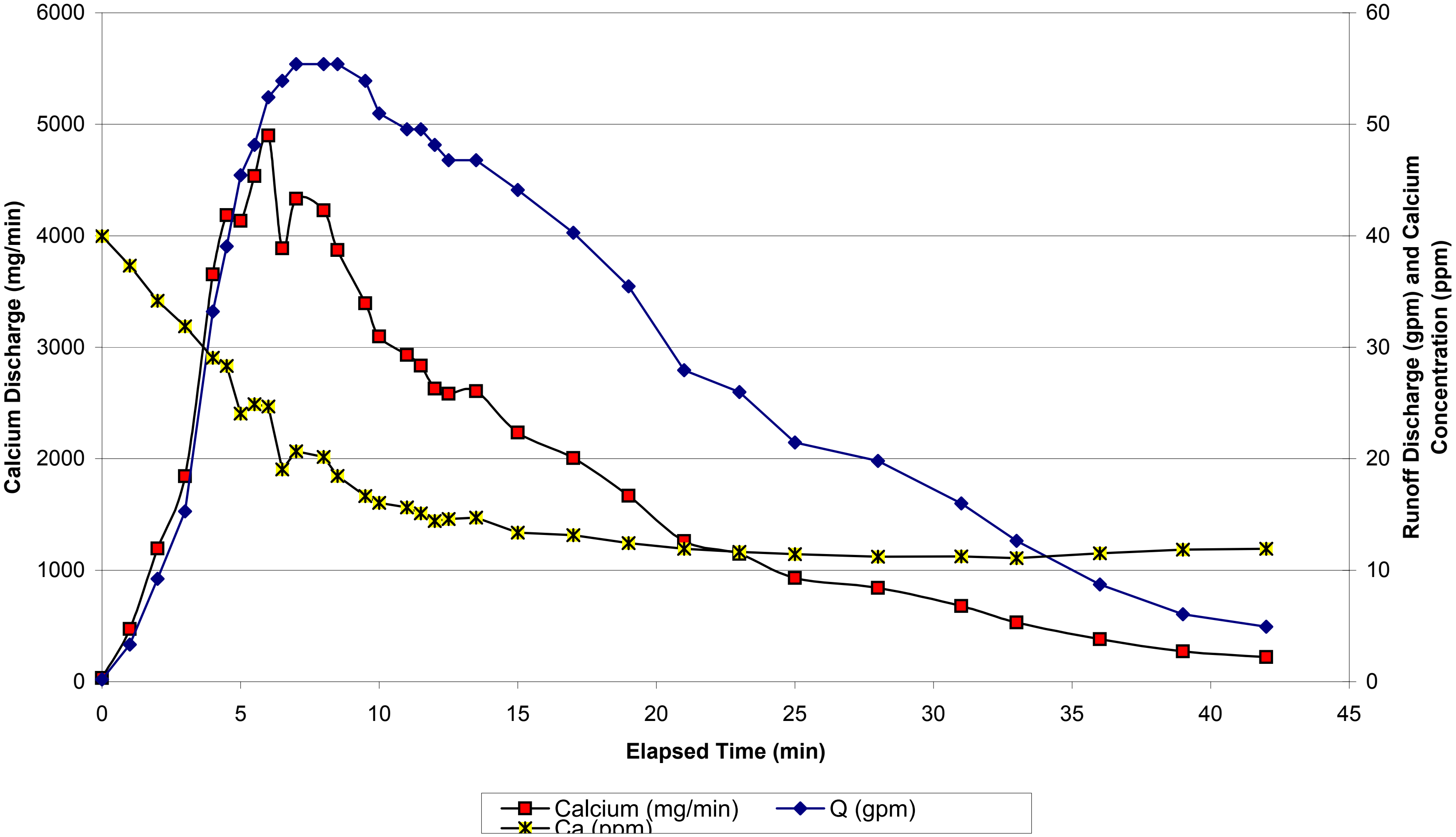


Figure 3.6

Calcium Concentration and Discharge with Runoff Discharge, Perkins weir 9/11/02



Chapter 4 – Discussion

Changes in Steady State Infiltration Rates with Remediation Treatment

Statistical analysis showed that, only one month after remediation, treatments consisting of compost, aeration, and seeding resulted in significantly greater infiltration rates than prior to remediation (Table 3.1). Such an increase was not seen after one month for either fenced plots or plots that received only aeration and seeding. Thus, to significantly and rapidly improve steady-state infiltration rates for compacted soils remediation must include both aeration and composting. However, after six months, sites which received only aeration and seeding did show a significantly greater infiltration rate than prior to remediation and the mean infiltration rates over these aerated sites were not significantly different than those which received compost and aeration. This suggests that with six months time, aeration and seeding may be just as effective in improving infiltration rates as the combined treatment of aeration, composting, and seeding. Improvement was seen in mean infiltration rates for all treatments over time (Table 3.1).

There are several explanations for these results. It has been shown that immediately after intense aeration, such as tilling, hydraulic conductivity is decreased because pore structure is lost (Coutadeur, 2002). This also has an effect on vegetative growth. Passioura, (2002), states that plant growth may be reduced in extremely loose soil. Immediately after aeration, it is likely that the soil did not have a healthy pore structure. Over time vegetative growth was seen, soil settling occurred, and the soil was probably reworked by earthworms. This resulted in a healthier pore structure yielding the infiltration improvement that was seen for all remediation treatments with time. I believe that composting added nutrients, which sped the growth of vegetative cover, improving pore structure (Coutadeur, 2002), resulting in the earlier improvements in infiltration rates over these sites.

After 6 months, sites which were only fenced had mean steady state infiltration rates of 8 cm/h, suggesting more than a 6 cm/h improvement over infiltration rates measured prior to fencing (Table 3.1). This result suggests that allowing compacted soils to stand alone with out further compaction allows their permeability to improve. This improvement must be the result of increased pore structure created by encroaching vegetation, such as the vine-like weeds that were seen on the cook control site, as well as macro-pore structures left by worm burrows.

After six months, sites which received aeration had mean infiltration rates more than 13 cm/h. Considering that precipitation in Burlington is typically of less intensity than these infiltration rates (http://www.erh.noaa.gov/btv/html/climo2.shtml) we can assume that the amount of runoff over remediated sites would be very little during most rain events in Burlington.

Changes in Normalized Suspended Sediment Loading with Remediation Treatment

After one month, significant improvements (drops) in normalized mean suspended sediment production were seen on sites that were both aerated and composted (Table 3.3). Statistically significant improvements were not seen over fenced or aerated sites until six months after remediation. I attribute these differences in large part to vegetative cover. After one month, vegetation was denser over the sites that received compost as treatment, while other sites had sparse grass cover. In general, vegetation prevents erosion, thus reducing suspended sediment production (Harden, 1992). After 6 months, sites that were aerated had dense grass cover and significantly less suspended sediment was produced compared to before remediation.

It is not clear what causes the significant drop in suspended sediment production on the sites that received just fencing. There was some vegetative cover over these surfaces; however, this cover was very superficial and patchy, so I do not believe this can account for all of the reduction in suspended sediment production. I also observed the presence of many pebbles covering the surface of the control plots. Reid and Dunne (1984) noted that abandoned dirt roads produced 130% less suspended sediment than active dirt roads. I believe that a similar result is seen here; there was less erosion over these fenced sites because their isolation allowed an armored layer of pebbles to develop and minimize the detachment of fine particles.

Prior to remediation, the mean mass of suspended sediment produced per square meter per cm of rainfall was 30.5 grams. Six months after remediation, mean normalized production of suspended sediment was less than 2 grams from fenced sites and less than 0.5 grams over aerated and composted sites. This indicates that through active remediation and an effort to protect greenspace from disturbance, total suspended sediment production could be drastically reduced throughout Burlington.

Changes in contaminant concentrations from the remediation test plots

Only three of the eight EPA priority pollutants that I tested for were detected regularly within the remediation plot runoff: Cu, Cr, and Zn (Table 3.4). However, these contaminants and the other EPA priority pollutants were detected in very low concentrations, well below their respective EPA MCL, and usually below the mean from the NURP (1981). Concentrations of these eight contaminants were similar to the concentrations seen in the study by Zartman (2001).

The elements that were most prevalent in the remediation runoff were Ca, K, Mg, Na, and Si (Table 3.5). Sodium concentrations showed a steady decrease over time for every site and testing round (Table 3.4, Figure 3.2). This makes sense since sodium is relatively soluble and its most likely source is deicing salt applied in the winter (Table 4.1). Over the summer, without a major source, its concentrations would naturally fall as it is washed out of the soils. I thought that I would see significant differences in chemical concentrations associated with remediation treatment differences; however, no significant chemical trends were associated with different treatments. Table 4.1 lists potential stormwater sources for the elements found in the remediation plots.

Stormwater flow, pH, and Conductivity analysis

Stormwater runoff flux responded rapidly on the rising and falling hydrograph limbs to increases and decreases in precipitation intensity through the 9/11/02 and 9/27/02 events (Figure 3.3 and Figure 3.4). My runoff verses rainfall analysis for the two drainage basins over the two storm events did not produce the data that I expected. Drainage basin delineations and land cover mapping (Figures 1.2 and 1.3 and Tables 1.1 and 1.2) suggested that the Perkins Parking lot and the Brookes Avenue drainage basins were covered by 85% and 75% impermeable surfaces, respectively, yet only 5-31% runoff was measured during the storm events using the weirs (Tables 3.6 through 3.9). The weirs were clearly inadequate for measuring storm flow from these drainage basins;

through significant portions of both the small and large storm events, the weirs were over topped (Tables 3.5 through 3.8). There are several other factors that may have contributed to this underestimate. There was water detention in puddles on the south side of the Perkins drainage basin. Also, greenspace was located down hill from impermeable areas at Perkins and Brookes Avenue (Figure 1.1 and 1.2). This greenspace could have acted as an infiltrating buffer for some of the runoff that was generated over the impermeable surfaces. This probably mattered more for the short, low-intensity storm because I suspect that during the high intensity, twelve-hour storm, runoff may have been generated over the green space. Weir design flaws including the lack of a uniform substrate leading to the weir and the lack of adequate height behind the weir may have also created errors within the runoff calculations.

Conductivity measurements showed dilution with increasing stormwater flux; that is, conductivity decreased when stormwater discharge increased because similar numbers of ions were dispersed in a greater volume of water (Figure 3.5). Rainwater pH was generally more acidic than stormwater pH suggesting that buffering of rainwater acidity occurred rapidly once flow moved over the drainage basins. Decreases in stormwater pH were associated with increases in rainfall intensity (Figure 3.5 and Appendix A). This must be because of a dilution of alkalinity ions in a greater volume of acidic runoff (Lepori, 2003). The opposite is also true; increases in pH are associated with lesser rainfall intensities and stormwater flow because there are more alkaline ions to buffering fewer acidic ions.

Stormwater Chemistry

Similar to the conductivity results, elements decreased in concentration (diluted) when stormwater discharge increased (Figure 3.6). Over entire storm events, chemical concentrations decreased per stormwater volume (Figure 3.6). This is important because it indicates that the first flush of stormwater has the highest concentrations of contaminants. Eight of the contaminants on the EPA's priority pollutant list were detected in stormwater samples (Ag, As, Cd, Cr, Cu, Ni, Pb, and Zn). In most samples these concentrations were low (Table 3.10 through Table 3.13), but in samples 3P1, 3B1, 3B2, and 3B3, the EPA MCL for lead was exceeded (Appendix B). The presence of these dissolved metals may be attributed to the sources listed in table 4.1 including corrosion of metal from cars, insecticides, gasoline combustion, tire degradation, oil, and natural sources such as the dissolution of soils.

Lead concentrations during the September 27th, 2002 storm event were much higher than during the short duration September 11th storm. At Perkins Parking lot, the first flush of stormwater contained 0.033 ppm of lead, more than twice the 0.015 MCL for lead and at Brookes Avenue lead was detected in 93% of the samples, with the first three samples above the MCL (Appendix B). It is very significant that three samples were above the MCL; this represents more than an hour of storm flow that had lead concentrations above the MCL. What is really intriguing about these lead concentrations is that they were so high during the 9/27/02 storm and so low during the 9/11/02 storm (Appendix B). Before the September 11th storm, there was a significant period of time without rainfall while before the September 27th storm there had been several recent and significant rainfalls. Thus, the higher lead concentrations are likely not due to runoff dissolving particulates on the basin surface, but perhaps due to the flushing of soil water. This hypothesis suggests that the soil over these sites may have high levels of lead. This is a real possibility especially in the Brookes drainage basin, which includes old houses. Runoff from the roof tops and sidewalls of old houses has elevated lead concentrations because of the lead in the materials that cover these surfaces (Steinberg, in progress). It is likely that particles of lead paint are common throughout the soils surrounding these houses, resulting in elevated lead concentrations within the soil; thus, lead may dissolve and flush out during storm events when the soils are saturated with water. These findings for lead are counter to the generally assumed paradigm that longer periods without rainfall are periods of deposition in urban environments and this results in higher concentrations of contaminants during a storm's first flush (Stephenson, 1981).

With rational method discharge calculations, I was able to estimate total dissolved chemical loads for the two drainage basins and storm events. I then normalized these data by unit depth of rainfall and drainage basin area, which allowed me to compare total loading between drainage basins and over two storms (Table 3.14). These data showed that there was more intense chemical loading for all chemicals during the short duration 9/11/02 storm than the long 9/27/02 storm except for Ag and Pb. This general trend is consistent with the paradigm that a greater period of dry deposition will result in a greater flushing of contaminants. The deviations seen in lead and silver may be associated with soil water flushing during the second, saturated storm.

Table 4.1
Typical Stormwater Sources for the 17 Elements Analyzed

Element	Sources
Ag	photo processing
Al	natural erosion, alloys
As	product of fossil fuel combustion, herbicides
Ca	deicing salts, natural erosion
Cd	fertilizers, insecticides
Cr	corrosion of alloys, electroplating wastes, natural erosion
Cu	corrosion of plumbing, metal platings, and brake linings, fungicides, and insecticides
Fe	rusting metals
K	natural erosion
Mg	natural erosion
Na	deicing salts
Ni	product of fossil fuel combustion, batteries
P	detergents, excrement, fertilizers, atmosphere
Pb	tire wear, car exhaust, oil, batteries
Si	natural erosion
Sr	natural erosion
Zn	Component of automobile tires, oils, and greese, ingredient in road salt

Sources:
NURP (1983), Whipple (1983), Dennison (1996)

Chapter 5 -Conclusions

Remediation consisting of aeration, composting, seeding and a barrier to prevent further compaction appears to be the best method for restoring soil permeability and reducing suspended sediment production from compacted soils. This treatment was able to significantly improve infiltration rates of compacted soils from about 1.5 cm/h to more than 15 cm/h, a ten-fold increase. This treatment was also able reduce suspended sediment production from 34 (g/m^2)/ (cm of rain) to less than 0.5 (g/m^2)/ (cm of rain), a seven 70 fold decrease. Burlington and other cities could significantly reduce stormwater runoff and suspended sediment production by remediating compacted soils and protecting existing greenspace.

