THE MUCKLAND DEMONSTRATION PROJECT

Agricultural
Non-Point Source Pollution Control

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

1. **An artificial wetland (3.7 acres) was constructed in the spring of 1997**. Water draining from muck fields (22.7 acres) in onions and sorghum was pumped into the wetland rather than draining directly to a stream.

2. **For two years, various chemical fractions in the water entering and leaving the wetland were monitored**. Fractions monitored included nitrate, soluble reactive phosphorus, total phosphorus, total Kjeldhal nitrogen, total suspended solids and potassium.

3. **Major reductions in nutrients and suspended solids were observed when drainage water was passing through the constructed wetland.** Reductions of dissolved fractions of nutrients (soluble reactive phosphorus, potassium and nitrate) and particulate fractions (total phosphorus and total suspended solids) that exceeded 90% were observed between the incoming drainage water from the muck field and exiting water from the constructed wetland.

4. **The use of constructed wetlands for the purpose of improving water quality of water draining from land in intensive agriculture is feasible.** There are many factors that influence the construction and placement of artificial wetlands. However, any wetland construction would have to carefully consider the potential volume of water available during peak flows during hydrometeorological events. It is during these periods that most of the soil and nutrients are lost from the watershed under consideration in Oswego County.

5. **Because of the potentially high volumes encountered, constructed wetlands are best placed near sources of point and non-point pollution**. This would require diversion of drainage tiles and/or drainage channels/streams into constructed wetlands.

6. **It should be stressed that constructed wetland-pond systems are supplemental to conservation practices to be used on cropland.** Conservation practices are important in reducing pollutants at their source and also protecting the resources of the farmer.

INTRODUCTION

One of the major issues identified from the Lake Neatahwanta watershed studies has been that losses of soils and nutrients from the Sheldon Creek watershed have been excessive (Makarewicz and Lewis 1994, 1998, 1999). Low cost methods to reduce these loadings into Lake Neatahwanta have been investigated by the Oswego Soil and Water Conservation District. One promising methodology is constructed wetlands. Constructed wetlands have several advantages compared to other methods and include:

1. low cost of construction and maintenance;
2. Low energy requirements;
3. Being a low-technology system, they can be established and run by relatively untrained personnel; and
4. If functional, allows the current land practices to continue.

In general, the major disadvantages of constructed wetlands systems are the increased land use and the possible decreased performance during the severe winters of New York State. In rural settings such as Oswego County, where land is plentiful, the issue of availability of land to construct artificial wetlands is not generally a problem. Other potential problems include "plugging" of the drainage system and possible problems with insect pests.

The many muck fields in agriculture that exist in Oswego County offer an opportunity to demonstrate the feasibility of using artificially constructed wetlands to reduce nutrient levels in water draining from these highly fertilized, productive agricultural systems. An artificial wetland was constructed adjacent to a large muckland farm raising onions and sorghum. Water draining from the muck fields was pumped into the constructed wetland and allowed to flow naturally out of the wetland after a retention period determined by the flow regime. The question being asked was can nutrients and sediments be effectively removed from muckland drainage water by an artificial wetland?

THE SITE

The muck fields adjacent to the constructed wetland represent two fields (C-1, 10.5 acres, and C-2 12.5 acres) (Fig. 1). Crops have been rotated between onions and sorghum during the two-year study period (Table1). Both fields were fertilized during the study period (Table 1) at

Figure 1. Ferlito Muck Fields

normal rates ranging from ~500 to 600 lbs per acre. The muck fields were intersected and drained by several channels that converged at one location. Normally the runoff from these fields would enter a stream channel. The outlet channel was dammed, and a large pump was used to move water to an artifically constructed wetland approximately 3.7 acres in size (Figure 2). Pumping of water was activated by a water-level trigger placed in the drainage channel. The artifical wetland was constructed in May of 1997 by creating an earthen dam (green boundary on

Figure 3) to the south and west of a pre-existing pond. At the outlet of the artificial wetland, a water level control structure was built and a Stevens' Water Level recorder and later an Isco Water Level recorder was installed to monitor outflow from the wetland. In Figure 3, transect lines indicate where plant samples were taken. In general, Cattail (Typha sp.), Coontail (Ceratophyllum spp.), pondweed (Elodea), water milfoil (Myriophyllum spp.) were dominant in the northern pre-existing pond. Moving to the south east, Phragmites and cattail graded into trees associated with wetlands (eastern cottonwood, quaking aspen and willow).

