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

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Project Goals

- To perform field tests on a typical Minnesota vegetative swale and determine its pollutant removal efficiency under different storm conditions
- To develop and implement a well-designed, cost effective check dam system to limit non-point source pollution
- To test soils used by Mn/DOT at their ability to retain KBr

Description

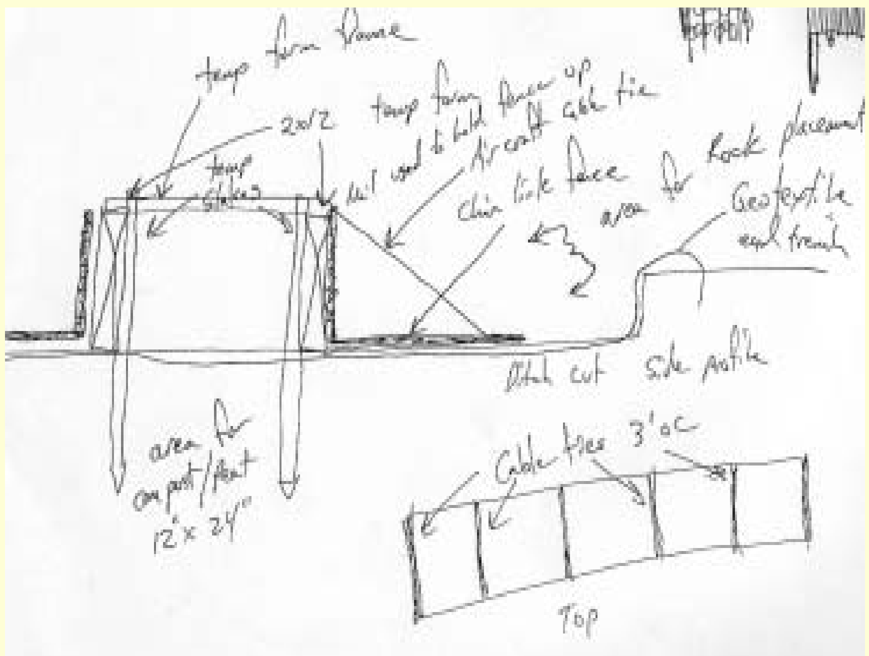
- The research site was located at the Mn/Road Research Project Facility in Otsego, Minnesota

Experimental vegetative swale

- Construction of the swale began in June of 2000
- The design was similar to a design by the Virginia Transportation Council (Yu et al., 1994)
- The test area was 40 meters by 5 meters
- Lateral flow barriers were installed to limit lateral inflow into the swale
- The ditch was ‘typical’ of a Minnesota road ditch, with a slope of 1% and a ditch bottom width of 2.4 meters

Check Dam Construction

- The check dam was designed in conjunction with Mn/DOT engineers and installed into the vegetative swale during the summer of 2001



The Check Dam

- 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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Materials and Methods

- Water samples were collected within two days of a rain event
- We also took on-site measurements of pH, temperature, and specific conductivity
- Total suspended solids (TSS) analysis was conducted according to *Standard Methods for the Examination of Water and Wastewater 1998*.
- Samples for total phosphorus (TP) and ortho-phosphorus (ortho-P) were analyzed by the University of Minnesota Research Analytical Lab
- A single pre- and post-check dam storm event was sampled and analyzed for heavy metals

