**The Role of Plants in the Removal of Nutrients at a Constructed Wetland
Treating Agricultural (Dairy) Wastewater**

A thesis submitted to the Faculty of Graduate Studies and Research in partial
fulfillment of the requirements for the degree of Master of Science

By

Natalie Gottschall, B.Sc.H.

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Abstract

A constructed wetland for the treatment of agricultural wastewater from a 150-cow dairy operation in eastern Ontario, Canada was monitored in its eighth operating season to evaluate the proportion of TN (approximated by TKN due to low NO_3^-) and TP removal that could be attributed to storage in *Typha* spp., which dominate this system. Nutrient loading rates were high, with 16.2 kg/ha/d N and 3.4 kg/ha/d P entering the system. Nutrient removal at the wetland was considerable, with TKN and TP removal efficiencies of 69.7% and 39.7%, respectively for the 2003 operating season. Plant uptake accounted for 0.7% of TKN removal when vegetated components were considered together. However, separately, in the cell with lower N and P loading rates, plants accounted for 9% of TKN and 4.6% of TP removal, and 21.4% of NH_4^+ removal. Plant uptake was significant to overall removal given wetland age and nutrient loading.

Acknowledgements

This project could not have been completed without the support and guidance of co-supervisors Céline Boutin and Pascale Champagne. Additional input from the advisory committee, Naomi Cappuccino, Frances Pick, Anna Crolla and Chris Kinsley was also very much appreciated. This research was supported by the National Wildlife Research Centre and the Research and Technology Transfer Unit of Alfred College (University of Guelph) through the generous provision of laboratory space and equipment. The author would also like to thank Lynne Evenson, Ed Gregorich, and Ron Stanley at Agriculture Canada, for their help with additional equipment and the use of facilities for preparing plant tissue samples for analysis, and Sean Speer for providing supplemental data from his own Masters project for use in mass removal and nutrient concentration estimates. Finally, thanks to Lisa Benedetti and Gilles Bechdolff for their assistance with field work.

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Introduction

As populations continue to rise, the demand on natural resources also increases and water resources are arguably put under the most stress. Water resources are also compromised by the increasing waste stream, and they must be protected by adequate treatment methods. While conventional treatment systems are effective, they are also expensive to construct and maintain. Passive treatment systems, such as constructed wetlands, offer a low-cost alternative that has the added advantage of being able to be integrated into the surrounding environment. They may be particularly useful in rural areas, because of the low cost and the greater availability of land than in urban areas, as a means of dealing with agricultural wastewater.

Constructed wetland systems for wastewater treatment have been gaining popularity over the last few decades. Europe is employing the technology on a large scale, with several hundred systems in use, mainly for municipal wastewater treatment (Kadlec and Knight, 1996). In North America, interest is also growing. In the United States, there are 197 systems (as of 1993), with the majority in South Dakota and Florida, again mainly for municipal wastewater treatment (Kadlec and Knight, 1996). Canada has approximately 70 systems, with the majority in Ontario, British Columbia and Quebec, treating primarily municipal wastewater (Kadlec and Knight, 1996; Pries, 1994). Once smaller-scale systems are included, such as for domestic use, numbers in North America exceed 700 (Water Environment Research Foundation, 2004).

As the technology of constructed wetlands continues to progress, there are several key points to consider. More recently, concerns over water pollution due to agricultural activities have provided an opportunity for more extensive implementation of constructed wetlands for agricultural wastewater treatment. Additionally, there is greater interest in expanding the technology in temperate regions. As systems currently in use age, there is increasing emphasis on evaluating long-term performance and viability. Finally, the importance of plants as part of constructed wetland systems is still being debated.

The information presented in this thesis is intended to address the aforementioned topics, with an emphasis on the role of plants in constructed wetland systems.

Background

Types of Constructed Wetland Systems

Free Water Surface

In free water surface (FWS) wetlands the wastewater flows above-ground. These systems tend to be shallow, and are typically planted with emergent macrophytes. The vegetation provides surface area for bacteria, which play a major role in the removal of nitrogen. The design of FWS wetlands can include multiple cells, operating in series or parallel, depending on requirements. Compared to conventional treatment, FWS wetlands are inexpensive to construct and maintain (Pries, 1994).

Subsurface Flow

In subsurface flow (SSF) wetlands, the wastewater flows below-ground through a porous substrate. These systems are planted with emergent macrophytes that, along with the substrate, provide a large surface area for bacteria. This allows SSF wetlands to be less land-intensive than FWS wetlands for the treatment of some pollutants. These systems are, however, prone to clogging, increasing maintenance costs. This, coupled with higher construction costs, can make SSF wetlands six to eight times more expensive than FWS wetlands (Pries, 1994).

Nutrient Removal Processes in Wetlands

Nitrogen

Nitrogen is found in a variety of organic and inorganic forms in wetlands and while the majority is stored in the soil, significant amounts are held in living and dead biomass, microorganisms, litter and sediments. Where treatment wetlands are concerned, the most critical forms of nitrogen are inorganic in nature, and typically include ammonia (NH_4^+) and nitrate (NO_3^-). While both ionized and un-ionized forms of ammonia are present, the ionized form is prevalent in wetland environments. Ionized, ammonium nitrogen is readily available to plants and is the preferred form for the majority of wetland species. Un-ionized ammonia can be cause for concern, because of its toxicity to aquatic life at low concentrations. Ammonia also has the potential for high oxygen

consumption, as its oxidation requires approximately 4.3 g of oxygen per gram ammonia. Nitrate is also readily absorbed by plants and is a water quality issue because of its toxic effect on infants, potentially causing asphyxiation (by methyoglobinemia) when present in drinking water supplies; consequently, concentrations are limited to 10 mg/L in both drinking- and groundwater (Kadlec and Knight, 1996).

The main nitrogen removal processes are nitrification/denitrification as well as assimilation and organic matter (peat) accumulation and burial. Nitrification/denitrification and burial are the only truly permanent means of nitrogen removal. Nitrification is the conversion of ammonium nitrogen to nitrite/nitrate under aerobic conditions, aided by *Nitrosomonas* and *Nitrobacter*.

Denitrification occurs under anaerobic conditions and converts nitrate back to atmospheric nitrogen, mediated by facultative bacteria such as *Bacillus*, *Enterobacter*, and *Pseudomonas*:

A portion of the nitrogen contained in the litter layer of wetlands can be removed from the nutrient cycle through processes such as new peat formation (organic matter accumulation from emergent macrophytes or sphagnum moss) and burial. In natural wetlands, peat contains up to 3% nitrogen, and treatment wetlands often exceed this amount. The peat formation rate also increases in treatment wetlands, by more than an order of magnitude over natural wetlands (Kadlec and Knight, 1996).

Phosphorus

Phosphorus in wetlands can be divided into three categories: dissolved, solid mineral (part of soil structure) and solid organic (part of biomass structure) phosphorus. While critical for growth, excess amounts of phosphorus can significantly change ecosystem structure, making wastewaters high in phosphorus an environmental concern. The typical dissolved form of phosphorus is phosphate (HPO_4^{-2}), which is readily available to plants (Kadlec and Knight, 1996).

The main removal processes for phosphorus are sorption, precipitation, sedimentation, and cycling through biota. Dissolved phosphorus can be precipitated out of solution with calcium, aluminum and iron, depending on the pH. It may also be sorbed in the wetland soil however this capacity is quickly saturated unless the soil contains large amounts of iron or aluminum. Particulate phosphorus in the water column can be removed through sedimentation, and residual detrital matter can also be incorporated into new sediments (soil building), although this process is quite slow. Because sedimentation is the only permanent removal mechanism, phosphorus removal is typically inefficient and therefore requires more wetland surface area for effectiveness than other parameters (Kadlec and Knight, 1996).

Constructed Wetlands for the Treatment of Agricultural Wastewater

The primary concern in agricultural wastewater treatment is the reduction of nutrients, particularly nitrogen and phosphorus. Constructed wetlands have

been shown to be quite effective in reducing nutrient concentration in agricultural wastewater (Hunt and Poach, 2000). In their review of several swine and dairy agricultural treatment wetlands in the United States, Hunt and Poach (2000) found that, while there was substantial variability between sites, all were effective for nutrient removal and removal efficiencies for TKN and TP were as high as 86% and 83%, respectively. Their own research of swine wastewater treatment over the first four years of operation showed nitrogen removal of 81 to 94% under loading conditions ranging from 3 to 25 kg/ha/d, while phosphorus removal was 35% or lower. Another study involving treatment of swine wastewater in Alabama showed removal efficiencies over 90% for nitrogen and over 75% for phosphorus, during the first year of operation (Hammer et al., 1993). In the state of Maryland, a system treating dairy wastewater was shown to be effective over the first 4 years of operation for nitrogen and phosphorus removal, with a 98% reduction in TKN and 96% reduction in TP, although nitrate levels were found to increase in the vegetated filter strip (Schaafsma et al., 2000). Newman et al. (2000), at a dairy milkhouse wastewater constructed wetland in Connecticut, found 53% TKN and 68% TP reduction over the first 3 years of operation. Another study of dairy wastewater treatment in New Zealand investigated the effect of nutrient loading rate on nitrogen and phosphorus removal. Tanner et al. (1995) found total nitrogen removal between 48 to 75% and total phosphorus removal of 37 to 74% under high and low loading rates, respectively, in wetlands over the first two years of operation. Florida has been using constructed wetlands since the late 1970s for phosphorus removal from

agricultural wastewater. A review of these systems by DeBusk et al. (2000) showed significant phosphorus reduction using a wide range of wetland configurations, treating agricultural drainage waters and dairy lagoon wastewaters.

Constructed and restored wetlands have also been used to treat agricultural runoff. Two to four-year old restored wetlands in Spain were used to treat runoff from ricefields, reducing nitrate by 98% and ammonia by 33 to 95%, under low nutrient loading conditions (Comin et al., 1997). Braskerud (2000) studied four constructed wetlands treating cereal and dairy farming runoff in Norway over the first 5 to 7 years of operation. These wetlands showed phosphorus reduction of 20 to 44% under high hydraulic loading conditions (0.7 to 1.8 m/d).

The Role of Plants in Nutrient Removal

It is widely accepted that the majority of treatment in wetlands is due to bacterial transformations and chemical reactions (Brix, 1997). The role of plants is thought to be mainly physical: reducing turbulence to aid in settling, and by providing the surface area for bacteria (Brix, 1997). Direct nutrient uptake by plants may only have a significant impact when wastewater nutrient levels are quite low (Brix, 1997). Comin et al. (1997) in their study of nitrogen retention in restored wetlands treating agricultural runoff, found that above-ground plant uptake (by *Phragmites australis*, *Typha latifolia* and *Scirpus lacustris*) accounted for between 66 and 100% of nitrogen removal under conditions of low nutrient

loading (maximum 270 mg N/m²/d). In another study of nutrient uptake in a 10-year old constructed wetland treating municipal wastewater in New Zealand, Cooke (1992) found that the above-ground plant tissues (*Typha orientalis*) could account for 8% of phosphorus removal. Kuusemets et al. (2002) determined plant uptake (mainly by *Scirpus sylvaticus*) of nitrogen and phosphorus in a small-scale subsurface flow wetland treating domestic wastewater (in Estonia) to be 8 and 5%, respectively. This study analyzed both above and below-ground tissues, but no indication of nutrient loading rates was given. To examine the effect of loading rates on nutrient uptake, Tanner et al. (1995) varied nitrogen loading between 0.6 and 8 g N/m²/d and phosphorus loading from 0.17 to 1.3 g P/m²/d. On an annual basis, plant uptake (by *Schoenoplectus validus*) accounted for between 3 and 19% of nitrogen removal and 3 to 60% of phosphorus removal. Here, again, both above and below ground tissues were sampled. Greenway and Woolley (2000) also investigated plant uptake under varied loading rates in wetlands dominated by *Typha domingensis*, *Schoenoplectus validus* and *Eleocharis* (in Australia). They found above-ground biomass accounted for between 27 and 47% of nitrogen removal and 44 to 65% of dissolved phosphorus removal, with higher removal under lower loading conditions. It should be noted that all but one of the wetlands presented here were monitored early in their operation, within the first 5 years.

