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Final Report

Improving the Design of Roadside Ditches to Decrease Transportation-Related Surface Water Pollution

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A field-monitoring program began in the spring of 2000 to test the ability of a grassy roadside swale to remove pollutants in stormwater. A check dam was designed and installed into the vegetative swale. The check dam system incorporated some unique design features, including a peat filter to trap nutrients and metals and a low rock pool to trap water for the settling of suspended solids and for biological processing. The check dam was cost effective and simple to install.

The system was quantified and evaluated hydrologically and qualitatively before and after the check dam installation. Pollutants monitored included total suspended solids, total phosphorus, and ortho-phosphorus. The average pollutant removal rates for the three storms following the installation of the check dam were 54 percent total phosphorus, 47 percent ortho-phosphorus, and 52 percent total suspended solids. Metals were also analyzed for two storm events, one before and one after installation of the check dam. Peat soil samples were analyzed for nutrients, organic content, water capacity, metals, and pH both before and after check dam installation. The results suggest that properly designed short vegetative strips and swales can reduce pollutant levels from the stormwater that drains off roadways.

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Improving the Design of Roadside Ditches to Decrease Transportation-Related Surface Water Pollution

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EXECUTIVE SUMMARY

A field-monitoring program began in the spring of 2000 to test the ability of a grassy roadside swale to remove pollutants in stormwater. In 2001, a check dam was designed in conjunction with Mn/DOT engineers and installed into the vegetative swale. The check dam system incorporated some unique design features, including a peat filter to trap nutrients and metals and a low rock pool to trap water for the settling of suspended solids and for biological processing. The check dam was designed to be cost effective and simple to install.

The entire system was quantified and evaluated hydrologically and qualitatively before and after the check dam installation. Pollutants monitored included total suspended solids, total phosphorus, and ortho-phosphorus. The average pollutant removal rates for the three storms following the installation of the check dam were 54 percent total phosphorus, 47 percent ortho-phosphorus, and 52 percent total suspended solids. Metals were also analyzed for two storm events, one before and one after installation of the check dam. The check dam significantly reduced metals. Peat soil samples were analyzed for nutrients, organic content, water capacity, metals, and pH both before and after check dam installation. The results suggest that properly designed short vegetative strips and swales, which include peat and rock check dams, can substantially reduce pollutant levels from the stormwater that drains off roadways.

CHAPTER 1

INTRODUCTION

The United States is highly dependent on its road system to support rapid, reliable movement of people, goods, and services. Even during adverse weather conditions, people expect roads and highways to be maintained to provide safe travel conditions. In many states, this requires substantial planning, training, manpower, equipment, and material resources to clear roads and streets throughout the year (EPA 1999). Minnesota maintains 130,613 miles of streets and highways. If road ditches are included in the calculation, approximately 260,000 acres are maintained by various government agencies (Sherkow 2000). About one-half of this acreage is in the form of ditches and drainage areas that funnel transportation related (e.g., hydrocarbons and heavy metals) and agriculturally related (nutrients from adjacent farm fields) non-point source pollution to surface waters. Numerous transportation studies have found high concentrations of petroleum, hydrocarbons, solids, metals, and nutrients in the soils, water, and air near roadways (Yousef et al. 1987).

Highways impact our society and the environment in both beneficial and non-beneficial ways. Consideration of the effects of a road system on the environment plays an important role in the design, construction, maintenance, and operation of the road system by the Minnesota Department of Transportation (Mn/DOT) and other transportation agencies. Stormwater pollution concerns environmentalists and public health officials, because of its possible detrimental effects to humans, aquatic life, and the overall health of the ecosystem.

Little research has been performed in Minnesota on developing and designing environmentally safe modifications to 'typical' roadside ditches adjacent to the thousands of miles of streets and highways. Ditches can be used to retain stormwater runoff, enhance infiltration, and bio-geochemically treat pollutants on-site. If pollutants can be reduced on site in green spaces, before transport downstream, improvements in water quality will result. On-site treatment is more cost effective and environmentally friendly than allowing polluted surface waters to flow downstream. Little scientific literature addresses the use of check dams in ditches to control pollution. The best perhaps comes from the Washington Department of Transportation (Kaighn, and Yu 1996). Related work is extensive in the area of controlling stormwater pollution by the use of rain gardens, sediment basins, and gravel, infiltration, and bioremediation systems.

The purpose of this research was to gain adequate data on the effectiveness of a vegetative swale in reducing stormwater pollutants. In addition, a goal of this research was to develop and implement a well-designed, cost effective check dam system to limit non-point source pollution.

The specific objectives of this research project were to:

- Perform field tests on a typical Minnesota vegetative swale and determine its pollutant removal efficiency under different storm conditions.
- Modify the swale with a simple rock and soil media system to limit non-point source pollution in stormwater.

Location

The research site was located at the Mn/Road Research Facility near Otsego, Minnesota, in Wright County. The Mn/Road Project is located 40 miles northwest of the metropolitan cities of Minneapolis/St. Paul on westbound Interstate 94. Construction of the Mn/Road site began in June of 1990 and was a joint effort between the Minnesota Department of Transportation and the University of Minnesota. Today, the Minnesota Road Research Project is the largest and most comprehensive outdoor pavement laboratory in the world, distinctive for its electronic sensor network embedded in the pavement and its weather station (Mn/Road 2002). More than 4,500 pavement sensors measuring the effects of traffic and the environment are installed in the three-mile test section. The Mn/Road Project allows researchers to pursue a wide variety of projects. Currently, there are 14 different projects being performed at Mn/Road (Mn/Road 2002). The goals of the Mn/Road Project include finding more efficient, cost effective, longer lasting, and safer roadways for the state of Minnesota and other transportation departments throughout the world. The facility provides data that will expectantly result in reliable, safer, and cheaper roadways (Mn/Road 2002).

Climate

The region has a continental climate with a mean annual precipitation of 76.2 centimeters, most of which occurs during the growing season (Midwestern Regional Climate Center 2002). The average snowfall is 152.4 centimeters (Minnesota State Climatology 2002). The daily average January temperature is -13.5 degrees Celsius. The average July temperature is 19 degrees Celsius (Midwestern Regional Climate Center 2002).

Vegetation

Smooth Brome (*Bromus inermis*) and Timothy grass (*Phleum pratense*), two common swale grasses were the dominant vegetative species at the site. The site was mowed three times over the growing season in June, July, and August. Grass clippings were not removed.

Watershed Area

The watershed area is 52 acres with a curve number of 73 and a time of concentration of 55 minutes. Peak discharges were calculated with a United States Geological Survey (USGS) quad and a Mn/Road contour map. The peak discharge estimates were:

- A one-year storm peak discharge of 4.5 cubic feet per second (cfs) in the ditch with a total storm volume of about 2.0 acre-feet.
- A two-year storm peak discharge of 8.0 cfs in the ditch with a total storm volume of about 2.9 acre-feet (Peterson, 2001; and Carlstrom 2001).

Experimental Design

The experimental vegetative swale was situated on the far western end of the Mn/Road facility (Fig. 1-1). Several factors were considered when choosing the site; these included the safety of the researcher at the research site, access to weather station data, depth of the water table, access to a power source, and the long-term nature of the research study.

Figure 1.1. Experimental Vegetative Swale.

Construction of the experimental vegetative swale began in June 2000. The experimental site was constructed similar to a design utilized by the Virginia Transportation Council (Yu et al. 1994). An area 40 meters by 5 meters was staked off in the ditch. Lateral flow barriers consisting of sheet metal pieces 4.5 meters long and 20 centimeters high were trenched into the ground with a backhoe. Barriers were utilized to limit lateral inflow into the swale, so that the pollutant mass balance estimates could be more accurately determined. The sheet metal trenches were repacked with clay material, which acted as a barrier to lateral water flow.