I learned many things about the difficulty of obtaining accurate stormwater flow measurements directly from the street, but by estimating stormwater flow using the rational runoff method I was able to make several important observations. During the September 11th rain event, which was preceded by a long period of dry deposition, more intense loading occurred over both Perkins Parking lot and Brookes Avenue than during the September 27th storm, which was preceded by a rainy period. This agrees with previous research that suggests chemical loading may be more intense after long periods of dry deposition. Perkins Parking lot contributed more intense loading of the elements Al, As, Ca, Cr, Cu, Fe, Mg, Ni, Si, and Sr, while Brookes Avenue had more intense loadings of K, Na, P, Pb, and Zn (Table 3.14). These data suggests that the two basins may have different dissolved load chemical sources.

During the 9/27/02 storm, Brookes Avenue and Perkins Parking lot experienced an initial flux of lead in concentrations exceeding the MCL for drinking water. Initial flushing, such as this, was observed in both storms with all the elements measured (Appendix B and C). However, even with dilution, significant contaminant loading occurred throughout the storm events and increased with increasing stormwater discharge (Figure 3.7). This indicates that contaminant loading continues throughout urban runoff events, even though elemental concentrations may decrease due to dilution.

Future research is needed to better understand both aspects my study. Clearly more research is needed to explain the differences in sources of chemical loading between the two drainage basins. The most important research would analyze soil chemistry on the remediation test plots and at select places throughout the two studied drainage basins. This would enable one to narrow down the potential sources of the contaminants detected in significant concentrations in the runoff. It might also be interesting to test smaller drainage basins with more uniform land cover; this would also be useful in narrowing down contaminant sources within the runoff. Further event sampling would also be helpful to determine differences in chemical loading between the drainage basins and storm types. I believe that the remediation test plot study should be followed up to check on the condition of the test plots. Another interesting idea would be to remove the barriers around some of the remediation test plots and replace some of the barriers with shrubs, then to record what effect this has. How fast would greenspace be lost over non-protected surfaces? Do natural, more aesthetically pleasing barriers provide enough protection for the greenspace?

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Appendices

Appendix A1: Perkins Parking Lot Flow Data 9/11/02

height to V-notch (cm) 5.6

Sample	Time	Elapsed Time	Stage (cm)	Head (cm)	Q (gpm)	Cond (mS)	pH
1P1	7:41 AM	0:00:00	5.6	0.0	0.21	0.229	6.9
2P1	7:42 AM	0:01:00	8.5	2.9	3.34	0.213	7.2
3P1	7:43 AM	0:02:00	10	4.4	9.24	0.206	7.3
4P1	7:44 AM	0:03:00	11	5.4	15.27	0.189	7.3
5P1	7:45 AM	0:04:00	13	7.4	33.21	0.176	7.3
6P1	7:45 AM	0:04:30	13.5	7.9	39.04	0.162	7.4
7P1	7:46 AM	0:05:00	14	8.4	45.44	0.140	7.4
8P1	7:46 AM	0:05:30	14.2	8.6	48.16	0.138	7.4
9P1	7:47 AM	0:06:00	14.5	8.9	52.43	0.137	7.4
10P1	7:47 AM	0:06:30	14.6	9.0	53.90	0.108	7.4
11P1	7:48 AM	0:07:00	14.7	9.1	55.39	0.114	7.4
12P1	7:49 AM	0:08:00	14.7	9.1	55.39	0.102	7.4
13P1	7:49 AM	0:08:30	14.7	9.1	55.39	0.102	7.5
14P1	7:50 AM	0:09:30	14.6	9.0	53.90	0.093	7.6
15P1	7:51 AM	0:10:00	14.4	8.8	50.98	0.091	7.5
16P1	7:52 AM	0:11:00	14.3	8.7	49.56	0.088	7.5
17P1	7:52 AM	0:11:30	14.3	8.7	49.56	0.087	7.5
18P1	7:53 AM	0:12:00	14.2	8.6	48.16	0.083	7.5
19P1	7:53 AM	0:12:30	14.1	8.5	46.79	0.084	7.5
20P1	7:54 AM	0:13:30	14.1	8.5	46.79	0.082	7.6
21P1	7:56 AM	0:15:00	13.9	8.3	44.12	0.079	7.5
22P1	7:58 AM	0:17:00	13.6	8.0	40.27	0.077	7.5
23P1	8:00 AM	0:19:00	13.2	7.6	35.48	0.072	7.5
24P1	8:02 AM	0:21:00	12.5	6.9	27.94	0.069	7.5
25P1	8:04 AM	0:23:00	12.3	6.7	25.99	0.070	7.4
26P1	8:06 AM	0:25:00	11.8	6.2	21.46	0.066	7.4
27P1	8:09 AM	0:28:00	11.6	6.0	19.80	0.064	7.4
28P1	8:12 AM	0:31:00	11.1	5.5	15.98	0.064	7.4
29P1	8:14 AM	0:33:00	10.6	5.0	12.64	0.063	7.5
30P1	8:17 AM	0:36:00	9.9	4.3	8.73	0.066	7.4
31P1	8:20 AM	0:39:00	9.3	3.7	6.05	0.068	7.4
32P1	8:23 AM	0:42:00	9	3.4	4.92	0.070	7.4
Rain:						**0.017**	**4.9**

Appendix A2: Brookes Avenue Flow Data 9/11/02

Height to V: 3.5 cm

Sample	Time	Elapsed Time	Stage (cm)	Head (cm)	Q (gpm)	Cond (mS)	pH
1B1	7:47:30	0:00	3.5	0.0	0.000	0.227	6.8
2B1	7:49:30	0:02	4.4	0.9	0.210	0.218	6.6
3B1	7:51:30	0:04	4.5	1.0	0.268	0.186	6.5
4B1	7:52:30	0:05	4.8	1.3	0.492	0.152	6.5
5B1	7:54:30	0:07	5.0	1.5	0.688	0.151	6.6
6B1	7:56:30	0:09	5.8	2.3	1.908	0.139	6.5
7B1	7:59:00	0:11	5.5	2.0	1.364	0.122	6.6
8B1	8:00:00	0:12	5.5	2.0	1.364	0.121	6.6
9B1	8:02:00	0:14	5.4	1.9	1.207	0.123	6.6
10B1	8:04:00	0:16	5.4	1.9	1.207	0.122	6.6
11B1	8:06:00	0:18	5.0	1.5	0.688	0.127	6.7
12B1	8:08:00	0:20	5.0	1.5	0.688	0.129	6.7
13B1	8:10:00	0:22	4.9	1.4	0.585	0.125	6.7
14B1	8:12:00	0:24	4.5	1.0	0.268	0.126	6.7
15B1	8:13:00	0:25	4.4	0.9	0.210	0.125	6.7
16B1	8:14:00	0:26	4.3	0.8	0.161	0.130	6.7
17B1	8:15:00	0:27	4.2	0.7	0.119	0.129	6.7
18B1	8:16:00	0:28	4.1	0.6	0.085	0.130	6.8
19B1	8:17:00	0:29	4.0	0.5	0.057	0.132	6.8
20B1	8:18:00	0:30	3.9	0.4	0.036	0.133	6.9
21B1	8:19:00	0:31	3.8	0.3	0.020	0.134	6.9
22B1	8:20:00	0:32	3.7	0.2	0.010	0.130	6.8
23B1	8:21:00	0:33	3.6	0.1	0.003	0.134	6.8
24B1	8:22:00	0:34	3.5	0.0	0.000	0.133	6.8
25B1	8:23:00	0:35	3.5	0.0	0.000	0.133	6.8
26B1	8:30:00	0:42	7.0	3.5	5.280	0.053	6.8
27B1	8:32:00	0:44	7.5	4.0	7.316	0.048	6.9
28B1	8:34:00	0:46	7.3	3.8	6.453	0.054	6.8
29B1	8:36:00	0:48	6.7	3.2	4.245	0.051	6.8
30B1	8:38:00	0:50	6.6	3.1	3.929	0.049	6.8
31B1	8:40:00	0:52	6.2	2.7	2.810	0.051	6.8
32B1	8:42:00	0:54	5.6	2.1	1.534	0.050	6.8
33B1	8:44:00	0:56	5.3	1.8	1.061	0.051	6.8
34B1	8:46:00	0:58	4.8	1.3	0.492	0.052	6.7
35B1	8:48:00	1:00	4.6	1.1	0.333	0.053	6.7
36B1	8:50:00	1:02	4.2	0.7	0.119	0.053	6.7
37B1	8:52:00	1:04	4.0	0.5	0.057	0.055	6.8
38B1	8:54:00	1:06	3.6	0.1	0.003	0.057	6.7
39B1	8:56:00	1:08	3.5	0.0	0.000	0.059	6.7
Rain:						**0.017**	**4.9**

Appendix A3: Perkins Parking Lot Flow Data 9/27/02

Height to V: 4.5 cm

Sample	**Time**	**Elapsed Time**	**Stage (cm)**	**Head (cm)**	**Q (gpm)**	**Cond (uS)**	**pH**
1P3	11:36:00	0:00:00	4.5	0.0	0.000	178.90	6.9
2P3	11:56:00	0:20:00	7.2	2.7	2.810	128.90	6.6
3P3	12:06:00	0:30:00	7.5	3.0	3.628	109.40	6.8
4P3	12:33:00	0:57:00	9.1	4.6	10.302	69.00	7
5P3	13:10:00	1:34:00	10.0	5.5	15.980	46.70	7.1
6P3	13:30:00	1:54:00	9.7	5.2	13.921	37.20	7.2
7P3	13:50:00	2:14:00	10.5	6.0	19.798	33.60	7.3
8P3	14:10:00	2:34:00	9.6	5.1	13.272	37.20	7.3
9P3	14:30:00	2:54:00	8.1	3.6	5.655	45.30	7.3
10P3	15:03:00	3:27:00	10.8	6.3	22.327	34.00	7.2
11P3	15:23:00	3:47:00	9.7	5.2	13.921	34.40	7.3
12P3	15:41:00	4:05:00	11.1	6.6	25.042	28.00	7.3
13P3	16:00:00	4:24:00	11.3	6.8	26.956	27.50	7.2
14P3	16:23:00	4:47:00	8.8	4.3	8.732	39.80	7.3
15P3	16:48:00	5:12:00	7.7	3.2	5.245	45.60	7.3
16P3	17:20:00	5:44:00	9.5	5.0	12.642	39.60	7.3
17P3	17:48:00	6:12:00	10.2	5.7	17.448	23.10	7.3
18P3	18:13:00	6:37:00	14.3	9.8	66.553	19.20	7.1
19P3	18:32:00	6:56:00	13.1	8.6	48.162	20.10	7
20P3	19:00:00	7:24:00	12.5	8.0	40.273	22.20	7.1
21P3	19:25:00	7:49:00	15.8	11.3	94.735	17.00	7.2
22P3	19:48:00	8:12:00	15.2	10.7	82.746	14.70	7.3
23P3	20:25:00	8:49:00	12.6	8.1	41.529	20.00	7.2
24P3	20:45:00	9:09:00	14.7	10.2	73.489	16.10	7.2
25P3	21:05:00	9:29:00	13.7	9.2	56.912	19.50	7
26P3	21:35:00	9:59:00	12.0	7.5	34.335	20.00	7
27P3	22:15:00	10:39:00	13.4	8.9	52.428	18.90	7.1
28P3	22:40:00	11:04:00	11.0	6.5	24.116	25.50	7.1
29P3	23:15:00	11:39:00	9.2	4.7	10.860	33.70	7.1
30P3	23:50:00	12:14:00	7.8	3.3	4.575	45.20	7.1
31P3	0:14:00	12:38:00	6.5	2.0	1.364	55.80	7.2
R1	12:53 PM					14.3	7.3
R2	1:53 PM					10.3	6.2
R3	3:07 PM					8.4	6.1
R4	3:55 PM					10.5	6.3
R5	5:10 PM					4.3	6
R6	6:00 PM					8.4	7.1
R7	6:22 PM					6.7	6.4
R8	6:44 PM					7	5.9
R9	7:13 PM					12.6	6.1
R10	7:30 PM					5.8	6.2
R11	8:17 PM					3.5	6.1
R12	8:40 PM					5.3	6.2
R13	9:15 PM					3.1	6.1
R14	10:15 PM					8.5	6.2
R15	11:15 PM					4.4	5.9
R16	24:14:00					n/a	6.3

Appendix A4: Brookes Avenue Flow Data 9/27/02

Height to V: 4.3

Sample	Time	Elapsed Time	Stage (cm)	Head (cm)	Q (gpm)	Cond (uS)	pH
1B3	12:36 PM	0:00:00	4.3	0.0	0.000	135.8	6.6
2B3	12:48 PM	0:12:00	5.0	0.7	0.119	95.3	6.7
3B3	1:11 PM	0:35:00	6.0	1.7	0.926	92	6.7
4B3	1:32 PM	0:56:00	6.6	2.3	1.908	57.1	7.1
5B3	1:53 PM	1:17:00	6.8	2.5	2.333	40.2	7.2
6B3	2:18 PM	1:42:00	5.5	1.2	0.408	48.8	7.1
7B3	2:45 PM	2:09:00	4.6	0.3	0.020	110.8	7.1
8B3	3:07 PM	2:31:00	6.8	2.5	2.333	38.8	7.2
9B3	3:31 PM	2:55:00	7.0	2.7	2.810	32.8	7.2
10B3	3:51 PM	3:15:00	7.0	2.7	2.810	29.9	7.3
11B3	4:14 PM	3:38:00	6.2	1.9	1.207	27.1	7.2
12B3	4:40 PM	4:04:00	5.6	1.3	0.492	55.4	7.2
13B3	5:10 PM	4:34:00	5.5	1.2	0.408	66.3	7.1
14B3	5:30 PM	4:54:00	8.7	4.4	9.238	33.2	7.3
15B3	6:00 PM	5:24:00	8.0	3.7	6.047	24.9	7.2
16B3	6:22 PM	5:46:00	9.4	5.1	13.272	11.2	6.9
17B3	6:45 PM	6:09:00	7.0	2.7	2.810	25.4	6.9
18B3	7:10 PM	6:34:00	9.8	5.5	15.980	14.4	6.8
19B3	7:35 PM	6:59:00	11.5	7.2	31.041	11.1	7
20B3	8:10 PM	7:34:00	7.8	3.5	5.280	16.2	7.1
21B3	8:35 PM	7:59:00	8.5	4.2	8.243	16.5	7.1
22B3	9:10 PM	8:34:00	11.4	7.1	29.987	11.3	7
23B3	9:32 PM	8:56:00	9.2	4.9	12.030	15.5	6.9
24B3	10:02 PM	9:26:00	11.2	6.9	27.945	11.3	7
25B3	10:25 PM	9:49:00	8.0	3.7	6.047	18.1	6.9
26B3	10:45 PM	10:09:00	7.2	2.9	3.342	21.3	6.8
27B3	11:10 PM	10:34:00	6.1	1.8	1.061	23.8	6.8
28B3	11:30 PM	10:54:00	4.9	0.6	0.085	45.5	6.8
R1	12:53					14.3	7.3
R2	13:53					10.3	6.2
R3	15:07					8.4	6.1
R4	15:55					10.5	6.3
R5	17:10					4.3	6
R6	18:00					8.4	7.1
R7	18:22					6.7	6.4
R8	18:44					7	5.9
R9	19:13					12.6	6.1
R10	19:30					5.8	6.2
R11	20:17					3.5	6.1
R12	20:40					5.3	6.2
R13	21:15					3.1	6.1
R14	22:15					8.5	6.2
R15	23:15					4.4	5.9
R16	24:14:00					n/a	6.3

Appendix B1: Perkins Parking Lot Samples: Chemical Concentrations (ppm) for 9/11/02 Rain Event