Figure 2. Intake Pump

DEFINITIONS

Total Phosphorus- A measure of all forms of the element phosphorus. Phosphorus is an element required for plant growth on land or in water. In lakes, phosphorus is often the limiting factor of phytoplankton growth and is the cause of eutrophication or overproduction of lakes. Phosphorus may enter a watershed in soluble or organic form from several sources including sewage, heavy-duty detergents, fertilizer and agricultural waste. Some forms of phosphorus are available to and cause more immediate activity in plants.

Soluble Reactive Phosphorus- A measure of the most available and active form of phosphorus.

Nitrates + Nitrites- A measure of the soluble forms of nitrogen used readily by plants for growth. Sources of nitrates in the environment are many and include barnyard waste and fertilizer.

Total Kjeldahl Nitrogen- The Kjeldahl method is a convenient method of analysis for nitrogen but cannot be used for all types of nitrogen compounds. It is, however, a good measure of organic nitrogen, including ammonia. Manure, for example, contains a large amount of organic nitrogen.

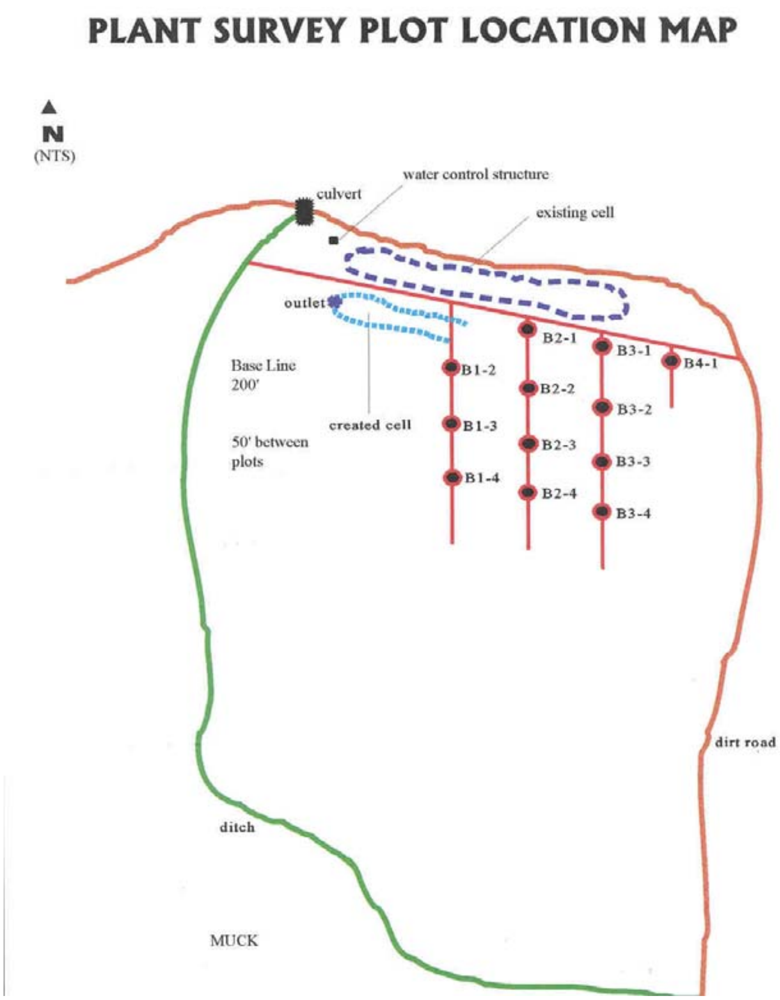

Figure 3. Constructed Artificial Wetland

Potassium - A measure of an element required for growth of some plants and a common constituent of fertilizer often used in agriclulture.