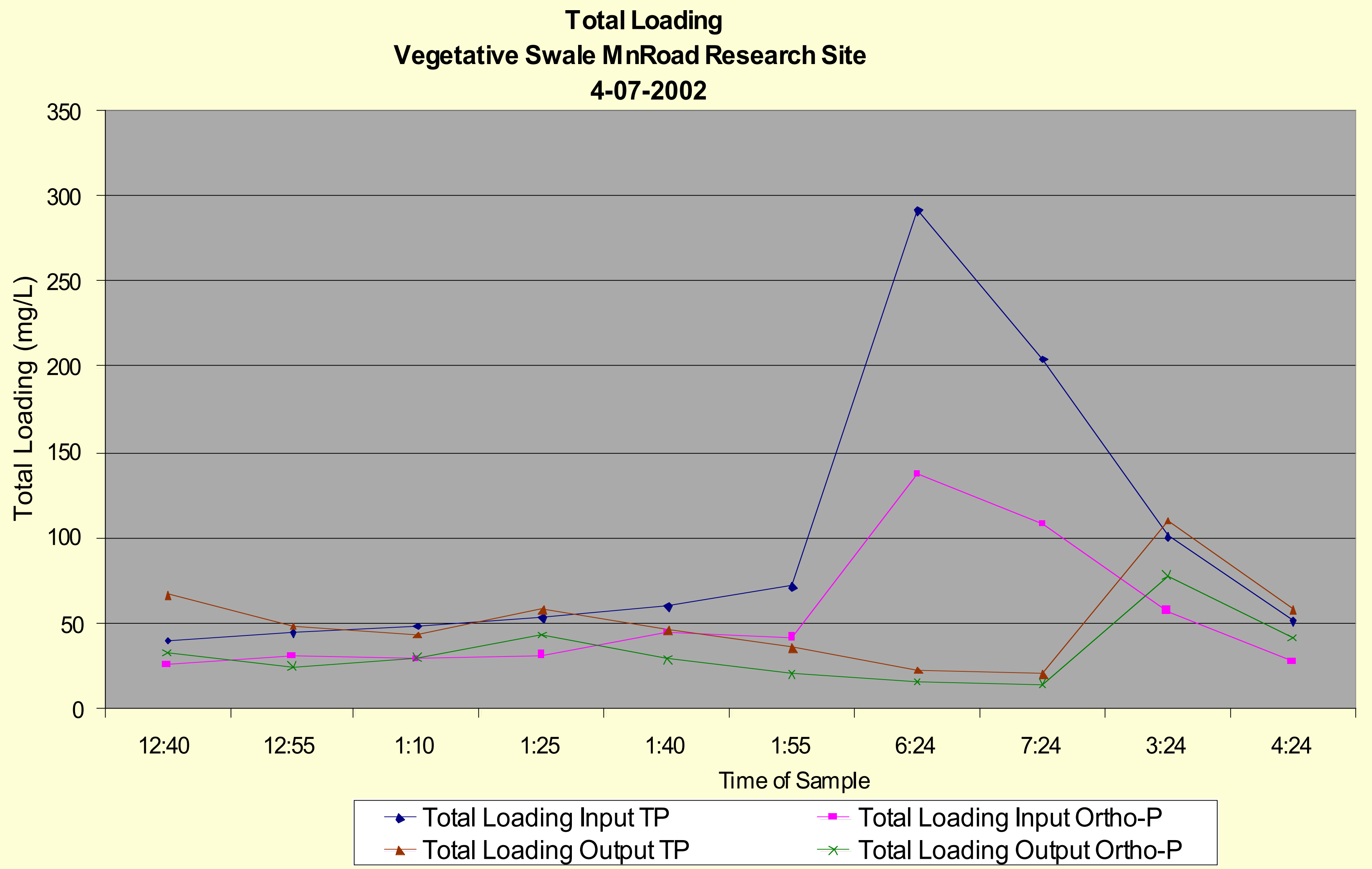
Pollutant Removal Efficiency (PRE)

- PRE is the percentage of the total pollutant loading change that occurs between the input flume and the output flume during a storm event

$$\text{Removal Efficiency (\%)} = \frac{\text{(mass in-mass out)}}{\text{(mass in)}} \times 100$$

A bunch of graphs

- Hydrographs detail the discharge of water with respect to time
- Pollutographs, like hydrographs, are graphs that detail the pollutant concentration of the water with respect to time
- Total loading graphs were constructed by multiplying average mass loadings by the time interval between sampling events


Total Loading
Vegetative Swale MnRoad Research Site
4-07-2002
Total Loading (mg/L)
350
300
250
200
150
100
50
0
12:40
12:55
1:10
1:25
1:40
1:55
6:24
7:24
3:24
4:24
Time of Sample
Total Loading Input TP
Total Loading Input Ortho-P
Total Loading Output TP
Total Loading Output Ortho-P

Event Mean Concentrations (EMCs)

- The EMC is a single index used to characterize stormwater pollution for the entire storm event (Sansalone et al 1995)
- The EMC is calculated by dividing the total pollutant load (mass) by the total runoff volume of the storm, or

