THE ELLIOT DITCH CONSTRUCTED WETLANDS

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ABSTRACT

The purpose of this experiment was to determine the contaminant load reduction incurred using a constructed wetland with an average hydraulic detention time of five days in treating agricultural runoff. The main contaminants present in the runoff were nitrogen and phosphorus from agricultural fertilizers. The findings of the experiment show that significant contaminant load reduction results can be achieved with a detention time, of as little as five days, in a properly constructed wetland system.

IMPLICATIONS

Constructed wetlands are a practical solution for treating and reducing the contaminant load of nutrient laden agricultural runoff.

INTRODUCTION

On a given day in April, 7.8 million pounds nitrate, from agricultural fertilizer, will spill from the Mississippi River into the Gulf of Mexico (1). This overabundance of nitrate creates a "dead zone" in the Gulf of Mexico of roughly 5,000 to 8,000 square miles, or the size of New Jersey. This dead zone is caused by algae blooms that are fed from the nutrient rich water. The algae eventually die and decompose—removing oxygen from the water.

Very little progress has been made in recent history in methods for reducing the harmful effects caused by agricultural runoff. Moreover, from 1990 to 2002, fertilizer usage increased by 2 billion pounds in the Mississippi River basin (1). Significant portions of this fertilizer are not utilized and become the agricultural runoff that is slowly choking the Gulf of Mexico of its oxygen.

One method of reducing the contaminant load in the agricultural runoff is to divert it through constructed wetlands. Wetlands are often referred to by environmentalists as nature's kidneys. Wetlands have shown the potential and ability to remove various contaminants and pollutants from a water flow in an aesthetic, environmentally pleasing, and economical manner.

OBJECTIVES

The goal of the Elliot Ditch Constructed Wetlands was to find an economical and environmentally friendly approach to reducing the nutrient load of a ditch primarily used to convey agricultural runoff. Elliot Ditch is part of the Indian River and Little Pine Creek Watershed which flows into the Wabash River, near Lafayette, IN.

Throughout the Indian River and Little Pine Creek watershed, the concentrations of nitrates, phosphorus, and total suspended solids in the water are among the highest in the nation (2). The largest inputs of chemicals to streams occur from March through June, corresponding to spray irrigation of lagoon water, agricultural cultivation, chemical application to crop fields, and storm events.

An effective method of treatment for the growing problem of agricultural runoff pollution has remained elusive (3). The agricultural lands surrounding Elliot Ditch are drained by a tile system; therefore, a practical and economically feasible treatment process was to construct wetlands.

The wetlands, sponsored by Purdue University and a grant from the Indiana Department of Environmental Management (IDEM), are located in unincorporated Tippecanoe County, Indiana.

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THE CONSTRUCTED WETLAND DESIGN

General Design and Planning Considerations

There are a host of variables that must be considered in preparation for constructing a wetland. Care should be taken to avoid creating adverse impacts to the surrounding environment. These impacts can include: alteration of existing natural wetlands or adjacent surface water bodies, degradation of downstream water quality and groundwater sources, and introduction and spread of undesirable species of flora and fauna (4).

Constructed wetland cell designs should avoid rectangular and/or rigid shapes and try to incorporate natural landscapes whenever possible. Gravity should be used to the designers' advantage and precautions should be taken to avoid stagnant waters when possible (5). A dedicated water source should be available for use in maintaining the wetlands in times of drought (6).

The Elliot Ditch Constructed Wetlands were constructed on uplands adjacent to the Elliot Ditch, an agricultural ditch the feeds the watershed. The wetlands were shaped in a way such to mimic the flow pattern of the adjacent ditch. Gravity was incorporated into the wetland design wherever possible. The flow of the agricultural ditch to the wetlands is supplemented by a near-continuous flow of wastewater from a nearby aquaculture center.

FIGURE 1. Aerial view of Elliot Ditch Constructed Wetlands.