Total Suspended Solids - A measure of the loss of soil and other materials suspended in the water from a watershed. Water-borne sediments act as an indicator, facilitator and agent of pollution. As an indicator, they add color to the water. As a facilitator, sediments often carry other pollutants, such as nutrients and toxic substances. As an agent, sediments smother organisms and clog pore spaces used by some species for spawning.

METHODS

General:

Water samples were collected as water was pumped into the wetland, the **"inlet",** from the drainage channel of the muck field and at the "**outlet"** structure of the constructed wetland by two separate Isco Automatic samplers. The trigger for firing the samplers was a simple water level actuator. At the outlet, samples would be taken every 30 minutes for 8.5 hours to form one composite sample. Since the automatic sampler could hold 24 bottles, sampling could proceed continuously for a period of seven days. At the inlet (pump) site, a sample was taken each time the pump was activated to form a composite containing nine such events. After the pump was activated nine times, a second bottle would be filled. Generally, the entire array of 24 bottles were filled during a week. Over 216 inlet samples were thus taken per week when water was draining off the muck field and composited into 24 samples for analysis. Sampling was initiated on 13 April 1998 and continued through 9 November 1998 and was resumed during a four week-period in May and June of 1999.

All sampling bottles were pre-coded so as to ensure exact identification of the particular sample. All filtration units and other processing apparatus were cleaned routinely with phosphate-free RBS. Containers were rinsed prior to sample collection with the water being collected. In general, all procedures followed EPA standard methods (EPA 1979) or Standard Methods for the Analysis of Water and Wastewater (APHA 1999) and were the same methods used in 1994 and 1998 (Makarewicz and Lewis 1994, 1998). Sample water for dissolved nutrient analyses (SRP, nitrate + nitrite) was filtered immediately with 0.45 μm MCI Magma Nylon 66 membrane filters and held at 4°C until analysis.

Water Chemistry

<u>Nitrate + Nitrite</u>**:** Dissolved nitrate+nitrite nitrogen analyses were performed by the automated (Technicon Autoanalyser) cadmium reduction method (EPA 1979).

<u>Potassium</u>**:** **P**otassium were determined by atomic absorption spectrophotometry (Perkin Elmer 3030) (APHA 1999) on filtered samples.

<u>Total Phosphorus and Soluble Reactive Phosphorus</u>**:** For total phosphorus, the persulfate digestion procedure was used prior to analysis. The digestate for total phosphorus and soluble reactive phosphorus were analyzed by the automated (Technicon autoanalyser) colorimetric ascorbic acid method (APHA 1999).

<u>Total Kjeldahl Nitrogen</u>**:** Analysis was performed using a modification of the Technicon Industrial Method 329-74W/B. The following modifications were performed:

1. In the sodium salicylate-sodium nitroprusside solution, sodium nitroferri-cyanide (0.4g) replaced the concentrated nitroprusside stock solution.
2. The reservoir of the autoanalyser was filled with 0.2M H_2SO_4 instead of distilled water.
3. Other reagents were made fresh prior to each analysis.

<u>Total Suspended Solids</u>**:** APHA (1999) Method 2540D was employed for this analysis.

Calculations for Discharge and Loading **Inlet Pipe:**

The pipe that carried water from the muckland to the wetland was 9.5 inches in diameter (4.75 inch radius), thus the area of the discharge pipe was $0.492 ft^2$. The pump that moved water from the muck side to the wetland side created an average water velocity through the pipe of 18 feet per second. Velocity was measured with a Global flow meter by SWCD personnel. For the purpose of calculations, it was assumed that the entire pipe was full during pumping. If so, discharge into the constructed wetland was 8.856 cubic feet per second. The amount of time spent pumping was measured by the Isco sampler. Therefore, multiplying the number of minutes the pump ran by 15.05 m^3/min (8.856 cfs) would give the amount of water pumped into the wetland.

