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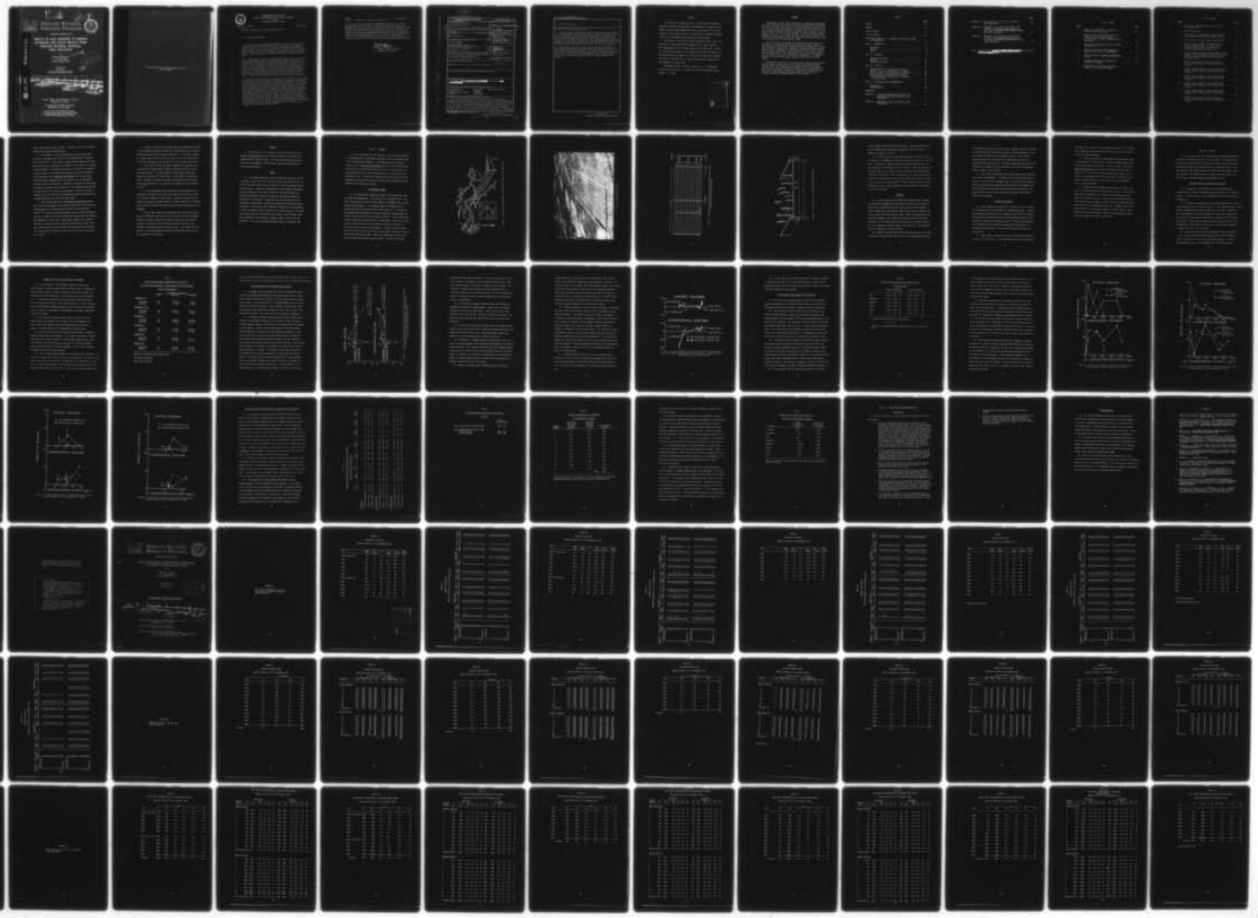

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-37

ABILITY OF SALT MARSHES TO REMOVE NUTRIENTS AND HEAVY METALS FROM DREDGED MATERIAL DISPOSAL AREA EFFLUENTS

by

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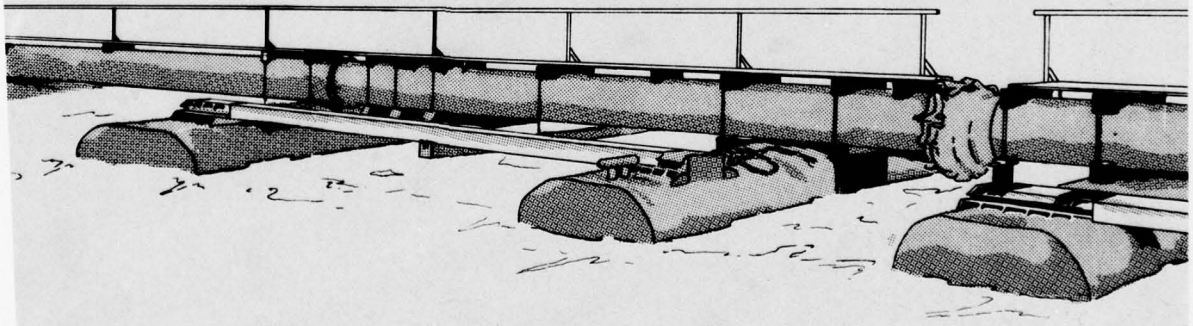
December 1977
Final Report



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IN REPLY REFER TO: WESYV

31 July 1978

SUBJECT: Transmittal of Technical Report D-77-37

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one research effort initiated in Task 6B, Treatment of Contaminated Dredged Material, of the Corps of Engineers' Dredged Material Research Program (DMRP). This task, included as part of the Disposal Operations Project of the DMRP, was concerned with evaluating physical, chemical, and/or biological methods for removing contaminants from dredged material.

2. In recent years, there has been continued concern about the potential adverse environmental impact of dredging and disposal operations on water quality and aquatic organisms. Rapid industrial and population growth in areas adjacent to navigable waterways has continued to contribute to the contamination of the water bodies and the sediments that eventually must be dredged. It became apparent during the planning phases of the DMRP that there could arise situations where it might be necessary to treat contaminated dredged material or the effluent discharged from containment areas before it could be returned to open water. Therefore, Task 6B was developed to meet this anticipated need.

3. Within the last several years, overland flow concepts have been used in wastewater treatment systems to decrease the biological oxygen demand, nutrient, and heavy metal levels in industrial and domestic wastewater. Because natural salt marshes also have an inherent ability to accumulate nutrients and heavy metals without apparent deleterious effects, this study, entitled "Ability of Salt Marshes to Remove Nutrients and Heavy Metals from Dredged Material Disposal Area Effluents," was undertaken to determine the potential use of salt marshes for treating the effluent from dredged material containment areas. The results of this study indicate that nutrients and heavy metals are removed from effluent water during flow through salt marshes. Because the majority of the metals and nutrients are associated with the fine-grained material suspended in the effluent water, this removal is probably caused primarily by settling of the solids as well as hydrated manganese and iron oxides as the effluent passes through the salt marsh.

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4. The utility of this study in predicting the potential treatment effectiveness of salt marshes is limited by the small scale of the experimental system, the lack of uptake data during the maximum growing season, and various problems encountered in the field. Therefore, the results from this study, although probably correct from a conceptual standpoint, must be interpreted very qualitatively. In addition, while vegetative filtering by marshes may be a viable treatment technique, it cannot be universally endorsed at this time due to the ecological importance of and political sensitivity surrounding wetland environments.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Dredged material disposal	Pollutants	
Effluents	Salt marshes	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experimental raceways were constructed in a salt marsh adjacent to a dredged material confinement area to evaluate the use of this environment as an overland flow advanced treatment system for the effluent resulting from dredged material disposal. The research program was designed to determine the ability of the salt marsh systems to remove nitrogen, phosphorus, iron, manganese, cadmium, copper, nickel and zinc from the effluent. Application rates varied between 0.06 and 3.7 acre inches per day and the concentrations of (Continued)

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20. ABSTRACT (Continued).

the contaminants were determined in the effluent from the disposal area and the discharge from the experimental system.

During the study all contaminants were found to decrease in the effluent as it passed through the experimental raceways. Removal efficiencies for nitrogen and phosphorus varied up to about 50 percent and 70 percent, respectively. Mean metal removal efficiencies ranged between 15 and 32 percent. The efficiency of removal did not appear to be related to application rate but did appear to increase with concentration. The contaminants accumulated in the sediments with only minor increases in the salt marsh vegetation. Inorganic chemical and physical processes probably account for much of the removal.

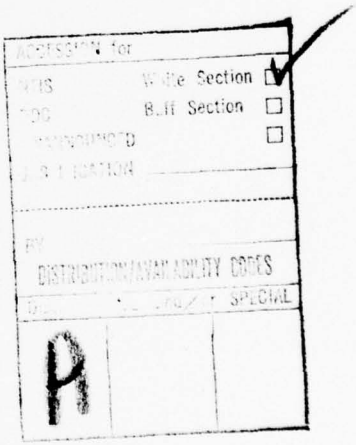
Although the results of this study clearly indicate that nutrients and heavy metal concentrations in effluents from dredged material disposal areas can be reduced during passage through a salt marsh, conclusions as to the efficiency of removal may be influenced by the size of the experimental system used. Large scale studies should be conducted to better judge the applicability of this approach to advanced treatment of dredged disposal area effluents.

PREFACE

This project was funded by the U. S. Army Corps of Engineers Waterways Experiment Station (WES), Dredged Material Research Program (DMRP), Contract Number DACW21-76-C-0134. The contract for this research was administered by the U. S. Army Corps of Engineers, Savannah District, for the DMRP Disposal Operations Project (DOP).

The design of the research program discussed in this report was developed in cooperation with and managed by Dr. Luther Holloway, Mr. Thomas Moore, and Dr. William Barnard of the DMRP staff. Technical and logistical support on the project was provided by members of the Savannah District (Messrs. W. Clarkson, W. Young, and H. Roberts). The research described in this report was initiated in August 1976 and completed in January 1977.

DOP Manager was Mr. Charles C. Calhoun, Jr. The Commander/Director of WES was COL J. L. Cannon, CE, and the Technical Director was Mr. F. R. Brown.



SUMMARY

Experimental raceways were constructed in a Spartina alterniflora salt marsh adjacent to a dredged material confinement area to evaluate the use of this environment as an overland flow advanced treatment system for the effluent resulting from a dredged material disposal site. The research program was designed to determine the ability of the salt marsh systems to remove nitrogen, phosphorus, iron, manganese, cadmium, copper, nickel and zinc from the effluent. Application rates varied between 0.06 and 3.7 acre inches per day and the concentrations of the contaminants were determined in the effluent from the disposal area and the discharge from the experimental system.

During the study all contaminants were found to decrease in the effluent as it passed through the experimental raceways. Removal efficiencies for nitrogen and phosphorus varied up to about 50 percent and 70 percent, respectively. Mean metal removal efficiencies ranged between 15 and 32 percent. The efficiency of removal did not appear to be related to application rate but did appear to increase with nutrient concentrations. The contaminants accumulated in the sediments with only minor increases in the salt marsh vegetation. Inorganic chemical and physical processes probably account for much of the removal.

Although the results of this study clearly indicate that nutrients and heavy metal concentrations in effluents from dredged material disposal areas can be reduced during passage through a salt marsh, conclusions as to the efficiency of removal may be influenced by the size of the experimental system used. Large scale studies should be conducted to better judge the applicability of this approach to advanced treatment of dredged disposal area effluents.

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NOTE: Appendices A-E [redacted] are enclosed [redacted] inside the back cover.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
gallons	3.78	liters

ABILITY OF SALT MARSHES TO REMOVE NUTRIENTS AND HEAVY METALS FROM DREDGED MATERIAL DISPOSAL AREA EFFLUENTS

PART I: INTRODUCTION

Background

1. The ability of wetlands to accumulate and store nutrients and metals is well established.[1,2,3,4,5,6,7] The feasibility of using wetland environments for overland flow as a method of wastewater treatment has been suggested by a number of researchers[8] and has recently received attention for the treatment of the effluents from dredged material disposal areas.[9]

2. Overland flow, like other land treatment systems, is becoming familiar to environmental engineers as an effective advanced waste water treatment system.[10,11,12,13] Unlike the infiltration systems where waste water is treated by the soil, plants and microorganisms as it moves through the soil, overland flow systems depend on treatment of the waste water as it flows over a relatively impermeable soil surface. In this system the surface vegetation and associated organic mat and microorganism play an important role.[11] The application of overland flow treatment system has been successful in decreasing BOD, nutrients and heavy metals in industrial and domestic wastes.

3. Overland flow systems are established on sites where soil permeability is low. A requirement for the satisfactory application of this system for waste treatment is that the site have a slight

slope, generally less than 8 percent. Wetlands, such as salt marshes, generally have these characteristics.

4. Salt marshes in the Southeastern United States have been studied to understand their role in the biogeochemistry of nutrients and heavy metals.[4,6] The results of these studies indicate that salt marsh systems exert considerable influence on the transfer of nutrients and trace elements, including heavy metals, in estuarine environments. In these studies it was demonstrated that both the marsh sediments and the dominant plant (Spartina alterniflora) and its associated floral and faunal components play an important role in the overall cycling of metals and nutrients. Materials transferred to and through salt marsh environments may accumulate in the sediments where they may be inertly bound or be taken up by vegetation. Nutrients and trace elements taken up by the plants subsequently become incorporated into the detritus based food chain upon plant death.

5. Some studies have shown that Spartina alterniflora accumulates nutrients and metals from sediments through its root system and transfers them to the water column by direct release from the leaves.[14,15] Some very volatile elements such as arsenic and mercury may also be taken up by the root system and released from the leaves to the atmosphere in vapor form. Rooted marsh plants do not normally accumulate nutrients or metals directly from the water column. However, these materials can be removed from the water due to sorption onto sediments and subsequently taken up by the plants through their root system.

6. Natural salt marshes have been shown to accumulate essentially all the nutrients supplied to them[4] and are apparently able to take up increased amounts through "luxury consumption." For example, studies of nitrogen applications on some salt marsh plants have shown favorable growth responses of the vegetation to the increased nutrients.[16]

7. The ability of the salt marsh vegetation to accumulate high concentrations of heavy metals without deleterious effects has also been demonstrated.[17] During laboratory studies where plants were exposed to high levels of heavy metals, little effect on growth was noted. Natural salt marshes that have been exposed to high inputs of heavy metal pollutants (e.g., mercury) also appear not to be greatly altered.[18]

8. In the Southeastern United States the major portion of the maintenance dredging by the Corps of Engineers and the private sector is in channels adjacent to salt marshes. Hydraulic dredges are more commonly used and the dredged material is often disposed of in impoundments designed to improve the quality of the effluent returning to the waterways.

9. Due to their capacity to accumulate both nutrients and heavy metals to relatively high levels, their filtering ability to decrease turbidity and their proximity to dredging activities, salt marshes represent a potential overland advanced treatment system for the effluents from dredged material disposal areas. This report discusses results of studies designed to evaluate the feasibility of the use of salt marshes for this purpose.

Purpose

10. The purpose of this study was to evaluate the ability of a Spartina alterniflora marsh for advanced treatment of effluent from dredged material disposal areas. The study was designed to provide preliminary information on which future, more detailed feasibility studies could be based.

Scope

11. The primary objective of this project was to make an initial assessment of the ability of a salt marsh system to remove certain nutrients and heavy metals from the effluent of confined dredged material disposal areas. A detailed investigation of the processes responsible was not included in this study. Within the time requirements and facilities available, however, the study was designed to develop an indication of how changes in conditions such as effluent flow rate, contaminant concentration, daylight and temperature affect the removal efficiency, since these are of fundamental importance in the management of such a treatment system. Because of the limited nature of the study, only certain types of contaminants were studied. They included nitrogen, phosphorus, iron, manganese, cadmium, copper, nickel, zinc and turbidity. The study was conducted between August and December 1976.

PART II: APPROACH

12. The site chosen for this study was a natural marsh adjacent to a dredged material confinement area which lies on the northern side of the Savannah River (Figure 1). The vegetation in this marsh is composed of short Spartina alterniflora and has a peak standing above-ground biomass of approximately 700 g/m^2 dry wt. Access to the site was accomplished along a road maintained on top of the dikes of the confinement area. The marsh was flooded twice daily by tides and was adjacent to a natural creek which ultimately drains eastward into the Savannah River distributary system.

Experimental System

13. The experimental system was located a few hundred feet from the diked confinement area. It consisted of 12 raceways built in the marsh and designed to allow effluent from the confinement area to drain through them (Figure 2). The raceways were built adjacent to one another and were 10 ft wide and 300 ft long (Figure 3). The sides of the raceways were constructed of plywood extending 18 inches above the surface of the marsh and 6 inches below (Figure 4). These retained the effluent waters and prevented entry of tidal waters. Weirs were located at the mid point and end of each raceway to maintain a depth of no more than 4 inches during the experiments. Effluent from the dredged material disposal area was delivered to the raceways through a 6 inch PVC pipe which penetrated the dike. Three inch pipes came off the 6 inch pipe to deliver the effluent to each raceway. The flow of effluent