The ditch was typical of a Minnesota road ditch, with a slope of 1 percent and a ditch bottom width of 2.4 meters. In 2001, a check dam was designed in conjunction with Mn/DOT engineers and installed into the vegetative swale during the summer (Figure 1-2). The designed check dam was installed in the experimental swale 1.5 meters from the outflow flume. The check dam was composed of a rock-lined shallow pool at its upstream end, a gabion-filled peat filter, and a shorter rock-filled outflow apron at its downstream end. The entire system was lined with mil polyethylene sheeting, isolating the system from the soils underneath.

Parshall flumes equipped with Isco® flow meters and Isco® automatic water samplers were installed at the input and output of the swale for monitoring stormwater flows entering and leaving the system. This defined area was studied from 2000 to 2002 to gain hydrologic and water quality data at the site and to determine the effectiveness of the swale at decreasing pollution.

During storm events water entered and filled the shallow upstream pool of the check dam system. The pool allowed for filtering and settling of suspended solids before the runoff entered the peat filled filter. Runoff filtered through the peat before seeping into a second but shorter rock-lined pool. During large storm events, excess water ran over the check dam and directly to the downstream output flume.

Figure 1.2. Completed Check Dam August 2001.

Samples were collected within two days of a rain event and were transported to the laboratory in iced coolers. *In situ* measurement of pH, temperature, and specific conductivity were conducted onsite with a handheld Hach® Meter. Total suspended solids (TSS) analysis was conducted according to *Standard Methods for the Examination of Water and Wastewater 1998*. The University of Minnesota Research Analytical Lab analyzed all samples for total phosphorus and ortho-phosphorus. The Research Analytical Lab also analyzed several storm samples for nitrate-nitrite but concentrations were less than .02 mg/L for all analyzed samples. Nitrogen was not considered a major nutrient pollutant in the system at these low concentrations and was not measured again. Two storm events were sampled and analyzed for heavy metals; where one storm event was analyzed before check dam installation, and the second sample collection was performed after check dam installation.

CHAPTER 2
LITERATURE SEARCH

Overview

The highway system is a contributor of harmful pollutants to the surrounding environment. Contaminants from vehicles and activities associated with travel, road construction, and maintenance are washed off roads when it rains or snows (EPA 1995). As water flows over these surfaces, it picks up dirt, dust, rubber, and metal deposits from tire wear, antifreeze, engine oil, lawn and agriculture fertilizers, and trash and debris (EPA 1995). Numerous transportation studies have found high concentrations of petroleum, hydrocarbons, solids, metals, and nutrients in the soils, water, and air near roadways (Yousef et al 1987). Sources of several common stormwater pollutants are listed in the table below.

Table: 2.1. Sources of Pollutants in Stormwater.

Category	Pollutant
Tire wear	Zn and Cd
Brake wear	Cu, Pb, Cr, and Mn
Engine wear and fluid leaks	Al, Cu, Ni, Cr, V, and Hydrocarbons
Vehicular component	Fe, Al, Cr, and Zn
Land use	BOD, PO_4^{3-}, NO_3-, N, Cd, nutrients, herbicides, preservatives, paints, Fe, Mn,
Construction	Sediments and nutrients
Road maintenance	Road salts, sediments

Adapted from Hamilton and Wanielista et al. 1991

Descriptions of the common stormwater pollutants are provided below.

Nutrients One of the principal causes of accelerated eutrophication in Minnesota lakes is the introduction of nutrients, particularly phosphorus. Although agriculture is considered a major source of phosphorus and nitrogen in the nutrient enrichment of lakes, evaluation of relative contributions of industrial, municipal, and suburban stormwater is also significant. Phosphate-free fertilizers and detergents are outlawed in many cities in the United States.

Road Salts The dependency on deicing chemicals has increased since the 1940s and 1950s to provide safe and efficient winter transportation (EPA 1999). Sodium chloride is one of the most common deicing agents used (EPA 1999) by transportation agencies. Sodium chloride use began in the 1930s (Salt Institute 1994). The application of salt has increased dramatically and with the increase, millions of roadside trees have been damaged, drinking water wells have been contaminated, automobiles have rusted, and bridges have corroded (Lord 1998). Excess salt can cause fish kills and water chemistry changes, affecting all aquatic life and vegetation. Annually, Minnesota on average applies 200,000 tons of salt at a cost of $6 million/year (Grilley 2002).

With the growing recognition of the harmful effects of road salts, researchers have studied alternative methods of maintaining safe road systems. Calcium magnesium acetate (CMA), which is less likely to harm the environment, is an alternative to sodium chloride (EPA 1999). Calcium magnesium acetate, however, is more expensive and requires a larger amount of material to deice than sodium chloride (Lord, 1998).

Heavy Metals Heavy metals are derived from natural sources such as mineral rocks, vegetation, sand, and salt. Auto exhaust, worn tires, engine parts, brake linings, paint, and rust are also sources of heavy metals. Toxic to aquatic life, heavy metals can also contaminate groundwater. Vehicle tire wear leaves lead and zinc deposits on the road surface (Umeda 1998).

Solids Sediment is produced when soil particles are eroded from the land and transported to surface waters. Natural erosion usually occurs gradually because vegetation protects the ground. When land is cleared or vegetation is disturbed to build a road or bridge, erosion increases. During storms silt, sediment, and other pollutants are washed off the sites. Sediment losses from construction sites range from 30 to 750 tons per acre (Davis et al. 1998).

An additional source of sediment in stormwater is road sand. Mn/DOT applies 200,000 tons of sand annually to roads during the winter, at a cost of $250,000 per year (Grilley 2002). The sand washes into road ditches and eventually travels to waterways. Sediments clog fish gills, prevent sunlight from reaching aquatic plants, cover spawning beds, and harm other aquatic organisms.

Hydrocarbons The oils, grease, and gas found in stormwater is leaked onto road surfaces from vehicle engines, is dumped into storm sewers, is leaked by underground storage tanks, or is caused by fueling station spills. These constituents eventually end up in our waterways (EPA 1995). Spilled petroleum products being washed off roads exhibit a rainbow color in the stormwater.

Debris Grass and shrub clippings, pet waste, and other litter can lead to polluted waters. Pet waste from urban areas can add enough nutrients to lakes to cause eutrophication (Wanielista and Yousef 1993).

Herbicides and Pesticides Herbicides are used by transportation departments to control weeds in ditches and around guardrails . Pesticides and herbicides, if applied excessively or improperly can be carried by stormwater. Wanielista and Yousef found that stormwater contained readily degradable toxic herbicides (1993). Herbicides and pesticides harmfully affect aquatic organisms, wetland animals, habitats, and humans.

Stormwater Regulations

Growing public awareness and concern for controlling water pollution led to the enactment of the Federal Water Pollution Control Act Amendments of 1972 (United States EPA 2002). Today, this law is known as the Clean Water Act. The Act established the basic structure for regulating discharges of pollutants into the waters of the United States (United States EPA 2002). The Act made it unlawful for any person to discharge a pollutant from a point source into navigable waters, unless a permit was obtained. Since its enactment in 1972, the Clean Water Act has funded the construction of sewage treatment plants and control of non-point source pollution (United States EPA 2002). Subsequent modifications to the Clean Water Act have occurred since 1972.

In November 1990, the U.S. Environmental Protection Agency (EPA) issued the first federal stormwater regulations. The regulations were published in the Phase I Stormwater Rules Manual as an effort to reduce contaminants from non-point runoff. In 1998, the EPA published a second manual, which required the regulation of smaller storm sewer systems. Currently, Minnesota does not include roadway runoff in these stormwater regulations, though numerous measures already have been put in place (Davis et al. 1998).

Managing Stormwater Pollution

Road runoff is difficult to monitor and manage due to location, diffuse sources of potential contaminants, varied climatic conditions, variable traffic patterns, and other associated factors (Davis et al. 1998). The principal factors affecting the amount and quality of highway runoff include precipitation type (rain or snow), intensity, duration and frequency, vehicular and truck count, highway surface, highway maintenance practices, pollutant accumulation and deposition, local land use, soil drainage characteristics, vegetation cover, geological and topographic characteristics, and pavement type and condition (Sansalone and Buchberger 1996 and Wanielista and Yousef 1993).