Sample	Ag	Al	As	Ca	Cd	Cr	Cu	Fe	K	Mg	Na	Ni	P	Pb	Si	Sr	Zn	
	0.001	**0.002**	**0.004**	**0.0001**	**0.0004**	**0.001**	**0.002**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.002**	**0.008**	**0.004**	**0.001**	**0.0002**	**3E-04**	**Detection Limit**
	0.1	**0.2**	**0.01**	**NA**	**0.005**	**0.1**	**1**	**0.3**	**NA**	**NA**	**20**	**0.1**	**NA**	**0.015**	**NA**	**4**	**2**	**MCL**
1P1	BDL	0.126	BDL	39.960	0.001	0.007	0.033	0.047	3.886	1.751	11.430	0.012	0.059	BDL	0.464	0.113	0.127	
2P1	BDL	0.115	0.004	37.330	BDL	0.007	0.031	0.033	3.238	1.615	6.519	0.009	0.016	BDL	0.381	0.105	0.087	
3P1	BDL	0.108	BDL	34.160	BDL	0.006	0.035	0.028	3.150	1.651	3.158	0.008	0.124	BDL	0.485	0.096	0.095	
4P1	BDL	0.112	BDL	31.880	BDL	0.004	0.034	0.032	2.276	1.427	5.556	0.007	0.010	BDL	0.316	0.090	0.111	
5P1	BDL	0.096	BDL	29.060	BDL	0.005	0.028	0.026	2.235	1.306	7.696	0.008	0.019	BDL	0.331	0.083	0.076	
6P1	BDL	0.095	BDL	28.320	BDL	0.004	0.023	0.023	1.728	1.228	6.100	0.010	0.012	BDL	0.302	0.079	0.068	
7P1	BDL	0.090	BDL	24.040	BDL	0.003	0.025	0.024	1.478	1.254	4.546	0.007	0.014	BDL	0.273	0.068	0.083	
8P1	BDL	0.094	BDL	24.880	0.002	0.005	0.027	0.034	1.312	1.091	5.937	0.008	BDL	BDL	0.301	0.071	0.099	
9P1	BDL	0.091	BDL	24.690	BDL	0.003	0.024	0.023	1.283	1.031	4.477	0.005	0.012	BDL	0.279	0.070	0.096	
10P1	BDL	0.077	BDL	19.050	BDL	0.003	0.019	0.015	1.076	0.854	3.246	0.004	0.013	BDL	0.231	0.054	0.085	
11P1	BDL	0.091	BDL	20.660	BDL	0.003	0.020	0.023	1.398	1.097	3.420	0.005	0.014	BDL	1.129	0.058	0.086	
12P1	BDL	0.097	BDL	20.160	BDL	0.002	0.012	0.047	0.732	1.080	2.609	BDL	0.014	BDL	0.252	0.064	0.028	
13P1	BDL	0.076	BDL	18.460	BDL	0.003	0.015	0.015	0.961	0.805	2.613	0.003	0.026	BDL	0.233	0.051	0.055	
14P1	BDL	0.066	BDL	16.640	BDL	0.003	0.015	0.011	0.701	0.700	3.595	0.002	BDL	BDL	0.210	0.047	0.057	
15P1	BDL	0.073	BDL	16.050	0.001	0.003	0.013	0.018	0.739	0.663	2.406	0.004	0.010	BDL	0.214	0.046	0.065	
16P1	0.002	0.067	BDL	15.630	BDL	0.002	0.012	0.009	0.781	0.636	2.256	0.002	0.011	BDL	0.200	0.045	0.047	
17P1	BDL	0.069	0.005	15.110	BDL	0.001	0.013	0.011	0.821	0.619	2.214	BDL	BDL	BDL	0.189	0.044	0.091	
18P1	0.003	0.076	0.004	14.420	BDL	0.002	0.014	0.010	0.779	0.599	2.113	BDL	BDL	BDL	0.190	0.041	0.036	
19P1	0.003	0.075	BDL	14.590	BDL	0.002	0.012	0.010	0.768	0.597	2.088	BDL	0.012	BDL	0.190	0.042	0.035	
20P1	BDL	0.072	BDL	14.720	BDL	0.002	0.012	0.009	0.778	0.584	2.046	BDL	BDL	BDL	0.187	0.043	0.035	
21P1	BDL	0.062	BDL	13.380	BDL	0.002	0.013	0.008	0.837	0.538	2.119	BDL	0.012	BDL	0.147	0.039	0.030	
22P1	BDL	0.069	BDL	13.150	0.001	0.003	0.013	0.016	0.828	0.522	2.003	BDL	BDL	BDL	0.197	0.039	0.030	
23P1	0.002	0.062	BDL	12.420	BDL	0.002	0.012	0.008	0.811	0.509	1.828	BDL	BDL	BDL	0.181	0.037	0.029	
24P1	BDL	0.064	0.004	11.930	BDL	0.003	0.009	0.007	0.772	0.477	1.737	BDL	BDL	BDL	0.191	0.035	0.027	
25P1	0.001	0.057	BDL	11.650	BDL	0.003	0.011	0.007	0.862	0.465	1.809	BDL	0.012	BDL	0.171	0.035	0.031	
26P1	BDL	0.057	0.004	11.440	BDL	0.002	0.011	0.005	0.854	0.441	1.656	BDL	BDL	BDL	0.178	0.034	0.030	
27P1	0.001	0.064	0.005	11.220	0.001	0.003	0.009	0.016	0.785	0.441	1.563	BDL	0.012	BDL	0.195	0.034	0.027	
28P1	0.003	0.059	BDL	11.230	BDL	0.002	0.010	0.006	0.834	0.427	1.638	BDL	0.017	BDL	0.187	0.033	0.025	
29P1	0.002	0.055	BDL	11.080	BDL	0.001	0.009	0.005	0.847	0.419	1.529	BDL	0.013	BDL	0.186	0.033	0.025	
30P1	0.003	0.055	BDL	11.510	BDL	0.002	0.011	0.005	0.827	0.447	1.616	BDL	0.011	BDL	0.198	0.034	0.033	
31P1	0.002	0.055	BDL	11.850	BDL	0.002	0.010	0.005	0.814	0.464	1.636	BDL	0.011	BDL	0.213	0.036	0.036	
32P1	BDL	0.063	0.005	11.930	0.002	0.003	0.010	0.057	0.818	0.497	1.934	BDL	0.020	BDL	0.237	0.038	0.081	
Rain	BDL	BDL	BDL	1.37	BDL	BDL	0.011	BDL	0.32	0.20	2.35	BDL	BDL	BDL	0.02	0.008	0.005	

Footnote: Rain was not filtered before acidification; Thus, concentrations in the rain may be elevated

Appendix B2: Brookes Ave Samples: Chemical Concentrations (ppm) for 9/11/02

Sample Name	**Ag**	**Al**	**As**	**Ca**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**Na**	**Ni**	**P**	**Pb**	**Si**	**Sr**	**Zn**
Detection Limit	**0.001**	**0.002**	**0.004**	**0.0001**	**0.0004**	**0.001**	**0.002**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.002**	**0.008**	**0.004**	**0.001**	**0.0002**	**0.0003**
MCL or Other	**0.1**	**0.2**	**0.01**	**NA**	**0.005**	**0.1**	**1**	**0.3**	**NA**	**NA**	**20**	**0.1**	**NA**	**0.015**	**NA**	**4**	**2**
1B1	BDL	0.105	BDL	35.170	0.001	0.004	0.021	0.020	6.719	1.606	10.550	0.003	0.282	0.005	0.372	0.113	0.175
2B1	BDL	0.090	BDL	25.750	BDL	0.003	0.030	0.012	9.547	1.774	11.720	0.002	0.409	BDL	0.211	0.084	0.177
3B1	BDL	0.086	BDL	18.970	BDL	0.002	0.024	0.012	9.067	1.825	11.200	BDL	0.395	BDL	0.227	0.062	0.152
4B1	BDL	0.063	BDL	13.330	BDL	0.002	0.016	0.014	7.827	1.734	13.440	BDL	0.309	BDL	0.269	0.043	0.112
5B1	BDL	0.061	BDL	11.660	BDL	0.002	0.016	0.013	6.491	1.442	13.920	BDL	0.175	BDL	0.267	0.038	0.088
6B1	0.003	0.055	BDL	10.020	BDL	0.002	0.014	0.014	5.590	1.227	13.740	BDL	0.115	BDL	0.255	0.033	0.074
7B1	0.003	0.048	BDL	8.518	BDL	0.002	0.011	0.016	4.647	1.019	12.130	BDL	0.132	BDL	0.159	0.028	0.055
8B1	0.001	BDL	BDL	BDL	BDL	BDL	BDL	0.003	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
9B1	BDL	0.063	BDL	8.187	0.001	0.005	0.011	0.026	4.263	0.955	13.110	BDL	0.116	0.007	0.187	0.028	0.096
10B1	BDL	0.050	BDL	8.122	BDL	0.003	0.010	0.022	4.036	0.901	13.080	BDL	0.093	BDL	0.220	0.027	0.067
11B1	BDL	0.050	BDL	8.249	BDL	0.003	0.012	0.017	3.918	0.896	13.600	BDL	0.095	BDL	0.160	0.027	0.045
12B1	0.002	0.051	BDL	8.025	BDL	0.003	0.009	0.014	3.745	0.867	14.160	BDL	0.097	0.004	0.149	0.027	0.079
13B1	0.002	0.043	BDL	7.873	BDL	0.003	0.013	0.013	3.523	0.864	16.570	BDL	0.057	BDL	0.220	0.027	0.094
14B1	0.002	0.047	BDL	7.555	BDL	0.003	0.010	0.016	3.446	0.780	14.780	BDL	0.070	BDL	0.196	0.026	0.064
15B1	0.002	0.045	BDL	7.334	BDL	0.002	0.015	0.020	3.356	0.763	15.130	BDL	0.066	BDL	0.181	0.024	0.051
16B1	0.002	0.046	BDL	7.152	BDL	0.001	0.014	0.018	3.242	0.761	15.530	BDL	0.053	BDL	0.190	0.024	0.085
17B1	0.001	0.043	BDL	7.226	BDL	0.002	0.012	0.014	3.312	0.752	16.120	BDL	0.033	BDL	0.217	0.025	0.051
18B1	BDL	0.046	BDL	7.301	BDL	0.003	0.010	0.015	3.180	0.736	15.530	BDL	0.043	BDL	0.213	0.025	0.044
19B1	BDL	0.048	BDL	7.418	BDL	0.002	0.010	0.022	3.109	0.754	15.940	BDL	0.021	0.004	0.202	0.026	0.070
20B1	0.002	0.046	BDL	9.223	BDL	0.002	0.007	0.014	3.036	0.773	15.750	BDL	0.020	0.005	0.197	0.040	0.034
21B1	0.001	0.044	BDL	7.664	BDL	0.002	0.007	0.016	3.114	0.774	16.120	BDL	0.046	BDL	0.231	0.027	0.028
22B1	0.002	0.044	BDL	7.904	BDL	0.003	0.047	0.058	3.146	0.785	16.200	BDL	0.046	BDL	0.629	0.080	0.040
23B1	BDL	BDL	BDL	8.403	BDL	0.003	0.011	0.012	3.301	0.794	15.800	BDL	0.033	BDL	0.227	0.032	0.035
24B1	0.002	BDL	BDL	8.321	BDL	0.002	0.015	0.016	3.417	0.825	16.260	BDL	0.035	BDL	0.215	0.031	0.072
25B1	0.001	BDL	0.005	8.349	BDL	0.001	0.016	0.012	3.423	0.798	16.380	BDL	0.023	BDL	0.192	0.030	0.040
26B1	0.002	BDL	BDL	4.346	BDL	BDL	0.007	0.012	1.840	0.440	4.526	BDL	0.080	BDL	0.109	0.016	0.048
27B1	BDL	BDL	BDL	3.668	0.001	0.002	0.005	0.021	2.147	0.426	3.529	BDL	0.111	BDL	0.125	0.013	0.031
28B1	BDL	BDL	BDL	4.145	BDL	BDL	0.005	0.010	2.639	0.456	3.884	BDL	0.138	BDL	0.114	0.013	0.024
29B1	0.002	BDL	BDL	3.934	BDL	0.001	0.004	0.009	2.398	0.445	3.511	BDL	0.121	BDL	0.093	0.013	0.026
30B1	BDL	BDL	BDL	3.700	BDL	BDL	0.006	0.007	2.328	0.421	3.587	BDL	0.106	BDL	0.065	0.012	0.040
31B1	0.002	BDL	BDL	3.731	BDL	BDL	0.009	0.006	2.277	0.429	3.896	BDL	0.108	BDL	0.063	0.013	0.034
32B1	BDL	BDL	BDL	3.518	0.001	0.002	0.006	0.017	1.988	0.382	4.049	BDL	0.089	BDL	0.078	0.012	0.025
33B1	BDL	BDL	BDL	3.649	BDL	0.002	0.005	0.005	2.046	0.401	4.124	BDL	0.086	BDL	0.083	0.012	0.039
34B1	0.003	BDL	BDL	3.680	BDL	0.002	0.006	0.009	2.090	0.402	4.112	BDL	0.099	BDL	0.082	0.012	0.042
35B1	0.002	BDL	BDL	3.749	BDL	0.003	0.025	0.014	2.479	0.427	4.994	BDL	0.086	BDL	0.111	0.013	0.045
36B1	0.004	BDL	BDL	3.540	BDL	0.002	0.007	0.010	2.047	0.412	4.437	BDL	0.087	BDL	0.083	0.012	0.039
37B1	BDL	BDL	BDL	3.888	BDL	0.001	0.007	0.008	2.099	0.426	4.580	BDL	0.089	BDL	0.063	0.013	0.064
38B1	BDL	BDL	BDL	4.374	BDL	0.002	0.008	0.002	2.166	0.436	4.593	BDL	0.094	BDL	0.098	0.015	0.060
39B1	0.001	BDL	BDL	4.575	0.002	0.004	0.012	0.023	2.144	0.461	4.801	BDL	0.084	BDL	0.121	0.017	0.115
Rain	BDL	BDL	BDL	1.365	BDL	BDL	0.011	BDL	0.322	0.200	2.345	BDL	BDL	BDL	0.018	0.008	0.005

Footnote: rain was not filtered before acidication; thus, concentrations within the rain may be elevated

Appendix B3: Perkins Parking Lot Samples: Chemical Concentrations (ppm) for 9/27/02 Rain Event

