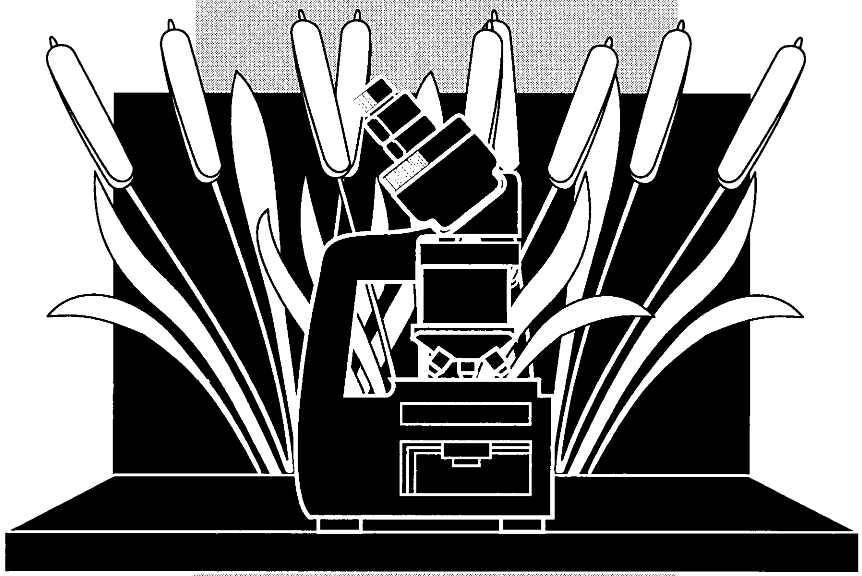
FINAL REPORT

THE CONTROL OF POLLUTION IN HIGHWAY RUNOFF THROUGH BIOFILTRATION

VOLUME III: LABORATORY TEST OF ROADSIDE VEGETATION



SHAW L. YU
Faculty Research Scientist

SHIH-LONG LIAO
Graduate Research Assistant

V·I·R·G·I·N·I·A
VTRC
TRANSPORTATION RESEARCH COUNCIL

VIRGINIA TRANSPORTATION RESEARCH COUNCIL

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/VTRC 95-R30		
4. Title and Subtitle The Control of Pollution in Highway Runoff through Biofiltration Volume III: Laboratory Test of Roadside Vegetation		5. Report Date September 1995
		6. Performing Organization Code
7. Author(s) Yu, S. L. and Liao, S-L.		8. Performing Organization Report No. VTRC 95-R30
9. Performing Organization Name and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, Virginia 23219		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, Virginia 23219		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes

In cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This study compared the effectiveness of pollutant removal in bucket wetlands with cattails (Typha latifolia), reeds (Phragmites sp.), bulrushes (Scirpus), and an unvegetated bucket, and assessed nutrient dynamics in the substrate and water column. The pollutants monitored included total phosphorus (TP), orthophosphate (OP), Zinc (Zn) and chemical oxygen demand (COD). Pollutant removal rates were calculated on a mass balance method. The results were comparable to values reported in the literature. The detention times in this study ranged from 1 day to 21 days. The removal rate differential between vegetated buckets and the control bucket was highest for OP and lowest for COD. Detention time seemed to be important for pollutant removal in this study. The average concentration versus time showed an increased removal of TP, OP, and Zn, but not COD, as time increased. Total suspended solids (TSS) removal is not a function of plant species. The study results suggested that of the three plants, bulrush was most effective for TP and OP removal. Cattail and reed were very effective for Zn and COD removal, respectively. For design considerations, the combination of bulrushes, cattails and reeds is encouraged for pollutant removal. However, the reed used in this study is an invasive species, and should be used with caution.

17. Key Words	18. Distribution Statement
vegetation, biofiltration, pollution control, wetlands	No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	66	

FINAL REPORT

THE CONTROL OF POLLUTION IN HIGHWAY RUNOFF THROUGH BIOFILTRATION

VOLUME III:

LABORATORY TEST OF MARSH VEGETATION

Shaw L. Yu, Ph.D.
Faculty Research Scientist

Shih-Long Liao
Graduate Research Assistant

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Transportation and the University of Virginia)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

VTRC 95-R30

September 1995

Environmental Research Advisory Committee

ABSTRACT

The purpose of this study was to compare the effectiveness of pollutant removal in bucket wetlands with cattails (*Typha latifolia*), reeds (*Phragmites sp.*), bulrushes (*Scirpus*), and an unvegetated bucket, and to assess nutrient dynamics in the substrate and water column. The pollutants monitored included total phosphorus (TP), orthophosphate (OP), Zinc (Zn) and chemical oxygen demand (COD). Pollutant removal rates were calculated on a mass balance method. The results showed that the removal rates for bucket wetlands were comparable to values reported in the literature. The detention times in this study ranged from 1 day to 21 days. The removal rate differential between vegetated buckets and the control bucket was highest for OP and lowest for COD. Detention time seemed to play an important role in pollutant removal in this study. The average concentration versus time showed an increased removal of TP, OP, and Zn, but not COD, as time increased. Total suspended solids (TSS) removal is not a function of plant species. The main removal mechanism of phosphorus was in the OP forms. The three vegetated buckets tolerated the potentially toxic Zn concentration of 5.9 mg/l. However, lower Zn uptake at higher concentrations (4.8 to 5.9 mg/l) in wastewater samples was observed. For COD removal, the presence of vegetation was insignificant for all the data. The regression results showed two main removal mechanisms, sedimentation and adsorption to substrate, accounting for 40 to 60% of pollutant removal. The study results suggest that of the three plants, bulrush is the most effective species for TP and OP removal. However, cattail and reed were very effective for Zn and COD removal, respectively. The results of these three vegetated buckets show better pollutant removal (except for COD at low concentration), which is a function of time and vegetation. The presence of wetland species should provide improved water quality and could allow the use of smaller basins. For design considerations, the combination of bulrushes, cattails, and reeds is encouraged for pollutant removal. However, the reed used in this study is a very invasive noxious species, and it should be used cautiously with proper design and maintenance.

LIST OF TABLES

LIST OF FIGURES

FINAL REPORT

THE CONTROL OF POLLUTION IN HIGHWAY RUNOFF THROUGH BIOFILTRATION

VOLUME III:

LABORATORY TEST OF MARSH VEGETATION

Shaw L. Yu, Ph.D.
Faculty Research Scientist

Shih-Long Liao
Graduate Research Assistant

INTRODUCTION

Biofiltration is the technique of using vegetation for treating stormwater runoff. Vegetation such as grass and marsh plants slow the velocity of runoff, enhancing the settling of sediment-bound pollutants. Vegetation also removes dissolved pollutants as nutrients through plant uptake. This report considers the biofiltration of runoff from highways. Since grassed swales and roadside ditches are an integrated part of a highway drainage system, it would be most cost-effective to consider using them as a stormwater best management practice (BMP). A study of the pollutant removal performance of highway swales was initiated in 1992 and continued through 1993. Two previous reports[1,2] detail the work conducted at a site on U.S. Route 29 south of Charlottesville.

Wetlands have long been recognized as sinks for many pollutants, especially nitrogen and phosphorus. For decades, constructed wetland systems have been used to treat municipal and industrial wastewater and are considered to be more cost-effective than advanced wastewater treatment systems. However, using natural or constructed wetlands for controlling stormwater pollution has only recently been considered. A recent Federal Highway Administration (FHWA) report[3] stated that wetlands constructed within the right-of way (median strips, cloverleafs, etc.) can be designed to provide a specific residence time, thus controlling highway runoff.

This report presents the results of an experimental study of marsh plants. Laboratory "bucket" wetland systems were constructed and planted with three different wetland plant species, namely, cattail (*Typha latifolia*), reeds (*Phragmites sp.*), and bulrushes (*Scirpus*). The study also considered existing mitigation wetland sites constructed by Virginia Department of Transportation (VDOT). Information on the sites was analyzed and certain sites were visited to prepare a list of potential sites for a full-scale field monitoring study, to be initiated in 1995.

PURPOSE AND SCOPE

The objectives of this study were as follows:

1. To use bucket wetlands to study nutrient dynamics for given detention times and pollutant loadings.

2. To compare the relative pollutant removal efficiencies of various wetland plants, such as cattails, reeds, and bulrushes using data collected with laboratory bucket wetlands.

3. To plan the full-scale field monitoring of a VDOT mitigation wetland site in Virginia.

MATERIALS AND METHODS

Literature Review

An extensive literature exists on the performance of wastewater wetland systems. Using wetland systems for treating stormwater, however, is a more recent idea and little information is available. Wastewater treatment wetlands operate quite differently from stormwater treatment wetlands, for the following reasons:

- Municipal wastewater treatment systems usually have a relatively steady flow rate but stormwater wetland systems have highly variable flow rates and the flows are intermittent and seasonal.

- The concentration of suspended solids (SS) in wastewater can usually be estimated within a narrow range, but in stormwater the SS concentration may vary by two to three orders of magnitude between storm events. Also, urban area construction and other erosion-causing activities could result in much higher suspended solids concentration compared to wastewater in stormwater runoff.[4,5]

- Nutrient concentration in wastewater wetland systems can be much higher than in stormwater wetland systems. The ratio of nitrogen/phosphorus (N/P) is also different. Usually N/P is 2.4

(nitrogen limited) but is site-specific for stormwater. A typical cropland runoff may have an N/P exceeding 30.

- Flow and seasonal factors influence pollutant removal capacities for stormwater wetland systems. Nutrient removal varies widely among stormwater wetland systems but usually has a narrow range in wastewater wetland systems.

- The chemical composition of secondary effluent from a wastewater treatment system is very consistent, but is variable for stormwater runoff. Typically, the N/P ratio may vary by one order of magnitude.[6]

- For wastewater wetlands, the biological degradation processes can be sized and maintained for optimal removal rates. For stormwater wetlands, the performance is tied to the biota's ability to tolerate the extremely variable conditions.[4,7]

- For stormwater wetland systems, wetland vegetation types, such as peatland, cypress dome, and marsh meadow, may influence the suitability of wetland systems. For wastewater wetlands, the most commonly used plants are bulrushes and reeds.

Pollutants are removed in stormwater wetlands mainly through the following mechanisms:

- *Sedimentation.* Sedimentation is the dominant removal mechanism for larger particulates in stormwater treatment systems where morphology and vegetation provide conditions conductive to sedimentation. The system stabilizes sediment and inhibits its resuspension because of (a) sheet flow conditions, (b) slower runoff velocities, and (c) hydraulic resistance by vegetation and roots of emergent plants.[8,9]

- *Adsorption.* The main mechanism of removal is the adsorption of pollutants to the surfaces of suspended sediments, bottom sediments, wetland vegetation, and organic detritus. This mechanism is responsible for the removal of phosphorous, trace metals, and hydrocarbons. Also, with a high organic content, hydric soil is a good reservoir for heavy metals due to its adsorption capacity.[10,11]

- *Physical filtration.* Physical filtration (by vegetation and soil) removes trash, debris, and floatables, but not trace metals. Also, infiltration by substrate may remove finer particles, except clay.[11]

- *Plant uptake.* Uptake by wetland plants occurs mainly from the root zone, as the plants take up nutrients from deposited sediment (not from the water column). The higher N/P of stormwater may suggest plant uptake as a long-term phosphorus retention process.[5]

A few experimental studies have been conducted since the mid-1980's on the use of wetlands for stormwater treatment. Athanas[13] reported high metal removal rates for stormwater wetlands and suggested that this might be due to the high sedimentation rate of heavy metals. In another study, Kappel[10] monitored various nutrients in a wetland system receiving stormwater runoff and found positive removal rates for all parameters except for dissolved nitrate and dissolved orthophosphate.

Galli[14] reported a study on nine marsh systems in Maryland and found that the age of marsh plants affected their pollutant removal performance. Two or more growing seasons may be needed to provide enough plant density for runoff velocity dissipation, biofiltration, pollutant uptake, and wildlife habitat.

Martin and Smoot[15] studied the pollutant removal efficiency of a detention pond-wetland system that receives stormwater runoff from a four-lane concrete roadway and adjacent areas. Their results show wetland was effective in reducing both suspended and dissolved loads of solids and metals, with a removal rate between 41 and 73% for total solids, lead, and zinc. Removal rates for nitrogen and phosphorus were lower.

In summary, the ability of wetlands to successfully absorb nutrients depends on their nutrient capacity and hydrology. In engineering practice, the design of a treatment system is based on detention time. It is expected that a longer detention time for a system results in increased interaction between nutrients and nutrient removal mechanisms, and thus higher pollutant removal. In addition, the larger the nutrient capacity of the system, the longer the expected performance life will be.