Event Mean Concentration=Mass/Volume

M = total mass of pollutant [M]

V = total liquid volume of flow or sample, [L^3]

Data Analysis

- The small number of samples may have led to variation in the calculated r-value and paired T-tests
- Paired T-tests and correlation tests between total loadings for TSS and TP were performed
- Paired T-tests for EMCs and for total loadings were conducted both before and after check dam installation

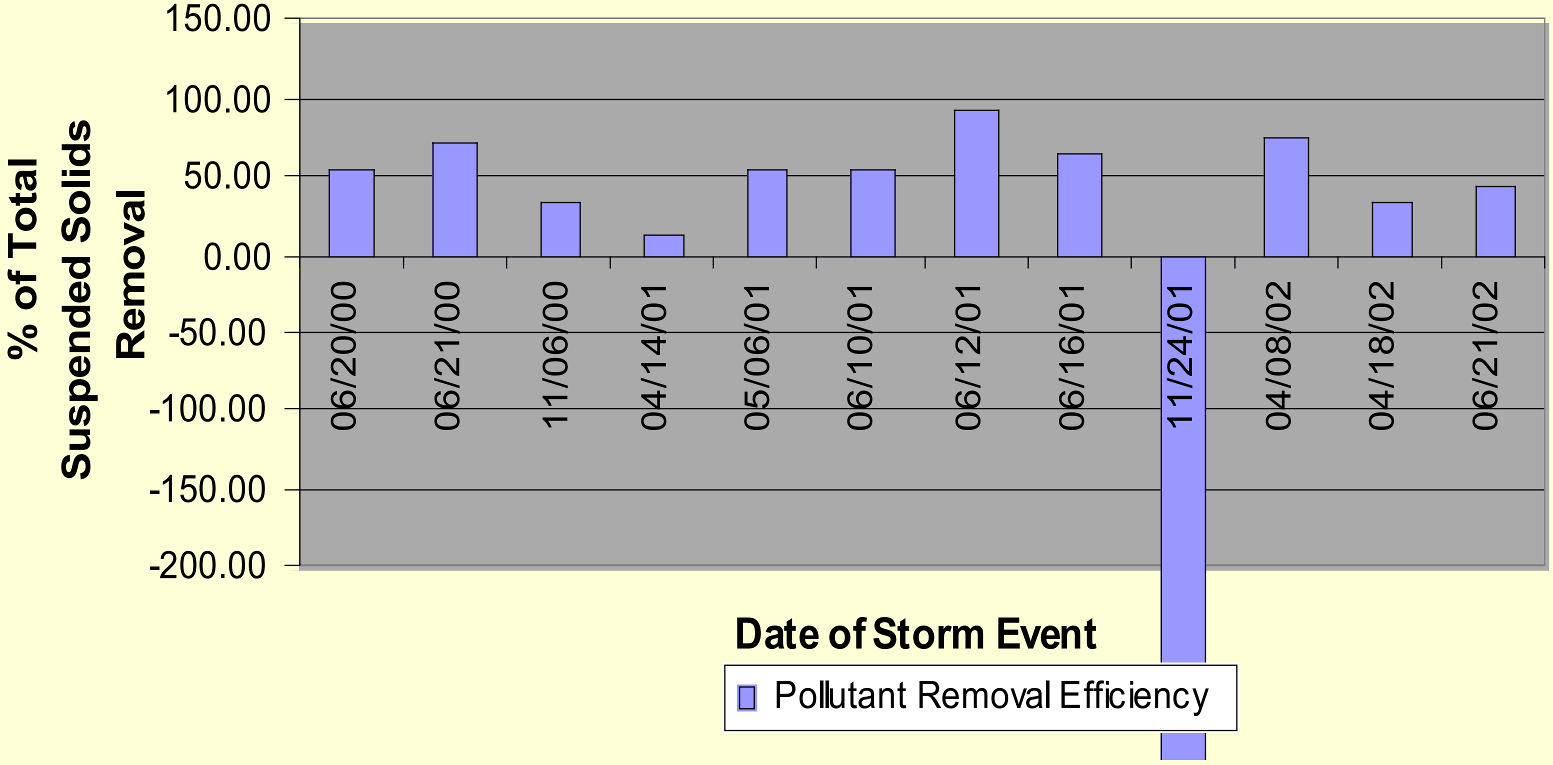
Results

- TP and TSS were greater in all samples at the input than the output flume both prior to and after the installation of the check dam
- We are 90% confident that the input total phosphorus loadings were greater than the output TP for both pre- and post-installation of check dam