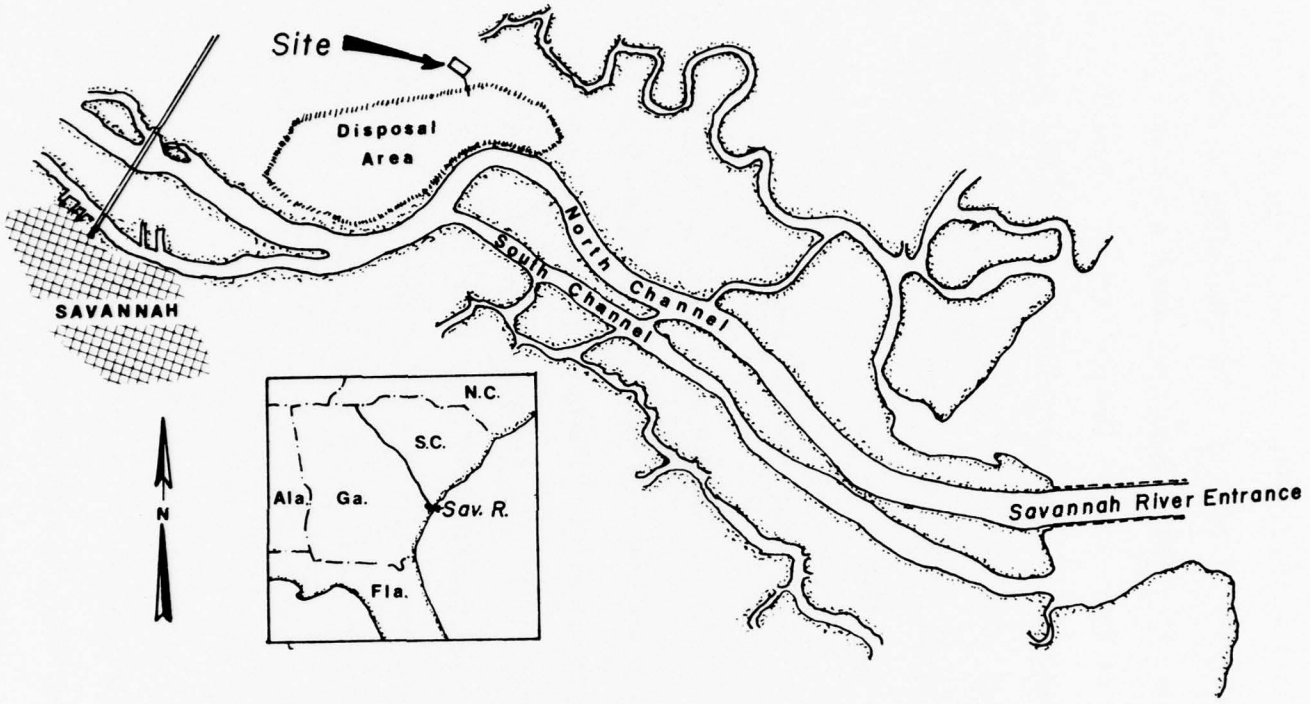

Figure 1. Location of experimental site on north side of Savannah River

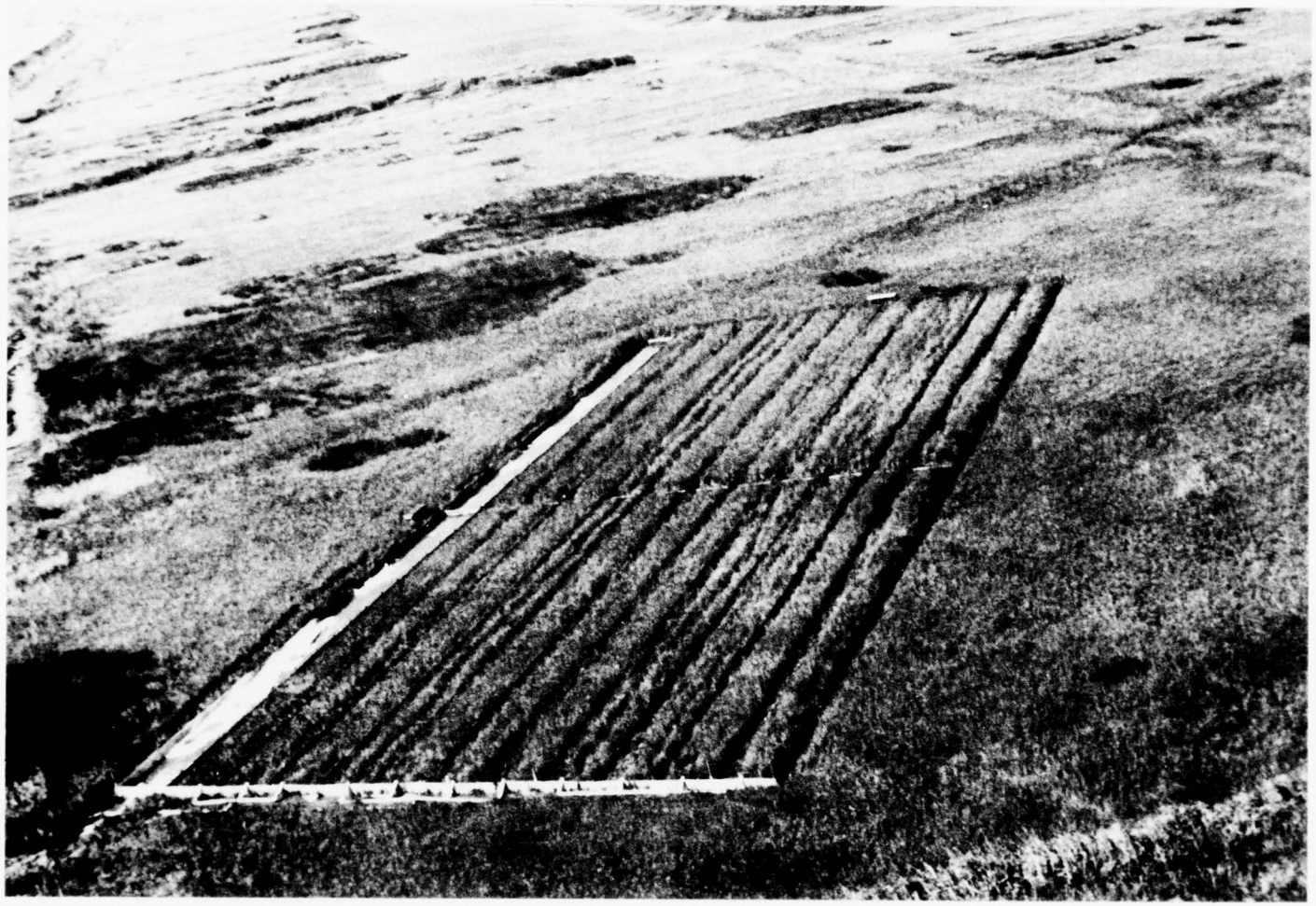

Fig. 2. Experimental system

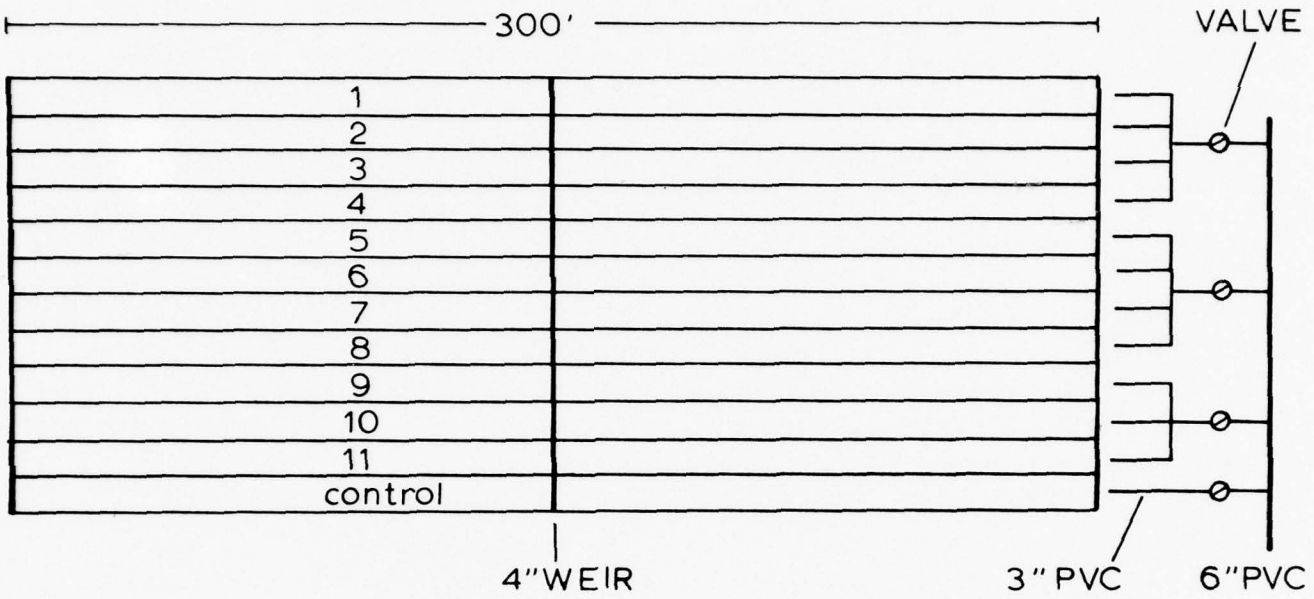

Figure 3. Configuration of experimental system showing input system to the marsh and control raceways

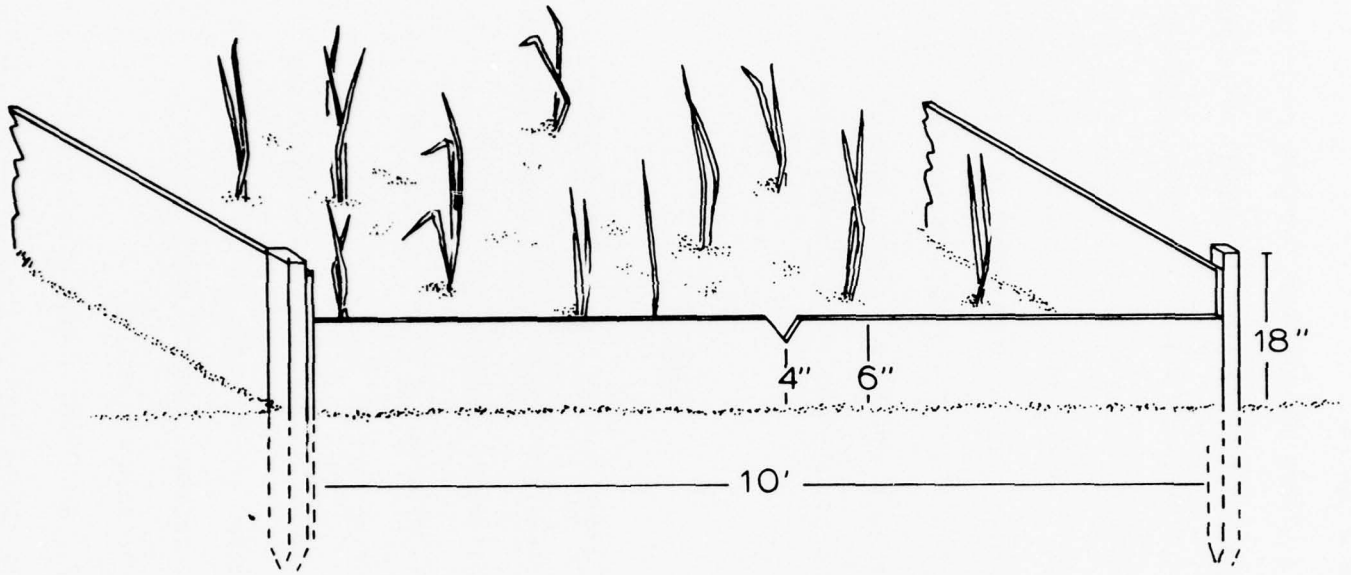

Figure 4. Cross-section of a marsh raceway showing weir

to the raceways was controlled by PVC valves. The bottom of one raceway was covered with plywood and subsequently lined with plastic sheeting to serve as a control.

14. Using this system the effluent from the confinement area was delivered to the raceways to evaluate the removal efficiency of the salt marsh. The control raceway was used to evaluate processes where the marsh vegetation and sediment were not involved. With the delivery system used, flows to any raceway could be controlled from approximately 1 gal/min to 60 gal/min. This is equivalent to a range of overland applications of from about 0.06 to 3.7 acre inches per day and is similar to the rates used by other workers.[10] This range of applications also represents a range in the residence time of the water in the raceways of from 20 to 120 hrs.

Sampling

15. Prior to conducting the experiments (August 1976), sediment and vegetation (Spartina roots and leaves) samples were collected at three evenly spaced stations within each of the 11 marsh raceways. Similar samples were collected at eight outside control stations (two on each side of the experimental system). After the experiments were completed (December 1976), samples were again collected from these locations. All of these samples were analyzed for nitrogen, phosphorus, iron, manganese, cadmium, copper, nickel and zinc. The sediments were also analyzed for volatile solids.

16. Samples of the effluent input to the raceways were collected at two-hour intervals during each of the six 24-hour sampling periods

(experiments) conducted during this study. Samples were also collected at the mid point and end of each raceway in the morning (0630), and in the afternoon (1430) during each sampling period. Each of these samples was analyzed in the field for temperature, salinity, pH, dissolved oxygen and turbidity. They were subsequently analyzed in the laboratory for ammonia, nitrate, phosphate, and total iron manganese, cadmium, copper, nickel and zinc.

17. Two of the six sampling periods (experiments) were conducted on 5-6 and 11-12 September. The other four were carried out continuously on 13, 14, 15 and 16 November 1976. The timing of each sampling period was controlled by dredging activities along the Savannah River and by weather conditions which during one occasion resulted in the destruction of the dike system therefore diminishing the effluent supply to the raceways.

Analytical Procedure

18. Water samples were analyzed for nutrients on site or frozen to be transported to the laboratory for subsequent analysis. Ammonia was determined colorimetrically as indophenol blue which is formed by the reaction of hyperchlorite with alkaline ammonium solution in the presence of phenol and nitroprusside ions.[19] Nitrate was determined by a cadmium reduction method[20] and phosphate was determined by a molybdenum blue technique.[21] Blanks were determined on quartz distilled water.

19. Water samples collected for metal analyses were acidified to a pH of 1 in the field. In the laboratory the pH was adjusted and

the metals were extracted by an APDC-MIBK technique.[22] The solvent phase (MIBK) was then analyzed for the particular metal by atomic absorption spectrophotometry.

20. Field measurements on water samples were conducted using a refractometer for salinity, pH and dissolved oxygen meters and a candle turbidimeter for turbidity. Prior to analysis, samples of Spartina alterniflora were washed with double distilled water to remove salts. The grass was then cut into pieces (about 2 cm in length) and thoroughly mixed in a plastic bag. A portion of this material (about 10 grams) was then dried and later homogenized using a mortar and pestle.

21. Sediment and grass samples were analyzed for total nitrogen by the Kjeldahl method using about 1 gram of each. Phosphorus was determined as phosphate on acid digests of approximately 1 gram samples of sediment and grass. Total metal concentrations were determined on the grass samples by atomic absorption spectrophotometry after digestion in concentrated nitric acid. Sediment samples were leached with nitric acid and analyzed in a similar manner. Total volatile solids in the sediment samples were determined by weight loss after combustion at 600^{o} C for 3 hours.

PART III: RESULTS

22. All the data from field observations and laboratory analyses are given in appendices at the end of this report. The appendices are broken into sections dealing with specific classes of data and within each appendix tables are grouped according to sampling period. Input data and data from raceway samples are given in separate tables within each appendix. All chemical data on sediment and grass samples are also listed in separate appendices (Appendices D and E).

Characteristics of Disposal Area Effluent

23. The quality of the effluent from the confinement area (referred to as influent in appendices) varied during the six sampling periods. Variations within a given sampling period were also observed (Appendix A).

24. The range in concentrations of the eight contaminants investigated during the study are given in Table 1. For comparison local, assumed ambient concentrations of these elements are also given. Generally, the concentrations of the eight elements in the effluent ranged from the high side of the ambient concentration to about an order of magnitude greater. During any one sampling period, however, only iron and manganese were found to vary significantly in the effluent (Appendix C, Tables C1, C3, C5, C7, C9 and C11).

25. During the study the water temperature varied from about 18 to 31^{o} C during the two September sampling periods down to temperatures of around 5-13^{o} C during the November experiments. Salinity ranged between 8 and 14 $^{o}/_{00}$ throughout the six sampling periods.

Table 1

Ranges in Concentration of Elements in Effluent

During Experiments

	Conc. in Effluent (µg/ℓ) Min.	Max.	Mean*	Ambient Conc. (Range) (µg/ℓ)	Reference
Nitrogen	270	16400	3170	70 - 300	(4)
Phosphorus	15	115	44	9 - 60	(4)
Iron	10	3000	760	5 - 50	(5)
Manganese	250	14000	2030	5 - 60	(5)
Cadmium	0.1	0.6	0.26	0.1 - 0.4	(6)
Copper	2.2	29	8.1	0.1 - 3.9	(7)
Nickel	1.0	5.2	2.2	0.7 - 16	(7)
Zinc	8	24	12	0.5 - 10	(7)

*Mean of all effluent analyses

26. The dissolved oxygen concentration in the effluent varied diurnally with concentrations reaching super saturation during daylight and decreasing to less than 50 percent saturation in some cases during night time. Supersaturation of oxygen is a feature commonly observed for discharges from dredged material confinement areas[23] and is apparently due to the increased primary production (due to phytoplankton and/or benthic algae) stimulated by nutrient release from the dredged sediment. This leads to increased photosynthetic oxygen production.

27. pH also varied diurnally and appears to be related to the dissolved oxygen concentration. This phenomenon has been previously observed[23] and is apparently due to utilization of CO_2 by phytoplankton with simultaneous production of oxygen.

28. Turbidity varied considerably during the study. The values observed ranged from less than 40 to over 100 JTUs. This variation is apparently due to variations in the residence time of the water in the disposal area which is a function of the point in discharge for the dredge. This varied considerably during the course of the study.

29. The quality of the effluent from the disposal area was not much lower than typical estuarine waters[4-7] during the experiments as judged from the data presented in Table 1. Clearly the effluent from the disposal area is not as contaminated as industrial or municipal wastes to which overland flow treatment systems have been applied. Mean levels of contaminants were generally equal to the highest ambient levels (P, Cd, and Zn) or as much as 30 times this value (Mn), and, therefore, sufficed for the purpose of this study.

Changes in DO, pH, and Turbidity in Raceways

30. During transit of the effluent through the experimental marsh raceways, dissolved oxygen always decreased (Table 2, Appendix A). This was more evident in samples collected in the morning (0630) indicating the effect of respiration in the marsh system over phytosynthesis. In the control raceways the large decrease in dissolved oxygen was not observed during any of the sampling periods. In fact, increased oxygen concentrations commonly occurred at the mid point and discharge end as a result of a substantial phytoplankton and epiphyte populations within this raceway.

31. The change in dissolved oxygen from the input to the discharge side of the raceways did not appear to be influenced by flow rate. Within each sampling period the concentration of dissolved oxygen in a given raceway varied independently of water flow.

32. As was the case with the disposal area effluent, pH increases with increasing oxygen concentration. For example, the mean pH increases from about 7.0 or lower to about 8.0 as dissolved oxygen percent saturation increases from less than 10 to about 100. pH usually decreased from input to discharge in the marsh raceways. In the control raceways the opposite trend was always observed.

33. In the marsh raceways turbidity of the water always decreased. In the control raceway this was not the case (see Appendix A). At the mid point and discharge end of the raceways, turbidity was less than 40 JTU in every case even though the turbidity of the effluent from the disposal area once reached a level greater than 100 JTU. In the control raceway, however, the

Table 2

Mean Dissolved Oxygen Concentrations of Effluent Passing Through Raceways. Concentration in Control Raceway Given in Parentheses

	DO Percent Saturation		
	Input[1]	Mid Point	Discharge
September 5-6			
Afternoon	143	54(140)	7(167)
Morning	57	7 (50)	6 (99)
September 11-12			
Afternoon	134	106(183)	30(133)
Morning	72	4 (41)	2 (42)
November 13			
Afternoon	107	80(110)	88 (98)
Morning	80	33 (62)	40 (64)
November 14			
Afternoon	114	73 (70)	64(115)
Morning	74	40 (54)	33 (61)
November 15			
Afternoon	96	72(106)	[2]
Morning	70	56 (90)	52 (75)
November 16			
Afternoon	7[3]	40 (13)	55 (21)
Morning	60	34 (62)	22 (44)

[1]Mean DO in effluent from disposal area

[2]DO meter malfunction

[3]Very high turbidity

turbidity did not generally decrease significantly below input levels. The filtering ability of the marsh vegetation clearly aids in decreasing turbidity.

Nutrient Removal from Disposal Area Effluent

34. Throughout the experimental and control raceways the distribution of nitrogen between ammonia and nitrate species varied. Generally, nitrate was higher than ammonia in both the input and the raceway water samples. The transformation of nitrogen between these two species followed no detectable pattern. Total inorganic nitrogen (NH_4 + NO_3) concentrations were therefore calculated and this value is used in the following discussion. The nutrient data are presented in Appendix B.