In general the removal of stormwater wetlands is similar to pond systems and wetland ponds. Reported ranges of removal rates for appropriate stormwater wetlands are: (a) 75-90 % for sediment, (b) 55-65 % for total phosphorus, (c) 40% for total nitrogen, (d) 40% for BOD and (e) 0-80 % for metals.[16]

Experimental Design

Four experimental bucket (batch-type) wetland systems were installed in the University of Virginia Environmental Engineering Laboratory. The design of the four experimental bucket wetlands is shown in Figure 1. Each system consists of a 10-liter plastic bucket filled with 12 kg of washed gravel (3-7 mm dia.) as substratum. The surface area and the water depth of the bucket were 0.0434 m^2 and 0.2 m respectively. Cattails, reeds and bulrushes were planted directly into the substratum. One bucket system was not planted and was used as the control.

Sampling Methods

The water quality parameters monitored were:

1. total suspended solids (TSS)
2. chemical oxygen demand (COD)
3. total phosphorus (TP)
4. orthophosphate (OP)
5. Zinc (Zn)

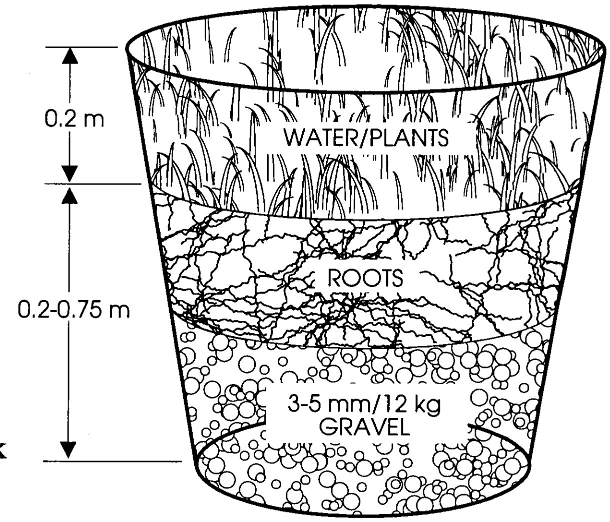


Figure 1. Bucket Wetlands

These water quality parameters are characteristic for highway storm runoff, and likely to be present in high concentrations.

Stormwater runoff and primary and secondary wastewater samples spiked with stock Zn solution (1000 mg/l Zn before dilution) were fed to the bucket wetlands. The stormwater runoff samples were taken from a highway median swale site on U.S. Route 29 South near Charlottesville. The primary and secondary wastewater samples were from the Rivanna Wastewater Treatment Plant. Detention times of 1, 5, 7, 14, and 21 days were used to assess the COD, TP, OP, and Zn dynamics and removal.

Parameters such as conductivity, redox potential, and pH were monitored constantly. The water depths were kept constant and recorded. Water quality parameters, including TSS, COD, OP, and TP in the water column, were monitored at 1, 5, 7, 14, and 21 days from the beginning of the experiments.

The pollutant storage in the system was divided into three components: water column, substrate, and plant. The component analysis was based on a simplified nutrient system described by Kadlec[17] (Figure 2).

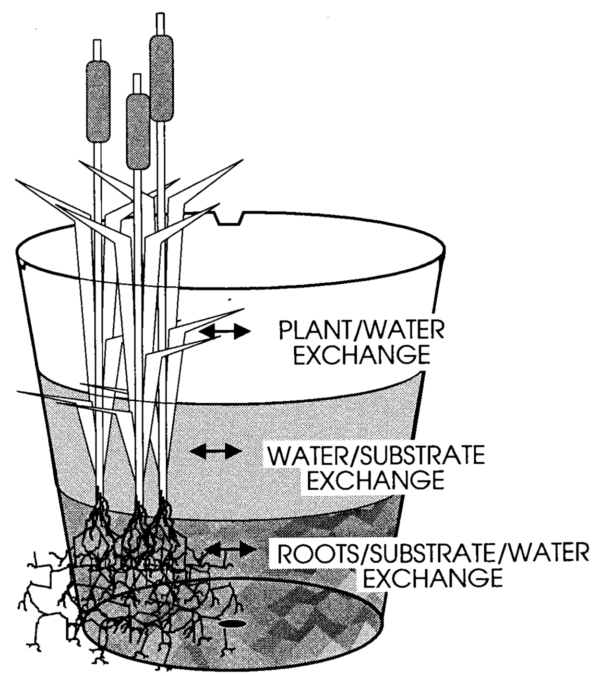


Figure 2. Diagrammatic representation of major components of nutrient removal.

Laboratory Analysis

All water samples were analyzed according to the EPA approved standard methodology or Hach's modified testing procedures.[18,19] TSS was detected by filtration and drying to constant weight at 103-105 ° C. COD was analyzed by reactor digestion followed by colorimetric determination. TP was analyzed by the acid persulfate digestion method and followed by molybdate colorimetric determination. Samples were regularly collected at the inlet and outlet locations of the bucket wetlands.

Calculation of Pollutant Removal Rate

Pollutant removal rates were calculated based on the difference in concentrations of pollutants between the initial values and values obtained after a given time interval. The method is illustrated by Equation 1.

$$\text{Removal Rate (\%)} = \frac{(\text{Initial Concentration}) - (\text{Concentration At Time } T)}{(\text{Initial Concentration})} \times 100 \qquad [1]$$

RESULTS

Data were collected for the bucket wetlands fed with both stormwater runoff and wastewater. Table 1 is a comparison of the ranges and averages of pollutant concentrations of stormwater runoff and wastewater. Zn concentration was originally low (0.07-0.25 mg/l) in wastewater. In order to examine the dose response of the vegetation to potentially toxic Zn concentrations (5.9 mg/l), wastewater spiked with stock Zn solution (1000 mg/l as Zn before dilution) was fed to the wetlands.

The stormwater runoff samples were considered to be low in COD, TP, OP, and Zn with average concentrations of 37, 3.6, 2.8 , and 1.8 mg/l, respectively, and the wastewater was considered to be high in COD, TP, OP, and Zn (with spiked results), with average concentrations of 96, 15.7 , 13.2 , and 4.1 mg/l, respectively. Data of average daily concentrations versus time were summarized for COD, TP, OP, and Zn. Average TP concentrations versus time for the control, bulrush, and reed buckets are shown in Table 2. The rest of the data are shown in Appendix A. Figure 3 depicts mean daily Zn concentration versus time for all the buckets. Figures of average daily TP, OP, and COD concentration versus time for all the buckets appear in Appendix B.

Table 1: Comparison of Ranges and Averages of Pollutant Concentrations of Stormwater Runoff and Wastewater

	Average (Range) (mg/l)				
	TSS	COD	TP	OP	Zn
Stormwater Runoff	55 (45-65)	37 (23-50)	3.6 (2.8-5.3)	2.8 (1.2-5.1)	1.8 (0.07-5.1)
Primary Influent	300	210	27.3	21.6	5.9*
Primary Effluent	160	113	15.0	13.6	4.8*
Secondary Influent	100	38	13.6	10.8	2.8*
Secondary Effluent	50	23	7.0	5.9	2.8*

* Spiked.

Table 2: Average TP Concentration vs. Time (mg/l)

Time (Day)	Initial	Control	Bulrush	Cattail	Reed
Stormwater					
1	3.67	2.41	1.65	1.85	1.74
7	3.67	2.10	1.13	1.36	1.36
14	3.67	2.05	1.21	1.11	1.28
21	3.67	1.81	1.18	1.01	1.08
Wastewater					
1	15.71	9.84	8.92	9.2	9.24
7	15.71	7.64	5.44	5.94	6.61
14	15.71	6.50	3.01	5.77	4.78
21	15.71	8.26	4.66	6.12	4.81
Average	10.55	5.87	3.93	4.74	4.54

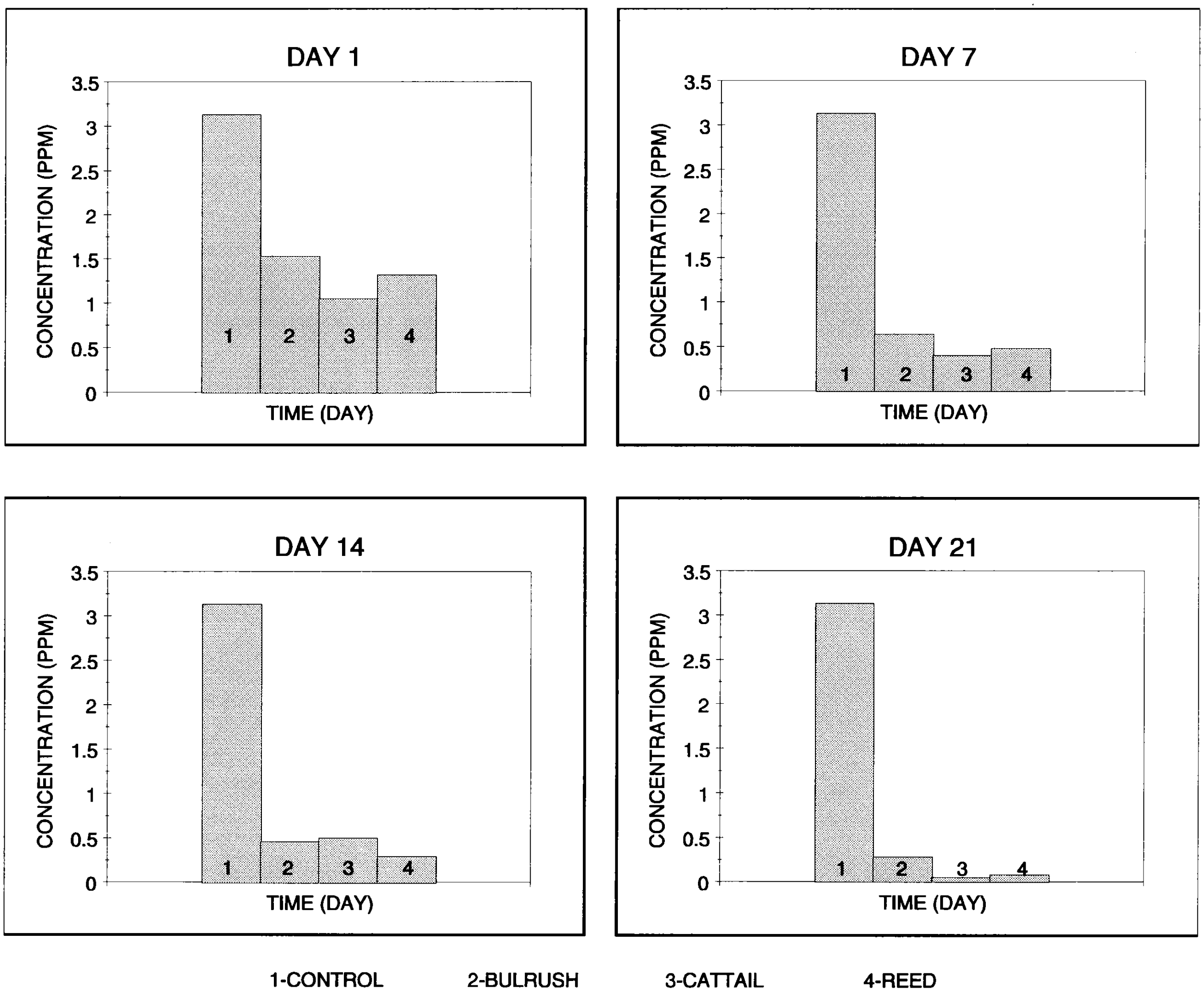


Figure 3. Average Zn concentration versus time for various vegetation.

Pollutant Removal Rates

Equation 1 was used to compute the bucket wetland removal rates of each pollutant for all the experimental runs. Appendix C shows the ranges and average removal rates of each pollutant for all buckets. Figure 4 shows mean pollutant removal rates versus time for the control, bulrush, and reed buckets. Pollutant removal rates for all buckets on Day 7 and Day 21 are shown in Figures 5 and 6, respectively.

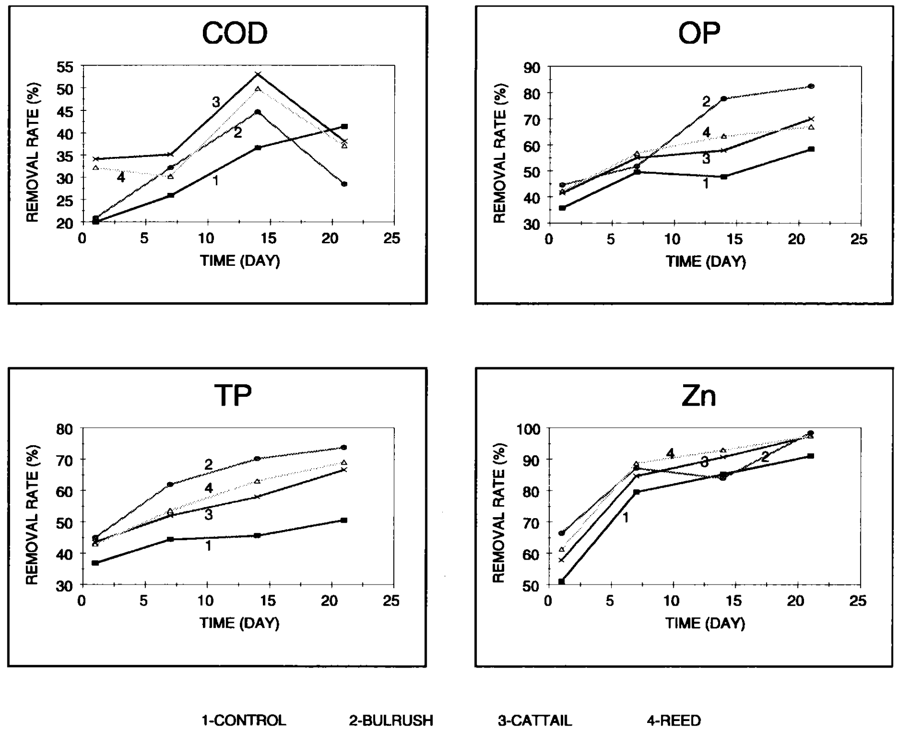


Figure 4. Average pollutant removal rates versus time for various vegetation.