Capturing and treating road runoff during the early part of a storm event is a significant way to decrease pollution. Considerable fractions of soluble, complexed, and particulate-bound fractions of pollutants are washed off roads during the rising limb of the runoff hydrograph (Sansalone and Buchberger 1996). Depending on the intensity and duration of a rainfall-runoff event, accumulated metal elements, solids, and other pollutants can be rapidly washed off the roadway surface. This phenomenon is commonly referred to as the first flush. Mitigation measures, which can isolate first flush loadings for "treatment" require smaller storage capacities than measures that aim to treat all the runoff, thereby requiring less area.

Best Management Practices for Stormwater

Efficiently conveying water away from the pavement surface and preventing standing water accumulation are two main functions of a road drainage system (Peterson 2001). Such a system, however, may not directly address other potential stormwater-related concerns such as quality, quantity, erosion control, and groundwater recharge (Sabourin and Associates 1999). The comparison of drainage alternatives cannot be limited to how well they convey or treat stormwater, but must also consider how well they can be integrated in our communities and at what cost (Sabourin and Associates 1999. In northern states, dealing with frozen ground conditions, special challenges may exist when choosing and implementing stormwater systems.

Numerous studies have reported on the benefits of stormwater ponds, zoning modifications, detention ponds, porous pavement, infiltration pits, grassy swales, infiltration swales, buffer areas, and street cleanings (Finley and Young 1993). Mild slopes, dense grass, small flows, and ponding of stormwater have also been used to improve pollutant removals. Most stormwater control strategies can be classified as infiltration, detention, vegetative, or wetlands systems (Sansalone et al. 1998). Each of these strategies has differing degrees of effectiveness for differing constituents and suitability constraints (Sansalone et al. 1995). Performance can be extremely variable for many parameters within a group of stormwater management practices. This is in addition to the variability, frequently seen from storm to storm, within an individual stormwater practice. "Essentially, any control strategy can be viewed as a 'garbage can' and like any garbage can, it must be emptied and cleaned periodically" (Sansalone et al 1998).

Peat

Previous research has shown that peat can act as both a nutrient filter and nutrient trap (Carlstrom 1982; Galli 1990; Nichols and Boelter 1982). Peat holds water and nutrients for growth, improves water infiltration when added to clay soils, and improves the soil's physical properties. Peat reduces the bulk density of soil, allowing for better root penetration and aeration; adds nutrient retention capacity to reduce cation leaching; and buffers the soil pH. Peat has a high cation exchange capacity and has the ability to bind strongly to heavy metals, treat sewage effluent, and clean oil spills.

Due to its relative availability and low cost, peat has found several uses in both industrial and domestic water treatment applications (Galli 1990). The development of a successful peat-sand filter system for the treatment of sewage effluent was pioneered by Dr. R.S. Farnham (Galli 1990). Farnham and Brown (1972) found that peat could treat 99 percent of fecal coliforms, and 98 percent Biological Oxygen Demand in wastewater treatment filters. Nichols and Boelter 1982, used peat filter beds in northern Minnesota to treat campground effluent. Ninety-nine percent of phosphorus loadings were decreased after flowing through the filter bed. Tilton and Kadlec, applied secondary effluent to a natural peat land in Michigan and found reductions of 73-96 percent phosphorus and 95-98 percent nitrate-nitrite (1979).

The term "peat" commonly refers to unconsolidated soil material consisting largely of undecomposed or slightly decomposed organic matter accumulated under conditions of excessive moisture (Brady and Weil 2000). Peat is complex both physically and chemically. Peat is a highly organic material composed of humic and fulvic acids and cellulose. The humic and fulvic acids make peat materials extremely resistant to decay (Galli 1990). Differences in peats are also affected by the types of plants (mosses, sedges, and other plants), from which they originate.

Peat materials are generally differentiated based on the state of decomposition, acidity, absorbency, botanical origin, and ash content (Galli 1990). Numerous classification systems exist to classify peat. The United States Department of Agriculture (USDA) system will be used and described here. The USDA classification of peat places peat into three classes based on decomposition: fibric, sapric, and hemic.

Fibric peats have low bulk densities, high porous structures, high hydraulic conductivities, high water-holding capacities, and are typically brown or yellow in color. The most common is sphagnum moss, which is extremely acid (Galli 1990).

Sapric peats are the most highly decomposed peats. The original plant fiber has mostly disappeared, and sapric peats have high bulk densities, low hydraulic conductivities, low water-holding capacity, and are dark gray to black in color (Galli 1990).

Hemic peats are more decomposed than fibric peat but less decomposed than sapric peat. Bulk densities range from .01 to .2 g/cm and have intermediate water-holding capacities (Galli 1990).

The permeability and hydraulic conductivities of peat vary and are largely determined by the degree of decomposition and differences in pore spaces. Porous peat exhibits higher water-holding capacities, higher hydraulic conductivities, and is more easily dewatered than non-porous peat. Undecayed or slightly decomposed moss or sedge peats hold water to the extent of

12 to 20 times their dry weight (Brady and Weil 2000). In contrast, a mineral soil will only hold 1/5 to 2/5 its weight in water (Galli 1990). Hydraulic conductivities for peat can range from as low as .025cm/hr to as high as 140cm/hr (Nichols and Boelter 1982).

Peat has a high buffering capacity, a high adsorptive surface, and a high cation exchange, which supports nutrient-deficient or low nutrient-tolerant plants. A high cation exchange capacity is good for copper, zinc, lead, and mercury uptake. Peat that is high in aluminum, calcium, and ash often tends to have high removal rates of phosphorus (Galli 1990). The high C: N: P ratio of peat, which often approaches 100:10:1, makes it an excellent substrate for microbial growth and assimilation of nutrients and organic waste materials (Galli 1990). High numbers of nitrifying and denitrifying bacteria are typically present in unprocessed peat materials (Galli 1990). Microbial assimilation of phosphorus in peat is related to its Ca, Al, Fe, and ash content (Nichols and Boelter and Miller 1979).

Owing to both its physical and chemical adsorptive/filtrative properties, peat is an excellent natural filter of many types of effluents and pollutants. High nutrient, heavy metal, BOD, and pathogen removal capabilities, in addition to maintenance requirements and affordability make peat an attractive alternative for on-site stormwater treatment practices.

CHAPTER 3

ANALYSIS, RESULTS, AND RECOMMENDATIONS

INTRODUCTION

Hydrographs and pollutographs were constructed for each of the twelve storms. Hydrographs detail the discharge of water with respect to time. An example of a hydrograph for 18May 2002 is shown in Figure 3-1. Pollutographs, like hydrographs are graphs that detail the pollutant concentration of the water with respect to time. Figure 3-2 is an example of a pollutograph.

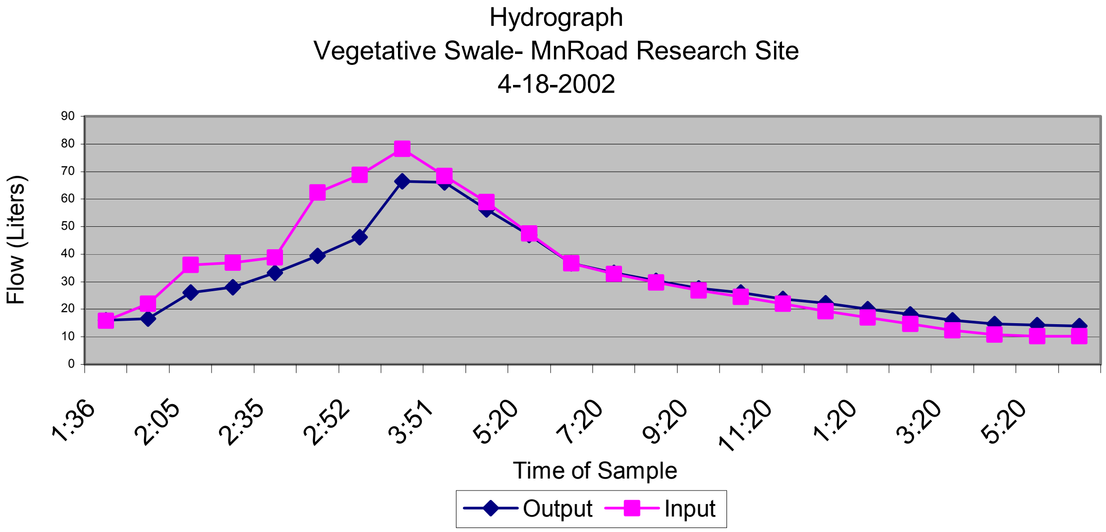

Figure 3.1. Water Discharge on 18 April 2002.