35. In general, nitrogen removal from the effluent during transit through the experimental raceways is not related to input flow rate. It does, however, appear to be related to the concentration of nitrogen in the effluent. Figure 5 shows the efficiency of nitrogen removal from the effluent as a function of its nitrogen concentration. Each point on this plot is based on the mean concentration of nitrogen in the effluent and the discharge from the raceways for each sampling period (one point each for morning and evening samplings). With increasing nitrogen in the effluent, the efficiency of removal (e.g., percent removal) appears to increase. For example, during sampling period 2 the average total nitrogen concentration in the effluent was 860 µg·atoms/ℓ. The average total nitrogen concentrations in the discharge from the experimental raceways were about 500 and 420 µg·atoms/ℓ for morning and evening samples, respectfully. This represents a 42-52 percent decrease in nitrogen during transit. At lower total nitrogen

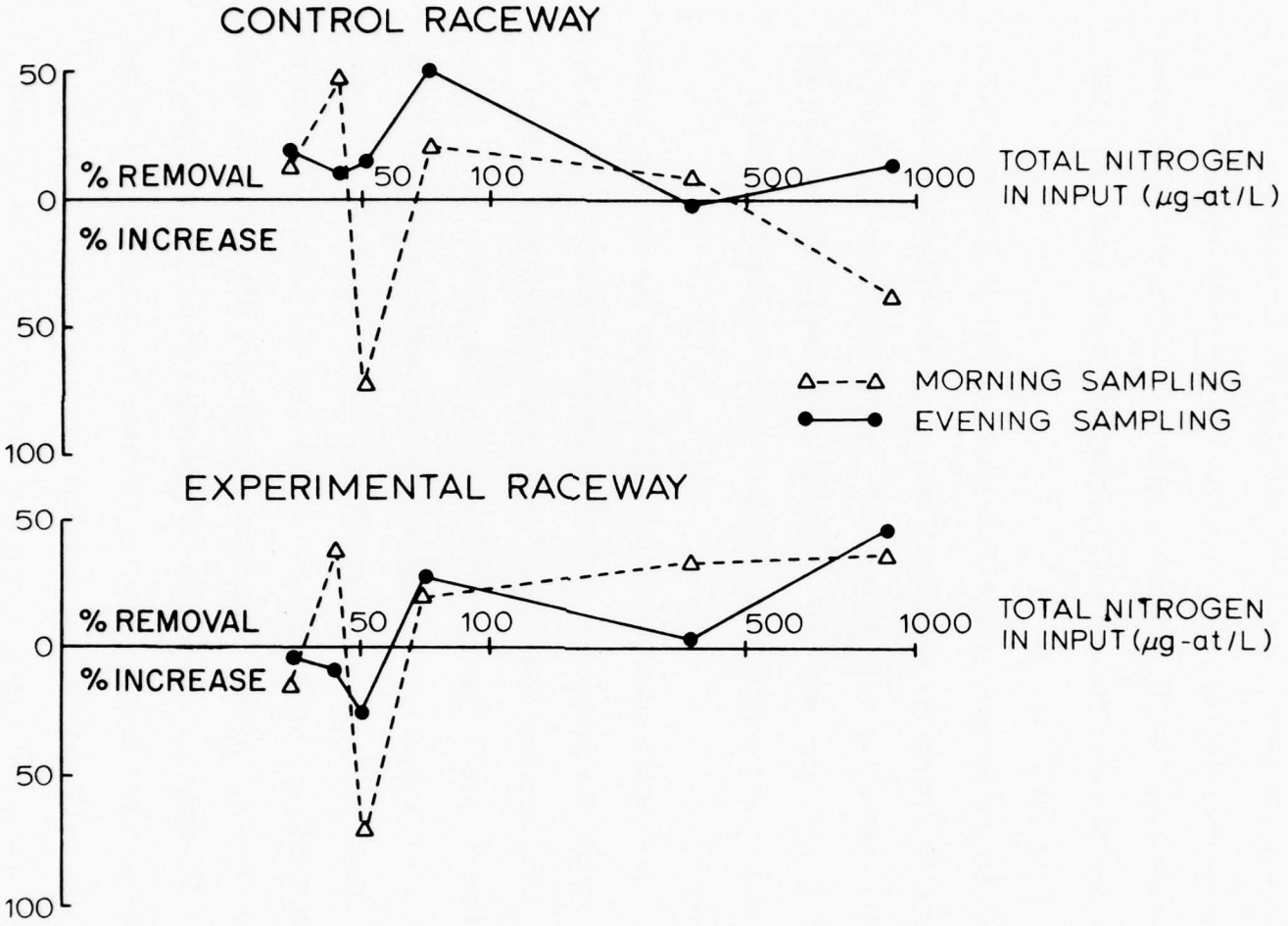

Figure 5. Percent nitrogen change in effluent during transit through raceways in relation to its nitrogen concentration. Average results from each sampling period were used

concentrations the average removal is lower and in some cases there is a net increase. For example, during sampling periods 4 and 5 almost every raceway showed an increase in nitrogen in its discharge. This increase is probably due to release from the sediments which is a continuing process due to microbial activity. At low nitrogen concentrations in the water column, nitrogen release must exceed nitrogen uptake in the sediments.

36. In the control raceway, nitrogen removal also appears to decrease with decreasing concentrations. Removal thus is probably completely controlled by algal uptake. During cold periods, total nitrogen in the input was low. Decrease in removal efficiency in the control and marsh raceways may therefore be due to decreased algal production.

37. For the first two sampling periods when the nitrogen concentration in the input was well above ambient and temperatures were high, removal efficiency was also high. Percentage removal ranged from around zero to over 50 percent with a mean of 30 percent.

38. The removal of nitrogen appears to take place in the first half of the marsh raceway so that decreased concentrations are observed at the mid point. This suggests that the most of the nitrogen removal occurs during the initial contact of the effluent with the salt marsh system. If removal is a function of concentration, then the absolute amount of nitrogen removed from the effluent would be expected to be greatest in the first half of the raceway.

39. Removal of nitrogen can be accomplished by adsorption on

sediment particles as they settle out into the marsh after initial entry of the effluent as suggested by the decrease in turbidity. As in other overland flow systems, an aerobic-anaerobic double layer exists consisting of the overlying water film and the underlying sediment. Under these conditions, both nitrification and denitrification occur leading to removal of nitrogen by volatilization as a gas.[10,13] These processes also control the availability of nitrogen to plants which ultimately provide another sink for the excess nitrogen.

40. Phosphate removal is similar to that of nitrogen. Here again the input rate of the effluent appears to have little effect on the removal efficiency. The removal efficiency, however, does appear to be related to the concentration of phosphate in the effluent (Figure 6). As in the case of nitrogen, at low phosphate concentrations during sampling periods 1 and 2, many of the marsh raceways showed an increase in phosphate in the discharge water. This suggests a chemical equilibration process similar to that described for the buffering of phosphate concentrations by salt marsh sediments.[24] The chemical processes which control this appear to involve ferric oxyhydroxides which adsorb phosphate.[25] Oxidation-reduction conditions of the sediment may alter the phosphate removal efficiency to a considerable degree at higher PO_4 concentrations.

41. Excluding sampling periods 1 and 2, the average removal efficiency of all of the marsh raceways for phosphate was 38 percent. During these experiments the effluent concentrations were between 1.6 and 1.8 $\mu g \cdot atoms/\ell$ or approximately twice those for sampling periods 1 and 2.

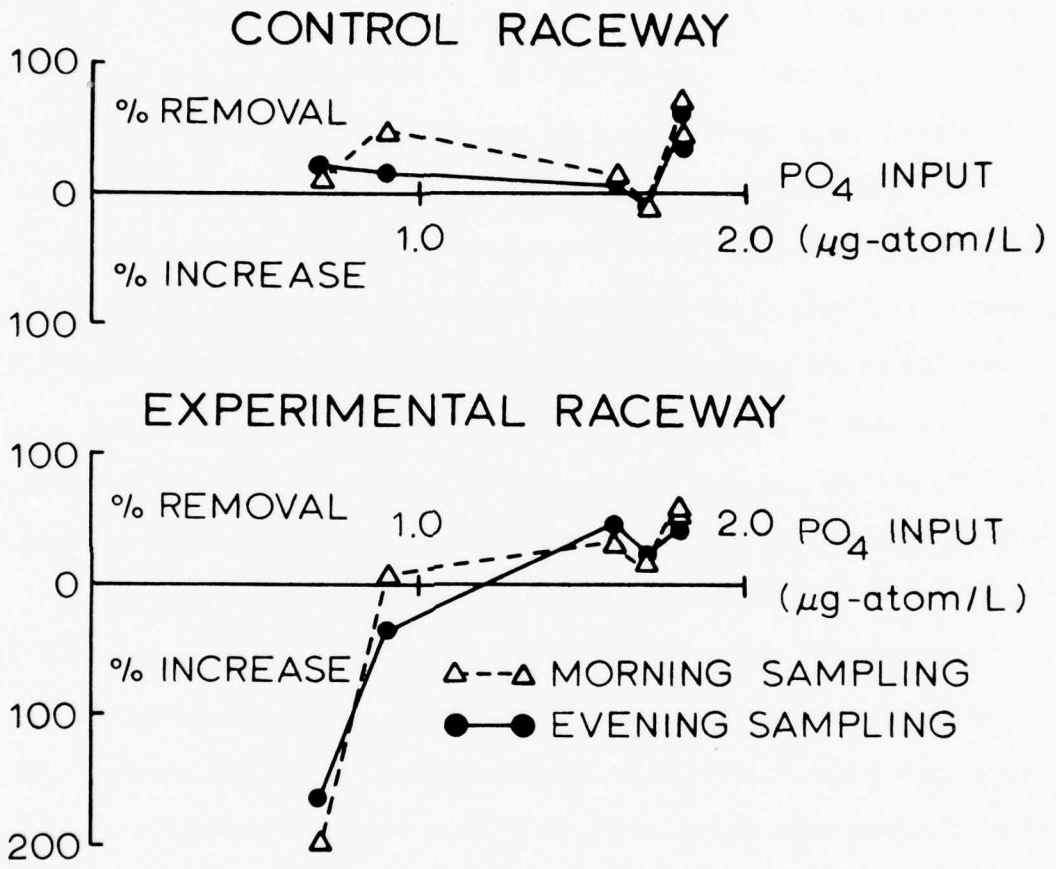

Figure 6. Percent phosphorous change during transit through raceways versus phosphorous concentration in the effluent. Average results from each sampling period were used

42. Similar again to the results observed for nitrogen, phosphate is removed in the first half of the marsh raceways. In most cases, phosphate reduction at the mid point was found to be equal to or greater than that observed at the discharge.

Metal Removal from Disposal Area Effluent

43. All data on the concentrations of metals in the effluent (input to raceways) and in samples collected from the mid point and discharge of the marsh and control raceways are given in Appendix C.

44. The efficiency of metal removal from the effluent during transit through the marsh raceways was evaluated by comparing the concentrations in the discharges with the average concentrations in the input prior to sampling. All the metals behaved similarly in the raceways showing some removal during transit. In every case the concentrations in the discharge from the raceways were lower than that in the input or not significantly different (i.e. differences are within the precision of the analyses which is conservatively estimated at $\pm$15%).

45. The percent of metal removal in the effluent passing through the raceways does not appear to be related to the input flow rate. Results of linear regression analysis of the relation between removal efficiency and effluent input rates for all samples collected yield insignificant correlation coefficients (Table 3). Using the most significant correlation (manganese percent removal versus flow rate for samples collected in the evening), a change of from 10 to 50 gpm in the flow rate only decreases the removal efficiency by about 10 percent.

46. The intercepts for the regression equations (b in Table 3)

Table 3

Relationship between Percent Metal Removal and Input Rate

	Morning Sampling			Evening Sampling		
	r	a	b	r	a	b
Iron	-0.06	-0.03	16	0.008	0.003	19
Manganese	-0.19	-0.08	19	-0.50	-0.23	32
Cadmium	0.19	0.004	15	0.08	0.06	19
Copper	-0.28	-0.12	21	-0.24	-0.12	27
Nickel	-0.21	-0.16	18	0.33	0.25	15
Zinc	0.23	0.37	15	-0.03	-0.03	20

r = correlation coefficient for the equation:

$$y = a x + b$$

where y is the percent metal removal and x is the input rate in gpm.

for each metal can be considered as the mean removal efficiency for all of the raceways and for all of the sampling periods for the experimental system used in this study. Therefore, depending on the metal, 15 to 32 percent removal efficiencies can be reasonably expected in a salt marsh, overland flow treatment system, under the conditions obtained during this study.

47. The above correlation of the removal efficiency with flow rate takes into consideration conditions of various metal concentrations in the effluent input. A comparison of the percentage removal of the metals versus the concentration of the metal in the effluent shows generally an increase with increasing concentrations (Figs. 7 through 12). The removal also takes place in the control raceway although not to the same degree (i.e. differences in efficiencies are outside the precision of analyses and therefore considered significant). In the case of the iron and manganese, the removal efficiency may reach a maximum at an input concentration of around 2 ppm, near the upper limit observed in this study.

48. Metal removal in the marsh and control raceways is probably controlled by inorganic chemical reactions and/or adsorptive scavenging by settling sediments. Because of the high pH and oxygen concentrations in the effluent, it is likely that hydrated iron and manganese oxide are formed in the raceway waters. These compounds probably exist in the effluent as fine colloidal particles which precipitate or adhere to plants upon entry into the raceways. These precipitates are capable of scavenging other metals as well, and probably account for their removal from the water column.

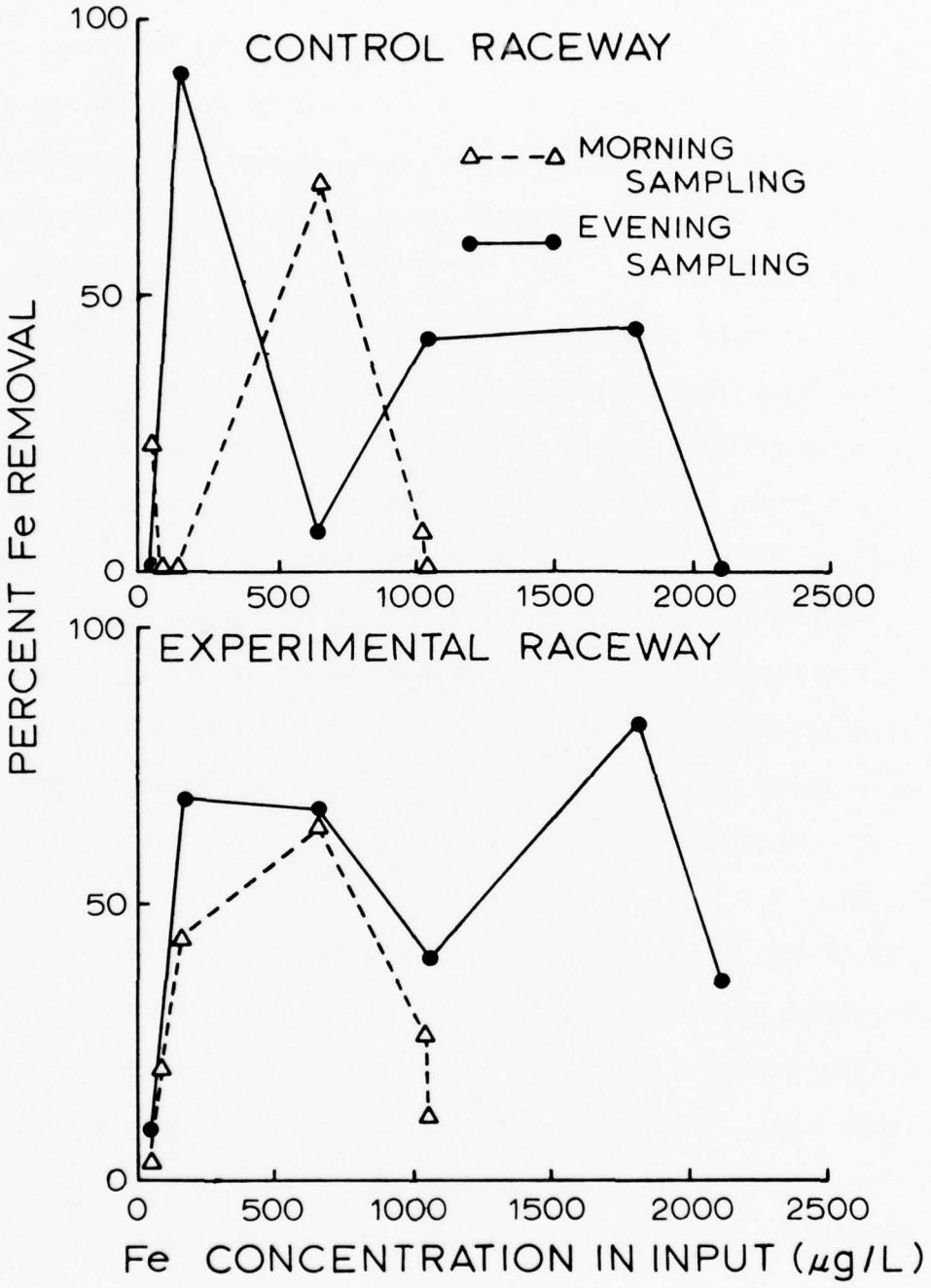

Figure 7. Percent iron removal in waste water during transit through raceways versus concentration in input

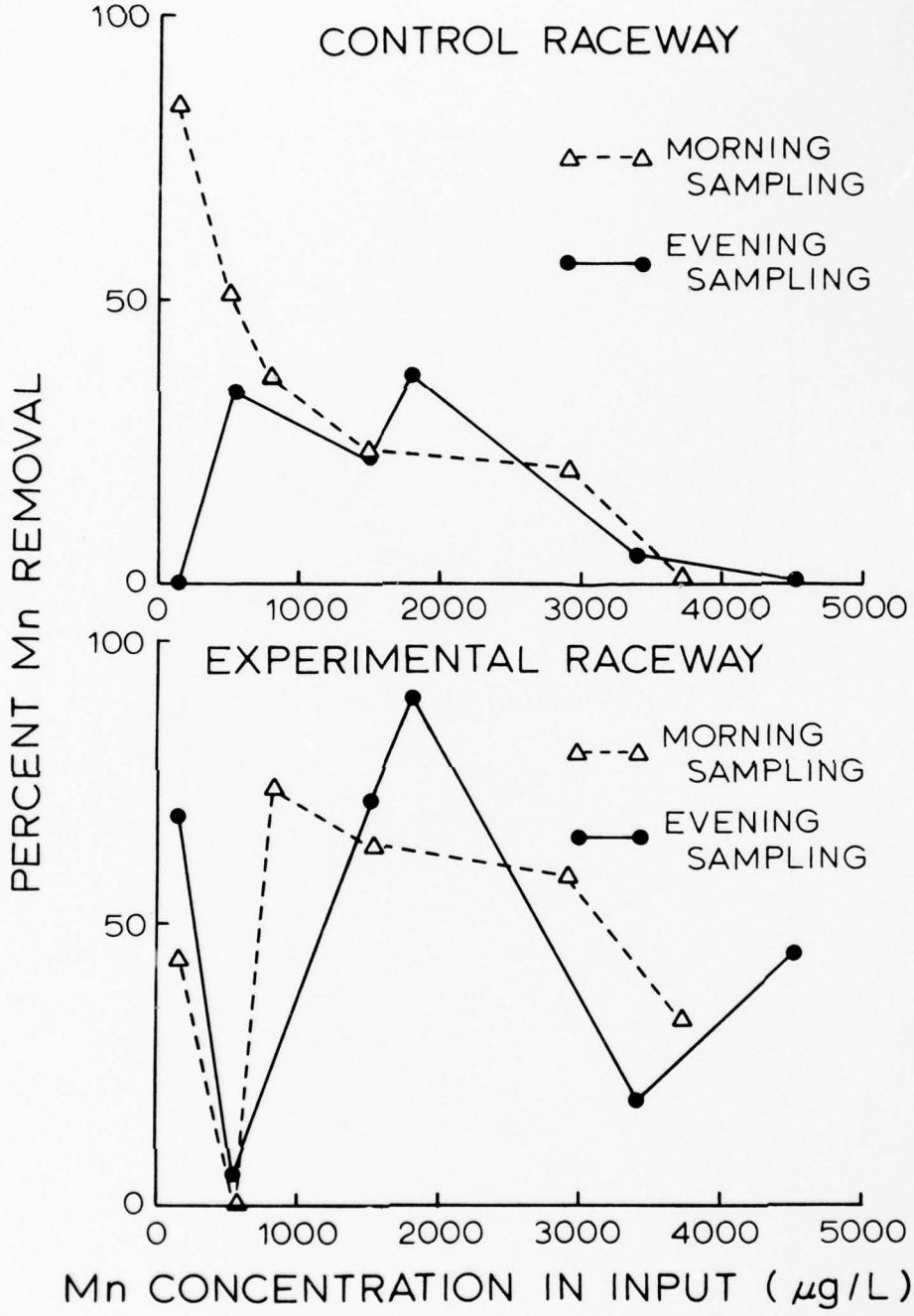

Figure 8. Percent manganese removal in waste water during transit through raceways versus concentration in input