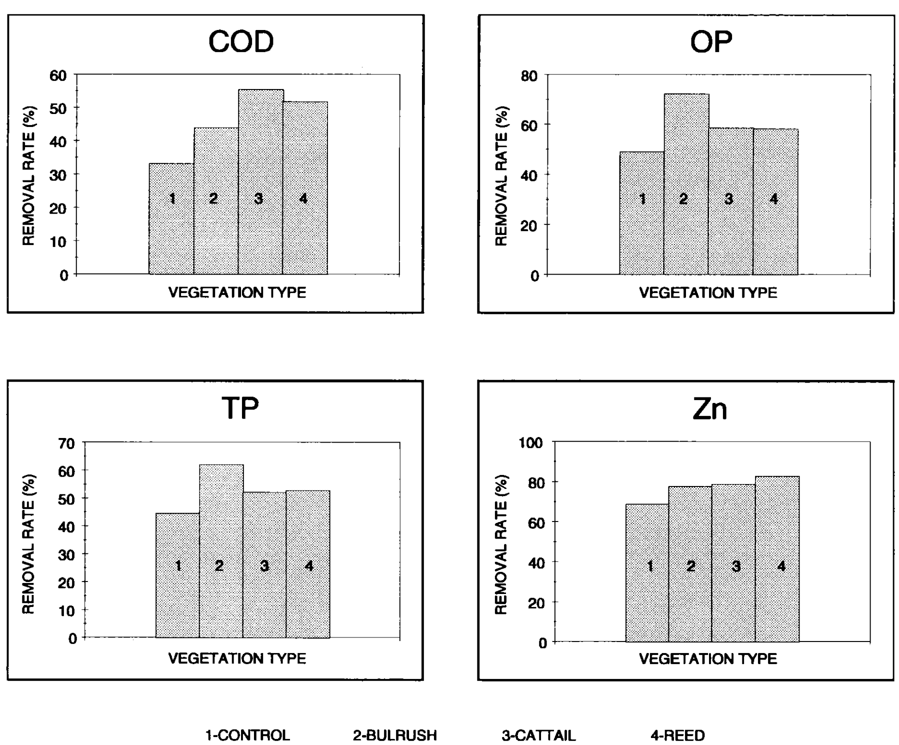


Figure 5. Pollutant removal rates for various vegetation @ day 7.

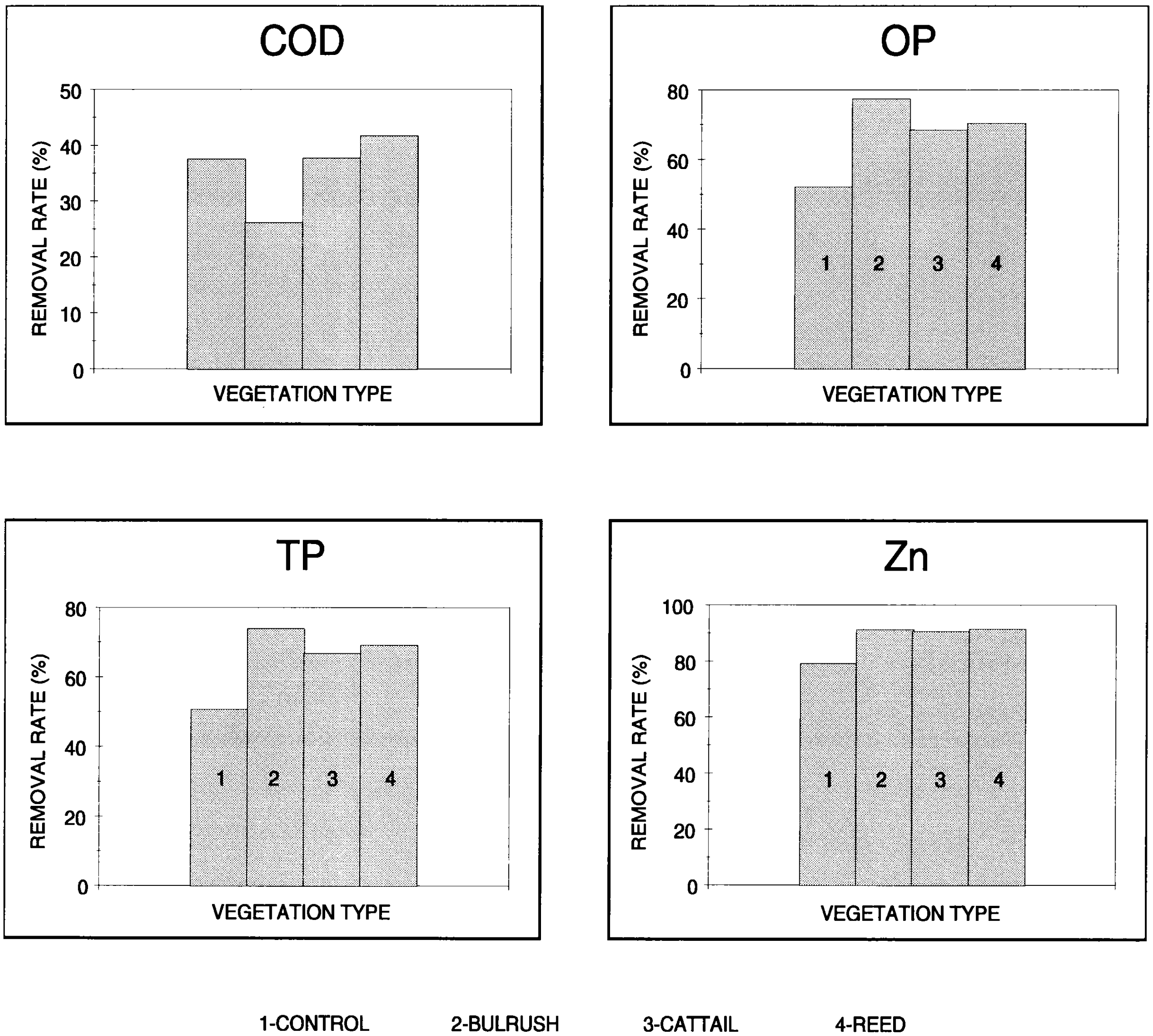


Figure 6. Pollutant removal rates for various vegetation @ day 21.

DISCUSSION

The pollutant reductions observed are attributed to three main mechanisms: adsorption to the wash-gravel bed, plant uptake, and sedimentation. Since the pH of the synthesis storms remained neutral and redox potential was also stable, chemical precipitation was not a significant factor in this study.

Comparative Pollutant Removal

A comparison was made of pollutant concentrations in the control, bulrush, cattail, and reed buckets against values reported in previous literature. Table 3 is a summary of water quality standards versus average pollutant concentrations from the control, bulrush, cattail, reed, Nationwide Urban Runoff Program (NURP), and typical treated municipal mean overflow. The results suggest that the average pollutant concentrations of studied wetland buckets yield better effluent quality for all the pollutant parameters. The bucket wetland effluents meet the water quality standard.

A comparison was also made of the pollutant removal rates for the control, bulrush, cattail, and reed experiments, and values reported in the literature. Table 4 is a summary of average removal rates for the four studied buckets and the values found in other literature. The results show that the removal rates for bucket wetlands are comparable to values reported in the literature. The retention times in this study ranged from 1 day to 21 days. TSS removal is not a function of plant species, but is related to discrete particle settling following Stock's law. For TP and OP, initial concentrations were 3.60 and 2.80 mg/l, respectively. After 14 days, average concentrations for both were reduced to about 1.00 mg/l and uptake of TP and OP was slowed. Ninety percent of TP is OP. The removal rate of TP is approximately ninety percent of OP. The main removal mechanism of phosphorus is in the OP forms, which is similar to Hanson and Westfalls' results.[26] For Zn, after seven days the only removal mechanism in the control bucket is adsorption. The Zn removal rates in the bucket with vegetation were higher at the seventh day and fourteenth day, but by the twenty-first day the removal rate in the control bucket was similar to the vegetated buckets.

Table 5 shows a comparison of the average pollutant removal rates for stormwater runoff samples and wastewater samples for the study buckets. Of the two samples, the results show lower COD removal rates and higher Zn removal rates in stormwater samples for all three types of vegetation. These results may be due to limited COD uptake at low concentration (14 mg/l). Similar results can be found in Green's[20] study. Also, the three vegetated buckets tolerated the potentially toxic Zn concentration of 5.9 mg/l. However, lower Zn uptake at higher concentration (4.8 to 5.9 mg/l) in wastewater samples was observed(see Appendix B). McNaughton[21] had similar results for cattails.

Table 6 compares the average pollutant removal rates between day 1 (shock loadings) and day 21. All the study buckets reacted relatively well for shock loadings in stormwater runoff samples for TP, OP, and Zn removal. However, all study buckets reacted poorly for shock loadings in wastewater samples for TP and OP removal. These results suggest that plants can better adjust to the lower shock loadings of TP (3.67 mg/l) and OP (2.95 mg/l) in stormwater samples than to the higher shock loadings of TP (15.7 mg/l) and OP (13.1 mg/l) in wastewater.

Table 3: Comparison of Pollutant Concentrations at Stormwater Facilities/Wetlands vs. Water Quality Standard (Freshwater Recreation, Fish and Wildlife) (mg/l)

Parameter	Water[23] Quality Standard	NURP[24]	Treated[25] Municipal Overflow	Control	Bulrush	Cattail	Reed
TSS	29 MTU	261	200	3	3	3	3
COD	N/A	147	500	21	16	14	14
DO	5		200	N/A	N/A	N/A	N/A
TN	0.3		40	N/A	N/A	N/A	N/A
TP	N/A	0.790	10	1.8	0.2	1.0	1.1
OP	N/A		N/A	1.2	0.7	0.6	0.7
Cu	0.0032	0.034	N/A	N/A	N/A	N/A	N/A
Pb	0.012	0.145	N/A	N/A	N/A	N/A	N/A
Zn	0.110	0.160	N/A	0.12	0.11	0.03	0.04

Table 4: Comparison of Pollutant Removal Rates (%) in Stormwater Wetlands

	TSS	COD	TN	TP	OP	Cu	Pb	Zn
Literature 8,12,16,22	43-90	0-40	21-54	17-65	N/A	0-80	0-80	0-80
Day 7								
Control	95	12	N/A	43	59	N/A	N/A	48
Bulrush	95	9	N/A	69	82	N/A	N/A	56
Cattail	95	5	N/A	63	74	N/A	N/A	66
Reed	95	2	N/A	63	74	N/A	N/A	70
Day 14								
Control	97	9	N/A	44	52	N/A	N/A	56
Bulrush	97	16	N/A	67	82	N/A	N/A	75
Cattail	97	9	N/A	70	77	N/A	N/A	81
Reed	97	21	N/A	75	80	N/A	N/A	82
Day 21								
Control	99	31	N/A	51	56	N/A	N/A	95
Bulrush	99	9	N/A	68	77	N/A	N/A	99
Cattail	99	39	N/A	73	78	N/A	N/A	99
Reed	99	37	N/A	70	76	N/A	N/A	98

Table 5: Comparison of Average Pollutant Removal Rates Between Stormwater Runoff Samples and Wastewater Samples for Various Vegetation (%)

Stormwater Samples	Control	Bulrush	Cattail	Reed
TP	41	66	62	63
OP	57	79	72	73
Zn	90	87	95	97
COD	35	39	48	43
Wastewater Samples				
TP	44	62	52	55
OP	47	68	51	55
Zn	70	83	77	81
COD	35	39	48	43

Table 6: Comparison of Pollutant Removal Rates Between Day 1 and Day 21 for Various Vegetation (%)

Stormwater Samples	Control	Bulrush	Cattail	Reed
Day 1				
TP	34	55	50	53
OP	46	65	59	60
Zn	83	95	93	96
COD	7	7	4	9
Day 21				
TP	51	68	73	70
OP	56	77	78	76
Zn	95	99	99	98
COD	31	9	39	37
Wastewater Samples				
Day 1				
TP	37	43	43	41
OP	34	42	39	39
Zn	33	56	44	48
COD	16	16	25	27
Day 21				
TP	47	70	61	69
OP	51	80	61	66
Zn	88	97	95	94
COD	52	56	57	56

One-Way ANOVA Analysis

One-Way ANOVA analyses were done to test the significance of pollutant removal rates with respect to time and type of vegetation. A One-Way ANOVA comparing the significance of TP removal rates with respect to time and type of vegetation is presented in Table 7. Homogeneity analysis and associated probabilities of significance among three vegetation species are also shown.