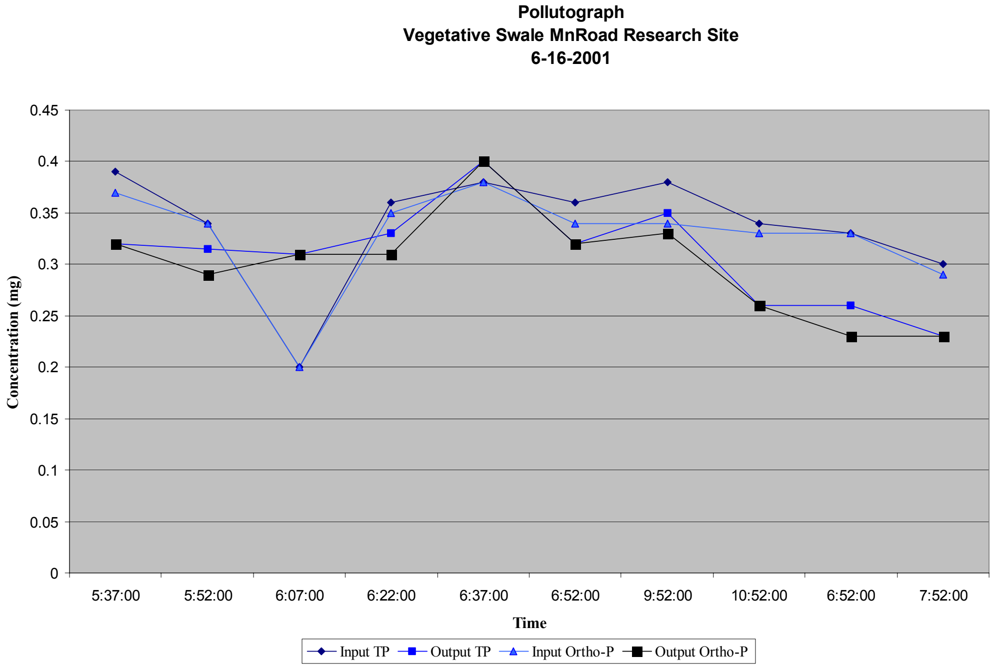

Figure 3.2. Pollution Concentration on 16 June 2001.

Mass loading and total loading graphs were constructed for the twelve storms. Values of mass and total loadings were based on a combination of both hydrographs and pollutographs. Mass loadings were calculated by multiplying the flow by the pollutant concentration at a given time. Values for total loadings were determined by multiplying average mass loadings by the time interval between sampling events. Figures 3.3 and 3.4 are examples of mass and total loading graphs.

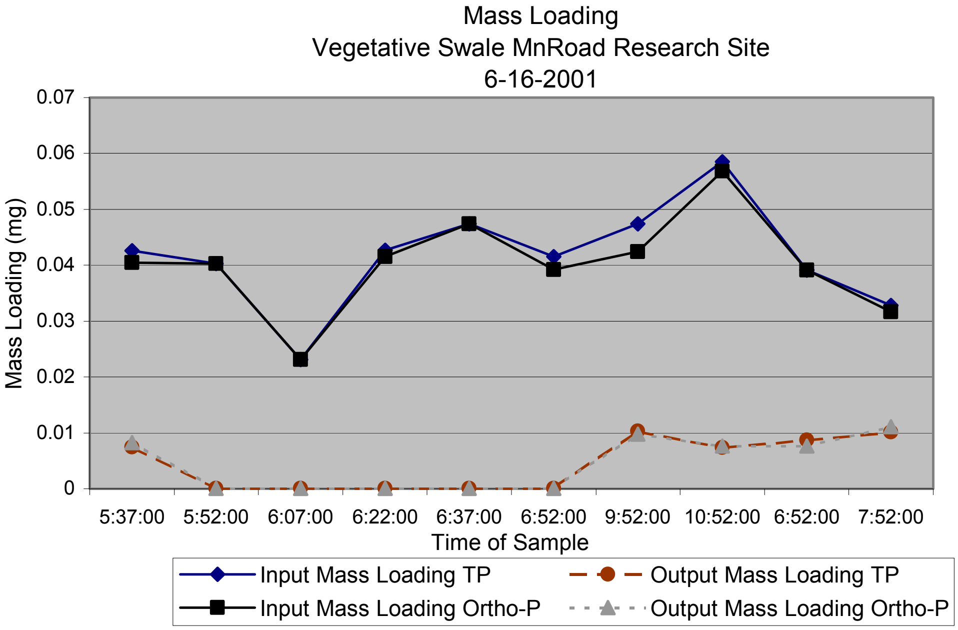

Figure 3.3. Mass Loading of 16 June 2001 Storm.

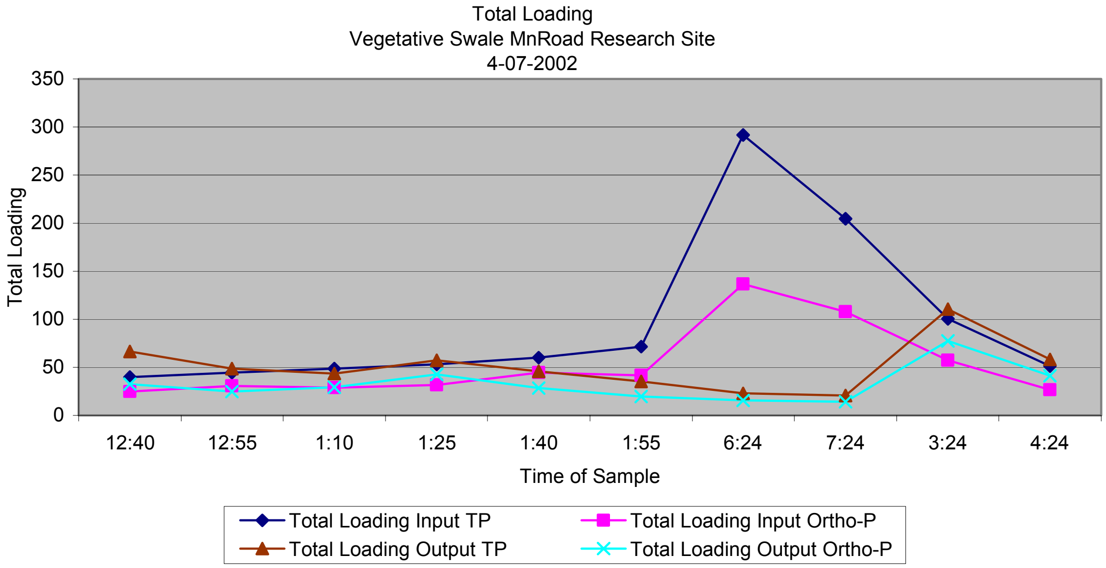

Figure 3.4. Total Loading 7 April 2002 Storm.

