CONSTRUCTED WETLANDS FOR USE AS A PART OF A DAIRY WASTEWATER MANAGEMENT SYSTEM

By

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ABSTRACT

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Animal waste disposal is of increasing concern due to larger and more concentrated livestock operations with less land available for manure application. Many treatment systems exist which treat the water effectively but are too expensive or labor intensive to be feasible for most farms. Wetlands provide an inexpensive and non-labor intensive means by which to treat wastewater and are favorable to farmers in many ways. A small-scale study investigated the feasibility of treating dairy lagoon effluent using a wetland treatment system with advanced phosphorus removal as a step in the treatment process.

Wastewater effluent from a solid separator and an anaerobic lagoon were applied to a small-scale wetland treatment system consisting of six sets of wetland cells with different retention times (6 and 12 day) and substrates (pea-stone, lava rock, and pea-stone/Septisorb mixture). Concentrations of nutrients were recorded at different stages of the wetland system and evaluated to aid in the development of design parameters for a pilot scale wetland treatment system. Pollutant reductions of 96% for phosphorus, 39% for total inorganic nitrogen, and 75% for COD were accomplished. It was concluded that the pea-stone substrate performed the best in phosphorus and COD reduction while the lava rock substrate performed the best in total inorganic nitrogen reduction.

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NOMENCLATURE

Kowalk (Chapters 2 and 3)

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EPA	Environmental Protection Agency
NH_4^+	Ammonium
NO_3^-	Nitrate
N_2	Dinitrogen gas
NO_2^-	Nitrite
N_2O	Nitrous Oxide
NH_3	Ammonia
PO_4^-	Phosphate
PVC	Polyvinylchloride
MAWN	Michigan Automated Weather Network

Drizo et al., 1997 (Section 2.4)

Fe	Iron
Al	Aluminum
Mn	Manganese

Kadlec and Knight, 1996 (Chapter 2)

kg	Kilogram
ha	Hectare
k	First order areal uptake constant [m/yr]
mg	Milligrams

Kadlec and Knight, 1996 (Chapter 2) Continued

C^*	Background concentration [mg/l]
C	Concentration of pollutant [g/m^3]
g	Grams
m	Meter
Q	Volumetric Flow Rate [m^3/d]
d	Days
t	Time [d]
t_m	Time period for averaging [d]
.	Indicates time averaging value
$\wedge$	Indicates flow weighted value
J	Net chemical reduction rate [$g/m^2/d$]
A	Wetland Surface Area [m^2]
W	Wetland width [m]
X	Distance from inlet end [m]
Λ	Flow rate per unit width [m^2/d]
q	Hydraulic loading rate [m/d]
C_i	Inlet concentration [mg/l]
Ce	Target outlet concentration [mg/l]

CHAPTER 1

INTRODUCTION

Livestock operations produce a number of wastes that require appropriate disposal or reuse. Many farmers store dairy wastewaters in anaerobic lagoons and dispose of the water through irrigation onto cropland, and by evaporation. The disadvantages of this type of system are that wastewater is extremely high in nitrogen, phosphorus, biochemical oxygen demand (BOD), and suspended solids. It can clog irrigation lines, overload the soil with nutrients, and damage young plants. Runoff from livestock farms on which excessive nutrient loadings (phosphorus and nitrogen) are generated, has been linked to downstream eutrophication of surface waters.

Some large-scale livestock operations are exploring alternative means by which to treat the wastewater. Different types of treatment options exist, such as anaerobic or aerobic digestion, activated sludge, and treating the effluent with ferric, aluminum, or calcium salts to precipitate phosphorus from the wastewater (Kadlec and Knight, 1996). While these systems have been proven to work, they are generally used for municipalities and are expensive and/or labor intensive. These systems also use electricity, plastics, concrete, and chemicals to reduce the pollution, which can result in other waste products.

Livestock waste management is tightly constrained by economics. It is necessary to develop inexpensive and sustainable management practices which require low energy inputs (Cronk, 1996). One treatment option that has proved to require little energy and still is effective in providing treatment for a variety of municipal, industrial, and agricultural wastewaters is a constructed wetland system. Wetland systems are generally more economical and less labor intensive than the wastewater treatment systems in use for municipalities (Kadlec and Knight, 1996; Hammer, D.A., 1989). For municipal systems, Kadlec and Knight (1996) cite construction costs for North American surface flow wetlands ranging from $10,000 to $100,000 per hectare, with a median of $44,600. Sub-surface wetland systems cost about eight times more, due to the need for gravel fill. Once established, the operation and maintenance costs for constructed wetlands can be lower than for alternative treatment options, generally less than $1,500/ha/year, including the cost of pumping, mechanical maintenance, and pest control (Kadlec and Knight, 1996).

According to Kadlec and Knight (1996), an irreversible first-order model does not fit wetland pollutant reduction. Two parameters, an areal uptake rate constant (k) and a background concentration (C*), are significant. The parameters allow projection of long-term average behavior of a wetland. The k-C* parameters effect the wetland area necessary for the reduction of specified pollutants (nitrogen, phosphorus, COD) to the required level, and can be used for both surface flow and sub-surface flow wetland sizing.

A treatment system based on wetlands has the potential to supply a clean source of irrigation water while reducing the use of groundwater for daily livestock use by re-circulation. It can also provide more storage volume for wastewater, reduce odors associated with wastewater storage and disposal, and reduce the threat of eutrophication to surrounding surface waters. However, wetland systems are not the entire answer for managing livestock waste; pre-treatments or post-treatments may need to be incorporated in order to maintain optimal system operation. The goal of this study is to investigate the potential of constructed wetlands, as an element of a larger system, for waste management. An example of such a system, (proposed for Green Meadows Farm in Elsie, Michigan), is shown in Figure 1.

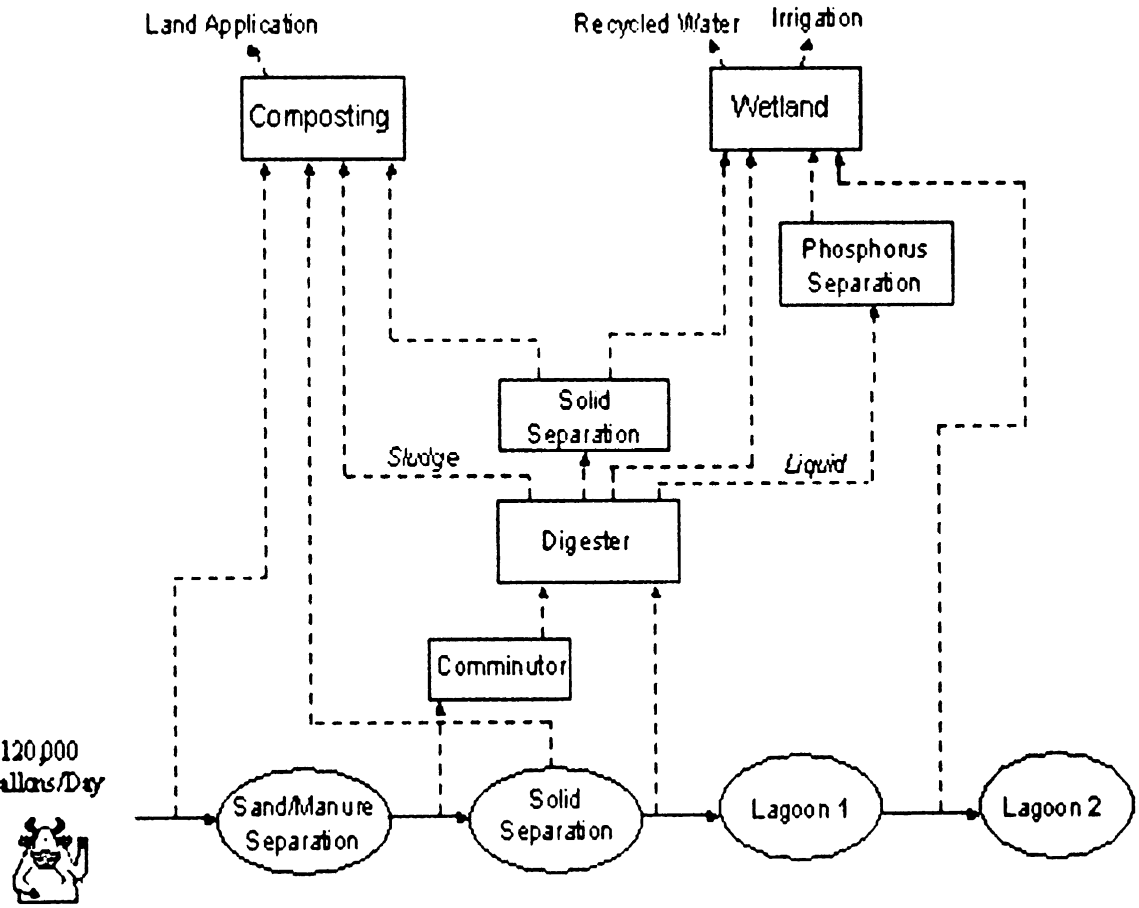

Figure 1.1: Green Meadows Wastewater Flow Chart

The constructed wetland component of the waste management system in Figure 1.1 follows other components such as a sand/manure separator, a solid separator, an anaerobic digester, a phosphorus separator, and a lagoon storage unit. These components are not necessary as a whole, but may be coordinated to bring an effective means of waste management to individual farms. The wetland in Figure 1.1 acts as the finishing treatment to the other types of systems.

There has been a significant amount of research conducted on the use of constructed wetlands for wastewater remediation. This project investigated the use of a constructed wetland as a component of a system, and in particular looked at three different substrates and two different retention times in order to establish the best combination for dairy wastewater treatment.

The primary objectives of this research were: 1) to determine the optimal retention time and substrate makeup of the constructed wetland, 2) to determine the areal rate constants for pollutant reduction, and 3) to determine the wetland area for a pilot scale treatment system.

CHAPTER 2

REVIEW OF LITERATURE

2.1 WASTE WATER CHARACTERIZATION

Wastewaters from intensive agricultural activities (cattle feedlots, swine operations, and dairies) typically have higher concentrations of organic matter and nutrients than treated municipal effluent (Geary and Moore, 1999). Dairy wastewater is characteristically high in nitrogen, phosphorus, biochemical and chemical oxygen demand (BOD & COD), and suspended solids. The average concentrations of these pollutants in dairy wastewater have been documented (Kadlec and Knight, 1996; Ahn *et al.,* 2001):

- nitrogen: 100-150 mg/l (nitrite, nitrate, ammonium, organic nitrogen)
- phosphorus: 150-200 mg/l
- COD: 30,000 mg/l
- suspended solids: 1-2% total solids

According to Part 651 of the Agricultural Waste Management Field Handbook published by the EPA (1996), 5 to 10 gallons per day of fresh water are used for each cow in a milking center in which flushing is used for waste disposal. Where manure flush cleaning, and automatic cow washers are employed, water usage can be 150 gallons per cow, per day, or more (EPA, 1996). At Green Meadows Dairy farm, wastewater inputs come from the flushing of the milking parlor, holding pen, and hospital area. The dilution is primarily due to the water added in the sand-manure separator and in the dumping of the cow drinkers, (each adds about 1 gallon per day per cow). All other wastes are scraped and not flushed. Waste characterization for the Green Meadows farm as measured by Ahn et al. (2001), and information provided by Green (2002), show the waste stream to be more concentrated than an average dairy operation due to the smaller amounts of water used for a scraping as opposed to a flushing system.

2.2 WASTE WATER TREATMENT OPTIONS

There are many treatment options to consider for dairy wastewater, including anaerobic digestion and anaerobic lagoons. These options often depend on economic situations. Treatments that are operated on an average dairy farm include; sand/manure separation, solids separation, anaerobic lagoons, land application, etc. None of these options can remove the nutrients from the wastewater to a suitable level for recycling or land application. Land application can be limited due to high phosphorus and nitrogen levels in the soil prior to treatment and the need for a lower concentration of nutrients being applied with the irrigation water. Treatments which have been explored to treat the wastewater, such as activated sludge, anaerobic or aerobic digestion, and treatment with salts, have been proven to work but are expensive and labor intensive (Kadlec and Knight, 1996). Wetlands provide an inexpensive, low-energy input to agriculture and add other advantages to the overall picture. These advantages include high treatment efficiency, minimum maintenance, low energy requirements, tolerance to variable loads, benefits to wildlife, aesthetically pleasing landscapes, and no chemical requirements. Constructed wetlands could potentially replace a wastewater lagoon and they could replace or precede land application of wastewater (Cronk, 1996). While a constructed wetland is not the only answer for a finishing treatment of wastewater on dairy farms, it seems to be the least costly treatment.

2.3 CONSTRUCTED WETLAND

A constructed wetland is an ecological system that combines physical, biological and chemical treatment mechanisms in removing pollutants from wastewater as it flows through the wetland (Environmental Protection Agency (EPA), 1999; Thomas et al., 1995). In numerous studies, wetland systems have been shown to greatly reduce BOD, suspended solids, and soluble nutrients from livestock lagoon water (Cronk, 1996; Tanner, 1994; Hammer et al., 1993; Hill et al., 1995). Because of the high rate of biological activity, a wetland can transform common pollutants into harmless byproducts and essential nutrients (Kadlec and Knight, 1996). The wetland components that affect wastewater decontamination are the substrate (sand, gravel, etc.), the vegetation (*Phragmites australis*, *Scripus*, *Typha*, *Iris*, *Glyceria*, *Schoenoplectus*, etc.), and the rhizosphere (root zone) organisms (Drizo *et al.*, 1997).

2.3.1 PLANT TYPES

The vegetation of a wetland is primarily hydrophytic, which is adapted for wet conditions. Many other plant types thrive under these conditions and are suited for treatment wetlands. Kadlec and Knight (1996) have listed nutrient removal potential among wetland plant species. Nitrogen uptake ranges from 125 kg/ha/year for *Scirpus* up to 5,850 kg/ha/year for *Eichhornia crassipes*.

Phosphorus removal ranges from 18 kg/ha/year for *Scirpus* up to 1,125 kg/ha/year for *Eichhornia crassipes.* While some plants have demonstrated the ability to take up large amounts of nutrients, most take longer periods of time to establish. However, the vegetation of a wetland is not designed for nutrient uptake but rather to enhance settling of solids and promote microbial growth (Pullin and Hammer, 1991).

Phragmites australis, or common reed, is the most widely used plant in constructed wetlands; it is used in this study. The common reed consists of rigid aerial shoots, normal roots, and flexible vertical and horizontal rhizomes. Its benefits in wastewater treatment are based on its ability to pass oxygen from the leaves through the root stems and rhizomes and out from the fine hair roots into the root zone. This causes the concentration of organisms to be significantly higher in the rhizosphere than in the surrounding soil by providing the microbes (bacteria, fungi, algae, and protozoa) a place to attach as they alter and remove nutrients for their growth cycles. The microbes also serve as predators which destroy pathogenic organisms (Langston and VanDevender, 1998).

When water passes through the root zone, it can be compared to the flow over a trickling filter in a wastewater treatment plant (Biddlestone *et al.*, 1991). The aerobic and anaerobic conditions in the root zone caused by the passing of oxygen through the plant aid the nitrification and de-nitrification processes in driving the nitrogen removal in the wetland.

2.3.2 CONSTRUCTED WETLAND TYPES

Constructed wetlands may be of two types, surface or sub-surface flow. Surface flow wetlands closely resemble natural wetlands in appearance; they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland with a combination of open-water areas, emergent vegetation, and varying water depths (EPA 1999; Kadlec and Knight, 1996; Wood, 1995). The water flows through the wetland and is treated by the leaves and stems of the emergent plants. Surface flow wetlands have become the desirable type due to the low cost of installation and attraction of wildlife. Figure 2.1 presents a diagram of a surface flow wetland cell.

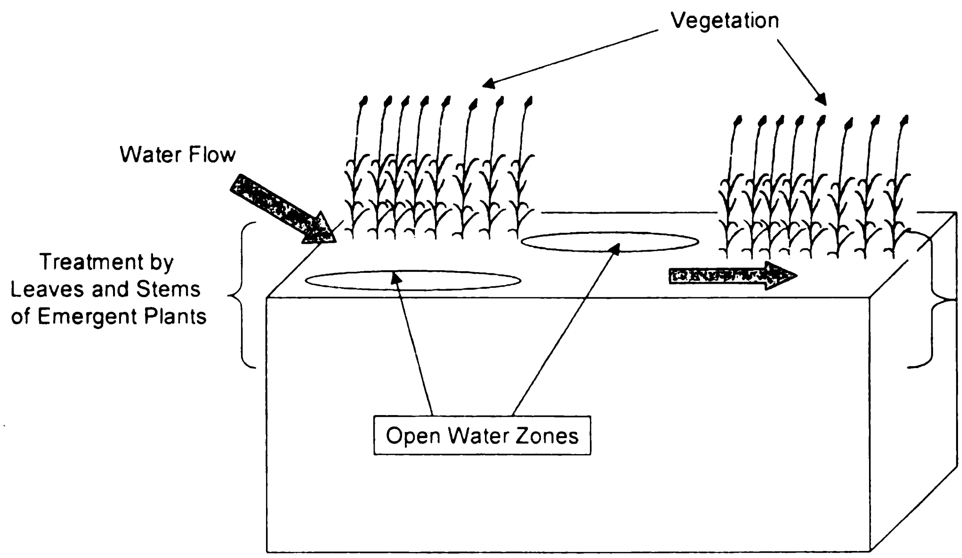

Figure 2.1: Surface Flow Wetland Cell

Sub-surface wetlands do not mirror natural wetlands because they have no standing water. They contain a bed of media (gravel, sand, crushed rock, etc.) that has been planted with aquatic plants. When properly designed and operated, wastewater stays beneath the surface of the media and flows in contact with and is treated by the roots and rhizomes of the plants (EPA, 1999; Wood, 1995). Sub-surface wetlands have demonstrated higher rates of contaminant removal than surface flow wetlands (Lorion, 2001). This has lead to many treatment wetlands designed as sub-surface flow. Other advantages of sub-surface flow include less contact with human and wildlife populations, reduction of odors associated with wastewater, and less potential for insect (Mosquito) infestation due to the water staying under the surface of the substrate. See Figure 2.2 for a diagram of a sub-surface flow wetland cell.

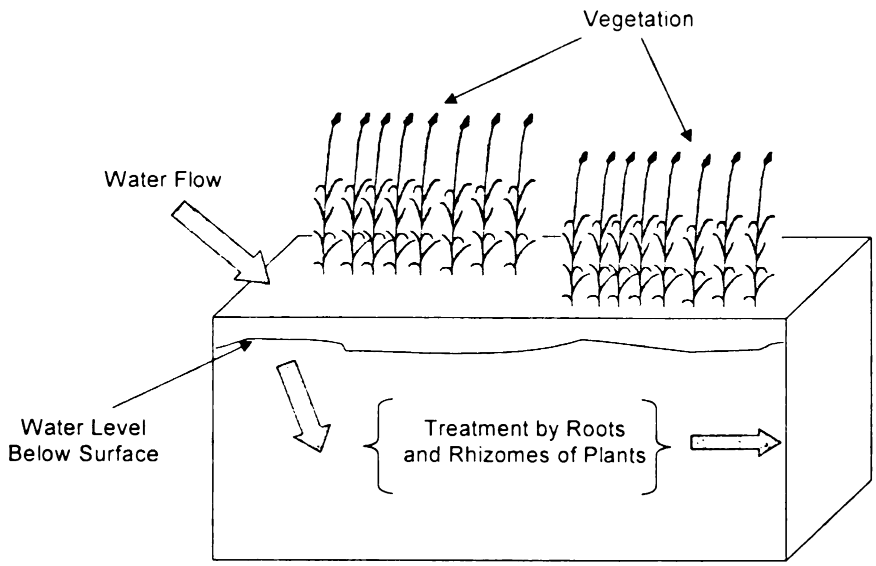

Figure 2.2: Sub-Surface Flow Wetland Cell

Oxygen enters the substrate in both types of wetlands through direct atmospheric diffusion and through plant leaves and the root system, resulting in a mixture of aerobic and anaerobic conditions (Kadlec and Knight, 1996). Wetlands remove pollutants through mechanisms such as sorption, nitrification, de-nitrification, and volatilization.

Recently, different types of wetlands have been introduced in series to provide enhanced pollutant removal (White, 1995). Skarda et al. (1994) used wetland cells which contained deep center zones, acting as surface and sub-surface flow wetlands combined, in order to provide an anaerobic area in the unplanted wetland sections. Reductions of 50-55% for nitrogen and phosphorus were obtained as well as 40-45% reduction of BOD/COD. Martin and Moshiri, (1994), found significant reductions in phosphorus (69.5%) and ammonia nitrogen (98%) in an in-series constructed wetland system used to treat landfill leachate. Sub-surface flow wetland cells, which in the past incorporated soil based substrates, experienced clogging problems and therefore have not been recommended except for tertiary polishing of effluents with low nutrient concentrations (Hammer, 1994). The use of a larger substrate in sub-surface flow wetlands has improved their ability to treat wastewater. Drizo et al. (1997) used shale as a substrate in a sub-surface flow wetland system to remove phosphorus and ammonium. The sub-surface wetlands proved effective by completely removing ammonium, removing phosphorus by 98-100% and removing nitrate by 85-95% without encountering clogging problems within the wetland. Overall, surface flow and sub-surface flow wetlands both have advantages and disadvantages.

2.4 MECHANISMS FOR POLLUTANT REMOVAL IN WETLANDS

Constructed wetlands are highly complex systems which separate and transform contaminants by physical, chemical, and biological mechanisms that may occur simultaneously or sequentially as the wastewater flows through the wetland. In the following sections, the removal mechanisms for the contaminants of concern are discussed.

2.4.1 NITROGEN

Nitrogen compounds are among the principal constituents of concern due to their role in eutrophication, their effect on the oxygen content of the receiving waters, and their benefits to plant growth (Kadlec and Knight, 1996). In the wetland studies in the past, it has been shown that they are very efficient at removing nitrogen from wastewater, with removal rates of greater than 80 percent (Kadlec and Knight, 1996). Nitrogen is removed primarily by the nitrification/de-nitrification cycle, with nitrification being the rate limiting process. Nitrogen enters constructed wetlands in particulate and dissolved organic and inorganic forms (NH_4^+, or NO_3^-). Particulate forms are removed through settling and burial, while the dissolved forms are removed by volatilization, plant and microbial uptake, and either nitrification or de-nitrification to N_2 or N_2O gas (Reddy and D'Angelo, 1997). These processes occur as follows:

- Nitrification: $NH_4^+ \longrightarrow NO_3^-, NO_2^-$
- De-Nitrification: $NO_3^- \longrightarrow N_2, N_2O$ (gases)
- Volatilization: $NH_4^+ \longrightarrow NH_3$ (gas)

The removal of NH_4^+ is largely dependent on the oxygen supply. With the substrate usually saturated and anaerobic, it is the role of the plants to supply the oxygen and subsequent aerobic regions (Drizo *et al.*, 1997). Thorough oxygenation of the substrate leads to the presence of both anaerobic and aerobic regions; each is important in the enhancement of the nitrification and de-nitrification cycles (Zhu and Sikora, 1995). See Figure 2.3 for the nitrogen removal mechanisms in a wetland.

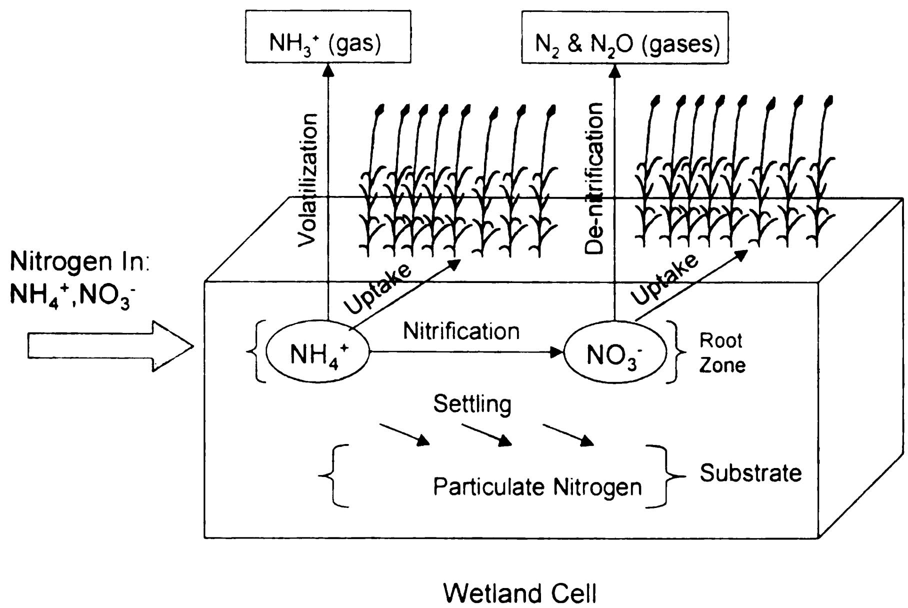

Figure 2.3: Nitrogen Removal Mechanisms in a Wetland

Nitrogen removal rates of up to 99% can be accomplished. Drizo et al. (1997) showed that virtually complete removal of ammonium occurred in wetlands planted with *Phragmites*, while unplanted wetlands yielded a removal efficiency of 40-75 percent. In the same experiment, phosphorus removal was nearly complete in both the planted and unplanted cells. Therefore, the contribution of *Phragmites* to nitrogen removal is large (between 25 and 60 percent), with little effect on phosphorus removal. According to Zhu and Sikora (1995), most wetland studies have been conducted in natural wetland soil. Their research was based on a gravel substrate and results showed that removal efficiencies were near 100 percent for nitrogen in planted cells, and lower for unplanted cells. It was believed that the larger pore space allowed more oxygen to penetrate into the substrate and aid in nitrification. Effective removal of nitrogen requires long retention times (8 to 33 days) or a large wetland area (Zhu and Sikora, 1995).