The results of One-Way ANOVA for TP, OP, Zn, and COD are summarized as follows:

Total Phosphorus (TP)

The average TP removal rates for detention times of 1, 7, 14, and 21 days are shown in Table 8. For day 21, the average TP removal rates for all three vegetation types were significantly below that of the control with F ratio and F probability equal to 6.16 and 0.0012, respectively (see Table 7). The results also hold true for day 14. For day 21 and day 14, the presence of vegetation did make a significant difference in TP removal.

However, for day 7, the average TP removal rates were only significant ($p < 0.05$) for bulrush. The Student's *t*-test values for cattail and reed were 0.084, and 0.043 (marginal), respectively. The success of reed for TP removal for Day 7 was marginal and not significant for cattail. Finally, for day 1, the mean TP removal rates were insignificant for all three types of vegetation. The Student's *t*-test values for bulrush, cattail, and reed were 0.044, 0.088, and 0.056, respectively. The success of bulrush for TP removal for day 1 was marginal, and insignificant for the other two vegetations.

Orthophosphate (OP)

The average OP removal rates for detention times of 1, 7, 14, and 21 days are shown in Table 8. For day 21, the average OP removal rates for all three types of vegetation were significantly below that for the control with F ratio and F probability equal to 7.48 and 0.0003, respectively (see Appendix D). Similar results can be observed for Day 14. The presence of vegetation was significant in OP removal for day 21 and day 14.

For Day 7, the average OP removal rates were only significant ($p < 0.05$) for bulrush. The Student's *t*-test values for cattail and reed were 0.167 and 0.171. The OP removal rates were insignificant for either cattail or reed. Finally, for Day 1, the average OP removal rates were insignificant for all three vegetations. The Student's *t*-test values for bulrush, cattail, and reed were 0.168, 0.247, and 0.066, respectively. The success of reed for OP removal for day 1 was marginal, and insignificant for the other two vegetations.

Table 7: One-Way ANOVA of 1, 7, 14, and 21 Day TP Removal Rates

System	Standard Mean	Standard Deviation	F-Ratio	F-Probability	Significant (t-test values in parentheses)
Day 1					
Control	31.1	15.7	1.99	0.1263	
Bulrush	48.9	16.3			(0.044)
Cattail	46.6	15.6			(0.088)
Reed	47.5	14.5			(0.056)
Day 7					
Control	42.4	15.5	3.95	0.013	
Bulrush	64.2	13.6			Yes
Cattail	52.3	19.2			(0.084)
Reed	56.4	18.9			(0.043)
Day 14					
Control	44.3	18.1	7.43	0.0003	
Bulrush	69.6	12.9			Yes
Cattail	59.9	12.2			Yes
Reed	63.3	15.5			Yes
Day 21					
Control	48.0	18.0	6.16	0.00012	
Bulrush	68.4	10.6			Yes
Cattail	65.0	12.2			Yes
Reed	67.0	15.4			Yes

Table 8: Comparison of Average Pollutant Removal Rates for Detention Times of 1, 7, 14, and 21 Days (%)

System	TP	OP	Zn	COD
Day 1				
Control	31.1	36.1	45.4	21.0
Bulrush	48.9	46.1	60.8	22.0
Cattail	46.6	44.6	54.2	28.2
Reed	47.5	48.7	54.3	30.5
Day 7				
Control	42.2	48.9	68.7	33.0
Bulrush	64.2	72.1	77.5	43.8
Cattail	52.3	58.4	78.6	55.4
Reed	56.4	58.1	82.6	51.7
Day 14				
Control	44.3	44.6	76.7	38.3
Bulrush	69.6	75.8	80.8	27.9
Cattail	59.9	62.4	88.1	39.4
Reed	63.3	65.6	90.3	42.7
Day 21				
Control	48.0	52.1	79.0	37.5
Bulrush	68.4	77.4	91.1	26.1
Cattail	65.0	68.5	90.5	37.7
Reed	67.0	70.4	91.3	41.7

Zinc (Zn)

The average Zn removal rates for detention times of 1, 7, 14, and 21 days are shown in Table 8. For day 21, the average Zn removal rates for both bulrush and cattail were significantly below that for the control with F ratio and F probability equal to 3.08 and 0.0369, respectively (see Appendix D). The success of reed for Zn removal was marginal with a Student's t-test of 0.086. However, for day 14, the average Zn removal rates for both cattail and reed were significantly below that for the control with F ratio and F probability equal to 1.98 and 0.131, respectively. The presence of bulrush was insignificant for Zn removal, with a Student's t-test of 0.624. For day 21 and day 14 , the presence of cattail did make a significant difference in Zn removal.

For day 7, the average Zn removal rates were insignificant for all three vegetation types. The Student's t-test values for bulrush, cattail, and reed were 0.313, 0.244, and 0.135 respectively. The Zn removal rates were insignificant for either bulrush, cattail or reed. Finally, for day 1, the average Zn removal rates were not significant for all three vegetation types. The Student's t-test values for bulrush, cattail, and reed were 0.112, 0.388, and 0.383 respectively.

Chemical Oxygen Demand (COD)

The average COD removal rates for detention times of 1, 7, 14, and 21 days are shown in Table 8. A comparison of COD removal rates for the four wetland buckets does not show strong effects in the presence of vegetation. For day 21, data shows 26% removal for bulrushes, 38% for cattails, and 42% for reeds, as compared with a close margin of 38% for control buckets. The reported COD removal rate was 40%.[16]

The study results suggest that the bulrush is the most effective of the three plants for TP and OP removal. However, cattail and reed were very effective for Zn and COD removal, respectively. For design consideration, the combination of bulrushes, cattails, and reeds is encouraged for the removal of various pollutants.

The buckets in this study contained a single plant. Removal rates of pollutants will vary for various plant densities. A higher plant density increases the contact area between plant species and the amount of pollutant removal increases.[27]

Another interesting research topic related to nutrient dynamics is seasonal effect. Seasonal effect usually plays an important role in the nutrient dynamics of wetland. During the growing season, when photosynthesis activity is high, pollutant uptake should be high. During the winter die-off, when photosynthesis activity is low, pollutant uptake should be low. The pollutant tends to be released from the plant. To prevent this, the plants should be harvested. Further study can be focused on the nutrient release rates of plants during winter die-off periods. During the summer, when the photosynthesis period is longer, the pollutant uptake should be higher. The photosynthesis period of this study is twelve hours. It would be interesting to study the pollutant uptake for different photosynthesis periods.

Linear Regression Analysis

Linear regression analyses were done to divide the pollutant storage in the system into three components: water column, substrate, and plant. Four removal mechanisms (sedimentation, adsorption to plant (suspended particulate), adsorption to gravel, and plant uptake) were included to examine removal rates with respect to time and type of vegetation.

In linear regression, the intercept (b0) accounts for removal due to sedimentation and suspended particulate (SP) adsorption to plant, and slope (b1) accounts for removal due to adsorption to gravel and plant uptake for all three vegetation types. For control, the intercept accounts for sedimentation, and the slope accounts for suspended particulate (SP) adsorption to plant. To validate the removal rates for sedimentation, the values of the percentage of TSS associated with pollutants were used to verify the intercept values generated from the linear regression. The percentage of TSS associated with pollutants for bucket wetlands is presented in Table 9. With known sedimentation and SP adsorption, the adsorption and plant uptake rate were calculated.

The linear regression results quantify the average pollutant removal rates for all three vegetation types and control. The results of linear regressions for TP, OP, Zn, and COD are summarized as follows:

Total Phosphorus (TP)

The regression results show no significant difference in plant uptake rates (0.40 1/day) for all three vegetation types (Table 10). However, the results show strong evidence that the SP adsorption to the plant was the determining factor for TP removal rates. Of the three types of vegetation, bulrush had the highest values at 15.78 1/day, followed by reed at 8.9 1/day, and then by cattail at 5.74 1/day. The linear regression results agree with the results of the One-Way ANOVA analysis.

Orthophosphate (OP)

The regression results show strong evidence that both SP adsorption to the plant and plant uptake affect OP removal rates (Table 11). Of these three vegetation types, bulrush has the highest values of adsorption (SP) and plant uptake. The linear regression results again agree with the results of One-Way ANOVA analysis.

Table 9: Percentage of Pollutant Associated with TSS for Bucket Wetlands

Parameter	COD	TP	OP	Zn
TSS%	37.6	30.6	28.6	20.1

Table 10: Values from the Results of Linear Regression for TP Removal

Parameter	Control	Bulrush	Cattail	Reed
Intercept (%)	36.52	52.29	42.26	45.42
Slope (l/day)	0.59	1.01	0.99	1.01
Sedimentation (%)	36.52	36.52	36.52	36.52
Adsorption (SP)	0.00	15.78	5.74	8.90
Adsorption (l/day)	0.59	0.59	0.59	0.59
Plant uptake (l/day)	0.00	0.42	0.40	0.42

Table 11: Values from the Results of Linear Regression for OP Removal

Parameter	Control	Bulrush	Cattail	Reed
Intercept (%)	33.12	44.30	38.32	42.69
Slope (l/day)	0.69	1.45	1.19	1.00
Sedimentation (%)	33.12	33.12	33.12	33.12
Adsorption (SP)	0.00	11.18	5.20	9.57
Adsorption (l/day)	0.69	0.69	0.69	0.69
Plant uptake (l/day)	0.00	0.76	0.50	0.31

Table 12: Values from the Results of Linear Regression for Zn Removal

Parameter	Control	Bulrush	Cattail	Reed
Intercept (%)	40.08	53.80	47.44	48.84
Slope (l/day)	1.57	1.36	1.57	1.57
Sedimentation (%)	40.08	40.08	40.08	40.08
Adsorption (SP)	0.00	13.72	7.36	8.76
Adsorption (l/day)	1.57	1.36	1.57	1.57
Plant uptake (l/day)	0.00	---	---	---

Zinc (Zn)

The regression results show strong evidence that only SP adsorption to the plant (not for plant uptake) affects Zn removal rates (Table 12). Of these three vegetation types, bulrush has the highest value of SP adsorption but none are significant in plant uptake. The linear regression results again agree with the results of One-Way ANOVA analysis.

Chemical Oxygen Demand (COD)

No linear regression analysis was done for COD since the comparison of COD removal rates for four wetland buckets did not show strong effects in the presence of vegetation.

In summary, the regression results show two main removal mechanisms, sedimentation and adsorption to substrate, which account for 40 to 60% of pollutant removal. Seventy-five percent of TSS is removed by sedimentation, and the other twenty-five percent is removed by adsorption to substrate. The regression results also show strong evidence that both plant uptake and suspended particulate (SP) adsorption to the plant affect TP and OP removal rates. The plant uptake rate and suspended particulate SP adsorption account for 40 to 60 % of the TP and OP removal. The plant uptake rate to SP ratio varies from 0.4 to 0.6 depending on the types of pollutants and types of vegetation. Of these three plant species, bulrush has the highest values of plant uptake and SP adsorption. For Zn removal, the regression results show strong evidence that only SP adsorption to the plant (not for plant uptake) affects Zn removal rates. Of these three plant species, bulrush has the highest value of SP adsorption for Zn removal, but none are significant in plant uptake.

PLAN FOR FIELD MONITORING OF VDOT MITIGATION WETLANDS

Collection of Information on Mitigated Wetland

One hundred and ninety mitigated wetland sites managed by the VDOT were documented. Figure 7 shows the distribution of these mitigated wetlands in Virginia.

Site Visit

Ten mitigated wetland sites of were visited for potential site selection in next year's study. They are, namely, South Fork Rivana River, Cedar Run, Covington (Culpeper), site 13 , site 14, Kingsland Creek (3 sites in Richmond), Sam's Club (W. Broad Street), and Emporia site. All but Sam's Club site are owned by VDOT.