Sample	Ag	Al	As	Ca	Cd	Cr	Cu	Fe	K	Mg	Na	Ni	P	Pb	Si	Sr	Zn
Detection Limit	**0.001**	**0.002**	**0.004**	**0.0001**	**0.0004**	**0.001**	**0.002**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.002**	**0.008**	**0.004**	**0.001**	**0.0002**	**0.0003**
MCL or Other	**0.1**	**0.2**	**0.01**	**NA**	**0.005**	**0.1**	**1**	**0.3**	**NA**	**NA**	**20**	**0.1**	**NA**	**0.015**	**NA**	**4**	**2**
3P1	BDL	0.128	0.006	33.22	0.0009	0.008	0.034	0.034	2.67	0.119	0.39	0.003	0.056	0.0325	0.131	0.005	0.069
3P2	BDL	0.114	0.004	25.58	BDL	0.005	0.019	0.024	1.37	1.166	9.68	0.009	0.096	BDL	3.441	0.083	0.058
3P3	BDL	0.102	0.004	20.76	BDL	0.004	0.014	0.015	1.15	0.872	5.45	0.005	0.037	BDL	2.090	0.064	0.056
3P4	BDL	0.090	0.004	13.04	BDL	0.003	0.011	0.026	0.76	0.724	4.25	0.003	0.039	0.0042	1.613	0.053	0.048
3P5	BDL	0.059	0.004	9.14	BDL	0.003	0.013	0.008	0.51	0.446	2.50	BDL	0.030	0.0047	0.836	0.035	0.047
3P6	0.002	0.071	BDL	7.20	BDL	0.002	0.014	0.011	0.60	0.288	1.48	BDL	0.013	BDL	0.440	0.024	0.037
3P7	BDL	0.065	BDL	7.01	BDL	0.002	0.012	0.002	0.45	0.222	0.91	BDL	0.024	BDL	0.248	0.019	0.034
3P8	0.002	0.069	0.006	7.78	BDL	0.002	0.006	0.002	0.39	0.201	0.70	BDL	0.011	0.0046	0.201	0.018	0.023
3P9	BDL	0.078	0.005	9.46	BDL	0.002	0.012	0.007	0.48	0.209	0.64	BDL	0.017	BDL	0.229	0.020	0.016
3P10	BDL	0.061	0.005	6.61	BDL	0.002	0.012	0.001	0.37	0.267	0.85	BDL	0.013	BDL	0.289	0.024	0.018
3P11	0.002	0.062	BDL	7.30	BDL	0.002	0.004	BDL	0.33	0.169	0.59	BDL	0.015	BDL	0.160	0.016	0.013
3P12	0.008	0.063	BDL	5.92	0.0015	0.004	0.007	0.005	0.27	0.187	0.61	BDL	0.014	BDL	0.173	0.018	0.010
3P13	0.006	0.052	BDL	5.70	BDL	0.003	0.009	BDL	0.26	0.164	0.50	BDL	0.015	BDL	0.137	0.016	0.012
3P14	0.004	0.062	BDL	8.16	BDL	0.003	0.003	BDL	0.28	0.142	0.45	BDL	BDL	BDL	0.112	0.015	0.009
3P15	0.006	0.072	BDL	9.49	BDL	0.002	0.003	BDL	0.31	0.193	0.58	BDL	0.017	BDL	0.168	0.021	0.010
3P16	0.007	0.061	BDL	8.21	BDL	0.002	0.006	BDL	0.29	0.244	0.65	BDL	0.018	BDL	0.226	0.024	0.012
3P17	0.007	0.040	BDL	4.75	0.002	0.005	0.010	0.010	0.10	0.204	0.59	BDL	BDL	BDL	0.172	0.021	0.013
3P18	0.005	0.029	BDL	3.78	BDL	0.002	0.011	BDL	0.25	0.122	0.57	BDL	BDL	0.0043	0.113	0.013	0.011
3P19	0.006	0.028	BDL	4.23	BDL	0.002	BDL	BDL	0.14	0.090	0.48	BDL	BDL	BDL	0.063	0.010	0.028
3P20	0.007	0.031	BDL	4.66	BDL	0.002	BDL	BDL	0.15	0.097	0.29	BDL	BDL	BDL	0.061	0.017	0.017
3P21	0.003	0.025	BDL	2.91	BDL	0.002	0.003	BDL	0.55	0.098	0.26	BDL	BDL	BDL	0.067	0.012	0.012
3P22	0.002	0.021	BDL	3.02	BDL	0.003	BDL	BDL	0.12	0.072	0.35	BDL	0.110	BDL	0.105	0.008	0.006
3P23	0.006	0.034	0.004	4.20	0.001	0.003	BDL	BDL	0.14	0.063	0.22	BDL	BDL	BDL	0.057	0.008	0.003
3P24	0.007	0.031	BDL	3.61	BDL	0.002	0.002	BDL	0.12	0.095	0.26	BDL	BDL	BDL	0.089	0.011	0.009
3P25	0.005	0.032	BDL	4.12	BDL	0.001	0.011	BDL	0.17	0.098	0.20	BDL	BDL	BDL	0.056	0.009	0.031
3P26	0.005	0.032	BDL	4.49	BDL	0.002	0.002	BDL	0.14	0.115	0.30	BDL	BDL	BDL	0.113	0.011	0.016
3P27	0.004	0.031	BDL	3.91	BDL	0.002	0.005	BDL	0.22	0.121	0.24	BDL	BDL	BDL	0.078	0.012	0.012
3P28	0.007	0.041	0.004	5.48	0.0014	0.003	BDL	BDL	0.15	0.120	0.40	BDL	BDL	BDL	0.091	0.011	0.011
3P29	BDL	0.044	BDL	7.62	BDL	0.001	BDL	BDL	0.17	0.116	0.32	BDL	BDL	BDL	0.090	0.015	0.010
3P30	BDL	0.054	BDL	10.19	BDL	0.001	BDL	BDL	0.20	0.141	0.35	BDL	BDL	BDL	0.099	0.019	0.009
3P31	0.001	0.070	BDL	11.25	BDL	0.001	0.002	BDL	0.26	0.199	0.49	BDL	BDL	BDL	0.148	0.026	0.012

Footnote: Rain data is on Appendix B5

Appendix B4: Brookes Ave. Samples: Chemical Concentrations (ppm) for 9/27/02

Sample Name	**Ag**	**Al**	**As**	**Ca**	**Cd**	**Cr7**	**Cu**	**Fe**	**K**	**Mg**	**Na**	**Ni**	**P**	**Pb**	**Si**	**Sr**	**Zn**
Detection Limit	**0.001**	**0.002**	**0.004**	**0.0001**	**0.0004**	**0.001**	**0.002**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.002**	**0.008**	**0.004**	**0.001**	**0.0002**	**0.0003**
MCL or Other	**0.1**	**0.2**	**0.01**	**NA**	**0.005**	**0.1**	**1**	**0.3**	**NA**	**NA**	**20**	**0.1**	**NA**	**0.015**	**NA**	**4**	**2**
3B1	0.002	0.093	BDL	11.750	BDL	0.002	0.011	0.074	2.330	0.797	4.881	BDL	BDL	BDL	0.511	0.081	0.058
3B2	0.005	0.077	0.005	7.492	0.001	0.004	0.009	0.070	1.841	1.023	18.270	BDL	0.071	0.015	0.313	0.036	0.103
3B3	0.005	0.072	BDL	11.730	BDL	0.001	0.007	0.027	1.414	0.713	14.350	BDL	0.056	0.017	0.270	0.023	0.054
3B4	0.004	0.052	BDL	7.189	BDL	0.001	0.011	0.020	1.300	0.564	7.886	BDL	0.052	0.016	0.191	0.032	0.037
3B5	0.005	0.039	BDL	5.190	BDL	0.004	0.004	0.009	0.947	0.396	4.030	BDL	0.034	0.008	0.119	0.019	0.049
3B6	0.004	0.045	BDL	6.435	BDL	0.002	0.005	0.015	0.886	0.333	2.559	BDL	0.028	0.009	0.090	0.014	0.026
3B7	0.002	0.077	BDL	18.560	BDL	0.001	0.003	0.007	0.857	0.358	3.012	BDL	0.024	0.007	0.103	0.018	0.040
3B8	0.003	0.057	BDL	5.703	0.002	0.002	0.005	0.025	0.780	0.457	3.903	BDL	0.032	0.008	0.144	0.051	0.061
3B9	0.005	0.031	BDL	4.486	BDL	0.002	0.003	BDL	0.686	0.307	2.328	BDL	0.020	0.011	0.110	0.017	0.044
3B10	0.003	0.030	BDL	4.089	BDL	0.002	0.002	0.001	0.781	0.274	1.918	BDL	0.031	0.007	0.077	0.013	0.031
3B11	0.005	0.024	BDL	3.559	BDL	0.001	0.002	BDL	0.698	0.246	1.460	BDL	0.026	0.006	0.065	0.011	0.023
3B12	BDL	0.046	BDL	8.348	BDL	0.001	0.005	BDL	0.625	0.250	1.649	BDL	0.014	0.005	0.063	0.010	0.020
3B13	0.003	0.054	BDL	10.070	BDL	0.001	0.004	0.002	0.553	0.298	2.387	BDL	0.019	0.005	0.087	0.024	0.021
3B14	0.007	0.041	0.005	4.564	0.002	0.006	0.013	0.015	0.725	0.331	3.229	BDL	BDL	0.005	0.113	0.029	0.022
3B15	0.003	0.027	BDL	3.884	BDL	0.002	0.003	BDL	0.558	0.259	1.608	BDL	0.016	0.007	0.082	0.014	0.026
3B16	0.004	0.030	BDL	3.630	BDL	0.015	0.040	0.009	1.610	0.195	0.813	BDL	0.016	0.006	0.044	0.011	0.014
3B17	0.005	0.027	BDL	3.891	BDL	0.003	0.006	BDL	0.624	0.240	1.859	0.004	0.013	0.005	0.057	0.013	0.050
3B18	0.002	0.018	BDL	2.173	BDL	BDL	0.002	BDL	0.407	0.191	0.840	BDL	0.015	0.006	0.037	0.011	0.014
3B19	0.003	0.025	BDL	1.863	0.002	0.004	0.003	0.009	0.384	0.115	0.407	BDL	BDL	0.004	0.027	0.006	0.008
3B20	0.003	0.020	BDL	2.568	BDL	BDL	0.007	BDL	0.356	0.111	0.271	BDL	0.013	0.007	0.048	0.007	0.007
3B21	0.001	0.016	BDL	2.445	BDL	0.001	BDL	BDL	0.225	0.129	0.440	BDL	BDL	0.005	0.025	0.008	0.010
3B22	0.001	0.016	BDL	1.766	BDL	0.001	0.005	BDL	0.295	0.131	0.653	BDL	0.011	0.004	0.024	0.007	0.009
3B23	0.003	0.023	BDL	3.351	BDL	0.001	0.005	0.001	0.350	0.102	0.355	BDL	BDL	0.006	0.026	0.005	0.029
3B24	0.005	0.025	BDL	1.836	0.002	0.003	0.002	0.007	0.301	0.138	0.403	BDL	BDL	BDL	0.025	0.007	0.030
3B25	0.004	0.026	BDL	3.076	BDL	0.002	0.004	BDL	0.306	0.104	0.273	BDL	0.013	0.006	0.045	0.006	0.020
3B26	0.002	0.024	BDL	3.495	BDL	0.002	0.004	BDL	0.264	0.137	0.418	BDL	BDL	BDL	0.024	0.008	0.024
3B27	BDL	0.027	BDL	4.065	BDL	0.001	0.002	BDL	0.271	0.170	0.535	BDL	BDL	0.005	0.031	0.011	0.026
3B28	0.004	0.037	BDL	7.736	BDL	0.002	0.002	BDL	0.272	0.191	0.768	BDL	0.010	0.005	0.035	0.012	0.020

Footnote: Rain data is on Appendix B5

Appendix B5: 9/27/02 Rain Data, Chemical Concentrations (ppm)

Sample Name	**Ag**	**Al**	**As**	**Ca**	**Cd**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**Na**	**Ni**	**P**	**Pb**	**Si**	**Sr**	**Zn**
Detection Limit	**0.001**	**0.002**	**0.004**	**0.0001**	**0.0004**	**0.001**	**0.002**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.002**	**0.008**	**0.004**	**0.001**	**0.0002**	**0.0003**
MCL or Other	**0.1**	**0.2**	**0.01**	**NA**	**0.005**	**0.1**	**1**	**0.3**	**NA**	**NA**	**20**	**0.1**	**NA**	**0.015**	**NA**	**4**	**2**
9/27 R1	0.002	0.036	BDL	1.457	BDL	BDL	0.076	0.011	0.579	5.044	12.690	BDL	0.968	0.001	1.099	0.135	0.121
9/27 R2	0.001	0.050	BDL	0.953	BDL	BDL	0.035	0.023	0.374	0.239	0.796	0.006	0.027	0.004	0.034	0.007	0.136
9/27 R3	BDL	0.061	BDL	0.989	BDL	0.005	0.032	0.039	0.275	0.084	0.587	BDL	BDL	0.018	0.029	0.005	0.071
9/27 R4	0.002	0.111	BDL	1.385	BDL	0.001	0.020	0.098	0.412	0.080	0.428	0.003	0.017	0.010	0.040	0.005	0.143
9/27 R5	0.005	0.138	BDL	0.383	BDL	0.001	0.013	0.120	0.196	0.115	0.502	BDL	0.024	0.018	0.088	0.009	0.088
9/27 R6	0.005	0.562	0.006	3.627	0.002	0.004	0.034	0.353	0.245	0.065	0.192	BDL	BDL	0.006	0.126	0.002	0.028
9/27 R7	0.005	0.234	BDL	1.236	BDL	0.006	0.019	0.237	0.189	0.256	0.273	0.005	0.098	0.087	0.358	0.021	0.067
9/27 R8	0.006	0.104	BDL	0.677	BDL	0.005	0.028	0.083	0.299	0.111	0.224	0.051	0.105	0.048	0.165	0.007	0.042
9/27 R9	0.008	0.505	BDL	2.351	0.002	0.034	0.040	0.330	0.605	0.067	0.391	0.003	0.017	0.022	0.076	0.004	0.036
9/27 R10	0.008	0.610	BDL	1.732	0.001	0.005	0.019	0.388	0.148	0.308	0.738	0.010	0.051	0.087	0.376	0.021	0.090
9/27 R11	0.007	0.262	BDL	1.495	BDL	0.002	0.011	0.159	0.047	0.660	0.153	0.006	0.082	0.086	0.583	0.011	0.050
9/27 R12	0.008	0.331	BDL	1.374	BDL	0.002	0.012	0.263	0.165	0.140	0.054	BDL	0.027	0.040	0.210	0.006	0.020
9/27 R13	0.006	0.202	BDL	0.880	BDL	0.002	0.009	0.172	0.061	0.202	0.168	BDL	0.034	0.094	0.278	0.009	0.033
9/27 R14	0.008	0.267	BDL	1.412	0.002	0.006	0.073	0.188	0.215	0.075	0.053	BDL	0.027	0.041	0.140	0.004	0.025
9/27 R15	0.004	0.085	BDL	0.633	BDL	0.003	0.012	0.080	0.084	0.203	0.285	0.011	0.021	0.057	0.178	0.008	0.097
9/27 R16	0.004	0.127	BDL	1.435	0.001	0.006	0.020	0.124	0.284	0.220	1.063	BDL	BDL	0.006	0.050	0.024	0.018

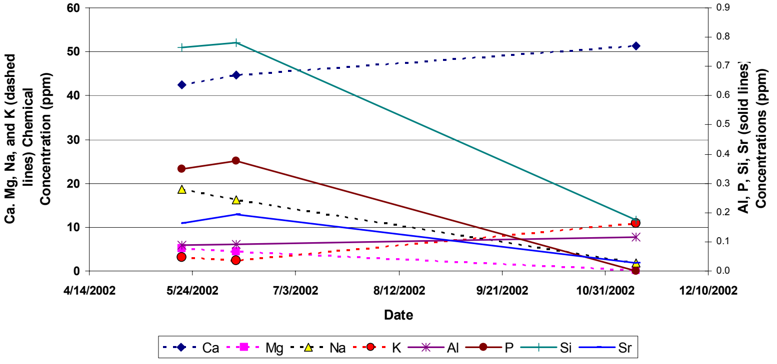
Footnote: Rain was not filtered before acidication; thus, concentrations may be elevated