Outfall Discharge at Control Structure

The volume of water leaving the constructed wetland via the control structure was determined by the following formula:

$$Q_{cfs} = clh^{3/2}$$

$$\begin{aligned}&Where:\\&\quad c = factor\ (3.3)\\&\quad l = length\ of\ flashboard\ (1.83\,ft)\\&\quad h = measured\ height\ of\ water\ flowing\ over\ the\ flashboard\end{aligned}$$

$$Q_{cfs} = (3.3)\times(1.83\,ft)\times\left(h^{3/2}\right)$$

The level (depth) of water flowing over the flashboards was monitored continuously with a Steven's Recorder during the first year and subsequently by an Isco level recorder with a pressure sensor.

QUALITY CONTROL

Quality Assurance Internal Quality Control: Multiple sample control charts (APHA 1999) were constructed for each parameter analyzed, except total suspended solids. A prepared quality control solution was placed in the analysis stream for each sampling date. If the control solution was beyond the set limits of the control chart, corrective action was taken and the samples re-run.

External Quality Control: The New York State Department of Health's Environmental Laboratory Approval Program (ELAP) proficiency test results for our laboratory are presented in Table 2.

RESULTS AND DISCUSSION

Concentration:

1998: **S**ignificant reductions in average concentrations of total phosphorus (81.5%), soluble reactive phosphorus (60.8%) and total suspended solids or soils (93.9%) were observed over the 22-week-study period during the summer of 1998 (Table 3). A reduction in total Kjeldahl nitrogen of 21% was also observed, but due to the high variability in the data, the reduction was not statistically significant. No reduction in nitrate or potassium was observed over the entire 22-week study period.

1999: The summer of 1999 was another very dry year and sampling was limited to a one-month period where water was flowing from the muck field into and out of the wetland. As 1998, similar reductions in TP (average =92.3%), SRP (average = 41.1%) and TSS (average=99.4) concentrations were observed in the water draining from the wetland (Tables 4-6).

Unlike 1998, we did observe substantial reductions in potassium (K), TKN and nitrate concentrations in 1999. Percent nitrate reductions ranged from 50 to 100% with an average reduction of 83.3%. The average decrease in TKN concentrations was 47.3% (range 39.9 to 60.4%). In 1998, we observed a slight but not significant increase in K concentrations. In 1999, the average decrease was 64.9% (range 43.8 to 89.3% reduction). The more effective reduction of nitrate, potassium and TKN in 1999 was most likely do to the condition of the wetland. 1998 was the first full year that the wetland was in use. By the second year, plant substrate (wetland plants) and sediments and the biofilm associated with these substrates were more developed allowing a more effective

reduction of nutrients.

The Constructed Wetland - Spring Conditions

Input-Output Budget:

Although concentration is a legitimate way of evaluating the effect of the constructed wetland on improving water quality, it does not consider the total mass of nutrients being removed while in the wetland. During four periods in 1998 and 19 consecutive days in 1999, nutrient and materials budgets were constructed that considered water volume entering and leaving the wetland multiplied by the concentration of the analyte. The data in Tables 7 and 8 support the conclusions from the concentration data.

1998: In 1998, significant reductions in all analytes were observed (range of reduction = 40 to 100%) when inflow exceeded outflow. Inflow exceeded outflow occurred when evapo-transpiration and loss as ground water reduced discharge at the outflow. That is, in some weeks, water did not flow continuously from the outflow structure/dam.