Of course, although nutrient storage in plant biomass can sometimes be significant, it is relatively short-term. The tissues eventually die and decompose, re-releasing nutrients into the wetland system. For this reason, biomass

harvesting has been investigated as a means of permanent removal. Kim and Geary (2000) simulated a high phosphorus-loaded constructed wetland using a series of large buckets planted with macrophytes (*Baumea articulata* and *Schoenoplectus mucronatus*) and investigated the effect of harvesting on phosphorus uptake. Their results showed that, after nine months of periodic harvesting, the rate of uptake had increased, however, this was countered by a reduction in regrowth of biomass, and only 5% of phosphorus removal was attributed to harvesting. A one-month tracer study by Matheson et al. (2002) to determine the fate of nitrogen in wetland microcosms found similar results. When above-ground biomass of *Glyceria declinata* was harvested, the roots were able to assimilate more nitrogen, but new root and shoot production was reduced. Biomass harvesting may also reduce transpiration, which may, in turn, reduce nitrate removal by denitrification by impeding nitrate transport through the soil. Martin et al. (2003) studied the short-term effect of harvesting *Typha latifolia* on transpiration rates and nitrate concentrations in wetland microcosms and found, with shoot harvesting of 70 and 85%, transpiration rates were reduced by 63 and 91%, respectively, which corresponded to nitrate removal reductions of 16 and 31%. However, the experiment lasted only 10 days, and differences in nitrate removal were less evident as nitrate levels decreased. As well, there were no significant differences in plant tissue nitrogen concentrations between harvested and un-harvested plants.

Nutrient Uptake and Biomass Allocation

Nutrient uptake by emergent plants and biomass allocation vary by site conditions and by individual species. These can also vary seasonally. Typically, for perennial plants in temperate climates, during periods of growth, nutrients and carbohydrates are translocated from roots and storage organs to above-ground tissues, and then moved back to below-ground tissues at the end of the growing season for storage. For *Typha* species in particular, studies have been conducted in the field and at the laboratory scale to investigate the impact of nutrient levels on allocation patterns. Miao and Sklar (1998) found that *Typha domingensis* growing along a nutrient gradient in the Everglades allocated more biomass to leaves than roots (65.8% versus 14.6%) in nutrient impacted areas, and also stored more phosphorus in leaves, shoot bases, roots and rhizomes. Additionally, density of plants increased from low to high nutrient areas, while overall biomass decreased. Their sampling was conducted over four months, from April through July. Another study of *Typha domingensis*, using a hydroponic set up, determined the effect of phosphorus on biomass allocation and nutrient use efficiency. Lorenzen et al. (2001) exposed *Typha domingensis* to levels of phosphorus ranging from 10 to 500 µg/L over 18 days in a growth solution made to resemble conditions in the Everglades study area of Miao and Sklar (1998). They found that growth rates and above to below-ground biomass ratios increased with greater phosphorus availability, which was consistent with the results of Miao and Sklar (1998). Decreasing levels of phosphorus were also found to reduce nitrogen use efficiency. An 8-week laboratory study of the

response of *Typha latifolia* to nutrient levels, however, showed some contrasting results. Wetzel and van der Valk (1998) found *Typha latifolia* increased shoot biomass allocation as nutrient levels decreased and overall biomass increased by 77% in their high nutrient treatment.

Long-term Performance

While previous work indicates effective reduction of nitrogen and phosphorus, it seems little research has been conducted to assess long-term performance. It is unknown how constructed wetlands will perform after several decades of wastewater treatment (Craft, 1997). Kadlec (1985) discussed some general changes that occur as a treatment wetland (natural or constructed) ages. Sorption of nutrients in the soil, as well as uptake by vegetation, will eventually reach a saturation point. There will be a saturated zone around the wastewater inflow, where removal rates will be generally low, and outside this, an unsaturated zone, where the most rapid removal will occur. Over time, these zones will expand until the area covered is enough to effectively remove nutrients entering the system through new soil accumulation or uptake into woody biomass, or release to the atmosphere. In order to predict the total area required for effective long-term treatment, both the ecosystem response and the change in water quality to wastewater addition must be taken into account.

Ongoing monitoring of a municipal constructed wetland in North Dakota has indicated sufficient nitrogen removal throughout the first 10 years of operation (Hammer and Burckhard, 2000). The wetland treats secondary

municipal wastewater and has average ammonia loading of 1.0 kg/ha/d. As a result of relatively low nutrient loads, total removal potential has yet to be determined. Phosphorus removal in a natural New Zealand wetland receiving municipal wastewater was also monitored after a decade of treatment. Cooke (1992) found phosphorus removal rates between 28-70%, mainly through deposition, with the potential to maintain high deposition rates due to the mixing of sewage impacted wetland with natural wetland waters. This water was high in Al and Fe, providing for chemical precipitation of much of the phosphorus contained in the wastewater. However, typical treatment wetlands are not expected to have sustainable phosphorus removal due to the progressive saturation of soil sorption sites over time, as phosphorus sorption is considered a major removal mechanism in young constructed wetlands (Kadlec and Knight, 1996).

To investigate general trends in long-term nutrient retention, Craft (1997) compared constructed estuarine wetlands in North Carolina ranging from 1 to 15 years old, with mature natural estuarine wetlands. Initially, both nitrogen and phosphorus removal is high in constructed wetlands. However, nitrogen removal rates tend to increase for the first decade and then level off, whereas phosphorus removal rates are highest in the first 3 years and subsequently decrease. The processes responsible for removal also change over time as the wetland matures. For nitrogen, most of the storage is in the increasing organic matter during early succession, when plants are becoming established. Within 5 to 10 years, enough organic carbon will have built up for effective denitrification, and

this process will soon remove similar amounts of nitrogen to organic matter accumulation. Under higher nitrogen loadings, denitrification becomes the dominant removal process to organic matter accumulation, potentially increasing by an order of magnitude over denitrification rates under low nutrient loading conditions. For phosphorus, the main removal processes in early succession are sedimentation and sorption/precipitation. Sedimentation increases while vegetation is established and then stabilizes. Sorption of phosphorus to Al and Fe is dependent on the amount present in the wetland soil, usually peaking in the first 3 years and this decreases over time as sorption sites are used up and soil redox potential changes. As the wetland ages, sedimentation and accumulation of organic phosphorus become the main processes for long-term storage.

Cold Climate Operation

Wetland systems have been shown to be effective in warmer climates but there have been concerns over their feasibility in more northern areas, especially for surface flow wetlands. While nitrogen removal rates are temperature dependent, phosphorus removal does not appear to be temperature sensitive as much as seasonally sensitive, in response to changes in plant growth rates and microbial activity affecting decomposition and subsequent nutrient release (Kadlec and Knight, 1996). Bachand and Horne (2000), found temperature to be a major factor affecting denitrification rates in free-water surface wetlands in southern California, although organic carbon availability also had an influence. Their investigation took place during the first year of operation. A one-year study

of nutrient removal at a Norwegian constructed wetland in its sixth year of operation (where temperatures ranged from 3 to 19 °C) concluded that phosphorus removal, while somewhat reduced at temperatures of less than 5 °C, remained high throughout the year as removal efficiencies ranged from 70 to 85% (Ydstebo et al., 2000). In this case, low temperatures coincided with higher hydraulic loading, which also had a major impact on removal efficiency (Ydstebo et al., 2000).

A review of constructed wetland systems in North America and Scandinavia demonstrates their feasibility in colder climates. Wittgren and Maehlum (1997) discuss the potential problems associated with operating under these conditions, as well as the possible reasons for the success of large-scale wetlands in these regions. The main concern is ice formation and its effect on wastewater flow. The accumulation of a snow layer can provide insulation against freezing. However, if freezing occurs, it may eventually restrict wastewater flow. Hence, it is advisable to increase the flow before freezing and then lower it afterwards, leaving air space under the ice. While there are models to predict ice formation, the complexity of large-scale systems requires conservative interpretation, and further study of cold climate constructed wetlands is necessary for more realistic estimates.

In addition to hydrology, the biological and biogeochemical processes within wetlands are affected by climate. Wittgren and Maehlum (1997) note that nutrient uptake by plants is considerably lower in colder regions and this is related to temperature effects on microbial activity, which is also sensitive to

oxygen availability, which can be limited by ice formation. Reduced microbial activity affects decomposition and nitrogen transformations. Physical and chemical removal of phosphorus is also affected indirectly by temperature, as oxygen availability influences redox potential (higher redox potential at higher oxygen concentrations), which is important to phosphorus adsorption to iron oxides. However, lower temperatures may not adversely affect treatment efficiency in large-scale constructed wetlands. Over-sizing with regard to temperature sensitive removal processes, as well as microbial adaptation to cold climates may explain the trend towards weaker observed temperature dependence in full-scale wetlands versus laboratory tests.

In order to help summarize the information presented as part of the background, the main performance related studies have been summarized in Table 1, which indicates geographic location, periods of study, plant species studied and nutrient removal data for each constructed wetland or laboratory study.

Objective

Previous research related to constructed wetlands has been focused on newly constructed systems, usually monitoring performance within the first five years of operation while removal processes and vegetation are still being established. The vast majority of these wetlands are designed for the treatment of municipal wastewater; only recently has there been more attention paid to

Table 1. Summary of constructed wetland studies (and one laboratory study) showing location, year established (est.), period of study, plants studied, type of wastewater treated (WW), as well as nutrient removal data, and are organized by location.

Study	Location	Year est.	Year(s) studied	Plant species	WW type	Nutrient removal
Crolla and Kinsley (2002)	Ontario Canada	1995	1 st 4 yrs	<i>Typha latifolia</i> <i>Typha angustifolia</i>	dairy milkhouse	72% TKN 58% TP
Hammer et al. (1993)	Alabama US	1988	1 st	<i>Typha latifolia</i> , <i>Scirpus validus</i> , <i>Phragmites australis</i>	swine	90% TN, 75% TP
Hunt and Poach (2000)	North Carolina US	1992	1 st 4 yrs	<i>Scirpus spp.</i> , <i>Typha spp.</i> , <i>Juncus effusus</i> , <i>Sparganium americanum</i>	swine	81 to 94% TKN, 35% TP
Bachand and Horne (2000)	California US	1993	1 st yr	<i>Scirpus spp.</i> , <i>Typha spp.</i>	municipal	~7% TN (estimated) TP not measured
Schaafsma et al. (2000)	Maryland US	1993	2 nd to 4 th yr	<i>Typha latifolia</i> , <i>Schoenoplectus tabernaemontani</i>	dairy	985 TKN, 96% TP
Newman et al. (2000)	Connecticut US	1994	1 st 3 yrs	<i>Typha angustifolia</i> , <i>Phragmites australis</i>	dairy milkhouse	53% TKN, 68% TP (3% of TKN due to plant uptake)
Hammer and Burckhard (2000)	North Dakota US	1990	1 st 10 yrs	<i>Typha latifolia</i> , <i>Scirpus validus</i> , <i>Lemna spp.</i>	municipal	54% NH ₄ ⁺ , TP not measured
Comin et al. (1997)	Spain	1989- 1991	2 nd to 4 th yr (4 wetlands, 1 season)	<i>Typha latifolia</i> , <i>Phragmites australis</i> , <i>Scirpus lacustris</i>	ricefield runoff	98% NO ₃ ⁻ , 33-95% NH ₄ ⁺ (66 to 100% TN due to plant uptake), TP not measured
Kuusemets et al. (2002)	Estonia	1996	5 th yr	<i>Scirpus sylvaticus</i>	domestic	8% of TN and 5% of TP removal due to plant uptake

Table 1 continued.