2.4.2 PHOSPHORUS

Phosphorus (PO_4^-) is considered the major limiting nutrient for freshwater systems. It is a concern to dairy farmers due to its high concentrations in wastewater and its role in eutrophication of surface water. The use of constructed wetlands to remove phosphorus has provided mixed results, most likely due to the fact that the key removal mechanism for soluble phosphorus is sorption on the wetland substrate and to a lesser extent, plant uptake (Kadlec and Knight, 1996).

Most soils can adsorb phosphorus, including those used in constructed wetlands (gravel or coarse sand), but the storage is quickly saturated under an increase in phosphorus loading (Kadlec and Knight, 1996). When the surface attachment sites available for phosphorus uptake are filled, the soluble phosphorus flows through the wetland without further treatment. Materials which contain aluminum, calcium, iron, or magnesium complexes and have large surface areas (such as clay minerals or peats) quickly and tightly bind soluble phosphorus (Faulkner and Richardson, 1989). Therefore, research has focused on substrates that have a high sorptive capacity for phosphorus and adding aluminum oxides or iron to the normal substrates to enhance phosphorus uptake.

While not the main removal pathways for phosphorus, plant and microorganism uptake do occur. Organisms within the wetland, (such as fungi, protozoa, algae, and bacteria), require phosphorus for growth and incorporate it into their tissues. Phosphorus removal by harvesting biomass of wetland plants has not proven feasible (Kadlec and Knight, 1996). It is difficult to harvest rooted emergent plants in wetlands, and when successful, relatively small amounts of phosphorus have been reclaimed in the harvested biomass (Kadlec and Knight, 1996). See Figure 2.4 for the phosphorus removal mechanisms in wetlands.

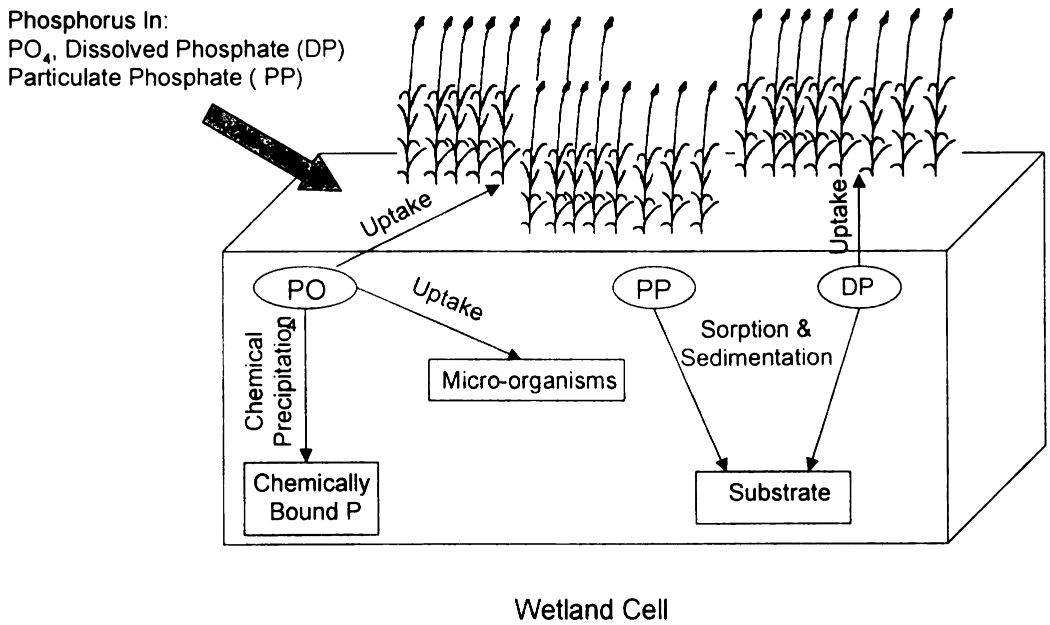

Figure 2.4: Phosphorus Removal Mechanisms in a Wetland

2.4.3 ADVANCED PHOSPHORUS REMOVAL

Immobilization of phosphorus can occur through chemical precipitation with metals (Fe, Al, Mn) and incorporation into organic matter (Drizo et al., 1997). Research conducted by James et al.(1992) established that adding small amounts of steel wool to peat (6% steel wool) can remove up to 95% of applied phosphorus; steal wool enhanced phosphorus sorption more than preformed rust; and adding steel wool to peat is more effective than mixing it with sand. It was also concluded that phosphorus sorption on iron oxides in sand and peat requires that aerobic conditions be maintained because microbial reduction of iron in the absence of oxygen as an electron acceptor releases soluble phosphorus to effluent.

2.4.4 BIOCHEMICAL/CHEMICAL OXYGEN DEMAND

Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. Chemical Oxygen Demand (COD) does not differentiate between biologically available and inert organic matter, but is a measure of total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values because it accounts for a larger group of compounds. Wastewater from livestock operations is extremely high in BOD and COD as compared to domestic sewage (Biddlestone et al., 1991). COD of municipal wastewater ranges from 250 to 1,000 mg/l while the COD of dairy wastewater ranges from 2,500 to 40,000 mg/l (Kadlec and Knight, 1996). The BOD and COD of waste that is discharged into surface waters accelerates bacterial growth and consumes oxygen levels in the rivers, leading to eutrophication and lethal oxygen levels for fish and aquatic insects.

The organic matter, or carbon, interacts strongly with wetland ecosystems. The carbon cycle in wetlands is strong and typically provides carbon exports from the wetland to receiving ecosystems. In general, the amounts of carbon cycled in the wetland far exceed the quantities added in wastewater (Kadlec and Knight, 1996). Therefore, substantial carbon reduction can be obtained from wastewater when cycled through a wetland ecosystem. Settling of particulates and breakdown of soluble BOD/COD are the main pathways for removal of BOD/COD added to wetlands during microbial respiration (Reddy and D'Angelo, 1997).

Geary and Moore (1999) showed that significant amounts of BOD are removed using a treatment wetland for dairy wastewater, with a mean monthly reduction of 61 percent. Studies by Niswander (1997) and Knight et al. (1996) reported BOD reductions of 52 percent and 68 percent, respectively. Reductions in BOD that have been reported in constructed wetland studies are due to the detention provided by storage, the presence of plants assisting with sedimentation and filtration, and various decomposition processes (Geary and Moore, 1999).

2.5 PREVIOUS INVESTIGATIONS

2.5.1 Treatment of Dairy Farm Wastewaters in Engineered Reed Bed Systems

Biddlestone, et al. (1991) investigated the use of horizontal flow reed beds to treat milking parlor washings and yard runoff at a dairy farm. Limestone chippings were used as the matrix of the wetlands and rhizome cuttings from *Phragmites* for the plant material. The rhizome cuttings proved to be an unsuccessful means of plant propagation (only an 18 percent success rate). With little root growth associated with the unsuccessful propagation, BOD reduction suffered with a removal efficiency of just 17 percent. With improved root growth after one year, the BOD reduction increased to 49 percent. The reeds flourished above ground but poor penetration of the roots into the matrix and black anaerobic conditions were observed below the surface. The reed bed design did not apply to high strength effluents with their substantial oxygen requirements as compared to dilute wastewaters. The oxygen in the system needed to be increased, and thus down-flow beds were introduced. The down-flow beds consisted of reeds planted in a thin sand layer placed above a pea-stone substrate. The open nature of the matrix and the down-flow draining of the system improved the overall BOD reduction by improved filtration of solids.

2.5.2 Suitability of a Treatment Wetland for Dairy Wastewaters

Geary and Moore (1999) studied constructed wetlands as part of a waste management system for dairy parlor water. The waste management system originally consisted of a solids separator and an anaerobic lagoon followed by land application. A 100 cubic meter wetland was introduced after the lagoon and waste was gravity fed into the wetland which was planted with three types of wetland plants including *Phragmites australis*. The retention time of the wastewater in the wetland was 10-14 days due to wide fluctuations in rainfall and water use within the dairy. Significant BOD reduction was obtained with an average reduction of 61 percent. Variable but smaller reduction was achieved for total nitrogen, (43 percent), phosphorus (28 percent), and nitrate (26 percent). The phosphorus reduction efficiencies decreased after four months, most likely due to the sorption sites of the soil slowly being filled to capacity. The wetland also proved to be oxygen limited, which reduces the nitrification process of the wetland.

2.5.3 Experiences with Two Constructed Wetlands for Treating Milking Center Wastewater in a Cold Climate

Holmes et al. (1995) conducted research on two cold-climate wetlands used to treat dairy wastewater. One of the wetlands, located in Wisconsin, treated wastewater from a 50 head dairy farm; a pre-treatment settling tank was used. The wetland was planted with river bulrush, giant burreed, and soft-stem bulrush. The wastewater was directed to the wetland from the dairy milkhouse; due to water-conserving practices, the average daily water use was only 200 gallons. The wetland successfully treated the wastewater with reductions of 75 percent in COD, 90 percent in BOD, 80 percent in phosphorus, and 75 percent in nitrogen. A difficulty faced with this system was that the flow of water did not keep the cells sufficiently moist, thereby reducing the plant height.

2.5.4 Performance of a Constructed Wetland for Dairy Waste Treatment in LaGrange County, Indiana

Reaves et al. (1994) studied the performance of a constructed wetland which treated dairy waste in Lagrange County, Indiana. A three celled surface flow wetland was installed to treat wash-water from a dairy barn. The wetland cells were approximately 200 feet by 20 feet. Hydric topsoil was used as the substrate in which cattails and smartweed were planted. Wastewater from barn wash-water and yard runoff was collected on a settling pad to remove solids prior to flow into the wetland. After one year of operation, significant reductions in the concentrations of BOD (50-75%), total Kjeldahl nitrogen (62-89%), and total suspended solids (65%) were found. Problems encountered in the system included excessive solid accumulation, insufficient water availability, lack of vegetation, and direct sunlight upon open water. The problems were detrimental to system performance. Solid build-up occurred within the first third of each cell, and shortened the life of the wetland. After the excessive solid load accumulated, the wetland became a shallow primary lagoon instead of a secondary treatment system. Insufficient water, solid build up and cattle-grazing led to a lack of vegetation. The cell which had the best plant growth also showed the best pollutant removal, suggesting vegetation played a role in system performance. Algal blooms were the result of open water areas receiving sunlight. This led to increased levels of total suspended solids in the outflow.

2.6 GENERAL DESIGN PARAMETERS

Constructed wetland design is based on a number of constraints, including site conditions (climate, geography, soils and geology, groundwater, biological conditions, etc.), characterization of the water to be treated (nutrients, BOD/COD, etc.), treatment goals, pre-treatment requirements, and post-wetland water-quality requirements (Kadlec and Knight, 1996). The most constraining of these requirements is the size of the wetland needed to reduce pollutants to an acceptable level.

According to Kadlec and Knight (1996), an irreversible first-order model does not fit wetland pollutant reduction due to the reduction of pollutants being dependant upon establishment of the root system within the wetland. Two parameters, an areal uptake rate constant (k) and a background concentration (C*), are significant. The parameters allow projection of long-term average behavior of a wetland. The k-C* parameters effect the wetland area necessary for the reduction of specified pollutants (nitrogen, phosphorus, COD) to the required level, and can be used for both surface flow and sub-surface flow wetland sizing.

Wetlands are designed for conditions after the start-up period, when adaptations have ceased and the system is in a steady-state. Time averaging of the performance of a wetland avoids the description of details involving short-term fluctuations (Kadlec and Knight, 1996). The definitions of time averaging can be applied to the water and chemical mass balances and lead to the definitions of the flow-weighted average concentration and the time average concentrations:

$$\overline{C} = \frac{1}{t_m}\int_0^{t_m} C\,dt \qquad (2.1)$$

$$\hat{C} = \frac{\frac{1}{t_m}\int_0^{t_m} QC\,dt}{\frac{1}{t_m}\int_0^{t_m} Q\,dt} = \frac{\int_0^{t_m} QC\,dt}{\overline{Q}t_m} \qquad (2.2)$$

where:

- C = concentration, g/m^3
- Q = volumetric flow rate, m^3/day
- t = time, day
- t_m = time period for averaging, day
- $^-$ = indicates time averaging value
- ^ = indicates flow-weighted average value

With inflows and influent concentrations of dairy wastewater being generally constant, short averaging periods can be used. The resulting ecosystem mass balance obtained is:

$$\frac{d(\overline{Q}\hat{C})}{dA} = -\overline{J} = -k(\overline{C} - C^*) \qquad (2.3)$$

where:

- J = net chemical reduction rate, g/m^2/day
- A = wetland surface area, m^2

If a wetland operates under relatively steady flow conditions, the averaging designation is dropped. When precipitation and evapo-transpiration are in balance over the averaging period, the volumetric flow of the wetland does not vary and the Q will be constant. Thus:

$$Q\frac{dC}{dA} = -J = -k(C - C^*) \tag{2.4}$$

Next, the area and shape of the wetland are considered. Most constructed wetlands are rectangular. The area upstream of a given point in the wetland, A, is equal to:

$$A = Wx \tag{2.5}$$

where:

- W = wetland width, m
- X = distance from inlet end, m

From equations 2.4 and 2.5:

$$Q\frac{dC}{dA} = \Lambda\frac{dC}{dx} = -k(C - C^*) \tag{2.6}$$

where:

- Λ = flow rate per unit width, = Q/W , m^2/day

Introduction of the fractional distance from the inlet to the outlet, y=x/L yields:

$$q\frac{dC}{dy} = -k(C - C^*) \tag{2.7}$$

where:

- q = hydraulic loading rate, m/d

Application of equation 2.7 requires integration from the wetland inlet, where the concentration is C_i, to an intermediate distance y, where the concentration is C. The resulting equation is the concentration profile throughout the wetland:

$$\ln(\frac{C - C^*}{C_i - C^*}) = -\frac{k}{q} y \qquad (2.8)$$

At the outlet, where the concentration is C_e:

$$\ln\left(\frac{C_e - C}{C_i - C}\right) = -\frac{k}{q} \qquad (2.9)$$

where

- C_e = outlet target concentration, mg/L
- C_i = inlet concentration, mg/L
- C^* = background concentration, mg/L
- k = first-order areal rate constant, m/yr
- q = hydraulic loading rate, m/yr

Rearrangement (and unit conversion) gives the area of the wetland required for a particular pollutant:

$$A = \left(\frac{0.0365 * Q}{k}\right) * \ln\left(\frac{C_i - C^*}{C_e - C^*}\right) \qquad (2.10)$$

where

- A = required wetland area, ha
- Q = water flow rate, m^3/day

With k, the design flow rate and the projected influent and effluent concentrations for each pollutant known, the wetland areas required to provide the target outlet concentration can be calculated. The required wetland area is the largest of the individual required areas for each pollutant.

2.7 CONSTRUCTED WETLAND COSTS

Constructed wetlands provide an inexpensive method to dairy wastewater management compared to traditional wastewater treatment processes (Kadlec and Knight, 1996; Cronk, 1996; EPA, 1999; Geary and Moore, 1999; Hammer, D.A., 1989). Constructed wetlands require low-cost earthwork, piping and pumps, and only a few concrete structures. They are inexpensive to operate and maintain (Kadlec and Knight, 1996). Because of the natural processes at work in a wetland treatment system, little fossil-fuel energy and no chemicals are necessary (Kadlec and Knight, 1996). The costs of construction and operation of a constructed wetland include capital costs as well as maintenance costs.

The major items included in the capital costs of a constructed wetland are (EPA, 1999):

- Land Costs
- Site Investigation
- Clearing and Grubbing
- Excavation and Earthwork
- Liner
- Media
- Plants
- Inlet & Outlet Structures
- Fencing
- Miscellaneous piping, pumps, etc.
- Engineering, legal, and contingencies

The capital costs are directly dependent on the treatment area of the system (EPA, 1999). The unit costs are the same for both surface flow and sub-surface flow wetlands with the exception of the media (these are more for sub-surface flow due to more substrate being used (EPA, 1999)). According to Kadlec and Knight (1996), capital costs for surface flow wetlands range between$10,000 and $100,000 per hectare ($4,000 and $40,000 per acre), with a median of $44,600 per hectare ($18,000 per acre). Costs for sub-surface flow wetlands are higher, with a median of $358,000 per hectare ($145,000 per acre). Some costs (such as land, investigation, and earthwork) are negligible when considering agricultural waste management wetlands. Most agricultural operations have land and equipment available for wetland construction, therefore the average cost for a constructed wetland for agricultural wastewater management is lower than for a municipal system. The operation costs of constructed wetland systems are similar to those of a facultative pond. The EPA (1999) found that the average annual cost for operation of a constructed wetland system was $3,000 per hectare in 1998 ($1,200 per acre).

CHAPTER 3

DESIGN RATIONALE

Both surface flow and sub-surface flow wetland types have proven to effectively reduce pollutants in previous studies (Drizo et al., 1997; Geary and Moore, 1999; Biddlestone et al., 1991; Reeves et al., 1994). Recent studies have focused on using sub-surface and surface flow wetlands in series (White, 1995), while others, such as (Skarda et al., 1994) have tried incorporating deep and shallow zones in order to gain the advantages of both surface and sub-surface wetlands.

In order to gain the advantages of both sub-surface and surface flow wetlands, this study focuses on using them in series to gain the anaerobic and aerobic zones which drive the nitrification and de-nitrification processes. Baffles were inserted in order to increase contact time between the wastewater and the rhizosphere organisms within the wetland. This increases the number of anaerobic and aerobic zones through which the wastewater passes.

The planting and propagation of wetland plants is an important step in the design of a wetland. Improper or poor propagation can lead to poor initial pollutant reduction (Biddlestone et al., 1991). In order to avoid poor propagation of the reeds in this study, the plants were grown from rhizomes and were matured in a greenhouse for four months before transplanting into the wetland cells.

A design feature that is important to pollutant reduction and wetland lifetime is the substrate makeup. Oxygen depletion in the substrate occurred in studies conducted by Biddlestone et al. (1991) and Geary and Moore (1999) due to the small pore space of the soil and little root penetration into the matrix. In an attempt to increase the oxygen in this system, a pea-stone substrate and a lava rock substrate were used to increase the pore space and allow greater root penetration into the matrix. The sub-surface and surface flow cells act as a down-flow system because the outlet of the cell is at the bottom of the soil matrix. With evaporation of water, oxygen is able to enter the top portion of the substrate to decrease the anaerobic conditions. The substrate make-up can also aid in solids removal and avoidance of clogging. Reaves et al. (1994) experienced solids accumulation which was detrimental to the wetland vegetation and decreased the lifespan of the wetland. In an attempt to remove the remaining solids, the sub-surface flow wetland cells (where the wastewater entered the wetland system) contained an unplanted pea-stone entry column that acted as a trickling filter for removal of solids before they reach the planted portion of the wetland. Wastewater was also gathered from an anaerobic lagoon which follows a solid-liquid separator; the wastewater contained approximately 1-2% solids at this point.

The major obstacle faced in the reduction of phosphorus in agricultural wastewaters is the sorption sites of the wetland substrate becoming filled quickly and soluble phosphorus flowing through the wetland freely. Geary and Moore (1994) experienced a decrease in the phosphorus removal after four months and

attributed that to the sorption sites being filled. In order to combat the phosphorus loading of the wetland, this study used an amended substrate (Septisorb) and advanced phosphorus removal in the form of a phosphorus trap/filter at the end of the wetland system. The phosphorus trap/filter was designed based on the work of James et al., 1992, who found that small amounts of steel wool, added to peat, increased the number of sorption sites for phosphorus.

Wetland flow is another important factor to consider in the design of the wetland. Holmes et al. (1995) faced the difficulty of inconsistent flow, which did not keep the wetland cells sufficiently moist. The dry conditions were detrimental to the vegetation and therefore limited the effect of the vegetation on the wetland system. In this study, the wetland does not depend on a variable flow, therefore allowing the moisture of the plants to stay above a detrimental state. Wastewater was applied at a regular dose every six days with evaporation as the only means of water loss during that period.

CHAPTER 4

EXPERIMENTAL DESIGN

4.1 WETLAND DESIGN

A small-scale wetland treatment system to receive and treat dairy lagoon wastewater was constructed at the Green Meadows Dairy farm in Elsie, Michigan. The effluent from a manure liquid-solid separator and an anaerobic lagoon at Green Meadows farm were used for the wastewater supply in this study. Because the wastewater at Green Meadow Dairy Farm is more concentrated than an average dairy wastewater (Green, 2002), it was diluted at a 4:1 ratio.

One of the goals of this study was to investigate the effects of different wetland substrates on pollutant removal. Therefore, this study examines a mixture of Septisorb (a specially formulated peat granule designed for the removal of dissolved heavy metals, phosphates, BOD, fecal coliforms, suspended solids, and organics from septic tank effluent) and pea gravel substrate, a lava rock substrate, and a pea-stone substrate to determine their sorptive efficiencies and/or capacities.

The design of the wetland system incorporates both sub-surface and surface flow wetland types in order to determine their ability to remove pollutants while working in tandem. The cells were constructed of Rubbermaid 0.568 cubic meter (150 gallon) feed tanks with PVC piping for drainage. Baffles were constructed of 2.54 cm (1 inch) foam insulation board. The total pore space of each wetland cell equals approximately 0.189 cubic meters (50 gallons).

Plug flow was assumed to occur in each wetland cell. Plug flow infers that the water maintains a constant velocity of flow in every part of the system; it allows a residence time to be defined which is the same for every streamline. The wastewater first flowed into the sub-surface cell of each set of cells (6 sets in all, including duplicates). The sub-surface wetland cells are baffled in order to control the flow of water through the wetland. Water is forced into the wetland through an unplanted section of substrate which acts as a trickling filter to remove the remaining settle-able solids before they reach the planted portion of the wetland. The first baffle routes the water through the bottom 15.24 cm (6 inches) of the wetland cell. The flow is next forced over a baffle and through the upper 15.24 cm (6 inches) of substrate before it is gravity fed to the drain. This design forces the water to have extended contact time with the roots and rhizomes of the plants. The total depth of the sub-surface flow wetland cells is 55.88 cm (22 inches). Figure 4.1 shows the design of the baffled sub-surface wetland.

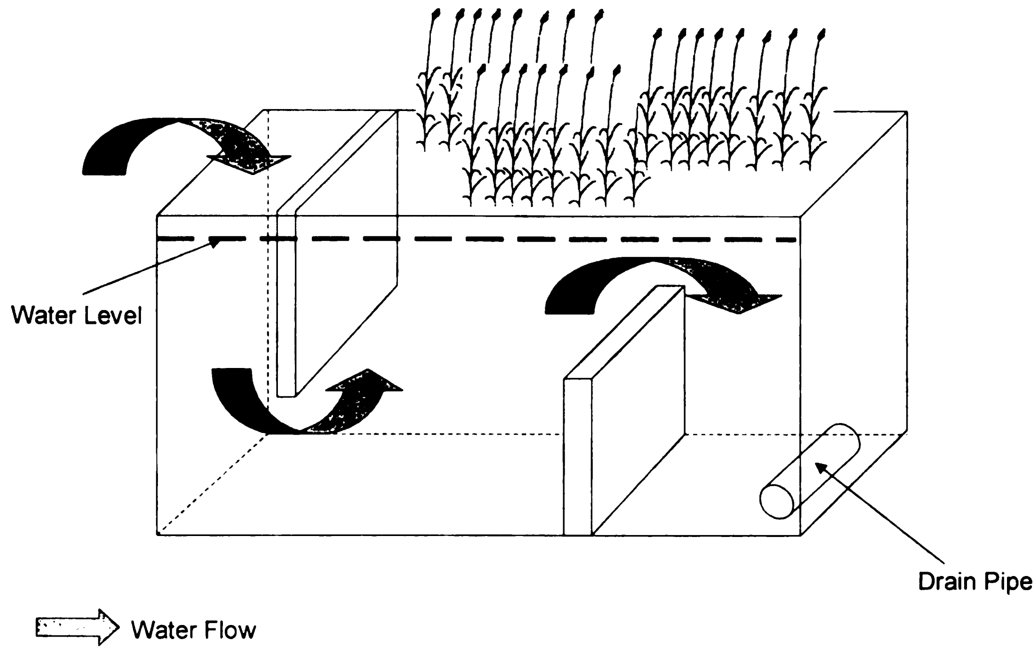

Figure 4.1: Sub-Surface Wetland Cell (Baffles)

The water then flowed via a head control device into the surface flow wetland cells. The surface flow cells have a substrate depth of 46 cm (18 inches). The water pours out of the surface flow wetland cell and into the phosphorus trap/filter for advanced phosphorus removal. The same phosphorus trap design was used for all three treatments. Each phosphorus trap/filter is 53 cm (21 inches) tall and is constructed of 15 cm (6 inch) PVC piping. Equal volumes of peat and filter sand (3.8 liters) were mixed into each trap/filter along with two sections of steel wool, each weighing 14 grams. The water flows, unsaturated, down through the peat and sand mixture and through the steel wool to a drain in the bottom of the PVC pipe. Figure 4.2 presents a diagram of the phosphorus trap and Figure 4.3 shows the wetland treatment system flow.

Figure 4.4 provides a diagram describing constructed wetland setup.