Values for event mean concentrations (EMCs) and pollutant removal efficiencies were calculated for each of the storms. Non-point pollutant concentrations often vary by several orders of magnitude during a runoff event. Therefore, a single index, known as event mean concentration, was calculated to characterize stormwater pollution for the entire storm event (Sansalone et al. 1995). Values for EMCs were calculated by dividing the total pollutant load mass (M) by the total runoff volume (V) of the storm, or

$$\mathbf{EMC} = \frac{\mathbf{M}}{\mathbf{V}} = \frac{\mathbf{C(t)Q(t)dt}}{\mathbf{Q(t)\ DT}}$$

Where:
M = total mass of pollutant [M]
V = total liquid volume of flow or sample, [L^3]
C(t) = time-variable concentration, [M/L^3]
Q(t) = time variable flow. [L^3/T]

The pollutant removal efficiency is the percentage of the total pollutant loading change that occurs between the input flume and the output flume over a storm event. Values for pollutant removal efficiencies were calculated by the equation

$$\textbf{Removal Efficiency (\%)} = \frac{\textbf{(mass in-mass out)}}{\textbf{(mass in)}} \ \mathbf{*100}$$

Graphs detailing the percentage of pollutant removal for total phosphorus (TP), Ortho-phosphorus (Ortho-P), and total suspended solids (TSS) can be seen in Figures 3-5, 3-6, and 3-7. Precipitation data for all of the storm events can be found in Tables 3-1 and 3-2.

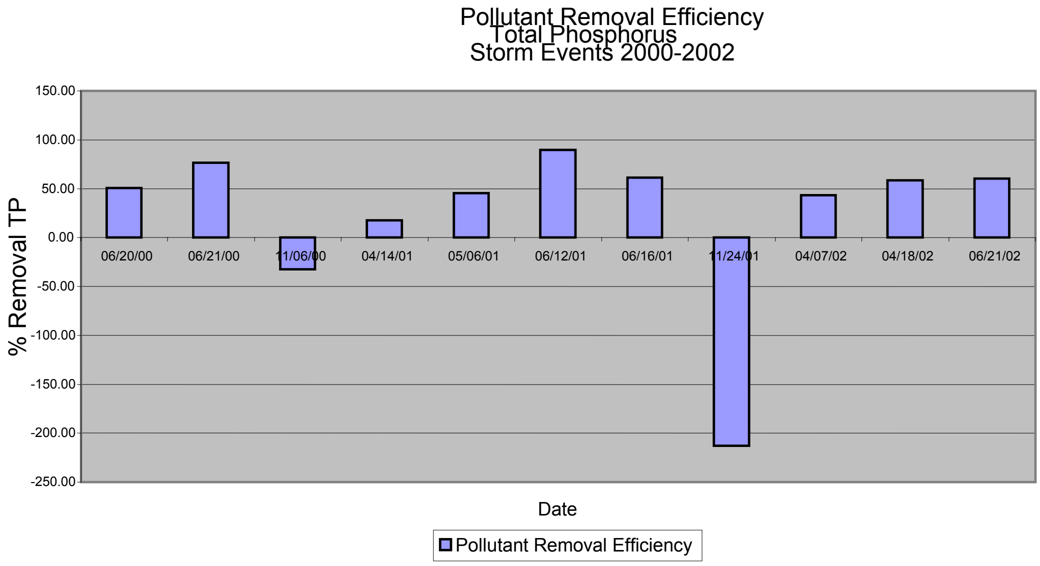

Figure 3.5. Pollutant Removal Efficiency, Total Phosphorus, Storm Events 2000-2002.

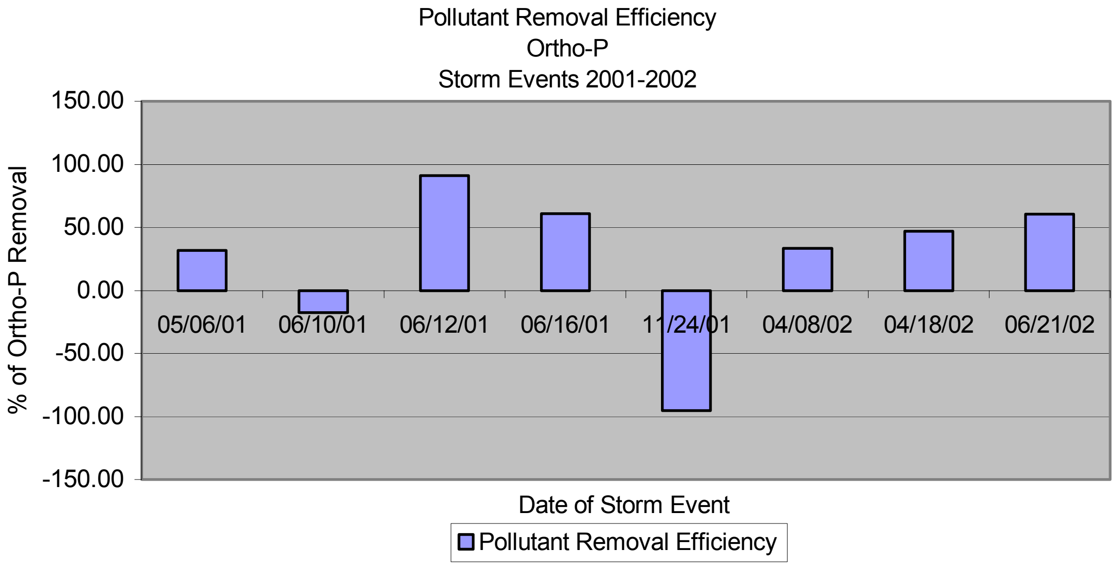

Figure 3.6. Pollutant Removal Efficiency, Ortho-phosphorus, Storm Events 2000-2002.

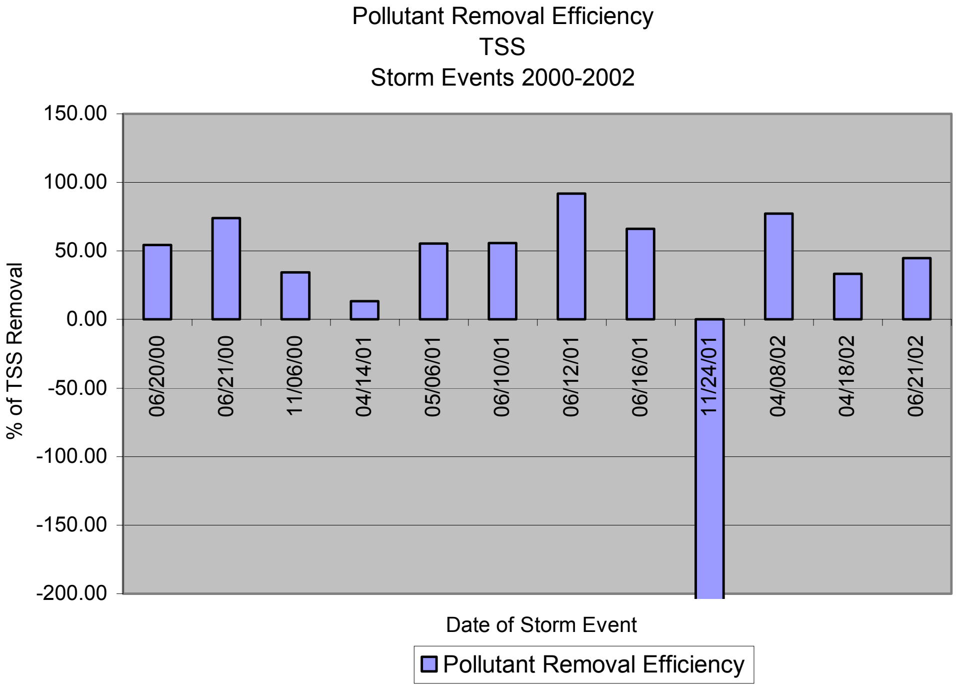

Figure 3.7. Pollutant Removal Efficiency, Total Suspended Solids, Storm Events 2000-2002.

Table 3.1. Storm Intensity and Depth for Each Rainfall Date.