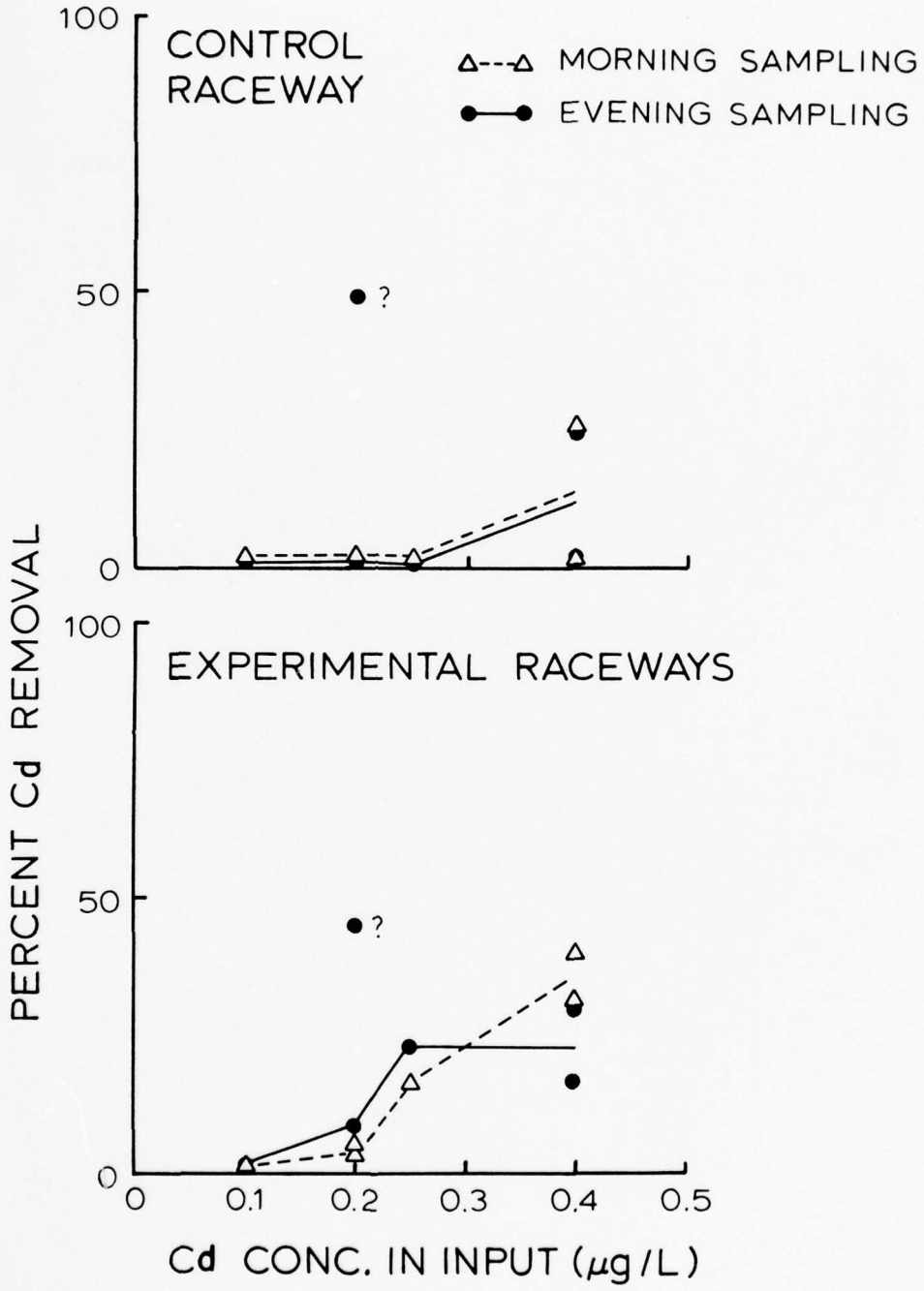

Figure 9. Percent cadmium removal in waste water during transit through raceways versus concentrations in input

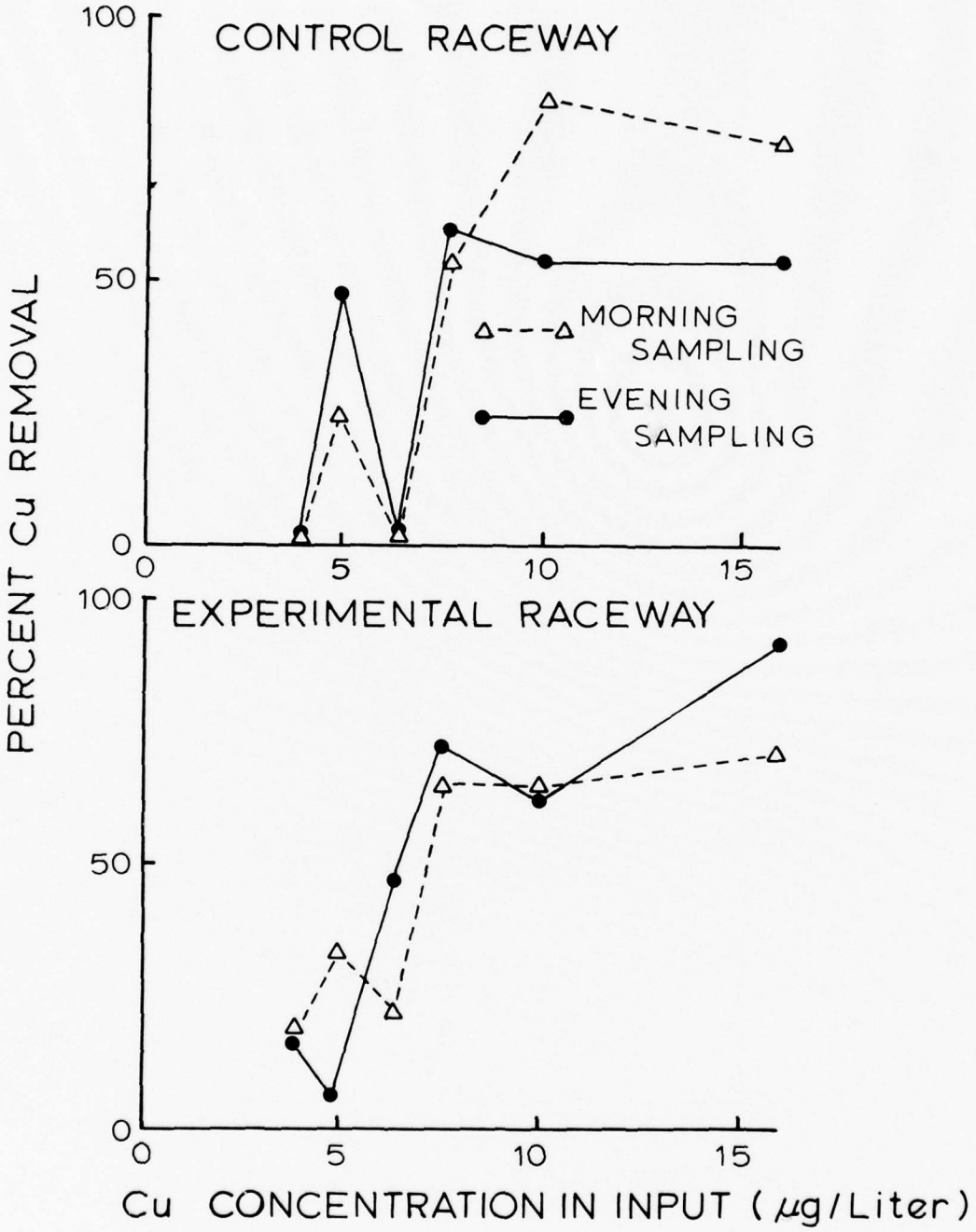

Figure 10. Percent copper removal in waste water during transit through raceways versus concentration in input

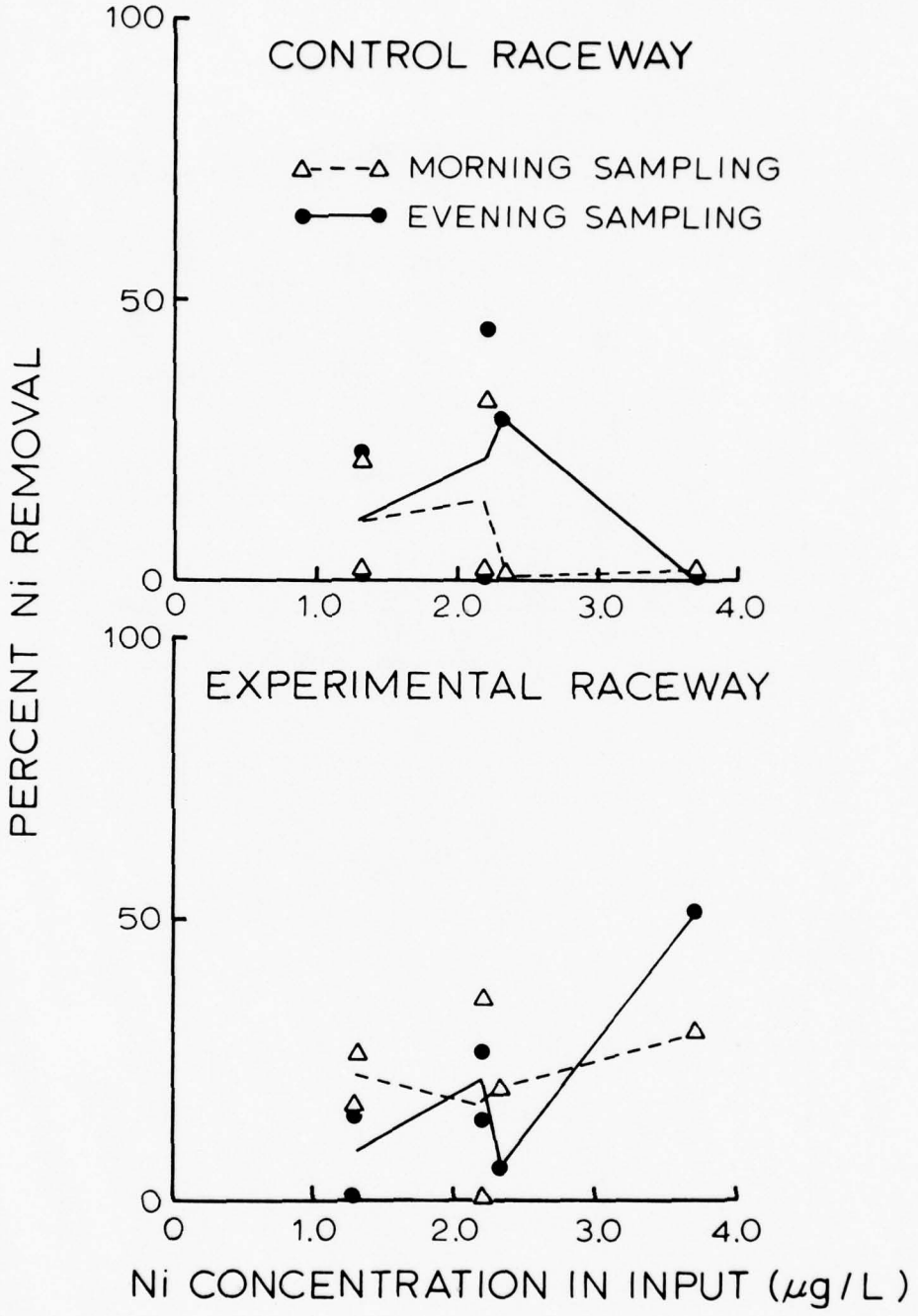

Figure 11. Percent nickel removal in waste water during transit through raceways versus concentration in input

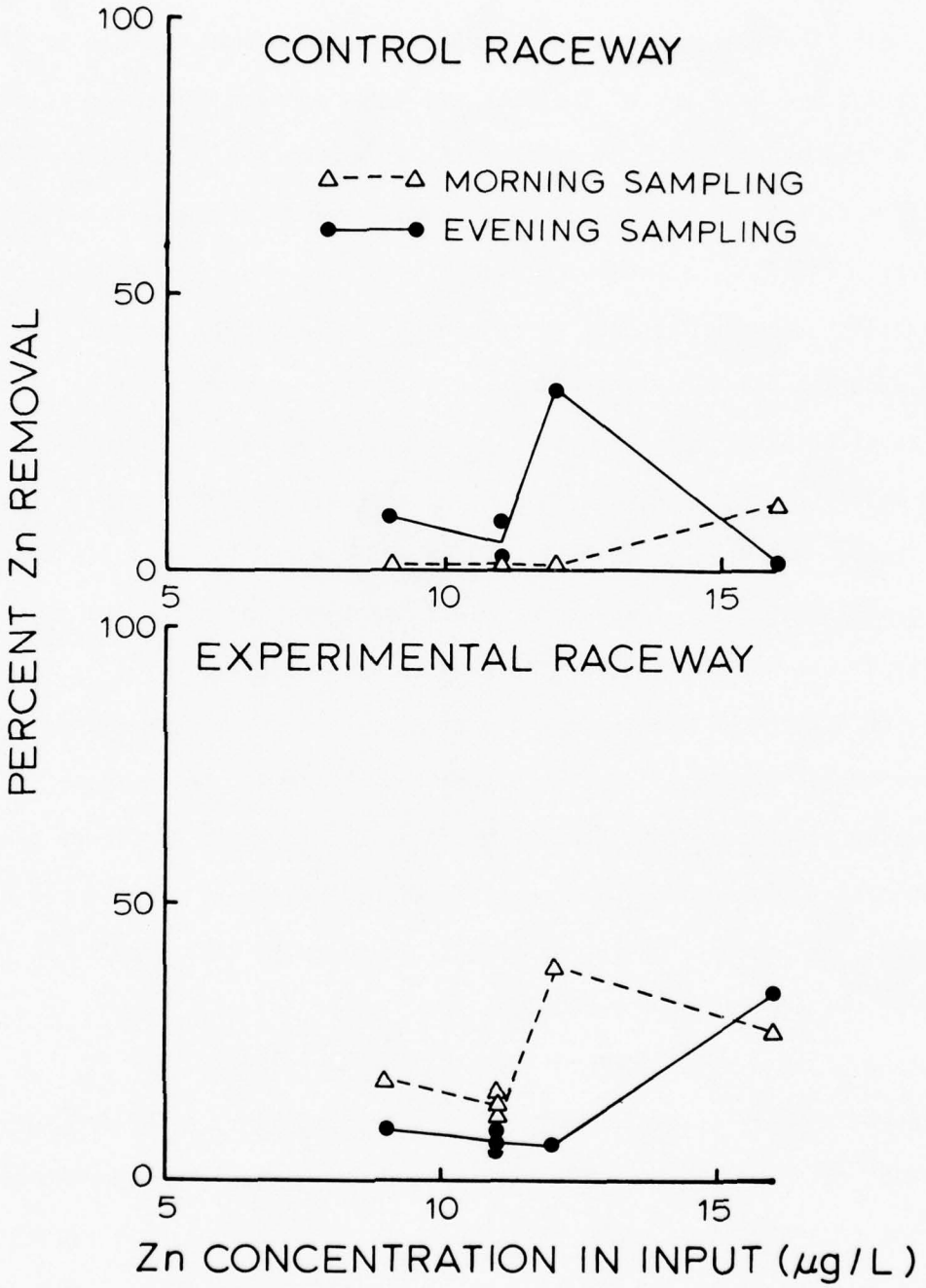

Figure 12. Percent zinc removal in waste water during transit through raceways versus concentration in input

Nutrient and Metal Accumulation in Sediments and Vegetation

49. To evaluate the accumulation of nutrients and metals in the marsh system, analyses of sediment and grass samples collected at the end of the experiments (December 1976) were compared to those on samples collected prior to the experiments (August 1976). Table 4 gives the average results of all the analyses of sediment and grass samples from control stations outside of the raceways (collected in December) and from the experimental raceways before and after the experiments were conducted. It is clear from these results that mean concentrations of both nutrients and metals increase in the sediment as a result of their removal from the effluent. Nitrogen also appears to have increased in the roots and leaves of Spartina in the raceways. No significant enrichment of the other elements in the plants, however, appears to have occurred.

50. Although a significant uptake of nitrogen by the plants in the experimental raceways apparently occurred, there was no increase in the standing biomass of the vegetation (Table 5). However a greater number of flowering culms was noted in the experimental raceways than in the natural marsh. The increase in the nitrogen levels in the plants could account for an average nitrogen removal of about 7 g/m^2 of salt marsh.

51. The accumulation of the contaminants removed from the effluent appears to occur dominantly in the sediments. The accumulation of nitrogen can be calculated by evaluating its absolute increase in the sediments during the experiments for each raceway and assuming this increase is to a depth of 1 cm (Table 6). Using this approach, the mean accumulation of nitrogen in the sediments is over 200 g/m^2. Therefore, the accumulation in the vegetation as compared to this

Table 4

Chemistry of Sediments and Spartina in Raceways

Before and After Experiments

	N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
Sediments								
Control (outside)	0.9 ± 0.3	36 ± 9	1.5 ± 0.4	320 ± 90	0.12 ± 0.06	24 ± 12	7.3 ± 3.6	36 ± 9
Raceway (8/76)	0.7 ± 0.3	30 ± 10	1.7 ± 0.2	370 ± 110	0.15 ± 0.06	14 ± 3	6.8 ± 1.4	29 ± 8
Raceway (12/76)	2.1 ± 0.6	43 ± 11	2.0 ± 0.5	560 ± 380	0.24 ± 0.06	36 ± 8	9.6 ± 2.2	41 ± 11
Spartina Roots								
Control (outside)	0.5 ± 0.3	300 ± 110	0.9 ± 0.8	360 ± 170	0.15 ± 0.06	14 ± 4	3.7 ± 1.7	29 ± 9
Raceway (8/76)	0.5 ± 0.2	240 ± 20	0.8 ± 0.3	410 ± 80	0.09 ± 0.02	10 ± 2	5.1 ± 1.2	35 ± 17
Raceway (12/76)	1.4 ± 0.4	350 ± 70	1.0 ± 0.6	300 ± 70	0.31 ± 0.12	12 ± 3	6.4 ± 1.1	40 ± 7
Spartina Leaves								
Control (outside)	0.4 ± 0.3	570 ± 150	0.1 ± 0.0	210 ± 60	0.04 ± 0.02	3.2 ± 1.2	1.1 ± 0.6	12 ± 2
Raceway (8/76)	0.5 ± 0.1	430 ± 60	0.03 ± 0.01	330 ± 110	0.04 ± 0.01	4.8 ± 1.0	3.5 ± 1.6	13 ± 3
Raceway (12/76)	1.7 ± 0.1	630 ± 80	0.06 ± 0.01	200 ± 50	0.05 ± 0.01	3.1 ± 0.7	1.5 ± 0.6	12 ± 3

Table 5

Standing Biomass of Spartina alterniflora

On Site

	Biomass ($g \cdot dry\ wt/m^2$)
Prior to experiments (August 1976)	710 ± 140
After experiments (November 1976)	
Inside Raceways	635 ± 110
Outside Raceways	560 ± 240

Table 6

Nitrogen Accumulation in Sediments of Experimental Raceways

Raceway Number	Estimated Total Input Volume (10^6 gal.)	Absolute Nitrogen Increase (%)	Accumulation* (g/m^2)
1	1.2	0.8	120
2	1.8	0.9	135
3	2.6	1.8	270
4	2.2	2.6	390
5	0.8	1.5	225
6	1.6	0.6	90
7	1.0	1.0	150
8	1.0	1.3	195
9	0.7	1.5	225
10	0.6	1.4	210
11	1.4	1.4	210
		Mean	202

*Assuming increase is to a depth of 1 cm and sediment has a moisture content of 50% and a density of 3.0 g/cm on a dry weight basis.

represents only a few percent of the total storage of nitrogen in the salt marsh system.

52. The total nitrogen accumulation in the sediments is higher than expected when considering the average concentration in the effluent (3.2 mg/ℓ) and the total volume of input (approximately 15 million gallons). Using these values, a total of at most 65 g/m^2 of nitrogen would be expected to accumulate in the salt marsh. The only nitrogen that was considered in the effluent was soluble inorganic species (i.e., NH_3 and NO_3). It is likely that most of the nitrogen was in particulate and organic forms accounting for the high accumulation in the sediments.

53. Following the example of nitrogen (Table 6), similar estimates of the accumulation of the other elements can be made. These estimates are shown in Table 7 and a ratio of their accumulation in the sediments to the average effluent concentration is also presented. From this ratio the relative efficiency of removal follows the order Fe>N>Cu>Ni>Zn>Cd>P>Mn.