Appendix B6 Remediation Test Plot Chemical Concentrations (ppm)

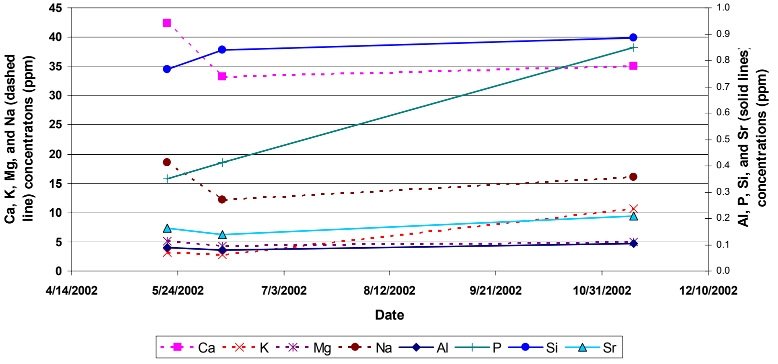
Sample Name	Date	Ag	As	Cd	Cr	Cu	Ni	Pb	Zn	Al	Ca	Fe	K	Mg	Na	P	Si	Sr
Detection Limit		**0.001**	**0.004**	**0.0004**	**0.001**	**0.002**	**0.002**	**0.004**	**0.0003**	**0.002**	**0.0001**	**0.0006**	**0.01**	**0.0002**	**0.004**	**0.008**	**0.001**	**0.0002**
MCL1		**0.1**	**0.01**	**0.005**	**0.1**	**1**	**0.1**	**0.015**	**2**	**0.2**	**NA**	**0.3**	**NA**	**NA**	**20**	**NA**	**NA**	**4**
Cook 1	5/20/02	BDL	BDL	BDL	0.002	0.010	BDL	BDL	0.005	0.090	42.41	0.001	3.22	5.17	18.61	0.350	0.76	0.163
(Control Site)	6/10/02	BDL	0.005	BDL	0.002	0.002	BDL	BDL	0.021	0.092	44.63	BDL2	2.31	4.46	16.26	0.378	0.78	0.193
	11/12/02	BDL	BDL	BDL	0.002	0.008	BDL	0.004	0.010	0.117	51.37	BDL	10.96	0.23	1.93	BDL	0.17	0.029
Cook 2	6/10/02	BDL	0.004	BDL	0.002	0.003	BDL	BDL	0.044	0.080	33.22	0.001	2.84	4.31	12.16	0.411	0.84	0.137
	11/12/02	BDL	0.006	BDL	0.001	0.005	BDL	BDL	0.032	0.106	34.99	0.003	10.71	5.02	16.04	0.851	0.89	0.209
Cook 3	6/10/02	BDL	0.004	0.001	0.002	0.005	BDL	BDL	0.084	0.106	56.48	0.018	4.29	4.84	12.08	0.447	1.22	0.227
	11/12/02	BDL	BDL	BDL	0.003	0.006	BDL	BDL	0.069	0.119	83.74	BDL	16.08	4.41	9.57	0.684	1.11	0.123
Cook4	6/10/02	BDL	0.006	BDL	BDL	BDL	BDL	BDL	0.025	0.090	50.77	BDL	1.61	4.74	12.45	0.335	0.86	0.234
	11/12/02	BDL	BDL	BDL	0.004	0.012	BDL	BDL	0.049	0.134	254.10	BDL	16.00	4.54	9.24	0.679	1.08	0.290
Cook 5	6/10/02	BDL	0.004	BDL	0.002	BDL	BDL	BDL	0.045	0.104	77.04	0.006	3.72	5.00	13.43	0.393	0.86	0.289
	11/12/02	BDL	BDL	BDL	0.005	0.005	BDL	BDL	0.129	0.119	66.33	BDL	9.32	8.81	17.17	0.586	1.26	0.894
Cook 6	6/10/02	BDL	0.005	BDL	0.002	0.003	BDL	BDL	0.062	0.104	96.32	0.012	14.41	5.18	14.25	1.047	0.98	0.322
	11/12/02	BDL	BDL	BDL	0.004	0.015	BDL	BDL	0.029	0.148	78.47	0.046	25.82	4.86	12.79	0.630	0.92	0.245
Cook 7	6/10/02	0.002	0.016	BDL	0.003	0.045	0.004	BDL	0.139	0.248	57.72	0.365	88.32	5.86	36.11	5.562	2.53	0.172
	11/12/02	BDL	BDL	BDL	0.003	0.003	BDL	BDL	0.042	0.119	83.83	BDL	9.56	7.63	13.73	3.197	1.71	0.232
Cook 8	6/10/02	BDL	BDL	BDL	0.003	0.002	BDL	BDL	0.038	0.002	93.67	BDL	6.04	5.44	14.99	0.471	0.83	0.337
	11/12/02	BDL	BDL	0.002	0.004	0.006	BDL	BDL	0.052	0.136	73.31	0.013	11.05	4.35	8.95	1.109	0.82	0.127
Fleming	5/16/02	BDL	BDL	BDL	0.002	0.016	BDL	BDL	0.012	0.100	29.89	0.020	3.87	3.92	24.93	0.373	1.27	0.179
	6/14/02	BDL	BDL	BDL	0.002	0.012	BDL	BDL	0.065	0.088	105.20	0.138	35.71	5.63	24.67	3.558	1.48	0.329
Torrey	5/16/02	BDL	0.006	BDL	0.002	0.021	BDL	BDL	0.355	0.089	24.86	0.006	3.05	3.82	18.93	0.297	0.87	0.122
	6/14/02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Old Mill	5/17/02	BDL	0.006	0.001	0.002	0.004	BDL	BDL	0.010	0.108	31.78	0.010	1.91	4.29	12.68	0.250	0.72	0.161
	6/17/02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Footnote: Simulation prinkling blanks are not included because they were not filtered before acidification
Also, one representative pre-remediation cook sample (5/20/02) was obtained.

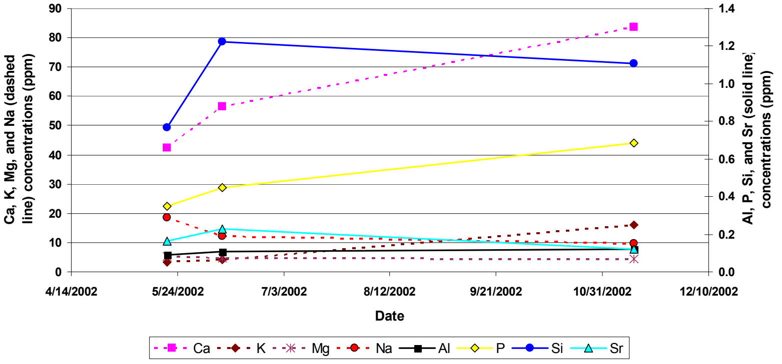
Appendix C: Cook 1- 4
Al, Ca, K, Mg, Na, P, Si, and Sr Chemical Changes



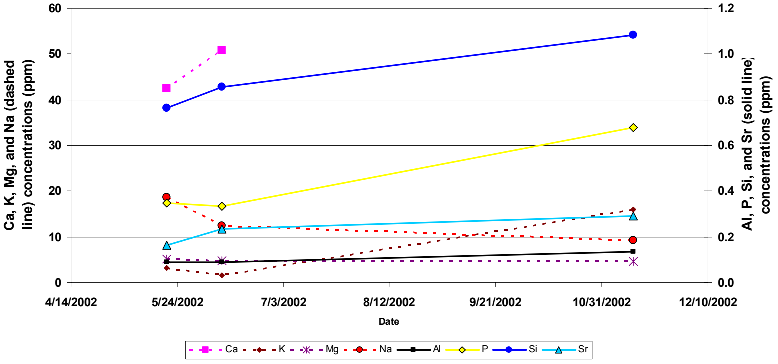
Cook control, changes in Ca, Mg, Na, K, Al, P, Si, and Sr concentrations



Cook 2 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)



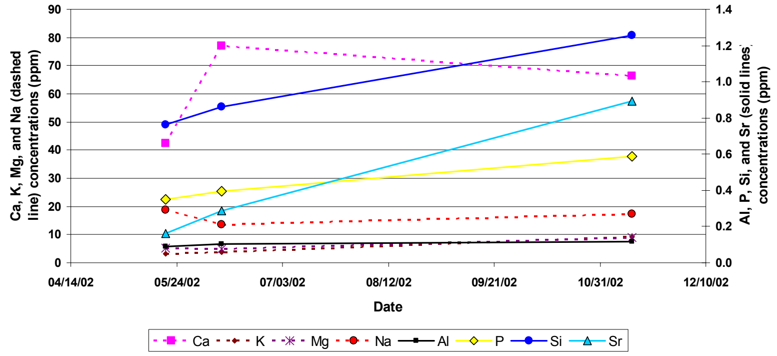
Cook 3 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)



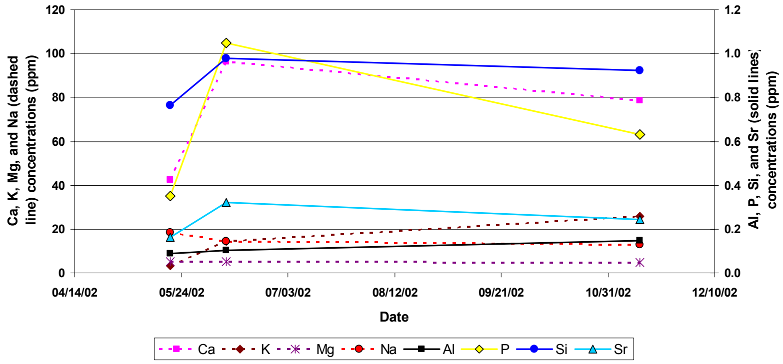
Cook 4 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)

Appendix C: Cook 5- 8
Al, Ca, K, Mg, Na, P, Si, and Sr Chemical Changes

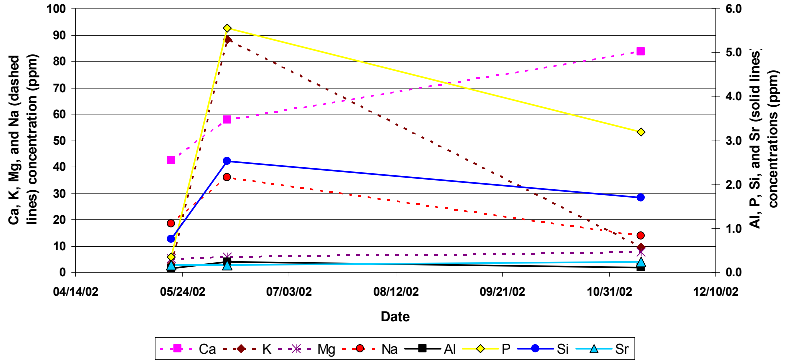
Cook 5 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)



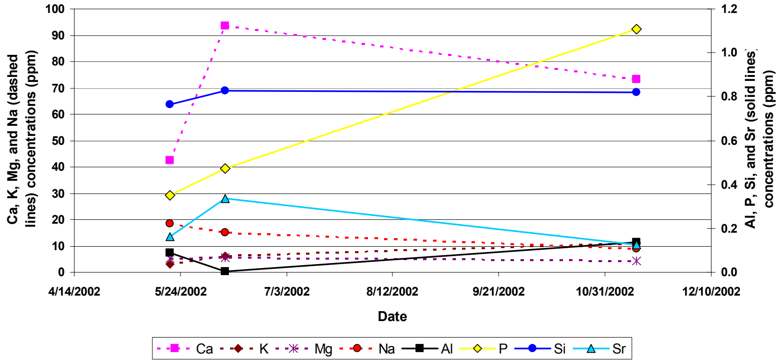
Cook 6 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)



Cook 7 Changes in Al , Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)

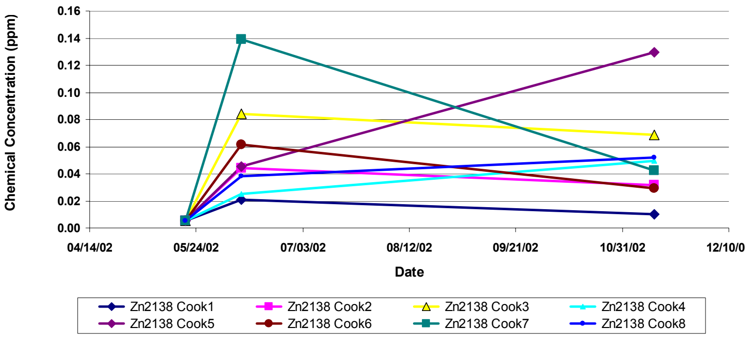


Cook 8 Changes in Al, Ca, K, Mg, Na, P, Si, and Sr Concentrations (ppm)

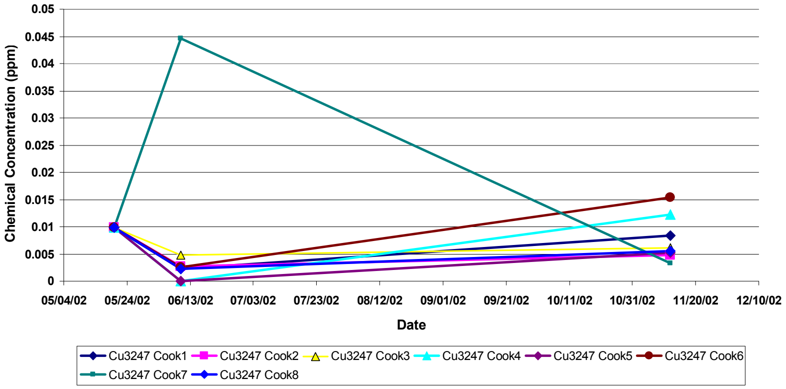


Appendix C: Cook plot comparison of Zn, Cu, and Cr chemical changes

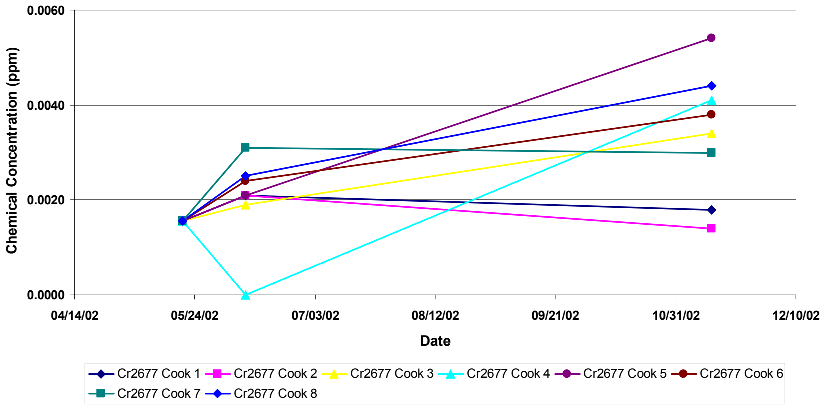
Cook plots change in zinc concentration



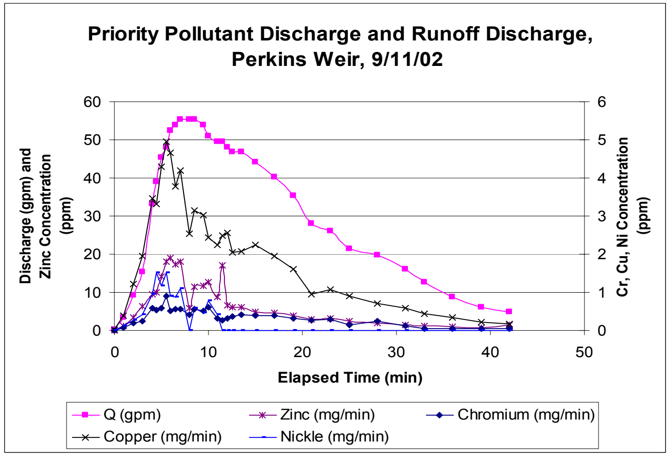
Cook plots change in copper concentration