Storm N	Date (mm/dd/yr)	Depth (mm)	Duration (hr)	Average intensity (mm/hr)
1	6-19-2000	7.62	4	1.78
2	6-21-2000	13.2	4	3.3
3	11-06-2000	36.8	24	1.52
4	4-14-2001	5.6	4	1.3
5	05-06-2001	7.7	3	2.54
6	06-10-2001	16.33	5	3.3
7	06-12-2001	14.2	3	4.75
8	06-16-2001	6.6	2	1.78
9	11-24-2001	39.0	19	2.3
10	4-07-2002	Snow melt	Snow melt	Snow melt
11	4-18-2002	15.2	3	5.08
12	6-21-2002	29.5	7	4.32

Table 3.2. Precipitation Data: 2000-2002.

Date:	Precipitation (mm)	Max Temp. °C	Min. Temp. °C	Snow (mm)
January 2000	14.98	-6	-17	236.22
February 2000	37.08	0	-10	271.78
March 2000	40.64	9	-3	0
April 2000	41.15	13	.5	76.2
May 2000	54.86	21	9	0
June 2000	103.63	23	12	0
July 2000	90.17	27	16	0
August 2000	45.72	27	16	0
September 2000	4.826	22	7	0
October 2000	32.51	17	4	0
November 2000	110.24	3	-5	76.2
December 2000	4.06	-11	-19	381
January 2001	11.68	-3	-14	185.42
February 2001	7.87	-7	-21	391.16
March 2001	32.268	1	9	157.48
April 2001	202.18	13	2	0
May 2001	103.37	20	9	0
June 2001	82.80	25	14	0
July 2001	36.32	29	16	0
August 2001	105.16	28	16	0
September 2001	78.74	21	9	0
October 2001	20.32	14	2	0
November 2001	67.31	12	1	241.3
December 2001	14.73	.67	-8	101.6
January 2002	4.83	-1	11	86.36
February 2002	30.23	2	9	238.76
March 2002	47.24	-2	12	495.3
April 2002	115.82	10	0	375.92
May 2002	75.69	M	M	0
June 2002	136.40	26	15	0
July 2002	228.6	M	M	0
August 2002	137.41	M	M	0
September 2002	117.60	M	M	0
October 2002	118.87	9	.5	63.5
November 2002	7.112	4	-5	12.7
December 2002	5.334	-.056	-9	0

Data Analysis

Statistical analysis was difficult because of the relatively low number of sample events. Paired T-tests and correlation tests between total loadings for suspended solids and total phosphorus were performed. Paired T-tests for EMCs and for total loadings were conducted both before and after check dam installation. The small number of samples may have led to variation in the calculated r-value and paired T-tests.

Soil Analysis

A core sample of the peat material was taken before installation into the check dam. An additional peat sample was taken following a year of stormwater treatment from the check dam. A simple bar graph was constructed that details the percentage change in the analyzed parameters from the pre and post check dam peat soils (Fig. 3-8).

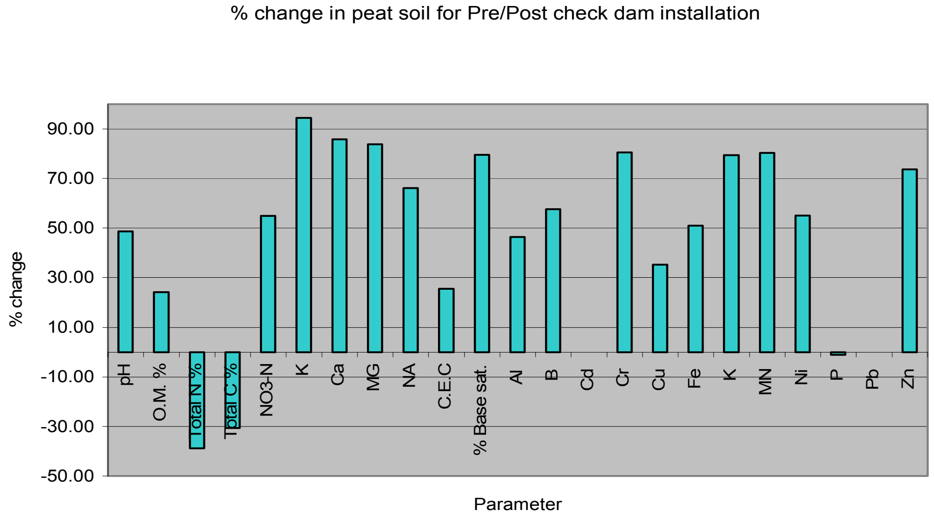

Figure 3.8. The Percentage Change in Pre-treatment and Post-treatment Peat Soil Samples.

Results

Total phosphorus and total suspended solids loading values were greater in all samples at the input flume than the output flume except for two storms from November 2000 and November 2001. The storms had total phosphorus and TSS loading values higher in the output than the input flume.

Prior to check dam installation, the average EMC value for the input was 8.3mg/L for TP, 1.40mg/L for Ortho-P, and 494mg/L for TSS. The average EMC values for the output were 5.7mg/L TP, 3.3mg/L Ortho-P, and 419mg/L TSS.

The average pollutant removal efficiency before the installation of the check dam was 22 percent for TP, 50 percent for TSS, and 42 percent for Ortho-P. Nine storms were sampled prior to check dam installation. Average pollutant removal efficiency values following the check dam installation were 54 percent TP, 52 percent TSS, and 47 percent Ortho-P. The average EMC value for the input was 3.5mg/L TP, 2.35mg/L Ortho-P, and 468mg/L TSS. The average EMC values for the output were 2.3mg/L TP, 1.69mg/L Ortho-P, and 219mg/L TSS.

Statistical differences were determined at the 90 percent confidence interval. We can be 90 percent confident that the input total phosphorus loadings were greater than the output total phosphorus loadings both before and after the check dam installation. The determined p-value was 0 .07. Correlation tests for total phosphorus and total suspended solids were performed on each of the twelve storms. There was not significant correlation between total phosphorus and total suspended solids. The calculated r-value for all the storms was 0.5.

It was difficult to analyze the heavy metals because of the small number of sample events, and the difficulty in comparing storms of different storm intensities, however, it was promising to see decreases in heavy metals both before and after check dam installation (Figures 3-9 and 3-10). Following check dam installation, all of the sampled heavy metals had decreased from the input to the output flume (Figure 3-9). Some metal levels decreased by as much as 70 percent.

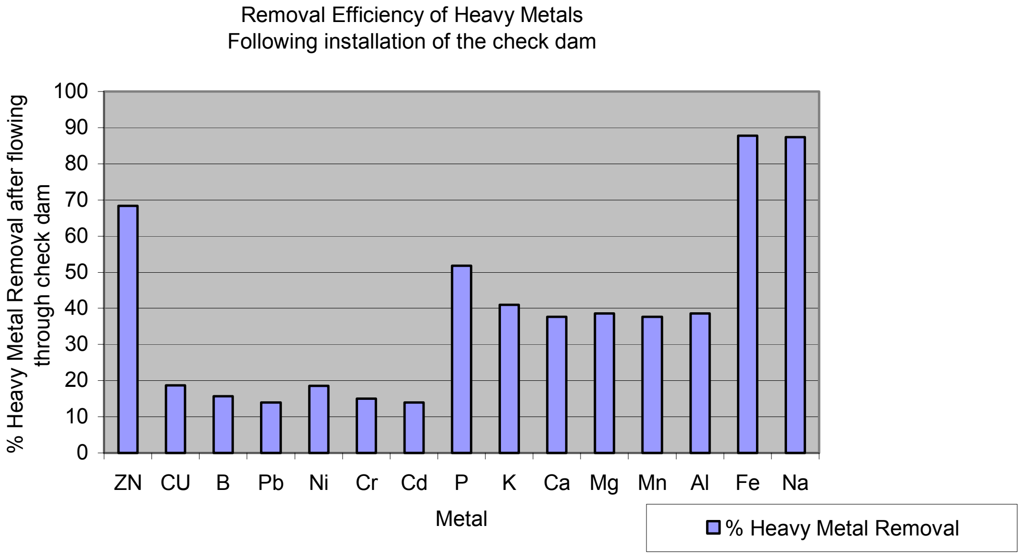

Figure 3.9. Percentage Removal of Heavy Metals Following Check Dam Installation.