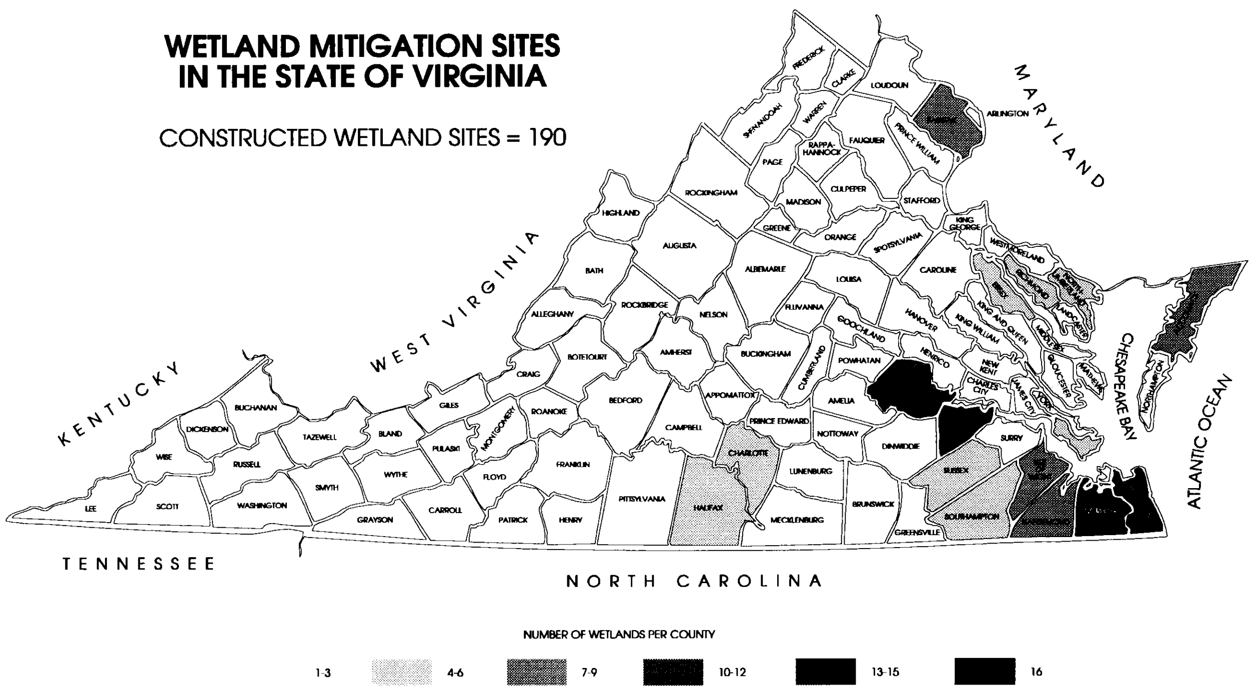


Figure 7. Wetland mitigation sites in the state of Virginia.

The site selection criteria are (a) state owned property, (b) relatively controllable drainage area, (c) known input resources (highway runoff is preferred), (d) easy access, (e) surface water (overland flow is preferred) and (f) existing and clearly defined inlet and outlet structures. Of these ten wetland mitigation sites, most fit the criteria relatively well except for meeting the existing and clearly defined outlet requirement. Most sites were originally designed for impoundment so the outlet structures were not well defined.

Sites 13 and 14 (approximately 2.9 acres of each) in highway median of US Route 288 are good candidates. Each has a very well defined outlet structure but the three inlets make the monitoring work difficult.

Mitigation area 2 of Kingsland Creek on US Route 637 (approximately 3.04 acres) is a very good site for monitoring except for the unclear ditch on the edge of the site. With proper modification, this site is the best of the ten. Figure 8 shows the Kingsland Creek site.

Another good candidate site is the Sam's Club parking lot mitigation site at the intersection of West Broad Street and Gaskins Road. This wetland mitigation was originally designed for stormwater management purposes and is approximately 0.7 acres in size. It also has a well defined inlet. With proper modification, this site can be acceptable for monitoring.

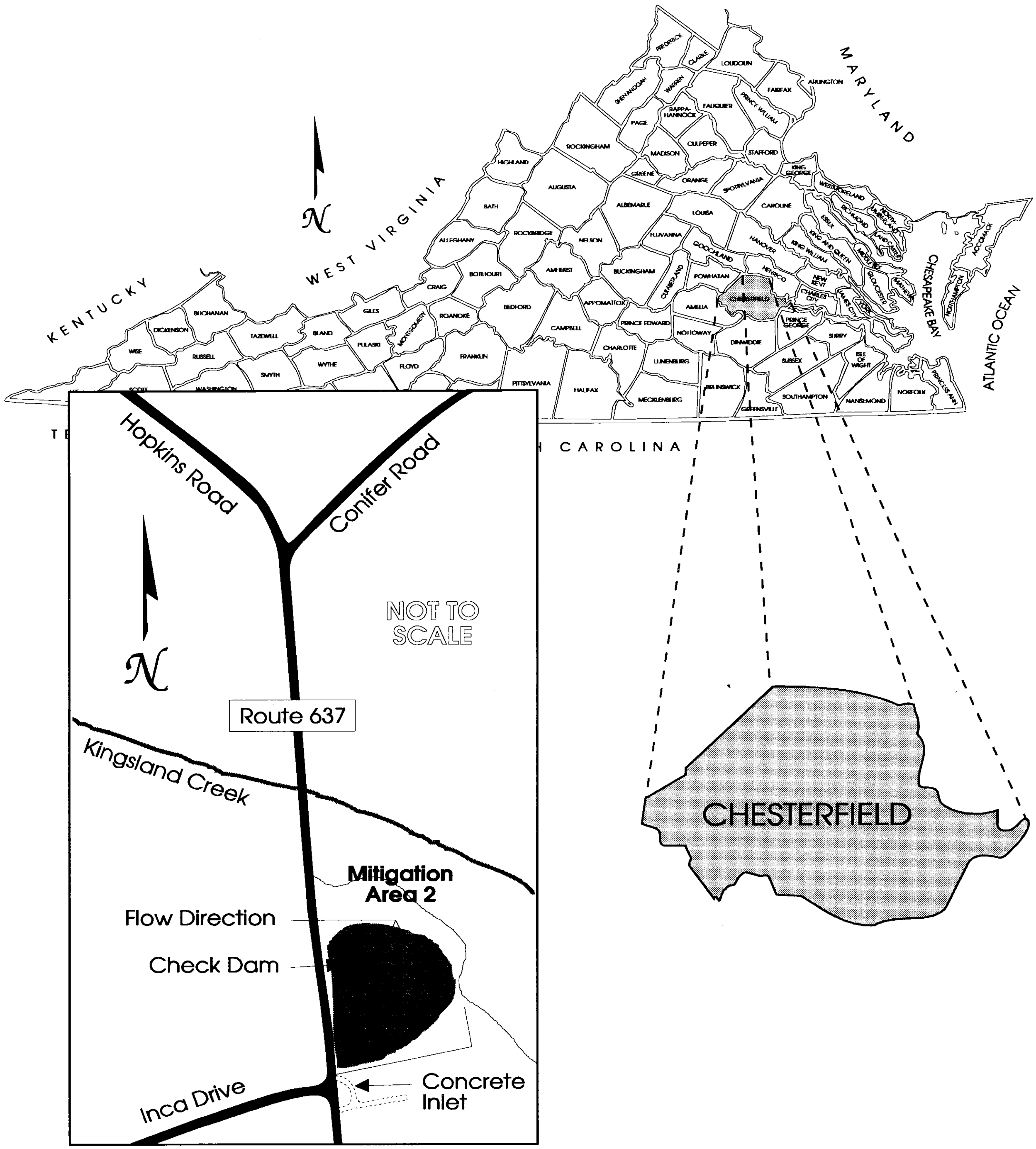


Figure 8. Chesterfield County, Route 637 - Hopkins Road Mitigation Wetland

CONCLUSIONS

1. The removal rate differential between vegetated buckets and control bucket is highest for OP and is lowest for COD.

2. TSS removal is not a function of plant species. The data show a larger percentage (about 30 - 40%) of TP, OP, and COD associated with TSS compared to Zn (20 %). Sedimentation was more important for TP, OP, and COD than for Zn.

3. Detention time seems to be important for pollutant removal in this study. The average concentration versus time showed an increased removal of TP, OP, and Zn, but not COD, as time increased. These results may be due to limited COD uptake at low concentration (14 mg/l).

4. For TP and OP, initial concentrations were 3.60 and 2.80 mg/l, respectively. After 14 days, average concentrations for both were reduced to about 1.00 mg/l and uptake of TP and OP was slowed. Ninety percent of TP is OP. The removal rate of TP is approximately ninety percent of OP. The main removal mechanism of phosphorus is in the OP forms. For TP and OP removal, One-Way ANOVA showed that the presence of all three vegetation types was significant ($p < 0.05$) for day 21 and day 14, but only bulrush was significant for day 7.

5. For Zn, after seven days, the only removal mechanism in the control bucket was adsorption. The Zn removal rates in the buckets with vegetation were higher at the seventh day and fourteenth day, but by the twenty-first day the removal rate in the control bucket was similar to the concentration of 5.9 mg/l. However, a lower Zn uptake at higher concentrations (4.8 to 5.9 mg/l) in wastewater samples was observed. For Zn removal, One-Way ANOVA showed that both cattail and reed were significant for day 14.

6. For COD removal, the presence of vegetation was insignificant for all the data.

7. The regression results show two main removal mechanisms, sedimentation and adsorption to substrate, which account for 40 to 60% of pollutant removal. Seventy-five percent of TSS is removed by sedimentation, and the other twenty-five percent is removed by adsorption to substrate. The regression results also show strong evidence that both plant uptake and suspended particulate (SP) adsorption to the plant affect TP and OP removal rates. The plant uptake rate and suspended particulate SP adsorption account for 40 to 60% of the TP and OP removal. The plant uptake rate to SP ratio varies from 0.4 to 0.6 depending on the types of pollutants and types of vegetation. Of these three plant species, bulrush has the highest values of plant uptake and SP adsorption for TP and OP removal. For Zn removal, the regression results show strong evidence that only SP adsorption to the plant (not for plant

uptake) affects Zn removal rates. Of these three plant species, bulrush has the highest value of SP adsorption for Zn removal.

8. In this study, the main removal mechanisms in control buckets were sedimentation and adsorption, analogous to a detention basin without vegetation. The three vegetated buckets showed better pollutant removal (except for COD at low concentration), which is a function of time and vegetation. The presence of wetland species should provide improved water quality and could allow the use of smaller basins.

RECOMMENDATIONS

1. The results suggest that of the three plants studied, bulrush is the most effective species for TP and OP removal. Cattail and reed were very effective for Zn and COD removal, respectively. For design considerations, the combination of bulrushes, cattails, and reeds is recommended for the removal of various pollutants.

2. Further investigations of other plant species are desirable, but the types of vegetation in this study (cattail, bulrush, and reed) seem to provide improved water quality (especially for phosphorus and Zn removal). The use these wetland species provides a reliable and cost-effective method for highway stormwater runoff treatment. However, the reed used in this study is a very invasive noxious species that provides little habitat or other ecological benefits. It should be used cautiously with proper design and maintenance. The authors recommend that VDOT plant bulrushes in its mitigation sites in the future.

3. This study used single plants for vegetation. More research is needed to compare the removal rates of pollutants at various plant densities. Higher plant density increases the contact area between plant species, and the amount of pollutant removal increases.

4. Seasonal effects are usually important in the nutrient dynamics of wetland. During the growing season, when photosynthesis activity is high, pollutant uptake should be high. During the winter die-off, when photosynthesis activity is low, pollutant uptake should be low. The pollutant has a tendency to be released from plant. To prevent this, plants should be harvested. Further study can be focused on the nutrient release rates of plants during winter die-off periods.

5. During the summer, when the photosynthesis period is longer, the pollutant uptake should be higher. The photosynthesis period of this study was twelve hours. It would be of interest to study the pollutant uptake for different photosynthesis periods.

6. This study started with the hypothesis that bucket wetlands could model water quality improvements to stormwater runoff and wastewater. We demonstrated that bucket wetlands have the ability to remove nutrients. We are convinced that similar results can be extended to a field study. If resources are available, the field study should be monitored on both an acute and long-term basis.

7. Ten wetland sites were visited for potential site selection. However, most of them were designed as impoundments, and no well-defined outlet structure could be found. It is difficult to balance a water budget without a well-defined inlet or outlet. Another possibility is to monitor a stormwater basin that has been colonized by wetland plants. More site visits are needed to find suitable sites.

ACKNOWLEDGMENTS

The research reported herein was conducted under the general supervision of Dr. Gary R. Allen, Director of the Virginia Transportation Research Council. Special thanks go to Michael M. Sprinkel, Research Manager of Materials and Environmental Group, for his assistance during the course of this study. The project was financed with HPR funds administered by the Federal Highway Administration.

Mr. Stephen J. Long, Environmental Program Manager, VDOT, and his colleagues Mr. Steven Russel and Ms. Amy Anstey for their help in obtaining mitigated wetlands information in this report. Richard Ziller, Steve Daigle, and E. Jeffrey Stevens are recognized for their help in experimental setup. Robert Kaighn, Jr and Christienne O'Flaherty are also thanked for their assistance.

The writers would like to thank Michael Sprinkel, Dan McGeehan, and Michael Fitch of VTRC, Steve Long of VDOT, and Edward Sundra of FHWA for peer reviewing the draft report. Last, but not least, the writers thank Margaret Edwards, Gary Mawyer, Randy Combs, Ed Deasy, Arlene Fewell, and Jerry Garrison for their assistance in the production for this report.

REFERENCES

1. Yu, S. L., Barnes, S. L., Gerde, V. W. 1993. *Testing of best management practices for controlling highway runoff.* VTRC Report No. 92-R13. Charlottesville: Virginia Transportation Research Council.