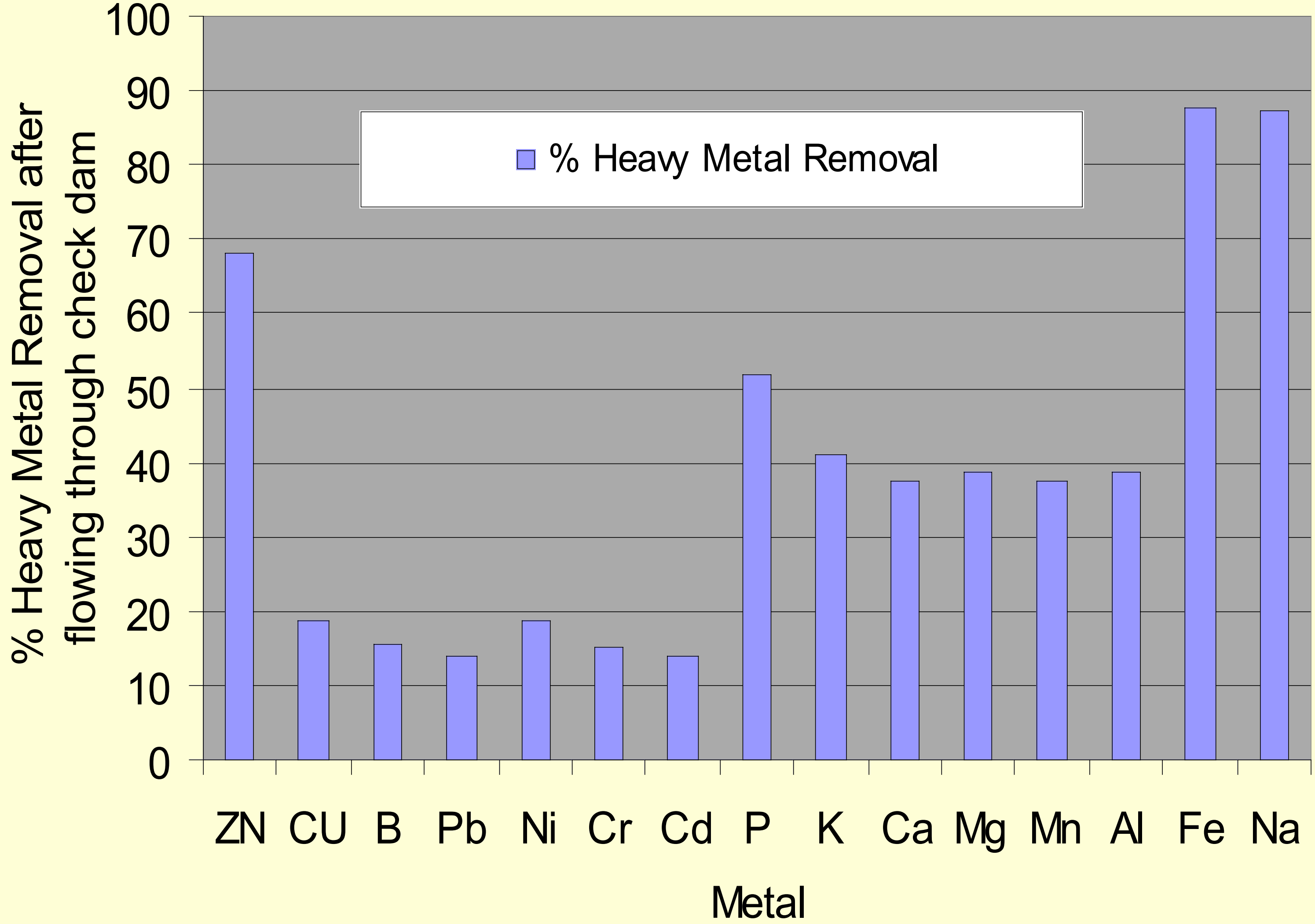
Average Pollutant Removal Efficiency

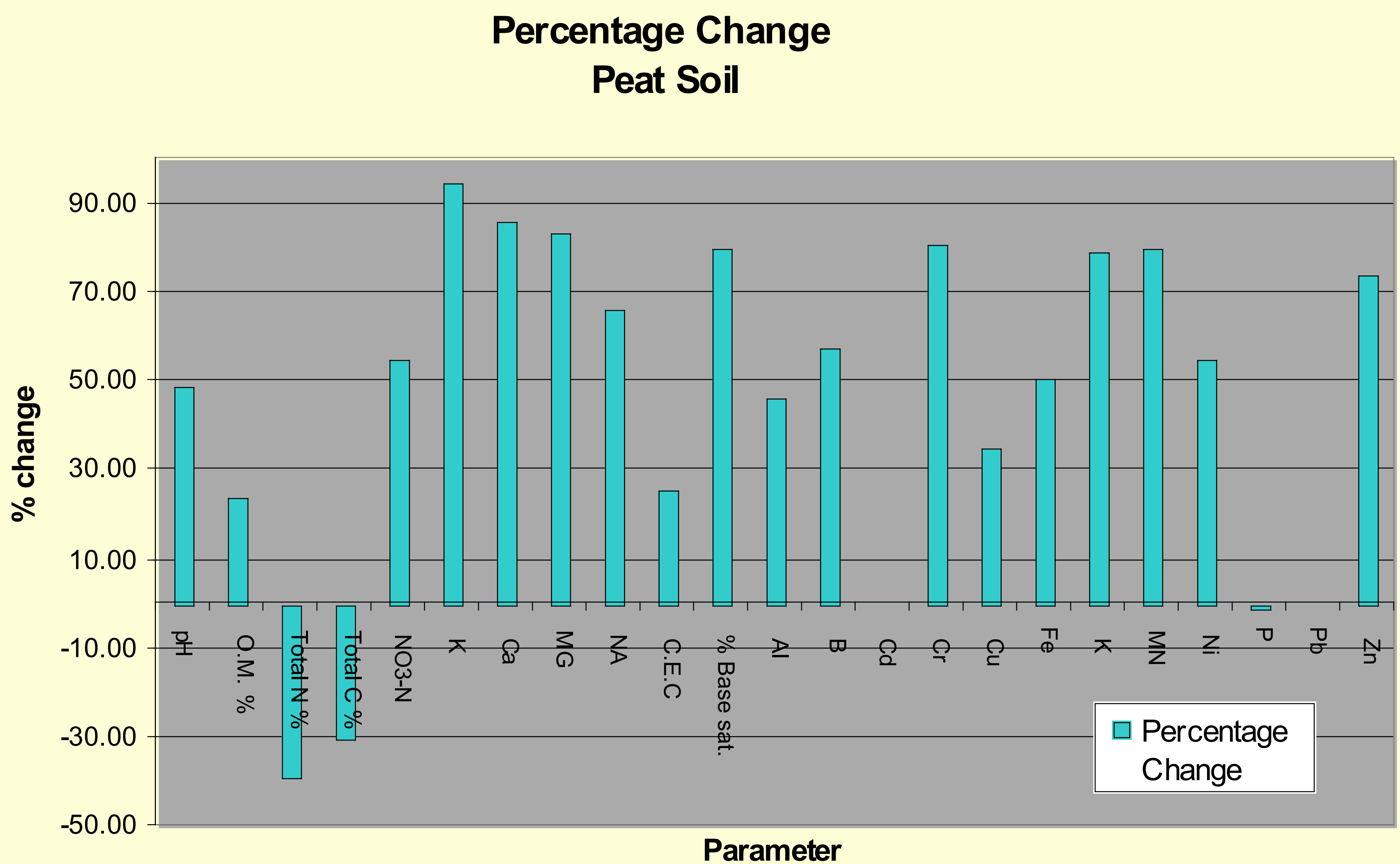
Parameter	**Prior to check dam installation**	**After check dam installation**
Total Phosphorus	22%	54%
Ortho-Phosphorus	42%	47%
TSS	48%	52%