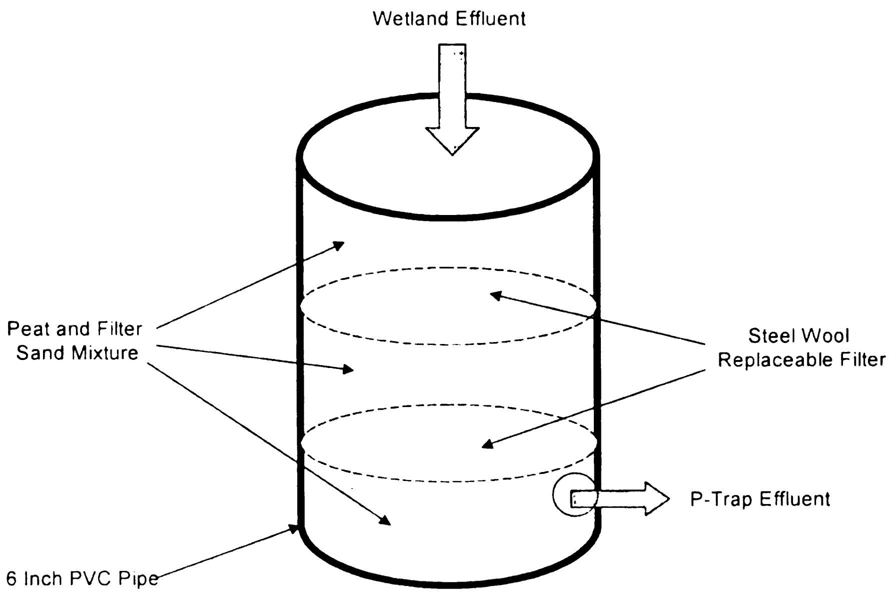

Figure 4.2: Phosphorus Trap Diagram

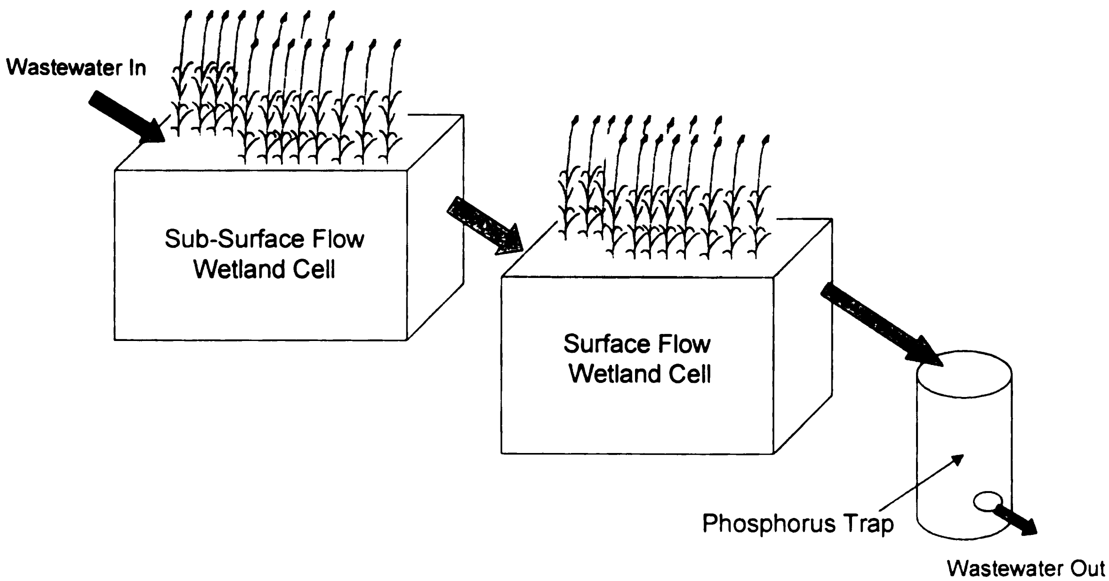

Figure 4.3: Constructed Wetland System and Wastewater Flow Pattern

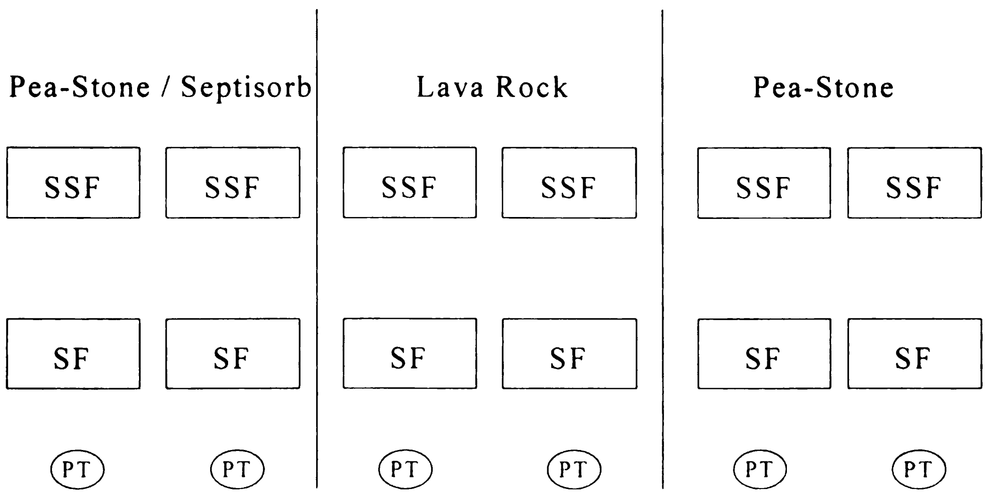

Figure 4.4: Constructed Wetland Set-up

4.2 ANALYSIS AND VARIABLES

The wetland system was set up so that different hydraulic-retention times and different substrates could be analyzed. The short retention time consisted of six days for the sub-surface cell, and six days for the surface flow cell. The long hydraulic-retention time consisted of twelve days in each wetland cell. Water flowed unsaturated through the phosphorus trap/filter. Two sets of cells incorporated a pea stone substrate, two sets had a substrate of pea stone with 10% Septisorb by weight, and the final two cells consisted of a lava rock substrate. The substrates were differed to test their capacity for phosphorus uptake and their available surface area for microbe attachment. The phosphorus trap/filter at the end of the treatment process consisted of a peat and filter sand mixture with two removable discs of steel wool.

Treatment cells were planted with *Phragmites australis* (Common Reed). Reeds matured in a greenhouse for three months before transplanting them into the wetland system. Each treatment cell set received a regular dose of approxiametly 95 liters (25 gallons) every six days. The lagoon effluent was applied for four months (June through October 2002). Rainfall data during this period was obtained from the Michigan Automated Weather Network (MAWN) station in Bath, Michigan, in order to get a close estimate of the additional water that entered the system.

Composite water samples were taken at each stage of the wetland system: at the start of a cycle (batch), at six and twelve days in sub-surface cell, at six and twelve days in surface flow cell, and before and after the phosphorus trap/filter. Figure 4.5 shows points in the wetland system where samples were taken.

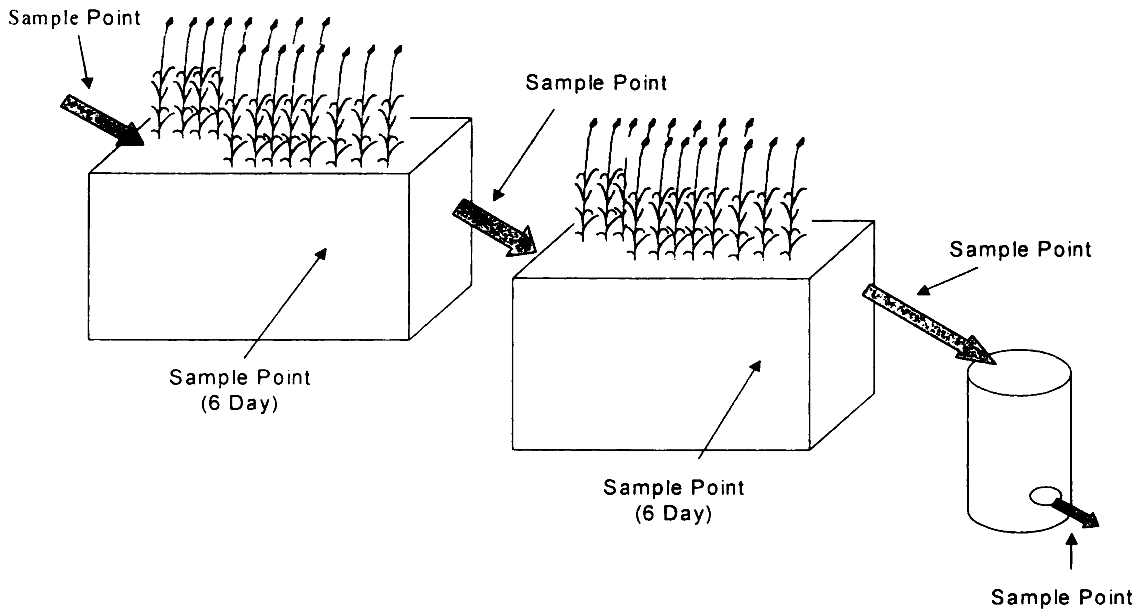

Figure 4.5: Sampling Points in Wetland System

The batch, twelve day, and phosphorus trap samples were gathered by sampling the natural flow from the inlets and outlets of the wetland and the phosphorus trap. The six day samples were gathered from stand pipes in the wetlands that were located near the drain pipe of each cell. Three well volumes were purged before sampling to insure the uniformity of the water sample. The water samples were sent to the Soil and Plant Nutrient Laboratory in the Crop and Soil Sciences Department at Michigan State University and analyzed for ortho-PO_4^- as phosphorus, NO_3^- as nitrogen, and NH_4^+ as nitrogen.

4.3 ANALYSIS OF NUTRIENTS (NO_3^-, NH_4^+, PO_4^-) and COD

The nitrate concentration in a sample was determined with a copperized cadmium column (Method 353.2 of the EPA, Methods for Chemical Analysis of Water and Wastes). The ammonium concentration was determined using the Salicylate Method (Nelson, 1983). The phosphorus concentration was determined by the QuikChem Method 10-115-01-1-A (EPA, 1983). COD analysis was performed using a closed reflux, colorimetric method (Greenberg et al., 1992).

CHAPTER 5

RESULTS AND DISCUSSION

Experimental data were collected from the pilot scale constructed wetland system at Green Meadows Dairy farm. Water quality data included samples taken at six points in the wastewater treatment process. These samples accounted for six and twelve day retention times, assuming that plug flow occurred. Due to mixing of influent with wastewater applied in previous doses, six-day samples were found to be inaccurate and therefore were not analyzed. Water samples were checked for phosphate (PO_4^-), nitrate (NO_3^-), ammonium (NH_4^+), and COD.

5.1 WETLAND DATA

Samples were taken at the outlet of each stage of the wetland cycle. Influent samples refer to the diluted wastewater stream taken from the anaerobic lagoon. Samples were taken from the outfall of the sub-surface flow wetland and the surface flow wetlands. Phosphorus trap (PT) samples were taken at the outlet. Sampling began after a dilute wastewater was applied for four months in order to establish the plants and nitrifying microorganisms in the wetland.

5.1.1 PHOSPHORUS

Selected results for phosphorus from one cycle of wastewater through the treatment system are shown in Table 5.1. One cycle refers to wastewater that has flowed through all three stages of the treatment process (24 days total). The data shows the concentrations for each substrate type through each step of the wetland treatment process (Batch, SSF, SF, and PT). The percentage reduction (%) for each wetland type is shown along with the percentage reduction for the total system.

TABLE 5.1 Phosphorus Concentration Through One Dosing Cycle

		Phosphorus Concentration								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
7/1/2002	Batch	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
	SSF	3	0.8	1.9	8.9	8.2	8.55	3	3.1	3.05
	SF	1.8	0.23	1.015	5.3	5.6	5.45	0.8	0.32	0.56
	PT Out	0.55	0.45	0.5	7.45	6.1	6.775	0.14	0.31	0.225
% RED SSF		80	95	88	42	46	44	80	80	80
% RED SF		40	71	47	40	32	36	73	90	82
% RED TOTAL		96	97	97	51	60	56	99	98	99

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells (% = (Batch - SSF Concentration)/Batch)
SF: Surface Flow Wetland Cells (% = (SSF-SF Concentration)/SSF Concentration)
PT: Phosphorus Trap

The average phosphorus reduction for the wastewater cycle was 97% for the Septisorb and pea-stone substrate, 56 % for the lava rock substrate, and 99% for the pea-stone substrate.

The average phosphorus concentration at each stage of the treatment system is shown in Table 5.2A.

Table 5.2A Average Phosphorus Concentration Through the Wetland System

	Septisorb/ Pea-Stone	Std. Dev.	Lava Rock	Std. Dev.	Pea-Stone	Std. Dev.
Batch (ppm)	21.98	6.38	21.98	6.38	21.98	6.38
SSF (ppm)	6.39	5.01	12.45	5.30	5.80	3.97
SF (ppm)	2.75	2.30	8.53	2.94	2.01	1.51
PT Out (ppm)	1.58	0.91	10.05	4.12	0.92	0.50

Concentration means based on 28 samples for Batch and SSF, 24 samples for SF and PT
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
Std. Dev.: Standard Deviation
Concentration in mg/l (ppm)

From Table 5.2A it is clear that the Septisorb and pea-stone and the pea-stone substrates reduce phosphorus better than the lava rock substrate. Due to the variability of the influent wastewater, comparing the substrate concentration may not be as accurate as comparing the percentage reduction. Table 5.2B shows the average percentage reduction for the substrates after each stage of the treatment system.

Table 5.2B Average Phosphorus Reduction at the Outlet of each Wetland Stage

	Septisorb/ Pea-Stone	Lava Rock	Pea-Stone
% Reduction SSF	73	44	74
% Reduction SF	72	12	59
% Reduction Overall	93	57	96

SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells

The average reduction of phosphorus over the entire sampling period was 93% for the Septisorb and pea-stone substrate, 57% for the lava rock, and 96% for the pea-stone. A t-test (assuming unequal variances) was performed to determine if the concentrations at the different stages of the wetland were significantly different compared to the influent concentration. Table 5.3 presents the results of the t-test.

Table 5.3 T-Test of Significance for Phosphorus Reduction Compared to Influent Concentration

Substrate	Septisorb / Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	5.79227E-08	1.72582E-08	2.80718E-08
Significant	Yes	Yes	Yes
Substrate	Lava Rock		
Stage	SSF	SF	TOTAL
T-Statistic	3.69813E-05	9.56691E-07	2.52817E-06
Significant	Yes	Yes	Yes
Substrate	Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	5.30186E-08	1.76315E-08	1.89302E-08
Significant	Yes	Yes	Yes

SSF: Sub-surface Flow
SF: Surface Flow

Effluent concentrations were significantly different than influent concentrations at an α equal to 0.05 for all three substrates. Figure 5.1 provides a graphical view of the average phosphorus concentration at each stage of the wetland treatment system.

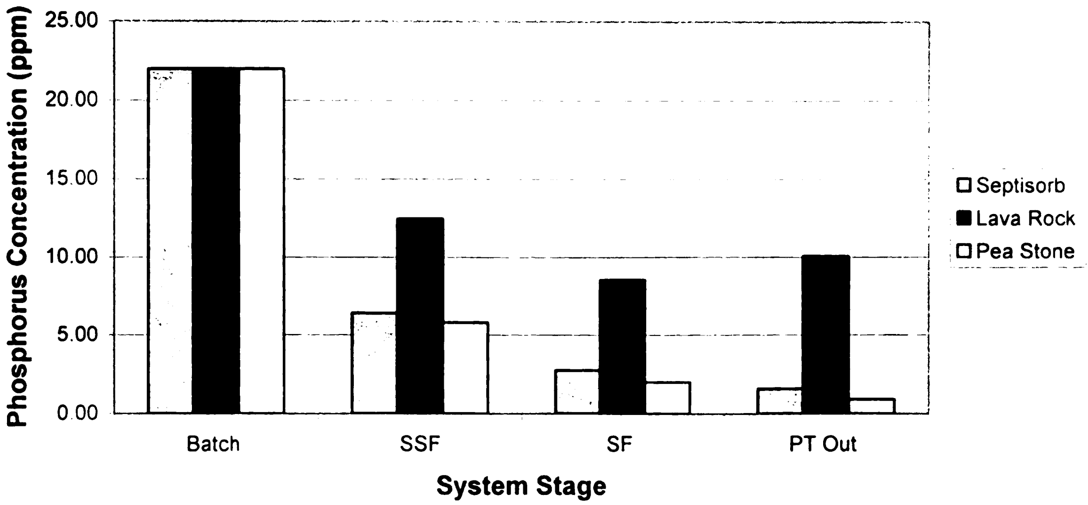

Figure 5.1 Average Phosphorus Concentration

Reductions of phosphorus in this study (93% and 96%) are equal to or greater than phosphorus reductions in studies by Drizo et al., 1997 (98%), Reaves et al., 1994 (89%), and Skarda et al., 1994 (55%). The pea-stone and the Septisorb and pea-stone mixed substrates removed phosphorus at a greater percentage than the lava rock substrate. This is likely due to the lava rock substrate having less sorptive sites for phosphorus adsorption. T-tests (assuming unequal variances) were performed in order to determine the statistical significance between substrates and wetland stages for phosphorus reduction. Table 5.4A shows the statistical difference between substrates for the mean phosphorus concentration while Table 5.4B illustrates the statistical significance between wetland stages for the percent reduction of phosphorus.

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Table 5.4A T Test Results for Statistical Significance of Phosphorus Concentration between Substrates

Substrate	SSF	SF	Total
Septisorb/Pea-Stone	6.39 a	2.75 a	1.58 a
Lava Rock	12.45 b	8.53 b	10.05 b
Pea Stone	5.80 a	2.01 a	0.92 c

Concenration in mg/L (ppm)
a,b,c: Show statistically significant difference by column

Table 5.4B T Test Results for Statistical Significance of Phosphorus Reduction between Wetland Stages

Stage	Sept/Pea	Lava	Pea-Stone
SSF	72.73 a	44 a	74.43 a
SF	71.83 a	11.95 b	59 b

Reduction in %
a,b: Show statistically significant difference by column

Results from the statistical tests show that the Septisorb and pea-stone substrate and the pea-stone substrate reduce the phosphorus in the wastewater significantly more than the lava rock, through both wetland stages. The total reduction is statistically different for each substrate. The results indicate that the pea-stone substrate performs the best in terms of phosphorus removal. The Septisorb had little effect on phosphorus reduction over the period of sampling. There is no significant difference between the sub-surface flow and the surface flow wetlands for the Septisorb and pea-stone substrate, while there is a significant difference between the wetland types for both the lava rock and pea-stone substrates. In these cases the sub-surface flow cell removed a greater percentage than the surface flow cell.

Phosphorus reduction decreased over time in each substrate due to the filling of available sorption sites. The results are illustrated in Figure 5.2.

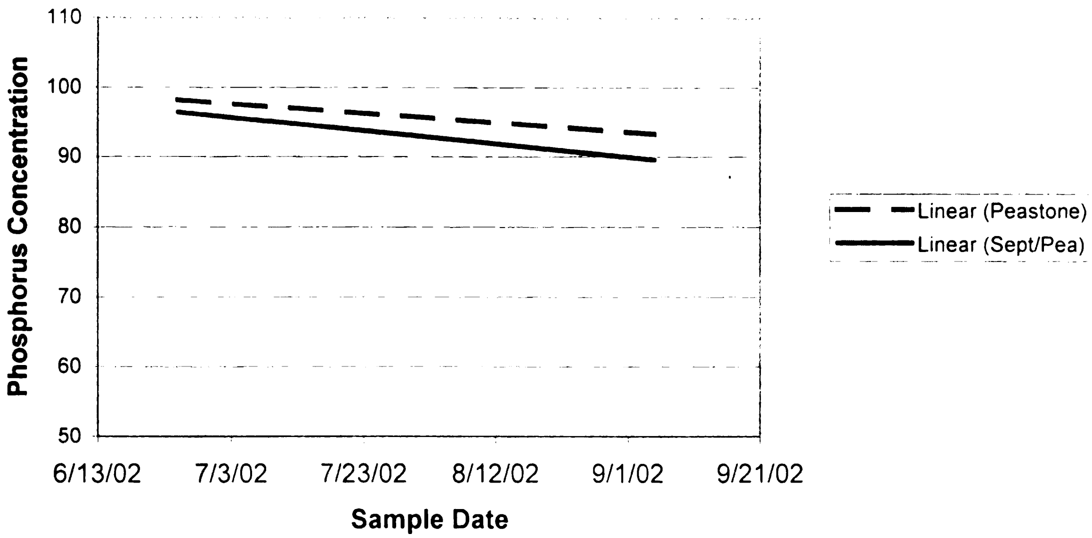

Figure 5.2 Total Phosphorus Reduction versus Time

5.1.2 NITROGEN

Results for ammonium concentration from one cycle of wastewater are shown in Table 5.5.

Table 5.5 Ammonium Concentration Through One Dosing Cycle

Ammonium Concentration										
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
6/25/02	Batch	196.57	196.57	196.57	196.57	196.57	196.57	196.57	196.57	196.57
	SSF	200.6	198.13	199.365	208.12	129.12	168.62	102.01	163.67	132.84
	SF	140.13	128.75	134.44	85.45	107.11	96.28	137.63	107.33	122.48
	PT(OUT)	96.39	90.81	93.6	21.4	75.43	48.415	92.12	57.95	75.035
	% RED SSF	-2	-1	-1	-6	34	14	48	17	32
	% RED SF	30	35	33	59	17	43	-35	34	8
	% RED TOTAL	51	54	52	89	62	75	53	71	62

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
Concentration in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells (% = (Batch - SSF Concentration)/Batch)
SF: Surface Flow Wetland Cells (% = (SSF-SF Concentration)/SSF Concentration)
PT: Phosphorus Trap

The average ammonium reduction for this cycle of wastewater was 52% for the Septisorb and pea-stone substrate, 75% for the lava rock substrate, and 62% for the pea-stone substrate. The average ammonium concentration at each stage of the treatment system is shown in Table 5.6A.

Table 5.6A Average Ammonium Concentration Through Wetland System

	Sept./Pea	Std. Dev	Lava Rock	Std. Dev.	Pea-Stone	Std. Dev.
Batch	230.96	102.57	230.96	102.57	230.96	102.57
12 SSF	174.16	40.28	149.77	31.82	179.79	65.84
12 SF	160.31	25.74	119.51	32.81	166.70	52.92
PT	84.27	24.96	67.22	27.52	93.95	48.38

Concentration means based on 28 samples for Batch and SSF, 24 samples for SF and PT
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
PT: Phosphorus Trap
Concentration in mg/l (ppm)
Std. Dev.: Standard Deviation

Due to the variability of the influent wastewater, a comparison of the substrates by concentration is not as accurate as a consideration of the percentage reduction. Table 5.6B shows the average percentage reduction in ammonium in each wetland stage.

Table 5.6B Average Ammonium Reduction at the Outlet of each Wetland Stage

Ammonium 12 Day Averages			
	Sept./Pea	Lava	Pea
%Reduction SSF	12	29	10
%Reduction SF	8	16	10
% Reduction Total	64	70	60

SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells

The average ammonium reduction during the entire sampling period was 64% for the Septisorb and pea-stone substrate, 70% for the lava rock substrate, and 60%

for the pea-stone substrate. A t-test (assuming unequal variances) was performed to determine if the concentration at the different stages of the wetland were significantly different compared to the influent concentration. Table 5.7 presents the results of the t-test for significance of ammonium concentration.

Table 5.7 T-Test of Significance for Ammonium Reduction Compared to Influent Concentration

Substrate	Septisorb / Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.0496	0.00798	2.06003E-05
Significant	Yes	Yes	Yes
Substrate	Lava Rock		
Stage	SSF	SF	TOTAL
T-Statistic	0.00342	0.000297	5.93136E-06
Significant	Yes	Yes	Yes
Substrate	Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.045155	0.016108	4.09965E-05
Significant	Yes	Yes	Yes

SSF: Sub-surface Flow
SF: Surface Flow

Effluent concentrations were significantly different than influent concentrations at an α equal to 0.05 for all three substrates. Figure 5.3 provides a graphical representation of the ammonium concentration at each stage of the wetland treatment system.

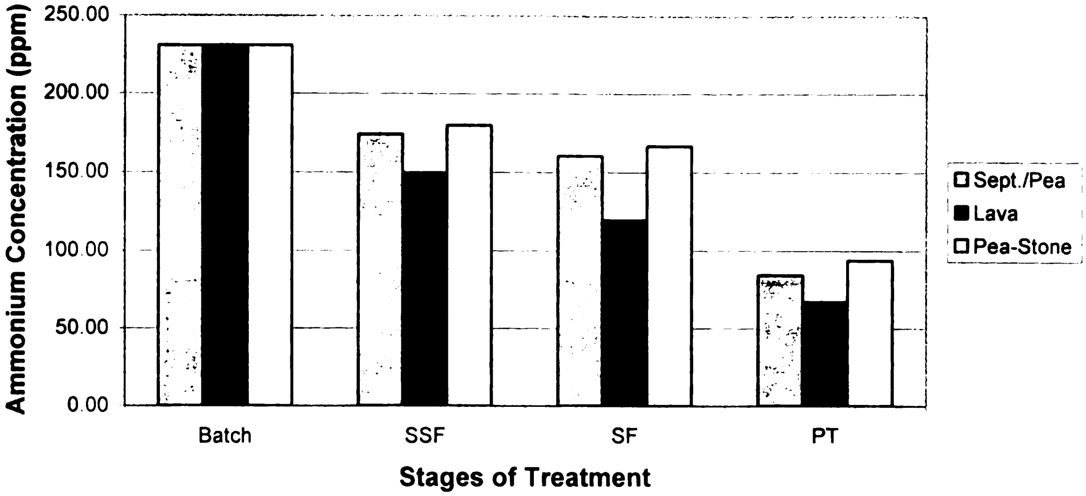

Figure 5.3 Average Overall Ammonium Concentration

Ammonium reductions in this study (64%, 70%, and 60%) were equal to or greater than ammonium reductions in studies by Skarda et al., 1994 (45%), Reaves et al., 1994 (70%), and Drizo et al., 1997 (75%). The lava rock substrate reduced the ammonium concentration the most in the wetland cells. This was likely due to more nitrifying bacteria being present on the larger surface area of the lava rock than the other substrates. The phosphorus traps removed a large amount of ammonium in each test set. This was likely caused by the ammonium attaching to the peat and sand mixture while the wastewater flows through the trap and is nitrified to nitrate in the subsequent aerobic conditions.