Surface or Subsurface Wetlands

Whether to construct a surface or subsurface wetland is a consideration that must be made. Assuming water levels are kept below the media surface, subsurface wetlands can offer some distinct advantages. With a subsurface wetland there is little risk of odors or insect vectors. In addition it is believed that the media provides a greater surface area for the treatment of certain contaminants, as well as greater thermal protection in colder environments (5).

Disadvantages to subsurface wetlands include: increased construction costs, increased time for initial flora development, and a decrease in aerobic conditions which are often desired for nutrient uptake.

In the Elliot Ditch Constructed Wetlands, three surface flow wetlands and one subsurface flow wetland were built. This was done in order to analyze the effectiveness of both subsurface and surface wetlands, cut our initial construction costs, and shorten the length of time before useful data could start to be collected.

Substrates

Substrates used in the construction of wetlands include soils, sand, gravel, rock, and organic materials. The substrate is important for several reasons:

- It supports many of the living organisms as well as a large number of the chemical and biological transformations that take place in the wetlands
- Substrates permeability affects the movement of water through the wetlands and may have adverse implications on groundwater
- Substrates provide a place of storage for many contaminants flowing through the wetland

It is important to note that the physical and chemical characteristics of a substrate are often altered upon saturation. Pore spaces are filled with water and microbial metabolism consumes the available oxygen. Since the available oxygen is consumed more quickly than it can be replaced, the substrate becomes anoxic. This reducing environment is important in the removal of nitrogen and other pollutants (7).

The soils of the Elliot Ditch watershed are generally fine-grained, with over 50% by weight finer than the no. 200 sieve. The soils are considered "prime farmland" due to their relatively low porosity and good water storage capacity. The soils are not subject to flooding during any season of the year.

FIGURE 2. Construction of Wetlands.

FIGURE 3. Emergent Flora.

FIGURE 4. Cattails dominate Elliot Ditch Constructed Wetland.

Flora

The plants are the lifeblood of most constructed wetlands. Both vascular and nonvascular plants are important. The nonvascular variety (algae) tend to affect the dissolved oxygen content of the water; while the vascular plants play more of a role in the reduction of chemical loads through conversion to cell tissue and gas transfer with the atmosphere. Other benefits of vascular plants are that they tend to stabilize the substrate, slow water flow velocities, and provide sites for microbial attachment (microorganisms aid in conversion of contaminants into innocuous or insoluble substances).

A disadvantage of both types of plants is that as they die they tend to accumulate on the floor of the wetland as organic materials; thus increasing BOD and potentially building up undesirable chemical loads in the substrate .

The type of vegetation to establish depends on the goals and objectives for the wetland. Ideally, vegetation should include a variety of species, however, many plant species have a habit of trying to 'take over', and thus choosing the one or two most appropriate species may be beneficial. Practicality might dictate limiting plant species to the most hardy, commonly found, and easily managed.

Cattails and reed canary grass have proven to be low cost, easy to establish, low maintenance, and tolerant of a wide range of climatic and contamination conditions. Cattails and reed canary grass (*Phalaris arundinacea*) can both tolerate drought conditions for several weeks. Broadleaf cattails (*Typha latifolia*) can withstand water depths up to 18 inches and narrow leaf cattails (*Typha angustifolia*) up to 12 inches. This makes control of water levels less critical for vegetation. The next most versatile and easily managed plants would be common reed (*Phragmites australis*) and various species of bulrush (*Scirpus*).

After determining the type of vegetation desired, thought should be given to the method of establishment. The common three choices for vegetation establishment, include: transplantation of rhizomes, stolons, or entire plants; mechanical seeding; and natural evolution. It has been suggested that a constructed wetland left to naturally evolve for a period of three years or more, will produce vegetation surpassing wetlands that were deliberately seeded or planted (8). The success of this method depends greatly on the source of the water used for wetland establishment and the proximity of naturally occurring wetlands and other aquatic vegetation.