During periods when water continuously flowed over the outflow structure/dam in 1998 (5-15 May, 29 August- 4 September), a different situation developed. Reductions in mass of total phosphorus, soluble reactive phosphorus and total suspended solids were observed, as with the nutrient budget data when outflow was not continuous. However, reduction in mass of total Kjeldahl nitrogen, potassium and nitrate (on one date) was not observed. Instead, mass of potassium, nitrate and total Kjeldahl nitrogen leaving the system increased over what was entering the wetland (Table 7) suggesting that these chemicals were generated within the wetland complex as a result of decomposition processes. Although possible, this is not likely. There was also the possibility that there was a problem with the outflow structure; that is, our measurements of discharge at the outlet were inaccurate. There was evidence to suggest this. During the same period that we had an increase in mass of nutrients lost from the wetland, we actually had a decrease in concentration of nutrients. Thus the increase we observed in the mass measurements were not real. Based on the 1998 results, we set up a better system (an Isco level pressure sensor) for monitoring flow (water level) at the outlet structure in 1999 and checked for leaks in the earthen dam.

1999:

Results for 1999 are presented in Table 8. Inflow and outflow and concentrations were monitored for 19 days during a period of continuous flow of water through the system. For the 19-day period, reductions in total mass of nutrients and total suspended solids were consistent and impressive. For TP, SRP, TSS, TKN, nitrate and potassium, reductions of mass greater than 90% were observed (Table 8). As would be expected, reductions were lower when water first began going into the wetland raising the water level into areas not previously covered. We suspect that it takes time for the microbial biofilm to build up before full efficiency of the system is realized.

Similar reductions in nutrients and suspended solids have been observed in other studies in the United States. In a constructed wetland used to reduce swine waste products, a 91.5% reduction in suspended solids, a 75.9% reduction in total phosphorus and a 91.4% reduction in total Kjeldahl nitrogen were observed (Hammer et al. 1993). In a situation more closely resembling the muck field, agricultural runoff from a potato field in Maine was "processed" through a constructed wetland. Reductions in total phosphorus and total suspended solids averaged over 85% and 95% (Higgins et al. 1993). If the constructed wetland is designed properly, the results from this demonstration project and from other studies indicate that wetlands can be a low-cost technology capable of improving water quality in streams draining watersheds in agriculture.

Outlet Dam and Monitoring Station

Mechanisms by which nutrients and suspended solids are removed by a wetland are many. The suspended and settable solids are removed by sedimentation and possibly by filtration through the plants in the wetland. These purely physical processes also remove a significant portion of the nutrients present in the particulate form (e.g., suspended phosphorus measured as part of the total phosphorus). Removal of nitrogen depends on the form of nitrogen present (nitrate, ammonia, or organic nitrogen). For example, plants remove ammonia, nitrate or nitrite, which are then incorporated into the cell mass. Ammonia, which was not present in our samples, is converted to nitrates and nitrites by aerobic autotrophic microorganisms (e.g., the bacteria Nitrosomonas and Nitrobacter) by the process of nitrification. The reduction of nitrate and nitrites to atmospheric N_2 is called denitrification and caused by denitrifying bacteria. Metals, such as potassium, are taken by plants and by sorption to sediments. Phosphorus removal in constructed wetlands occurs mainly as a consequence of adsorption, complexation and precipitation reactions with aluminum, iron, calcium and clay minerals in sediment. Plant uptake can also be significant.

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Table 1. Crop history and fertilization rates for the Ferlito Field. C-1, Carter Farm. C-2, Carter Farm.

	Field	Acreage	1996	1997	1998

Amount of Fertilizer	C-1 C-2	10.5 12.5	535 lbs/ acre 535 lbs/acre	No application 535 lbs/acre	670 lbs/acre No application
Fertilizer Type	C-1 C-2	10.5 12.5	23.3-11-19.4 with 0.4% borate	23.3-11-19.4 with 0.4% borate	14.9-11.9-29.9 with 0.25 borate
Crop	C-1 C-2	10.5 12.5	Onions Onions	Sorghum Onions	Onions Sorghum

Table 2. Results of the semi-annual New York State Environmental Laboratory Assurance Program (ELAP Lab # 11439, SUNY Brockport) Non-Potable Water Chemistry Proficiency Test, July 1999. Score Definition: 4 (Highest) = Satisfactory, 3 = Marginal, 2 = Poor, 1 = Unsatisfactory.