2. Yu, S. L., Kaighn, R. J., and Liao, S. L. 1994. *Testing of best management practices for controlling highway runoff -Phase II.* VTRC Report No. 94-R21. Charlottesville: Virginia Transportation Research Council.

3. Yu, S. L. 1993. *Stormwater management for transportation facilities.* National Cooperative Highway Research Program Synthesis of Highway Practice 174. Transportation Research Board: Washington, D.C. National Research Council.

4. Livingston, E. H. 1989. *Use of wetlands for stormwater management.* Constructed Wetlands for Wastewater Treatment. ed. Hammer, D. A., pp. 253-262.

5. Baker, L. 1993. *Introduction to nonpoint source pollution and wetland mitigation.* Created and Natural Wetlands for Controlling Nonpoint Source Pollution, ed. Olson, R. K. pp. 7-41.

6. Novotny, V. and Chesters, G. 1989. *Delivery of sediment and pollutants from nonpoint sources: a water quality perspective.* Journal of Soil and Water Conservation, Volume 44, pp. 568-76.

7. Silverman, G. S. 1989. *Development of urban runoff treatment wetlands in Fermont, CA-- treatment of nonpoint source pollutants, urban runoff and agricultural waste.* Constructed Wetlands for Wastewater Treatment. ed. Hammer , D. A., pp. 669-676

8. Schueler, T. R. 1992. *Design of stormwater wetland systems--Guidelines for creating diverse and effective stormwater systems in the Mid-Atlantic region.* Washington D.C.: Metropoliton Washington Council of Governments.

9. Federal Highway Administration. 1988. *Stormwater runoff pollutant removal, Interim guidelines for management--Retention, detention, and overland flow for pollutant removal from highway storm runoff.* FHWA/RD-87/056. Washington D.C..

10. Kappel, W. M., Yanger, R. M. and Zarriello, P. J. 1985. *Quantity and quality of urban storm runoff in the Irondequoit Creek Basin near Rochester, NY Part 2.* USGS Water-Resources Investigations Report 85-4113. Rochester, NY.: U.S. Geological Survey.

11. Daukas, P., Lowry, D., and Walk, W. W., Jr. 1989. *Design of wet detention basins and constructed wetlands for treatment of stormwater runoff from a regional shopping mall in MA.* Constructed Wetlands for Wastewater Treatment, ed. Hammer, D. A., pp. 686-694.

12. Martin, E. H. 1988. *Effectiveness of an urban runoff detention-pond-wetland system.* Journal of Environmental Engineering, Vol. 114, No. 4.

13. Athanas, C. 1988. *Wetlands creation for stormwater treatment.* National Wildlife Federation Corporate Conservation Council, Proceedings of a Conference, pp. 61-66.

14. Galli, J. 1992. *Analysis of urban BMP performance and longevity in Prince George's County.* Maryland Department Environmental Programs, Metropolitan Washington Council of Governments. Washington, D.C.

15. Martin, E. H. amd Smoot J. L. 1986. *Constituent loads changes in urban storm runoff route through a detention pond-wetlands system in central Florida.* USGS Water-Resources Investigations Report 85-4310. Tallahassee, Fla.: U.S. Geological Survey.

16. Linker, L. C. 1989. *Creation of wetlands for the improvement of water quality--A proposal for the joint use of highway right-of-way.* Constructed Wetlands for Wastewater Treatment, ed. Hammer, D. A., pp. 695-701.

17. Kadlec, J. A. 1987. *Nutrient dynamics in wetlands.* Aquatic Plants for Water Treatment and Resource Recovery, ed. Reddy, K.R. and Smith, W.H., pp. 393-419. Orlando, Florida: Magnolia Publishing Inc.

18. APHA 1989. *Standard methods for the examination of water and wastewater.* 17th edition. Washington D.C.: American Public Health Association.

19. Hach Company. 1993-1994. *Hach manual for water and wastewater examination* 1992-1993. Loveland, Colorado: Hach Company.

20. Green, B. 1994. *Constructed wetland are big in small commuties.* Water Environment & Technology. Volume 6, pp. 51-5.

21. McNaughton, S. J., Folsom, T.C. Lee, T., Park, F.Price, C., Roeder, D., Schmitz, J., and Stockwell, C. 1974. *Heavy metal tolerance in typha latifolia without the evolution of tolerant races.* Ecolog, Volume 55, pp. 1163-1165.

22. Knight, R. L., McKim, T. W., and Kohl, H. R. 1987. *Performance of a natural wetland system for wastewater management*. Journal of Water Pollution Control Federation. Volume 59, pp. 746-756.

23. U.S. Environmental Protection Agency, 1986 & 1987 update. *Quality criteria for water 1986, gold book.* EPA 44015-86-001, Washington, D.C.: U.S. Environmental Protection Agency.

24. Paulson C. and Amy, G. 1993. *Constructed wetland are big in small commuties*. Water Environment & Technology. Volume 5, pp. 46-9.

25. Hickok, E.A., Hannaman, M. C., and Wenck, N. 1977. *Urban runoff treatment methods, Vol. 1--Non-structure wetland treatment*, EPA Report No. 600-/2-77/217. Washington, D.C.

26. Hanson, R.L. and Westfall, D.G., 1985. *Orthophosphate solubility transformations and avalibility from dual applied nitrogen and phosphorus*. Soil Science Society of America Journal. Volume 49, pp. 1283-1289.

27. Kuehn E. J., 1994. *Plant surface area and treatment efficiency in wetlands*. ASAE summer meeting June 19-22, Kansas City, MO, ASAE Report No. 942003. St. Joseph, MI

Appendix A

Table A

Average COD Concentrations VS Time
Unit :ppm

Time (day)	Initial(Range)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	46.3	37.0	36.6	30.5	31.4
7	46.3	34.3	31.4	30.0	32.3
14	46.3	29.3	25.6	21.7	23.2
21	46.3	27.1	33.1	28.6	29.1
Average	46.3 (23,113)	31.9 (10,110)	31.7 (10.108)	27.7 (9,104)	29.0 (9,103)

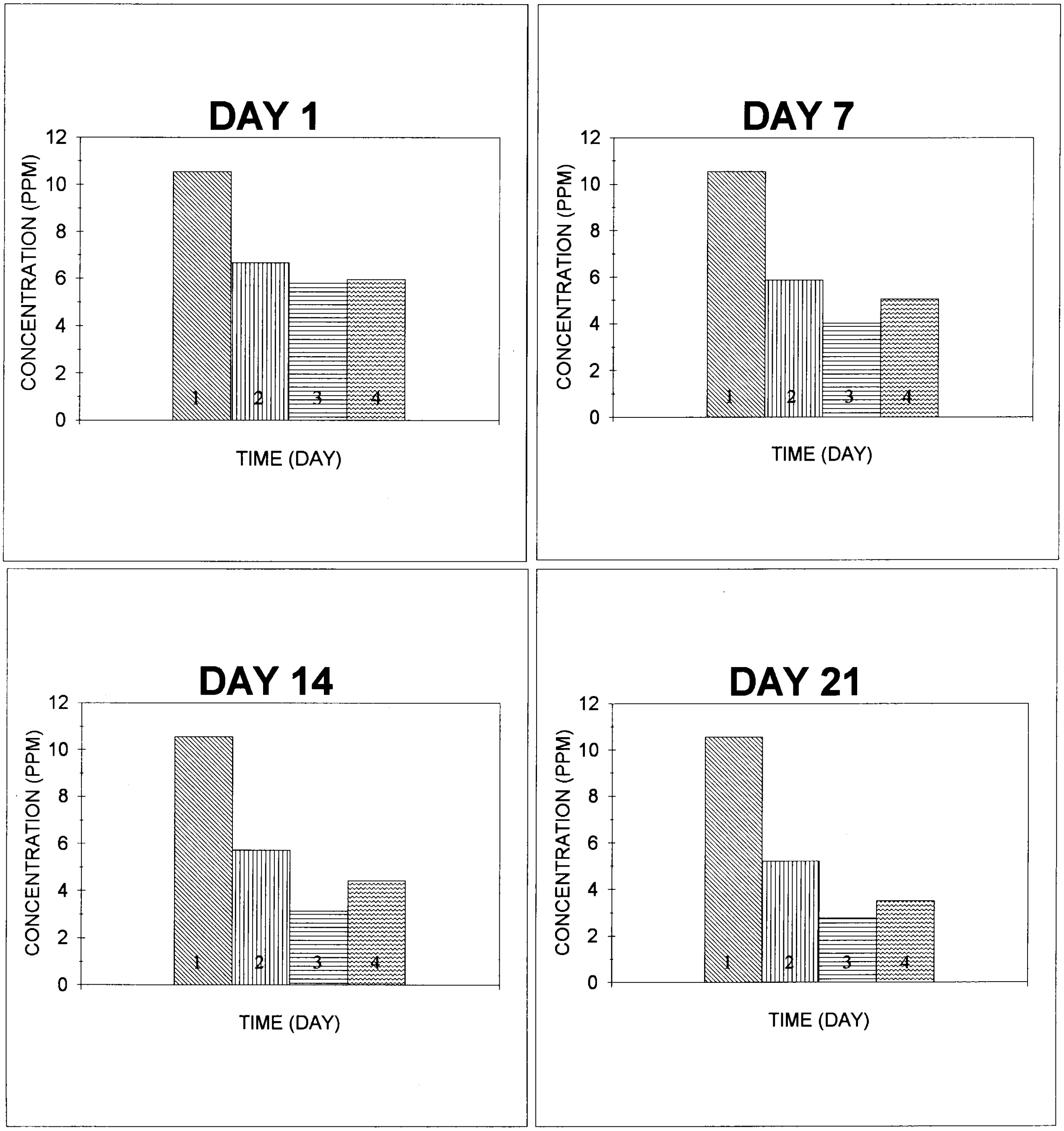
Average OP Concentrations VS Time
Unit :ppm

Time (day)	Initial(Range)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	8.73	5.61	4.84	5.11	5.05
7	8.73	4.40	4.21	3.92	3.76
14	8.73	4.56	1.94	3.67	3.19
21	8.73	3.63	1.53	2.61	2.88
Average	8.73(1.2,21.6)	4.55(0.7,13.3)	3.13(0.2,12.0)	3.83(0.4,12.8)	3.72(0.2,13.0)

Average Zn Concentrations VS Time
Unit :ppm

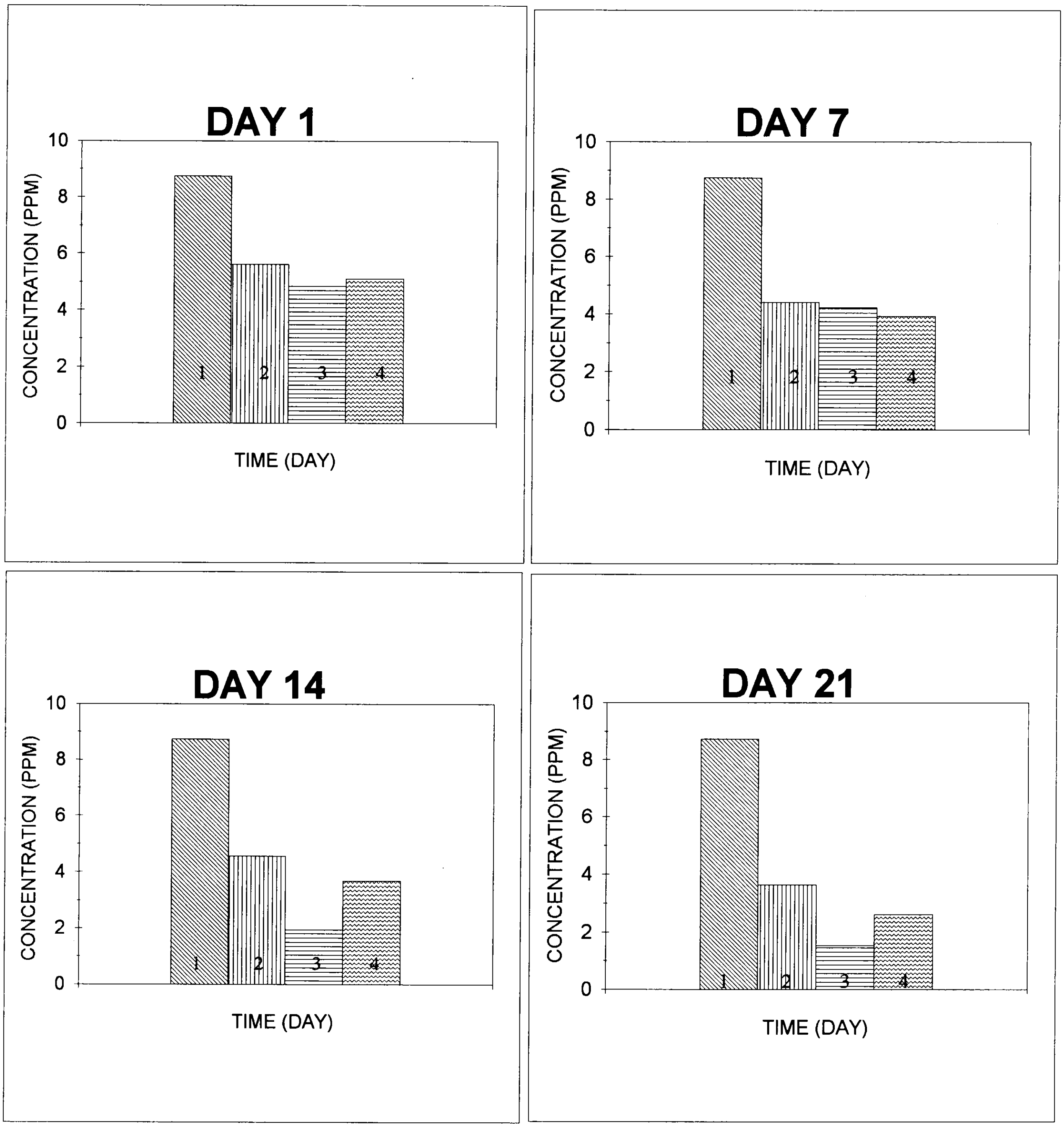
Time (day)	Initial(Range)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	3.13	1.53	1.05	1.32	1.21
7	3.13	0.64	0.40	0.48	0.35
14	3.13	0.46	0.50	0.29	0.22
21	3.13	0.28	0.05	0.08	0.08
Average	3.13(0.07,5.9)	0.73(0.02,3.81)	0.50(0.,3.42)	0.54(0.,3.61)	0.47(0.,3.71)