Study	Location	Year est.	Year(s) studied	Plant species	WW type	Nutrient removal
Braskerud (2000)	Norway	1990-1994	1 st 5 to 7 yrs (4 wetlands)	<i>Scirpus lacustris</i> , <i>Phragmites australis</i> , <i>Typha latifolia</i> , <i>Carex spp.</i>	cereal and dairy	20 to 44% TP, TN not measured
Ydstebo et al. (2000)	Norway	1994	6 th yr	Species names not given	agricultural runoff	70 to 85% TP, TN not measured
Tanner et al. (1995)	New Zealand	1990	1 st 2 yrs	<i>Schoenoplectus validus</i>	dairy	48 to 75% TN (3 to 19% due to plant uptake), 37 to 74% TP (3 to 60% due to plant uptake)
Cooke (1992)	New Zealand	1980	10 th yr	<i>Typha orientalis</i>	municipal	28 to 70% TP (8% due to plant uptake), TN not measured
Greenway and Woolley (2000)	Australia	1994	1 st 3 yrs	<i>Typha domingensis</i> , <i>Schoenoplectus validus</i> , <i>Ecleocharis</i>	municipal	81 to 87% TN (27 to 47% due to plant uptake), 21 to 28% TP (44 to 65% due to plant uptake)
Kim and Geary (2000)	laboratory study		9 month study	<i>Baumea articulata</i> , <i>Schoenoplectus mucronatus</i>	simulated high P loading	5% of P removal due to plant uptake, TN not measured

agricultural wastes, mainly over concerns of excess nutrients in waterways, but also human health risks due to pathogenic bacteria. Additionally, concerns over cold climate performance have slowed the development of this technology in more temperate regions. Finally, because the contribution of plants to nutrient removal is thought to be temporary, and largely insignificant, compared to physical and bacterial processes, systems are designed and performance is typically evaluated without considering this aspect. When nutrient uptake is measured, it is typically in above-ground biomass and studied under small-scale or laboratory conditions.

In order to continue to improve the design and function of constructed wetlands it is necessary to address these issues. For these systems to be fully accepted as a viable wastewater treatment option, long-term and cold-climate performance require further investigation. Concerns over non-point source agricultural pollution, along with the economic limitations to conventional treatment systems in rural areas, make constructed wetland systems ideal. However, the composition of agricultural wastewater, especially the high nutrient content, along with the smaller scale of operation compared with many municipal treatment wetlands, create a unique set of design challenges. To fully exploit the potential of constructed wetlands for agricultural wastewater treatment, more case studies of these small-scale systems are necessary. Continuing development of this technology also requires a re-examination of the typical “black box” approach to design and performance evaluation, particularly when attempting to predict long-term viability, as removal processes are expected to

change as a wetland system matures, and many of these are affected by changes in vegetation. Further, much of the investigation of individual processes within these systems has been on a small- or even laboratory-scale, whereas fully operational systems are much more complex. Monitoring of removal processes in the field is also necessary.

The objective of this study was to evaluate the contribution of nutrient uptake by emergent macrophytes to total mass nutrient removal in a well-established constructed wetland treating agricultural wastewater in a temperate climate. It was expected that there would be an overall increase in nutrient storage in emergent macrophytes at the end of the 2003 operating season, and that this would constitute a significant portion of overall nutrient removal from the wastewater.

Study Site

South Nation River Watershed

The constructed wetland studied for this project lies within the South Nation River Watershed in Eastern Ontario. The South Nation River runs 175 km from Brockville to Plantagenet, where it meets the Ottawa River. It drains an area of approximately 3810 km². Environmental degradation, previously from deforestation and now intense agriculture, has lead to water quality problems, mainly from eutrophication and erosion. Phosphorus levels in the South Nation River as well as its tributaries exceed provincial water quality standards of 0.03

mg/L. Agricultural runoff is considered a major non-point source of phosphorus in the watershed (Haughton, 2002).

The South Nation Conservation Authority has implemented programs to counter non-point source pollution in the watershed. Farmers in the area may apply for grants towards water quality improvement projects, including livestock restriction from watercourses, erosion control, milkhouse washwater treatment, runoff prevention, and constructed wetlands (SNC, 2004).

Dignard Constructed Wetland

A constructed wetland system was built at the Dignard family farm in Embrun, Ontario in 1995 and is being used to treat agricultural wastewater; runoff from dairy manure as well as milkhouse washwater and exercise yard runoff from 150 cows. The wetland itself is comprised of two free water surface (FWS) vegetated cells with an aerobic pond in between and a vegetated filter strip at the outflow of the second vegetated cell (Figure 1). These vegetated cells were originally planted with, and continue to be dominated by *Typha latifolia* and *T. angustifolia*. The wastewater is pretreated in a lagoon followed by a facultative pond. Effluent from the facultative pond is pumped into the first vegetated cell and flows through the rest of the system by gravity. The design retention time within the wetland is 112 days. The design and dimensions of the components are shown in Figure 1 (see also Crolla and Kinsley, 2002).

Water quality has been monitored since operation began. Throughout the operating season (typically May to November), wastewater samples were taken

Wetland components:

Facultative Pond – 33 m x 58 m

FWS cell 1 – 33 m x 41 m

Aerobic Pond – 33 x 66 m

FWS cell 2 – 33 m x 33 m

Filter Strip – 15 m x 180 m

Wastewater is pumped from the manure pile runoff, and flows from the exercise yard runoff, to the facultative pond and is then pumped into the first FWS vegetated cell. From here, the wastewater flows through the wetland system by gravity. Total retention time within the wetland is 112 days.

Figure 1. Schematic diagram of the Dignard Constructed Wetland System. Wastewater flow is indicated by arrows, while pumps are indicated by dots.

on a biweekly basis from the inflow and outflow of each component of the system. Prior to this study, no sampling had been conducted within the actual wetland cells, and no attempt had been made to try to evaluate the contribution of any particular removal process to total pollutant removal. Samples were typically analyzed for: pH, DO (dissolved oxygen), TSS (total suspended solids), BOD₅ (5-day biochemical oxygen demand), TKN (total kjeldahl nitrogen), TP (total phosphorus), DP (dissolved phosphorus), NO₃⁻ (nitrate), NH₄⁺ (ammonia), *E. coli*, and fecal coliforms. Additionally, wastewater temperatures were recorded and climatic data were collected from the site. Performance data for the wetland has been analyzed for the first four years of operation (1996-2001). Average removal rates in the wetland for TKN and TP were 71.7% and 58.3%, respectively (Crolla and Kinsley, 2002). Mass removal efficiencies for the 2003 operating season show reductions of 69.7% for TKN and 39.7% for TP. Average loading rates for FWS cell 1 were 16.2 kg/ha/d for TKN and 3.4 kg/ha/d for TP. For FWS cell 2, rates were 9.5 kg/ha/d for TKN and 3.3 kg/ha/d for TP.

Methodology

Prior to plant sampling, the vegetated wetland cells were divided into plots. Cell 1 was divided into 48, 5.5m x 5.125 m plots while cell 2 was divided into 36, 5.5m x 5.5m plots. Twelve sample locations were selected to take into account likely wastewater flow patterns in order to improve sampling efficiency (Figure 2).

FWS Cell #1 (33m x 41m)

FWS Cell #2 (33m x 33m)

Figure 2. Selected water quality sampling locations within each FWS vegetated cell are shown by numbers or letters, while the plant sampling locations are shown by cattail symbol, and additional water sampling sites are shown by dots. Only 6 of the original 9 sample locations for cell 1 and original 8 of cell 2 were retained for the purposes of regression analyses (to correspond approximately to plant sample locations), as well as simplifying visual representations of water quality trends over the course of the operating season.

Plant Sampling and Analyses

Collections were made on three occasions in 2003: May (1, 2 and 5), July (3 and 8), and October (16 and 18) to roughly follow the growing season, and once in early 2004 (April 20 and 22), to complete a full year of monitoring. Plants were sampled destructively in 0.25 m² subplots at three randomly selected locations within each of six plots in both vegetated cells (Figure 2). Plants were rinsed thoroughly in the field to remove as much sediment and sludge as possible. At the laboratory, plants were cleaned further and then separated into above and below-ground biomass. The samples were packed in brown paper bags and dried at 80°C for 5 days, after which the dry weight was recorded. The number of stems in each sample was recorded prior to processing the samples. The dried plant tissue was first coarsely ground and then sub-samples were further ground to less than 1 mm in preparation for nutrient analysis. The dried, ground plant tissue samples were sent to the University of Guelph Soil and Nutrient Laboratories for analysis of total nitrogen by dry combustion and total phosphorus by acid digestion followed by colourimetric analysis (Soil and Nutrient Laboratories Method #1019 and 1020).

Water Quality Sampling and Analyses

Water samples were collected on a biweekly basis throughout the 2003 operating season, at the inflow and outflow to all wetland components, as well as within the vegetated cells and the aerobic pond. Grab samples were taken at each location, using a handheld sampler at the inlet and outlet of all components,

and using a peristaltic pump to draw samples within each wetland cell and the aerobic pond. Grab samples of sediment water within wetland cells and the aerobic pond were collected using porous cups and a peristaltic pump. Sampling locations within the vegetated cells included the six locations selected for plant sampling, as well as 3 additional locations in cell 1 and 2 additional locations in cell 2. Additional water samples were collected within the aerobic pond, but these were not included as the pond has no emergent vegetation.

Water quality samples were analyzed at Alfred College (University of Guelph), in the Research and Technology Transfer Unit laboratory, as well as at the National Wildlife Research Centre (Environment Canada). Parameters measured were pH, redox potential, and temperature (in the field with electrodes), while NO_3^- , NH_4^+ , TKN, TP, DP, and BOD_5 were analyzed at the laboratory. These were preserved in accordance with procedures outlined in Csuros (1997) and analyzed in accordance with procedures outlined in Standard Methods for Water and Wastewater: 4500- NO_3^- D. Nitrate Electrode Method, 4500- NH_3 D. Ammonia-Selective Electrode Method, 4500-P E. Ascorbic Acid Method (4500-P B. Sample Preparation for TP), and 5210 B. 5-day BOD test (Standard Methods, 1998). The TKN analysis was modified from 4500- N_{org} B Macro-Kjeldahl Method (Standard Methods, 1998) and can be found in full in Appendix A.

Statistical Analyses

The compiled plant data was analyzed in SPSS (version 9) using a 3-way ANOVA to determine the effect of date of sampling, location and tissue type on the concentration and also the content of nitrogen and phosphorus in *Typha spp.*. Although there were potential problems with the independence of above and below-ground tissues, the observed large differences between tissue types indicated that overall results were not likely adversely affected. The six sampling locations within each vegetated cell were reduced to three location classes by pooling according to inflow-outflow positions for the purposes of statistical analyses. FWS vegetated cell 1 was designated as location classes 1 to 3 and cell 2 was designated as 4 to 6, with numbers increasing from inflow to outflow for each cell. This was done in order to increase the number of samples in each group.

Dry weight was not specifically used in any statistical analyses as it was incorporated into tissue nutrient content. Stem density for each plant sample was recorded initially to be used in regression analyses relating water quality parameters to plant density and tissue nutrient content. However, it was later decided that it would be more appropriate to relate plant tissue nutrient concentration and content (separately) to corresponding water quality parameters. Also, it was the aim of each collection to obtain a wide variety of densities at every sample location to ensure that samples were representative of each area as collections were made arbitrarily due to time constraints. As a

result, densities were not significantly different between sample locations, and so were not included in analyses.

The plant data was also combined with water quality data of nutrient concentration. Averages of TKN, NH_4^+ , NO_3^- , TP, and DP corresponding to each plant sample location were calculated for the intervening periods between plant collections. The water quality information from the start of operation in May to early July was averaged for the July plant collection, and from mid-July to late October was averaged for the October collection. For sediment water samples specifically, only a July to October average was calculated, as these samples were only collected during this time due to technical difficulties earlier in the season with respect to sampling equipment. The initial water quality sampling in May, taken at the time of the first plant collection, was used for any analyses concerning the May collection. For the ANOVAs examining the effects of location and date, all surface water quality sampling points were utilized. ANOVAs were not conducted for the sediment water samples because these were only collected for the period between the July and October plant collection, and so, only the effect of location could be tested. For the regression analyses, the surface water and sediment water sampling locations closest to the plant sampling locations were selected. This meant that for each FWS cell, only 6 water quality sampling locations were used, to correspond to 6 plant sampling locations, in order to have matched pairs for the regressions. To simplify summary figures of water quality parameters over the course of the operating

season, the same six sample locations were selected for each vegetated cell, following anticipated flow patterns as well as plant sample locations (Figure 2).

The combined plant and water quality data was used to determine relationships between the tissue nutrient content and concentration, and the concentration of nutrients in the wastewater. The nutrient content and concentration were ultimately compared only with the biologically available forms of nitrogen and phosphorus: NH_4^+ , NO_3^- , and DP. Additionally, regressions were only completed for July and October, as any plant and water quality data collected in May were essentially background data. The wetland had not started operating until after the first plant and water quality sampling, so measured wastewater parameters were not representative of typical concentrations, and new plant growth was just beginning at that time.