In order to determine the statistical significance between substrates and wetland stages for ammonium reduction, t-tests (assuming unequal variances) were performed. Table 5.8A illustrates the statistical difference between substrates for the mean ammonium concentration while Table 5.8B shows the statistical significance between wetland stages for the percent reduction in ammonium.

Table 5.8A T Test Results for Statistical Significance of Ammonium Concentration between Substrates

	Stage		
Substrate	SSF	SF	Total
Septisorb/Pea-Stone	174.16 a	160.31 a	84.27 a
Lava Rock	149.77 b	119.51 b	67.23 b
Pea Stone	179.78 a	166.70 a	93.95 a

Concentration in mg/L (ppm)
a,b: Shows statistically significant difference by column

Table 5.8B T Test Results for Statistical Significance of Ammonium Reduction between Wetland Stages

	Substrate		
Stage	Sept/Pea	Lava	Pea-Stone
SSF	12.04 a	29.38 a	9.96 a
SF	8.36 a	15.82 b	10.22 a

Reduction in %
a,b: Shows statistically significant difference by column

Results from the statistical tests show that the lava rock substrate reduces ammonium in the wastewater significantly more than the Septisorb and pea-stone and the pea-stone substrates throughout the entire treatment system. There was no significant difference in the reduction between the wetland stages for the Septisorb and pea-stone substrate and the pea-stone substrate. Also, the sub-surface flow wetland cell reduced ammonium more than the surface flow wetland cell for the lava rock substrate.

Results for nitrate from one cycle of wastewater are shown in Table 5.9.

Table 5.9 Nitrate Concentration Through One Dosing Cycle

Nitrate Concentration										
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
6/25/02	Batch	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	SSF	0.40	0.24	0.32	0.54	0.31	0.43	0.10	0.12	0.11
	SF	0.00	0.05	0.03	0.00	0.17	0.09	0.06	0.06	0.06
	PT(OUT)	21.69	88.54	55.12	48.12	68.15	58.14	25.63	74.54	50.09
	% RED SSF	52	71	62	35	63	49	88	86	87
	% RED SF	100	79	92	100	45	80	40	50	45
	% RED TOTAL	-2498	-10504	-6501	-5663	-8062	-6862	-2969	-8827	-5898

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
Concentration in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells (% = (Batch - SSF Concentration)/Batch)
SF: Surface Flow Wetland Cells (% = (SSF-SF Concentration)/SSF Concentration)
PT: Phosphorus Trap

Influent nitrate concentration was low, as is expected in dairy wastewater since there is little opportunity for nitrification. The average nitrate reduction through the wetland system was 92% for the Septisorb and pea-stone substrate, 80% for the lava rock substrate, and 45% for the pea-stone substrate. The phosphorus trap produced a spike in the nitrate levels from 0.03 mg/L to 55.12 mg/L in the Septisorb and pea-stone substrate, from 0.09 mg/L to 58.14 mg/L in the lava rock substrate, and from 0.06 mg/L to 50.09 mg/L in the pea-stone substrate. The spike was likely due to the ammonium in the wastewater attaching to the peat and sand mixture of the phosphorus trap/filter, with subsequent nitrification taking place under aerobic conditions within the phosphorus trap. The nitrate was washed from the system with the next flow of wastewater through the phosphorus trap/filter. The average overall nitrate reductions are shown in Table 5.10.

Table 5.10 Average Nitrate Concentration and % Reduction

	Sept./Pea	Std.Dev.	Lava Rock	Std. Dev.	Pea-Stone	Std. Dev.
Batch	0.49	0.54	0.49	0.54	0.49	0.54
SSF	0.20	0.19	0.24	0.19	0.15	0.13
SF	0.10	0.11	0.30	0.33	0.11	0.14
PT	108.01	53.87	74.05	47.22	113.07	102.33
%RED SSF	65		60		57	
%RED SF	6		-115		-42	
% RED TOT	-25582		-9620		-24397	

Concentration means based on 28 samples for Batch and SSF, 24 samples for SF and PT
SSF: Sub-Surface Flow Wetland Cells (% = (Batch - SSF Concentration)/Batch)
SF: Surface Flow Wetland Cells (% = (SSF-SF Concentration)/SSF Concentration)
PT: Phosphorus Trap
Concentration in mg/l (ppm)
Std. Dev.: Standard Deviation

The average nitrate reductions through the sub-surface flow wetland cells were 65%, 60%, and 57% for the Septisorb and pea stone substrate, lava rock substrate, and pea-stone substrate, respectively. A t-test (assuming unequal variances) was performed to determine if the concentrations at the different stages of the wetland were significantly different compared to the influent concentration. Table 5.11 presents the results of the t-test for significance of nitrate concentration.

Table 5.11 T-Test of Significance for Nitrate Reduction Compared to Influent Concentration

Substrate	Septisorb / Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.034974	0.009301	3.03708E-09
Significant	Yes	Yes	Yes
Substrate	Lava Rock		
Stage	SSF	SF	TOTAL
T-Statistic	0.054166	0.12244	4.78516E-08
Significant	No	No	Yes
Substrate	Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.016934	0.011168	1.35364E-05
Significant	Yes	Yes	Yes

SSF: Sub-surface Flow
SF: Surface Flow

Effluent concentrations were significantly different than influent concentrations at an α equal to 0.05 for the Septisorb and pea-stone and the pea-stone substrates, while the lava rock substrate was not significantly different. Each substrate showed a significant difference between the influent and effluent concentrations of nitrate due to the increase occurring in the phosphorus trap. Nitrate concentrations in the wastewater effluent of 0.1 mg/L in this study are similar to nitrate effluent concentrations in studies conducted by Skarda et al., 1994 (0.1 mg/L), and Reaves et al., 1994 (0.2 mg/L).

T-tests (assuming unequal variances) were performed in order to determine the statistical significance between the substrates and wetland stages for nitrate reduction. Table 5.12A shows the statistical difference between the substrates for the mean nitrate concentrations. Table 5.12B illustrates the statistical significance between the wetland stages for the percent reduction of nitrate.

Table 5.12A T Test Results for Statistical Significance of Nitrate Concentration between Substrates

Substrate	Stage SSF	SF	Total
Septisorb/Pea-Stone	0.20 a	0.10 a	108.01 a
Lava Rock	0.24 a	0.30 a	74.05 a
Pea Stone	0.15 a	0.11 a	113.07 a

Concentration in mg/L (ppm)
a,b: Show statistically significant difference by column

Table 5.12B T Test Results for Statistical Significance of Nitrate Reduction between Wetland Stages

Stage	Substrate Sept/Pea	Lava	Pea-Stone
SSF	64.71 a	59.77 a	56.64 a
SF	6.44 a	-114.75 b	-42.15 b

Reduction in %
a,b: Show statistically significant difference by column

The statistical tests show that there is no significant difference in the concentration of nitrate between the three substrates. In the lava rock and the pea-stone substrates, the surface flow wetland was significantly different from the sub-surface flow. The concentration increased on average in the surface flow wetland cell. This is likely due to the ammonium in the wastewater being nitrified, either as it freely drains into the surface wetland cell, or within the wetland because of oxygen diffusion in to the surface and oxygen transport through the plants to the root zone.

Total inorganic nitrogen (ammonium and nitrate) is the main concern to farmers who will use wetland effluent for irrigation onto cropland. Irrigation water is applied on a nitrogen basis if it is low in phosphorus. Table 5.13 shows the overall nitrogen concentrations in the influent and effluent from the system.

Table 5.13 Overall Nitrogen Concentrations

	Sept./Pea	Lava Rock	Pea-Stone
Inorg. N Influent	231.47	231.47	231.47
NH_4^+ Influent	230.96	230.96	230.96
NO_3^- Influent	0.49	0.49	0.49
Inorg. N Efflluent	192.28	141.27	207.02
NH4+ Effluent	84.27	67.22	93.95
NO3- Effluent	108.01	74.05	113.07
Tot. N % Red.	17	39	11

Concentrations in mg/L Total Inorganic Nitrogen

Lava rock removes significantly more total inorganic nitrogen in this study. Total inorganic nitrogen removals of 17, 39 and 11 percent were slightly lower than total inorganic nitrogen removals in studies performed by Reaves et al., 1994 (36%), and Skarda et al., 1994 (50%). The reductions of 17, 39, and 11 percent could be increased with a re-circulation of the wastewater through the system. This would prove successful due to the conversion of ammonium to nitrate which takes place in the phosphorus trap, and subsequent de-nitrification of nitrate in the wetland cells.

5.1.3 COD

The results for COD concentration from one wastewater dosing cycle are shown in Table 5.14.

Table 5.14 COD Concentration Through One Dosing Cycle

Date: 7/25/2002	COD Concentrations (mg/L)								
	A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24
SSF	1032.03	1896.91	1464.47	913.41	903.53	908.47	636.65	661.36	649.01
SF	1423.93	1733.82	1578.88	977.66	639.12	808.39	495.80	770.09	632.95
PT Out	893.65	1365.63	1129.64	641.59	708.31	674.95	498.27	698.43	598.35
% Reduction	53	29	41	67	63	65	74	64	69
k value (Total)	3.43	1.52	2.37	4.92	4.48	4.69	6.07	4.54	5.24

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
Concentration in mg/l (ppm) / Avg. Total Reduction in %
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

COD reduction was 41% for the Septisorb and pea-stone substrate, 65% for the lava rock substrate, and 69% for the pea-stone substrate. The average COD reduction and k-values for the sub-surface flow wetland are shown in Table 5.15.

Table 5.15 Average COD Reduction and K-Values

COD Averages						
Avgs	Sept./Pea	Std. Dev.	Lava Rock	Std. Dev	Pea-stone	Std. Dev
Batch	2348.46	1336.80	2348.46	1336.80	2348.46	1336.80
SSF	890.81	415.88	708.97	199.12	743.52	287.83
SF	1131.45	320.39	812.99	411.98	697.48	261.77
PT	1023.87	259.74	722.69	267.28	596.23	194.11
% RED TOT	63	19	75	15	75	12
k value SSF	4.63		5.78		5.54	

Concentration means based on 28 samples for Batch and SSF, 24 samples for SF and PT
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
Concentration in mg/l (ppm)

Average COD reductions of 63%, 75%, and 75% were attained for the Septisorb and pea-stone substrate, the lava rock substrate, and the pea-stone substrate respectively. T-Tests (assuming unequal variances) were executed to determine if the concentration at the different stages of the wetland were significantly different compared to the influent concentration. Table 5.16 presents the results of the t-test for significance of COD concentration.

Table 5.16 T-Test of Significance for COD Reduction Compared to Influent Concentration

Substrate	Septisorb / Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.000911407	0.0018939	0.0012295
Significant	Yes	Yes	Yes
Substrate	Lava Rock		
Stage	SSF	SF	TOTAL
T-Statistic	0.000425817	0.0006826	0.0004951
Significant	Yes	Yes	Yes
Substrate	Pea-Stone		
Stage	SSF	SF	TOTAL
T-Statistic	0.000545909	0.0004566	0.0003106
Significant	Yes	Yes	Yes

SSF: Sub-surface Flow
SF: Surface Flow

Effluent concentrations were significantly different than influent concentrations at an α equal to 0.5 for all three substrates. Figure 5.4 presents the average COD concentration at each stage of the treatment system.

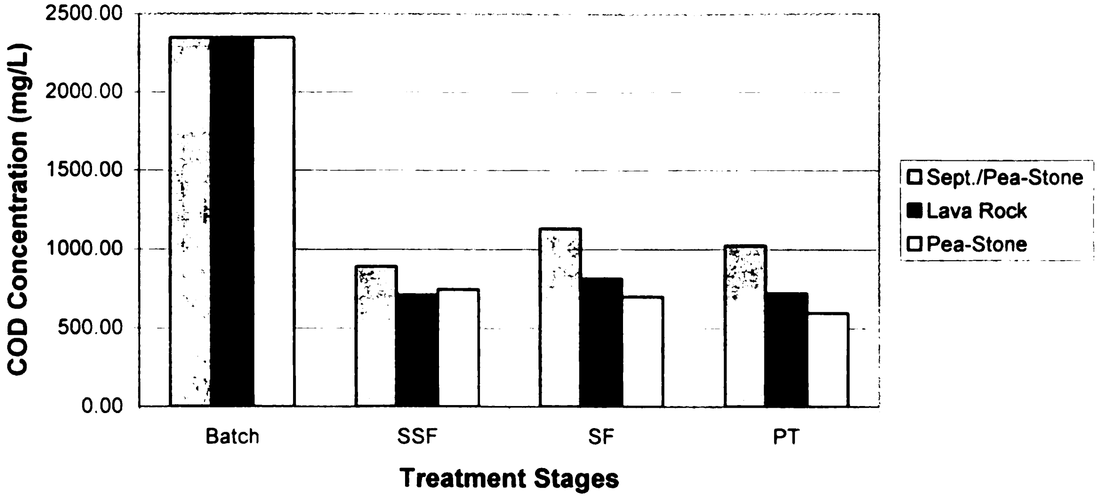

Figure 5.4 Average COD Concentration

The COD reduction of 75% found in the lava rock and the pea-stone substrates is equal to or greater than reduction found in studies by Skarda et al., 1994 (50%), and Reaves et al., 1994 (62%). The COD concentration was reduced initially in the sub-surface flow wetland cells and experienced a slight increase after the surface flow cell. This was likely due to solids flushing through the system. The COD may also have increased due to peat material washing away from the phosphorus trap/filter.

In order to determine statistical significance between substrate and wetland stage for COD reduction, t-tests (assuming unequal variances) were executed. Table 5.17A shows the statistical difference between substrates for the mean COD concentration. Table 5.17B illustrates the statistical significance between the substrates for the percent reduction of COD.

Table 5.17A T Test Results for Statistical Significance of COD Concentration between Substrates

Substrate	Stage SSF	SF	Total
Septisorb/Pea-Stone	890.81 a	1131.45 a	1023.87 a
Lava Rock	708.97 a	812.99 b	722.69 b
Pea Stone	743.52 a	697.48 b	596.23 b

Concentration in mg/L (ppm)
a,b: Show statistically significant difference by column

Table 5.17B T Test Results for Statistical Significance of Total Percentage Reduction of COD between Substrates

Substrate	% Reduction Total
Septisorb/Pea-Stone	62.75 a
Lava Rock	75 b
Pea Stone	75.25 b

a,b: Show statistically significant difference

Table 5.17A shows that there is no significant difference between the three substrates in COD reduction through the sub-surface flow wetland cell. The COD concentrations are significantly higher in the Septisorb and pea-stone mixed substrate than the other substrates after the surface flow cell and at the end of the treatment system. This can likely be attributed to the Septisorb and other organic matter washing through the system. Table 5.17B shows that the pea-stone and lava rock substrates performed significantly better than the Septisorb and pea-stone mixed substrate for overall reduction in COD.

5.1.4 WEATHER INFLUENCE

The effects of weather (precipitation and evapo-transpiration) were studied in order to determine if significant changes in the nutrient concentration occurred due to fluctuations in water supplied to the wetland system by precipitation and evapo-transpiration. Weather data was collected from the Michigan Automated Weather Network weather station in Bath, Michigan. See Appendix B for complete weather data for the entire sampling period.

Figure 5.5 represents the precipitation and evapo-transpiration data for the sampling period.

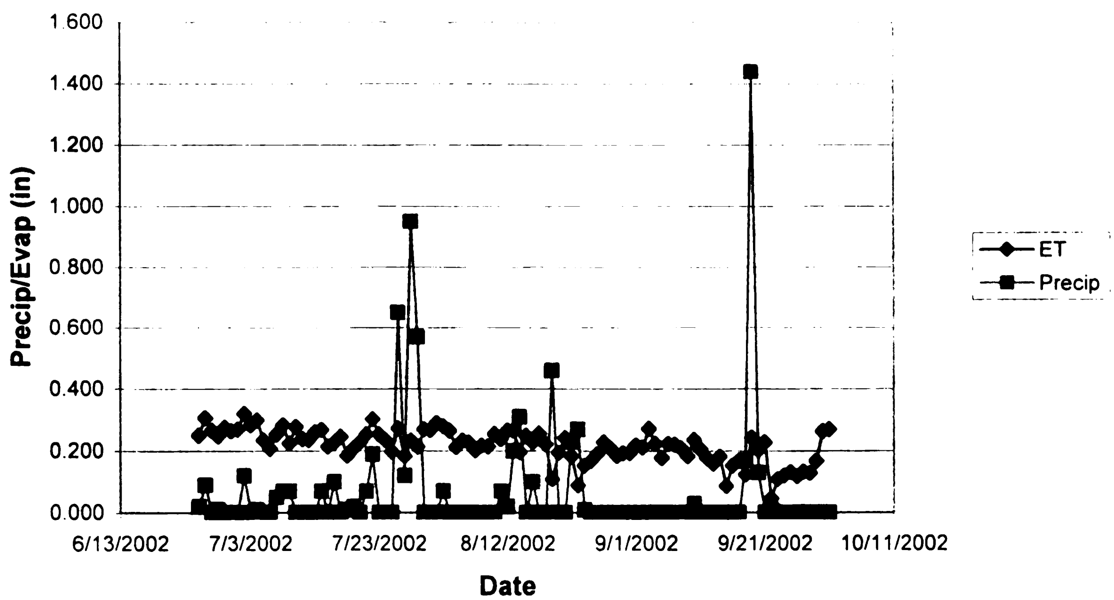

Figure 5.5 Precipitation and Evapo-Transpiration Data (MAWN Weather Station; Bath, MI.)

In order to determine if reductions of nutrients increased or decreased due to dilution of the wastewater caused by precipitation and evapo-transpiration, the nutrient reductions were graphed along with the precipitation and evapo-transpiration data (See Figure 5.6).

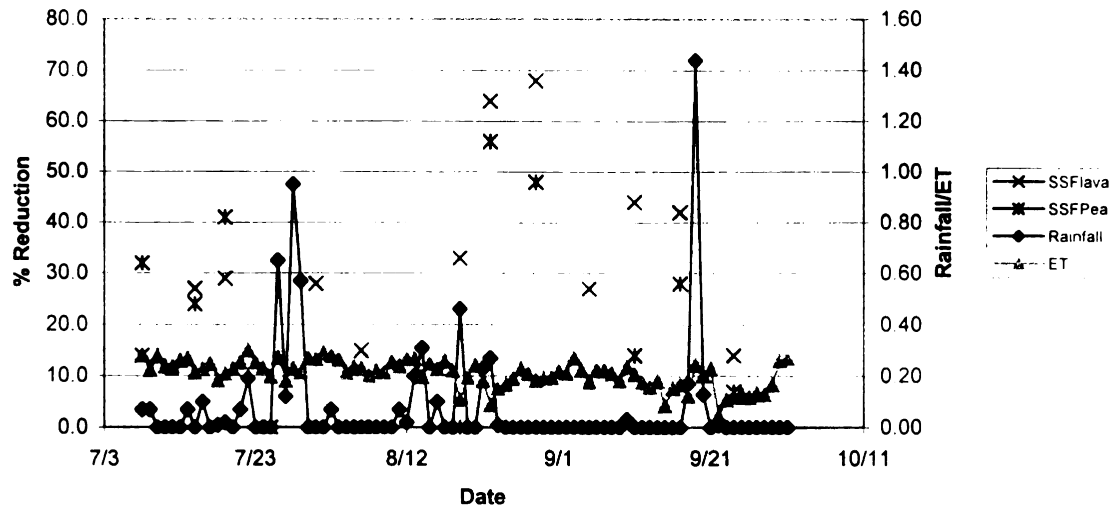

Figure 5.6 Nutrient Concentration Reduction (Ammonium) Corresponding to Rainfall and Evapo-Transpiration Effects

There were three rainfall events with precipitation of over 0.4 inches with which to compare ammonium reduction. It shows that the nutrient reduction was not effected by rainfall and evapo-transpiration. There was no increase in the reduction during periods of heavy rainfall which could have effected the results by diluting the wastewater within the wetland, thereby reducing the concentration of ammonium. Evapo-transpiration also appears to have no effect on the nutrient concentration in a wetland system.

5.2 PILOT SCALE WETLAND DESIGN

Wetland design is based on the areal uptake constant (k value) for a target pollutant (Kadlec and Knight, 1996). In the case of constructed wetlands for dairy wastewater management, phosphorus, nitrogen, and COD are the main pollutants of concern. K values were determined for both COD and ammonium. Phosphorus was not considered because the main pathway for phosphorus reduction is adsorption to the soil substrate. Areal uptake constants (K values) for each substrate were determined for the sub-surface flow wetland type using equation 2.10. Background concentrations of 1 mg/L and 100 mg/L were used for ammonium and COD based on research conducted by Kadlec and Knight, 1996. The k values are shown in Table 5.18.

Table 5.18 Average K Values for Ammonium & COD

SSF	Septisorb	Lava Rock	Pea-Stone
Ammonium	0.87	1.70	0.54
COD	4.65	5.78	5.54

SSF: Sub-Surface Flow Wetland Cells
k values in m/yr

Ammonium reduction occurred mainly in the phosphorus trap of the wetland system, and therefore COD k-values will be used to size a pilot scale constructed wetland for dairy wastewater remediation.

Figure 5.7 shows the area required for the three wetland substrates studied (Septisorb / Pea-stone, Lava Rock, Pea-stone) for increasing influent concentrations (500 mg/L – 5000 mg/L) at a constant flow rate of 37,854 L/day (10,000 g/d) with a target effluent COD concentration of 500 mg/L.

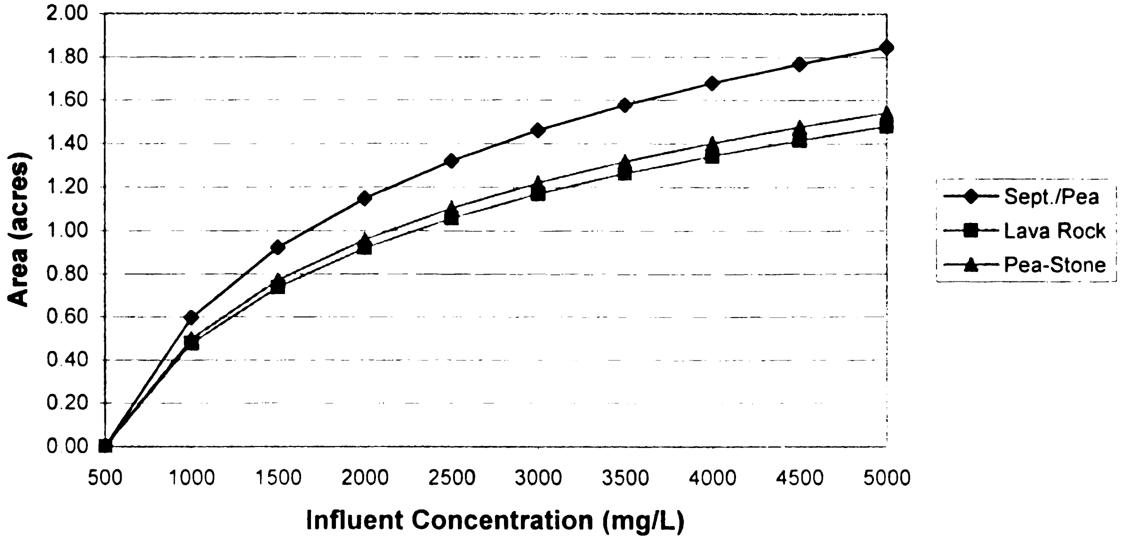

Figure 5.7 Wetland Area versus Influent Concentration for 10,000 gal/day of Dairy Wastewater

As the influent COD concentration increases, the area required for reduction to 500 mg/L COD increases. The increase slows as the COD concentrations rise. Lava rock requires the least amount of area for a wetland for COD removal due to its slightly lower k value than pea-stone.

Figure 5.8 shows the area requirement for the three wetland substrates for increasing flows of 37,854 L/d to 208,197 L/d (10,000 g/d – 55,000 g/d), at a constant influent COD concentration of 3,000 mg/L and a target effluent concentration of 500 mg/L.