Analyte	Mean/Target	Result	Score
Residue			
Solids, Total Suspended	18.3 mg/L	18.2 mg/L	4
Hydrogen Ion (pH)			
Hydrogen Ion (pH)	6.00	5.96	4
Organic Nutrients			
Kjeldahl Nitrogen, Total	14.70 mg/L	15.60 mg/L	4
Phosphorus, Total	1.56 mg/L	1.59 mg/L	4
Total Alkalinity			
Alkalinity	94.60 mg $CaCO_3$/L	98.32 mg $CaCO_3$/L	4
Inorganic Nutrients			
Nitrate (as N)	14.80 mg/L as N	13.33 mg/L as N	4
Orthophosphate (as P)	0.914 mg/L as P	0.920 mg/L as P	4
Minerals			
Chloride	180.0 mg/L	183.2 mg/L	4
Wastewater Metals I and II			
Calcium, Total	20.30 mg/L	19.54 mg/L	4
Magnesium, Total	13.00 mg/L	14.22 mg/L	4
Potassium, Total	5.03 mg/L	5.29 mg/L	4
Sodium, Total	35.70 mg/L	36.68 mg/L	4

Table 3. Percent reduction of nutrients and sediments from muckland drainage water after passing through a constructed wetland for the entire summer of 1998. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total kjeldahl nitrogen, K = potassium. Asterisk (*) indicates a significant difference at P = 0.001, n = 22.

1998 (entire summer)	TP (ug/L)	SRP (ug/L)	NO_3 (mg/L)	TSS (mg/L)	TKN (ug/L)	K (mg/L)
Inflow	362	19	0	332	1529	2.03
Outflow	49	7	0.26	20	1207	2.23
Percent Reduction	81.5*	60.8*	+4.0	93.9*	21	+9.9

Table 4. Percent reduction of nutrients and sediments in 1999 from muckland drainage water after passing through a constructed wetland on 19 May – 1June 1999. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total kjeldahl nitrogen, K = potassium. Asterisk (*) indicates a significant difference at P = 0.001.

1999 19 May-1 June	TP (ug/L)	SRP (ug/L)	NO_3 (mg/L)	TSS (mg/L)	TKN (ug/L)	K (mg/L)
Inflow	1291.6	43	0.2	1121	1832.5	3.2
Outflow	63.2	33	0.1	5.5	1100.9	1.8
Percent Reduction	95.1*	23.2*	50*	99.5*	39.9*	43.8*

Table 5. Percent reduction of nutrients and sediments from muckland drainage water after passing through a constructed wetland on 18-21 June 1999. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total kjeldahl nitrogen, K = potassium. Asterisk (*) indicates a significant difference at P = 0.001.

1999 18-21 June	TP (ug/L)	SRP (ug/L)	NO_3 (mg/L)	TSS (mg/L)	TKN (ug/L)	K (mg/L)
Inflow	888.3	22.1	0.35	890	3200	1.68
Outflow	75.9	13.5	0	3.4	1267	.18
Percent Reduction	91.4*	38.9*	100*	99.6*	60.4*	89.3*

Table 6. Percent reduction of nutrients and sediments from muckland drainage water after passing through a constructed wetland on 7-8 July 1999. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total kjeldahl nitrogen, K = potassium. Asterisk (*) indicates a significant difference at P = 0.001.

1999 7-8 July	TP (ug/L)	SRP (ug/L)	NO_3 (mg/L)	TSS (mg/L)	TKN (ug/L)	K (mg/L)
Inflow	984.4	28.2	.1	665.5	1070	2.1
Outflow	49.7	10.9	0	4.9	625.6	0.8
Percent Reduction	94.9*	61.3*	100*	99.3*	41.5*	61.9*

Table 7. Nutrient and material budget for the constructed wetland in 1988. Values represent flow times concentration of analyte. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total kjeldahl nitrogen, K = potassium.