Appendix B



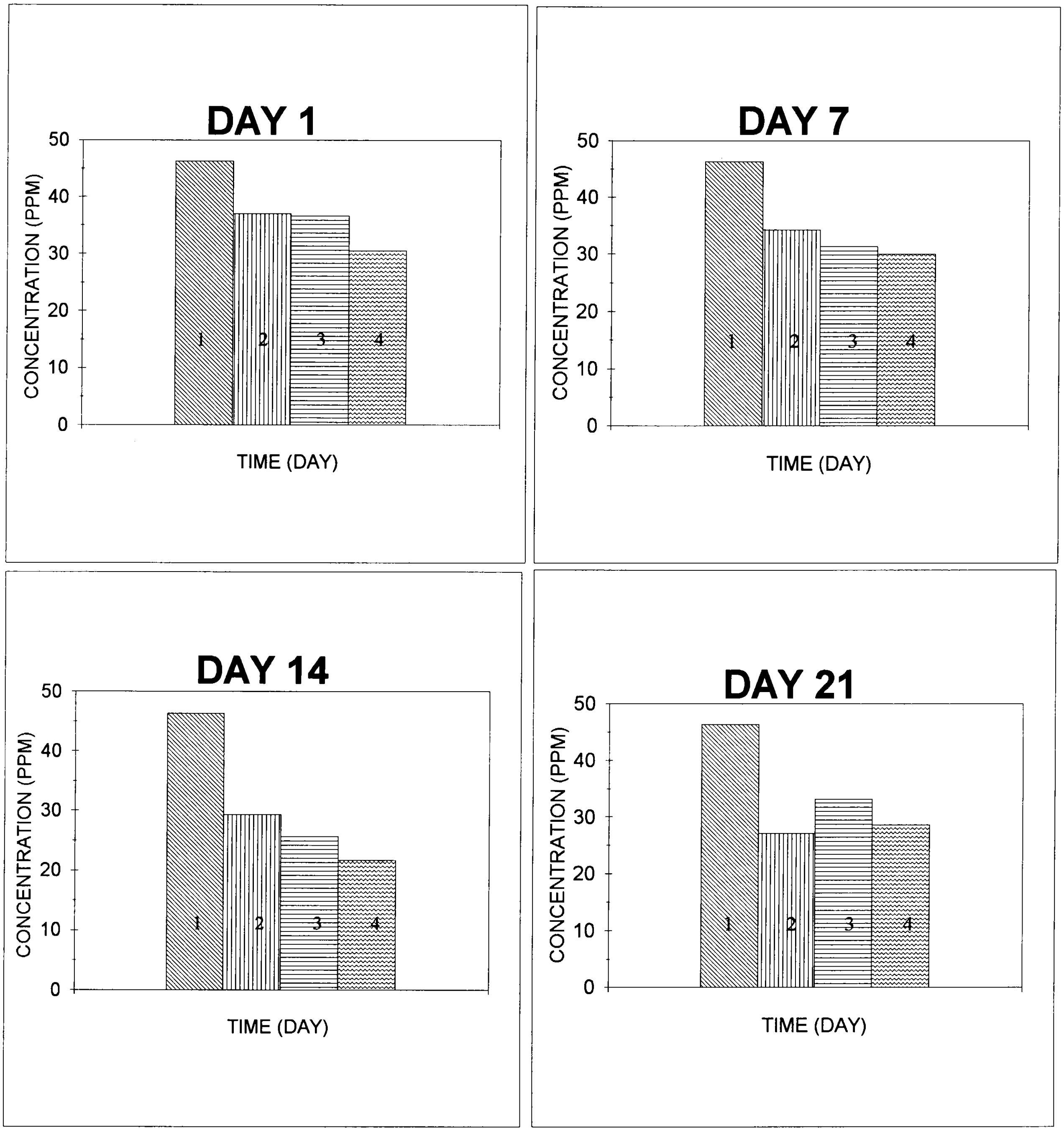
1 CONTROL   2 BULRUSH   3 CATTAIL   4 REED

Average TP concentration versus time for various vegetation



1 CONTROL 2 BULRUSH 3 CATTAIL 4 REED

Average OP concentration versus time for various vegetation



1 CONTROL 2 BULRUSH 3 CATTAIL 4 REED

Average COD concentration versus time for various vegetation

Appendix C

Table C-1

One Way ANOVA Analysis of 1, 7, 14, 21 Days Removal Rates of TP For Bucket Wetlands

System	Standard Mean	Standard Deviation	Max.	Min.	F ratio	F prob.	Significant
Day 1							
Control	31.1	15.7	69.0	11.0	1.99	0.1263	
Bulrush	48.9	16.3	70.0	13.0			(0.044)
Cattail	46.6	15.6	76.0	31.0			(0.088)
Reed	47.5	14.5	70.0	22.0			(0.056)
Day 7							
Control	42.4	15.5	62.0	17.0	3.95	0.013	
Bulrush	64.2	13.6	88.0	45.0			*
Cattail	52.3	19.2	86.0	22.0			(.084)
Reed	56.4	18.9	82.0	20.0			(.043)
Day 14							
Control	44.3	18.1	63.0	4.0	7.34	0.0003	
Bulrush	69.6	12.9	88.0	46.0			*
Cattail	59.9	12.2	81.0	40.0			*
Reed	63.3	15.5	86.0	32.0			*
Day 21							
Control	48.0	18.0	72.0	5.0	6.16	0.0012	
Bulrush	68.4	10.6	92.0	53.0			*
Cattail	65.0	12.2	85.0	43.0			*
Reed	67.0	15.4	91.0	36.0			*

All the distribution are homogenous

Table C-2
One Way ANOVA Analysis of 1, 7, 14, 21 Days Removal Rates of OP
For Bucket Wetlands

System	Standard Mean	Standard Deviation	Max.	Min.	F ratio	F prob.	Significant
Day 1							
Control	36.1	18.3	75.0	3.0	1.226	0.310	
Bulrush	46.1	19.2	81.0	12.0			(0.168)
Cattail	44.6	19.9	82.0	12.0			(0.247)
Reed	48.7	16.4	76.0	12.0			(0.066)
Day 7							
Control	48.9	22.2	85.0	1.0	4.000	0.012	
Bulrush	72.1	13.2	96.0	49.0			*
Cattail	58.4	20.6	93.0	15.0			(0.167)
Reed	58.1	20.0	91.0	7.0			(0.171)
Day 14							
Control	44.6	20.8	66.0	7.0	8.48	0.0001	
Bulrush	75.8	12.8	92.0	52.0			*
Cattail	62.4	14.5	85.0	32.0			*
Reed	65.6	17.3	87.0	16.0			*
Day 21							
Control	52.1	12.5	78.0	22.0	7.48	0.0003	
Bulrush	77.4	11.6	98.0	58.0			*
Cattail	68.5	14.5	85.0	46.0			*
Reed	70.4	14.4	90.0	36.0			*

All the distribution are homogenous

Table C-3
One Way ANOVA Analysis of 1, 7, 14, 21 Days Removal Rates of Zn
For Bucket Wetlands

System	Standard Mean	Standard Deviation	Max.	Min.	F ratio	F prob.	Significant
Day 1							
Control	45.4	22.9	92.0	20.0	0.8108	0.4947	
Bulrush	60.8	22.5	98.0	29.0			(0.112)
Cattail	54.2	25.7	97.0	20.0			(0.388)
Reed	54.3	25.6	98.0	20.0			(0.383)
Day 7							
Control	68.7	22.7	95.0	2.0	1.0112	0.3968	
Bulrush	77.5	19.0	98.0	4.0			(0.313)
Cattail	78.6	17.5	97.0	4.0			(0.244)
Reed	82.6	21.2	98.0	2.0			(0.135)
Day 14							
Control	76.7	17.5	97.0	43.0	1.98	0.131	
Bulrush	80.8	23.2	99.0	22.0			(0.624)
Cattail	88.1	8.5	99.0	74.0			(0.054)
Reed	90.3	7.8	99.0	78.0			(0.022)
Day 21							
Control	79.0	17.6	99.0	50.0	3.08	0.0369	
Bulrush	91.1	9.4	100.0	74.0			(0.058)
Cattail	90.5	9.3	99.0	74.0			(0.057)
Reed	91.3	8.7	99.0	74.0			(0.086)

All the distribution are homogenous

Appendix D

Table D

Average COD Removal Rates VS Time
Unit:%

Time (day)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	21.0	22.0	28.2	30.5
7	33.0	43.8	55.4	51.7
14	38.3	27.9	39.4	42.7
21	37.5	26.1	37.7	41.7
Average	32.5 (-10,74)	30.0 (-50,74)	40.2 (-26,83)	41.7 (5,78)

Average TP Removal Rates VS Time
Unit:%

Time (day)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	36.1	48.9	46.6	47.5
7	42.4	64.2	54.3	56.4
14	44.3	69.6	59.9	63.3
21	48.0	68.4	65.0	67.0
Average	42.7 (4,72)	62.3 (13,92)	56.5 (22,86)	58.6 (22,91)

Unit :ppm

Average OP Removal Rates VS Time
Unit:%

Time (day)	Control(Range)	Bulrush(Range)	Cattail(Range)	Reed(Range)
1	35.1	46.1	46.6	48.7
7	46.9	72.1	58.4	58.1
14	44.6	75.8	62.4	65.6
21	57.1	77.4	68.5	70.4
Average	46.2 (1,85)	67.9 (12,98)	59.0 (12,93)	60.7 (5,78)

Unit :ppm

Appendix E

Table E-1

TP Concentration VS time for various vegetation

UNIT: TIME (DAY), CONCENTRATION (PPM)

JUNE 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	2.80	1.99	1.08	1.64	0.86
	5.00	2.80	2.13	1.51	1.54	1.04
	7.00	2.80	1.82	0.85	1.09	1.34
	20.00	2.80	1.36	1.07	0.93	1.00

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	2.80	1.75	0.91	0.86	0.95
	5.00	2.80	2.68	0.80	2.28	0.61
	7.00	2.80	2.27	1.02	2.20	0.77
	20.00	2.80	1.68	1.19	0.70	1.05

JULY 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	2.88	2.00	1.90	1.90	1.90
	8.00	2.88	2.07	1.59	1.59	2.07
	12.00	2.88	2.19	1.01	1.22	1.91
	15.00	2.88	2.07	1.21	1.36	1.97
	32.00	2.88	1.78	0.91	1.11	1.58

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	2.88	2.45	1.59	1.67	1.63
	8.00	2.88	2.09	1.55	1.04	1.61
	12.00	2.88	2.51	1.42	1.01	1.05
	15.00	2.88	2.78	1.57	0.90	1.17
	32.00	2.88	1.52	0.99	0.54	0.83

(to be continued)

Table E-1 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

AUGUST 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	5.34	3.83	2.02	3.54	2.69
	5.00	5.34	2.84	1.16	2.13	1.71
	7.00	5.34	2.31	1.14	1.51	1.38
	12.00	5.34	2.29	1.42	1.69	1.28
	17.00	5.34	2.24	1.55	1.44	1.27

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	5.34	2.45	2.40	1.50	2.40
	5.00	5.34	2.48	1.15	1.27	1.50
	7.00	5.34	2.01	0.65	0.72	0.97
	12.00	5.34	2.11	0.78	1.06	1.23
	17.00	5.34	2.30	1.35	1.34	0.77

SEPTEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	6.99	4.45	3.18	3.79	4.00
	5.00	6.99	2.89	2.12	3.13	2.79
	7.00	6.99	2.79	1.85	2.55	2.49
	15.00	6.99	2.71	1.68	2.75	1.98
	19.00	6.99	2.50	2.16	3.46	1.76

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	6.99	3.98	3.83	3.80	3.81
	5.00	6.99	4.66	3.70	3.82	2.11
	7.00	6.99	4.19	3.16	4.20	2.13
	15.00	6.99	3.22	2.13	3.83	1.66
	19.00	6.99	3.09	2.41	2.96	1.83

(to be continued)

Table E-1 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

OCTOBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	14.92	13.22	12.94	9.94	11.69
	4.00	14.92	13.95	6.65	12.59	11.38
	6.00	14.92	12.44	4.39	11.17	11.98
	11.00	14.92	12.12	2.97	6.25	10.06
	18.00	14.92	12.17	3.30	4.15	8.10

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	14.92	10.69	10.60	10.30	9.11
	4.00	14.92	8.54	4.70	5.12	5.84
	6.00	14.92	6.69	3.16	3.24	3.07
	11.00	14.92	5.84	1.93	2.88	2.12
	18.00	14.92	5.20	2.42	2.26	1.32

NOVEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	13.64	5.88	5.80	5.80	5.78
	6.00	13.64	5.44	4.40	4.40	5.11
	12.00	13.64	5.21	5.66	5.42	4.51
	16.00	13.64	4.89	4.37	4.60	4.77
	23.00	13.64	3.80	4.10	3.35	3.37

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	13.64	5.58	5.32	7.81	4.12
	6.00	13.64	7.47	4.32	7.77	6.49
	12.00	13.64	6.72	1.69	8.36	6.12
	16.00	13.64	6.15	1.52	6.93	6.15
	23.00	13.64	4.26	1.15	3.29	4.12

(to be continued)

Table E-1 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

DECEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	27.28	17.53	17.00	17.20	17.40
	6.00	27.28	16.45	13.07	16.00	15.98
	12.00	27.28	15.30	13.09	13.53	11.00
	16.00	27.28	16.60	12.34	13.75	10.45

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	27.28	18.72	14.47	18.00	17.98
	6.00	27.28	13.94	13.87	13.34	14.27
	12.00	27.28	14.93	8.09	12.25	12.85
	16.00	27.28	14.13	7.57	9.85	5.62

Table E-2

OP Concentration VS time for various vegetation

UNIT: TIME (DAY), CONCENTRATION (PPM)

JUNE 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	1.95	0.87	0.86	0.86	0.73
	5.00	1.95	1.15	0.53	0.50	0.47
	7.00	1.95	0.95	0.66	0.57	0.58
	20.00	1.95	0.86	0.62	0.36	0.64

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	1.95	1.15	1.10	0.34	0.66
	5.00	1.95	1.81	0.90	0.31	1.71
	7.00	1.95	1.55	0.90	0.94	0.98
	20.00	1.95	1.24	0.50	0.31	0.20

JULY 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	1.18	0.93	0.69	0.88	0.49
	8.00	1.18	0.91	0.33	0.51	0.71
	12.00	1.18	0.86	0.35	0.40	0.74
	15.00	1.18	0.80	0.40	0.56	0.60
	32.00	1.18	0.75	0.58	0.57	0.55

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	1.18	1.14	0.96	0.96	0.60
	8.00	1.18	0.74	0.19	0.40	0.51
	12.00	1.18	0.90	0.31	0.48	0.24
	15.00	1.18	0.81	0.16	0.34	0.25
	32.00	1.18	0.69	0.22	0.40	0.54

(to be continued)

Table E-2 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

AUGUST 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	5.13	3.64	0.95	2.55	2.93
	5.00	5.13	1.56	1.01	1.79	1.90
	7.00	5.13	1.79	0.75	1.53	1.00
	12.00	5.13	1.82	0.70	1.36	0.81
	17.00	5.13	1.77	1.68	1.16	1.36

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	5.13	1.27	1.26	1.23	1.25
	5.00	5.13	1.54	0.40	0.74	0.71
	7.00	5.13	0.78	0.19	0.37	0.49
	12.00	5.13	0.75	0.24	0.40	0.33
	17.00	5.13	0.70	0.19	0.38	0.36

SEPTEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	6.90	3.98	3.97	3.96	3.96
	7.00	6.90	4.64	3.50	3.85	2.99
	15.00	6.90	4.19	3.35	3.79	2.86
	19.00	6.90	2.84	2.30	3.30	2.48

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	6.90	3.36	3.00	2.93	3.29
	7.00	6.90	2.70	1.91	2.18	2.68
	15.00	6.90	2.73	1.57	1.47	2.35
	19.00	6.90	2.64	1.27	1.65	1.11

(to be continued)

Table E-2 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

OCTOBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	13.64	12.05	11.98	12.00	11.98
	4.00	13.64	11.28	5.96	12.71	11.80
	6.00	13.64	11.52	3.49	9.82	10.73
	11.00	13.64	11.61	2.16	9.29	11.47
	18.00	13.64	9.58	1.61	3.73	8.72

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	13.64	10.02	9.98	9.94	9.99
	4.00	13.64	6.34	4.56	9.21	4.11
	6.00	13.64	6.48	3.81	8.85	6.01
	11.00	13.64	6.42	1.06	6.09	5.08
	18.00	13.64	4.42	1.58	2.62	4.49

NOVEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	10.79	6.14	5.80	5.55	5.79
	6.00	10.79	5.33	4.93	4.08	5.23
	12.00	10.79	4.16	4.68	3.76	3.98
	16.00	10.79	3.82	3.72	2.91	3.96
	23.00	10.79	3.52	3.10	3.30	3.25

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	10.79	7.72	6.50	6.55	4.09
	6.00	10.79	4.17	1.73	4.07	4.10
	12.00	10.79	3.32	0.99	3.12	2.94
	16.00	10.79	3.99	0.64	3.39	3.91
	23.00	10.79	2.34	0.18	1.77	2.17

(to be continued)

Table E-2 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

DECEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	21.57	12.63	8.26	11.95	11.96
	6.00	21.57	10.65	6.07	10.25	7.52
	12.00	21.57	9.73	6.00	9.75	5.71
	16.00	21.57	8.92	3.18	7.90	7.06

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	21.57	13.70	12.00	11.90	13.00
	6.00	21.57	9.99	5.32	8.90	3.86
	12.00	21.57	6.42	4.26	4.18	6.17
	16.00	21.57	6.75	2.88	4.52	2.16

Table E-3 (continue)

Zn Concentration VS time for various vegetation

UNIT: TIME (DAY), CONCENTRATION (PPM)

JULY 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.000	0.070	0.058	0.028	0.058	0.048
	7.000	0.070	0.042	0.028	0.042	0.009
	15.000	0.070	0.020	0.007	0.010	0.007
	32.000	0.070	0.020	0.007	0.000	0.007

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.000	0.070	0.056	0.036	0.048	0.042
	7.000	0.070	0.056	0.042	0.028	0.056
	15.000	0.070	0.040	0.030	0.010	0.010
	32.000	0.070	0.030	0.000	0.020	0.000

AUGUST 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.000	5.100	0.388	0.306	0.153	0.122
	7.000	5.100	0.246	0.154	0.154	0.123
	12.000	5.100	0.160	0.040	0.060	0.110
	17.000	5.100	0.072	0.031	0.051	0.103

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.000	5.100	1.204	0.122	0.428	0.163
	7.000	5.100	0.584	0.113	0.358	0.092
	12.000	5.100	0.440	0.050	0.290	0.060
	17.000	5.100	0.360	0.010	0.031	0.051

Table E-3 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

SEPTEMBER 1994

INLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	0.100	0.070	0.070	0.070	0.070
5.000	0.100	0.033	0.043	0.026	0.017
7.000	0.100	0.033	0.035	0.026	0.017
20.000	0.100	0.044	0.026	0.026	0.026

OUTLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	0.100	0.080	0.060	0.080	0.080
5.000	0.100	0.067	0.067	0.020	0.020
7.000	0.100	0.044	0.044	0.020	0.020
20.000	0.100	0.044	0.022	0.020	0.020

OCTOBER 1994

INLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	4.800	3.730	3.416	3.673	3.707
4.000	4.800	2.912	0.844	1.419	0.400
6.000	4.800	2.192	0.855	1.106	0.435
11.000	4.800	1.566	0.152	0.404	0.137
18.000	4.800	1.020	0.040	0.252	0.072

OUTLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	4.800	2.832	1.600	2.768	2.270
4.000	4.800	1.182	0.738	1.751	0.949
6.000	4.800	0.636	0.449	1.019	0.570
11.000	4.800	0.543	0.303	1.036	0.518
18.000	4.800	0.370	0.140	0.160	0.290

Table E-3 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

NOVEMBER 1994

INLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	2.800	1.200	0.440	1.010	0.970
6.000	2.800	0.532	0.098	0.283	0.123
12.000	2.800	0.110	0.079	0.079	0.079
16.000	2.800	0.212	0.047	0.070	0.058
23.000	2.800	0.156	0.041	0.071	0.061

OUTLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	2.800	1.300	1.250	0.600	0.850
6.000	2.800	0.408	0.197	0.111	0.148
12.000	2.800	0.302	0.092	0.105	0.119
16.000	2.800	0.246	0.078	0.065	0.052
23.000	2.800	0.156	0.051	0.051	0.041

DECEMBER 1994

INLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	5.900	3.813	2.440	3.440	2.860
6.000	5.900	1.996	1.699	2.269	1.595
12.000	5.900	2.080	1.222	1.569	1.624
16.000	5.900	1.172	0.332	0.750	0.787

OUTLET TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
1.000	5.900	3.650	2.780	3.500	3.380
6.000	5.900	0.918	1.143	0.303	1.042
12.000	5.900	0.681	0.559	0.385	0.559
16.000	5.900	0.318	0.227	0.151	0.242

Table E-4

COD Concentration VS time for various vegetation

UNIT: TIME (DAY), CONCENTRATION (PPM)

JUNE 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	23.00	21.95	21.45	21.49	21.50
	5.00	23.00	18.82	17.72	19.70	18.57
	7.00	23.00	18.00	10.26	12.54	15.26
	20.00	23.00	17.00	19.59	19.70	15.64

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	23.00	13.59	13.59	8.36	8.36
	5.00	23.00	10.45	14.40	24.05	28.23
	7.00	23.00	10.25	6.85	7.36	6.86
	20.00	23.00	10.00	9.60	7.65	10.58

JULY 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	50.00	38.37	38.00	37.97	37.95
	8.00	50.00	27.50	29.31	8.63	14.34
	12.00	50.00	25.35	27.94	21.97	21.79
	15.00	50.00	23.00	27.11	20.84	20.32
	32.00	50.00	22.50	23.66	20.21	16.51

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	50.00	37.21	37.21	22.09	15.12
	8.00	50.00	38.75	33.75	13.75	12.50
	12.00	50.00	25.00	23.67	10.93	15.70
	15.00	50.00	25.00	13.00	10.00	13.00
	32.00	50.00	24.25	14.35	10.25	15.25

(to be continued)

Table E-4 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

AUGUST 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	38.00	20.73	20.45	20.42	20.44
	5.00	38.00	31.49	13.82	17.97	15.50
	7.00	38.00	22.59	12.72	11.44	12.68
	12.00	38.00	12.00	9.95	13.07	8.46
	17.00	38.00	17.46	11.06	14.70	11.98

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	38.00	16.12	15.95	15.98	15.96
	5.00	38.00	16.29	14.36	13.16	19.58
	7.00	38.00	20.54	19.94	11.28	14.51
	12.00	38.00	21.00	28.71	16.92	16.68
	17.00	38.00	23.62	18.34	16.22	16.28

SEPTEMBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	23.00	24.15	24.15	24.00	21.85
	5.00	23.00	18.82	19.86	22.00	19.86
	7.00	23.00	18.62	23.00	24.00	19.71
	15.00	23.00	12.11	24.21	29.00	15.74
	19.00	23.00	15.00	29.00	29.00	16.00

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	23.00	20.70	20.45	20.50	20.26
	5.00	23.00	24.05	23.68	17.94	18.42
	7.00	23.00	25.19	18.30	17.94	16.58
	15.00	23.00	15.74	30.14	15.38	16.58
	19.00	23.00	16.00	34.45	15.38	15.66

(to be continued)

Table E-4 (continue)

UNIT: TIME (DAY), CONCENTRATION (PPM)

OCTOBER 1994

INLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	113.00	110.00	108.00	100.00	103.00
	6.00	113.00	76.21	53.87	65.70	101.17
	11.00	113.00	49.34	41.38	42.97	49.34
	18.00	113.00	46.96	67.51	67.51	58.70

OUTLET	TIME	INITIAL	CONTROL	BULRUSH	CATTAIL	REED
	1.00	113.00	108.00	105.00	104.00	102.00
	6.00	113.00	93.29	89.35	84.94	82.78
	11.00	113.00	31.83	39.79	20.97	36.61
	18.00	113.00	29.35	44.03	36.70	58.70