In 1999 a combination a plant species were planted in the Elliot Ditch constructed wetlands (River Bulrush, Hard-stem Bulrush, Soft-stem Bulrush, Reeds and Cattails). However, it soon became evident that the bulrush and the reeds were the dominant species; and were, within several years, the only remaining plant species.

Cell Layout

The cell layout and type of a constructed wetland is another feature that is often site specific and thus needs to be considered carefully. Planning should be done in order to effectively utilize land. Care should be taken to avoid placing the wetlands in floodplains. Wherever possible, a multiple cell layout should be used. Advantages of multiple cell layouts include:

- Flexibility to manage different individual cells for different stated purposes (sediment settling, Phosphorus removal, algae stripping)
- Ability to shut down flow to individual cell for maintenance (residuals clean-out, embankment repair) without the disruption of the overall system operation
- Minimization of "short circuiting" of water flows (5).

The Elliot Ditch Constructed Wetlands consist of three 400′ × 40′ × 1.5′ surface-flow cells and one 400′ × 40′ × 1.5′ subsurface flow cell. This was done so that a cell could be shut down for maintenance with little effect on the treatment efficiency of the raw water and in order to test and study the treatment efficiencies of the two wetland types (surface and subsurface).

Water Budget

A water budget reflects the relationship between input and output of water through a system. Water inputs into the system can include inflows (wastewater and supplemental) and precipitation. Evapotranspiration, seepage, and outflows are the system outputs.

Residence time refers to the amount of time water spends in the wetlands system. In planning a constructed wetland analysis must be place upon the water budget. Literature suggests that it is necessary to have a minimum of 12 days (5) residence time to remove the necessary contaminants.

Water levels in a wetland need to remain relatively stable in order to facilitate plant growth.

The total, weir controlled, inflow/outflow of the Elliot Ditch Constructed Wetlands is approximately 0.25 cubic feet per second (cfs). The inflow of the wetland system consists of two sources (approximately 0.2 cfs being pumped from Elliot Ditch and approximate constant inflow of 0.05 cfs from a local aquaculture center). The varied sources allow the wetlands to remain relatively charged even in times of drought when the natural flow of the Elliot Ditch is stunted. The average flow of the ditch at the wetland inflow structure is approximately 0.50 cfs. The total

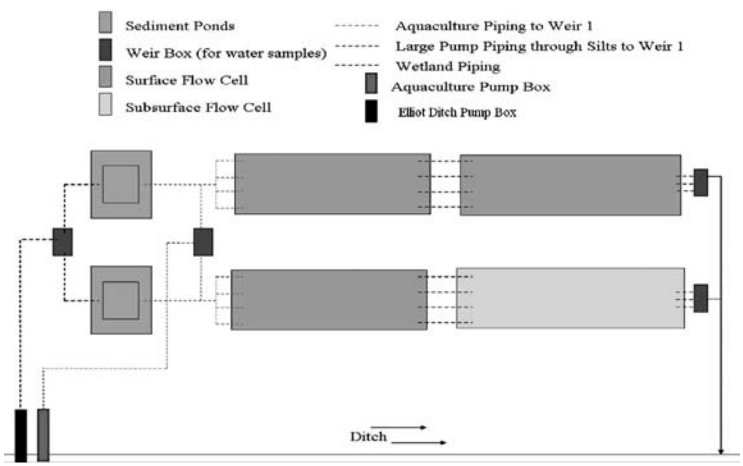


FIGURE 5. Cell Layout.

size of the wetlands is approximately 96,000 cubic feet and the hydraulic residence time of the wetlands system is approximately five days.

Due to the relatively low porosity of the soils and smaller size of the wetland system; limited attention was placed on seepage and precipitation in design calculations.

Primary Control Structure, Piping, and Pumps

If a primary control structure is to be used in order to provide a constant flow; care must be used in determining the size of both the primary control structure (PCS) and the pump(s).