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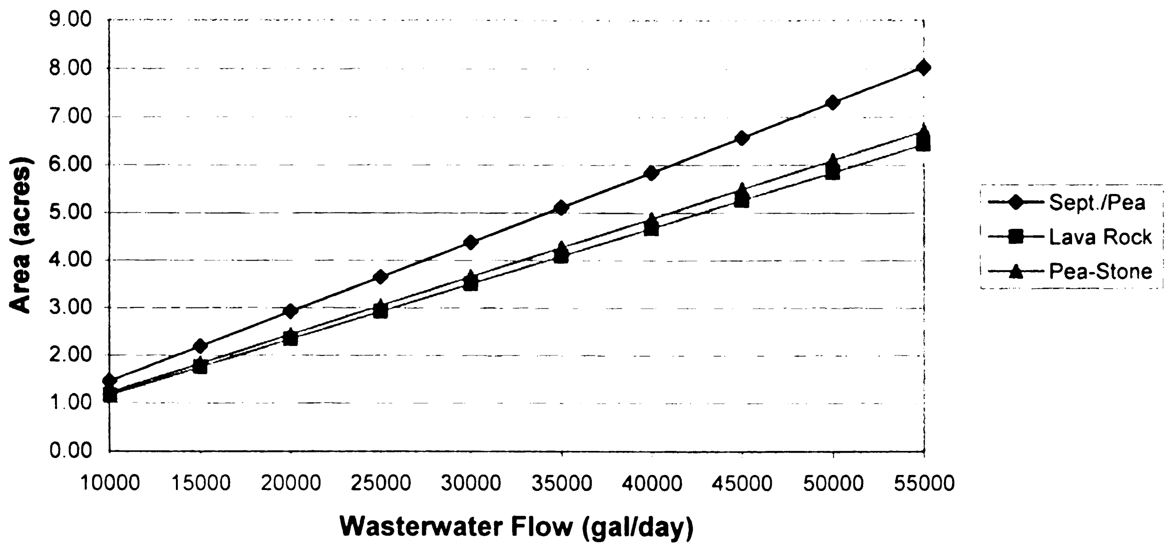

Figure 5.8 Wetland Area versus Wastewater Flow for Influent Concentration of 3,000 mg/L

As the wastewater flow increases, the wetland area needed for treatment increases. Lava rock requires the smallest area. At lower flows, i.e. 37,854 L/d (10,000 g/d), the area required for each substrate is similar (< 1.5 acres). At larger flows, i.e. 189,270 L/d (50,000 g/d), the area required for the lava rock and the pea-stone substrates is six acres and for the Septisorb and pea-stone substrate, less than eight acres.

Target effluent concentrations of the wetlands can be changed if the water use will be different. For instance, a higher concentration of COD could be allowed for irrigation while a lower concentration would be used for flushing barns. A decrease in the target effluent concentration will increase the area requirements of the wetland. Figure 5.9 shows the wetland area versus the influ

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influent concentration for a 37,854 L/d (10,000 g/d) dairy farm if the effluent concentration is 250 mg/L.

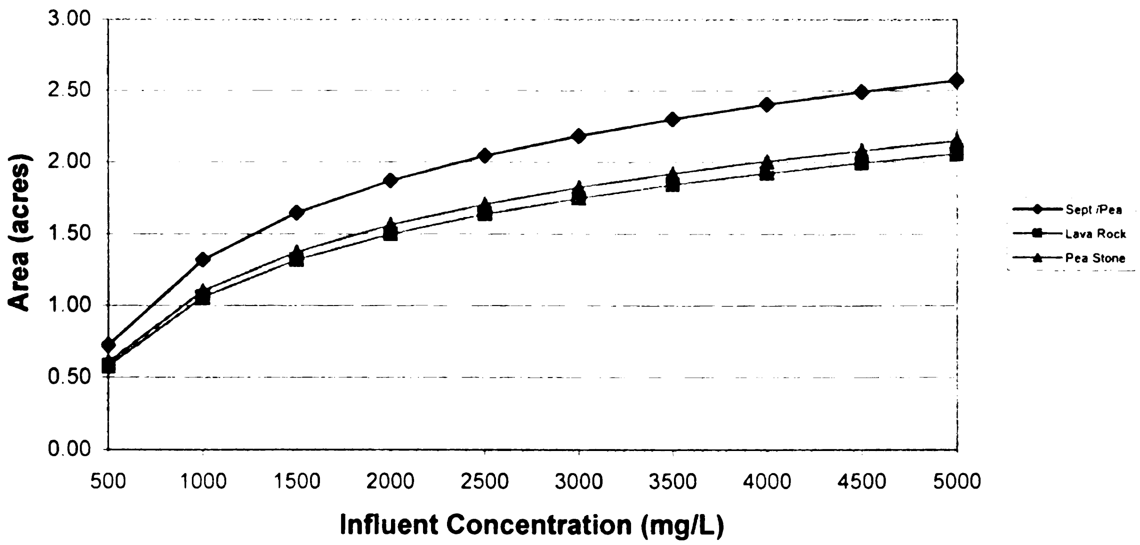

Figure 5.9 Wetland Area versus Influent Concentration for 10,000 gal/day of Dairy Wastewater

Comparing Figure 5.9 and 5.7 shows that wetland area requirements are increased by approximately one half acre with a decrease of 250 mg/L in the target effluent concentration.

Even though the lava rock substrate performs the best when considering ammonium reduction and requires less land for treatment, it may not always be the best choice. Phosphorus and nitrogen reduction must also be taken into account when designing a wetland system. In this study, the Septisorb and pea-stone and the pea-stone substrates both removed more phosphorus from wastewater than did the lava rock substrate. COD reduction is the largest in the lava rock substrate and the pea-stone substrate with the Septisorb and pea-stone substrate the reducing as well. Therefore, the substrate options must be weighed for each dairy farm since farms will differ in the nutrient needs for irrigation and the nutrient loading of the soil.

Pilot scale wetland design must also take into account the order of the treatments. In this study, the phosphorus trap nitrified ammonium to nitrate. The trap was located at the end of the treatment system. Nitrate is a major concern for surface and groundwater contamination, and therefore must be lowered before release to surface waters, irrigation, or flushing. Total inorganic nitrogen is the main concern to agriculture and may need to be reduced before being land applied. In order to account for these concerns the order of the treatment stages can be switched. The phosphorus trap can be located between the sub-surface and surface flow wetland cells in order to both remove phosphorus and nitrify the ammonium to nitrate which in turn can be reduced in a following cell. Another way to reduce the nitrate and total inorganic nitrogen is to re-circulate the water through the wetland. This would be advantageous by both reducing COD further and keeping a constant flow of wastewater to the wetland to assure that the system does not dry out.

5.2.1 Green Meadows Pilot Scale Design

Pilot scale wetland design for Green Meadows Dairy farm in Elsie, Michigan is based on one tenth of the approximate daily wastewater produced on the site. This equates to a wastewater flow of 37,854 liters per day (10,000 g/d) for the constructed wetland to handle. Flow determines the size of each wetland cell. The pilot scale system will incorporate two sub-surface flow cells along with a phosphorus trap. The sequence of the treatments will be the same as the sequence used in this study. A sub-surface flow cell will be followed by a second sub-surface flow cell which will be followed by the phosphorus trap. This second wetland cell could be a surface flow cell if economic restrictions require a lower cost wetland. In order to reduce the nutrients to a further extent, the wastewater will be stored in a pond and re-circulated and/or re-circulated directly through the wetland system.

Two substrates will be used for the pilot scale design. Due to its high removal rate for phosphorus and COD, its solids removal and its lower cost, pea-stone will be used in the first sub-surface flow wetland cell. Lava rock will be employed in the second sub-surface flow cell because of its high total inorganic nitrogen and COD removal capacity. Pea-stone may also be used in the second sub-surface flow wetland cell due to its low cost. Most of the ammonium conversion will take place in the phosphorus trap and with re-circulation denitrifying the nitrate; therefore, lava rock may not be needed. The phosphorus trap will be comprised of a sand and peat mixture with steel wool.

The size of the wetland cells are determined by the k value for COD. Using an average influent COD estimation of 3,000 mg/L, the sub-surface flow wetland cell (pea-stone) will be 0.5 hectare (1.22 acres) in size according to figure 5.7 and equation 2.10; the second sub-surface flow wetland cell (lava rock or pea-stone) will have approximately the same size.

The phosphorus trap size is based on the sorption isotherms of phosphorus on peat and steel wool; steel wool can adsorb 100% of added phosphorus up to a level of 32.2 milligrams of phosphorus per gram of steel wool while peat can adsorb 2.2 milligrams of phosphorus per gram of peat (James et al., 1992). Peat with 6% steel wool added can adsorb up to 4 milligrams of phosphorus per gram of material (peat and steel wool mixture) (James et al., 1992). A peat and steel wool mixture will be amended with filter sand in order to improve the hydraulic conductivity of the material, and thus the drainage. Equal volumes of peat and filter sand will be used.

The phosphorus trap is designed to handle the pilot scale flow of 37,854 liters per day (10,000 g/d) at a phosphorus concentration of 2 mg/L flowing from the second wetland cell. This equates to a total phosphorus load of 75,700 mg/d of phosphorus reaching the phosphorus trap. According to the reduction isotherm for peat with 6% steel wool, adsorption sites in one cubic meter will be filled in approximately three days. Therefore, the dimensions of the phosphorus trap should be one meter deep, 30 meters long and 30 meters wide (900 m^3). The phosphorus trap has an estimated lifetime of 2,700 days. The approximate amounts of peat, sand, and steel wool needed for one cubic meter of phosphorus trap material are;

- Peat: 120 lbs
- Sand: 1600 lbs
- Steel Wool: 7 lbs

The trap will be designed so that the water will enter the surface of the trap uniformly, using a pressure dosed system, and flow downward thru the media to a drain pipe. This will provide the oxygen needed for nitrification of ammonium.

CHAPTER 6

CONCLUSIONS

A constructed wetland was investigated for use as a part of a dairy wastewater management system. The following steps were taken to determine its feasibility:

- A small scale wetland treatment system was designed and constructed at the Green Meadows Dairy Farm in Elsie, Michigan.
- Data was collected on nutrient (phosphorus, ammonium, nitrate) and COD reductions for three separate substrates (Septisorb/Pea-stone mixture, Lava Rock, Pea-Stone) for a 12 day retention time, over a period of three months.
- A pilot scale wetland system was designed.

Each substrate and wetland type showed a statistically significant reduction of phosphorus. The Septisorb and pea-stone substrate and the pea-stone substrate had a significantly larger reduction in phosphorus than the lava rock. The sub-surface flow wetland cells removed significantly more phosphorus than did the surface flow cells in both the lava rock substrate and the pea-stone substrate, while the surface and sub-surface flow cells did not show a significant difference in the Septisorb and pea-stone substrate. Each substrate and wetland type showed a statistically significant reduction of total inorganic nitrogen. The lava rock substrate had a significantly larger reduction of total inorganic nitrogen than did the other substrates. Nitrification of ammonium occurred mainly in the phosphorus trap filter under aerobic conditions which promoted an increase in effluent nitrate from the system. Significant reductions of COD were obtained in the sub-surface flow cells of each of the substrates. The lava rock and the pea-stone substrates removed significantly more COD then the Septisorb and pea-stone substrate.

An optimal pilot scale design for a wastewater flow 10,000 g/d with an influent COD concentration of 3,000 mg/L and a target effluent concentration of 500 mg/L yields a necessary wetland area of 1.22 acres. Effluent concentrations of phosphorus and ammonium can be expected to be reduced by greater than 90% and 70% respectively. Re-circulation of the wetland effluent will provide a greater reduction in total inorganic nitrogen by denitrifying the nitrate produced in the phosphorus trap.

CHAPTER 7

RECOMMENDATIONS FOR FUTURE STUDY

The recommendations for future study are:Examine the period of time necessary to effectively fill all of the phosphorus sorption sites on several substrates.

1) Examine the effects on pollutant removal of providing additional oxygen to the wetland system by pumping air into, or draining water from, the wetland cell.
2) Determine the mechanisms involved in the nitrification of ammonium to nitrate that occurs in the phosphorus trap.
3) Verify if re-circulation of wetland effluent will further reduce pollutant concentrations.
4) Determine if concentrated wastewater streams are detrimental to wetland system performance.

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APPENDICES

APPENDIX A	Experimental Data
APPENDIX B	Weather Data
APPENDIX C	Wetland Photographs
APPENDIX D	Pilot Scale Wetland Design Data
APPENDIX E	Statistical Data Tables

APPENDIX A

Experimental Data

Data Tables for Phosphorus Analysis

		Phosphorus Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
6/25/2002	Batch	57.50	57.50	57.50	57.50	57.50	57.50	57.50	57.50	57.50
	SSF	6.70	7.30	7.00	24.60	19.50	22.05	5.60	1.80	3.70
	SF	0.50	0.50	0.50	3.90	6.00	4.95	0.40	2.00	1.20
	PT Out	0.80	1.30	1.05	3.20	6.50	4.85	0.60	1.00	0.80
	% RED SSF	88	87	88	57	66	62	90	97	94
	% RED SF	93	93	93	84	69	78	93	-11	68
	% RED TOTAL	99	98	98	94	89	92	99	98	99
7/1/2002	Batch	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3	15.3
	SSF	3	0.8	1.9	8.9	8.2	8.55	3	3.1	3.05
	SF	1.8	0.23	1.015	5.3	5.6	5.45	0.8	0.32	0.56
	PT Out	0.55	0.45	0.5	7.45	6.1	6.775	0.14	0.31	0.225
	% RED SSF	80	95	88	42	46	44	80	80	80
	% RED SF	40	71	47	40	32	36	73	90	82
	% RED TOTAL	96	97	97	51	60	56	99	98	99
7/8/02	Batch	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1	20.1
	SSF (12)	2.5	2.6	2.55	7.6	9.4	8.5	3.7	0.9	2.3
	SF(12)	0.29	0.3	0.295	8.08	12.9	10.49	0.18	0.39	0.285
	PT(OUT)	0.4	0.36	0.38	7.3	8.35	7.825	0.11	0.3	0.205
	% RED SSF	88	87	87	62	53	58	82	96	89
	% RED SF	88	88	88	-6	-37	-23	95	57	88
	% RED TOTAL	98	98	98	64	58	61	99	99	99
7/15/02	Batch	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
	SSF (12)	0.25	1.19	0.72	5.2	6	5.6	0.36	0.39	0.375
	SF(12)	2.45	1.98	2.215	10.4	10.3	10.35	1.05	1.65	1.35
	PT(OUT)	0.35	1	0.675	4.5	10	7.25	0.38	0.85	0.615
	% RED SSF	99	93	96	71	66	68	98	98	98
	% RED SF	-880	-66	-208	-100	-72	-85	-192	-323	-260
	% RED TOTAL	98	94	96	75	44	59	98	95	97
7/19/02	Batch	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
	SSF (12)	0.44	1.9	1.17	9.08	12.9	10.99	2.1	0.65	1.375
	SF(12)									
	PT(OUT)	No Samples Taken								
	% RED SSF	98	93	96	68	54	61	93	98	95
	% RED SF									
	% RED TOTAL									
7/25/02	Batch	14.75	14.75	14.75	14.75	14.75	14.75	14.75	14.75	14.75
	SSF (12)	4.15	4.58	4.365	15.3	15.9	15.6	5	5	5
	SF(12)	3.4	3.1	3.25	14.6	19.5	17.05	1.6	2.4	2
	PT(OUT)	1.7	2.2	1.95	12.3	14.2	13.25	1	1.1	1.05
	% RED SSF	72	69	70	-4	-8	-6	66	66	66
	% RED SF	18	32	26	5	-23	-9	68	52	60
	% RED TOTAL	88	85	87	17	4	10	93	93	93

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

Phosphorus Tables

		Phosphorus Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
7/31/02	Batch	16.44	16.44	16.44	16.44	16.44	16.44	16.44	16.44	16.44
	SSF (12)					No Samples Taken				
	SF(12)	4.6	3.8	4.2	8	7.5	7.75	2.7	0.5	1.6
	PT(OUT)	1.4	1.9	1.65	12.9	15.4	14.15	1.1	1.5	1.3
	% RED SSF									
	% RED SF									
	% RED TOTAL	91	88	90	22	6	14	93	91	92
8/6/02	Batch	24.525	24.525	24.525	24.525	24.525	24.525	24.525	24.525	24.525
	SSF (12)	7.8	7.6	7.7	13	20.1	16.55	9.7	10	9.85
	SF(12)	0.4	0.3	0.35	8.4	7.4	7.9	2	0.9	1.45
	PT(OUT)	2.8	2.8	2.8	14	9	11.5	0.8	1	0.9
	% RED SSF	68	69	69	47	18	33	60	59	60
	% RED SF	95	96	95	35	63	52	79	91	85
	% RED TOTAL	89	89	89	43	63	53	97	96	96
8/12/02	Batch	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45
	SSF (12)	1.6	2.5	2.05	8.4	9.5	8.95	5.2	9.7	7.45
	SF(12)	7	7	7	16.4	14.4	15.4	3.7	6.5	5.1
	PT(OUT)	1.8	3.6	2.7	16.7	16.7	16.7	1.1	1.8	1.45
	% RED SSF	95	92	93	72	69	71	83	68	76
	% RED SF	-338	-180	-241	-95	-52	-72	29	33	32
	% RED TOTAL	94	88	91	45	45	45	96	94	95
8/19/02	Batch	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5	35.5
	SSF (12)	17.1	6.8	11.95	8.4	7.2	7.8	6.7	8.8	7.75
	SF(12)	5.4	3.8	4.6	10	9.5	9.75	2.8	5.8	4.3
	PT(OUT)	1.2	2.7	1.95	16	13.6	14.8	1.6	2.5	2.05
	% RED SSF	52	81	66	76	80	78	81	75	78
	% RED SF	68	44	62	-19	-32	-25	58	34	45
	% RED TOTAL	97	92	95	55	62	58	95	93	94
8/23/02	Batch	25.15	25.15	25.15	25.15	25.15	25.15	25.15	25.15	25.15
	SSF (12)	17.1	14.8	15.95	17.1	17.1	17.1	14	12.3	13.15
	SF(12)	3.8	6.8	5.3	4	5.3	4.65	2	4.6	3.3
	PT(OUT)	2	1.8	1.9	8	3.7	5.85	0.6	1.2	0.9
	% RED SSF	32	41	37	32	32	32	44	51	48
	% RED SF	78	54	67	77	69	73	86	63	75
	% RED TOTAL	92	93	92	68	85	77	98	95	96
8/29/02	Batch	18.25	18.25	18.25	18.25	18.25	18.25	18.25	18.25	18.25
	SSF (12)	9.5	9.7	9.6	16.4	15.6	16	12.6	10	11.3
	SF(12)	1.8	1.8	1.8	9.4	8.7	9.05	1.3	3.6	2.45
	PT(OUT)	1.7	1.7	1.7	9.2	7.3	8.25	0.9	2	1.45
	% RED SSF	48	47	47	10	15	12	31	45	38
	% RED SF	81	81	81	43	44	43	90	64	78
	% RED TOTAL	91	91	91	50	60	55	95	89	92

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

Phosphorus Tables

		Phosphorus Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
9/5/02	Batch	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7
	SSF (12)	13.6	7.8	10.7	2.5	7.5	5	3	3.5	3.25
	SF(12)	1.3	1.3	1.3	9.2	8.7	8.95	1.5	4	2.75
	PT(OUT)	2	2	2	8.7	10	9.35	0.7	1.1	0.9
	% RED SSF	37	64	51	88	65	77	86	84	85
	% RED SF	90	83	88	-268	-16	-79	50	-14	15
	% RED TOTAL	91	91	91	60	54	57	97	95	96
9/11/02	Batch	24.55	24.55	24.55	24.55	24.55	24.55	24.55	24.55	24.55
	SSF (12)	5.5	5.5	5.5	15	14.1	14.55	9.2	6.2	7.7
	SF(12)									
	PT(OUT)									
	% RED SSF	78	78	78	39	43	41	63	75	69
	% RED SF									
	% RED TOTAL									
9/17/02	Batch	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05	15.05
	SSF (12)	9.4	9.4	9.4	17.3	16.9	17.1	6.8	3	4.9
	SF(12)									
	PT(OUT)									
	% RED SSF	38	38	38	-15	-12	-14	55	80	67
	% RED SF									
	% RED TOTAL									

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

Data Tables for Ammonium Analysis

		Ammonium Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
6/25/02	Batch	196.57	196.57	196.57	196.57	196.57	196.57	196.57	196.57	196.57
	SSF (12)	200.6	198.13	199.365	208.12	129.12	168.62	102.01	163.67	132.84
	SF(12)	140.13	128.75	134.44	85.45	107.11	96.28	137.63	107.33	122.48
	PT(OUT)	96.39	90.81	93.6	21.4	75.43	48.415	92.12	57.95	75.035
% RED SSF		-2	-1	-1	-6	34	14	48	17	32
% RED SF		30	35	33	59	17	43	-35	34	8
% RED TOTAL		51	54	52	89	62	75	53	71	62
k value	SSF	-0.09	-0.04	-0.06	-0.25	1.87	0.68	2.93	0.82	1.75
k value	SF	1.60	1.92	1.76	3.97	0.83	2.50	-1.34	1.88	0.36
k value	PT	1.67	1.56	1.62	6.29	1.57	3.09	1.79	2.76	2.19
k value	Total	3.18	3.45	3.31	10.01	4.28	6.27	3.38	5.46	4.30
7/1/02	Batch	157.32	157.32	157.32	157.32	157.32	157.32	157.32	157.32	157.32
	SSF (12)	201.5	132.99	167.245	116.6	113.76	115.18	138.99	101.68	120.335
	SF(12)	142.97	170.09	156.53	83.06	109.56	96.31	196.07	162.79	179.43
	PT(OUT)	69.43	82.32	75.875	81.93	100.68	91.305	125.58	135.23	130.405
% RED SSF		-28	15	-6	26	28	27	12	35	24
% RED SF		29	-28	6	29	4	16	-41	-60	-49
% RED TOTAL		56	48	52	48	36	42	20	14	17
k value	SSF	-1.10	0.75	-0.27	1.34	1.45	1.39	0.55	1.95	1.20
k value	SF	1.53	-1.10	0.30	1.52	0.17	0.80	-1.53	-2.10	-1.78
k value	PT	3.23	3.24	3.24	0.06	0.38	0.24	1.99	0.83	1.42
k value	Total	3.66	2.89	3.26	2.92	1.99	2.43	1.00	0.67	0.84
7/8/02	Batch	164.36	164.36	164.36	164.36	164.36	164.36	164.36	164.36	164.36
	SSF (12)	124.95	95.37	110.16	142.41	91.05	116.73	100.4	94.91	97.655
	SF(12)	197.59	124.59	161.09	108.75	100.58	104.665	148.83	117.21	133.02
	PT(OUT)	18.59	106.19	62.39	44.21	50.72	47.465	100.44	109.06	104.75
% RED SSF		24	42	33	13	45	29	39	42	41
% RED SF		-58	-31	-46	24	-10	10	-48	-23	-36
% RED TOTAL		89	35	62	73	69	71	39	34	36
k value	SSF	1.22	2.43	1.79	0.64	2.64	1.53	2.20	2.45	2.32
k value	SF	-2.04	-1.19	-1.70	1.20	-0.45	0.49	-1.76	-0.94	-1.38
k value	PT	10.69	0.71	4.24	4.05	3.08	3.55	1.76	0.32	1.07
k value	Total	9.87	1.95	4.33	5.89	5.27	5.57	2.20	1.83	2.01

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
k value : Areal Rate Constant (m/yr)

Ammonium Tables

Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
		Ammonium Concentrations and Reductions								
7/15/02	Batch	116.47	116.47	116.465	116.47	116.47	116.465	116.47	116.47	116.465
	SSF (12)	169.88	154.32	162.1	148.1	142.9	145.5	164.1	187.28	175.69
	SF(12)	169.67	179.46	174.565	99.48	118.34	108.91	157.73	131.63	144.68
	PT(OUT)	99.62	72.27	85.945	29.76	50.76	40.26	155.25	55.4	105.325
	% RED SSF	-46	-33	-39	-27	-23	-25	-41	-61	-51
	% RED SF	0	-16	-8	33	17	25	4	30	18
	% RED TOTAL	14	38	26	74	56	65	-33	52	10
k value	SSF	-1.68	-1.26	-1.47	-1.07	-0.91	-0.99	-1.53	-2.12	-1.83
k value	SF	0.01	-0.67	-0.33	1.78	0.84	1.29	0.18	1.57	0.87
k value	PT	2.38	4.06	3.16	5.45	3.80	4.48	0.07	3.88	1.42
k value	Total	0.70	2.14	1.36	6.15	3.73	4.78	-1.28	3.33	0.45
7/19/02	Batch	160.27	160.27	160.27	160.27	160.27	160.27	160.27	160.27	160.27
	SSF (12)	158.88	136.03	147.455	112.28	118.58	115.43	172.27	175.68	173.975
	SF(12)									
	PT(OUT)					No Samples Taken				
	% RED SSF	1	15	8	30	26	28	-7	-10	-9
	% RED SF									
	% RED TOTAL									
k value	SSF	0.04	0.73	0.37	1.59	1.34	1.46	-0.32	-0.41	-0.37
k value	SF									
k value	PT									
k value	Total									
7/25/02	Batch	180.76	180.76	180.76	180.76	180.76	180.76	180.76	180.76	180.76
	SSF (12)	208.96	211.5	210.23	146.72	160.74	153.73	210.35	187.89	199.12
	SF(12)	152.56	158.31	155.435	127.44	161.26	144.35	165.77	138.48	152.125
	PT(OUT)	75.87	72.68	74.275	90.93	107.54	99.235	89.92	90.8	90.36
	% RED SSF	-16	-17	-16	19	11	15	-16	-4	-10
	% RED SF	27	25	26	13	0	6	21	26	24
	% RED TOTAL	58	60	59	50	41	45	50	50	50
k value	SSF	-0.65	-0.70	-0.67	0.93	0.52	0.72	-0.67	-0.17	-0.43
k value	SF	1.40	1.29	1.34	0.63	-0.01	0.28	1.06	1.36	1.20
k value	PT	3.12	3.48	3.30	1.51	1.81	1.67	2.73	1.89	2.33
k value	Total	3.88	4.07	3.97	3.07	2.32	2.68	3.12	3.07	3.09

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
k value : Areal Rate Constant (m/yr)