Pollutant Removal Efficiency
Total Suspended Solids
Storm Events 2000-2002



Removal Efficiency of Heavy Metals Following installation of the check dam




Percentage Change
Peat Soil
% change
90.00
70.00
50.00
30.00
10.00
-10.00
-30.00
-50.00
pH
O.M. %
Total N %
Total C %
NO3-N
K
Ca
MG
NA
C.E.C
% Base sat.
Al
B
Cd
Cr
Cu
Fe
K
MN
Ni
P
Pb
Zn
Percentage Change
Parameter

Conclusions

- The average removal efficiency of total phosphorus (TP) was 54 percent and ortho-phosphorus (ortho-P) was 47 percent
- The average removal efficiency of total suspended solids (TSS) with this check dam was 52 percent

Heavy Metals

- It was difficult to analyze metals because of the small number of sample events; however, it was promising to see significant decreases in metal loadings both before and after check dam installation
- Following the check dam installation, metals decreased substantially after flowing through the check dam
- Some metal levels decreased by as much as 70 percent

Experiments Using KSAT to Calculate Hydraulic Conductivity and Bromide Displacement From Several Soils

Research Objective

- Little scientific research has been performed on utilizing bench-scale columns to study soils that are used in road construction, ditches, or management practices
- The purpose of this research was to test soils used by the Mn/DOT for the ability to retain potassium bromide
- By using potassium bromide as a conservative tracer, we were able to gauge the potential leaching capabilities of the different soils

Materials and Methods

- An apparatus was used to determine Ksat and breakthrough curves
- Soil media was packed into 30 cm long by 5.08 cm diameter PVC columns
- Soils tested included Coarse Class 1, Fine Class 1, Fine Filter Sand, and Filter Pea Rock samples, along with two Aitkin® peat samples used in the construction of the check dam