Flow rates and head requirements need to be carefully determined in sizing both the PCS and the pumps. Special attention may also be required for any piping used in locations with the potential for cold weather. If the piping is placed to near to the surface, there is the potential for the pipes to freeze and crack; reducing or eliminating the fluid flow to and through the wetlands. In order to prevent this potential hazard, pipes should be placed a minimum of 3 feet below ground surface in geographic areas with moderate winters and the potential to freeze, such as the Midwest. In colder areas, constructed wetlands may not be recommended for remediation purposes, without more detailed analysis.

The Elliot Ditch wetlands utilized an adjustable and removable PCS and one five horsepower pump. A combination of two and six inch PVC piping was used throughout the project. Wherever possible, piping was laid three feet below the ground surface in order to prevent overall system damage during times of inclimate weather.

ANALYTICAL METHODOLOGY

Samples were taken daily for 21 consecutive days at six points in the wetland system

- Elliot Ditch near the intake structure
- Post sedimentation pond entering the surface wetlands
- Post sedimentation pond entering the surface/subsurface wetlands
- The surface wetlands outflow
- The surface/subsurface wetland outflow
- Elliot Ditch just downstream of the wetlands outfall.

Water samples were collected at middle water column depths utilizing a peristaltic pump and stored in sterilized glass containers. Total phosphorus (TP) samples were acidified with ultra-pure concentrated sulfuric acid. Water samples were preserved with ice until being transferred to a 4° Celsius refrigerator. Nitrate concentrations were determined by the colorimetric method (9). Total Phosphorus concentrations were determined by the automated ascorbic acid reduction method (10).

RESULTS

Sampling and monitoring continue to show impressive results at these constructed wetlands. Results of this experiment and analysis have shown:

- An average 64.8% nitrate reduction in water flowing thru the two surface wetland system
- An average 56.7% nitrate reduction in water flowing thru the surface/subsurface wetland system
- A reduction of more than 60 parts per million in nitrate concentration in the water treated by the system after an intense rain event
- An average 53.2% phosphorus reduction in water flowing thru the two surface wetland system
- An average 45.5% phosphorus reduction in water flowing thru the surface/subsurface wetland system
- A reduction of near 70 parts per billion in phosphorus concentration in the water being treated by the system after an intense rain event

The reduction in nitrate and phosphorus concentration varies depending on spray irrigation timing and precipitation. The surface wetland system was favored over the subsurface/surface system; as it had lower initial costs, a more expedited start-up time, and appealing analytical results. Monitoring the success of this project in terms of the nonpoint source pollution mitigation continues. Various wildlife species, including reptiles and amphibians, birds, and mammals, have colonized the wetlands, showing their value as habitat.

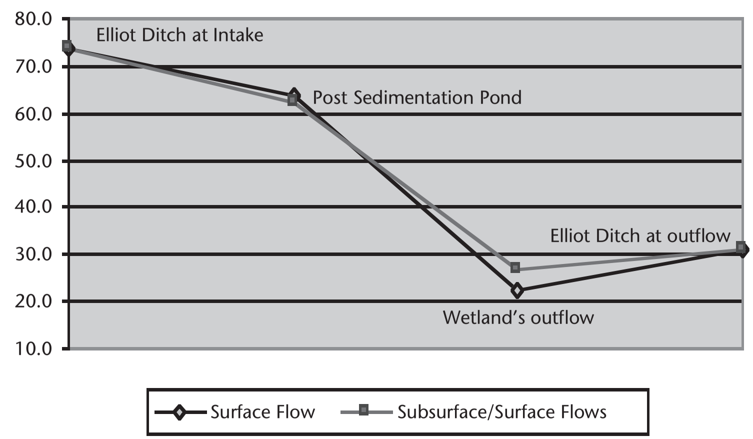
THE SPILL

In August of 2001, a hydraulic line on a manure spreader located upstream of the Elliot Ditch wetlands was ruptured. The result was a manure spill that went

FIGURES 6–7. Nitrate Reduction through Wetlands.