To best meet the assumptions of ANOVA and regression analyses, the water quality data for both surface and sediment water as well as plant nutrient data were log-transformed where necessary to improve the appearance of residuals.

Mass Removal

Mass removal for TKN, NH_4^+ and TP were calculated using annual average inflow and outflow concentrations and annual average wastewater inflow and outflow rates for each FWS vegetated cell, as well as overall mass removal efficiency for the entire wetland system. TKN was used to approximate TN for

the wetland due to the consistently low nitrate levels throughout the system.

The following formula was used for annual mass removal:

$$[(C_i \times Q_i) - (C_o \times Q_o)] \times \text{days of operation} \times 1000 \text{ L/m}^3 \times 1 \text{ kg/1.0} \times 10^6 \text{ mg},$$

where C_i is the annual average inflow concentration (mg/L), Q_i is the annual average inflow rate (m³/d), C_o is the annual average outflow concentration, and Q_o is the annual average outflow rate (m³/d). The average inflow and outflow rates to each FWS vegetated cell were calculated using the annual water budget for the Dignard constructed wetland (Appendix B).

Mass removal efficiency for TKN, NH₄⁺ and TP was calculated, using:

$$[(C_i \times Q_i) - (C_o \times Q_o)] / (C_i \times Q_i) \times 100$$

During the 2003 operating season, the normal inlet pipe at the head of FWS cell 1 was clogged, so an alternate inlet pipe was placed approximately 10 to 15 m down the side (Figure 2). However, due to a miscommunication, inflow samples were taken at the normal inflow site. Therefore, actual inflow concentrations of water quality parameters (TKN, NH₄⁺, TP) had to be estimated from concentrations at the closest sample location to the new inlet. The simplified Kadlec and Knight (1996) model for treatment was used:

$$(C - C^*) / (C_i - C^*) = e^{-kt/h},$$

where C is the concentration at the point closest to the inlet (mg/L), C^* is the background concentration of the pollutant, C_i is the estimated inlet concentration, k is the kinetic rate constant for the given pollutant (m/yr) determined through a tracer study (Speer, 2004), t is the time to reach the closest sample point (yr), and h is the height, or depth, of the wetland cell (m). No calculations were done

for DP, as no k value had been calculated for this parameter. This would have been necessary for estimating inflow concentrations for both FWS cell 1 and 2 as DP was only analyzed for samples within each wetland cell, not at inflow and outflow points. Additional information for this calculation is contained in Appendix C.

Nutrient Storage Estimates

Averages of plant biomass and nutrient content by location were used to estimate nutrient storage in each FWS vegetated cell for each collection period, using the formula below:

$$\text{Nutrient Storage} = \text{Area} \times \text{Biomass} \times \text{Nutrient Concentration},$$

or more specifically, :

$$\text{Storage (kg)} = \text{area (m}^2\text{)} \times \% \text{ cover} \times \text{biomass (g/0.25 m}^2\text{)} \times \text{nutrient concentration (\% dry weight)} \times 1 \text{ kg/1000 g}$$

Above- and below-ground nutrient storage were calculated separately. As for the area covered, roots/rhizomes were assumed to have 100% coverage, while shoots were estimated to have approximately 90% coverage in FWS cell 1 and 95% coverage in FWS cell 2, based on a visual inspection of each cell in July, at the height of the growing season. Three separate calculations were done for each FWS cell, one for each location class. The total storage in kg was summed for each FWS cell, for above- and below-ground tissues, for each collection period throughout the growing season. The change in storage at the end of the growing season for each FWS cell was also calculated by subtracting

the total kg stored in October from the total kg stored in May. The change in total storage in kg was then divided by the total area of each FWS cell, to determine the storage per square meter. Storage estimates were converted to kg/ha/yr, by multiplying by 10 000 m²/ha, to be comparable to mass nutrient removal estimates for TKN and TP, to determine the contribution of plant uptake to total nutrient removal over the 2003 operating season. In order to estimate the total storage for both FWS cells together, the change in storage for each of the cells was summed, divided by the total area of both cells, and then converted to kg/ha/yr.

Results

Water Quality

Water quality graphs for redox potential, TP, DP, TKN, NH₄⁺, NO₃⁻ and BOD₅ were plotted for both FWS cells, showing surface water and sediment water concentrations (Figures 3 to 9). Redox potential remained fairly consistent throughout mid-summer in both FWS cells, with a downward trend observed in surface water samples of both cells towards the end of the year (Figure 3). TP showed generally higher values in FWS cell 1 versus cell 2, and for TP and DP both cells exhibited higher concentrations towards the end of the season, although these increases were more pronounced in cell 1 for TP (Figure 4 and 5). TKN and NH₄⁺ followed similar patterns over the course of the operating season. FWS cell 1 showed higher levels than FWS cell 2, for both surface and sediment water samples (Figures 6 and 7). Levels of NO₃⁻ were consistently low

Figure 3. Redox potential (mV) of surface and sediment water in FWS vegetated cells 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland. Locations as in Figure 2 (1 to 6 for cell 1 and a to f for cell 2).

Figure 4. Total phosphorus (mg/L) of surface and sediment water in FWS vegetated cell 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland.

Figure 5. Dissolved Phosphorus (mg/L) of surface and sediment water in FWS vegetated cell 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland.

Figure 7. Ammonia (mg/L) of surface and sediment water in FWS vegetated cell 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland.

Figure 8. Nitrate (mg/L) of surface and sediment water in FWS vegetated cells 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland.

Figure 9. 5-Day Biochemical Oxygen Demand (mg/L) of surface water in FWS vegetated cells 1 and 2 throughout the 2003 operating season at the Dignard constructed wetland.

in 2003, with similar concentrations in both FWS cells. Sediment water samples showed higher concentrations than surface water (Figure 8). The amount of organic matter entering each vegetated cell is indicated by the BOD_5 concentrations. FWS cell 1 shows higher values overall than cell 2. Towards the end of the operating season there is a pronounced increase in BOD_5 in cell 1 (Figure 9).

ANOVAs conducted for surface water nutrient parameters indicate significant effects of location, date and their interaction on TP, TKN, NH_4^+ , and NO_3^- , but for DP, only the effect of date was found to be significant (Table 2). Location effects are evident in the water quality figures (except DP), showing distinct differences in nutrient concentrations between FWS cell 1 and cell 2. For NO_3^- , the location effect was due to one location class, which corresponds to the area of cell 2 closest to the aerobic pond. Differences according to date are evident as well, especially towards the end of the season, as TKN, NH_4^+ , TP and DP show increases in concentration in surface water, particularly in FWS cell 1 for all but DP. Full ANOVA results for surface water nutrient concentrations can be found in Appendix D.

Mass Removal

For FWS cell 1, TKN mass removal for 2003 was 1160 kg/ha/yr, with a mass removal efficiency of 46.7%. For cell 2, TKN removal was 521 kg/ha/yr, with a mass removal efficiency of 35.8%. Mass removal of NH_4^+ for cell 1 was 1739 kg/ha/yr, with a mass removal efficiency of 82%. Cell 2 had NH_4^+ mass

Table 2. 2-way ANOVA for surface water quality, testing effects of date (May, July and October) and location (within FWS vegetated cells). Average concentrations of parameters at each location were used for each time period.

Factor		TP	DP	TKN	NH ₄ ⁺	NO ₃ ⁻
Main Effects						
Date						
	df	2	1	2	2	2
	F	113.636	71.955	13.531	131.425	15.860
	p	0.000	0.000	0.000	0.000	0.000
Location						
	df	5	5	5	5	5
	F	21.040	1.183	6.123	26.380	11.541
	p	0.000	0.354	0.001	0.000	0.000
Interaction						
Date*Location						
	df	10	4*	10	10	10
	F	2.281	1.486	3.668	5.622	5.137
	p	0.042	0.246	0.003	0.000	0.000

* There are only 4 df in this case (rather than 5) due to missing data for one of the location classes in July.

removal of 219 kg/ha/yr, with a mass removal efficiency of 50.2%. Mass removal of TP was 45.9 kg/ha/yr for cell 1, with a mass removal efficiency of 8.8%. For cell 2, TP removal was 120.1 kg/ha/yr, with a mass removal efficiency of 23.5%. The mass removal efficiencies for TKN, NH_4^+ , and TP for FWS cell 1, the aerobic pond and FWS cell 2 (the marsh-pond-marsh system) were 69.7%, 91.8% and 39.7%, respectively.

Vegetation

Biomass and Nutrient Allocation

Biomass and nutrient allocation patterns were graphed for 2003, and additional data collected in early 2004 (Figure 10). Early in the 2003 growing season, the majority of biomass and nutrients were contained below-ground. By July, there was a shift towards above-ground tissues, and by late October, biomass production and nutrient storage had shifted back to below-ground tissues. A subsequent collection in April 2004 revealed a slight decrease in biomass and nutrient content in below-ground tissues in FWS cell 2. The observed changes over the course of 2003 were substantiated by statistical analyses. Analyses of variance for 2003 nitrogen and phosphorus content of plant tissues showed significant effects of tissue type (above versus below-ground), location, and date of sampling as well as 2-way interactive effects (Tables 3a and b). For both nitrogen and phosphorus, there were significant differences in content by sampling date ($p=0.000$), as shown by the shifts between above and below-ground tissues over the growing season. As well,

Figure 10. Changes in biomass, total nitrogen content and total phosphorus content of *Typha latifolia* and *T. angustifolia* plant tissues throughout 2003 and early 2004 at the Dignard treatment wetland for agricultural (dairy) wastewater. Above-ground tissues are shown as positive values, while below-ground tissues are shown as negative values. Biomass and content are in g/0.25 m², representing averages of sample quadrats. Locations 1 to 3 represent FWS cell 1, from inflow to outflow, while locations 4 to 6 represent FWS cell 2, from inflow to outflow. The original 6 sample locations within each cell were reclassified to make 3 broader location classes for the purposes of statistical analysis as well as simplifying visual comparisons of nutrient and biomass allocation between cells and throughout the growing season.

Table 3a. 3-way ANOVA for total nitrogen content of *Typha spp.* at Dignard constructed wetland (2003), testing effects of tissue type (above- versus below-ground), location (within FWS vegetated cells), and date (May, July and October).

Factor	df	F	p-value
Main Effect			
Tissue	1	265.653	0.000
Location	5	9.893	0.000
Date	2	117.703	0.000
Interactions			
Tissue*Location	5	3.173	0.009
Tissue*Date	2	406.658	0.000
Location*Date	10	3.253	0.001
Loc*Date*Tissue	10	1.667	0.092

Table 3b. 3-way ANOVA for total phosphorus content of *Typha spp.* at Dignard constructed wetland (2003), testing effects of tissue type (above- versus below-ground), location (within FWS vegetated cells), and date (May, July and October).

Factor	df	F	p-value
Main Effects			
Tissue	1	514.876	0.000
Location	5	6.620	0.000
Date	2	126.829	0.000
Interactions			
Tissue*Location	5	2.239	0.052
Tissue*Date	2	365.688	0.000
Location*Date	10	3.093	0.001
Loc*Date*Tissue	10	1.236	0.271

there were significant differences in nutrient content among sampling locations ($p=0.000$), shown by generally lower nitrogen and phosphorus values in FWS cell 2 (locations 4 to 6). Full results of nutrient content ANOVAs can be found in Appendix E.

Changes throughout the season are not as noticeable when only nutrient concentrations are considered (Figure 11). Total nitrogen concentration appears to decrease only slightly in below-ground biomass by July and then increases slightly by October. Above-ground biomass, on the other hand, appears to decrease over the entire season for TN and TP. For below-ground tissues, TP concentrations appear consistent throughout the year. Nutrient concentrations in April are similar to May for below-ground tissues. There was no new growth to sample in April, so there is no comparison for above-ground tissues in May. While differences may not be obvious in the figure, the 3-way ANOVA conducted for 2003 nutrient concentrations still reveals a significant effect of tissue type, date and location as well as the interactive effects of location*date and tissue*date for TN and TP, with p -values of 0.000 for all significant effects (Tables 4a and b). Full results of nutrient concentration ANOVAs can be found in Appendix F.