Ammonium Tables

Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
Ammonium Concentrations and Reductions										
7/31/02	Batch	203.64	203.64	203.64	203.64	203.64	203.64	203.64	203.64	203.64
	SSF (12)	No Samples Taken								
	SF(12)	156.18	132.02	144.1	80.9	71.13	76.015	158.49	125.34	141.915
	PT(OUT)	76.71	96.26	86.485	80.44	72.73	76.585	103.32	63.37	83.345
% RED SSF										
% RED SF										
% RED TOTAL		62	53	58	60	64	62	49	69	59
k value	ssf									
k value	sf									
k value	pt	3.18	1.41	2.28	0.03	-0.10	-0.03	1.91	3.06	2.38
k value	Total	4.36	3.34	3.82	4.15	4.60	4.37	3.03	5.22	3.99
8/6/02	Batch	262.43	262.43	262.43	262.43	262.43	262.43	262.43	262.43	262.43
	SSF (12)	279.22	201.2	240.21	173.92	175.15	174.535	340.21	323.22	331.715
	SF(12)	167.29	108.94	138.115	172.19	92.87	132.53	186.05	166.11	176.08
	PT(OUT)	45.86	45.86	45.86	80.59	89.28	84.935	159.08	71.38	115.23
% RED SSF		-6	23	8	34	33	33	-30	-23	-26
% RED SF		40	46	43	1	47	24	45	49	47
% RED TOTAL		83	83	83	69	66	68	39	73	56
k value	ssf	-0.28	1.18	0.39	1.83	1.80	1.81	-1.15	-0.93	-1.04
k value	sf	2.28	2.74	2.46	0.04	2.83	1.23	2.68	2.96	2.82
k value	pt	5.80	3.89	4.95	3.39	0.18	1.99	0.70	3.78	1.89
k value	Total	7.80	7.80	7.80	5.27	4.81	5.03	2.23	5.81	3.67
8/12/02	Batch	428.22	428.22	428.22	428.22	428.22	428.22	428.22	428.22	428.22
	SSF (12)	175.12	187.2	181.16	154.34	155.67	155.005	181.15	195.86	188.505
	SF(12)	194.16	187.15	190.655	179.05	163.94	171.495	341.2	292.34	316.77
	PT(OUT)	128.86	64.47	96.665	71.84	113.26	92.55	59.96	49.16	54.56
% RED SSF		59	56	58	64	64	64	58	54	56
% RED SF		-11	0	-5	-16	-5	-11	-88	-49	-68
% RED TOTAL		70	85	77	83	74	78	86	89	87
k value	ssf	3.97	3.68	3.82	4.54	4.50	4.52	3.82	3.48	3.65
k value	sf	-0.46	0.00	-0.23	-0.66	-0.23	-0.45	-2.82	-1.78	-2.31
k value	pt	1.83	4.76	3.03	4.08	1.65	2.75	7.76	7.97	7.86
k value	Total	5.34	8.44	6.63	7.96	5.92	6.82	8.77	9.67	9.19

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All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
k value : Areal Rate Constant (m/yr)

Ammonium Tables

Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
		Ammonium Concentrations and Reductions								
8/19/02	Batch	416.51	416.51	416.51	416.51	416.51	416.51	416.51	416.51	416.51
	SSF (12)	174.65	188.79	181.72	134.27	129.03	131.65	264.86	166.74	215.8
	SF(12)	197.37	180.38	188.875	155.8	143.96	149.88	346.18	274.53	310.355
	PT(OUT)	125.91	74.44	100.175	60.67	91.16	75.915	189.97	187.05	188.51
% RED SSF		58	55	56	68	69	68	36	60	48
% RED SF		-13	4	-4	-16	-12	-14	-31	-65	-44
% RED TOTAL		70	82	76	85	78	82	54	55	55
k value	SSF	3.86	3.52	3.69	5.04	5.21	5.12	2.01	4.07	2.92
k value	SF	-0.54	0.20	-0.17	-0.66	-0.49	-0.58	-1.19	-2.22	-1.62
k value	PT	2.00	3.95	2.83	4.22	2.04	3.04	2.67	1.71	2.22
k value	Total	5.32	7.67	6.34	8.59	6.77	7.59	3.49	3.56	3.52
8/23/02	Batch	354.2	354.2	354.2	354.2	354.2	354.2	354.2	354.2	354.2
	SSF (12)	342.44	299.71	321.075	262.76	254.96	258.86	416.67	396.04	406.355
	SF(12)	173.18	127.79	150.485	86.5	74.16	80.33	120.06	127.16	123.61
	PT(OUT)	113.47	29.68	71.575	20.47	38	29.235	31.27	39.16	35.215
% RED SSF		3	15	9	26	28	27	-18	-12	-15
% RED SF		49	57	53	67	71	69	71	68	70
% RED TOTAL		68	92	80	94	89	92	91	89	90
k value	SSF	0.15	0.74	0.44	1.33	1.46	1.39	-0.72	-0.50	-0.61
k value	SF	3.03	3.79	3.37	4.95	5.51	5.22	5.54	5.05	5.29
k value	PT	1.89	6.58	3.32	6.55	3.02	4.57	6.06	5.29	5.65
k value	Total	5.07	11.12	7.13	12.83	9.99	11.19	10.88	9.85	10.34
8/29/02	Batch	361.89	361.89	361.89	361.89	361.89	361.89	361.89	361.89	361.89
	SSF (12)	285.5	211.33	248.415	199.17	203.89	201.53	329.78	293.75	311.765
	SF(12)	183.26	183.26	183.26	148.31	125.97	137.14	183.04	185.28	184.16
	PT(OUT)	79.92	79.92	79.92	88.04	81.24	84.64	85.18	139.65	112.415
% RED SSF		21	42	31	45	44	44	9	19	14
% RED SF		36	13	26	26	38	32	44	37	41
% RED TOTAL		78	78	78	76	78	77	76	61	69
k value	SSF	1.05	2.39	1.67	2.65	2.55	2.60	0.41	0.93	0.66
k value	SF	1.97	0.63	1.35	1.31	2.15	1.71	2.62	2.05	2.34
k value	PT	3.71	3.71	3.71	2.33	1.96	2.16	3.42	1.26	2.20
k value	Total	6.73	6.73	6.73	6.30	6.66	6.47	6.45	4.24	5.20

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All Concentrations in mg/l (ppm)
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SF: Surface Flow Wetland Cells
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k value : Areal Rate Constant (m/yr)

Ammonium Tables

		Ammonium Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
9/5/02	Batch	199.04	199.04	199.035	199.04	199.04	199.035	199.04	199.04	199.035
	SSF (12)	112.48	138.12	125.3	122.09	107.06	114.575	131.1	155.04	143.07
	SF(12)	154.96	154.96	154.96	133.91	138.46	136.185	175.78	160.95	168.365
	PT(OUT)	10.43	10.43	10.43	33.13	39.04	36.085	51.79	12.79	32.29
% RED SSF		43	31	37	39	46	42	34	22	28
% RED SF		-38	-12	-24	-10	-29	-19	-34	-4	-18
% RED TOTAL		95	95	95	83	80	82	74	94	84
k value	SSF	2.54	1.63	2.06	2.18	2.77	2.46	1.86	1.11	1.47
k value	SF	-1.43	-0.51	-0.95	-0.41	-1.15	-0.77	-1.31	-0.17	-0.73
k value	PT	12.37	12.37	12.37	6.29	5.69	5.97	5.47	11.55	7.43
k value	Total	13.48	13.48	13.48	8.05	7.31	7.66	6.03	12.49	8.17
9/11/02	Batch	201.25	201.25	201.245	201.25	201.25	201.245	201.25	201.25	201.245
	SSF (12)	172.13	172.13	172.13	175.17	171.25	173.21	194.66	181.22	187.94
	SF(12)									
	PT(OUT)									
% RED SSF		14	14	14	13	15	14	3	10	7
% RED SF										
% RED TOTAL										
k value	SSF	0.70	0.70	0.70	0.62	0.72	0.67	0.15	0.47	0.30
k value	SF									
k value	PT									
k value	Total									
9/17/02	Batch	111.02	111.02	111.02	111.02	111.02	111.02	111.02	111.02	111.02
	SSF (12)	172.4	172.4	172.4	179.76	182.93	181.345	185.27	169.7	177.485
	SF(12)									
	PT(OUT)									
% RED SSF		-55	-55	-55	-62	-65	-63	-67	-53	-60
% RED SF										
% RED TOTAL										
k value	SSF	-1.96	-1.96	-1.96	-2.15	-2.23	-2.19	-2.28	-1.89	-2.09
k value	SF									
k value	PT									
k value	Total									

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All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap
k value : Areal Rate Constant (m/yr)

Data Tables for Nitrate Analysis

Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
		Nitrate Concentrations and Reductions								
6/25/02	Batch	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835	0.835
	SSF (12)	0.4	0.24	0.32	0.54	0.31	0.425	0.1	0.12	0.11
	SF(12)	0	0.05	0.025	0	0.17	0.085	0.06	0.06	0.06
	PT(OUT)	21.69	88.54	55.115	48.12	68.15	58.135	25.63	74.54	50.085
	% RED SSF	52	71	62	35	63	49	88	86	87
	% RED SF	100	79	92	100	45	80	40	50	45
	% RED TOTAL	-2498	-10504	-6501	-5663	-8062	-6862	-2969	-8827	-5898
7/1/02	Batch	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395
	SSF (12)	0.07	0.1	0.085	0.3	0.2	0.25	0.06	0.05	0.055
	SF(12)	0	0.02	0.01	1.29	0.33	0.81	0.05	0.04	0.045
	PT(OUT)	80.6	53.81	67.205	5.44	6.53	5.985	7.94	15.73	11.835
	% RED SSF	82	75	78	24	49	37	85	87	86
	% RED SF	100	80	88	-330	-65	-224	17	20	18
	% RED TOTAL	-20305	-13523	-16914	-1277	-1553	-1415	-1910	-3882	-2896
7/8/02	Batch	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
	SSF (12)	0.05	0	0.025	0.05	0.06	0.055	0.03	0.06	0.045
	SF(12)	0.15	0.15	0.15	0.13	0.19	0.16	0.17	0	0.085
	PT(OUT)	42.51	33.51	38.01	7.1	4.42	5.76	39.22	24.08	31.65
	% RED SSF	86	100	93	86	83	84	91	83	87
	% RED SF	-200	#DIV/0!	-500	-160	-217	-191	-467	100	-89
	% RED TOTAL	-12046	-9474	-10760	-1929	-1163	-1546	-11106	-6780	-8943
7/15/02	Batch	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225
	SSF (12)	0.05	0.03	0.04	0.03	0.03	0.03	0.02	0.04	0.03
	SF(12)	0.21	0	0.105	0.14	0	0.07	0.05	0	0.025
	PT(OUT)	133.76	114.16	123.96	136.93	112.38	124.655	533.08	148.37	340.725
	% RED SSF	78	87	82	87	87	87	91	82	87
	% RED SF	78	78	78	78	78	78	78	78	17
	% RED TOTAL	-59349	-50638	-54993	-60758	-49847	-55302	-236824	-65842	-151333
7/19/02	Batch	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
	SSF (12)	0.18	0.16	0.17	0.64	0.2	0.42	0.1	0.18	0.14
	SF(12)									
	PT(OUT)	No Samples Taken								
	% RED SSF	38	45	41	-121	31	-45	66	38	52
	% RED SF									
	% RED TOTAL									

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All Concentrations in mg/l (ppm)
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Nitrate Tables

		Nitrate Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
7/25/02	Batch	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	SSF (12)	0.24	0	0.12	0.09	0.25	0.17	0.27	0.15	0.21
	SF(12)	0.38	0.12	0.25	0.87	0.83	0.85	0.19	0	0.095
	PT(OUT)	157.76	155	156.38	12.24	9.98	11.11	80.24	85.24	82.74
	% RED SSF	-100	100	0	25	-108	-42	-125	-25	-75
	% RED SF	-58	#DIV/0!	-108	-867	-232	-400	30	100	55
	% RED TOTAL	-131367	-129067	-130217	-10100	-8217	-9158	-66767	-70933	-68850
7/31/02	Batch	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	SSF (12)	No Samples Taken								
	SF(12)	0.05	0	0.025	0.21	0.04	0.125	0	0.02	0.01
	PT(OUT)	124.04	65.29	94.665	78.96	73.27	76.115	22.4	33.59	27.995
	% RED SSF									
	% RED SF									
	% RED TOTAL	-103267	-54308	-78788	-65700	-60958	-63329	-18567	-27892	-23229
8/6/02	Batch	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	SSF (12)	0.34	0.35	0.345	0.38	1.24	0.81	0.46	0.44	0.45
	SF(12)	0	0.05	0.025	0.62	0.16	0.39	0.05	0.03	0.04
	PT(OUT)	101.35	101.35	101.35	72.13	69.82	70.975	55.66	69.77	62.715
	% RED SSF	0	-3	-1	-12	-265	-138	-35	-29	-32
	% RED SF	100	86	93	-63	87	52	89	93	91
	% RED TOTAL	-29709	-29709	-29709	-21115	-20435	-20775	-16271	-20421	-18346
8/12/02	Batch	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
	SSF (12)	0.06	0.09	0.075	0.18	0.17	0.175	0.09	0.19	0.14
	SF(12)	0.21	0.24	0.225	7.57	0.26	3.915	0.43	0.4	0.415
	PT(OUT)	41.6	162.54	102.07	129.6	103.95	116.775	249.48	203.58	226.53
	% RED SSF	97	96	97	92	92	92	96	91	94
	% RED SF	-250	-167	-200	-4106	-53	-2137	-378	-111	-196
	% RED TOTAL	-1774	-7222	-4498	-5738	-4582	-5160	-11138	-9070	-10104
8/19/02	Batch	3.165	3.165	3.165	3.165	3.165	3.165	3.165	3.165	3.165
	SSF (12)	0.19	0.16	0.175	0.18	0.15	0.165	0.07	0.16	0.115
	SF(12)	0.13	0.76	0.445	1.5	1.9	1.7	0.37	0.25	0.31
	PT(OUT)	119.76	149.52	134.64	136.17	101.62	118.895	59.14	57.87	58.505
	% RED SSF	94	95	94	94	95	95	98	95	96
	% RED SF	32	-375	-154	-733	-1167	-930	-429	-56	-170
	% RED TOTAL	-3684	-4624	-4154	-4202	-3111	-3657	-1769	-1728	-1748

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All Concentrations in mg/l (ppm)
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Nitrate Tables

		Nitrate Concentrations and Reductions								
Date In	Stage	A	B	AVG (AB)	C	D	AVG (CD)	E	F	AVG (EF)
8/23/02	Batch	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	SSF (12)	0.48	0.41	0.445	0.33	0.21	0.27	0.25	0.34	0.295
	SF(12)	0.21	33.51	16.86	0.23	0.11	0.17	19.52	1.8	10.66
	PT(OUT)	78.99	147.02	113.005	88.61	111.43	100.02	334.51	116.24	225.375
	% RED SSF	31	41	36	53	70	61	64	51	58
	% RED SF	56	-8073	-3689	30	48	37	-7708	-429	-3514
	% RED TOTAL	-11184	-20903	-16044	-12559	-15819	-14189	-47687	-16506	-32096
8/29/02	Batch	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	SSF (12)	0.35	0.3	0.325	0.81	4.59	2.7	0.19	0.75	0.47
	SF(12)	0.01	0.01	0.01	0.17	0.21	0.19	2.92	0.03	1.475
	PT(OUT)	164.04	164.04	164.04	89.55	58.17	73.86	244.56	72.84	158.7
	% RED SSF	51	58	55	-13	-538	-275	74	-4	35
	% RED SF	97	97	97	79	95	93	-1437	96	-214
	% RED TOTAL	-22683	-22683	-22683	-12338	-7979	-10158	-33867	-10017	-21942
9/5/02	Batch	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
	SSF (12)	0.49	0.78	0.635	0.38	5.22	2.8	7.47	0.67	4.07
	SF(12)	0.05	0.05	0.05	0.2	0.1	0.15	13.67	0.03	6.85
	PT(OUT)	239.44	239.44	239.44	161.15	91.39	126.27	265.11	314.79	289.95
	% RED SSF	9	-44	-18	30	-867	-419	-1283	-24	-654
	% RED SF	90	94	92	47	98	95	0	96	-68
	% RED TOTAL	-44241	-44241	-44241	-29743	-16824	-23283	-48994	-58194	-53594
9/11/02	Batch	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
	SSF (12)	0	0	0	0.06	0.12	0.09	0.02	0.09	0.055
	SF(12)									
	PT(OUT)									
	% RED SSF	100	100	100	90	81	85	97	85	91
	% RED SF									
	% RED TOTAL									
9/17/02	Batch	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165	0.165
	SSF (12)	0.05	0.05	0.05	0.1	0.13	0.115	0.03	0.86	0.445
	SF(12)									
	PT(OUT)									
	% RED SSF	70	70	70	39	21	30	82	-421	-170
	% RED SF									
	% RED TOTAL									

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All Concentrations in mg/l (ppm)
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Data Tables For COD Analysis

Date:	COD Concentrations (mg/L)								
7/19/2002	A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	2511.59	2511.59	2511.59	2511.59	2511.59	2511.59	2511.59	2511.59	2511.59
SSF (12)	267.36	848.07	557.72	563.89	390.91	477.40	316.78	514.47	415.63
SF (12)	1580.61	611.94	1096.28	700.90	740.44	720.67	666.30	505.68	585.99
PT Out	1197.59	1274.19	1235.89	503.21	886.23	694.72	555.10	757.73	656.42
Reduction (%)	52	73	51	80	65	72	78	70	74
k value (Total)	3.49	3.19	3.33	7.92	4.96	6.20	7.38	5.75	6.49
7/25/2002	A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24	1920.24
SSF (12)	1032.03	1896.91	1464.47	913.41	903.53	908.47	636.65	661.36	649.01
SF (12)	1423.93	1733.82	1578.88	977.66	639.12	808.39	495.80	770.09	632.95
PT Out	893.65	1365.63	1129.64	641.59	708.31	674.95	498.27	698.43	598.35
Reduction (%)	53	29	41	67	63	65	74	64	69
k value (Total)	3.68	1.61	2.52	5.37	4.85	5.10	6.73	4.93	5.74
8/6/2002	A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	3129.37	3129.37	3129.37	3129.37	3129.37	3129.37	3129.37	3129.37	3129.37
SSF (12)	569.93	587.23	578.58	604.53	503.21	553.87	527.92	446.38	487.15
SF (12)	846.69	792.33	819.51	589.70	532.86	561.28	389.54	354.95	372.25
PT Out	631.71	715.00	673.36	456.26	394.48	425.37	280.81	345.06	312.94
Reduction (%)	80	73	78	85	87	86	91	89	90
k value (Total)	7.70	7.06	7.37	9.48	10.32	9.88	12.48	11.13	11.76
8/19/2002	A	B	AVG(A&B)	C	D	AVG(C&D)	E	F	AVG(E&F)
Batch	5434.95	5434.95	5434.95	5434.95	5434.95	5434.95	5434.95	5434.95	5434.95
SSF (12)	1110.29	1071.64	1090.97	887.75	629.31	758.53	1126.31	1255.53	1190.92
SF (12)	1214.25	1188.44	1201.35	1513.97	1881.75	1697.86	671.56	505.06	588.31
PT Out	1117.72	1061.70	1089.71	957.33	969.76	963.55	572.16	442.94	507.55
Reduction (%)	79	80	80	82	82	82	89	92	91
k value (Total)	7.34	7.59	7.46	8.10	8.03	8.06	10.74	12.15	11.39
9/5/2002	A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	1942.77	1942.77	1942.77	1942.77	1942.77	1942.77	1942.77	1942.77	1942.77
SSF (12)	1325.04	1206.02	1265.53	1052.65	732.19	892.42	961.09	1002.29	981.69
SF (12)	1249.51	1270.11	1259.81	1036.63	656.66	846.65	1114.46	947.36	1030.91
PT Out	1444.07	864.95	1154.51	1313.60	569.67	941.64	736.77	597.14	666.96
Reduction (%)	26	73	41	32	71	52	62	69	66
k value (Total)	1.40	3.89	2.47	1.85	6.05	3.47	4.71	5.80	5.22

A,B: Septisorb
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

COD Tables

Date: 9/11/2002	COD Concentrations (mg/L) A	B	AVG (A&B)	C	D	AVG (C&D)	E	F	AVG (E&F)
Batch	2238.35	2238.35	2238.35	2238.35	2238.35	2238.35	2238.35	2238.35	2238.35
SSF (12)	903.12	878.22	890.67	762.74	563.48	663.11	717.54	755.95	736.75
SF (12)	1136.35	1131.82	1134.09	932.56	622.35	777.46	1097.85	851.05	974.45
PT Out	841.99	878.22	860.11	740.10	531.78	635.94	986.90	683.49	835.20
Reduction (%)	62	73	62	67	76	72	56	69	63
k value (Total)	4.69	4.48	4.58	5.34	7.08	6.13	3.90	5.75	4.73

A,B: Septisorb and Pea-Stone Substrate
C,D: Lava Rock Substrate
E,F: Pea-Stone Substrate
All Concentrations in mg/l (ppm)
SSF: Sub-Surface Flow Wetland Cells
SF: Surface Flow Wetland Cells
PT: Phosphorus Trap

APPENDIX B

Weather Data

Weather Data Collected From Michigan Agricultural Weather Network Weather Station, Bath, MI.

Date	Air Temp Max	Air Temp Min	Total Precip (in)	Avg. Rel Humidity (%)	Total Wind (mi/day)	Total Solar Rad. (ly/day)	Estimated PET (in/day)
6/25/2002	91.4	59.5	0.02	74.4	62.2	485.1	0.251
6/26/2002	83.8	68.6	0.09	75.3	128.5	516.8	0.307
6/27/2002	80.6	60.0	0.00	71.8	119.6	471.5	0.267
6/28/2002	84.8	51.4	0.01	72.9	39.9	656.2	0.249
6/29/2002	88.7	54.3	0.00	69.1	57.8	635.2	0.276
6/30/2002	90.3	60.0	0.00	70.2	64.2	533.2	0.264
7/1/2002	92.0	66.8	0.00	72.8	69.0	572.1	0.270
7/2/2002	89.8	65.8	0.12	68.9	94.4	652.0	0.320
7/3/2002	90.9	63.1	0.00	69.3	84.8	541.0	0.283
7/4/2002	91.0	67.7	0.01	59.6	91.7	606.0	0.299
7/5/2002	77.0	50.4	0.00	68.9	86.2	536.3	0.235
7/6/2002	83.3	46.6	0.00	71.0	33.5	532.2	0.207
7/7/2002	88.9	50.3	0.05	64.7	40.0	626.4	0.254
7/8/2002	90.3	55.7	0.07	68.3	79.4	553.3	0.283
7/9/2002	81.4	64.0	0.07	84.7	105.2	342.0	0.224
7/10/2002	75.3	51.0	0.00	62.6	124.1	615.4	0.278
7/11/2002	77.6	43.0	0.00	68.2	67.2	634.3	0.239
7/12/2002	80.8	39.7	0.00	62.3	36.3	689.0	0.236
7/13/2002	86.9	43.2	0.00	62.0	40.6	687.0	0.26
7/14/2002	86.1	46.6	0.07	61.7	53.2	676.9	0.269
7/15/2002	88.6	50.4	0.00	72.6	64.6	377.2	0.215
7/16/2002	90.0	58.2	0.10	72.8	45.2	482.8	0.227
7/17/2002	85.9	59.0	0.00	71.7	78.5	477.5	0.247
7/18/2002	86.1	62.5	0.01	80.5	51.4	326.8	0.184
7/19/2002	83.5	58.3	0.02	78.1	62.5	423.1	0.209
7/20/2002	88.2	50.7	0.00	68.0	35.4	558.5	0.229
7/21/2002	91.1	66.0	0.07	71.1	126.4	289.3	0.254
7/22/2002	92.0	71.4	0.19	72.9	137.5	477.4	0.302
7/23/2002	73.6	46.9	0.00	74.1	123.1	596.1	0.254
7/24/2002	79.7	40.9	0.00	69.2	62.7	616.4	0.235
7/25/2002	78.9	48.5	0.00	69.0	60.2	454.6	0.198
7/26/2002	86.0	64.8	0.65	78.5	100.1	495.5	0.273
7/27/2002	81.8	59.8	0.12	86.9	72.4	310.2	0.183
7/28/2002	85.0	68.9	0.95	84.5	125.9	251.3	0.234
7/29/2002	85.6	68.1	0.57	87.1	91.0	301.7	0.214
7/30/2002	86.0	64.0	0.00	78.4	68.0	614.9	0.27
7/31/2002	89.9	63.6	0.00	72.6	55.3	615.9	0.268
8/1/2002	88.6	62.5	0.00	72.3	109.4	500.1	0.291
8/2/2002	82.5	57.8	0.07	73.2	94.6	619.0	0.28
8/3/2002	86.9	50.4	0.00	72.5	64.2	630.7	0.265