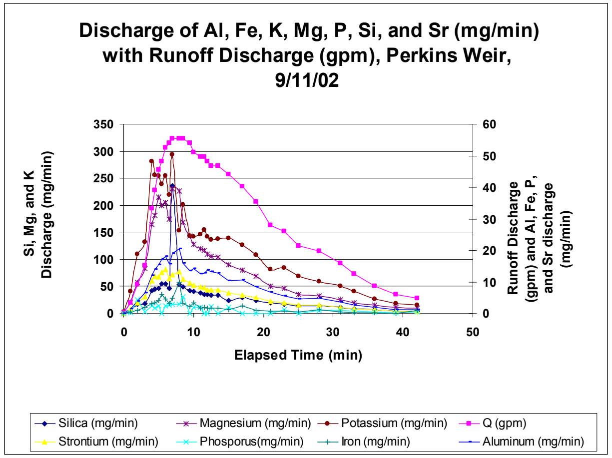


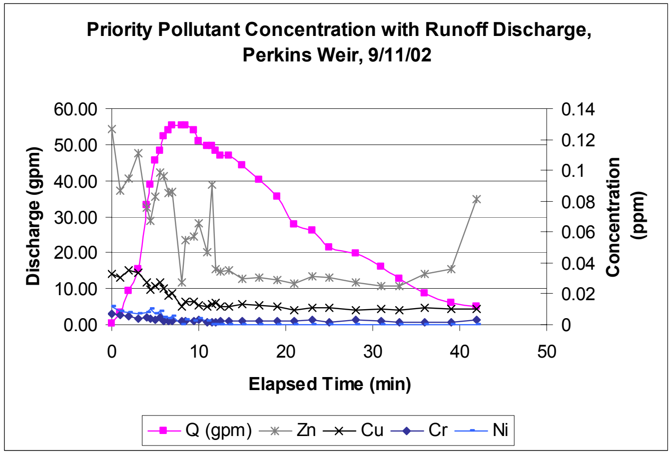
Cook plots change in chromium concentration



Appendix C: Perkins Parking lot, 9/11/02: Concentrations and Chemical Discharges


Priority Pollutant Discharge and Runoff Discharge, Perkins Weir, 9/11/02


Discharge of Al, Fe, K, Mg, P, Si, and Sr (mg/min) with Runoff Discharge (gpm), Perkins Weir, 9/11/02


Priority Pollutant Concentration with Runoff Discharge, Perkins Weir, 9/11/02

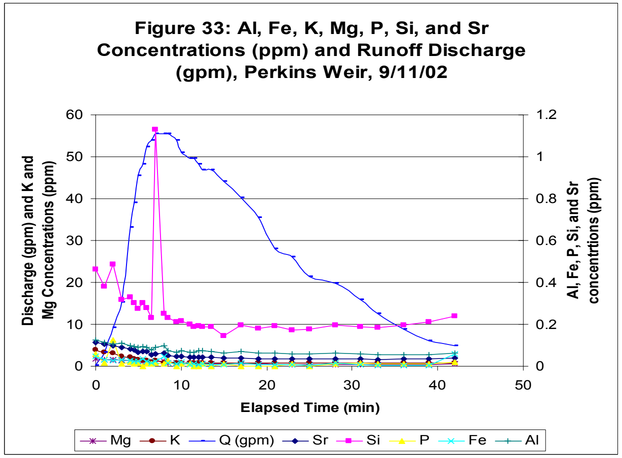


Figure 33: Al, Fe, K, Mg, P, Si, and Sr Concentrations (ppm) and Runoff Discharge (gpm), Perkins Weir, 9/11/02

Appendix C: Brookes Avenue, 9/11/02: Concentrations and Chemical Discharges

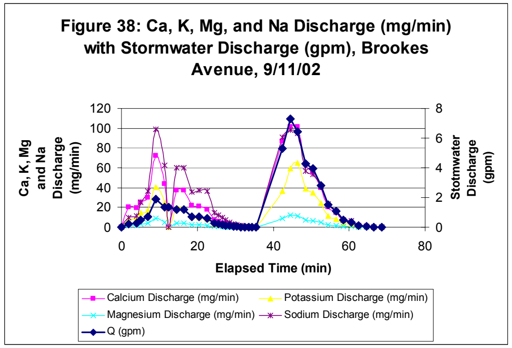


Figure 38: Ca, K, Mg, and Na Discharge (mg/min) with Stormwater Discharge (gpm), Brookes Avenue, 9/11/02

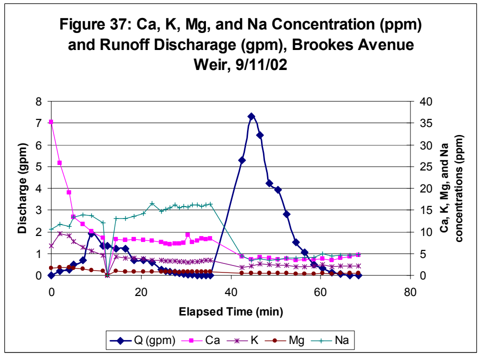


Figure 37: Ca, K, Mg, and Na Concentration (ppm) and Runoff Discharage (gpm), Brookes Avenue Weir, 9/11/02

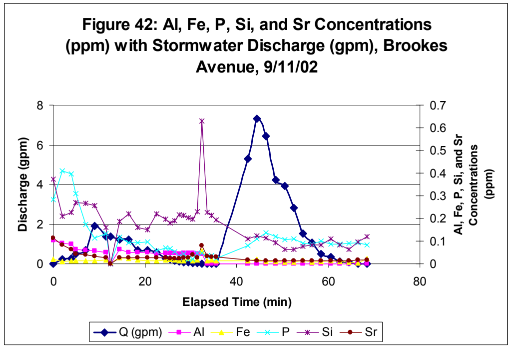


Figure 42: Al, Fe, P, Si, and Sr Concentrations (ppm) with Stormwater Discharge (gpm), Brookes Avenue, 9/11/02

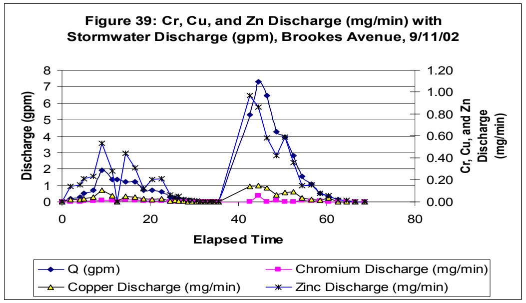


Figure 39: Cr, Cu, and Zn Discharge (mg/min) with Stormwater Discharge (gpm), Brookes Avenue, 9/11/02

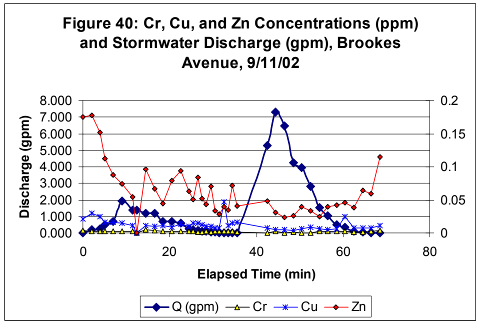


Figure 40: Cr, Cu, and Zn Concentrations (ppm) and Stormwater Discharge (gpm), Brookes Avenue, 9/11/02

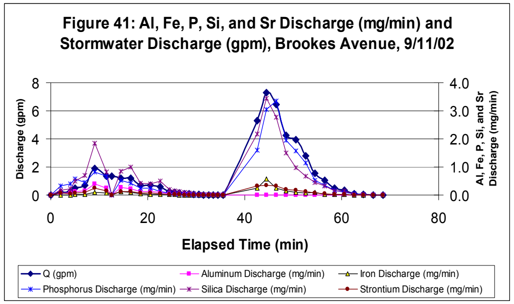


Figure 41: Al, Fe, P, Si, and Sr Discharge (mg/min) and Stormwater Discharge (gpm), Brookes Avenue, 9/11/02

Appendix C: Perkins Parking lot 9/27/02: Concentrations and Chemical Discharges

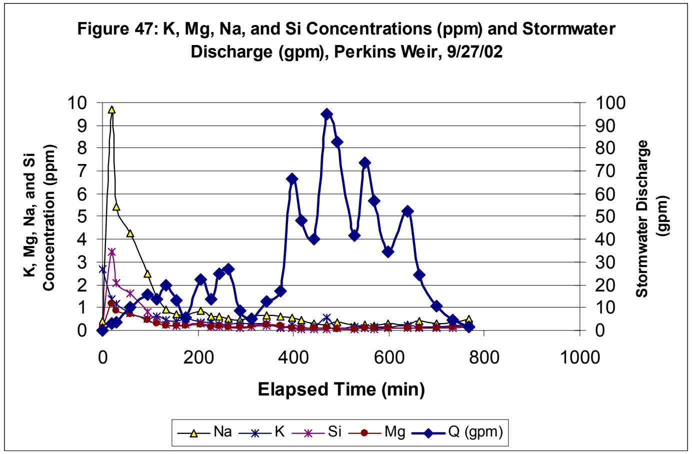


Figure 47: K, Mg, Na, and Si Concentrations (ppm) and Stormwater Discharge (gpm), Perkins Weir, 9/27/02

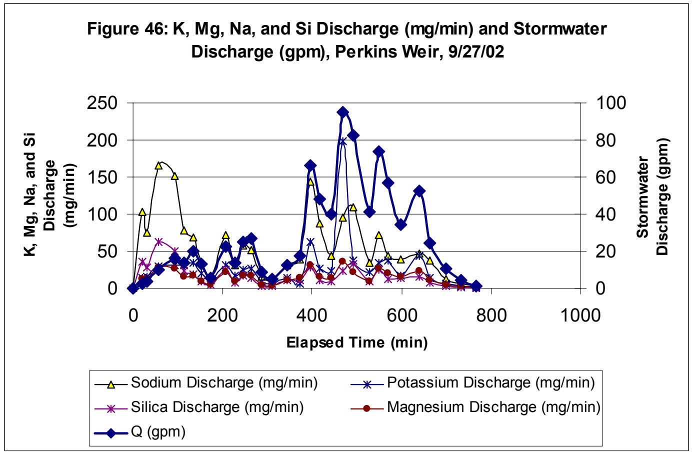


Figure 46: K, Mg, Na, and Si Discharge (mg/min) and Stormwater Discharge (gpm), Perkins Weir, 9/27/02

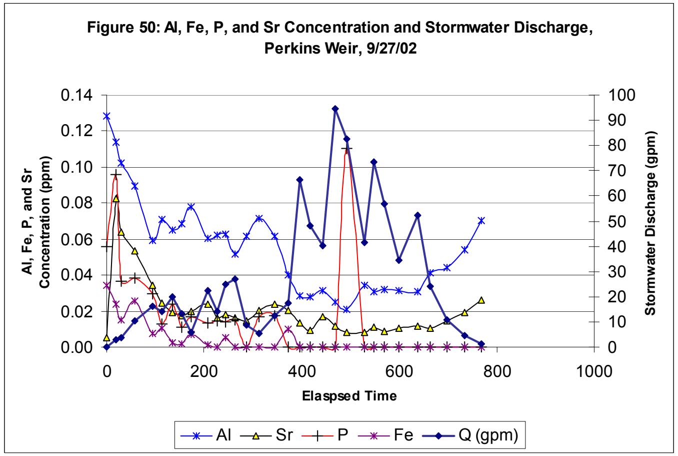


Figure 50: Al, Fe, P, and Sr Concentration and Stormwater Discharge, Perkins Weir, 9/27/02

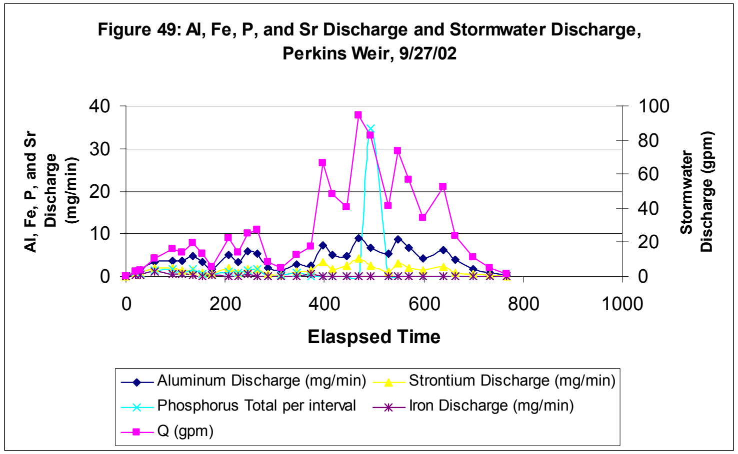
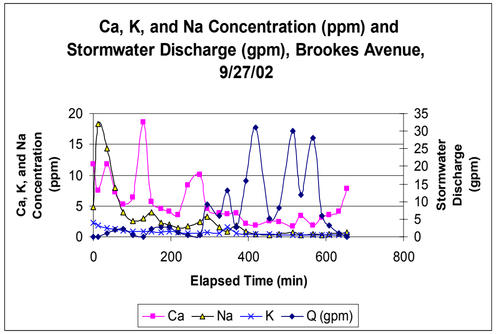
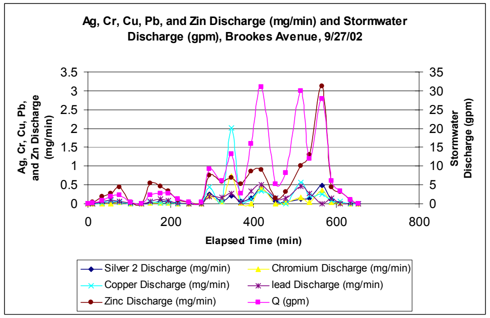
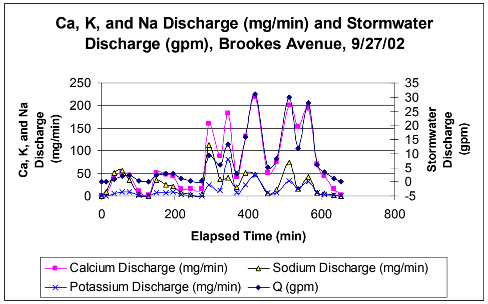


Figure 49: Al, Fe, P, and Sr Discharge and Stormwater Discharge, Perkins Weir, 9/27/02

Appendix C: Brookes Avenue 9/27/02:
Concentrations and Chemical Discharges


Ca, K, and Na Concentration (ppm) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02


Ag, Cr, Cu, Pb, and Zin Discharge (mg/min) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02


Ca, K, and Na Discharge (mg/min) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02