54. Considering the results in Table D4 for the concentration of the elements in raceway sediments after the experiments, it is clear that the concentrations of many are highest near the head of the raceway (location A). This suggests that accumulation occurs fairly soon after input of the effluent due to rapid precipitation. Phosphorus and iron concentrations in the sediments appear to be related with a coefficient of correlation of 0.87. A similar correlation ($r = 0.70$) between nitrogen and iron also occurs. These relationships suggest that the nutrients are also scavenged by the precipitation of hydrated iron oxides in the experimental raceways.

Table 7

Accumulation of Nutrients and Metals in

Sediment of Experimental Raceways

Element	Mean Accumulation (g/m^2)	Ratio of Accumulation to Input*
Nitrogen	202	0.064
Phosphorus	0.18	0.004
Iron	54	0.070
Manganese	2.8	0.002
Cadmium	0.0014	0.006
Copper	0.34	0.042
Nickel	0.04	0.018
Zinc	0.16	0.014

*Mean accumulation in g/m^2 divided by the mean input concentration (Table 1) in $\mu g/\ell$.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

55. Based on the results of this study, the following conclusions can be made:

a. Nutrients (nitrogen and phosphorus) and metals (iron, manganese, cadmium, copper, nickel, and zinc) are removed from effluent during overland flow in salt marshes. During the period of this study the mean metal concentrations of the effluent from the experimental salt marsh raceways were between 15 and 32 percent lower than the mean metal concentrations of the input. Excluding periods when concentrations were near ambient, the mean phosphorus and nitrogen removal efficiencies were above 30 percent. These removal efficiencies are considerably less than those reported for overland flow treatment of industrial and domestic wastes.[10,11,12] In these cases, however, the concentrations of contaminants in the effluents to be treated were considerably higher than in the present study.

b. The most important mechanism of removal appears to be due to inorganic chemical processes which lead to the accumulation of nutrients and metals on particles which are subsequently deposited in the salt marsh sediments, although biological processes are also active and may be more important during more productive seasons.

c. Because of the nature of the processes involved, removal occurs shortly after the initial introduction of the effluent to the salt marsh system.

d. The removal processes may be controlled to a large degree by the formation of hydrated iron and manganese oxides which scavenge both nutrients and metals. Since these compounds form more readily at high pH and high oxygen concentrations, removal is more efficient during daylight hours.

e. With the system used in this study and the rates of application employed (1-60 gal/min), removal did not appear to be strongly related to flow rate. Generally, overland flow systems employ very slow application rates. Additional studies at lower flow rates could show different patterns of contaminant removal.

f. The efficiency of removal of most contaminants appears to be a function of their concentration in the effluent over the range of concentrations encountered during this study

(approximately an order of magnitude above ambient levels).

g. The use of salt marshes for overland flow, advanced treatment of effluents from disposal areas appears to be feasible. Further larger scale studies, however, are necessary to clearly define the degree to which treatment can be accomplished.

Recommendations

56. The removal mechanisms appear to be the most efficient shortly after introduction of the waste water to the marsh system. It is therefore recommended that future designs for the application of this method employ a system producing a greater initial interface between the disposal area effluent and the salt marsh system. Such a system might utilize a spraying device to maximize the interface.

57. The small scale nature of the experimental system used in this study could possibly have limited its utility in determining the removal of contaminant from disposal area effluents by salt marshes. Future studies should employ larger scale systems and have greater control on the levels of contaminants studied.

58. During the spring and summer, the maximum growing season, increased contaminant removal by salt marshes may occur due to increased uptake by plants (including epiphytes). Since the present study was conducted during winter it is recommended that some comparative experiments be carried out during a more favorable growing period.

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ix, 43, [50] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-37)
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References: p. 41-43.

1. Containment areas. 2. Disposal areas. 3. Dredged material disposal. 4. Effluents. 5. Heavy metals. 6. Nutrients. 7. Pollutants. 8. Salt marshes. 9. Waste disposal sites. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-37.
TA7.W34 no.D-77-37

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-37

ABILITY OF SALT MARSHES TO REMOVE NUTRIENTS AND HEAVY METALS FROM DREDGED MATERIAL DISPOSAL AREA EFFLUENTS

by

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P. O. Box 14208
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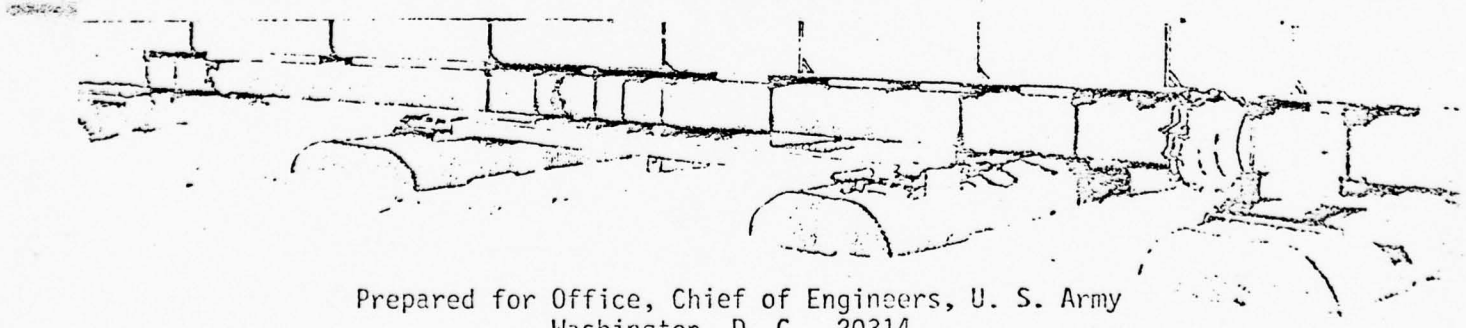
December 1977

Final Report



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Under Contract No. DACW21-76-C-0134
(DMRP Work Unit No. 6B09)

Monitored by Environmental Effects Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

APPENDIX A

FIELD DATA (TEMPERATURE, SALINITY
pH, DISSOLVED OXYGEN AND TURBIDITY
FROM EXPERIMENTS)

TABLE A1

INFLUENT FIELD DATA

SAMPLING PERIOD #1 (5-6 SEPTEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
1300 (5 Sept 76)	31	8	8.9	9.7	134	65
1500	30	8	9.0	10.0	137	72
1700	29	8	8.9	12.2	165	110
1900	28	9	8.3	9.0	120	47
2100	26	9	8.1	5.4	69	30
2300	25	9	7.9	4.8	60	30
0100 (6 Sept 76)	24	9	7.8	4.7	58	30
0300	23.5	9	7.8	3.6	44	30
0500	22.5	9	7.4	4.0	48	30
0700	21.5	9	7.8	5.3	62	35
0900	23	10	8.3	8.8	106	35
1100	28	10	8.2	14.8	197	37

TABLE A2

RACEWAY FIELD DATA

SAMPLING PERIOD #1 (5-6 SEPTEMBER 1976)

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
1500 5 Sept 76													
1	40	29	8	8.2	2.1	28	28	27	8	7.5	0.2	3	<25
2	40	28.5	8	8.4	5.7	77	<25	27	8	7.5	0.2	3	<25
3	55	29.5	8	8.5	5.8	78	38	27	8	7.5	0.3	4	<25
4	60	29	8	8.4	6.7	90	30	28	8	7.6	1.5	20	<25
5	14	28	8	8.4	6.0	80	30	27	8	7.5	1.2	16	<25
6	40	28	8	8.4	6.0	80	37	27	8	7.6	0.5	7	<25
7	20	28	8	8.0	2.8	37	29	27	9	7.6	0.4	5	<25
8	20	29	8	8.2	3.7	50	30	28	8	7.5	0.2	3	<25
9	10	29	8	8.2	2.8	38	<25	27	8	7.5	0.4	5	<25
10	10	27	8	7.9	2.8	36	30	27	8	7.4	0.2	3	<25
11	20	27	8	7.9	0.5	6	40	27	8	7.2	0.5	7	<25
12(control)	20	30	8	8.9	10.2	140	63	31	8	8.9	12.5	167	46
0630 6 Sept 76													
1	8	23	9	7.5	0.4	5	<25	24	9	7.6	0.4	5	<25
2	24	23	9	7.8	0.8	10	<25	24	9	7.7	0.4	5	<25
3	32	23	9	7.7	0.9	11	<25	24	9	7.7	0.4	5	<25
4	24	23	9	7.7	0.8	10	<25	24	9	7.5	0.4	5	<25
5	12	23	9	7.7	0.6	7	<25	24	9	7.3	0.4	5	<25
6	15	23	9	7.6	0.5	6	<25	24	9	7.2	0.5	6	<25
7	9	23	9	7.5	0.7	8	<25	24	9	7.2	0.6	7	<25
8	24	23	9	7.6	0.5	6	<25	23	9	6.8	0.5	6	<25
9	5	23	9	7.6	0.5	6	<25	23.5	9	6.8	0.5	6	<25
10	4	23.5	9	7.5	0.5	6	<25	23.5	9	6.9	0.5	6	<25
11	12	23.5	9	7.5	0.7	8	<25	23	9	7.0	0.5	6	<25
12(control)	12	22	9	8.0	4.2	50	50	22	9	8.3	4.2	99	50

TABLE A3

INFLUENT FIELD DATA

SAMPLING PERIOD #2 (11-12 SEPTEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
1030 (11 Sept 76)	21	14	7.8	8.4	98	<40
1230	24.5	14	8.1	11.8	147	<40
1430	27	13	8.5	12.8	166	<40
1630	29.5	12	8.5	13.3	182	<40
1830	28.5	10	8.5	11.5	153	<40
2030	25	10	8.3	10.6	132	<40
2230	23	10	8.1	7.2	87	<40
0030 (12 Sept 76)	22	10	8.0	5.0	59	<40
0230	21	10	7.8	4.2	49	<40
0430	20	9	7.2	4.0	46	<40
0630	18.5	8	7.2	5.4	60	<40
0830	18	9	7.5	5.4	59	<40

TABLE A4

RACEWAY FIELD DATA

SAMPLING PERIOD #2 (11-12 SEPTEMBER 1976)

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
1430 5 Sept 76													
1	10	25.5	11	8.3	5.6	73	<40	26	10	7.8	1.4	18	<40
2	22	25.5	10	8.1	9.9	128	<40	26	10	7.9	4.3	55	<40
3	30	26.5	10	8.5	13.0	166	<40	25	10	7.8	3.6	43	<40
4	20	26	11	8.2	11.5	147	<40	25.5	10	7.8	3.7	47	<40
5	9	25.5	10	8.1	10.3	133	<40	25.5	10	8.0	3.8	48	<40
6	20	25.5	11	8.5	13.5	175	<40	26	10	8.0	4.9	63	<40
7	12	25.5	12	8.0	7.0	91	<40	25.5	10	7.6	1.8	23	<40
8	10	26	11	8.1	10.7	137	<40	25.5	10	7.6	2.2	28	<40
9	5	25	10	7.5	3.2	40	<40	25	10	7.2	0.1	1	<40
10	4	26	12	7.5	2.0	26	<40	26.5	10	7.2	0.4	5	<40
11	13	25.5	11	7.5	3.6	47	<40	26	10	7.3	0.3	4	<40
12(control)	30	30	13	8.6	13.4	183	<40	31.5	10	8.8	15	133	<40
0630 6 Sept 76													
1	8	20	10	6.7	0.4	4	<40	19.5	10	6.5	0.6	6	<40
2	15	19.5	10	6.6	0.6	6	<40	20	10	6.5	0.2	2	<40
3	30	19.5	10	6.5	0.6	6	<40	19.5	10	6.5	0.2	2	<40
4	19	19.5	10	6.5	0.3	4	<40	19.5	10	6.5	0.3	3	<40
5	8	19.5	10	6.4	0.5	5	<40	20	10	6.5	0.3	3	<40
6	19	20	10	6.3	0.7	7	<40	19	10	6.5	0.2	2	<40
7	11	19.5	10	6.3	0.4	4	<40	19	10	6.5	0.2	2	<40
8	10	19.5	10	6.4	0.3	3	<40	19	1.0	6.3	0.2	2	<40
9	5	19.5	9	6.3	0.3	3	<40	19	10	6.3	0.2	2	<40
10	4	19.0	9	6.3	0.2	2	<40	19	10	6.2	0.2	2	<40
11	13	19.5	10	6.3	0.2	2	<40	19.5	10	6.2	0.1	1	<40
12(control)	20	18.5	10	6.7	3.7	41	<40	16	10	7.0	3.8	42	<40

TABLE A5

INFLUENT FIELD DATA

SAMPLING PERIOD #3 (13 NOVEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0830	7.0	11	7.2	11.0	95	<40
1030	9.5	12	7.7	12.2	112	<40
1230	12.0	14	7.8	11.8	114	45
1430	13.0	15	7.8	10.4	103	40
1630	12.0	15	7.7	10.4	101	<40
1830	9.0	13	7.8	9.0	82	<40
2030	8.0	12	8.0	8.0	71	<40
2230	7.5	12	7.6	8.0	70	<40

TABLE A6

RACEWAY FIELD DATA

SAMPLING PERIOD #3 (13 NOVEMBER 1976)

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0630 13 Nov 76													
1	2	7	11	6.7	0.9	7	<40	6	11	7.4	5.4	43	<40
2	4	6	11	6.3	1.2	10	<40	6	11	7.2	3.8	30	<40
3	6	6	11	6.4	1.7	13	<40	6.5	11	7.1	4.9	39	<40
4	2	6.5	11	7.4	2.2	18	<40	6.5	11	6.5	5.0	40	<40
5	2	6.5	11	7.5	3.6	29	<40	7.0	11	6.4	4.2	34	<40
6	2	7	11	7.2	3.2	26	<40	7.0	11	6.8	4.8	39	<40
7	1	7	11	7.5	6.6	54	<40	6.5	11	6.8	6.1	49	<40
8	1	7	11	7.0	6.5	53	<40	6.5	11	7.4	4.2	34	<40
9	12	6	11	7.5	6.6	53	<40	6.5	11	7.3	5.0	40	<40
10	8	6	11	7.2	7.0	56	<40	6.5	11	7.3	5.4	44	<40
11	12	7	11	7.4	5.0	41	<40	7	11	6.8	6.4	52	<40
12(control)	9	5	11	7.5	7.9	62	62	5	11	7.8	8.2	64	57
1430 13 Nov 76													
1	4	12	14	7.2	5.0	46	<40	11	14	7.7	9.0	82	<40
2	7	11.5	15	7.4	5.9	54	<40	10.5	14	7.7	9.4	82	<40
3	12	11	15	7.7	6.6	60	<40	10.5	14	7.8	10.0	87	<40
4	5	11.5	14	7.8	10.1	93	<40	10.5	14	7.8	10.3	90	<40
5	4	11	14	7.3	10.6	96	<40	10.5	14	7.9	10.3	90	<40
6	10	11	14	7.7	9.6	87	<40	10.5	14	7.5	10.4	91	<40
7	3	11	15	7.9	9.8	89	<40	10.5	14	7.5	11.2	98	<40
8	2	11	15	7.8	9.6	87	<40	11	14	7.9	11.0	100	<40
9	25	11	15	7.8	9.2	84	<40	10.5	14	7.5	7.4	65	<40
10	20	11	15	7.7	9.1	83	<40	10.5	14	7.6	10.0	87	<40
11	30	11	15	7.4	10.6	96	<40	10	14	7.9	10.5	93	<40
12(control)	20	14	15	7.8	11.2	110	50	14.5	14	8.2	10.0	98	45

TABLE A7

INFLUENT FIELD DATA

SAMPLING PERIOD #4 (14 NOVEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0030	7.0	12	7.5	8.2	71	44
0230	6.0	11	7.1	8.8	74	46
0430	6.0	12	7.5	9.0	76	40
0630	5.5	12	7.6	9.1	76	48
0830	5.5	13	7.6	9.2	76	56
1030	9.0	16	7.9	13.0	118	52
1230	8.5	14	8.0	14.7	132	54
1430	8.0	14	8.4	15.0	133	54
1630	7.5	10	__*	15.0	132	67
1830	7.0	9	__	10.2	89	45
2030	6.0	10	__	9.5	80	40
2230	6.0	10	__	8.5	72	50

*pH meter malfunction

TABLE A8

RACEWAY FIELD DATA

SAMPLING PERIOD #4 (14 NOVEMBER 1976)

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0630 14 Nov 76													
1	1	6.0	11	7.4	2.6	21	<40	7.0	12	7.3	3.8	31	<40
2	6	6.5	11	7.7	3.6	29	<40	6.5	12	7.4	3.0	29	<40
3	9	6.5	12	7.6	3.6	29	<40	6.5	12	7.4	3.3	27	<40
4	3	6.5	12	7.6	4.2	34	<40	6.5	12	7.5	2.8	23	<40
5	3	7.0	12	7.6	3.6	30	<40	7.0	12	7.4	3.8	31	<40
6	7	6.5	12	7.6	2.3	19	<40	6.5	12	7.5	4.1	33	<40
7	1	6.0	12	7.6	6.7	54	<40	6.5	12	7.6	5.2	42	<40
8	1	6.0	12	7.6	6.8	54	<40	6.5	12	7.6	4.2	34	<40
9	14	6.0	12	7.6	7.4	59	40	6.5	12	7.5	5.1	41	<40
10	10	6.0	12	7.6	7.1	57	40	6.5	12	7.5	4.2	34	<40
11	18	6.0	12	7.6	6.3	50	70	6.5	12	7.6	5.1	41	<40
12(control)	15	6.0	12	7.7	6.8	54	87	5.5	12	7.7	7.0	61	40
1430 14 Nov 76													
1	1	7.0	12	7.9	3.1	25	<40	7.0	11	-	6.9	56	<40
2	7	7.5	12	8.2	11.2	93	<40	7.0	12	8.2	7.5	61	<40
3	10	7.0	13	8.0	7.6	62	<40	7.0	11	8.1	7.6	62	<40
4	5	7.5	14	8.2	9.6	80	<40	7.0	11	8.1	8.2	67	<40
5	7	8.0	14	7.9	8.9	75	<40	7.0	12	8.0	7.2	59	<40
6	9	7.5	13	7.9	8.9	74	<40	7.0	11	8.1	8.5	70	<40
7	1	7.5	13	8.0	9.1	76	<40	7.0	12	8.0	7.9	65	<40
8	1	7.5	14	7.9	9.8	81	<40	7.0	12	8.1	7.8	64	<40
9	20	8.0	13	7.5	9.9	83	<40	7.0	12	8.2	7.8	64	<40
10	15	8.0	13	8.0	10.0	84	<40	7.0	12	8.0	7.8	64	<40
11	30	7.5	12	7.8	9.2	76	<40	7.0	14	8.1	8.3	68	<40
12(control)	20	8.0	12	8.3	15.0	70	110	7.0	12	8.4	14.0	115	47

TABLE A9

INFLUENT FIELD DATA

SAMPLING PERIOD #5 (15 NOVEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0030	5.5	10	__*	7.5	62	58
0230	5.5	10	__	7.5	62	70
0430	5.5	11	__	7.0	58	60
0630	5.5	12	__	9.4	78	62
0830	5.5	12	__	11.3	94	66
1030	7	11	7.4	__**	__	61
1230	6.5	11	7.5	__	__	45
1430	5.5	12	7.5	10.8	90	46
1630	7.0	11	7.5	12.6	109	45
1830	7.0	11	7.5	10.6	92	43
2030	7.0	11	7.5	9.5	82	<40
2230	8.0	10	7.5	8.5	76	<40