Date	Air Temp Max	Air Temp Min	Total Precip (in)	Avg. Rel Humidity (%)	Total Wind (mi/day)	Total Solar Rad. (ly/day)	Estimated PET (in/day)
8/4/2002	88.5	64.4	0.00	74.3	64.5	365.5	0.213
8/5/2002	81.6	64.9	0.00	74.8	91.0	429.1	0.234
8/6/2002	70.7	46.6	0.00	69.8	116.0	553.9	0.228
8/7/2002	74.6	40.1	0.00	75.5	76.3	526.5	0.202
8/8/2002	78.9	40.2	0.00	73.0	54.6	604.7	0.218
8/9/2002	82.6	45.0	0.00	71.2	35.7	600.1	0.215
8/10/2002	86.1	48.4	0.00	68.3	70.7	577.1	0.255
8/11/2002	88.4	58.9	0.07	73.2	65.8	487.9	0.239
8/12/2002	88.6	58.6	0.02	78.9	89.6	511.5	0.267
8/13/2002	86.8	66.0	0.20	80.4	120.7	392.2	0.266
8/14/2002	75.9	67.0	0.31	85.7	130.8	214.4	0.197
8/15/2002	82.6	61.4	0.00	79.0	132.3	363.1	0.25
8/16/2002	82.9	61.3	0.10	78.7	127.7	287.4	0.229
8/17/2002	84.2	61.4	0.00	80.7	157.8	272.0	0.257
8/18/2002	77.9	51.3	0.00	64.4	87.7	490.1	0.222
8/19/2002	71.2	48.9	0.46	89.0	56.5	195.6	0.108
8/20/2002	77.6	45.0	0.00	76.6	50.2	544.5	0.195
8/21/2002	82.1	46.5	0.00	73.0	98.1	502.7	0.242
8/22/2002	77.5	66.0	0.23	87.3	123.1	179.1	0.183
8/23/2002	71.8	65.3	0.27	93.4	44.2	84.1	0.088
8/24/2002	78.5	59.1	0.01	86.7	58.4	285.1	0.153
8/25/2002	80.7	53.1	0.00	83.9	35.3	423.5	0.167
8/26/2002	83.2	50.6	0.00	76.8	32.6	520.3	0.191
8/27/2002	79.4	53.0	0.00	84.2	115.8	442.0	0.229
8/28/2002	76.6	45.1	0.00	75.5	78.4	537.7	0.209
8/29/2002	82.2	51.2	0.00	80.1	44.0	459.5	0.184
8/30/2002	81.8	49.5	0.00	77.4	46.2	500.9	0.193
8/31/2002	84.1	46.9	0.00	75.7	44.5	488.2	0.194
9/1/2002	86.6	49.9	0.00	71.8	67.0	459.2	0.218
9/2/2002	82.6	65.8	0.00	75.5	116.0	252.3	0.212
9/3/2002	81.1	50.7	0.00	61.4	136.3	499.8	0.272
9/4/2002	81.2	46.3	0.00	67.8	80.2	520.3	0.223
9/5/2002	78.5	46.2	0.00	78.7	47.8	485.9	0.178
9/6/2002	86.8	45.6	0.00	69.3	65.6	490.7	0.223
9/7/2002	92.4	49.0	0.00	67.2	48.4	483.4	0.221
9/8/2002	92.6	54.0	0.00	67.9	44.2	458.0	0.209
9/9/2002	91.3	50.9	0.00	72.5	31.4	412.5	0.183
9/10/2002	88.1	57.9	0.03	74.4	107.9	343.8	0.236
9/11/2002	75.4	44.9	0.00	67.2	104.3	455.9	0.205
9/12/2002	77.9	37.4	0.00	67.9	55.0	475.3	0.177
9/13/2002	79.5	42.5	0.00	71.7	46.0	397.7	0.159
9/14/2002	85.7	44.8	0.00	66.1	48.1	406.7	0.182
9/15/2002	66.6	45.2	0.00	84.4	89.5	59.5	0.086

Date	Air Temp Max	Min	Total Precip (in)	Avg. Rel Humidity (%)	Total Wind (mi/day)	Total Solar Rad. (ly/day)	Estimated PET (in/day)
9/16/2002	75.4	36.1	0.00	74.6	40.7	466.9	0.153
9/17/2002	83.3	38.0	0.00	71.4	38.6	434.2	0.169
9/18/2002	77.0	49.2	0.17	88.0	74.7	156.6	0.123
9/19/2002	86.5	66.0	1.44	84.6	144.1	255.6	0.243
9/20/2002	77.0	65.3	0.13	87.3	168.1	136.0	0.203
9/21/2002	79.0	52.4	0.00	73.0	125.6	439.7	0.229
9/22/2002	55.4	40.7	0.01	88.2	52.6	82.6	0.046
9/23/2002	64.8	34.6	0.00	74.7	52.1	3436.0	0.108
9/24/2002	62.9	36.9	0.00	69.7	78.7	354.2	0.12
9/25/2002	71.7	31.0	0.00	75.7	53.7	383.2	0.132
9/26/2002	74.9	39.2	0.00	80.0	42.4	293.7	0.118
9/27/2002	72.1	51.8	0.00	84.9	85.5	244.9	0.133
9/28/2002	71.8	36.8	0.00	70.4	61.0	321.3	0.128
9/29/2002	77.6	54.1	0.00	71.8	103.5	239.8	0.168
9/30/2002	84.1	62.6	0.00	60.7	153.6	339.7	0.263
10/1/2002	84.5	67.6	0.00	68.0	164.8	307.0	0.27

APPENDIX C

Wetland Photographs

Photo 1: Constructed Wetland System at Green Meadows Dairy Farm

Photo 2: Constructed Wetland System at Green Meadows Dairy Farm


Photo 3: Constructed Wetland System at Green Meadows Farm


Photo 4: Constructed Wetland System at Green Meadows Farm

Photo 5: Septisorb/Pea Gravel Wetland Cells (I)

Photo 6: Septisorb/Pea Gravel Wetland Cells (Duplicate)

Photo 7: Lava Rock Wetland Cells (I)

Photo 8: Lava Rock Wetland Cells (Duplicate)

Photo 9: Pea Stone Wetland Cells (I)

Photo 10: Pea Stone Wetland Cells (Duplicate)

Photo 11: Lagoon Effluent to be Applied to Wetland

APPENDIX D

Pilot Scale Wetland Design Data

Wetland Design Data Tables for Variable Influent COD Concentration with Constant Wastewater Flow of 10,000 gal/d and Target Effluent Concentration of 500 mg/L

Substrate	K value m/yr	Concentrations (mg/L) Influent	Effluent	Bckgrnd	Required Wetland Area (ha)	Required Wetland Area (acres)	Water Flow Rate (m^3/d)	Water Flow Rate (g/d)
Septisorb/	4.63	500	500	100	0.00	0.00	37.85	10000
Pea-Stone	4.63	1000	500	100	0.24	0.60	37.85	10000
	4.63	1500	500	100	0.37	0.92	37.85	10000
	4.63	2000	500	100	0.46	1.15	37.85	10000
	4.63	2500	500	100	0.53	1.32	37.85	10000
	4.63	3000	500	100	0.59	1.46	37.85	10000
	4.63	3500	500	100	0.64	1.58	37.85	10000
	4.63	4000	500	100	0.68	1.68	37.85	10000
	4.63	4500	500	100	0.72	1.77	37.85	10000
	4.63	5000	500	100	0.75	1.85	37.85	10000
Lava Rock	5.78	500	500	100	0.00	0.00	37.85	10000
	5.78	1000	500	100	0.19	0.48	37.85	10000
	5.78	1500	500	100	0.30	0.74	37.85	10000
	5.78	2000	500	100	0.37	0.92	37.85	10000
	5.78	2500	500	100	0.43	1.06	37.85	10000
	5.78	3000	500	100	0.47	1.17	37.85	10000
	5.78	3500	500	100	0.51	1.26	37.85	10000
	5.78	4000	500	100	0.54	1.35	37.85	10000
	5.78	4500	500	100	0.57	1.42	37.85	10000
	5.78	5000	500	100	0.60	1.48	37.85	10000
Pea-Stone	5.54	500	500	100	0.00	0.00	37.85	10000
	5.54	1000	500	100	0.20	0.50	37.85	10000
	5.54	1500	500	100	0.31	0.77	37.85	10000
	5.54	2000	500	100	0.39	0.96	37.85	10000
	5.54	2500	500	100	0.45	1.10	37.85	10000
	5.54	3000	500	100	0.49	1.22	37.85	10000
	5.54	3500	500	100	0.53	1.32	37.85	10000
	5.54	4000	500	100	0.57	1.40	37.85	10000
	5.54	4500	500	100	0.60	1.48	37.85	10000
	5.54	5000	500	100	0.62	1.54	37.85	10000

Wetland Design Data Tables for Variable Wastewater Flow with Constant Influent COD Concentration of 3,000 mg/L and Target Effluent Concentration of 500 mg/L

Substrate	K value m/yr	Concentrations (mg/L) Influent	Effluent	Bckgrnd	Required Wetland Area (ha)	Required Wetland Area (acres)	Water Flow Rate (m^3/d)	Water Flow Rate (g/d)
Septisorb/	4.63	3000	500	100	0.59	1.46	37.85	10000
Pea-Stone	4.63	3000	500	100	0.89	2.19	56.775	15000
	4.63	3000	500	100	1.18	2.92	75.7	20000
	4.63	3000	500	100	1.48	3.65	94.625	25000
	4.63	3000	500	100	1.77	4.38	113.55	30000
	4.63	3000	500	100	2.07	5.11	132.475	35000
	4.63	3000	500	100	2.36	5.84	151.4	40000
	4.63	3000	500	100	2.66	6.57	170.325	45000
	4.63	3000	500	100	2.96	7.30	189.25	50000
	4.63	3000	500	100	3.25	8.03	208.175	55000
Lava Rock	5.78	3000	500	100	0.47	1.17	37.85	10000
	5.78	3000	500	100	0.71	1.76	56.775	15000
	5.78	3000	500	100	0.95	2.34	75.7	20000
	5.78	3000	500	100	1.18	2.93	94.625	25000
	5.78	3000	500	100	1.42	3.51	113.55	30000
	5.78	3000	500	100	1.66	4.10	132.475	35000
	5.78	3000	500	100	1.89	4.68	151.4	40000
	5.78	3000	500	100	2.13	5.27	170.325	45000
	5.78	3000	500	100	2.37	5.85	189.25	50000
	5.78	3000	500	100	2.60	6.44	208.175	55000
Pea-Stone	5.54	3000	500	100	0.49	1.22	37.85	10000
	5.54	3000	500	100	0.74	1.83	56.775	15000
	5.54	3000	500	100	0.99	2.44	75.7	20000
	5.54	3000	500	100	1.24	3.05	94.625	25000
	5.54	3000	500	100	1.48	3.66	113.55	30000
	5.54	3000	500	100	1.73	4.27	132.475	35000
	5.54	3000	500	100	1.98	4.88	151.4	40000
	5.54	3000	500	100	2.22	5.49	170.325	45000
	5.54	3000	500	100	2.47	6.10	189.25	50000
	5.54	3000	500	100	2.72	6.71	208.175	55000

Wetland Design Data Tables for Variable Influent COD Concentration with Constant Wastewater Flow of 10,000 gal/d and Target Effluent Concentration of 250 mg/L

Substrate	K value m/yr	Concentrations (mg/L) Influent	Effluent	Bckgrnd	Required Wetland Area (ha)	Required Wetland Area (acres)	Water Flow Rate (m^3/d)	Water Flow Rate (g/d)
Septisorb/	4.63	500	250	100	0.29	0.72	37.85	10000
Pea-Stone	4.63	1000	250	100	0.53	1.32	37.85	10000
	4.63	1500	250	100	0.67	1.65	37.85	10000
	4.63	2000	250	100	0.76	1.87	37.85	10000
	4.63	2500	250	100	0.83	2.04	37.85	10000
	4.63	3000	250	100	0.88	2.18	37.85	10000
	4.63	3500	250	100	0.93	2.30	37.85	10000
	4.63	4000	250	100	0.97	2.40	37.85	10000
	4.63	4500	250	100	1.01	2.49	37.85	10000
	4.63	5000	250	100	1.04	2.57	37.85	10000
Lava Rock	5.78	500	250	100	0.23	0.58	37.85	10000
	5.78	1000	250	100	0.43	1.06	37.85	10000
	5.78	1500	250	100	0.53	1.32	37.85	10000
	5.78	2000	250	100	0.61	1.50	37.85	10000
	5.78	2500	250	100	0.66	1.64	37.85	10000
	5.78	3000	250	100	0.71	1.75	37.85	10000
	5.78	3500	250	100	0.75	1.84	37.85	10000
	5.78	4000	250	100	0.78	1.92	37.85	10000
	5.78	4500	250	100	0.81	2.00	37.85	10000
	5.78	5000	250	100	0.83	2.06	37.85	10000
Pea-Stone	5.54	500	250	100	0.24	0.60	37.85	10000
	5.54	1000	250	100	0.45	1.10	37.85	10000
	5.54	1500	250	100	0.56	1.38	37.85	10000
	5.54	2000	250	100	0.63	1.56	37.85	10000
	5.54	2500	250	100	0.69	1.71	37.85	10000
	5.54	3000	250	100	0.74	1.83	37.85	10000
	5.54	3500	250	100	0.78	1.92	37.85	10000
	5.54	4000	250	100	0.81	2.01	37.85	10000
	5.54	4500	250	100	0.84	2.08	37.85	10000
	5.54	5000	250	100	0.87	2.15	37.85	10000

Wetland Design Data Tables for Variable Wastewater Flow with Constant COD Influent Concentration of 3,000 mg/L and Target Effluent Concentration of 250 mg/L

Substrate	K value m/yr	Concentrations (mg/L) Influent	Effluent	Bckgrnd	Required Wetland Area (ha)	Required Wetland Area (acres)	Water Flow Rate (m^3/d)	Water Flow Rate (g/d)
Septisorb/	4.63	3000	250	100	0.88	2.18	37.85	10000
Pea-Stone	4.63	3000	250	100	1.33	3.28	56.775	15000
	4.63	3000	250	100	1.77	4.37	75.7	20000
	4.63	3000	250	100	2.21	5.46	94.625	25000
	4.63	3000	250	100	2.65	6.55	113.55	30000
	4.63	3000	250	100	3.09	7.64	132.475	35000
	4.63	3000	250	100	3.54	8.74	151.4	40000
	4.63	3000	250	100	3.98	9.83	170.325	45000
	4.63	3000	250	100	4.42	10.92	189.25	50000
	4.63	3000	250	100	4.86	12.01	208.175	55000
Lava Rock	5.78	3000	250	100	0.71	1.75	37.85	10000
	5.78	3000	250	100	1.06	2.62	56.775	15000
	5.78	3000	250	100	1.42	3.50	75.7	20000
	5.78	3000	250	100	1.77	4.37	94.625	25000
	5.78	3000	250	100	2.12	5.25	113.55	30000
	5.78	3000	250	100	2.48	6.12	132.475	35000
	5.78	3000	250	100	2.83	7.00	151.4	40000
	5.78	3000	250	100	3.19	7.87	170.325	45000
	5.78	3000	250	100	3.54	8.75	189.25	50000
	5.78	3000	250	100	3.89	9.62	208.175	55000
Pea-Stone	5.54	3000	250	100	0.74	1.83	37.85	10000
	5.54	3000	250	100	1.11	2.74	56.775	15000
	5.54	3000	250	100	1.48	3.65	75.7	20000
	5.54	3000	250	100	1.85	4.56	94.625	25000
	5.54	3000	250	100	2.22	5.48	113.55	30000
	5.54	3000	250	100	2.59	6.39	132.475	35000
	5.54	3000	250	100	2.95	7.30	151.4	40000
	5.54	3000	250	100	3.32	8.21	170.325	45000
	5.54	3000	250	100	3.69	9.13	189.25	50000
	5.54	3000	250	100	4.06	10.04	208.175	55000

APPENDIX E

Statistical Data Tables

Ammonium Concentrations with Outliers

		Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	196.57	200.6	140.13	96.39	208.12	85.45	21.4	102.01	137.63	92.12
	157.32	198.13	128.75	90.81	129.12	107.11	75.43	163.67	107.33	57.95
	164.36	201.5	142.97	69.43	116.6	83.06	81.93	101.68	162.79	125.58
	116.465	132.99	170.09	82.32	113.76	109.56	100.68	138.99	196.07	135.23
	160.27	124.95	197.59	18.59	142.41	108.75	44.21	94.91	117.21	100.44
	180.76	95.37	124.59	106.19	91.05	100.58	50.72	100.4	148.83	109.06
	203.64	169.88	169.67	99.62	148.1	99.48	29.76	187.28	131.63	155.25
	262.43	154.32	179.46	72.27	142.9	118.34	50.76	164.1	157.73	55.4
	428.22	158.88	152.56	75.87	112.28	127.44	90.93	175.68	138.48	89.92
	416.51	136.03	158.31	72.68	118.58	161.26	107.54	172.27	165.77	90.8
	354.2	208.96	156.18	76.71	146.72	80.9	80.44	187.89	125.34	103.32
	361.89	211.5	132.02	96.26	160.74	71.13	72.73	210.35	158.49	63.37
	199.04	279.22	167.29	45.86	173.92	172.19	80.59	323.22	166.11	159.08
	201.25	201.2	108.94	128.86	175.15	92.87	89.28	340.21	186.05	71.38
	111.02	175.12	194.16	64.47	154.34	179.05	71.84	195.86	292.34	59.96
	181.49	187.2	187.15	125.91	155.67	163.94	113.26	181.15	341.2	49.16
		174.65	197.37	74.44	134.27	155.8	60.67	166.74	274.53	189.97
		188.79	180.38	113.47	129.03	143.96	91.16	264.86	346.18	187.05
		342.44	173.18	29.68	262.76	86.5	20.47	396.04	127.16	31.27
		299.71	127.79	79.92	254.96	74.16	38	416.67	120.06	39.16
		285.5	183.26	10.43	199.17	148.31	88.04	293.75	183.04	85.18
		211.33	154.96		203.89	125.97	81.24	329.78	185.28	139.65
		112.48			122.09	133.91	33.13	131.1	175.78	51.79
		138.12			107.06	138.46	39.04	155.04	160.95	12.79
		172.13			175.17			194.66		
		172.4			171.25			169.7		
					179.76			185.27		
					182.93			181.22		
Mean	230.96	189.75	160.31	77.63	157.56	119.51	67.22	204.45	179.42	93.95
Std Dev	102.57	58.60	25.74	31.67	41.92	32.81	27.52	87.69	66.90	48.38
Boxplot										
Quartile 1	163.338	155.46	140.84	69.43	127.3	91.2775	42.9175	161.51	136.13	57.3125
Quartile 3	285.373	207.1	180.15	96.39	176.32	145.048	88.35	223.98	185.473	127.993
IQR	122.035	51.635	39.31	26.96	49.023	53.77	45.4325	62.465	49.3425	70.68
Upper Bound	468.425	284.55	239.115	136.83	249.85	225.703	156.499	317.68	259.486	234.013
Lower Bound	-19.715	78.008	81.875	28.99	53.761	10.6225	-25.231	67.815	62.1163	-48.708
outlier										

Ammonium Concentrations without Outliers; P-Values for T-test to Determine Statistical Significance from Influent Concentration

		Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	196.57	200.6	140.13	96.39	208.12	85.45	21.4	102.01	137.63	92.12
	157.32	198.13	128.75	90.81	129.12	107.11	75.43	163.67	107.33	57.95
	164.36	201.5	142.97	69.43	116.6	83.06	81.93	101.68	162.79	125.58
	116.465	132.99	170.09	82.32	113.76	109.56	100.68	138.99	196.07	135.23
	160.27	124.95	197.59	106.19	142.41	108.75	44.21	94.91	117.21	100.44
	180.76	95.37	124.59	99.62	91.05	100.58	50.72	100.4	148.83	109.06
	203.64	169.88	169.67	72.27	148.1	99.48	29.76	187.28	131.63	155.25
	262.43	154.32	179.46	75.87	142.9	118.34	50.76	164.1	157.73	55.4
	428.22	158.88	152.56	72.68	112.28	127.44	90.93	175.68	138.48	89.92
	416.51	136.03	158.31	76.71	118.58	161.26	107.54	172.27	165.77	90.8
	354.2	208.96	156.18	96.26	146.72	80.9	80.44	187.89	125.34	103.32
	361.89	211.5	132.02	45.86	160.74	71.13	72.73	210.35	158.49	63.37
	199.04	279.22	167.29	128.86	173.92	172.19	80.59	195.86	166.11	159.08
	201.25	201.2	108.94	64.47	175.15	92.87	89.28	181.15	186.05	71.38
	111.02	175.12	194.16	125.91	154.34	179.05	71.84	166.74	341.2	59.96
	181.49	187.2	187.15	74.44	155.67	163.94	113.26	264.86	274.53	49.16
		174.65	197.37	113.47	134.27	155.8	60.67	396.04	127.16	189.97
		188.79	180.38	29.68	129.03	143.96	91.16	293.75	120.06	187.05
		211.33	173.18	79.92	199.17	86.5	20.47	131.1	183.04	31.27
		112.48	127.79		203.89	74.16	38	155.04	185.28	39.16
		138.12	183.26		122.09	148.31	88.04	194.66	175.78	85.18
		172.13	154.96		107.06	125.97	81.24	169.7	160.95	139.65
		172.4			175.17	133.91	33.13	185.27		51.79
					171.25	138.46	39.04	181.22		12.79
					179.76					
					182.93					
Mean	230.96	174.16	160.31	84.27	149.77	119.51	67.22	179.78	166.70	93.95
Std Dev.	102.57	40.28	25.74	24.96	31.82	32.81	27.52	65.84	52.92	48.38
T Test P Value		0.0496	0.00798	2.1E-05	0.0034	0.0003	5.9E-06	0.0452	0.01611	4.1E-05
Reduction from Influent										

Ammonium % Reductions with Outliers

	Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL
	-2	30	51	-6	59	89	48	-35	53
	-1	35	54	34	17	62	17	34	71
	-28	29	56	26	29	48	12	-41	20
	15	-28	48	28	4	36	35	-60	14
	24	-58	89	13	24	73	39	-48	39
	42	-31	35	45	-10	69	42	-23	34
	-46	0	14	-27	33	74	-41	4	0
	-33	-16	38	-23	17	56	-61	30	52
	1	27	58	30	13	50	-7	21	50
	15	25	60	26	0	41	-10	26	50
	-16	40	62	19	1	60	-16	45	49
	-17	46	53	11	47	64	-4	49	69
	-6	-11	83	34	-16	69	-30	-88	39
	23	0	70	33	-5	66	-23	-49	73
	59	-13	85	64	-16	83	58	-31	86
	56	4	70	64	-12	74	54	-65	89
	58	49	82	68	67	85	36	71	54
	55	57	68	69	71	78	60	68	55
	3	36	92	26	26	94	-18	44	91
	15	13	78	28	38	89	-12	37	89
	21	-38	95	45	-10	76	9	-34	76
	42	-12		44	-29	78	19	-4	61
	43			39		83	34		74
	31			46		80	22		94
	14			13			3		
	-55			15			10		
				-62			-67		
				-65			-53		
Mean	12.04	8.36	63.86	22.75	15.82	69.88	5.57	-2.23	57.58
Std Dev	32.00	31.53	20.69	33.89	28.31	15.41	35.88	46.96	25.13
Quartile 1	-5	-12.75	53	13	-8.75	61.5	-16.5	-39.5	46.5
Quartile 3	39.25	33.75	82	44.25	32	80.75	35.25	36.25	74.5
IQR	44.25	46.5	29	31.25	40.75	19.25	51.75	75.75	28
Upper Bound	105.63	103.5	125.5	91.125	93.125	109.63	112.88	149.875	116.5
Lower Bound	-71.375	-82.5	9.5	-33.875	-69.875	32.625	-94.125	-153.125	4.5
outlier									

Ammonium % Reductions without Outliers

	Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	-2	30	51	-6	59	89	48	-35	53
	-1	35	54	34	17	62	17	34	71
	-28	29	56	26	29	48	12	-41	20
	15	-28	48	28	4	36	35	-60	14
	24	-58	89	13	24	73	39	-48	39
	42	-31	35	45	-10	69	42	-23	34
	-46	0	14	-27	33	74	-41	4	52
	-33	-16	38	-23	17	56	-61	30	50
	1	27	58	30	13	50	-7	21	50
	15	25	60	26	0	41	-10	26	49
	-16	40	62	19	1	60	-16	45	69
	-17	46	53	11	47	64	-4	49	39
	-6	-11	83	34	-16	69	58	71	73
	23	0	70	33	-5	66	54	68	86
	59	-13	85	64	-16	83	36	44	89
	56	4	70	64	-12	74	60	37	54
	58	49	82	68	67	85	9	-34	55
	55	57	68	69	71	78	19	-4	91
	3	36	92	26	26	94	34		89
	15	13	78	28	38	89	22		76
	21	-38	95	45	-10	76	3		61
	42	-12		44	-29	78	10		74
	43			39		83	-67		94
	31			46		80	-53		
	14			13					
	-55			15					
Mean	12.04	8.36	63.86	29.38	15.82	69.88	9.96	10.22	60.09
Std Dev.	32.00	31.53	20.69	24.48	28.31	15.41	36.92	41.46	22.43

T-Test Tables for Ammonium

T-test for Substrate Comparison

	SSF Comparison		
	S-L	L-P	S-P
P Value	0.01231	0.0255	0.36259
	SF Comparison		
	S-L	L-P	S-P
P Value	1.3E-05	0.0005	0.30704
	Total Comparison		
	S-L	L-P	S-P
P Value	0.01988	0.0242	0.20099

S: Septisorb and Pea-Stone Substrate
L: Lava Rock Substrate
P: Pea-Stone Substrate
SSF: Sub-Surface Flow Wetland
SF: Surface Flow Wetland