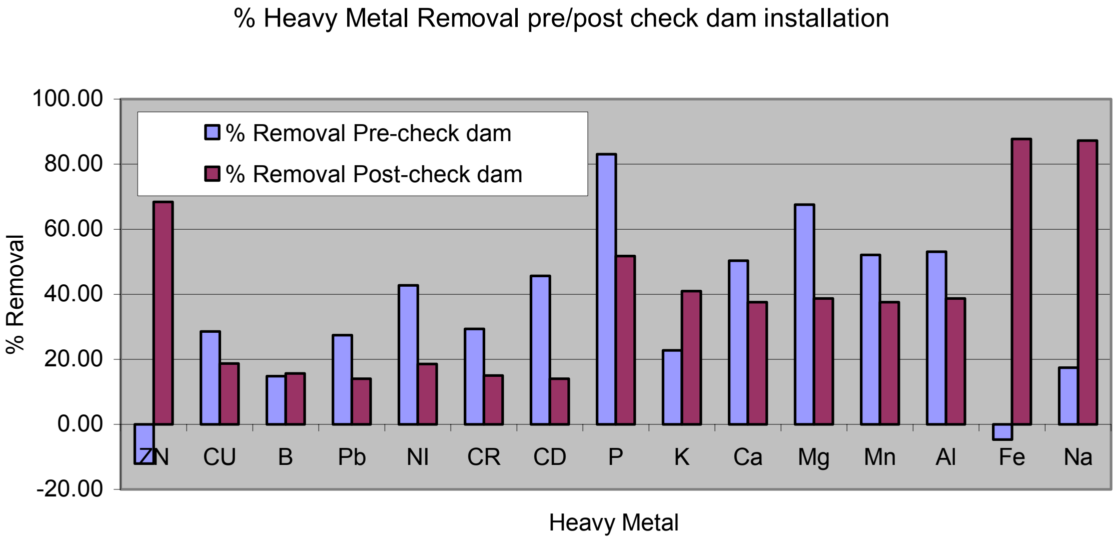

Figure 3.10. The Percentage Reduction in Heavy Metals.

Discussion

In analyzing these storms, it was evident that a 130-foot vegetative swale was effective at reducing total suspended solids and total phosphorus given an adequate vegetative cover. Average removal efficiency values were greater than 40 percent for all of the storms before the check dam installation. This is very promising in that vegetative ditches can significantly reduce a percentage of the pollution exiting roadways. It is promising, yet the concentrations of pollutants in this study were relatively small. Vegetative swales alone will not be as effective in removing large pollutant loadings.

Many studies have attempted to show the water quality benefits of grassed swales, with varying degrees of success (Kaighn and Yu 1996). Finley and Young (1993) found that the average efficiencies of phosphorus removal were 10 to 20 percent for grassy swales with 50 percent removal as the upper limit. Yousef et al. (1987) found average reductions of 23 and 27 percent TP and Ortho-P removal for one swale, and 13 and 14 percent removals for a second study swale. Similarly, the EPA (1999) suggests that a properly designed vegetated swale may achieve a 25 to 50 percent reduction in particulate pollutants and lower removal rates with dissolved pollutants. Thus, the conventional wisdom of the benefit of swales and natural buffers is 10 to 40 percent phosphorus removal with 50 percent as an upper limit.

The average pollutant removals for the three storms following the installation of the check dam were 54 percent TP, 47 percent Ortho-P, and 52 percent TSS. The average pollutant removals for the storms prior to the check dam installation had removal efficiencies of 22 percent for TP, 50 percent for TSS, and 42 percent for Ortho-P. It was evident that the check dam was effective at reducing both TP and Ortho-P for storm events. Seasonally, the percentages of pollutant removals for phosphorous and TSS continued to increase throughout the growing season.

The storm events of 6 November 2000, 10 June 2001, and 24 November 2001 had higher total phosphorus loadings in the output than input. A possible explanation for the November 2000 storm was that the twenty days prior to the storm event were below freezing, i.e., night time temperatures were below 0°C (Minnesota State Climatology Office 2002). Soluble phosphorus may have been released directly to the system by the frozen vegetation. This explanation is supported by the observation that TSS was higher at the input flume than the output flume. TSS was limited by the vegetative swale system. The total phosphorus loading therefore was not greater in the output because of the absorption to suspended solids. No decrease in event mean concentration levels for total phosphorus and totals suspended solids between the input and output were observed. Again, vegetation re-growth had not occurred before this storm event.

The 10 June 2001 storm event was sampled following the mowing of the grass within the defined swale area. The area was mowed the first week of June. The antecedent conditions were dry prior to the 10 June 2001 rain event. Soluble phosphorus may have been released directly to the system by the dead vegetation. This explanation is supported by the fact that TSS was higher at the input flume than the output flume. Again, TSS was limited by the vegetative swale system. The TP loading therefore was not greater in the output because of the absorption to suspended solids. This explanation is also supported by the observation that 90 percent of the TP was Ortho-P.

The 24 November 2001 storm event was sampled following the installation of the check dam and may have had higher TP, Ortho-P, and TSS values because of the disturbance to the experimental swale during check dam construction. Most likely, disturbance of soils during construction and initial leaching from the field and peat material caused the observed increase in pollutant loadings.

The check dam was efficient at reducing the heavy metals flowing through the vegetative swale and check dam system. Fe, K, Na, and P were reduced by greater than 50 percent, after flowing through the swale plus check dam system. Prior to the check dam installation, the vegetative swale was highly efficient at reducing heavy metals. Figure 3-10 compares the percentage of heavy metal removal between a pre and a post check dam installation storm event. When analyzing the events, it is important to note that the storm intensities were not of equal magnitudes. The pre check dam storm event was a less intense precipitation event than the post check dam storm event.

Recommendations

This model vegetated ditch and check dam were found to reduce pollution in the swale by as much as 54 percent. Phosphorus carried in stormwater is approximately 50 percent soluble and 50 percent affixed to sediment (Finley and Young 1993). Thus, if sediment can be efficiently trapped by a check dam system, 50 percent of the phosphorus load can be removed from stormwater. The average removal efficiency of TSS with this check dam was 52 percent.

Clearly, the removal rates for phosphorus and TSS with the addition of the check dam in a vegetated swale are significantly higher than without a check dam. The average Ortho-P EMC value prior to installation of the check dam was greater in the output than the input flume. Following the installation of the check dam, the average EMC value for Ortho-P was reduced by 30 percent. Heavy metal levels decreased with the installation of the check dam, which may offer insight into the ability of the peat check dam to further enhance the treatment of stormwater.

This research is promising in that the installation of the check dam was effective in reducing pollutant levels for all storm events, even during early spring storms. The check dam was able to compensate for the lack of vegetation during these seasonal changes. The average pollutant removals for the storms following the installation of the check dam were 54 percent TP, 47 percent Ortho-P, and 52 percent TSS. All heavy metal levels were decreased after flowing through the check dam.

The frequency with which the peat layer must be replaced, when subjected to various stormwater-loading rates, is still largely unknown. In this study, P removal was still excellent after one year. Heavier record stormwater loadings such as those in June and July 2002 may have resulted in a shorter life span of the check dam.

Further research is also needed to determine the efficiency of the check dam at removing large pollutant loadings similar to those exiting highly traveled roads. The pollutant loadings in this research were relatively small. Greater removal efficiency values may be realized with the addition of a series of check dams in longer roadside swales. Also, more research needs to performed analyzing the check dam efficiency at reducing heavy metals.

Further studies also need to be performed that investigate the economic benefits and costs of the check dam system to the State of Minnesota and the Department of Transportation. Costs for the construction of the check dam are listed in Appendix C. In comparing the cost of check dam construction with the cost of building a mile stretch of roadway, the check dam is very inexpensive. More research needs to be performed in determining how many check dams are needed for a given area of roadway.