Multiple regressions for both tissue nutrient content and concentration showed significant positive relationships between nitrogen in plant tissues and ammonia in the wastewater for July and October (Tables 5a and b). When sediment water samples were considered, similar relationships were found between ammonia concentration in water and nitrogen content and concentration

Figure 11. Changes in total nitrogen and total phosphorus concentration of *Typha latifolia* and *T. angustifolia* plant tissues throughout 2003 and early 2004 at the Dignard treatment wetland for agricultural (dairy) wastewater. Above-ground tissues are shown as positive values, while below-ground tissues are shown as negative values. Concentration is shown as percent dry weight. Locations 1 to 3 represent FWS cell 1, from inflow to outflow, while locations 4 to 6 represent FWS cell 2, from inflow to outflow. The original 6 sample locations within each cell were reclassified to make 3 broader location classes for the purposes of statistical analysis as well as simplifying visual comparisons of nutrient concentrations between cells and throughout the growing season.

Table 4a. 3-way ANOVA for total nitrogen concentration of *Typha spp.* at Dignard constructed wetland (2003), testing effects of tissue type (above- versus below-ground), location (within FWS vegetated cells) and date (May, July and October).

Factor	df	F	p-value
Main Effects			
Tissue	1	105.210	0.000
Location	5	20.987	0.000
Date	2	129.877	0.000
Interactions			
Tissue*Location	5	2.244	0.052
Tissue*Date	2	179.6	0.000
Location*Date	10	4.245	0.000
Loc*Date*Tissue	10	1.801	0.063

Table 4b. 3-way ANOVA for total phosphorus concentration of *Typha spp.* at Dignard constructed wetland (2003), testing effects of tissue type (above- versus below-ground), location (within FWS vegetated cells) and date (May, July and October).

Factor	df	F	p-value
Main Effects			
Tissue	1	104.201	0.000
Location	5	6.754	0.000
Date	2	295.870	0.000
Interactions			
Tissue*Location	5	0.893	0.487
Tissue*Date	2	309.848	0.000
Location*Date	10	3.935	0.000
Loc*Date*Tissue	10	0.0697	0.726

Table 5. Results of significant regression analyses for plant and water quality (surface water and sediment water) data at Dignard constructed wetland (2003). Ab denotes above ground tissues, while Be denotes below-ground tissues. ns = non-significant

a) Surface water nutrient concentrations vs concentrations of nutrients in plants

	Dependent Variable	Predictor	Sign diff	R²	P
July	TN in Ab and Be	NH_4^+	Ab*	.651	.002
			Be	ns	ns
	TN in Ab and Be	NO_3^-	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	ns	ns
			Be	ns	ns
October	TN in Ab and Be	NH_4^+	Ab*	.447	.017
			Be*	.607	.003
	TN in Ab and Be	NO_3^-	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	ns	ns
			Be	ns	ns

b) Surface water nutrient concentrations vs content of nutrients in plants

	Dependent Variable	Predictor	Sign diff	R²	P
July	TN in Ab and Be	NH_4^+	Ab*	.366	.037
			Be	ns	ns
	TN in Ab and Be	NO_3^-	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	ns	ns
			Be	ns	ns
October	TN in Ab and Be	NH_4^+	Ab*	.538	.007
			Be	ns	ns
	TN in Ab and Be	NO_3^-	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	ns	ns
			Be	ns	ns

Table 5 continued. Results of significant regression analyses for plant and water quality (surface water and sediment water) data at Dignard constructed wetland (2003). Ab denotes above ground tissues, while Be denotes below-ground tissues.

ns = non-significant

c) Sediment water nutrient concentrations vs concentrations of nutrients in plants

	Dependent Variable	Predictor	Sign diff	R²	p
October	TN in Ab and Be	NH ₄ ⁺	Ab [*]	.393	.029
			Be [*]	.577	.004
	TN in Ab and Be	NO ₃ ⁻	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	ns	ns
			Be	ns	ns

d) Sediment water nutrient concentrations vs content of nutrients in plants

	Dependent Variable	Predictor	Sign diff	R²	p
October	TN in Ab and Be	NH ₄ ⁺	Ab [*]	.545	.006
			Be	ns	ns
	TN in Ab and Be	NO ₃ ⁻	Ab	ns	ns
			Be	ns	ns
	TP in Ab and Be	DP	Ab	-.339	.047
			Be	ns	ns

in plants (Tables 5c and d). The majority of analyses revealed relationships between wastewater concentrations and above-ground nutrient content or concentration. In October, however, there was a significant relationship between below-ground nitrogen concentration and ammonia, for both surface and sediment water.

When phosphorus content and concentrations were considered, the only significant (and negative) relationship found was between phosphorus content in above-ground tissues and dissolved phosphorus concentrations in sediment water for October (Tables 5c and d). Full results for all regression analyses can be found in Appendix G.

Nutrient Storage

Nutrient storage was calculated for both nitrogen and phosphorus in both FWS cells separately throughout the 2003 growing season, following Greenway and Woolley (2000), in order to show nutrient storage under relatively high versus low nutrient loading conditions. While nutrient storage in both above and below-ground tissues was generally higher in FWS cell 1 than cell 2, the overall change in storage over the course of the growing season was greater in FWS cell 2 (Table 6). There was a net increase in nutrient storage in cell 2 for both nitrogen and phosphorus, while there was effectively no storage in cell 1.

The total change in plant nitrogen storage for FWS cell 1 was -26.6 kg/ha/yr and for cell 2, was 46.8 kg/ha/yr. When both cells were considered together, net plant nitrogen storage accounted for approximately 0.7% of total

Table 6. Total nitrogen and total phosphorus nutrient storage estimates (in kg) for the 2003 operating season at Dignard constructed wetland.

TN	May	July	October	October-May	Change in storage (kg/ha/yr)
FWS Cell 1					
Above-ground	0.9	20.1	13.6	12.7	
Below-ground	42.2	12.5	25.9	-16.3	
Total	43.1	32.6	39.5	-3.6	-26.6
FWS Cell 2					
Above-ground	0.9	13	6.7	5.8	
Below-ground	17.6	4.7	16.9	-0.7	
Total	18.5	17.7	23.6	5.1	46.8
TP					
FWS Cell 1					
Above-ground	0.1	3.6	1.4	1.3	
Below-ground	7	3.1	4.8	-2.2	
Total	7.1	6.7	6.2	-0.9	-6.7
FWS Cell 2					
Above-ground	0.1	2.4	0.8	0.7	
Below-ground	3.6	1.2	3.5	-0.1	
Total	3.7	3.6	4.3	0.6	5.5

nitrogen removal. However, when FWS cell 2 was considered separately, approximately 9% of nitrogen removal could be attributed to plant storage. When only NH_4^+ removal was considered, as this is the form available for plant uptake, 21.4% of removal in FWS cell 2 could be attributed to plant storage. For TP removal, an overall estimate for both FWS cells could not be calculated because the net nutrient storage was negative. For FWS cell 2, however, 4.6% of TP removal could be attributed to plant storage. FWS cell 1 was not compared to TKN, NH_4^+ and TP removal separately as there was no net nutrient storage for the year.

Discussion

Water Quality

The observed differences in nitrogen concentrations of surface water samples between FWS vegetated cells 1 and 2 can be attributed to the difference in loading rates (16.2 kg/ha/d for cell 1 and 9.5 kg/ha/d for cell 2). While there were significant differences observed for TP between both FWS cells, the phosphorus loading rates were similar (3.4 kg/ha/d for cell 1; 3.3 kg/ha/d for cell 2); the reason for the lower concentrations in cell 2 is unclear. As for the differences according to collection period, in most cases, the July average concentrations were lower than the October averages. Towards the end of the operating season, the lagoon was emptied into the facultative pond for winter storage and treatment. The extra input during this period may account for the significant increase in concentrations of TKN, NH_4^+ , TP and DP observed in FWS

cell 1 versus cell 2. This would also explain the increase in BOD₅ in cell 1 over the same period, although this was not tested for significance. There was an increase in DP concentrations at this time in both FWS cells, and these concentrations did not differ significantly between cells. This increase may be due in part to release of phosphorus as a result of biomass decomposition at the end of the growing season.

Mass Removal

Within FWS cell 1, annual mass removal efficiency of TKN (46.7%) has remained fairly consistent with previous years' results. The average mass removal efficiency over the first four years of operation (1996-2001), was 41.2% (Crolla and Kinsley, 2002). The same holds true for TP in FWS cell 1, with 2003 mass removal efficiency of 8.8% consistent with the 1996-2001 average of 8.6%, although there has been a downward trend in the annual average removal in cell 1 since operation began (Crolla and Kinsley, 2002).

For FWS cell 2, TKN mass removal efficiency of 35.8% also appears to be in line with previous seasons, which indicate approximately 37% removal over 1996-2001 (Crolla and Kinsley, 2002). For TP, the mass removal efficiency of 23.5% falls below the 1996-2001 average of approximately 34% (Crolla and Kinsley, 2002).

Total mass removal efficiency for the marsh-pond-marsh system (FWS cell 1, aerobic pond and FWS cell 2), shows 69.7% for TKN and 39.7% for TP. While TKN removal continues to be stable, TP removal has declined since

operation began, and the 2003 average is considerably less than the 1996-2001 average of 58.3% for the entire system (Crolla and Kinsley, 2002). The general decrease in TP removal is likely due to a reduction in soil sorptive capacity as the wetland ages (Crolla and Kinsley, 2002). This is consistent with the findings of Craft (1997) that phosphorus removal is greatest during the first 3 years, with sedimentation, precipitation and sorption rates decreasing after this point. Constructed wetlands surveyed (in North Carolina) showed a marked decrease in phosphorus sorption after 10 years of operation, with negligible phosphorus removal by sorption after 15 years (Craft, 1997).

Annual mass removal efficiencies of NH_4^+ are quite high in both FWS cells; 82% in cell 1 and 50.2% in cell 2, respectively, with NO_3^- concentrations remaining low throughout the year. This suggests effective nitrification and denitrification are occurring in both vegetated cells. The redox potential of both cells throughout most of the year was in the range of 200 to 400 mV in surface water samples, dropping only towards the end of the season. Sediment water samples generally maintained redox levels between 300 and 400 mV in both cells, with FWS cell 2 dropping into the 200 mV range towards the end of the season. In both the surface water and sediment water, it is likely that nitrification is occurring. While redox levels tend to range between 400 to 700 mV when oxygen is present, conditions are still considered to be aerobic at levels above 300 mV (Kadlec and Knight, 1996; Mitsch and Gosselink, 1993). These values are well within the range for surface and sediment water. Denitrification occurs under oxygen depleted conditions, generally in the range of 100 to 300 mV,

however it may begin under low oxygen levels (Kadlec and Knight, 1996). So, although the redox levels seem to stay within the aerobic range, denitrification may still be occurring. Also, it should be noted that sediment water samples were taken fairly close to the soil surface (within a few centimeters), where conditions tend to be aerobic. Had samples been taken deeper in the soil column, redox levels would likely have shown a more reduced environment.

It is unlikely that any appreciable amount of nitrogen was removed from the wastewater as a result of volatilization of un-ionized ammonia. This typically is not a significant removal mechanism unless pH levels exceed 8, especially given that un-ionized ammonia accounts for approximately 1% of ammonia present in wetlands (Kadlec and Knight, 1996). The average pH values for both FWS vegetated cells ranged between 7.2 and 7.6 for the year. This pH range is also within the optimum levels for denitrification observed in conventional treatment systems of 7 to 8, providing further support that this process is occurring within the vegetated cells (Kadlec and Knight, 1996).

It is difficult to find many similar agricultural treatment wetland case studies in terms of nutrient loading and climatic conditions. Two systems in the northeastern United States treating dairy wastewater, however, are suitable for comparison. A surface flow system was constructed in Connecticut to treat milkhouse wastewater from a 100-cow operation. Newman et al. (2000) found mass removal efficiencies of 53% for TKN, and 68% for TP, while there was an overall increase in NH_4^+ , possibly due to low nitrification rates. Another system constructed in Maryland for treatment of barnyard runoff as well as milkhouse

wastewater from a 170 cow operation showed removal efficiencies of 98% for TKN, 56% for ammonia, and 96% for TP (Schaafsma et al., 2000). The considerably higher removals of TP in both these wetlands is likely due to their age, as both were monitored during the first 2 to 3 years of operation, when phosphorus removal rates are still high.