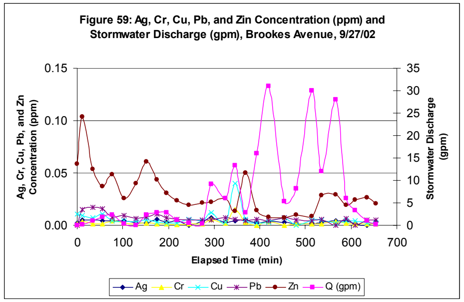
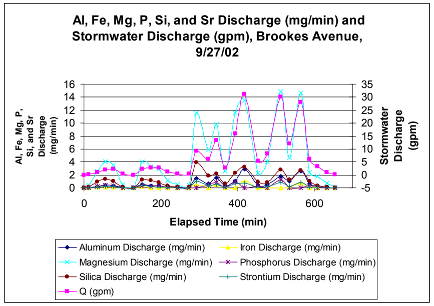
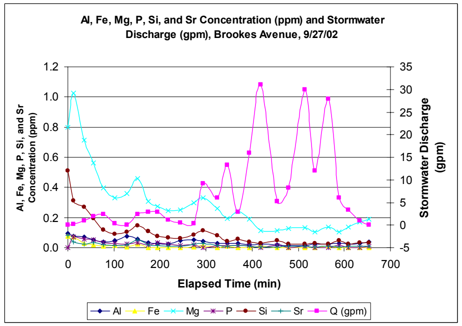


Figure 59: Ag, Cr, Cu, Pb, and Zin Concentration (ppm) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02


Al, Fe, Mg, P, Si, and Sr Discharge (mg/min) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02


Al, Fe, Mg, P, Si, and Sr Concentration (ppm) and Stormwater Discharge (gpm), Brookes Avenue, 9/27/02

Appendix D
Steady State Infiltration Rates Statistical Analysis

```
Two-sample T for Fencing Only (June) vs Pre-remediation
          N      Mean     StDev   SE Mean
Control   2     3.350     0.919      0.65
Before R  4     1.500     0.408      0.20

Difference = mu Control Post 1 - mu Before Remediation
Estimate for difference:  1.850
60% CI for difference: (0.912, 2.788)
T-Test of difference = 0 (vs not =): T-Value = 2.72  P-Value = 0.225  DF = 1

Two-sample T for Fencing Only (Nov) vs Pre-remediation
          N      Mean     StDev   SE Mean
Control   2      8.15      4.31       3.0
Before R  4     1.500     0.408      0.20

Difference = mu Control Post 2 - mu Before Remediation
Estimate for difference:  6.65
70% CI for difference: (0.65, 12.65)
T-Test of difference = 0 (vs not =): T-Value = 2.18  P-Value = 0.274  DF = 1

Two-sample T for Aeration and Seed (June) vs Pre-remediation
         N      Mean     StDev   SE Mean
Aeration  2      7.05      2.33       1.6
Before R  4     1.500     0.408      0.20

Difference = mu Aeration Post 1 - mu Before Remediation
Estimate for difference:  5.55
70% CI for difference: (2.29, 8.81)
T-Test of difference = 0 (vs not =): T-Value = 3.34  P-Value = 0.185  DF = 1

Two-sample T for Aeration and Seed (Nov) vs Pre-remediation
          N      Mean     StDev   SE Mean
Aeration  2     13.45      2.05       1.5
Before R  4     1.500     0.408      0.20

Difference = mu Aeration Post 2 - mu Before Remediation
Estimate for difference:  11.95
70% CI for difference: (9.08, 14.82)
T-Test of difference = 0 (vs not =): T-Value = 8.16  P-Value = 0.078  DF = 1

Two-sample T for Compost, Aeration, and Seed (June) vs Pre-remediation
          N      Mean     StDev   SE Mean
Compost   5      9.64      4.53       2.0
Before R  4     1.500     0.408      0.20

Difference = mu Compost Post 1 - mu Before Remediation
Estimate for difference:  8.14
70% CI for difference: (5.72, 10.56)
T-Test of difference = 0 (vs not =): T-Value = 3.99  P-Value = 0.016  DF = 4

Two-sample T for Compost, Aeration, and Seed (Nov) vs Pre-remediation
          N      Mean     StDev   SE Mean
Compost   4     15.43      1.71      0.85
Before R  4     1.500     0.408      0.20

Difference = mu Compost Post 2 - mu Before Remediation
Estimate for difference:  13.925
70% CI for difference: (12.829, 15.021)
T-Test of difference = 0 (vs not =): T-Value = 15.88  P-Value = 0.001  DF = 3

Two-sample T for Fencing only (Nov) vs Fencing Only (June)
         N      Mean     StDev   SE Mean
Control  2      8.15      4.31       3.0
Control  2     3.350     0.919      0.65

Difference = mu Control Post 2 - mu Control Post 1
Estimate for difference:  4.80
70% CI for difference: (-1.32, 10.92)
T-Test of difference = 0 (vs not =): T-Value = 1.54  P-Value = 0.367  DF = 1
```

Appendix D

Steady State Infiltration Rates Statistical Analysis

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Two-sample T for Aeration and Seeding (June) vs Fencing Only (Nov)
          N      Mean     StDev   SE Mean
Aeration  2      7.05      2.33       1.6
Control   2     3.350     0.919      0.65

Difference = mu Aeration Post 1 - mu Control Post 1
Estimate for difference:  3.70
70% CI for difference: (0.22, 7.18)
T-Test of difference = 0 (vs not =): T-Value = 2.09  P-Value = 0.285  DF = 1

Two-sample T for Aeration and Seeding (Nov) vs Fencing Only (June)
          N      Mean     StDev   SE Mean
Aeration  2     13.45      2.05       1.5
Control   2     3.350     0.919      0.65

Difference = mu Aeration Post 2 - mu Control Post 1
Estimate for difference:  10.10
70% CI for difference: (6.98, 13.22)
T-Test of difference = 0 (vs not =): T-Value = 6.36  P-Value = 0.099  DF = 1

Two-sample T for Compost (June) vs Fencing Only (June)
         N      Mean     StDev   SE Mean
Compost  5      9.64      4.53       2.0
Control  2     3.350     0.919      0.65

Difference = mu Compost Post 1 - mu Control Post 1
Estimate for difference:  6.29
70% CI for difference: (3.76, 8.82)
T-Test of difference = 0 (vs not =): T-Value = 2.95  P-Value = 0.042  DF = 4

Two-sample T for Compost (Nov) vs Fencing Only (June)
         N      Mean     StDev   SE Mean
Compost  4     15.43      1.71      0.85
Control  2     3.350     0.919      0.65

Difference = mu Compost Post 2 - mu Control Post 1
Estimate for difference:  12.08
70% CI for difference: (10.73, 13.42)
T-Test of difference = 0 (vs not =): T-Value = 11.26  P-Value = 0.002  DF = 3

Two-sample T for Aeration (June) vs Control (Nov)
          N      Mean     StDev   SE Mean
Aeration  2      7.05      2.33       1.6
Control   2      8.15      4.31       3.0

Difference = mu Aeration Post 1 - mu Control Post 2
Estimate for difference:  -1.10
70% CI for difference: (-7.91, 5.71)
T-Test of difference = 0 (vs not =): T-Value = -0.32  P-Value = 0.804  DF = 1

Two-sample T for Aeration (Nov) vs Fencing Only (Nov)
          N      Mean     StDev   SE Mean
Aeration  2     13.45      2.05       1.5
Control   2      8.15      4.31       3.0

Difference = mu Aeration Post 2 - mu Control Post 2
Estimate for difference:  5.30
70% CI for difference: (-1.33, 11.93)
T-Test of difference = 0 (vs not =): T-Value = 1.57  P-Value = 0.361  DF = 1

Two-sample T for Compost (June) vs Fencing Only (Nov)
         N      Mean     StDev   SE Mean
Compost  5      9.64      4.53       2.0
Control  2      8.15      4.31       3.0

Difference = mu Compost Post 1 - mu Control Post 2
Estimate for difference:  1.49
70% CI for difference: (-5.70, 8.68)
T-Test of difference = 0 (vs not =): T-Value = 0.41  P-Value = 0.754  DF = 1
```

Appendix D

Steady State Infiltration Rates Statistical Analysis

```
Two-sample T for Compost (Nov) vs Fencing Only (Nov)
         N      Mean     StDev   SE Mean
Compost  4     15.43      1.71      0.85
Control  2      8.15      4.31       3.0

Difference = mu Compost Post 2 - mu Control Post 2
Estimate for difference:  7.28
70% CI for difference: (1.06, 13.49)
T-Test of difference = 0 (vs not =): T-Value = 2.30  P-Value = 0.261  DF = 1

Two-sample T for Aeration (Nov) vs Aeration (June)
          N      Mean     StDev   SE Mean
Aeration  2     13.45      2.05       1.5
Aeration  2      7.05      2.33       1.6

Difference = mu Aeration Post 2 - mu Aeration Post 1
Estimate for difference:  6.40
70% CI for difference: (2.09, 10.71)
T-Test of difference = 0 (vs not =): T-Value = 2.91  P-Value = 0.210  DF = 1

Two-sample T for Compost Post 1 vs Aeration Post 1
          N      Mean     StDev   SE Mean
Compost   5      9.64      4.53       2.0
Aeration  2      7.05      2.33       1.6

Difference = mu Compost Post 1 - mu Aeration Post 1
Estimate for difference:  2.59
70% CI for difference: (-0.52, 5.70)
T-Test of difference = 0 (vs not =): T-Value = 0.99  P-Value = 0.378  DF = 4

Two-sample T for Compost (Nov) vs Aeration (June)
          N      Mean     StDev   SE Mean
Compost   4     15.43      1.71      0.85
Aeration  2      7.05      2.33       1.6

Difference = mu Compost Post 2 - mu Aeration Post 1
Estimate for difference:  8.38
70% CI for difference: (4.73, 12.02)
T-Test of difference = 0 (vs not =): T-Value = 4.51  P-Value = 0.139  DF = 1

Two-sample T for Compost (June) vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Compost   5      9.64      4.53       2.0
Aeration  2     13.45      2.05       1.5

Difference = mu Compost Post 1 - mu Aeration Post 2
Estimate for difference:  -3.81
70% CI for difference: (-6.78, -0.84)
T-Test of difference = 0 (vs not =): T-Value = -1.53  P-Value = 0.201  DF = 4



Two-sample T for Compost (Nov) vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Compost   4     15.43      1.71      0.85
Aeration  2     13.45      2.05       1.5

Difference = mu Compost Post 2 - mu Aeration Post 2
Estimate for difference:  1.97
70% CI for difference: (-1.33, 5.28)
T-Test of difference = 0 (vs not =): T-Value = 1.17  P-Value = 0.449  DF = 1

Two-sample T for Compost (Nov) vs Compost (June)
         N      Mean     StDev   SE Mean
Compost  4     15.43      1.71      0.85
Compost  5      9.64      4.53       2.0

Difference = mu Compost Post 2 - mu Compost Post 1
Estimate for difference:  5.78
70% CI for difference: (3.24, 8.33)
T-Test of difference = 0 (vs not =): T-Value = 2.63  P-Value = 0.047  DF = 5
```

Appendix D

Normalized Suspended Sediment Statistics

```
Two-sample T for Pre-remediation vs Fence (Nov)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
Non aera  2     1.540     0.905      0.64

Difference = mu Before remediation - mu Non aeration Post-remediation 2
Estimate for difference:  28.9
60% CI for difference: (17.4, 40.4)
T-Test of difference = 0 (vs not =): T-Value = 2.46  P-Value = 0.091  DF = 3

Two-sample T for Pre-remediation vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
Aeration  2     0.160     0.226      0.16

Difference = mu Before remediation - mu Aeration Post-remediation 2
Estimate for difference:  30.3
60% CI for difference: (18.8, 41.8)
T-Test of difference = 0 (vs not =): T-Value = 2.58  P-Value = 0.081  DF = 3

Two-sample T for Pre-remediation vs fence (June)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
Non aera  2      7.38      2.26       1.6

Difference = mu Before remediation - mu Non aeration Post-remediation 1
Estimate for difference:  23.1
60% CI for difference: (11.5, 34.7)
T-Test of difference = 0 (vs not =): T-Value = 1.95  P-Value = 0.146  DF = 3

Two-sample T for Pre-remediation vs Aeration (June)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
Aeration  2      3.72      4.54       3.2

Difference = mu Before remediation - mu Aeration Post-remediation 1
Estimate for difference:  26.8
60% CI for difference: (14.9, 38.7)
T-Test of difference = 0 (vs not =): T-Value = 2.20  P-Value = 0.115  DF = 3

Two-sample T for Fence (June) vs Aeration (June)
          N      Mean     StDev   SE Mean
Non aera  2      7.38      2.26       1.6
Aeration  2      3.72      4.54       3.2

Difference = mu Non aeration Post-remediation 1 - mu Aeration Post-remediation 1
Estimate for difference:  3.66
60% CI for difference: (-1.28, 8.59)
T-Test of difference = 0 (vs not =): T-Value = 1.02  P-Value = 0.494  DF = 1

Two-sample T for Fence (June) vs Fence (Nov)
          N      Mean     StDev   SE Mean
Non aera  2      7.38      2.26       1.6
Non aera  2     1.540     0.905      0.64

Difference = mu Non aeration Post-remediation 1 - mu Non aeration Post-remediation 2
Estimate for difference:  5.84
60% CI for difference: (3.47, 8.20)
T-Test of difference = 0 (vs not =): T-Value = 3.40  P-Value = 0.182  DF = 1

Two-sample T for Fence (June) vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Non aera  2      7.38      2.26       1.6
Aeration  2     0.160     0.226      0.16

Difference = mu Non aeration Post-remediation 1 - mu Aeration Post-remediation 2
Estimate for difference:  7.22
60% CI for difference: (5.01, 9.42)
T-Test of difference = 0 (vs not =): T-Value = 4.50  P-Value = 0.139  DF = 1

Two-sample T for Aeration (June) vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Aeration  2      3.72      4.54       3.2
Aeration  2     0.160     0.226      0.16

Difference = mu Aeration Post-remediation 1 - mu Aeration Post-remediation 2
Estimate for difference:  3.56
60% CI for difference: (-0.86, 7.98)
T-Test of difference = 0 (vs not =): T-Value = 1.11  P-Value = 0.468  DF = 1
```

Appendix D

Normalized Suspended Sediment Statistics

```
Two-sample T for Fence (June) vs Aeration (Nov)
          N      Mean     StDev   SE Mean
Non aera  2     1.540     0.905      0.64
Aeration  2     0.160     0.226      0.16

Difference = mu Non aeration Post-remediation 2 - mu Aeration Post-remediation 2
Estimate for difference:  1.380
60% CI for difference: (0.472, 2.288)
T-Test of difference = 0 (vs not =): T-Value = 2.09  P-Value = 0.284  DF = 1

Two-sample T for Pre-remediation vs compost (June)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
compost   5      2.50      2.26       1.0

Difference = mu Before remediation - mu compost after remediation 1
Estimate for difference:  28.0
60% CI for difference: (16.5, 39.5)
T-Test of difference = 0 (vs not =): T-Value = 2.38  P-Value = 0.098  DF = 3

Two-sample T for Pre-remediation vs compost (Nov)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
compost   4     0.393     0.398      0.20

Difference = mu Before remediation - mu compost after remediation 2
Estimate for difference:  30.1
60% CI for difference: (18.6, 41.6)
T-Test of difference = 0 (vs not =): T-Value = 2.56  P-Value = 0.083  DF = 3

Two-sample T for Aeration (June) vs compost (June)
          N      Mean     StDev   SE Mean
Aeration  2      3.72      4.54       3.2
compost   5      2.50      2.26       1.0