Average Wetlands Nitrate Reduction Performance

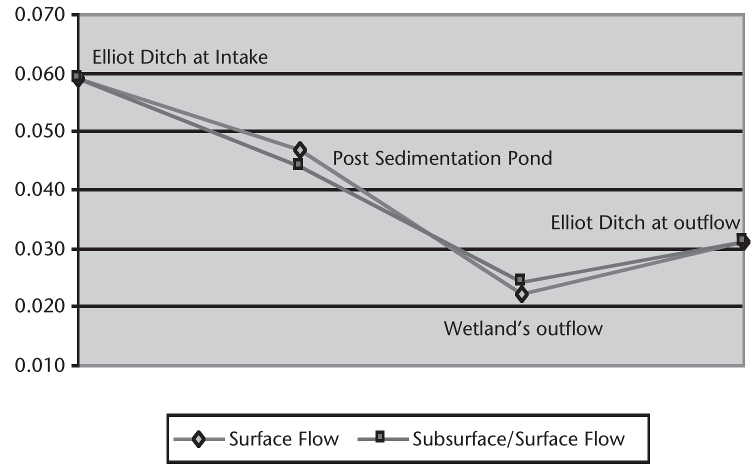
	Surface CW (mg/L)	Sub/Surface CW (mg/L)
Elliot Ditch (at intake)	73.6	73.6
CW's inflow	63.6	62.3
CW's outflow	22.4	27.0
Elliot Ditch (at outflow)	31.0	31.0
Nitrate Reduction by CW's	64.8%	56.7%
Nitrate Reduction by dilution/CW's	69.6%	63.3%
Nitrate Reduction in Elliot Ditch due to CW system	57.9%	



FIGURES 8–9. Phosphorus Reduction thru Wetlands

Average Wetlands Total Phosphorus Reduction Performance

	Surface CW (mg/L)	Sub/Surface CW (mg/L)
Elliot Ditch (at intake)	0.059	0.059
CW's inflow	0.047	0.044
CW's outflow	0.022	0.024
Elliot Ditch (at outflow)	0.031	0.031
Phosphorus Reduction by CW's	53.2%	45.5%
Phosphorus Reduction by dilution/CW's	62.7%	59.3%
Phosphorus Reduction in Elliot Ditch due to CW system	47.5%	



directly into Elliot Ditch, the ditch that the wetlands get the majority of their water from. The hydraulic line rupture led to a major excess of nitrogen potentially flowing into the Indian Creek and Little Pine watershed. Officials from the Indiana Department of Environmental Management (IDEM) came to assess the damage and determine ways to minimize the environmental damage from the spill. The ammonia concentrations in the water upstream of the wetlands were as high as 83 mg/L (11). The IDEM officials opted to build a temporary dam in the ditch and divert all the flow into the wetlands. Fortunately, the wetlands worked. The wetlands absorbed the high levels of nitrogen from the contaminated water. Following the spill, analysis of water samples by area laboratories showed that outflow from the wetland contained dramatically lower nitrogen concentrations (30-90%, depending on various factors, including the timing of sampling) than the contaminated inflow (11).

CONCLUSIONS AND FUTURE RESEARCH

The results of this experiment show that constructed wetlands have their place in the solution to the serious problems posed by nutrient laden agricultural runoff. Furthermore, the results show that a residence time of as little as five days in a constructed wetland can produce a significant improvement in water quality. The main contaminants of agricultural runoff (phosphorus and nitrogen) showed dramatically lower concentrations after being run through a constructed wetland. Additional research is still needed to ascertain the effectiveness and advantages of surface/subsurface wetlands and varieties of flora. However, constructed wetlands, built with contaminant load reduction in mind, have a great future in the restoration of waterways around the world.