	Discharge (m3)	SRP (kg)	TP (kg)	NO_3 (kg)	TSS (kg)	TKN (kg)	K (kg)
4/14 - 4/20/98							
Inflow	10234	0.11	7.48	1.05	6396.37	20.06	17.68
Outflow	3933	0.04	0.11	0.28	40.12	1.65	5.70
Outflow - Inflow	-6301	-0.08	-7.37	-0.78	-6356.26	-18.41	-11.98
Percent Change		-73%	-99%	-74%	-99%	-92%	-68%
5/9 - 5/15/98							
Inflow	602	0.01	0.69	0.02	585.22	1.06	0.94
Outflow	1960	0.01	0.08	0.01	14.77	2.16	2.62
Outflow - Inflow	1358	0.00	-0.60	-0.01	-570.45	1.10	1.68
Percent Change		0%	-87%	-50%	-98%	+104%	+179%
8/29 - 9/4							
Inflow	1505	0.02	0.33	0.21	272.43	2.73	3.96
Outflow	1680	0.01	0.12	1.89	22.67	5.32	7.92
Outflow - Inflow	175	-0.01	-0.20	1.69	-249.76	2.59	3.96
Percent Change		-50%	-61%	+805%	-92%	+95%	+100%
9/8 - 9/14							
Inflow	1384.6	0.02	0.14	0.02	126.76	1.22	3.25
Outflow	571	0.00	0.01	0.00	0.23	0.73	1.75
Outflow - Inflow	-814	-0.02	-0.13	-0.02	-126.53	-0.49	-1.50
		-100%	-93%	-100%	-99%	-40%	-46%

Table 8. Percent reduction in nutrient and soil (TSS) loads (concentration x flow) from the inlet pipe to the outlet structure after passing through the constructed wetland during a two week period in May and June 1999. SRP = soluble reactive phosphorus, TP = total phosphorus, NO_3 = nitrate, TSS = total suspended solids, TKN = total Kjeldahl nitrogen, K = potassium.

	Percent Reduction					
Date	**SRP**	**TP**	**NO_3**	**TSS**	**TKN**	**K**
05/27/99	75.5	97.5	42.9	99.7	75.2	78.5
05/28/99	88.1	98.7	72.1	99.8	86.0	87.9
05/29/99	93.8	98.9	92.6	99.9	84.3	89.1
05/30/99	94.2	99.0	93.1	99.9	85.5	89.9
05/31/99	98.3	99.5	98.9	100.0	95.0	94.7
06/01/99	84.5	98.3	100.0	100.0	76.1	58.6
06/02/99	98.2	99.8	100.0	100.0	97.3	95.3
06/03/99	92.1	99.2	100.0	99.9	88.6	87.8
06/04/99	95.5	99.6	100.0	99.9	93.5	93.1
06/05/99	98.1	99.4	100.0	99.9	95.3	98.5
06/06/99	97.7	99.3	100.0	99.9	96.0	97.3
06/07/99	91.5	99.0	100.0	99.9	91.9	96.4
06/08/99	84.6	98.9	99.4	99.9	91.6	94.4
06/09/99	88.1	99.0	99.6	100.0	94.0	96.9
06/10/99	79.4	97.5	99.1	99.9	86.5	93.8
06/11/99	92.0	98.6	99.7	99.7	96.1	98.4
06/12/99	92.1	99.2	98.4	100.0	97.9	99.2
06/13/99	84.1	98.6	97.9	100.0	96.9	99.3
06/14/99	98.4	99.7	99.4	100.0	99.0	99.7
Average Percent Reduction	**90.5**	**98.9**	**99.5**	**99.9**	**92.9**	**93.8**