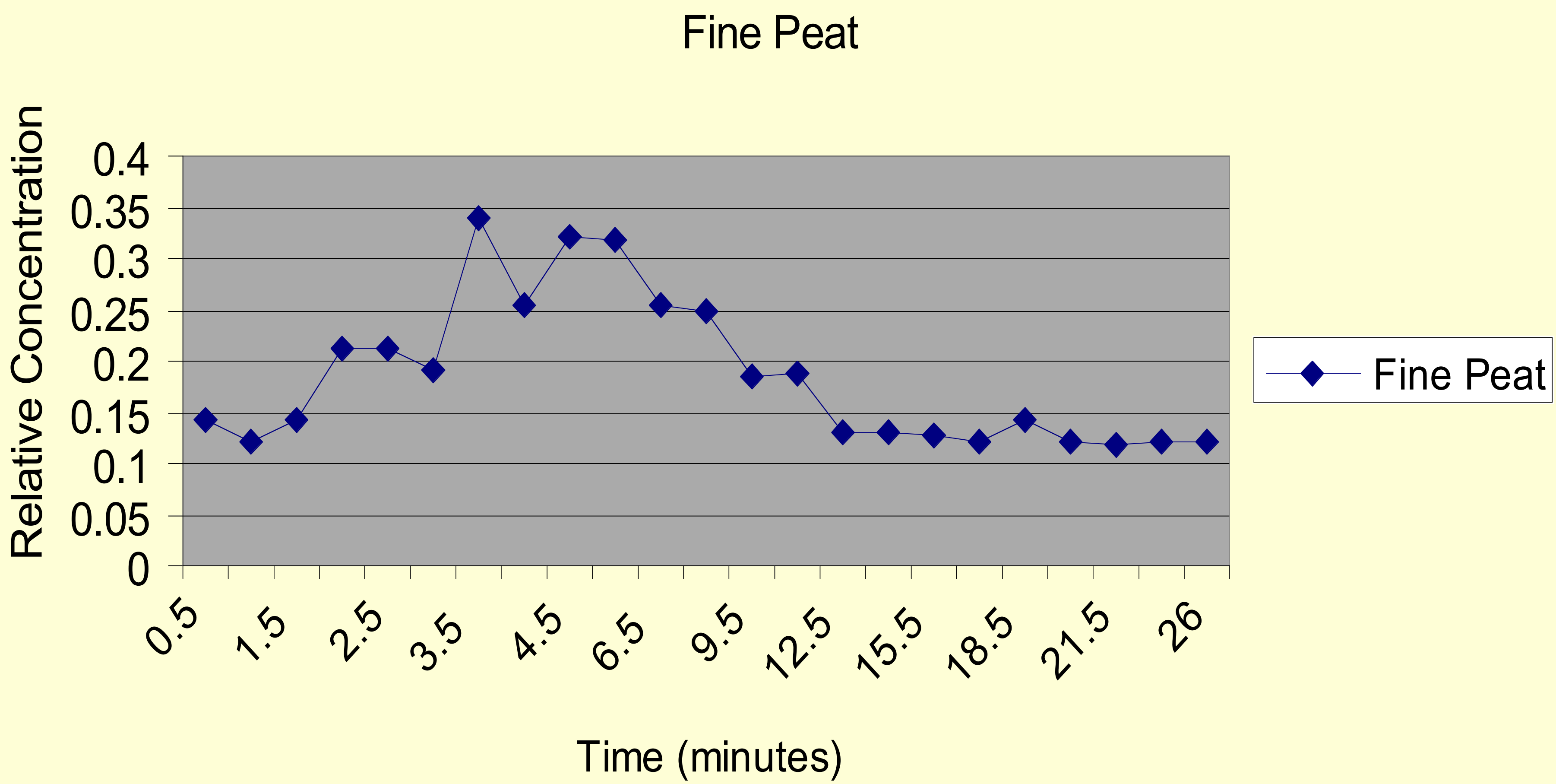
Materials and Methods

- Samples placed in the Ksat apparatus were saturated overnight in de-ionized water
- Anion tracer, in granular form, was added to the top of each soil column
- Effluent samples were collected continuously at a rate of 1 sample every 30 seconds for the first 5 minutes and every 90 seconds for the next 25 minutes in acid washed culture tubes
- Samples of effluents were collected without disturbing the steady-state flow conditions