Vegetation

Biomass and Nutrient Allocation

The biomass allocation patterns observed in both FWS vegetated cells were consistent with a study by Grace and Wetzel (1982) in Michigan. Changes in biomass allocation in both *Typha latifolia* and *Typha angustifolia* were monitored from May through September, and decreases in below-ground biomass in both species occurred through June and July while above-ground biomass was increasing (Grace and Wetzel, 1982). Towards September, there was a shift back towards below-ground tissues (Grace and Wetzel, 1982). Nutrient content changes throughout the year were also consistent with expected patterns for perennials, where there is a maximum in above-ground tissues half-way through the growing season, followed by translocation to below-ground tissues at the end of the season (Chapin and van Cleve, 1991). The apparent decrease in biomass and nutrient content in below-ground tissues sampled in April 2004 may be due to sampling problems, as the soil was still somewhat frozen, especially in FWS cell 2, making it difficult to extract roots and rhizomes.

This reduced biomass, and consequently nutrient content, for this sampling period.

In warmer climates, in comparison, changes in biomass and nutrient content over the growing season are generally not as pronounced. Miao and Sklar (1998) found no significant differences in biomass over April through July in their study of biomass and nutrient allocation in *Typha domingensis* and *Cladium jamaicense* in Florida. While the sampling time did affect nutrient concentrations, this was less important than the effect of nutrient gradients on nutrient concentrations.

The actual concentrations of nitrogen and phosphorus in above and below-ground tissues also varied throughout the growing season. Average concentrations of phosphorus in both below- and above-ground tissues varied between 0.3 to 0.5 % dry weight for both cells throughout the year, except for a decrease in above-ground tissues in October, likely due to translocation to below-ground tissues for winter storage. Nitrogen concentrations were more variable between above- and below-ground tissues as well as between FWS cells. However, concentrations did typically exceed 2 % dry weight in above-ground tissues, and 1.5% in below-ground tissues. Typical uptake for *Typha latifolia* has been summarized by Kadlec and Knight (1996) as ranging between 0.9 to 2.1% dry weight for nitrogen, with an average of 1.4%, and a range of 0.08 to 0.4 % dry weight for phosphorus, with an average of 0.2%. It is unclear, however, whether these averages are for normal or high nutrient conditions. When grown in excess fertilizer, *Typha glauca*, a hybrid of *T. angustifolia* and *T.*

latifolia, achieved percentages of nitrogen and phosphorus in above-ground tissues of ~1.2 % and ~0.25%, respectively (McJannet et al., 1995). The nutrient concentrations measured in 2003 were generally higher than these averages, with the exception of above-ground phosphorus concentrations in October.

Both nitrogen and phosphorus concentrations were generally lower in FWS cell 2 versus FWS cell 1, as cell 2 had lower nutrient inputs. Regression analyses demonstrated that areas of higher NH_4^+ concentration in water samples and sediment water samples tended to have higher plant nutrient concentrations and content. This confirms that the total uptake of nitrogen was ammonia-driven, as both concentrations of nitrogen and total content (i.e. biomass) increased with increasing ammonia in the water. While a linear relationship was found in this study, typical uptake patterns would show an eventual leveling off, or saturation effect. It may be that the concentrations of ammonia in the wastewater at the Dignard site are still within the linear range of typical nitrogen uptake for *Typha* spp..

A study of nitrogen uptake kinetics of *T. latifolia* also confirms the preference for NH_4^+ over NO_3^- . Brix et al. (2002) found that *T. latifolia* had higher nutrient uptake and higher growth rates when supplied with NH_4^+ , rather than NO_3^- , as the nitrogen source. The only significant relationship between DP (in sediment samples) and TP concentration in plants was found at the end of the growing season, and was negative ($R^2 = -0.339$). At this time of year, DP concentrations were on the increase in both FWS vegetated cells at the same time that there were marked decreases in TP concentration in above-ground

plant tissues, due to translocation to storage organs. However, because the p-value for this relationship (0.047) indicates only marginal significance, and given that many regressions were conducted, this particular result should be viewed with caution.

Nutrient Storage

The annual nutrient storage estimates for each FWS vegetated cell show the impact of nutrient loading on uptake. While the above- and below-ground uptake in FWS cell 1 is higher overall for both TN and TP, there is no net increase in nutrient storage over the course of the year. FWS cell 2, on the other hand, showed an increase in both TN and TP. When compared to total mass removal of TKN and NH_4^+ , plant uptake in FWS cell 2 contributed 9% and 21.4%, respectively. The negative change in storage in the case of FWS cell 1 is the result of lower nutrient content in the below-ground tissues in October compared to May. There was also lower nutrient storage in below-ground tissues in FWS cell 2, although not to the same extent. The relatively higher nutrient content values obtained in May could be due in part to sampling difficulties during that collection. Initially, the plants were not cleaned in the field, but only back at the lab. In the intervening period, this residue had a chance to dry out somewhat, and it became very difficult, and time-consuming, to remove. As a result, some sediment remained, mostly on below-ground material, adding both to the dry weight and possibly the nutrient content of the May samples.

A possible overestimation of baseline nutrient levels alone, however, does not explain that there was effectively no new storage of nitrogen or phosphorus in FWS cell 1. Shaver and Melillo (1984) studied nutrient uptake efficiency (proportion of available nutrients taken up) in *T. latifolia* and found that with greater nutrient availability, nutrient uptake efficiency decreased, although total uptake increased. Additionally, nutrient recovery from senescing tissues also decreased with greater nutrient availability (Shaver and Melillo, 1984). This reduction in nutrient uptake efficiency and recovery efficiency may have been occurring in FWS cell 1 under its higher nutrient loading conditions, resulting in effectively no increase in storage at the end of the growing season. While overall biomass and nutrient content was higher than FWS cell 2, plant uptake had less of an impact on nutrient removal from the wastewater. This also ties in with Brix's (1997) contention that plant uptake is only significant under low nutrient loading conditions. Certainly the contribution to total removal of nitrogen and phosphorus in FWS cell 2 could be considered significant, especially in the case of NH_4^+ removal. Most of the studies surveyed estimated the contribution of nutrient uptake to removal of total nitrogen and phosphorus, but perhaps it is more appropriate that only the fractions of nutrients that are biologically available are considered. In the case of nitrogen this would be especially relevant for systems that are ammonia-dominated, such as agricultural wastewater treatment systems.

As for other nutrient uptake studies, it is difficult to find suitable comparisons given the wide range of nutrient loadings, ages and geographic

locations of treatment wetlands studied as well as the types of plants used and the wastewater being treated. Comin et al. (1997) found that uptake of dissolved inorganic nitrogen accounted for at least 66% of total removal in restored wetlands treating agricultural runoff from ricefields in northeastern Spain. These wetlands were naturally restored and were dominated by *Phragmites australis*, *Typha latifolia*, and *Scirpus lacustris* (Comin et al., 1997). The incredible nitrogen uptake observed in their study is likely due to the age of the wetlands studied (all under 5 years old) as well as the lower nutrient loading (2.7 kg/ha/d TN, calculated from Comin et al., 1997) than at the Dignard site (9.5 to 16.2 kg/ha/d TKN). Their wetland was also monitored for one growing season, as at the Dignard wetland.

Another, longer-term study of nutrient uptake was conducted by Greenway and Woolley (2000) at a constructed wetland treating secondary municipal wastewater in Queensland, Australia. Loadings of TN were lower than at the Dignard site (2.4 to 3.7 kg/ha/d), but TP was quite similar (2.0 to 3.3 kg/ha/d) (Greenway and Woolley, 2000). Over the first 3 years of operation, plant uptake was found to account for between 27 to 47% of TN, and 47 to 65% of dissolved phosphorus (Greenway and Woolley, 2000). Again, this wetland was monitored while vegetation and removal processes were still being established. Also, it contained a wider variety of plant species, emergent and floating macrophytes, and some floating plants such as duckweed (*Lemna minor*) had more than three times the uptake capacity of the *Typha spp.* at the Dignard site. These differences could account for the higher nutrient uptake observed. However, the

way nutrient uptake was determined may also have contributed. Nutrient concentrations were measured by sampling the whole plant (above- and below-ground portions) and analyzing the tissues together. However, actual uptake was calculated by applying the whole plant nutrient concentrations to above-ground biomass measurements from six separate harvests. Additionally, biomass of standing stock at each sampling period was estimated using shoot density.

Possibly the most similar evaluation of plant nutrient uptake comes from Newman et al. (2000). As part of their study on seasonal performance of a dairy wastewater system in Connecticut, plant uptake (*T. angustifolia* and *P. australis*) of nitrogen was measured to construct a mass balance for nitrogen. Plant nutrient uptake was found to account for approximately 3% of nitrogen removal within the wetland. However, only above-ground biomass was sampled, and at the end of the growing season, possibly underestimating uptake. Nutrient loading was also lower at this wetland than at the Dignard site, as well as it being studied over the first three years of operation, so it was expected that nutrient uptake would be higher than reported. However, this wetland was not meeting its outflow requirements due to an overload of BOD₅, which appears to have impaired nitrogen transformation processes and may have contributed to the lower plant uptake.

While the increase in nutrient storage in FWS cell 2 was significant to overall mass removal, the majority of this storage is temporary, as plant tissues die and decompose, re-releasing nutrients to the wetland system. Approximately

20 % of the organic material does not decompose and will add to the wetland soil, and there may be substantial leaching of nutrients before this occurs (Kadlec, 1999). However, in a study of nitrogen retention in *T. angustifolia* and *Phragmites australis* litter (over 3 years of decay) in New York, Findlay et al. (2002) found that, while there was substantial mass loss once litter had fallen to the wetland surface, the standing dead shoots had negligible mass loss. Additionally, standing dead shoots of *T. angustifolia* had concentrations of nitrogen and phosphorus of 0.36% and 0.3% dry weight, respectively, compared to living shoot (at peak biomass) concentrations of 0.43% and 0.4% (Findlay et al., 2002). Both nitrogen and phosphorus concentrations increased again on fallen litter of *T. angustifolia*, due in part to microbial growth, and over the study period litter contained roughly half of the nitrogen content of living tissues (Findlay et al., 2002). Kadlec and Knight (1996) also note that below-ground tissues in *Typha spp.* are viable for up to 2 years, storing nutrients for a longer period than above-ground tissues. Aside from nutrient retention, litter also provides a labile carbon source, important for effective denitrification (Craft, 1997).

While a re-release of nutrients occurs when above-ground tissues decompose, there is a significant time lag between uptake and release (Tanner, 2000). So, although the majority of storage is on a short-term basis, these nutrients are removed from the wastewater during the growing season. This significantly affects the quality of effluent from the Dignard constructed wetland, which reduces the amount of nitrogen and, especially, phosphorus entering the

South Nation River Watershed, already stressed by intensive agriculture. Prior to the construction of this wetland system, milkhouse wastewater and exercise runoff simply flowed overland untreated, as well as any overflow of the lagoon for runoff from the manure stack.

Conclusions and Recommendations

After nearly a decade of operation, under high nutrient loading, the Dignard constructed wetland has maintained substantial nitrogen and phosphorus removal. Although phosphorus removal efficiency has decreased over previous years, likely due to a reduction in sorptive capacity, there was consistent removal of nitrogen, and there was evidence of effective nitrification and denitrification in both FWS vegetated cells. While there were significant differences in water quality between FWS cells, there were little significant differences within cells.

Overall, nutrient storage at the Dignard constructed wetland over the 2003 growing season was significant to the removal of nitrogen and phosphorus given the age of the wetland and its high nutrient loading. There were clear differences in storage based on nutrient loading rates between FWS vegetated cells, with greater retention under relatively lower nutrient loading. As the wetland was ammonia-dominated, there was preferential uptake of ammonia over nitrate, and total uptake, as well as biomass, appeared to increase with increasing ammonia in wastewater. While nutrient storage in biomass is transitory, the uptake during the growing season at the Dignard site prevented the release of nitrogen and

phosphorus into the South Nation River Watershed, helping to reduce the impact of nutrient loading due to agricultural activities.

Although nitrogen removal is still quite effective at the Dignard wetland, phosphorus removal is steadily decreasing, and mitigating measures are needed to improve efficiency. At present, it appears that dredging of the first FWS cell would be necessary to improve long-term TP removal. FWS cell 2, however, does not appear to have reached its saturation point for TP. Another option to improve phosphorus removal in the short-term would be to re-plant (and maintain) the vegetated filter strip with barley, thereby increasing plant uptake of phosphorus.