*pH meter malfunction

**probe membrane malfunction

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0630 15 Nov 76													
1	30	5.5	11		3.4	27	<40	5.5	12		5.4	43	<40
2	35	5.5	10		5.4	43	<40	5.4	12		6.6	52	<40
3	35	5.5	10		5.8	46	<40	5.5	10		5.8	46	<40
4	45	5.5	10		9.0	71	<40	5.5	10		5.8	46	<40
5	15	5.5	10		5.4	43	<40	5.5	10		5.7	45	<40
6	15	5.5	10		7.0	55	<40	5.5	10		5.2	41	<40
7	17	5.5	10		8.1	64	<40	5.5	10		7.1	56	<40
8	18	5.5	10		8.6	68	<40	5.5	10		7.4	58	<40
9	20	5.5	10		8.2	65	<40	5.5	10		7.6	60	<40
10	20	5.5	10		9.0	71	<40	5.5	10		8.1	64	<40
11	60	5.5	12		9.2	73	<40	5.5	10		8.0	63	<40
12(control)	50	5.5	12		11.4	90	<40	5.5	10		9.5	75	<40
1430 14 Nov 76													
1	30	7.5	10	7.5	-	-	<40	7.5	10	7.3			<40
2	35	7.5	10	7.5	-	-	<40	7.5	11	7.4			<40
3	35	8.0	10	7.5	12.8	107	<40	7.5	12	7.4			<40
4	45	7.5	10	7.6	9.0	75	<40	7.5	11	7.4			<40
5	14	7.5	11	7.5	9.1	76	<40	7.5	12	7.5			<40
6	15	7.5	10	7.5	8.6	71	<40	7.5	12	7.6			<40
7	17	7.5	10	7.5	7.8	65	<40	8.0	11	7.7			<40
8	20	8.0	11	7.5	7.8	65	<40	8.0	11	7.8			<40
9	20	8.0	11	7.5	6.0	50	<40	8.0	11	7.8			<40
10	20	8.0	12	7.5	10.3	86	<40	8.0	12	7.9			<40
11	60	8.0	12	7.5	6.4	54	<40	8.0	11	7.8			<40
12(control)	50	8.0	11	7.5	12.6	106	<40	7.5	12	7.6			<40

TABLE A11

INFLUENT FIELD DATA

SAMPLING PERIOD #6 (16 NOVEMBER 1976)

Time	Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0030	7.0	9	7.7	7.8	67	40
0230	7.0	10	7.7	6.6	57	40
0430	6.5	8	6.7	6.6	56	60
0630	6.5	8	6.7	7.3	63	78
0830	7.0	9	6.5	6.2	54	120
1030	9.5	14	6.7	0.8*	7	*
1230	9.5	15	6.4	0.6*	6	*
1430	9.5	14	6.4	0.7*	6	*

*influent opaque (high concentrations of suspended matter)

TABLE A12

RACEWAY FIELD DATA

SAMPLING PERIOD #6 (16 NOVEMBER 1976)

Raceway	Flow Rate (GPM)	MID POINT Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)	DISCHARGE Temp (°C)	Sal (°/oo)	pH	Do (ppm)	Do (% SAT)	Turb (JTU)
0630 16 Nov 76													
1	25	6.5	9		5.4	43	<40	7.0	8		1.2	10	<40
2	20	6.5	9		3.3	27	<40	7.0	8		4.1	34	<40
3	12	6.5	9		2.3	18	<40	6.0	8		4.2	34	<40
4	10	7.0	9		1.5	12	<40	7.0	9		2.8	23	<40
5	15	6.5	9		4.0	32	<40	7.5	9		2.9	24	<40
6	12	6.5	9		4.2	34	<40	7.0	9		2.2	18	<40
7	16	6.0	8		4.2	34	<40	6.5	9		3.0	24	<40
8	14	6.5	9		4.5	36	<40	7.0	9		3.0	24	<40
9	40	6.5	8		5.0	40	<40	6.5	9		1.1	9	<40
10	50	6.5	8		6.2	50	<40	6.5	9		2.8	23	<40
11	40	6.5	8		6.2	50	<40	7.5	9		2.7	22	<40
12(control)	35	6.0	8		7.7	62	75	6.0	9		5.5	44	76
1430 16 Nov 76													
1	10	7.5	10	6.5	4.0	33	<40	8.0	10	6.3	5.7	48	<40
2	15	8.5	10	7.4	7.1	60	<40	7.5	10	7.0	4.7	39	<40
3	20	9.0	11	7.2	3.3	28	<40	8.0	10	7.2	7.4	62	<40
4	25	8.0	10	7.2	9.4	79	<40	8.0	10	7.2	8.4	70	<40
5	18	8.0	11	7.2	6.4	54	<40	8.0	10	7.1	7.2	61	<40
6	12	8.0	11	7.1	3.9	33	<40	8.0	10	7.2	6.8	57	<40
7	20	8.0	10	7.3	5.4	45	<40	8.0	10	7.2	6.0	50	<40
8	20	8.0	12	7.3	6.2	52	<40	8.0	10	6.9	7.5	63	<40
9	50	9.5	13	6.7	2.2	19	<40	8.0	10	6.8	5.9	49	<40
10	40	9.5	13	6.8	3.8	33	<40	8.0	10	7.1	8.3	69	<40
11	60	9.5	13	6.7	1.1	9	48	8.0	10	7.1	4.3	36	<40
12(control)	40	10.0	12	6.6	1.5	13	46	9.0	11	6.7	2.5	21	62

APPENDIX B

NUTRIENT DATA (PO_4, NO_3 AND NH_4) FROM EXPERIMENTS

TABLE B1

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #1 (5-6 SEPTEMBER 1976)

			μg·atoms/ℓ	
	Time	PO_4	NO_3	NH_3	ΣN
	1300	1.2	350	18	368
	1500	0.7	370	8	378
	1700	0.9	390	12	402
	1900	0.6	290	9	299
	2100	0.7	420	14	434
	2300	0.7	210	13	223
	0100	0.5	210	19	229
	0300	0.8	210	34	244
	0500	0.7	210	41	251
	0700	0.5	180	72	252
	0900	0.5	110	89	199
	1100	0.5	210	89	299
Average		0.7			298

TABLE B2

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #1 (5-6 SEPTEMBER 1976)

Concentrations in μg·atom/ℓ

Raceway	MID POINT PO_4	MID POINT NO_3	MID POINT NH_3	MID POINT ΣN		DISCHARGE PO_4	DISCHARGE NO_3	DISCHARGE NH_3	DISCHARGE ΣN
1500 5 Sept 76									
1	1.0	180	83	263		1.0	145	150	295
2	1.1	210	185	395		0.9	110	211	321
3	0.4	145	45	201		1.2	145	78	223
4	0.8	210	100	310		1.0	110	180	290
5	0.9	210	120	330		1.0	145	165	310
6	0.9	290	95	385		1.2	145	200	345
7	0.8	210	130	340		1.4	110	180	290
8	0.9	290	140	430		1.9	100	140	240
9	0.9	220	180	400		2.6	100	180	280
10	1.5	210	205	415		4.4	145	172	317
11*	2.6	340	115	455		4.0	180	150	330
12(control)	0.9	350	24	374		0.8	280	20	300
					Av.	1.8			294
0630 6 Sep 76									
1	1.2	64	49	113		1.5	180	45	225
2	0.9	64	40	104		1.3	115	48	163
3	0.8	100	39	139		1.4	110	31	141
4	1.0	100	34	134		1.6	145	31	176
5	1.1	100	36	136		1.8	145	31	176
6	1.5	100	32	132		2.0	145	35	180
7	2.5	115	30	145		2.2	110	49	159
8	1.5	110	31	141		2.3	180	33	213
9	1.5	115	30	145		2.5	180	44	224
10	3.0	106	30	136		3.0	180	35	215
11*	3.6	180	30	210		3.6	210	30	240
12(control)	0.7	210	67	277		0.6	240	31	271
					Av.	2.1			192

TABLE B3

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #2 (11-12 SEPTEMBER 1976)

		μg·atom/ℓ			
	Time	PO_3	NO_3	NH_3	ΣN
	1030	1.3	290	430	720
	1230	1.3	290	500	790
	1430	1.2	483	410	893
	1630	1.0	419	410	829
	1830	0.6	322	388	710
	2030	0.5	355	445	800
	2230	0.5	483	305	788
	0030	0.6	548	372	920
	0230	0.7	742	428	1170
	0430	0.8	710	350	1060
	0630	1.1	480	517	997
	0830	1.0	225	405	630
Average		0.9			859

TABLE B4

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #2 (11-12 SEPTEMBER 1976)

Concentrations in μg·atoms/ℓ

Raceway	MID POINT PO_4	MID POINT NO_3	MID POINT NH_3	MID POINT ΣN	DISCHARGE PO_4	DISCHARGE NO_3	DISCHARGE NH_3	DISCHARGE ΣN
1500 11 Sept 76								
1	0.9	350	260	610	0.5	290	195	485
2	0.9	390	280	670	0.5	290	270	560
3	0.7	420	250	670	0.7	290	250	540
4	0.7	225	270	495	0.5	230	255	485
5	0.8	220	285	605	0.7	160	240	400
6	0.7	420	330	750	0.7	160	220	380
7	1.8	290	255	545	1.2	320	220	540
8	1.4	480	230	710	2.3	360	48	408
9	1.1	350	290	640	1.8	230	160	390
10	3.3	350	210	560	1.5	320	180	500
11*	1.4	350	260	610	3.3	330	105	435
12(control)	1.2	550	350	900	0.8	420	320	740
				Av.	1.4			465
0630 12 Sept 76								
1	0.7	550	360	910	0.3	230	360	590
2	0.4	290	330	620	0.3	100	320	420
3	0.4	350	370	720	0.3	100	305	405
4	0.4	230	290	520	0.3	130	270	400
5	0.5	230	460	690	0.3	35	380	415
6	0.5	550	370	920	0.3	230	330	560
7	1.2	480	495	975	0.5	230	380	610
8	0.8	320	420	740	0.7	480	260	740
9	1.0	230	380	610	1.0	310	230	530
10	1.4	230	470	700	0.9	420	250	670
11*	1.0	230	495	725	4.1	350	250	600
12(control)	1.0	610	610	1220	0.5	680	500	1180
				Av.	0.5			540

TABLE B5

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #3 (13 NOVEMBER 1976)

	---------- μg·atom/ℓ ----------			
Time	PO_4	NO_3	NH_3	ΣN
0830	1.5	24	33	57
1030	1.0	40	21	61
1230	1.8	42	67	109
1430.	1.1	24	39	63
1630	1.5	53	22	75
1830	1.1	32	19	51
2030	2.3	58	27	85
2230	2.4	60	10	70
Average	1.6			71

TABLE B6

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #3 (13 NOVEMBER 1976)

Concentrations in μg·atoms/ℓ

Raceway	-----MID POINT--------- PO_4	NO_3	NH_3	ΣN	-----DISCHARGE--------- PO_4	NO_3	NH_3	ΣN
0630 13 Nov 76								
1	--*	20	37	57	0.9	5	21	26
2	--	17	50	67	0.8	8	25	33
3	--	31	25	56	0.8	11	39	50
4	--	21	45	66	1.0	18	67	85
5	--	26	30	56	1.2	21	66	87
6	--	18	42	60	0.7	3	55	58
7	--	19	40	59	0.9	3	47	50
8	--	12	67	79	1.3	6	32	38
9	--	17	49	66	1.5	19	34	53
10	--	29	27	56	1.4	24	48	72
11	--	30	29	59	1.7	29	41	70
12(control)	--	39	48	87	1.4	24	32	56
				Av.	1.1			56
1430 13 Nov 76								
1	2.6	1.0	15	25	0.5	13	29	42
2	0.9	21	37	58	1.4	35	31	67
3	1.0	29	26	55	0.8	21	28	49
4	0.7	25	22	47	0.7	24	31	55
5	1.1	45	20	65	0.9	26	16	42
6	1.1	34	27	61	0.6	14	29	43
7	1.2	35	28	63	0.3	3	26	29
8	1.1	32	13	45	0.4	45	16	61
9	1.2	37	14	51	1.0	32	13	45
10	1.3	26	22	48	2.0	32	30	62
11	1.4	32	32	64	0.9	37	34	71
12(control)	3.8	21	20	41	1.5	14	18	32
				Av.	0.9			51

*samples lost

TABLE B7

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #4 (14 NOVEMBER 1976)

	μg·atoms/ℓ			
Time	PO_4	NO_3	NH_3	ΣN
0030	1.1	52	22	74
0230	1.0	45	13	58
0430	0.9	48	23	71
0630	1.7	26	37	63
0830	0.7	39	35	74
1030	1.5	31	14	45
1230	2.7	24	13	37
1430	1.2	40	8	48
1630	1.8	24	5	29
1030	2.2	45	5	50
2030	3.7	26	3	29
2230	2.9	29	5	34
Average	1.8			51

TABLE B8

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #4 (14 NOVEMBER 1976)

Concentrations in μg·atoms/ℓ

Raceway	MID POINT PO_4	MID POINT NO_3	MID POINT NH_3	MID POINT ΣN	DISCHARGE PO_4	DISCHARGE NO_3	DISCHARGE NH_3	DISCHARGE ΣN
0630 14 Nov 76								
1	0.5	6	10	16	0.8	22	13	35
2	0.7	71	23	94	0.9	40	19	59
3	0.7	60	15	75	1.0	35	15	50
4	0.5	52	52	104	0.8	64	37	91
5	0.6	60	52	112	0.8	63	41	104
6	0.6	61	72	133	0.7	58	40	98
7	0.6	52	49	101	0.8	63	38	91
8	0.5	55	49	104	0.9	52	45	97
9	0.6	53	56	109	1.0	68	50	118
10	0.5	58	49	107	0.6	58	67	125
11	0.6	56	44	100	0.6	56	34	90
12(control)	0.7	45	42	87	0.6	52	37	89
				Av.	0.8			87
1430 14 Nov 76								
1	0.3	14	18	32	0.5	43	24	67
2	0.1	41	9	50	0.5	50	29	79
3	0.7	37	14	51	1.2	42	25	67
4	0.5	27	17	44	0.8	24	19	43
5	0.6	48	18	66	1.3	26	24	50
6	0.6	39	11	50	1.0	60	29	89
7	1.7	39	17	56	0.9	52	16	68
8	0.5	48	22	70	0.8	50	12	62
9	0.7	31	24	55	0.8	40	23	63
10	1.3	35	7	42	1.4	43	16	59
11	0.7	37	19	56	1.0	43	14	57
12(control)	0.7	18	8	26	0.7	26	17	43
				Av.	0.9			64

TABLE B9

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #5 (15 NOVEMBER 1976)

	μg·atom/ℓ			
Time	PO_4	NO_3	NH_3	ΣN
0030	2.4	21	11	32
0230	1.5	16	6	22
0430	2.2	15	4	19
0630	1.6	16	12	28
0830	1.4	18	17	35
1030	2.1	18	29	47
1230	2.0	21	17	38
1430	1.7	16	33	49
1630	1.6	18	10	28
1830	1.4	21	10	31
2030	1.3	16	22	38
2230	1.2	18	17	35
Average	1.7			34

TABLE B10

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #5 (15 NOVEMBER 1976)

Concentrations in μg·atoms/ℓ

Raceway	-----MID POINT--------- PO_4	NO_3	NH_3	ΣN	-----DISCHARGE--------- PO_4	NO_3	NH_3	ΣN
0630 15 Nov 76								
1	2.4	26	17	43	0.8	35	10	45
2	1.5	24	11	35	2.0	27	11	38
3	1.2	22	9	31	1.6	30	17	47
4	2.0	24	10	34	1.1	27	12	39
5	2.2	26	13	39	1.8	29	11	40
6	1.3	22	8	30	1.1	37	10	47
7	2.7	27	8	35	1.7	29	10	39
8	1.7	24	11	35	1.3	26	10	36
9	1.2	21	11	32	1.8	24	10	34
10	2.5	22	10	32	2.2	25	8	33
11	1.6	18	15	33	1.4	24	9	33
12(control)	2.1	14	13	27	2.0	17	13	30
				Av.	1.5			39
1430 15 Nov 76								
1	0.8	19	22	41	1.2	16	10	26
2	2.0	3	14	17	1.9	13	19	32
3	1.6	14	19	33	0.7	18	14	32
4	1.8	14	32	46	1.6	22	22	44
5	1.6	16	15	31	1.5	19	12	31
6	1.2	17	21	38	1.1	22	19	41
7	2.0	21	24	45	1.0	16	14	30
8	1.2	8	18	26	1.6	18	24	42
9	1.6	19	25	44	1.6	14	20	34
10	1.6	16	33	39	1.7	16	17	33
11	1.6	10	18	28	1.7	21	27	48
12(control)	1.7	14	13	27	2.0	16	12	28
				Av.	1.4			36

TABLE B11

INFLUENT NUTRIENT DATA

SAMPLING PERIOD #6 (16 NOVEMBER 1976)

	μg·atoms/ℓ			
Time	PO_4	NO_3	NH_3	ΣN
0030	2.6	19	14	33
0230	1.0	19	28	47
0430	1.1	18	13	31
0630	1.4	16	17	33
0830	1.4	18	3	21
1030	2.0	19	23	42
1230	2.5	27	40	67
1430	2.6	29	49	78
Average	1.8			44

TABLE B12

RACEWAY NUTRIENT DATA

SAMPLING PERIOD #6 (16 NOVEMBER 1976)

Concentrations in μg·atoms/ℓ

Raceway	MID POINT PO_4	MID POINT NO_3	MID POINT NH_3	MID POINT ΣN	DISCHARGE PO_4	DISCHARGE NO_3	DISCHARGE NH_3	DISCHARGE ΣN
0630 16 Nov 76								
1	0.9	26	14	40	0.8	13	11	24
2	1.1	24	12	36	0.8	16	9	25
3	0.9	21	16	37	0.9	18	14	32
4	0.9	19	17	36	0.8	11	9	20
5	1.0	16	8	24	0.9	14	9	23
6	1.1	16	8	24	0.8	21	9	30
7	1.0	18	17	35	0.7	14	13	27
8	1.1	16	14	30	1.0	18	14	32
9	1.0	24	18	42	1.0	16	12	28
10	1.2	16	10	26	1.1	21	13	34
11	1.2	21	12	33	0.9	18	2	20
12(control)	1.3	14	12	26	1.0	14	9	23
				Av.	0.9			27
1430 16 Nov 76								
1	1.0	17	12	29	0.8	16	11	27
2	2.2	13	10	23	0.9	16	11	27
3	1.0	16	20	36	0.9	14	22	36
4	1.0	11	36	47	1.0	14	52	66
5	1.1	18	42	60	1.0	14	50	64
6	1.1	14	28	42	1.2	10	50	60
7	1.0	11	32	43	1.1	19	53	72
8	1.1	13	38	51	1.6	13	13	26
9	1.6	3	35	48	1.0	14	47	61
10	2.0	6	30	36	1.1	13	21	34
11	1.8	2	37	49	1.0	16	47	63
12(control)	2.5	14	32	36	1.2	5	44	49
				Av.	1.0			49

APPENDIX C

METAL DATA (Fe, Mn, Cd, Cu, Ni, AND Zn)
FROM EXPERIMENTS

TABLE C1

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #1 (5-6 September 1976)

Time	ppb					
	Fe	Mn	Cd	Cu	Ni	Zn
1300 (5 Sep 76)	1000	410	0.1	5.0	2.6	10
1500	1000	280	0.1	5.6	3.3	10
1700	1000	340	0.2	8.4	4.3	16
1900	1000	250	0.1	5.6	3.6	10
2100	1000	380	0.2	6.0	2.4	13
2300	1000	520	0.2	7.0	4.2	10
0100 (6 Sep 76)	1100	680	0.2	6.6	2.8	13
0300	1100	960	0.2	6.6	5.2	11
0500	1000	1300	0.2	7.0	3.8	9
0700	1100	1900	0.3	7.0	4.2	9
0900	1100	300	0.2	6.5	3.6	10
1100	1100	285	0.2	6.2	4.1	11
Average	1040	530	0.2	6.4	3.7	11

TOTAL METAL CONCENTRATION IN RACEWAY WATER SAMPLES

Sampling Period #1 (5-6 September 1976)