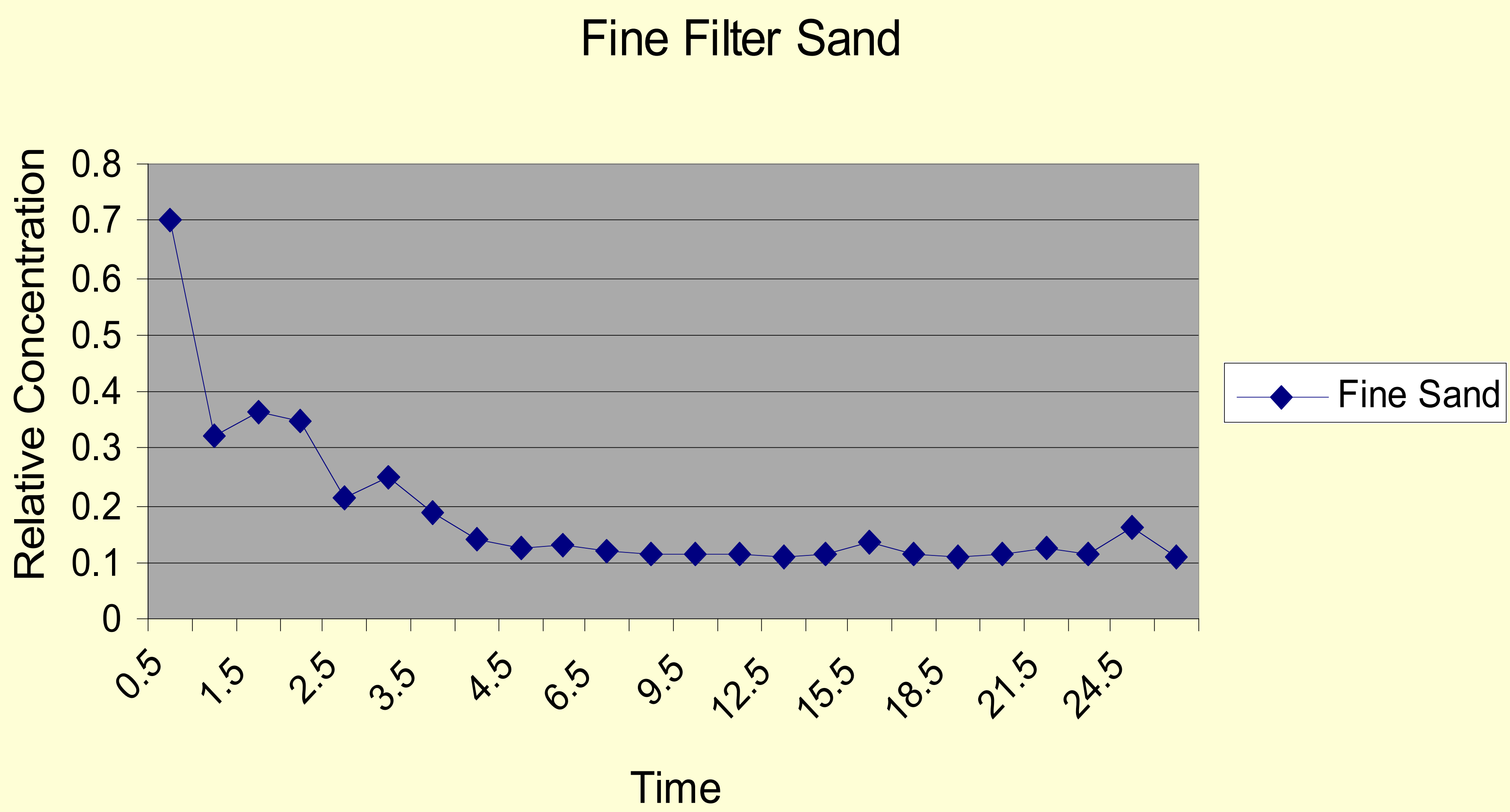
Breakthrough Curve

- The ratio of potassium bromide concentration of the effluent solution, to the initial concentration entering the column, was plotted against the time of the sample event for each soil

Breakthrough Curve



Breakthrough Curve



Results

Soil Type	Flow Rate	Max.Relative Concentration
Fine Filter Sand	121 cm/hr	0.7 30 seconds
Pea Filter Rock	123 cm/hr	0.27 11 minutes
Fine Class 1	9 cm/hr	0.65 9.5 minutes
Coarse Class 1	106 cm/hr	1.0 2.5 minutes
Coarse Peat	4.46 cm/hr	0.194 9.5 minutes
Fine Peat	4.35 cm/hr	0.338 3.5 minutes

Discussion

- The results indicate that leaching is less efficient under smaller pores and relatively slow rate conditions
- Flow velocity is less in small than in large pores and so was leaching
- Dispersion becomes extreme where macropores are present, resulting in bypass flow

Conclusion

- Our results show that filters used by MnDOT and stormwater managers will be more effective at mediating stormwater runoff only if they avoid laminar flow
- Laminar flow can occur when you have large pore sizes
- Smaller pore soils, such as the peat soils, were able to retain the anion tracer throughout the 30-minute sampling period and indicate the ability of the peat to retain potassium bromide
- Soils that have higher organic matter content, such as the peat materials, were also more effective at retaining bromide due to the larger surface area and the higher adsorption rate

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Water Resource Sciences and Plant Biology Depts.

Approximate Cost

Check Dam Costs	Limestone Rock	Peat	Labor	Gabions	Approx: Total Cost
	Buff Limestone 4-9 inches in diameter @ $39.25/ton plus tax and delivery	$24.75/ yard^2	$125/hr	$0.08/ft^2	$1097
	Approx: coverage 32 to 35 ft^2/ton coverage				
	8 ton = $320	=$100.00	$125*5hrs= $625	64ft^2*$.08 =$52	

COARSE AGGREGATE FRACTION

Percent by mass passing square opening sieves

(Mn/DOT Standard Specifications for Construction Book 2003)

Size fraction	37.5 mm	19 mm	9.5 mm	4.75 mm	1.18 mm	300 um	150 um	75 um
Class 1	80-100	5-30	5-25	0-5	25-75			0-15
Fine Filter sand	100		100	95-100	45-80	10-30	2-10	0-1
Filter pea rock			100	90-100	45-90			0-3
Fine Class I			65-95	35-75	25-45	5-30	0-10	0-15
Coarse Peat								
Fine Peat								

The American Society for Testing and Materials (ASTM) grades peat by particle size as follows (2003):

Coarse Peat: all particles > 2.38 mm Fine Peat: all particles < 0.84mm