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APPENDIX A
CONSTRUCTION OF THE CHECK DAM

The prototype of the check dam system was installed in the experimental site already functioning at the Mn/Road Research Facility. In 2001, a check dam was designed in conjunction with Mn/DOT engineers and installed into the vegetative swale during the summer. The check dam was composed of a rock-lined shallow pool at its upstream end, a gabion-filled peat filter, and a shorter rock-filled outflow apron at its downstream end. During storm events, water entered and filled the shallow upstream pool of the check dam system allowing for filtering and setting of suspended solids. Runoff filtered through the peat, and then seeped into a second but shorter rock-lined pool. The purpose of this research was to develop and implement a well-designed, cost effective check dam system to limit non-point source pollution. The goal was to develop a check dam that would treat the first flush, and allow the excess water to bypass the system. To accomplish this, the stormwater needed to be slowed down and controlled. The shape, slope, and depth of the ditch were considered.

Design of check dam

Several factors were considered when designing the check dam. These included available space, level of the ditch bottom, vegetation, slope, and watershed area, public safety, and ease of integration within the road right-of-way, plus site characteristics such as groundwater levels, infiltration rates, climate, and ability to meet stormwater management objectives were considered. In addition, the check dam needed to channel flow for at least a two-year storm event (Peterson and Carlstrom 2001). The check dam had to be capable of carrying and draining normal volumes of water away from the road, without damage to the road infrastructure (Figure A-2).

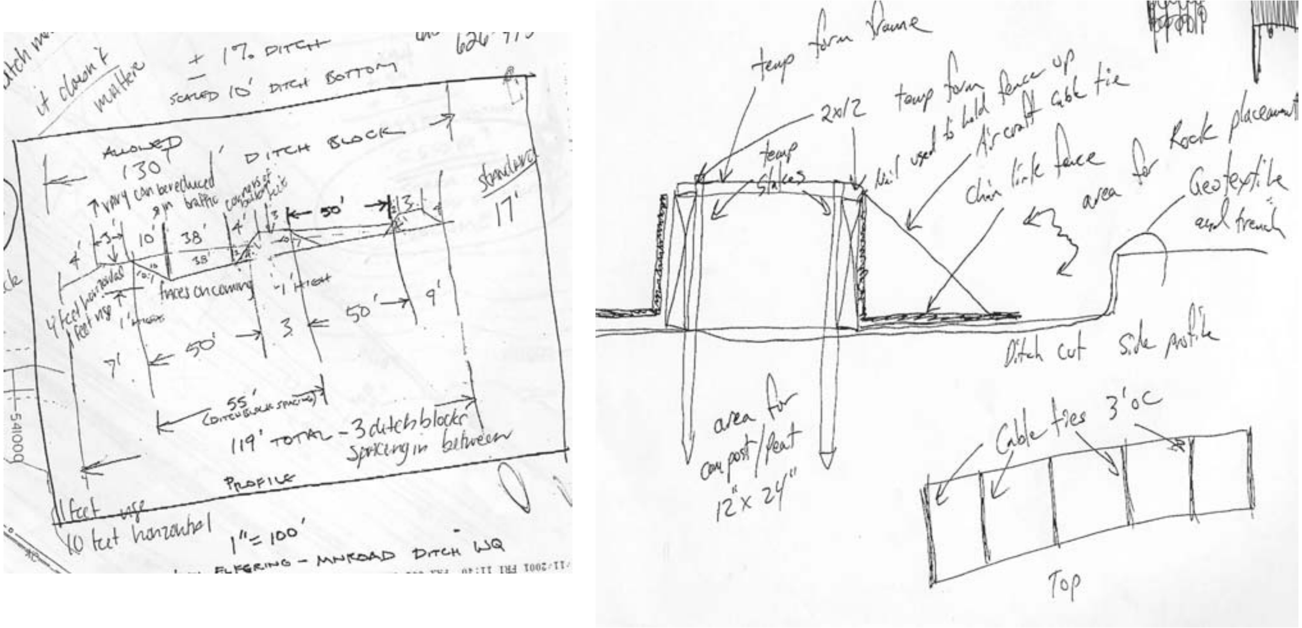

Figure A-2. Preliminary check dam designs courtesy of Peterson (2001) and Stenlund (2001).

Excavation

An area 16 feet long by 16 feet wide was determined and staked off with flags. This area was placed near the output flume due to earlier data collected, suggesting that a larger quantity of water exits this output flume than the input flume. Excavation of the soil from the designated area was accomplished with the use of a backhoe. The area was excavated six inches following the contours of the ditch bottom.

Lining of the check dam area

Following the excavation, edging shovels and rakes were used to smooth and define the check dam area. The exposed soil was covered with mil polyethylene lining. The lining was secured to the soil surface with staples and nails.

Construction of temporary forms

Temporary wooden 2’ by 12’ forms were constructed to establish three check dam sections; a 10’ by 16’ rock area, a 2’ by 16’ filter peat area, and a 4’ by 16’ rock area. Wooden stakes were used to position and secure the forms.

Rock Gabions

Chain link fencing was secured to the forms with the use of nails. Geo-textile (100 gal/min/ft2) lining was placed on the fencing.

Rocks

Rocks collected were between 4 and 8 inches in diameter. This size of rock was used based on flow characteristics of the ditch bottom and safety. Rocks impeded water flow and allowed the stormwater to infiltrate into the peat. The rocks were placed in the check dam with a maximum height of six inches adjacent to the peat section with a gradual decreasing slope outward. This height of six inches is the maximum height allowed by the Department of Transportation for safety reasons.

PVC Stilling Wells
Stilling wells were built with the use of 17-inch PVC pipes. Holes that were 1.27 centimeters in size were drilled into the base of the PVC pipes. Tulle was superglued to the PVC pipes to help prevent clogging. Water quality samples were sampled from the wells. Three PVC stilling wells were installed into the peat area.

Peat
Peat was hauled from Aitkin Peat in Elk River, Minnesota. Specifications for the Aitkin Peat are shown in Appendix B. Twenty-four inches of Agri-peat material was shoveled into the center area of the check dam. Geo-textile (100 gal/min/ft2) was placed over the peat surface and secured with wires to the rock gabions. A Bubbler Flow Meter and a 6712 Isco® Sampler tube were inserted into one of the PVC pipes through a hole in the end caps.

APPENDIX: B

AITKIN PEAT SPECIFICATIONS

AITKIN PEAT SPECIFICATIONS

Organic Matter Content	87.32%
Ash Content	12.7%
Moisture Content	49.92%
Water Holding Capacity	119%
Bulk Density (dry weight)	.17 g/cm^3
pH	4.1
Total Nitrogen	20.63 lb/ton
Phosphorus	1.74 lb/ton
Potassium	2.44 lb/ton
Calcium	5.8l b/ton
Magnesium	1.17 lb/ton
Sulfur	2.49 lb/ton
Sodium	.14 lb/ton
Carbon :Nitrogen	25
Total salts	17.52 lb/ton

Aitkin agri-peat® Incorporated. 2001.

APPENDIX: C
CHECK DAM CONSTRUCTION COSTS

Check Dam Costs

Item	**Cost**
Limestone Rock	\$ 39.25/ton*8 ton =\$320.00
Peat	\$24.75/yard*5 yards=\$100.00
Labor	\$125/hr*5hours=\$625.00
Gabions	65ft^2 * \$.08/ft^2 =\$52.00
Approx Total Cost	\$1097

Buff Limestone 4-9 inches in diameter @ \$39.25/ton plus tax and delivery
Approx: coverage 32 to 35 ft^2/ton coverage
**The specific gravity of rock varies, but 2.60 is typically used.

The cost of excavation, with mobilization to the job is \$125/hour (Stenlund 2003).

*The gabion/reno/green terramesh system is \$12/ft^2 face (the face is the exposed area for the compost), which usually includes the excavation, and rock (Stenlund 2003).