Raceway Number	MID POINT ppb						DISCHARGE ppb					
	Fe	Mn	Cd	Cu	Ni	Zn	Fe	Mn	Cd	Cu	Ni	Zn
1500 5 Sept 76												
1	750	550	0.2	4.8	1.1	11	690	550	0.1	2.8	1.5	10
2	750	420	0.2	4.2	1.5	13	700	480	0.1	4.8	1.7	11
3	700	260	0.2	5.7	1.1	11	700	480	0.1	2.8	1.4	11
4	750	420	0.3	4.2	2.0	21	600	550	0.1	3.3	1.2	12
5	740	420	0.2	5.2	2.0	14	600	420	0.1	4.8	1.4	12
6	760	480	0.2	5.7	1.8	13	600	580	0.1	2.8	1.2	10
7	700	580	0.2	3.8	1.2	16	650	520	0.2	3.3	1.5	8
8	650	650	0.1	4.8	1.2	24	600	480	0.1	3.8	1.6	10
9	790	480	0.2	3.8	1.4	14	600	550	0.1	2.8	2.4	9
10	800	620	0.3	8.0	1.4	23	690	790	0.1	2.2	2.4	8
11	750	790	0.2	5.2	1.4	11	600	820	0.1	3.9	3.6	16
12(control)	700	310	0.3	8.5	1.8	17	600	350	0.1	6.6	4.8	13
0630 6 Sept 76												
1	910	820	0.3	5.2	2.8	8	540	900	0.4	4.6	2.5	10
2	890	960	0.4	6.6	3.3	11	730	820	0.1	5.6	3.1	10
3	1000	860	0.3	5.6	3.1	9	560	620	0.3	5.6	2.0	10
4	980	900	0.4	6.6	3.1	16	670	680	0.3	5.6	2.0	8
5	980	820	0.4	5.9	3.1	7	740	650	0.4	5.0	2.5	12
6	1000	1000	0.8	6.2	2.8	8	720	760	0.3	5.0	2.5	9
7	1000	1500	0.8	5.0	2.5	8	870	820	0.3	4.6	2.5	9
8	1000	1000	0.6	6.8	2.8	8	770	760	0.3	3.6	3.1	8
9	1100	1000	0.6	5.6	2.8	7	760	820	0.2	4.6	2.5	9
10	1100	1000	0.6	5.9	3.6	8	870	900	0.4	4.3	2.5	18
11	1100	1000	0.6	5.6	3.6	10	1100	860	0.3	6.6	3.5	20
12(control)	1100	1900	1.0	9.5	5.4	22	960	260	0.3	10	4.5	17

TABLE C3

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #2 (11-12 September 1976)

Time	ppb					
	Fe	Mn	Cd	Cu	Ni	Zn
1030 (11 Sep 76)	1000	1400	0.1	4.6	2.5	9
1230	1000	1200	0.1	4.6	3.3	9
1430	1300	1600	0.1	3.2	2.7	10
1630	900	1600	0.1	4.2	2.4	12
1830	850	1400	0.1	5.2	2.7	9
2030	300	900	0.3	12	2.2	10
2230	300	680	0.1	13	2.2	9
0030 (12 Sep 76)	350	680	0.1	17	2.0	10
0230	750	960	0.1	12	1.3	8
0430	350	1600	0.1	5.0	1.8	9
0630	260	2000	0.1	4.2	1.3	9
0830	380	4500	0.1	4.6	1.8	8
Average	645	1540	0.1	7.5	2.2	9

TABLE C4

TOTAL METAL CONCENTRATION IN RACEWAY WATER SAMPLES

Sampling Period #2 (11-12 September 1976)

Raceway Number	MID POINT ppb						DISCHARGE ppb					
	Fe	Mn	Cd	Cu	Ni	Zn	Fe	Mn	Cd	Cu	Ni	Zn
1430 11 Sept 76												
1	250	380	0.1	1.6	1.9	11	190	250	0.1	2.0	2.1	8
2	300	720	0.1	3.4	1.9	9	180	250	0.1	2.0	1.4	8
3	260	660	0.1	2.2	1.6	9	180	350	0.1	2.0	1.4	7
4	260	550	0.1	2.2	1.8	7	160	250	0.1	2.0	1.4	8
5	240	420	0.1	2.2	1.2	8	270	180	0.1	1.4	1.5	7
6	320	450	0.1	2.8	1.8	8	290	250	0.1	2.0	1.4	9
7	500	450	0.1	2.8	1.6	9	300	310	0.1	2.5	1.6	7
8	500	520	0.1	2.8	1.8	11	140	820	0.1	2.5	1.5	10
9	500	580	0.1	2.2	1.6	8	250	500	0.1	2.0	2.0	8
10	500	520	0.1	2.2	1.7	5	160	650	0.1	2.0	2.0	10
11	500	720	0.1	2.2	2.4	10	175	920	0.1	2.5	1.6	12
12(control)	500	1600	0.2	3.9	2.4	11	600	1200	0.3	3.0	2.2	8
0630 12 Sept 76												
1	100	480	0.1	1.0	1.4	6	150	380	0.1	1.2	1.2	5
2	120	250	0.1	1.4	1.4	11	230	720	0.1	1.2	1.0	6
3	100	450	0.1	1.4	1.6	8	260	660	0.1	1.8	1.0	8
4	360	860	0.2	1.4	1.6	8	230	550	0.1	1.2	1.0	8
5	160	360	0.2	1.4	1.6	8	260	420	0.1	1.2	1.0	6
6	130	250	0.2	1.4	1.6	7	250	450	0.1	1.4	1.8	8
7	360	350	0.2	1.4	1.6	6	240	450	0.1	3.8	2.4	10
8	300	550	0.1	1.8	1.0	6	180	520	0.1	6.5	1.8	6
9	320	280	0.1	1.8	1.2	5	220	580	0.2	4.2	1.5	7
10	380	310	0.1	1.8	1.0	6	190	520	0.1	1.5	1.6	9
11	340	250	0.1	1.8	1.2	8	330	720	0.1	4.6	1.5	10
12(control)	1500	2000	0.2	3.6	2.5	20	190	1200	0.1	4.2	1.5	9

TABLE C5

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #3 (13 November 1976)

Time	ppb					
	Fe	Mn	Cd	Cu	Ni	Zn
0830	140	900	0.4	29	1.4	13
1030	200	800	0.2	15	1.2	9
1230	230	600	0.5	11	1.5	12
1430	200	590	0.6	13	2.4	12
1630	90	600	0.5	11	1.0	11
1830	100	630	0.3	16	1.0	13
2030	100	480	0.3	19	1.0	8
2230	110	630	0.3	12	1.0	9
Average	145	650	0.4	16	1.3	11

TABLE C6

TOTAL METAL CONCENTRATION IN RACEWAY WATER SAMPLES

Sampling Period #3 (13 November 1976)

Raceway Number	MID POINT ppb Fe	Mn	Cd	Cu	Ni	Zn	DISCHARGE ppb Fe	Mn	Cd	Cu	Ni	Zn
0630 13 Nov 76												
1	50	790	0.4	6.6	0.8	17	130	110	0.2	5.6	1.0	11
2	100	550	0.1	2.7	1.5	8	70	220	0.2	5.4	1.0	9
3	130	480	0.1	4.4	1.0	6	10	90	0.2	8.0	1.0	7
4	50	570	0.1	4.5	1.2	6	110	280	0.3	6.4	1.0	8
5	40	150	0.1	6.4	1.0	5	75	480	0.2	5.7	1.0	8
6	120	300	0.2	3.5	1.0	9	90	130	0.1	3.0	0.8	9
7	90	150	0.1	9.0	1.0	6	35	150	0.2	4.0	1.0	13
8	40	240	0.4	6.0	0.8	14	20	110	0.3	2.6	1.0	10
9	30	530	0.2	8.7	1.0	9	130	100	0.3	2.6	0.8	8
10	160	330	0.4	8.2	1.5	7	120	60	0.2	1.3	1.0	9
11	200	310	0.3	7.5	1.2	10	100	90	0.4	6.0	1.0	12
12(control)	250	300	0.2	4.2	1.5	13	200	100	0.3	3.8	1.0	13
1430 13 Nov 76												
1	75	200	0.1	8.0	3.2	24	60	150	0.3	1.4	1.4	17
2	120	350	0.1	2.5	2.0	10	55	130	0.4	1.5	1.4	12
3	170	190	0.1	2.3	2.0	10	120	110	0.6	0.9	1.4	11
4	320	60	0.2	1.4	2.0	19	85	130	0.6	1.0	1.4	14
5	180	250	0.1	7.2	2.0	11	15	150	0.3	1.5	1.0	11
6	180	300	0.1	1.5	1.8	11	15	150	0.3	1.0	1.0	9
7	240	330	0.2	7.2	2.0	15	20	130	0.4	1.8	1.0	8
8	260	570	0.2	6.3	2.0	16	25	60	0.2	1.2	1.0	11
9	170	500	0.1	6.3	3.2	11	15	60	0.3	2.0	1.0	8
10	120	610	0.4	5.4	1.4	14	75	110	0.3	1.4	1.0	14
11	140	470	0.1	5.4	1.8	9	15	60	0.5	1.8	1.0	9
12(control)	170	1400	1.0	9.0	1.8	31	15	900	0.5	7.4	1.0	10

TABLE C7

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #4 (14 November 1976)

Time	Fe	Mn	Cd	Cu	Ni	Zn
	ppb					
0030	250	800	0.4	10	1.2	14
0230	130	810	0.4	11	1.0	15
0430	20	810	0.4	16	1.0	8
0630	10	830	0.4	12	1.0	9
0830	90	1200	0.4	13	2.4	9
1030	25	1500	0.4	12	1.6	9
1230	40	1700	0.5	10	1.6	10
1430	40	1700	0.3	9	1.0	12
1630	40	1900	0.3	7	1.6	17
1830	50	2400	0.3	6	1.0	10
2030	50	2000	0.3	7	1.0	8
2230	50	2200	0.3	7	1.6	8
Average	65	1500	0.4	10	1.3	11

TABLE C8

TOTAL METAL CONCENTRATION IN RACEWAY WATER SAMPLES

Sampling Period #4 (14 November 1976)

Raceway Number	MID POINT ppb						DISCHARGE ppb					
	Fe	Mn	Cd	Cu	Ni	Zn	Fe	Mn	Cd	Cu	Ni	Zn
0630 14 Nov 76												
1	50	260	0.4	4.2	1.4	9	110	190	0.2	7.8	1.2	8
2	75	240	0.3	4.2	1.4	10	180	170	0.2	9.8	1.0	19
3	45	390	0.4	5.2	1.4	8	250	110	0.2	8.2	1.2	15
4	90	240	0.4	4.2	1.2	8	180	220	0.2	1.5	1.0	8
5	130	390	0.4	4.0	1.2	14	110	140	0.3	1.1	1.2	8
6	95	390	0.4	4.8	1.0	13	60	170	0.3	1.4	1.0	8
7	130	420	0.5	5.1	1.0	9	50	170	0.3	1.0	1.0	8
8	250	520	0.5	4.2	1.0	10	70	300	0.3	8.0	1.0	7
9	250	630	0.5	4.0	1.0	8	150	260	0.3	6.2	1.0	13
10	50	660	0.5	4.0	1.0	9	250	280	0.5	2.5	1.0	11
11	50	660	0.5	4.2	1.2	13	190	280	0.3	1.8	2.0	16
12(control)	250	1200	0.7	4.2	2.0	20	50	940	0.4	1.5	2.0	26
1430 14 Nov 76												
1	130	500	0.3	6.4	1.2	15	40	40	0.2	2.2	1.8	8
2	40	370	0.3	3.0	1.0	9	65	200	0.3	1.4	2.0	10
3	40	390	0.4	1.1	1.2	15	90	150	0.2	1.0	1.4	15
4	40	110	0.2	2.5	1.2	7	60	200	0.4	8.2	2.5	19
5	130	440	0.3	1.0	1.2	8	35	170	0.2	5.8	2.2	9
6	40	310	0.3	1.1	1.0	12	160	170	0.3	1.2	2.2	14
7	50	350	0.4	6.0	1.0	10	170	200	0.3	1.0	2.5	19
8	170	480	0.7	1.1	4.4	16	140	150	0.3	9.1	1.8	17
9	80	610	0.3	9.1	2.5	17	75	150	0.3	9.6	1.8	11
10	60	530	0.3	9.1	2.5	12	65	190	0.3	1.2	1.8	9
11	90	550	0.2	9.6	4.4	10	85	280	0.3	1.1	1.8	14
12(control)	40	1500	1.0	1.5	4.4	40	130	940	0.3	4.6	1.8	11

TABLE C9

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #5 (15 November 1976)

Time	ppb					
	Fe	Mn	Cd	Cu	Ni	Zn
0030	50	2200	0.3	7.0	1.6	8
0230	75	2700	0.2	6.0	1.9	18
0430	100	3000	0.2	5.6	1.6	9
0630	120	3800	0.2	3.2	2.6	20
0830	95	3600	0.2	3.2	2.0	12
1030	1900	3500	0.2	4.6	2.5	19
1230	1300	3500	0.2	3.9	1.7	12
1430	1600	3400	0.2	5.6	2.2	10
1630	2200	3300	0.3	5.4	2.3	9
1830	2500	3200	0.4	4.6	3.2	9
2030	1300	3300	0.3	3.6	2.3	10
2230	1800	3500	0.3	5.0	3.0	12
Average	1080	3250	0.2	4.8	2.2	12

TABLE C10

TOTAL METAL CONCENTRATION IN RACEWAY WATER SAMPLES

Sampling Period #5 (15 November 1976)

Raceway Number	MID POINT ppb						DISCHARGE ppb					
	Fe	Mn	Cd	Cu	Ni	Zn	Fe	Mn	Cd	Cu	Ni	Zn
0630 15 Nov 76												
1	250	770	0.7	5.8	2.2	30	110	630	0.1	6.6	2.2	8
2	60	1700	0.3	4.6	2.2	8	80	1000	0.3	2.5	2.5	11
3	85	900	0.3	4.6	1.4	15	55	970	0.3	2.0	3.4	8
4	90	2300	0.4	5.8	2.9	10	80	950	0.6	3.2	3.4	7
5	95	1900	0.3	4.5	2.9	16	110	1300	0.3	2.0	3.4	8
6	110	2500	0.3	4.5	2.9	16	55	1100	0.3	4.2	3.4	18
7	120	2000	0.3	4.5	2.5	20	90	1100	0.3	3.2	2.5	20
8	130	2200	0.3	4.1	2.4	21	65	1500	0.3	3.2	2.5	5
9	250	2100	0.3	4.1	2.4	21	110	1800	0.3	3.2	2.5	5
10	70	2900	0.4	3.2	2.5	9	60	1800	0.3	3.2	2.5	4
11	150	2200	0.4	4.1	2.6	8	40	1000	0.3	3.2	2.5	2
12(control)	110	3300	0.4	3.2	2.5	11	130	2600	0.3	3.6	2.3	18
1430 15 Nov 76												
1	1500	1700	0.4	8.6	2.5	15	150	1300	0.3	5.2	1.4	9
2	210	2200	0.3	9.5	2.9	20	170	1800	0.2	5.2	1.4	19
3	130	2800	0.2	7.0	3.4	25	50	1900	0.2	4.8	1.6	30
4	1500	3000	0.2	9.9	3.4	13	1500	2500	0.3	7.6	1.6	25
5	210	2900	0.2	6.6	1.9	13	160	2300	0.3	4.8	1.6	18
6	1500	2800	0.2	8.0	2.0	13	240	2100	0.4	6.2	2.2	17
7	1500	2700	0.3	9.5	2.8	23	170	2400	0.3	4.2	2.2	13
8	1500	3000	0.4	9.7	3.6	15	450	2600	0.4	4.8	2.4	25
9	1500	3000	0.7	5.6	2.2	8	230	2800	0.2	4.2	2.4	11
10	1500	3000	0.3	8.0	2.8	9	200	2900	0.1	4.1	2.6	8
11	1500	3300	0.5	9.9	5.0	13	250	2700	0.1	3.6	3.0	12
12(control)	1500	3400	1.0	12.0	5.0	25	1000	3100	0.2	2.5	1.2	8

TABLE C11

TOTAL METAL CONCENTRATION IN INFLUENT WATER SAMPLES

Sampling Period #6 (16 November 1976)

Time	Fe (ppb)	Mn (ppb)	Cd (ppb)	Cu (ppb)	Ni (ppb)	Zn (ppb)
0030	250	3600	0.2	2.2	1.4	9
0230	1200	3600	0.2	3.6	2.3	9
0430	1650	3700	0.2	2.2	1.2	16
0630	1100	3900	0.2	3.6	2.6	24
0830	1100	3900	0.3	2.5	1.6	15
1030*	1900	4500	0.3	4.5	2.8	16
1230*	1400	8500	0.3	5.6	3.1	18
1430*	3000	14,000	0.3	6.8	3.2	19
Average	1575	4700	0.25	3.9	2.3	16

*High suspended load

AD-A063 643 WINDOM (HERBERT L) SAVANNAH GA F/G 13/3
ABILITY OF SALT MARSHES TO REMOVE NUTRIENTS AND HEAVY METALS FR--ETC(U)
DEC 77 H L WINDOM DACW21-76-C-0134
UNCLASSIFIED WES-TR-D-77-37 NL

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TABLE C12

TOTAL METAL CONCENTRATION IN RACEWAY
WATER SAMPLES
Sampling Period #6 (16 November 1976)

Raceway Number	MID POINT ppb Fe	Mn	Cd	Cu	Ni	Zn	DISCHARGE ppb Fe	Mn	Cd	Cu	Ni	Zn
0630 16 Nov 76												
1	1400	3,100	0.2	3.8	1.9	12	850	1900	0.2	2.2	1.4	6
2	1300	3,000	0.2	4.2	2.6	15	1200	2500	0.2	3.6	1.9	13
3	1050	2,950	0.3	3.7	2.2	19	700	2700	0.2	2.2	1.1	14
4	1100	3,200	0.2	3.5	2.4	11	950	2300	0.2	3.2	1.8	7
5	1650	3,300	0.3	4.4	3.8	15	1400	2400	0.2	4.0	3.4	13
6	2500	3,200	0.2	3.2	19	18	2400	2800	0.4	4.0	3.2	14
7	1400	3,100	0.2	4.4	2.5	11	1500	2700	0.3	4.2	2.3	7
8	1900	2,900	0.1	4.4	2.6	12	2000	2700	0.3	5.0	2.9	11
9	1500	3,200	0.3	5.4	2.6	12	550	2900	0.2	1.8	1.1	12
10	2500	3,100	0.3	4.6	2.9	16	1300	3000	0.3	3.8	2.2	16
11	1900	3,400	0.2	3.9	2.9	12	850	1000	0.1	2.5	1.5	18
12(control)	1900	3,900	0.2	4.2	3.4	12	1500	3600	0.4	3.9	4.5	14
1	980	2,900	0.3	2.5	2.7	17	1100	2200	0.1	3.2	3.0	13
2	1300	2,700	0.3	3.6	2.5	13	1800	2700	0.2	4.6	2.6	12
3	2200	3,200	0.3	4.2	3.5	18	1400	2600	0.2	4.2	2.6	7
4	1800	2,800	0.2	3.6	3.6	16	2000	2600	0.2	4.2	2.6	7
5	1700	2,900	0.2	4.0	3.1	17	250	2400	0.2	1.8	1.7	9
6	2500	3,500	0.2	4.2	3.3	16	900	2600	0.2	3.2	2.3	15
7	650	3,200	0.2	2.2	2.1	18	800	2600	0.2	4.0	2.5	8
8	700	3,100	0.3	2.8	2.5	19	850	2800	0.2	4.2	2.9	6
9	3000	1,100	0.1	5.0	1.9	20	1600	3000	0.2	2.2	2.0	14
10	2500	9,600	0.2	4.6	1.4	12	2000	2800	0.2	2.8	1.9	9
11	2500	10,000	0.1	6.4	0.9	12	2000	2800	0.2	3.2	2.5	16
12(control)	2700	14,000	0.2	5.2	1.9	20	3000	9900	0.2	5.4	1.4	20