As the Dignard wetland continues to age, there is vast potential for further study of nutrient dynamics. In order to develop a more complete understanding of removal processes and overall performance, it would be necessary to determine a nitrogen and phosphorus budget for the wetland. This would involve continued plant and water quality sampling, determining nutrient stores in soil and litter, as well as measuring accretion rates. It would also be important to quantify denitrification rates within the wetland. This would help determine the long-term viability of this particular system.

By investigating the contribution of plants to total nutrient removal in a mature agricultural wastewater constructed wetland operating in a cold temperate climate under high nutrient loading conditions, this work serves to advance the future design of constructed wetlands. It expands the geographic

range of study, adds to the literature on long-term performance and viability of these systems, and also supplements the work on plant uptake.

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Appendix A - Modified Macro-Kjeldahl Method

1. 25 mL of wastewater sample was added to a Kjeldahl flask and a catalyst tablet was added (3.5 g of K_2SO_4 , 0.4 g of $CuSO_4$).
2. 5 mL of concentrated H_2SO_4 was added to the flask and it was placed in the Tecator Kjeldahl Digestion System Unit 6 1007, at 400 °C, and the flask was capped.
3. The sample was digested for 30 to 35 minutes.
4. The sample was removed from the digester and cooled, after which 75 mL of distilled water was added to the flask.
5. A 250 mL Erlenmeyer flask was filled with 50 mL of 0.04 N H_2SO_4 and placed in the Tecator Distillation System 1002.
6. The Kjeldahl flask was placed in the distillation unit and 50 mL of the $NaOH-Na_2S_2O_3 \cdot 5H_2O$ solution (prepared as in 4500-N_{org} B. Macro-Kjeldahl Method) was added. The distillation unit was turned on and run until 200 mL of ammonia distillate had been collected in the Erlenmeyer flask.
7. The collected distillate was then analyzed for ammonia as in 4500-NH₃ D. Ammonia-Selective Electrode Method.

Appendix B – Water Budget for Dignard Constructed Wetland (2003)

Source: Speer, 2004.

Appendix C – Estimates of Inflow Concentrations for FWS cell 1

The following are values for variables needed for the calculations to estimate inflow concentrations of total phosphorus, total kjeldahl nitrogen, and ammonia to FWS cell 1, where t is the time to reach the closest sample point, h is the height of the wetland cell, k is the rate constant for the given pollutant, and C^* is the background concentration of the pollutant:

$$t = 5 \text{ d, or } 0.014 \text{ yr}$$
$$h = 0.15 \text{ m}$$

Total Phosphorus:

$$k = -3.08 \text{ m/yr}$$
$$C^* = 2 \text{ mg/L}$$

Total Kjeldahl Nitrogen:

$$k = 4.36 \text{ m/yr}$$
$$C^* = 10 \text{ mg/L}$$

Ammonia:

$$k = 9.11 \text{ m/yr}$$
$$C^* = 0 \text{ mg/L}$$

These values were obtained from Speer (2004).

Appendix D. – Complete Results of 2-way ANOVAs for Surface Water Nutrient Concentrations

Total Phosphorus

Tests of Between-Subjects Effects

Dependent Variable. TP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2727.226 ^a	17	160.425	23.168	.000
Intercept	9570.303	1	9570.303	1382.137	.000
LOCATION	728.419	5	145.684	21.040	.000
DATE	1573.695	2	786.847	113.636	.000
LOCATION * DATE	157.948	10	15.795	2.281	.042
Error	193.880	28	6.924		
Total	14498.650	46			
Corrected Total	2921.105	45			

^a R Squared = .934 (Adjusted R Squared = .893)

Multiple Comparisons

Dependent Variable: TP

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	5.7704*	.9921	.000	3.3155	8.2253
	o	-9.3162*	.9026	.000	-11.5495	-7.0830
m	j	-5.7704*	.9921	.000	-8.2253	-3.3155
	o	-15.0866*	.9921	.000	-17.5415	-12.6317
o	j	9.3162*	.9026	.000	7.0830	11.5495
	m	15.0866*	.9921	.000	12.6317	17.5415

Based on observed means

*. The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: TP

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2.00	-1.0851	1.4211	.971	-5.4279	3.2577
	3 00	-4.1300*	1.2482	.028	-7.9444	-.3157
	4.00	5.8048*	1.3157	.002	1.7842	9.8255
	5.00	7.3717*	1.4211	.000	3.0289	11.7145
	6 00	6.8482*	1.3157	.000	2.8275	10.8689
2 00	1 00	1.0851	1.4211	.971	-3.2577	5.4279
	3 00	-3.0449	1.3589	.252	-7.1974	1.1076
	4 00	6.8899*	1.4211	.001	2.5471	11.2327
	5 00	8.4568*	1.5192	.000	3.8141	13.0994
	6.00	7.9333*	1.4211	.000	3.5905	12.2761
3 00	1.00	4.1300*	1.2482	.028	.3157	7.9444
	2 00	3.0449	1.3589	.252	-1.1076	7.1974
	4.00	9.9349*	1.2482	.000	6.1205	13.7492
	5 00	11.5017*	1.3589	.000	7.3492	15.6542
	6.00	10.9782*	1.2482	.000	7.1639	14.7926
4.00	1 00	-5.8048*	1.3157	.002	-9.8255	-1.7842
	2.00	-6.8899*	1.4211	.001	-11.2327	-2.5471
	3.00	-9.9349*	1.2482	.000	-13.7492	-6.1205
	5.00	1.5668	1.4211	.876	-2.7760	5.9097
	6.00	1.0434	1.3157	.966	-2.9773	5.0640
5.00	1.00	-7.3717*	1.4211	.000	-11.7145	-3.0289
	2.00	-8.4568*	1.5192	.000	-13.0994	-3.8141
	3 00	-11.5017*	1.3589	.000	-15.6542	-7.3492
	4 00	-1.5668	1.4211	.876	-5.9097	2.7760
	6 00	-.5235	1.4211	.999	-4.8663	3.8193
6.00	1.00	-6.8482*	1.3157	.000	-10.8689	-2.8275
	2 00	-7.9333*	1.4211	.000	-12.2761	-3.5905
	3.00	-10.9782*	1.2482	.000	-14.7926	-7.1639
	4 00	-1.0434	1.3157	.966	-5.0640	2.9773
	5 00	.5235	1.4211	.999	-3.8193	4.8663

Based on observed means.

* The mean difference is significant at the .05 level.

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: TP

Std Residual

Model: Intercept + LOCATION + DATE + LOCATION*DATE

Dependent Variable: TP

Predicted

Model: Intercept + LOCATION + DATE + LOCATION*DATE

Dissolved Phosphorus

Tests of Between-Subjects Effects

Dependent Variable: DP

Source	Type III Sum of Squares	df	Mean Square	F	Sig
Corrected Model	588.830 ^a	10	58.883	8.973	.000
Intercept	1829.867	1	1829.867	278.846	.000
LOCATION	38.827	5	7.765	1.183	.354
DATE	472.189	1	472.189	71.955	.000
LOCATION * DATE	39.018	4	9.754	1.486	.246
Error	124.683	19	6.562		
Total	2970.245	30			
Corrected Total	713.513	29			

^a R Squared = .825 (Adjusted R Squared = .733)

*No post-hoc analyses could be done for differences by date as samples for dissolved phosphorus were not collected until after the May collection, so there were only two time periods for comparison.

Multiple Comparisons

Dependent Variable: DP

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-1.3864	1.6536	.956	-6.6112	3.8383
	3.00	-.9686	1.4252	.982	-5.4718	3.5346
	4.00	1.1505	1.4790	.968	-3.5227	5.8237
	5.00	2.0276	1.6536	.819	-3.1971	7.2524
	6.00	-2.1324	1.8114	.842	-7.8559	3.5911
2.00	1.00	1.3864	1.6536	.956	-3.8383	6.6112
	3.00	.4179	1.6056	1.000	-4.6555	5.4912
	4.00	2.5370	1.6536	.648	-2.6878	7.7618
	5.00	3.4141	1.8114	.440	-2.3094	9.1375
	6.00	-.7459	1.9565	.999	-6.9280	5.4361
3.00	1.00	.9686	1.4252	.982	-3.5346	5.4718
	2.00	-.4179	1.6056	1.000	-5.4912	4.6555
	4.00	2.1191	1.4252	.676	-2.3841	6.6223
	5.00	2.9962	1.6056	.451	-2.0771	8.0695
	6.00	-1.1638	1.7677	.984	-6.7493	4.4217
4.00	1.00	-1.1505	1.4790	.968	-5.8237	3.5227
	2.00	-2.5370	1.6536	.648	-7.7618	2.6878
	3.00	-2.1191	1.4252	.676	-6.6223	2.3841
	5.00	.8771	1.6536	.994	-4.3477	6.1019
	6.00	-3.2829	1.8114	.482	-9.0064	2.4405
5.00	1.00	-2.0276	1.6536	.819	-7.2524	3.1971
	2.00	-3.4141	1.8114	.440	-9.1375	2.3094
	3.00	-2.9962	1.6056	.451	-8.0695	2.0771
	4.00	-.8771	1.6536	.994	-6.1019	4.3477
	6.00	-4.1600	1.9565	.316	-10.3421	2.0220
6.00	1.00	2.1324	1.8114	.842	-3.5911	7.8559
	2.00	.7459	1.9565	.999	-5.4361	6.9280
	3.00	1.1638	1.7677	.984	-4.4217	6.7493
	4.00	3.2829	1.8114	.482	-2.4405	9.0064
	5.00	4.1600	1.9565	.316	-2.0220	10.3421

Based on observed means.

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: DP

Std Residual

Model Intercept + LOCATION + DATE + LOCATION*DATE

Dependent Variable: DP

Predicted

Model Intercept + LOCATION + DATE + LOCATION*DATE

Total Kjeldahl Nitrogen

Tests of Between-Subjects Effects

Dependent Variable: LTKN

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.799 ^a	17	.106	6.160	.000
Intercept	104.013	1	104.013	6052.843	.000
DATE	.465	2	.233	13.531	.000
LOCATION	.526	5	.105	6.123	.001
DATE * LOCATION	.630	10	6.303E-02	3.668	.003
Error	.481	28	1.718E-02		
Total	112.982	46			
Corrected Total	2.281	45			

a. R Squared = .789 (Adjusted R Squared = .661)

Multiple Comparisons

Dependent Variable: LTKN

Tukey HSD

		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
(I) DATE	(J) DATE				Lower Bound	Upper Bound
j	m	-.1578*	4.943E-02	.009	-.2801	-.0355
	o	-.2422*	4.496E-02	.000	-.3535	-.1310
m	j	.1578*	4.943E-02	.009	3.554E-02	.2801
	o	-.0844	4.943E-02	.220	-.2067	3.790E-02
o	j	.2422*	4.496E-02	.000	.1310	.3535
	m	8.440E-02	4.943E-02	.220	-.0379	.2067

Based on observed means.

*. The mean difference is significant at the .05 level

*The variable LTKN refers to the log-transformed total kjeldahl nitrogen concentration of surface water.

Multiple Comparisons

Dependent Variable: LTKN

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.1643	7.080E-02	.220	-.3806	.5208E-02
	3.00	-.0726	6.218E-02	.848	-.2627	.1174
	4.00	.1957	6.554E-02	.058	-.0046	.3960
	5.00	.1090	7.080E-02	.643	-.1073	.3254
	6.00	.1187	6.554E-02	.475	-.0816	.3190
2.00	1.00	.1643	7.080E-02	.220	-.0521	.3806
	3.00	9.163E-02	6.769E-02	.753	-.1152	.2985
	4.00	.3600*	7.080E-02	.000	.1436	.5763
	5.00	.2733*	7.568E-02	.014	4.201E-02	.5046
	6.00	.2830*	7.080E-02	.005	6.661E-02	.4993
3.00	1.00	7.264E-02	6.218E-02	.848	-.1174	.2627
	2.00	-.0916	6.769E-02	.753	-.2985	.1152
	4.00	.2683*	6.218E-02	.002	7.832E-02	.4584
	5.00	.1817	6.769E-02	.111	-.0252	.3885
	6.00	.1913*	6.218E-02	.048	1.306E-03	.3813
4.00	1.00	-.1957	6.554E-02	.058	-.3960	4.602E-03
	2.00	-.3600*	7.080E-02	.000	-.5763	-.1436
	3.00	-.2683*	6.218E-02	.002	-.4584	-.0783
	5.00	-.0867	7.080E-02	.821	-.3030	.1297
	6.00	-.0770	6.554E-02	.845	-.2773	.1233
5.00	1.00	-.1090	7.080E-02	.643	-.3254	.1073
	2.00	-.2733*	7.568E-02	.014	-.5046	-.0420
	3.00	-.1817	6.769E-02	.111	-.3885	2.521E-02
	4.00	8.668E-02	7.080E-02	.821	-.1297	.3030
	6.00	9.664E-03	7.080E-02	1.000	-.2067	.2260
6.00	1.00	-.1187	6.554E-02	.475	-.3190	8.161E-02
	2.00	-.2830*	7.080E-02	.005	-.4993	-.0666
	3.00	-.1913*	6.218E-02	.048	-.3813	-.0013
	4.00	7.701E-02	6.554E-02	.845	-.1233	.2773
	5.00	-.0097	7.080E-02	1.000	-.2260	.2067

Based on observed means.