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APPENDIX—RAW DATA

Date	Nitrate Levels (mg/L): Sample Point					
	Elliot Ditch (at intake)	Surface CW inflow	Sub/Surface CW inflow	Surface CW Outflow	Sub/Surface CW Outflow	Elliot Ditch (at outflow)
24-Aug	80.1	69.7	69.1	23.5	30.1	33.6
25-Aug	82.2	71.5	64.8	24.5	30.9	34.6
26-Aug	77.3	63.3	63.8	21.7	23.9	29.6
27-Aug	69.4	61.4	59.4	22.4	27.6	30.7
28-Aug	85.2	71.1	69.2	23.5	30.7	34.5
29-Aug	70.4	61.2	57.2	21.6	26.5	29.9
30-Aug	68.8	57.9	60.9	20.7	25.8	29.0
31-Aug	67.8	58.0	58.1	22.0	25.1	29.1
1-Sep	77.4	67.3	62.9	23.8	25.3	31.2
2-Sep	74.7	65.0	65.6	22.9	28.4	31.9
3-Sep	71.3	62.0	59.9	22.6	26.8	30.6
4-Sep	73.5	64.9	59.8	22.6	26.9	30.9
5-Sep	79.3	69.0	64.4	22.3	29.8	33.7
6-Sep	84.8	72.9	68.1	23.1	24.7	31.6
7-Sep	72.1	62.7	68.6	23.9	28.5	32.9
8-Sep	73.9	64.3	60.0	22.7	27.8	31.4
9-Sep	69.9	60.8	59.8	22.6	26.3	30.2
10-Sep	64.3	55.9	52.2	17.8	24.2	26.5
11-Sep	58.4	50.8	57.4	21.7	22.3	26.6
12-Sep	71.5	62.2	62.1	21.5	26.9	31.0
13-Sep	73.5	63.9	64.1	22.6	27.6	31.2
AVERAGE	73.6	63.6	62.3	22.4	27.0	31.0

Date	Total Phosphorus Levels (mg/L): Sample Point					
	Elliot Ditch (at intake)	Surface CW inflow	Sub/Surface CW inflow	Surface CW Outflow	Sub/Surface CW Outflow	Elliot Ditch (at outflow)
24-Aug	0.074	0.047	0.046	0.023	0.021	0.031
25-Aug	0.067	0.039	0.040	0.022	0.017	0.026
26-Aug	0.044	0.038	0.040	0.018	0.021	0.025
27-Aug	0.039	0.037	0.033	0.022	0.017	0.024
28-Aug	0.075	0.064	0.062	0.030	0.030	0.042
29-Aug	0.047	0.029	0.027	0.016	0.041	0.031
30-Aug	0.046	0.039	0.039	0.018	0.023	0.026
31-Aug	0.049	0.042	0.044	0.020	0.015	0.027
1-Sep	0.051	0.042	0.044	0.027	0.021	0.029
2-Sep	0.082	0.052	0.055	0.025	0.026	0.034
3-Sep	0.058	0.050	0.043	0.019	0.021	0.032
4-Sep	0.058	0.066	0.050	0.016	0.030	0.043
5-Sep	0.047	0.046	0.048	0.023	0.023	0.030
6-Sep	0.091	0.037	0.033	0.018	0.022	0.024
7-Sep	0.058	0.058	0.037	0.027	0.036	0.038
8-Sep	0.061	0.054	0.051	0.026	0.019	0.035
9-Sep	0.054	0.047	0.046	0.022	0.023	0.031
10-Sep	0.061	0.052	0.038	0.023	0.019	0.034
11-Sep	0.055	0.045	0.047	0.024	0.022	0.029
12-Sep	0.072	0.062	0.062	0.029	0.037	0.040
13-Sep	0.047	0.040	0.040	0.021	0.027	0.026
AVERAGE	0.059	0.047	0.044	0.022	0.024	0.031