T-Test for Wetland Stage Comparison

	P Value
Septisorb / Pea-Stone	0.34567
Lava Rock	0.04292
Pea-Stone	0.49153

Phosphorus Concentrations with Outliers

		Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	57.5	6.7	0.5	0.8	24.6	3.9	3.2	5.6	0.4	0.6
	15.3	7.3	0.5	1.3	19.5	6	6.5	1.8	2	1
	20.1	3	1.8	0.55	8.9	5.3	7.45	3	0.8	0.14
	17.7	0.8	0.23	0.45	8.2	5.6	6.1	3.1	0.32	0.31
	28.3	2.5	0.29	0.4	7.6	8.1	7.3	3.7	0.18	0.11
	14.75	2.6	0.3	0.36	9.4	12.9	8.35	0.9	0.39	0.3
	16.44	0.25	2.45	0.35	5.2	10.4	4.5	0.36	1.05	0.38
	24.53	1.19	1.98	1	6	10.3	10	0.39	1.65	0.85
	30.45	0.44	3.4	1.7	9.1	14.6	12.3	2.1	1.6	1
	35.5	1.9	3.1	2.2	12.9	19.5	14.2	0.65	2.4	1.1
	25.15	4.15	4.6	1.4	15.3	8	12.9	5	2.7	1.1
	18.25	4.58	3.8	1.9	15.9	7.5	15.4	5	0.5	1.5
	21.7	7.8	0.4	2.8	13	8.4	14	9.7	2	0.8
	24.55	7.6	0.3	2.8	20.1	7.4	9	10	0.9	1
	15.05	1.6	7	1.8	8.4	16.4	16.7	5.2	3.7	1.1
		2.5	5.4	3.6	9.5	14.4	16.7	9.7	6.5	1.8
		17.1	3.8	1.2	8.4	10	16	6.7	2.8	1.6
		6.8	3.8	2.7	7.2	9.5	13.6	8.8	5.8	2.5
		17.1	6.8	2	17.1	4	8	14	2	0.6
		14.8	1.8	1.8	17.1	5.3	3.7	12.3	4.6	1.2
		9.5	1.3	1.7	16.4	9.4	9.2	12.6	1.3	0.9
		9.7	7	2	15.6	8.7	7.3	10	3.6	2
		13.6			2.5	9.2	8.7	3	1.5	0.7
		7.8			7.5	8.7	10	3.5	4	1.1
		5.5			15			9.2		
		9.4			14.1			6.2		
					17.3			6.8		
					16.9			3		
Mean	24.35	6.39	2.75	1.58	12.45	9.31	10.05	5.80	2.20	0.99
Std Dev	11.04	5.01	2.15	0.905	5.3	3.9	4.12	3.97	1.74	0.59
Boxplot										
Quartile 1	17.07	2.5	0.5	0.85	8.35	7.05	7.3	3	0.875	0.6
Quartile 3	26.725	9	3.8	2	16.525	10.325	13.7	9.325	3	1.125
IQR	9.655	6.5	3.3	1.15	8.175	3.275	6.4	6.325	2.125	0.525
Upper Bound	41.208	18.75	8.75	3.725	28.788	15.238	23.3	18.8125	6.1875	1.9125
Lower Bound	2.5875	-7.25	-4.45	-0.875	-3.9125	2.1375	-2.3	-6.4875	-2.3125	-0.1875
outlier										

Phosphorus Concentrations without Outliers; P-Values for T-test to Determine Statistical Significance from Influent Concentration

		Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	15.3	6.7	0.5	0.8	24.6	3.9	3.2	5.6	0.4	0.6
	20.1	7.3	0.5	1.3	19.5	6	6.5	1.8	2	1
	17.7	3	1.8	0.55	8.9	5.3	7.45	3	0.8	0.14
	28.3	0.8	0.23	0.45	8.2	5.6	6.1	3.1	0.32	0.31
	14.75	2.5	0.29	0.4	7.6	8.1	7.3	3.7	0.18	0.11
	16.44	2.6	0.3	0.36	9.4	12.9	8.35	0.9	0.39	0.3
	24.53	0.25	2.45	0.35	5.2	10.4	4.5	0.36	1.05	0.38
	30.45	1.19	1.98	1	6	10.3	10	0.39	1.65	0.85
	35.5	0.44	3.4	1.7	9.1	14.6	12.3	2.1	1.6	1
	25.15	1.9	3.1	2.2	12.9	8	14.2	0.65	2.4	1.1
	18.25	4.15	4.6	1.4	15.3	7.5	12.9	5	2.7	1.1
	21.7	4.58	3.8	1.9	15.9	8.4	15.4	5	0.5	1.5
	24.55	7.8	0.4	2.8	13	7.4	14	9.7	2	0.8
	15.05	7.6	0.3	2.8	20.1	14.4	9	10	0.9	1
		1.6	7	1.8	8.4	10	16.7	5.2	3.7	1.1
		2.5	5.4	3.6	9.5	9.5	16.7	9.7	2.8	1.8
		17.1	3.8	1.2	8.4	4	16	6.7	5.8	1.6
		6.8	3.8	2.7	7.2	5.3	13.6	8.8	2	0.6
		17.1	6.8	2	17.1	9.4	8	14	4.6	1.2
		14.8	1.8	1.8	17.1	8.7	3.7	12.3	1.3	0.9
		9.5	1.3	1.7	16.4	9.2	9.2	12.6	3.6	2
		9.7	7	2	15.6	8.7	7.3	10	1.5	0.7
		13.6			2.5		8.7	3	4	1.1
		7.8			7.5		10	3.5		
		5.5			15			9.2		
		9.4			14.1			6.2		
					17.3			6.8		
					16.9			3		
Mean	21.98	6.39	2.75	1.58	12.45	8.53	10.05	5.80	2.01	0.92
Std Dev.	6.38	5.01	2.30	0.91	5.30	2.94	4.12	3.97	1.51	0.50
T Test P Value Reduction from Influent		5.8E-08	1.7E-08	2.8E-08	4E-05	1E-06	2.5E-06	5.3E-08	1.8E-08	1.9E-08

Phosphorus % Reductions with Outliers

	Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL
	88	93	99	57	84	94	90	93	98
	87	93	98	66	69	88	97	-11	99
	80	40	96	42	40	51	80	73	99
	95	71	97	46	32	60	80	90	98
	88	88	98	62	-6	64	82	95	99
	87	88	98	53	-37	58	96	57	99
	98	-880	98	71	-100	75	98	-192	98
	93	-66	94	66	-72	44	98	-323	95
	99	18	88	68	5	17	93	68	93
	93	32	85	54	-23	4	98	52	93
	72	95	91	-4	35	22	66	79	93
	69	96	88	-8	63	6	66	91	91
	68	-338	89	47	-95	43	60	29	97
	69	-180	89	18	-52	63	59	33	96
	95	68	94	72	-19	45	83	58	96
	92	44	88	69	-32	45	68	34	94
	52	78	97	76	77	55	81	86	95
	81	54	92	80	69	62	75	63	93
	32	81	92	32	43	68	44	90	98
	41	81	93	32	44	85	51	64	95
	48	90	91	10	-268	50	31	50	95
	47	83	91	15	-16	60	45	-14	89
	37			88		60	86		97
	64			65		54	84		95
	78			39			63		
	38			43			75		
				-15			55		
				-12			80		
Mean	72.73	-7.77	93.00	44.00	-7.23	53.04	74.43	30.23	95.63
Std Dev	21.46	221.12	4.16	29.62	80.27	23.13	18.35	100.03	2.72
Boxplot									
Quartile 1	55	34	89.5	28.5	-35.75	44.75	62.25	33.25	93.75
Quartile 3	91	88	97	66.5	43.75	63.25	87	84.25	98
IQR	36	54	7.5	38	79.5	18.5	24.75	51	4.25
Upper Bound	145	169	108.25	123.5	163	91	124.13	160.75	104.38
Lower Bound	1	-47	78.25	-28.5	-155	17	25.125	-43.25	87.375
outlier									

Phosphorus % Reductions without Outliers

	Septisorb / Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL	SSF 12	SF 12	TOTAL
	88	93	99	57	84	94	90	93	98
	87	93	98	66	69	88	97	-11	99
	80	40	96	42	40	51	80	73	99
	95	71	97	46	32	60	80	90	98
	88	88	98	62	-6	64	82	95	99
	87	88	98	53	-37	58	96	57	99
	98	18	98	71	-100	75	98	68	98
	93	32	94	66	-72	44	98	52	95
	99	95	88	68	5	17	93	79	93
	93	96	85	54	35	22	98	91	93
	72	68	91	-4	63	43	66	29	93
	69	44	88	-8	-52	63	66	33	91
	68	78	89	47	-19	45	60	58	97
	69	54	89	18	-32	45	59	34	96
	95	81	94	72	77	55	83	86	96
	92	81	88	69	69	62	68	63	94
	52	90	97	76	43	68	81	90	95
	81	83	92	80	44	85	75	64	93
	32		92	32	-16	50	44	50	98
	41		93	32		60	51	-14	95
	48		91	10		60	31		95
	47		91	15		54	45		89
	37			88			86		97
	64			65			84		95
	78			39			63		
	38			43			75		
				-15			55		
				-12			80		
Mean	72.73	71.83	93.00	44.00	11.95	57.41	74.43	59.00	95.63
Std Dev.	21.46	41.89	4.16	29.62	53.93	18.61	18.35	31.96	2.72

T-Test Tables for Phosphorus

T-test for Substrate Comparison

	SSF Comparison		
	S-L	L-P	S-P
P Value	4E-05	1.2E-06	0.31591
	SF Comparison		
	S-L	L-P	S-P
P Value	4E-09	9.1E-11	0.10513
	Total Comparison		
	S-L	L-P	S-P
P Value	2E-10	5.6E-11	0.00249

S: Septisorb and Pea-Stone Substrate
L: Lava Rock Substrate
P: Pea-Stone Substrate
SSF: Sub-Surface Flow Wetland
SF: Surface Flow Wetland

T-Test for Wetland Stage Comparisoı

	P Value
Septisorb / Pea-Stone	0.44976
Lava Rock	0.01319
Pea-Stone	0.03111

Nitrate Concentrations with Outliers

		Septisorb/Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	0.0835	0.4	0	21.69	0.54	0	48.12	0.1	0.06	25.63
	0.395	0.24	0.05	88.54	0.31	0.17	68.15	0.12	0.06	74.54
	0.35	0.07	0	80.6	0.3	1.29	5.44	0.06	0.05	7.94
	0.225	0.1	0.02	53.81	0.2	0.33	6.53	0.05	0.04	15.73
	0.29	0.05	0.15	42.51	0.05	0.13	7.1	0.03	0.17	39.22
	0.12	0	0.15	33.51	0.06	0.19	4.42	0.06	0	24.08
	0.12	0.05	0.21	133.76	0.03	0.14	136.93	0.02	0.05	533.08
	0.34	0.03	0	114.16	0.03	0	112.38	0.04	0	148.37
	2.22	0.18	0.38	157.76	0.64	0.87	12.24	0.1	0.19	80.24
	3.165	0.16	0.12	155	0.2	0.83	9.98	0.18	0	85.24
	0.7	0.24	0.05	124.04	0.09	0.21	78.96	0.27	0	22.4
	0.72	0	0	65.29	0.25	0.04	73.27	0.15	0.02	33.59
	0.54	0.34	0	101.35	0.38	0.62	72.13	0.46	0.05	55.66
	0.62	0.35	0.05	101.35	1.24	0.16	69.82	0.44	0.03	69.77
	0.17	0.06	0.21	41.6	0.18	7.57	129.6	0.09	0.43	249.48
		0.09	0.24	162.54	0.17	0.26	103.95	0.19	0.4	203.58
		0.19	0.13	119.76	0.18	1.5	136.17	0.07	0.37	59.14
		0.16	0.76	149.52	0.15	1.9	101.62	0.16	0.25	57.87
		0.48	0.21	78.99	0.33	0.23	88.61	0.25	19.52	334.51
		0.41	33.51	147.02	0.21	0.11	111.43	0.34	1.8	116.24
		0.35	0.01	164.04	0.81	0.17	89.55	0.19	2.92	244.56
		0.3	0.05	239.44	4.59	0.21	58.17	0.75	0.03	72.84
		0.49			0.38	0.2	161.15	7.47	13.67	265.11
		0.78			5.22	0.1	91.39	0.67	0.03	314.79
		0			0.06			0.02		
		0			0.12			0.09		
		0.05			0.1			0.03		
		0.05			0.13			0.86		
Mean	0.67	0.20	1.65	108.01	0.61	0.72	74.05	0.47	1.67	130.57
Std Dev	0.87	0.19	7.12	53.87	1.25	1.54	47.22	1.39	4.72	131.78
Boxplot										
Quartile 1	0.195	0.05	0.0125	68.715	0.115	0.1375	39.15	0.06	0.03	37.8125
Quartile 3	0.66	0.3425	0.21	148.895	0.38	0.6725	105.82	0.2875	0.3775	213.825
IQR	0.465	0.2925	0.1975	80.18	0.265	0.535	66.67	0.2275	0.3475	176.0125
Upper Bound	1.3575	0.7813	0.5063	269.165	0.7775	1.475	205.825	0.6288	0.89875	477.8438
Lower Bound	-0.5025	-0.3888	-0.2838	-51.555	-0.2825	-0.665	-60.855	-0.2813	-0.4913	-226.206
outlier										

Nitrate Concentrations without Outliers; P-Values for T-test to Determine Statistical Significance from Influent Concentration

		Septisorb/Pea-Stone			Lava Rock			Pea-Stone		
	Batch	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	0.0835	0.4	0	21.69	0.54	0	48.12	0.1	0.06	25.63
	0.395	0.24	0.05	88.54	0.31	0.17	68.15	0.12	0.06	74.54
	0.35	0.07	0	80.6	0.3	1.29	5.44	0.06	0.05	7.94
	0.225	0.1	0.02	53.81	0.2	0.33	6.53	0.05	0.04	15.73
	0.29	0.05	0.15	42.51	0.05	0.13	7.1	0.03	0.17	39.22
	0.12	0	0.15	33.51	0.06	0.19	4.42	0.06	0	24.08
	0.12	0.05	0.21	133.76	0.03	0.14	136.93	0.02	0.05	148.37
	0.34	0.03	0	114.16	0.03	0	112.38	0.04	0	80.24
	2.22	0.18	0.38	157.76	0.64	0.87	12.24	0.1	0.19	85.24
	0.7	0.16	0.12	155	0.2	0.83	9.98	0.18	0	22.4
	0.72	0.24	0.05	124.04	0.09	0.21	78.96	0.27	0	33.59
	0.54	0	0	65.29	0.25	0.04	73.27	0.15	0.02	55.66
	0.62	0.34	0	101.35	0.38	0.62	72.13	0.46	0.05	69.77
	0.17	0.35	0.05	101.35	0.18	0.16	69.82	0.44	0.03	249.48
		0.06	0.21	41.6	0.17	0.26	129.6	0.09	0.43	203.58
		0.09	0.24	162.54	0.18	0.23	103.95	0.19	0.4	59.14
		0.19	0.13	119.76	0.15	0.11	136.17	0.07	0.37	57.87
		0.16	0.21	149.52	0.33	0.17	101.62	0.16	0.25	334.51
		0.48	0.01	78.99	0.21	0.21	88.61	0.25	0.03	116.24
		0.41	0.05	147.02	0.81	0.2	111.43	0.34	0.03	244.56
		0.35		164.04	0.38	0.1	89.55	0.19		72.84
		0.3		239.44	0.06		58.17	0.02		265.11
		0.49			0.12		161.15	0.09		314.79
		0.78			0.1		91.39	0.03		
		0			0.13					
		0								
		0.05								
		0.05								
Mean	0.49	0.20	0.10	108.01	0.24	0.30	74.05	0.15	0.11	113.07
Std Dev.	0.54	0.19	0.11	53.87	0.19	0.33	47.22	0.13	0.14	102.33
T Test P Value		0.035	0.0093	3.04E-09	0.05417	0.1224	4.79E-08	0.0169	0.01117	1.35E-05
Reduction from Influent										

Nitrate % Reductions with Outliers

	Septisorb/Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	52	100	-2498	35	100	-5663	88	40	-2969
	71	79	-10504	63	45	-8062	86	50	-8827
	82	100	-20305	24	-330	-1277	85	17	-1910
	75	80	-13523	49	-65	-1553	87	20	-3882
	86	-200	-12046	86	-160	-1929	91	-467	-11106
	100	-320	-9474	83	-217	-1163	83	100	-6780
	78	100	-59349	87	-367	-60758	91	-150	-236824
	87	-58	-50638	87	100	-49847	82	100	-65842
	38	100	-131367	-121	-867	-10100	66	30	-66767
	45	86	-129067	31	-232	-8217	38	100	-70933
	-100	-250	-103267	25	0	-65700	-125	89	-18567
	100	-167	-54308	-108	87	-60958	-25	93	-27892
	0	32	-29709	-12	-4106	-21115	-35	-378	-16271
	-3	-375	-29709	-265	-53	-20435	-29	-111	-20421
	97	56	-1774	92	-733	-5738	96	-429	-11138
	96	-8073	-7222	92	-1167	-4582	91	-56	-9070
	94	97	-3684	94	30	-4202	98	-7708	-1769
	95	97	-4624	95	48	-3111	95	-429	-1728
	31	90	-11184	53	79	-12559	64	0	-47687
	41	94	-20903	70	95	-15819	51	96	-16506
	51		-22683	-13	47	-12338	74	-83	-33867
	58		-44241	-538	98	-7979	0	96	-10017
	9			30		-29743	-1283		-48994
	-44			-867		-16824	-24		-58194
	100			90			97		
	70			81			85		
				39			82		
				21			-421		
Mean	54.19	-416.60	-35094.50	-21.32	-344.00	-17903.00	-11.14	-408.18	-33248.38
Std Dev.	49.10	1809.03	39252.36	212.96	908.79	20353.57	270.55	1641.61	49012.69
Boxplot									
Quartile 1	38.75	-175.25	-49038.75	12.75	-305.5	-20605	-6	-140.25	-48013.75
Quartile 3	92.25	97	-9731.5	86.25	71.25	-4487	88.75	92	-8315.25
IQR	53.5	272.25	39307.25	73.5	376.75	16118	94.75	232.25	39698.5
Upper Bound	172.5	505.375	49229.375	196.5	636.375	19690	230.875	440.375	51232.5
Lower Bound	-41.5	-583.63	-107999.6	-97.5	-870.625	-44782	-148.13	-488.63	-107561.5
outlier									

Nitrate % Reductions without Outliers

	Septisorb/Pea-Stone			Lava Rock			Pea-Stone		
	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out	SSF 12	SF 12	PT Out
	52	100	-2498	35	100	-5663	88	40	-2969
	71	79	-10504	63	45	-8062	86	50	-8827
	82	100	-20305	24	-330	-1277	85	17	-1910
	75	80	-13523	49	-65	-1553	87	20	-3882
	86	-200	-12046	86	-160	-1929	91	-467	-11106
	100	-320	-9474	83	-217	-1163	83	100	-6780
	78	100	-59349	87	-367	-10100	91	-150	-65842
	87	-58	-50638	87	100	-8217	82	100	-66767
	38	100	-103267	31	-867	-21115	66	30	-70933
	45	86	-54308	25	-232	-20435	38	100	-18567
	100	-250	-29709	-12	0	-5738	-125	89	-27892
	0	-167	-29709	92	87	-4582	-25	93	-16271
	-3	32	-1774	92	-53	-4202	-35	-378	-20421
	97	56	-7222	94	-733	-3111	-29	-111	-11138
	96	97	-3684	95	30	-12559	96	-56	-9070
	94	97	-4624	53	48	-15819	91	-429	-1769
	95	90	-11184	70	79	-12338	98	0	-1728
	31	94	-20903	30	95	-7979	95	96	-47687
	41		-22683	90	47	-29743	64	-83	-16506
	51		-44241	81	98	-16824	51	96	-33867
	58			39			74		-10017
	9			21			0		-48994
	100						97		-58194
	70						85		
							82		
Mean	64.71	6.44	-25582.25	59.77	-114.75	-9620.45	56.64	-42.15	-24397.26
Std Dev.	32.44	140.45	25594.84	31.43	277.45	7816.61	56.15	181.37	23361.49

T-Test Tables for Nitrate

T-test for Substrate Comparison

	SSF Comparison		
	S-L	L-P	S-P
P Value	0.25569	0.0308	0.1139
	SF Comparison		
	S-L	L-P	S-P
P Value	0.00787	0.0124	0.401
	Total Comparison		
	S-L	L-P	S-P
P Value	0.01435	0.0528	0.418

S: Septisorb and Pea-Stone Substrate
L: Lava Rock Substrate
P: Pea-Stone Substrate
SSF: Sub-Surface Flow Wetland
SF: Surface Flow Wetland

T-Test for Wetland Stage Comparison

	P Value
Septisorb / Pea-Stone	0.05075
Lava Rock	0.00575
Pea-Stone	0.01415

COD Concentrations & Total % Reductions with Outliers

		Septisorb / Pea-Stone			% Reduction	Lava Rock			% Reduction	Pea-Stone			% Reduction
	Batch	SSF 12	SF 12	PT Out	TOTAL	SSF 12	SF 12	PT Out	TOTAL	SSF 12	SF 12	PT Out	TOTAL
	2511.59	267.36	1580.61	1197.59	52	563.89	700.9	503.21	80	316.78	666.3	555.1	78
	1920.24	848.07	611.94	1274.19	73	390.91	740.44	886.23	65	514.47	505.68	757.73	70
	3129.37	1032.03	1423.93	893.65	53	913.41	977.66	641.59	67	636.65	495.8	498.27	74
	5434.95	1896.91	1733.82	1365.63	29	903.53	639.12	708.31	63	661.36	770.09	698.43	64
	1942.77	569.93	846.69	631.71	80	604.53	589.7	456.26	85	527.92	389.54	280.81	91
	2238.35	587.23	792.33	715	73	503.21	532.86	394.48	87	446.38	354.95	345.06	89
		1110.29	1214.25	1117.72	79	887.75	1513.97	957.33	82	1126.3	671.56	572.16	89
		1071.64	1188.44	1061.7	80	629.31	1881.75	969.76	82	1255.5	505.06	442.94	92
		1325.04	1249.51	1444.07	26	1052.65	1036.63	1313.6	32	961.09	1114.46	736.77	62
		1206.02	1270.11	864.96	73	732.19	656.66	569.67	71	1002.3	947.36	597.14	69
		903.12	1136.35	841.99	62	762.74	932.56	740.1	67	717.54	1097.85	986.9	56
		878.22	1131.82	878.22	73	563.48	622.35	531.78	76	755.95	851.05	683.49	69
Mean	2862.88	974.66	1181.65	1023.87	62.75	708.97	902.05	722.69	71.42	743.52	697.48	596.23	75.25
Std Dev	1336.80	415.88	320.39	259.74	19.02	199.12	411.98	267.28	14.93	287.83	261.77	194.11	12.41
Boxplot													
Quartile 1	2016.665	782.86	1060.538	859.218	52.75	563.788	634.928	524.638	66.5	524.56	502.745	484.438	67.75
Quartile 3	2974.925	1134.22	1308.565	1216.74	74.5	891.695	992.403	904.005	82	971.39	875.128	708.015	89
IQR	958.26	351.363	248.0275	357.523	21.75	327.908	357.475	379.368	15.5	446.83	372.383	223.578	21.25
Upper Bound	4412.315	1661.27	1680.606	1753.02	107.125	1383.56	1528.62	1473.06	105.25	1641.6	1433.7	1043.38	120.875
Lower Bound	579.275	255.816	688.4963	322.934	20.125	71.9263	98.715	-44.414	43.25	-145.69	-55.829	149.071	35.875
outlier													

COD Concentrations &% Reductions with Outliers; P-Values for T-test to Determine Statistical Significance from Influent Concentration

		Septisorb / Pea-Stone			% Reduction	Lava Rock			% Reduction	Pea-Stone			% Reduction
	Batch	SSF 12	SF 12	PT Out	TOTAL	SSF 12	SF 12	PT Out	TOTAL	SSF 12	SF 12	PT Out	TOTAL
	2511.59	267.36	1580.61	1197.59	52	563.89	700.9	503.21	80	316.78	666.3	555.1	78
	1920.24	848.07	611.94	1274.19	73	390.91	740.44	886.23	65	514.47	505.68	757.73	70
	3129.37	1032.03	1423.93	893.65	53	913.41	977.66	641.59	67	636.65	495.8	498.27	74
	1942.77	569.93	846.69	1365.63	29	903.53	639.12	708.31	63	661.36	770.09	698.43	64
	2238.35	587.23	792.33	631.71	80	604.53	589.7	456.26	85	527.92	389.54	280.81	91
		1110.29	1214.25	715	73	503.21	532.86	394.48	87	446.38	354.95	345.06	89
		1071.64	1188.44	1117.72	79	887.75	1513.97	957.33	82	1126.3	671.56	572.16	89
		1325.04	1249.51	1061.7	80	629.31	1036.63	969.76	82	1255.5	505.06	442.94	92
		1206.02	1270.11	1444.07	26	1052.65	656.66	1313.6	71	961.09	1114.46	736.77	62
		903.12	1136.35	864.96	73	732.19	932.56	569.67	67	1002.3	947.36	597.14	69
		878.22	1131.82	841.99	62	762.74	622.35	740.1	76	717.54	1097.85	986.9	56
				878.22	73	563.48		531.78		755.95	851.05	683.49	69
Mean	2348.46	890.81	1131.45	1023.87	62.75	708.97	812.99	722.69	75.00	743.52	697.48	596.23	75.25
Std Dev.	499.13	312.20	282.23	259.74	19.02	199.12	286.35	267.28	8.69	287.83	261.77	194.11	12.41
T Test P Value		0.00091	0.001894	0.00123		0.00043	0.00068	0.0005		0.0005	0.00046	0.00031	

Reduction from Influent

T-Test Tables for COD

T-test for Substrate Comparison

	SSF Comparison		
	S-L	L-P	S-P
P Value	0.058777	0.36795	0.12727
	SF Comparison		
	S-L	L-P	S-P
P Value	0.008076	0.16304	0.000544
	Total Comparison		
	S-L	L-P	S-P
P Value	0.005226	0.09987	9.33E-05
	% Reduction		
	S-L	L-P	S-P
P-Value	0.030618	0.47783	0.035913

S: Septisorb and Pea-Stone Substrate
L: Lava Rock Substrate
P: Pea-Stone Substrate
SSF: Sub-Surface Flow Wetland
SF: Surface Flow Wetland