Difference = mu Aeration Post-remediation 1 - mu compost after remediation 1
Estimate for difference:  1.22
60% CI for difference: (-3.41, 5.85)
T-Test of difference = 0 (vs not =): T-Value = 0.36  P-Value = 0.779  DF = 1

Two-sample T for Aeration (June) vs compost (Nov)
          N      Mean     StDev   SE Mean
Aeration  2      3.72      4.54       3.2
compost   4     0.393     0.398      0.20

Difference = mu Aeration Post-remediation 1 - mu compost after remediation 2
Estimate for difference:  3.33
60% CI for difference: (-1.10, 7.75)
T-Test of difference = 0 (vs not =): T-Value = 1.03  P-Value = 0.489  DF = 1

Two-sample T for Aeration (Nov) vs compost (Nov)
          N      Mean     StDev   SE Mean
Aeration  2     0.160     0.226      0.16
compost   4     0.393     0.398      0.20

Difference = mu Aeration Post-remediation 2 - mu compost after remediation 2
Estimate for difference:  -0.233
60% CI for difference: (-0.482, 0.017)
T-Test of difference = 0 (vs not =): T-Value = -0.91  P-Value = 0.430  DF = 3

Two-sample T for Aeration (Nov) vs compost (June)
          N      Mean     StDev   SE Mean
Aeration  2     0.160     0.226      0.16
compost   5      2.50      2.26       1.0

Difference = mu Aeration Post-remediation 2 - mu compost after remediation 1
Estimate for difference:  -2.34
60% CI for difference: (-3.30, -1.38)
T-Test of difference = 0 (vs not =): T-Value = -2.29  P-Value = 0.084  DF = 4

Two-sample T for compost (June) vs compost (Nov)
         N      Mean     StDev   SE Mean
compost  5      2.50      2.26       1.0
compost  4     0.393     0.398      0.20

Difference = mu compost after remediation 1 - mu compost after remediation 2
Estimate for difference:  2.11
60% CI for difference: (1.14, 3.08)
T-Test of difference = 0 (vs not =): T-Value = 2.04  P-Value = 0.110  DF = 4
```

Appendix D

Normalized Suspended Sediment Statistics

```
Two-sample T for Fence (Nov) vs compost (Nov)
          N      Mean     StDev   SE Mean
Non aera  2     1.540     0.905      0.64
compost   4     0.393     0.398      0.20

Difference = mu Non aeration Post-remediation 2 - mu compost after remediation 2
Estimate for difference:  1.148
60% CI for difference: (0.225, 2.070)
T-Test of difference = 0 (vs not =): T-Value = 1.71  P-Value = 0.337  DF = 1

Two-sample T for Fence (June) vs compost (Nov)
          N      Mean     StDev   SE Mean
Non aera  2      7.38      2.26       1.6
compost   4     0.393     0.398      0.20

Difference = mu Non aeration Post-remediation 1 - mu compost after remediation 2
Estimate for difference:  6.98
60% CI for difference: (4.77, 9.19)
T-Test of difference = 0 (vs not =): T-Value = 4.34  P-Value = 0.144  DF = 1

Two-sample T for Fence (June) vs compost (June)
          N      Mean     StDev   SE Mean
Non aera  2      7.38      2.26       1.6
compost   5      2.50      2.26       1.0

Difference = mu Non aeration Post-remediation 1 - mu compost after remediation 1
Estimate for difference:  4.88
60% CI for difference: (2.28, 7.47)
T-Test of difference = 0 (vs not =): T-Value = 2.58  P-Value = 0.235  DF = 1

Two-sample T for Pre-remediation vs compost (June)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
compost   5      2.50      2.26       1.0

Difference = mu Before remediation - mu compost after remediation 1
Estimate for difference:  28.0
60% CI for difference: (16.5, 39.5)
T-Test of difference = 0 (vs not =): T-Value = 2.38  P-Value = 0.098  DF = 3

Two-sample T for Pre-remediation vs compost (Nov)
          N      Mean     StDev   SE Mean
Before r  4      30.5      23.5        12
compost   4     0.393     0.398      0.20

Difference = mu Before remediation - mu compost after remediation 2
Estimate for difference:  30.1
60% CI for difference: (18.6, 41.6)
T-Test of difference = 0 (vs not =): T-Value = 2.56  P-Value = 0.083  DF = 3

Two-sample T for Fence (Nov) vs Aeration (June)
          N      Mean     StDev   SE Mean
Non aera  2     1.540     0.905      0.64
Aeration  2      3.72      4.54       3.2

Difference = mu Non aeration Post-remediation 2 - mu Aeration Post-remediation 1
Estimate for difference:  -2.18
60% CI for difference: (-6.69, 2.33)
T-Test of difference = 0 (vs not =): T-Value = -0.67  P-Value = 0.626  DF = 1

Two-sample T for Fence (Nov) vs compost (June)
          N      Mean     StDev   SE Mean
Non aera  2     1.540     0.905      0.64
compost   5      2.50      2.26       1.0

Difference = mu Non aeration Post-remediation 2 - mu compost after remediation 1
Estimate for difference:  -0.96
60% CI for difference: (-2.09, 0.17)
T-Test of difference = 0 (vs not =): T-Value = -0.80  P-Value = 0.467  DF = 4
```

Appendix E

Contaminants, Maximum Concentration (ppm), Total Loading (g),
Percent Detection, and Normalized loading (g/cm of rain) at Perkins Parking Lot,
9/11/2002, (based upon a rational method calculation for discharge)

Element	MCL[1]	Max Concentration (ppm)	Total Loading (g)	Detection %	Loading^{Normal}
Ag	0.1	0.003	0.006	31	0.019
Al	0.2	0.13	0.949	100	2.876
As	0.01	0.005	0.014	22	0.042
Ca	NA[2]	40.0	223.154	100	676.225
Cd	0.005	0.002	0.001	19	0.004
Cr	0.1	0.007	0.035	100	0.106
Cu	1	0.035	0.191	100	0.579
Fe	0.3	0.047	0.199	100	0.604
K	NA	3.9	14.249	100	43.179
Mg	NA	1.8	9.649	100	29.240
Na	20	11.4	39.504	100	119.708
Ni	0.1	0.012	0.030	47	0.091
P	NA	0.059	0.128	72	0.389
Pb	0.015	BDL[3]	0.000	0	0.000
Si	NA	0.49	3.142	100	9.521
Sr	4	0.11	0.644	100	1.953
Zn	2	0.13	0.635	100	1.925

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

3: BDL = below detection limit, in this case it also indicates that Pb was not detected in any of the samples.

Loading^{Normal} = chemical loading normalized per cm of rainfall.

Appendix E

Contaminants, Maximum Concentration (ppm), Total Loading (g), and percent detection, Brookes Avenue, 9/11/02

Element	MCL[1]	Maximum Concentration (ppm)	Total Loading (g)	Detection %	Loading^{Normal}
Ag	0.1	0.004	0.003	54	0
Al	0.2	0.10	0.127	54	0
As	0.01	0.005	0.000	3	0
Ca	NA[2]	35.2	40.170	97	50
Cd	0.005	0.002	0.002	13	0
Cr	0.1	0.005	0.009	85	0
Cu	1	0.030	0.049	97	0
Fe	0.3	0.020	0.075	100	0
K	NA	9.5	18.400	97	23
Mg	NA	1.8	3.756	97	5
Na	20	16.6	35.465	97	44
Ni	0.1	0.003	0.001	5	0
P	NA	0.41	0.742	97	1
Pb	0.015	0.007	0.004	13	0
Si	NA	0.37	0.747	97	1
Sr	4	0.11	0.133	97	0
Zn	2	0.18	0.309	97	0

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

[1] MCL = maximum contaminant level allowed in drinking water, EPA enforceable

[2] NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressurerecommendation

Loading^{Normal} = chemical loading normalized per inch of rainfall.

Appendix E

Contaminants, Maximum Concentration (ppm), Total Loading (mg)
and Percent Detection, Perkins Parking Lot, 9/27/02

Element	MCL[1]	Maxium Concentration (ppm)	Total Loading (g)	Detection %	Loading^{Normal}
Ag	**0.1**	**0.008**	**0.00**	**68**	**0.000**
Al	**0.2**	**0.13**	**8.57**	**100**	**1.302**
As	**0.01**	**0.006**	**0.18**	**32**	**0.028**
Ca	**NA[2]**	**33.2**	**1184.86**	**100**	**180.070**
Cd	**0.005**	**0.002**	**0.03**	**16**	**0.004**
Cr	**0.1**	**0.008**	**0.44**	**100**	**0.067**
Cu	**1**	**0.034**	**1.07**	**77**	**0.162**
Fe	**0.3**	**0.034**	**0.42**	**39**	**0.064**
K	**NA**	**2.7**	**56.96**	**100**	**8.656**
Mg	**NA**	**1.2**	**33.99**	**100**	**5.166**
Na	**20**	**9.7**	**145.01**	**100**	**22.039**
Ni	**0.1**	**0.009**	**0.05**	**13**	**0.007**
P	**NA**	**0.11**	**2.86**	**52**	**0.435**
Pb	**0.015**	**0.033**	**0.15**	**16**	**0.023**
Si	**NA**	**3.4**	**44.93**	**100**	**6.829**
Sr	**4**	**0.083**	**3.27**	**100**	**0.498**
Zn	**2**	**0.069**	**3.89**	**100**	**0.592**

Footnotes:

Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

Loading^{Normal} = chemical loading normalized per inch of rainfall.

Appendix E

Contaminants, Maximum Concentration (ppm), Total Loading (g),
Percent Detection, and Normalized loading (g/cm rainfall) at Brookes Avenue, 9/27/02

Element	MCL[1]	Maximum Concentration (ppm)	Total Loading (g)	Detection %	Loading^{Normal}
Ag	0.1	0.007	0.115	93	0.018
Al	0.2	0.093	1.205	100	0.183
As	0.01	0.005	0.009	7	0.001
Ca	NA[2]	18.6	172.066	100	26.150
Cd	0.005	0.002	0.010	18	0.001
Cr	0.1	0.015	0.121	93	0.018
Cu	1	0.040	0.326	96	0.049
Fe	0.3	0.074	0.270	54	0.041
K	NA	2.3	26.075	100	3.963
Mg	NA	1.0	9.077	100	1.379
Na	20	18.3	73.493	100	11.169
Ni	0.1	0.004	0.012	4	0.002
P	NA	0.071	0.545	75	0.083
Pb	0.015	0.017	0.210	93	0.032
Si	NA	0.51	2.791	100	0.424
Sr	4	0.081	0.547	100	0.083
Zn	2	0.10	0.886	100	0.135

Footnotes:

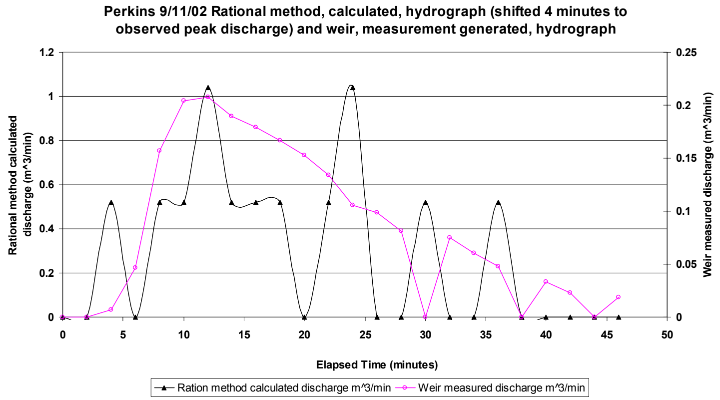
Elements on the EPA's Priority Pollutant List are highlighted yellow

1: MCL = maximum contaminant level allowed in drinking water, EPA enforceable

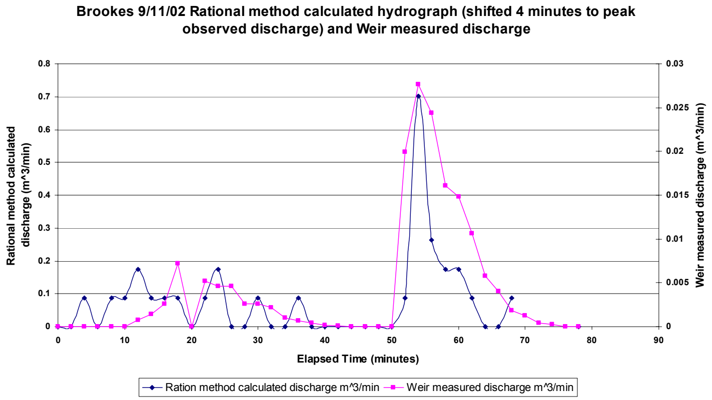
2: NA = no MCL or other standard found. I used 20ppm as a standard for Sodium, this is not an MCL, but a high blood pressure recommendation

Loading^{Normal} = chemical loading normalized per cm of rainfall.

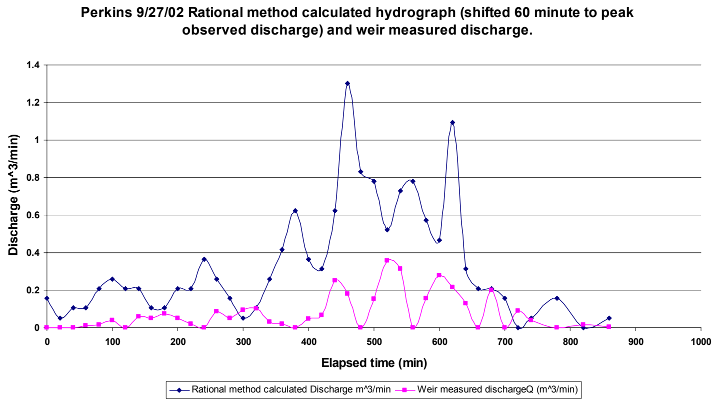
Rational Method Calculated Hydrographs Compared to Weir Measured Hydrographs



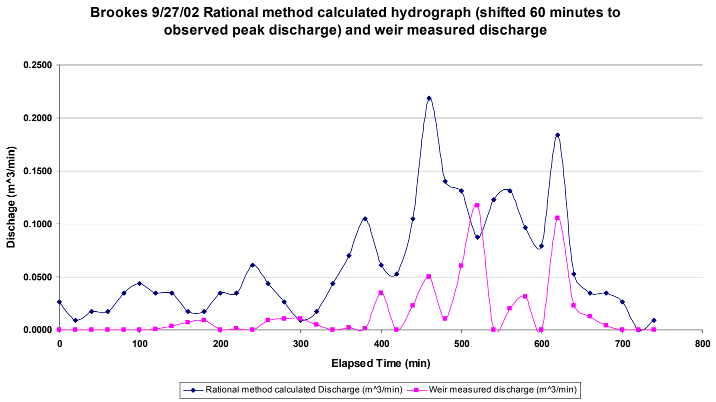
Perkins 9/11/02 Rational method, calculated, hydrograph (shifted 4 minutes to observed peak discharge) and weir, measurement generated, hydrograph



Brookes 9/11/02 Rational method calculated hydrograph (shifted 4 minutes to peak observed discharge) and Weir measured discharge



Perkins 9/27/02 Rational method calculated hydrograph (shifted 60 minute to peak observed discharge) and weir measured discharge.



Brookes 9/27/02 Rational method calculated hydrograph (shifted 60 minutes to observed peak discharge) and weir measured discharge