APPENDIX D

CHEMISTRY (N, P, Fe, Mn, Cd, Cu, Ni AND Zn) OF SEDIMENTS AND *Spartina alterniflora* ROOTS AND LEAVES FROM EXPERIMENTAL RACEWAYS BEFORE AND AFTER EXPERIMENTS

TABLE D1

RACEWAY SEDIMENT CHEMISTRY BEFORE EXPERIMENTS

(August 1976)

Raceway	Volatile Solids (%)	(Concentrations on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1 A	22	0.8	21	1.4	150	0.16	9	4.0	31
B	75	1.6	120	1.2	940	0.03	5	2.9	40
C	17	0.2	36	1.8	290	0.12	12	7.3	30
2 A	19	0.7	28	1.4	200	0.11	13	4.2	32
B	34	0.7	34	2.4	470	0.22	20	8.4	56
C	15	0.6	32	1.9	180	0.16	14	4.6	38
3 A	25	0.8	14	1.3	170	0.14	11	7.2	30
B	35	0.6	36	1.9	330	0.11	11	8.8	26
C	20	0.1	30	1.8	250	0.11	14	5.7	30
4 A	18	0.8	19	1.1	200	0.11	11	5.0	18
B	41	1.3	32	2.0	330	0.13	18	11	31
C	26	0.9	44	1.6	350	0.10	6	1.2	31
5 A	23	1.1	22	1.2	150	0.14	11	4.2	23
B	37	0.9	38	2.2	440	0.16	17	10	46
C	24	0.5	18	1.0	250	0.07	9	3.8	17
6 A	27	0.9	26	1.5	300	0.09	15	7.8	19
B	40	0.9	25	1.8	370	0.12	10	8.3	29
C	30	1.6	23	2.7	610	0.16	30	7.4	47
7 A	27	1.2	29	1.5	190	0.16	13	2.6	32
B	44	1.3	33	2.3	460	0.29	22	5.9	32
C	37	0.9	22	1.5	330	0.11	8	11	14
8 A	32	0.5	24	1.2	280	0.08	11	6.6	44
B	39	0.1	30	2.2	490	0.31	35	7.5	29
C	32	0.7	30	2.1	500	0.16	14	14	42
9 A	29	0.8	28	1.5	340	0.06	12	5.6	22
B	46	0.1	34	2.2	1100	0.10	15	9.5	37
C	39	0.2	24	1.5	400	0.08	12	2.1	20
10 A	34	0.4	19	1.1	320	0.07	10	7.1	17
B	49	0.5	33	1.8	580	0.20	17	13	13
C	52	0.8	18	1.2	310	0.07	5	3.5	19
11 A	42	0.2	21	1.1	290	0.07	10	5.5	19
B	54	0.3	21	1.2	320	0.25	19	12	43
C	45	0.9	23	1.2	300	0.16	12	7.2	25

TABLE D2

CHEMISTRY OF *Spartina alterniflora* ROOTS IN RACEWAYS BEFORE EXPERIMENTS

(August 1976)

Raceway		(Concentration on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1	A	0.7	130	0.1	40	0.08	10	5.8	25
	B	0.4	300	1.3	240	0.14	15	3.3	36
	C	0.8	400	2.1	850	0.11	17	11.0	53
2	A	0.3	120	0.3	150	0.04	7	5.8	120
	B	0.1	260	1.1	110	0.07	12	1.2	20
	C	0.6	410	1.5	570	0.06	15	8.4	90
3	A	0.1	150	0.3	220	0.11	10	5.8	35
	B	0.2	100	0.9	440	0.07	3	0.6	13
	C	0.4	480	2.5	760	0.05	9	3.7	15
4	A	0.5	100	0.1	70	0.08	6	2.9	13
	B	0.9	80	0.1	80	0.07	4	0.6	14
	C	0.3	620	1.4	790	0.09	18	8.9	38
5	A	0.4	130	0.4	270	0.15	11	7.0	25
	B	0.6	360	2.5	650	0.10	7	1.3	23
	C	1.0	230	1.4	560	0.06	13	7.7	39
6	A	0.1	460	0.4	400	0.10	16	8.6	53
	B	0.3	140	0.5	300	0.05	6	2.0	17
	C	0.5	230	1.3	640	0.07	8	6.2	50
7	A	0.2	180	0.4	290	0.13	9	7.6	90
	B	0.3	240	1.1	980	0.08	9	5.8	23
	C	0.7	270	1.0	150	0.09	9	8.1	29
8	A	0.6	100	0.1	70	0.10	14	6.8	27
	B	1.0	200	0.6	840	0.09	9	1.4	27
	C	0.2	400	1.5	120	0.09	12	7.1	25
9	A	0.3	120	0.2	120	0.11	11	5.5	22
	B	0.7	220	0.6	580	0.10	10	2.9	30
	C	0.8	240	0.8	490	0.09	9	7.3	29
10	A	0.3	200	0.6	490	0.24	25	1.6	43
	B	0.6	280	.13	210	0.06	9	7.4	24
	C	0.4	200	0.7	650	0.08	10	4.6	29
11	A	0.9	240	0.4	490	0.23	16	1.0	37
	B	1.0	230	0.5	830	0.06	5	5.8	14
	C	0.3	220	0.3	260	0.05	7	3.7	17

TABLE D3

CHEMISTRY OF *Spartina alterniflora* LEAVES IN RACEWAYS BEFORE EXPERIMENTS

(August 1976)

Raceway		(Concentration on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1	A	0.2	500	0.06	150	0.08	4.8	5.6	8
	B	0.5	450	0.04	220	0.03	8.6	2.2	14
	C	0.7	240	0.02	430	0.08	3.4	7.5	17
2	A	0.3	650	0.05	210	0.06	8.2	1.0	11
	B	0.9	370	0.02	130	0.02	5.6	1.5	7
	C	0.8	420	0.02	210	0.04	4.3	3.5	8
3	A	0.6	600	0.01	360	0.05	4.1	3.3	22
	B	0.7	400	0.02	110	0.02	4.0	4.2	13
	C	0.4	510	0.03	390	0.03	4.7	6.6	7
4	A	0.1	420	0.03	350	0.05	4.8	5.5	18
	B	0.5	380	0.06	140	0.03	6.6	5.8	10
	C	0.7	650	0.03	240	0.05	7.2	7.5	21
5	A	0.3	520	0.03	290	0.09	4.9	3.8	16
	B	0.7	390	0.02	130	0.03	2.9	3.5	11
	C	0.6	510	0.03	100	0.03	4.1	4.3	15
6	A	0.6	430	0.02	350	0.03	3.4	4.7	19
	B	0.7	370	0.02	340	0.02	4.3	3.1	14
	C	0.7	390	0.03	250	0.04	9.0	5.1	12
7	A	0.4	430	0.02	320	0.04	3.3	4.0	16
	B	0.4	360	0.01	400	0.02	3.3	0.7	12
	C	0.7	110	0.03	390	0.10	5.3	0.9	9
8	A	0.1	530	0.08	730	0.07	7.3	1.1	32
	B	0.9	320	0.01	440	0.03	4.8	1.5	13
	C	0.7	430	0.03	320	0.07	4.6	1.1	12
9	A	0.3	460	0.01	530	0.07	4.6	3.3	22
	B	0.2	350	0.01	470	0.03	2.1	1.8	12
	C	08	410	0.03	280	0.07	4.8	1.0	7
10	A	0.9	330	0.05	530	0.07	6.3	4.0	14
	B	0.1	370	0.01	690	0.02	4.0	5.6	9
	C	0.3	460	0.03	120	0.04	4.1	1.1	8
11	A	0.4	340	0.03	290	0.05	3.1	6.7	18
	B	0.5	570	0.01	570	0.02	3.8	1.0	10
	C	0.7	420	0.02	310	0.03	3.7	1 7	12

TABLE D4

RACEWAY SEDIMENT CHEMISTRY AFTER EXPERIMENTS

(December 1976)

Raceway	Volatile Solids (%)	(Concentrations on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1 A	12	2.0	50	2.4	690	0.24	27	8.6	50
B	44	1.5	36	1.2	210	0.28	40	7.3	35
C	51	1.7	27	1.1	320	0.25	70	16	18
2 A	12	1.4	47	2.1	610	0.22	25	9.3	43
B	40	1.7	20	0.8	200	0.37	27	13	34
C	42	1.6	27	1.1	360	0.63	68	2.8	27
3 A	14	1.8	51	2.5	710	0.24	26	9.9	18
B	28	2.3	26	1.1	260	0.35	21	5.7	24
C	44	2.7	16	0.8	180	0.08	33	3.8	27
4 A	14	1.8	49	3.0	800	0.26	25	12	41
B	36	5.5	80	2.5	290	0.14	44	15	69
C	45	3.6	48	1.3	310	0.15	66	16	47
5 A	22	2.4	43	3.9	1100	0.26	27	9.4	39
B	31	2.7	27	1.4	270	0.14	30	14	47
C	39	1.8	32	1.4	270	0.22	31	12	18
6 A	16	1.3	43	1.0	270	0.15	24	7.7	41
B	34	1.8	44	2.2	350	0.15	43	6.6	47
C	29	2.0	46	2.4	450	0.25	39	11	39
7 A	17	2.1	42	1.8	740	0.26	24	9.0	41
B	30	2.2	33	1.6	290	0.20	28	8.4	32
C	36	1.9	34	1.2	240	0.14	28	17	23
8 A	17	1.8	53	2.1	490	0.20	30	9.0	58
B	33	1.7	33	1.2	400	0.33	44	6.7	26
C	24	1.6	36	2.1	310	0.16	28	13	52
9 A	14	2.0	54	2.2	640	0.13	26	8.9	47
B	21	1.7	31	1.4	390	0.15	19	5.1	34
C	29	2.1	40	2.0	370	0.29	45	6.7	44
10 A	12	1.8	53	2.1	3600	0.26	31	7.6	45
B	22	2.0	103	5.1	1100	0.28	87	14	92
C	19	2.2	42	2.4	420	0.24	28	7.2	53
11 A	13	1.7	43	1.7	550	0.13	32	5.5	40
B	15	1.6	44	2.0	510	0.14	25	6.8	38
C	24	2.4	57	3.4	810	0.54	45	14	55

TABLE D5

CHEMISTRY OF *Spartina alterniflora* ROOTS IN RACEWAYS AFTER EXPERIMENTS

(December 1976)

Raceway		(Concentration on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1	A	2.0	510	0.6	500	0.08	16	9.8	53
	B	2.1	340	0.3	200	0.06	11	2.4	41
	C	1.8	300	0.3	160	0.34	26	13	50
2	A	1.9	500	1.6	770	0.63	18	11	46
	B	2.1	300	1.4	310	0.20	9	4.3	35
	C	2.0	420	0.5	290	0.36	12	3.2	43
3	A	1.8	330	0.7	560	0.35	15	10	41
	B	1.7	840	0.4	420	0.37	11	1.6	27
	C	0.8	330	0.3	230	0.24	6	4.6	36
4	A	1.7	300	0.4	520	0.35	10	11	30
	B	1.9	600	0.4	190	0.38	7	4.3	32
	C	1.6	200	0.2	70	0.14	10	6.4	45
5	A	0.5	230	0.5	160	0.36	25	9.6	82
	B	1.8	280	0.3	270	0.30	11	4.4	39
	C	2.1	270	0.4	340	0.28	9	6.1	43
6	A	0.3	180	0.3	170	0.52	14	9.6	51
	B	1.7	500	0.5	380	0.29	11	4.9	31
	C	1.9	330	1.1	320	0.17	7	4.6	32
7	A	0.6	330	1.8	280	0.82	16	2.8	39
	B	1.8	240	0.5	340	0.75	13	10	54
	C	1.6	210	0.4	60	0.35	9	11	51
8	A	1.8	170	1.6	220	0.23	14	9.0	44
	B	0.4	210	0.7	130	0.20	6	4.0	37
	C	1.3	340	1.2	320	0.35	12	7.2	38
9	A	0.8	580	2.8	590	0.22	11	5.8	32
	B	0.7	220	0.7	160	0.25	9	3.9	41
	C	1.2	300	2.3	200	0.22	8	5.1	31
10	A	0.4	400	2.5	240	0.24	11	2.9	32
	B	0.9	480	1.0	250	0.38	10	4.1	38
	C	1.3	200	1.2	170	0.18	6	10	42
11	A	1.6	340	2.5	380	0.18	11	7.8	33
	B	2.0	410	1.9	390	0.31	11	7.1	31
	C	0.5	300	1.1	180	0.20	8	1.3	27

TABLE D6

CHEMISTRY OF *Spartina alterniflora* LEAVES IN RACEWAYS AFTER EXPERIMENTS

(December 1976)

Raceway		(Concentration on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
1	A	1.8	760	0.13	210	0.07	4.8	2.4	20
	B	1.7	600	0.05	210	0.02	3.7	3.2	27
	C	1.5	480	0.02	350	0.04	3.1	2.0	22
2	A	2.1	700	0.08	100	0.05	3.2	2.1	15
	B	1.6	620	0.04	190	0.05	1.9	1.5	11
	C	1.8	460	0.02	170	0.03	3.6	0.6	10
3	A	1.5	540	0.07	100	0.04	3.1	2.0	11
	B	1.0	700	0.05	210	0.08	1.4	0.1	11
	C	1.7	360	0.02	70	0.06	2.4	0.7	8
4	A	1.0	640	0.07	120	0.07	4.3	0.8	13
	B	2.1	1500	0.03	300	0.06	3.1	0.9	16
	C	1.7	450	0.03	120	0.06	3.4	0.7	11
5	A	1.8	730	0.05	190	0.06	6.3	0.7	12
	B	1.9	600	0.03	150	0.03	1.4	3.9	14
	C	2.1	490	0.03	110	0.03	3.1	0.7	8
6	A	1.4	620	0.13	400	0.04	3.6	0.1	16
	B	2.3	630	0.03	89	0.05	2.0	3.3	10
	C	1.0	500	0.02	65	0.04	3.0	0.7	8
7	A	2.1	750	0.05	200	0.10	3.3	1.4	14
	B	1.8	590	0.04	110	0.07	2.3	0.7	20
	C	1.3	460	0.04	300	0.04	2.1	1.4	9
8	A	1.4	770	0.12	530	0.09	3.8	0.7	14
	B	1.9	700	0.04	170	0.03	2.6	0.1	15
	C	1.8	370	0.04	140	0.09	3.2	2.1	8
9	A	1.7	820	0.08	340	0.02	3.5	0.1	12
	B	2.0	760	0.11	210	0.04	2.7	1.8	12
	C	1.9	370	0.02	100	0.08	2.0	0.5	7
10	A	1.4	760	0.11	270	0.02	3.2	0.9	13
	B	1.7	750	0.10	210	0.04	3.1	1.5	13
	C	1.7	360	0.02	120	0.02	2.2	1.9	6
11	A	1.8	820	0.13	460	0.11	6.4	3.6	21
	B	1.9	760	0.11	210	0.05	3.9	1.7	13
	C	2.1	490	0.04	100	0.04	3.4	2.5	8

APPENDIX E

CHEMISTRY (N, P, Fe, Mn, Cd, Cu, Ni AND Zn) OF SEDIMENTS AND *Spartina alterniflora* ROOTS AND LEAVES FROM CONTROL STATIONS BEFORE AND AFTER EXPERIMENTS

TABLE E1

CHEMISTRY OF SEDIMENTS FROM CONTROL STATIONS

Station Number	Volatile Solids (%)	(Concentration on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
August 76									
1	14	0.9	50	1.5	320	0.25	16	5.5	60
2	16	1.4	37	1.6	340	0.19	15	3.7	48
3	36	0.8	29	1.8	280	0.19	18	14	14
4	53	1.0	23	1.7	350	0.30	25	12	55
5	47	0.9	22	1.3	220	0.10	19	6.4	22
6	31	1.1	64	1.9	780	0.20	21	11	56
7	18	0.4	47	1.1	540	0.19	15	3.1	35
8	15	0.6	54	1.8	190	0.18	15	6.6	49
Average	29	0.9	41	1.6	380	0.20	18	7.8	42
Standard Deviation	±15	±0.3	±15	±0.3	±190	±0.06	± 3	±4.0	±17
December 76									
1	15	1.0	42	1.9	300	0.22	23	4.9	40
2	11	1.2	27	1.0	320	0.09	12	1.8	24
3	23	0.4	33	1.6	430	0.07	19	5.8	31
4	46	0.9	53	1.5	440	0.10	5.2	14	35
5	36	1.0	23	0.7	180	0.04	18	7.2	25
6	34	1.6	32	1.5	330	0.14	22	9.6	40
7	17	0.6	42	1.8	260	0.21	24	9.0	50
8	17	0.5	35	1.8	290	0.13	22	5.7	40
Average	25	0.9	36	1.5	320	0.12	24	7.3	36
Standard Deviation	±12	±0.3	± 9	±0.4	± 90	±0.06	±12	±3.6	± 9

TABLE E2

CHEMISTRY OF *Spartina alterniflora* ROOTS FROM CONTROL STATIONS

(Concentrations on a Dry Weight Basis)

Station Number	N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
August 76								
1	0.3	130	2.0	320	0.22	17	3.5	39
2	0.5	380	2.0	400	0.22	14	1.0	23
3	1.0	360	1.3	500	0.20	19	5.3	39
4	0.7	230	0.3	130	0.15	10	3.9	14
5	0.4	190	0.2	410	0.11	15	3.6	30
6	0.5	280	0.7	120	0.12	9	4.2	20
7	0.2	320	0.3	640	0.14	17	6.4	30
8	0.1	480	0.3	360	0.04	9	2.2	35
Average	0.5	300	0.9	360	0.15	14	3.7	29
Standard Deviation	±0.3	±110	±0.8	±170	±0.06	± 4	±1.7	± 9
December 76								
1	1.1	400	1.8	300	0.04	11	4.1	85
2	0.8	120	1.7	260	0.03	8	2.4	33
3	0.6	610	1.1	490	0.02	22	3.9	28
4	0.1	300	0.3	700	0.04	10	2.5	18
5	0.4	290	0.5	80	0.19	12	3.0	66
6	0.3	220	1.1	170	0.17	14	9.6	37
7	0.6	280	1.7	310	0.19	16	5.0	54
8	0.7	420	1.6	160	0.19	9	6.0	25
Average	0.6	330	1.2	310	0.11	13	4.5	43
Standard Deviation	±0.3	±150	±0.6	±200	±0.08	± 4	±2.3	±23

TABLE E3

CHEMISTRY OF *Spartina alterniflora* LEAVES FROM CONTROL STATIONS

Station Number	(Concentrations on a Dry Weight Basis) N (%)	P (ppm)	Fe (%)	Mn (ppm)	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)
August 76								
1	0.5	570	0.1	150	0.03	8.7	1.9	11
2	0.4	640	0.2	260	0.08	6.2	2.4	10
3	0.7	390	0.1	260	0.11	5.6	1.5	10
4	0.1	360	0.1	250	0.02	0.2	1.1	8
5	0.2	300	0.1	350	0.01	3.1	0.8	10
6	0.3	430	0.1	170	0.04	3.8	1.0	14
7	0.2	500	0.2	390	0.02	6.3	1.8	14
8	0.4	370	0.3	140	0.02	4.8	2.8	11
Average	0.4	440	0.14	240	0.04	5.6	1.7	11
Standard Deviation	±0.2	±120	±0.07	± 90	±0.03	±1.7	±0.7	± 2
December 76								
1	0.9	880	0.1	300	0.03	4.6	0.8	16
2	0.3	540	0.1	150	0.07	2.3	0.5	10
3	0.2	670	0.1	170	0.04	2.7	0.6	11
4	0.3	470	0.1	220	0.04	2.6	1.4	10
5	0.1	460	0.1	150	0.02	2.1	1.4	12
6	0.9	430	0.1	170	0.03	1.7	0.5	10
7	0.2	520	0.1	290	0.02	4.3	2.1	16
8	0.1	600	0.1	210	0.04	5.0	1.5	13
Average	0.4	570	0.1	210	0.04	3.2	1.1	12
Standard Deviation	±0.3	±150	±0.0	± 60	±0.02	±1.2	±0.6	± 2