*. The mean difference is significant at the .05 level.

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: LTKN

Std Residual

Model Intercept + DATE + LOCATION + DATE*LOCATION

Dependent Variable: LTKN

Model Intercept + DATE + LOCATION + DATE*LOCATION

Ammonia

Tests of Between-Subjects Effects

Dependent Variable: LNH3

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11.141 ^a	17	.655	28.707	.000
Intercept	28.676	1	28.676	1256.123	.000
DATE	6.001	2	3.000	131.425	.000
LOCATION	3.011	5	.602	26.380	.000
DATE * LOCATION	1.283	10	.128	5.622	.000
Error	.639	28	2.283E-02		
Total	46.887	46			
Corrected Total	11.780	45			

a. R Squared = .946 (Adjusted R Squared = .913)

Multiple Comparisons

Dependent Variable: LNH3

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	.4464*	5.697E-02	.000	.3055	.5874
	o	-.4953*	5.182E-02	.000	-.6235	-.3670
m	j	-.4464*	5.697E-02	.000	-.5874	-.3055
	o	-.9417*	5.697E-02	.000	-1.0826	-.8007
o	j	.4953*	5.182E-02	.000	.3670	.6235
	m	.9417*	5.697E-02	.000	.8007	1.0826

Based on observed means.

*. The mean difference is significant at the .05 level

*The variable LNH3 refers to the log-transformed ammonia concentration of surface water.

Multiple Comparisons

Dependent Variable LNH3

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2.00	.1383	8.160E-02	.546	- .1111	.3876
	3.00	6.622E-02	7.167E-02	.937	- .1528	.2852
	4 00	.5607*	7.555E-02	.000	.3299	.7916
	5 00	.6913*	8.160E-02	.000	.4419	.9407
	6 00	.6366*	7.555E-02	.000	.4058	.8675
2.00	1.00	-.1383	8.160E-02	.546	-.3876	.1111
	3.00	-.0721	7.802E-02	.937	-.3105	.1664
	4 00	.4224*	8.160E-02	.000	.1731	.6718
	5.00	.5530*	8.723E-02	.000	.2865	.8196
	6 00	.4983*	8.160E-02	.000	.2490	.7477
3.00	1 00	-.0662	7.167E-02	.937	-.2852	.1528
	2.00	7.205E-02	7.802E-02	.937	-.1664	.3105
	4 00	.4945*	7.167E-02	.000	.2755	.7135
	5 00	.6251*	7.802E-02	.000	.3867	.8635
	6 00	.5704*	7.167E-02	.000	.3514	.7894
4 00	1.00	-.5607*	7.555E-02	.000	-.7916	-.3299
	2 00	-.4224*	8.160E-02	.000	-.6718	-.1731
	3 00	-.4945*	7.167E-02	.000	-.7135	-.2755
	5 00	.1306	8.160E-02	.605	-.1188	.3799
	6 00	7.589E-02	7.555E-02	.913	-.1550	.3068
5 00	1.00	-.6913*	8.160E-02	.000	-.9407	-.4419
	2 00	-.5530*	8.723E-02	.000	-.8196	-.2865
	3 00	-.6251*	7.802E-02	.000	-.8635	-.3867
	4.00	-.1306	8.160E-02	.605	-.3799	.1188
	6.00	-.0547	8.160E-02	.984	-.3041	.1947
6 00	1.00	-.6366*	7.555E-02	.000	-.8675	-.4058
	2 00	-.4983*	8.160E-02	.000	-.7477	-.2490
	3.00	-.5704*	7.167E-02	.000	-.7894	-.3514
	4 00	-.0759	7.555E-02	.913	-.3068	.1550
	5 00	5.469E-02	8.160E-02	.984	-.1947	.3041

Based on observed means

* The mean difference is significant at the .05 level.

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: LNH3

Std Residual

Model Intercept + DATE + LOCATION + DATE*LOCATION

Dependent Variable: LNH3

Predicted

Model Intercept + DATE + LOCATION + DATE*LOCATION

Nitrate

Tests of Between-Subjects Effects

Dependent Variable: LNO3

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.323 ^a	17	7.785E-02	7.388	.000
Intercept	.825	1	.825	78.259	.000
DATE	.334	2	.167	15.860	.000
LOCATION	.608	5	.122	11.541	.000
DATE * LOCATION	.541	10	5.413E-02	5.137	.000
Error	.295	28	1.054E-02		
Total	2.371	46			
Corrected Total	1.618	45			

^a R Squared = .818 (Adjusted R Squared = .707)

Multiple Comparisons

Dependent Variable: LNO3

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	-.0756	3.870E-02	.143	-.1714	2.016E-02
	o	.1294*	3.521E-02	.003	4.223E-02	.2165
m	j	7.561E-02	3.870E-02	.143	-.0202	.1714
	o	.2050*	3.870E-02	.000	.1092	.3007
o	j	-.1294*	3.521E-02	.003	-.2165	-.0422
	m	-.2050*	3.870E-02	.000	-.3007	-.1092

Based on observed means

*. The mean difference is significant at the .05 level

*The variable LNO3 refers to the log-transformed nitrate concentration of surface water.

Multiple Comparisons

Dependent Variable LNO3

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2 00	-.0626	5.544E-02	.865	-.2320	.1068
	3 00	-.0230	4.869E-02	.997	-.1718	.1258
	4 00	-.2916*	5.133E-02	.000	-.4484	-.1347
	5 00	-.1079	5.544E-02	.396	-.2774	.6147E-02
	6 00	-.0248	5.133E-02	.996	-.1817	.1320
2.00	1.00	6.259E-02	5.544E-02	.865	-.1068	.2320
	3 00	3.963E-02	5.301E-02	.974	-.1224	.2016
	4.00	-.2290*	5.544E-02	.004	-.3984	-.0596
	5.00	-.0454	5.927E-02	.971	-.2265	.1358
	6 00	3.775E-02	5.544E-02	.983	-.1317	.2072
3 00	1.00	2.295E-02	4.869E-02	.997	-.1258	.1718
	2 00	-.0396	5.301E-02	.974	-.2016	.1224
	4.00	-.2686*	4.869E-02	.000	-.4174	-.1198
	5 00	-.0850	5.301E-02	.603	-.2470	.7700E-02
	6 00	-.0019	4.869E-02	1.000	-.1507	.1469
4 00	1.00	.2916*	5.133E-02	.000	.1347	.4484
	2 00	.2290*	5.544E-02	.004	5.959E-02	.3984
	3.00	.2686*	4.869E-02	.000	.1198	.4174
	5 00	.1837*	5.544E-02	.028	1.424E-02	.3531
	6 00	.2668*	5.133E-02	.000	.1099	.4236
5 00	1 00	.1079	5.544E-02	.396	-.0615	.2774
	2 00	4.535E-02	5.927E-02	.971	-.1358	.2265
	3.00	8.499E-02	5.301E-02	.603	-.0770	.2470
	4.00	-.1837*	5.544E-02	.028	-.3531	-.0142
	6.00	8.310E-02	5.544E-02	.668	-.0863	.2525
6.00	1.00	2.484E-02	5.133E-02	.996	-.1320	.1817
	2.00	-.0377	5.544E-02	.983	-.2072	.1317
	3 00	1.889E-03	4.869E-02	1.000	-.1469	.1507
	4 00	-.2668*	5.133E-02	.000	-.4236	-.1099
	5 00	-.0831	5.544E-02	.668	-.2525	.8632E-02

Based on observed means.

*. The mean difference is significant at the .05 level.

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: LNO3

Dependent Variable: LNO3

Appendix E. – Complete Results of 3-way ANOVAs for Nutrient Content

Total Nitrogen Content

Tests of Between-Subjects Effects

Dependent Variable: LTNGRAMS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	59.226 ^a	35	1.692	40.535	.000
Intercept	10.336	1	10.336	247.601	.000
TISSUE	11.090	1	11.090	265.653	.000
LOCATION	2.065	5	.413	9.893	.000
DATE	9.827	2	4.914	117.703	.000
TISSUE * LOCATION	.662	5	.132	3.173	.009
TISSUE * DATE	33.953	2	16.976	406.658	.000
LOCATION * DATE	1.358	10	.136	3.253	.001
TISSUE * LOCATION * DATE	.696	106	.958E-02	1.667	.092
Error	7.431	178	4.175E-02		
Total	77.447	214			
Corrected Total	66.657	213			

^a R Squared = .889 (Adjusted R Squared = .867)

Multiple Comparisons

Dependent Variable: LTNGRAMS

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	3571*	3.429E-02	.000	.2767	.4374
	o	-1395*	3.417E-02	.000	-.2196	-.594E-02
m	j	-3571*	3.429E-02	.000	-.4374	-.2767
	o	-4965*	3.417E-02	.000	-.5766	-.4164
o	j	1395*	3.417E-02	.000	5.937E-02	.2196
	m	4965*	3.417E-02	.000	.4164	.5766

Based on observed means.

* The mean difference is significant at the .05 level

* The variable LTNGRAMS refers to the log-transformed total nitrogen content of plant tissues.

Multiple Comparisons

Dependent Variable LTNGRAMS

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2 00	8 773E-02	4 850E-02	.460	-5 05E-02	.2259
	3 00	2 522E-03	4 884E-02	1 000	-.1367	.1417
	4 00	.1190	4 850E-02	.138	-.192E-02	.2572
	5 00	.2539*	4 850E-02	.000	.1157	.3921
	6 00	.2546*	4 850E-02	.000	.1164	.3928
2 00	1 00	-8 773E-02	4 850E-02	.460	-.2259	.5 048E-02
	3 00	-8 521E-02	4 850E-02	.494	-.2234	.5 300E-02
	4 00	.3 130E-02	4 816E-02	.987	-.1059	.1685
	5 00	.1662*	4 816E-02	.007	.2 895E-02	.3034
	6 00	.1669*	4 816E-02	.007	.2 963E-02	.3041
3 00	1 00	-2 522E-03	4 884E-02	1 000	-.1417	.1367
	2 00	.8 521E-02	4 850E-02	.494	-.5 30E-02	.2234
	4 00	.1165	4 850E-02	.155	-.2 17E-02	.2547
	5 00	.2514*	4 850E-02	.000	.1132	.3896
	6 00	.2521*	4 850E-02	.000	.1139	.3903
4 00	1 00	-.1190	4 850E-02	.138	-.2572	.1 918E-02
	2 00	-.3 130E-02	4 816E-02	.987	-.1685	.1059
	3 00	-.1165	4 850E-02	.155	-.2547	.2 170E-02
	5 00	.1349	4 816E-02	.057	-.2 35E-03	.2721
	6 00	.1356	4 816E-02	.055	-.1 68E-03	.2728
5 00	1 00	-.2539*	4 850E-02	.000	-.3921	-.1157
	2 00	-.1662*	4 816E-02	.007	-.3034	-.2 90E-02
	3 00	-.2514*	4 850E-02	.000	-.3896	-.1132
	4 00	-.1349	4 816E-02	.057	-.2721	.2 348E-03
	6 00	.6 724E-04	4 816E-02	1 000	-.1366	.1379
6 00	1 00	-.2546*	4 850E-02	.000	-.3928	-.1164
	2 00	-.1669*	4 816E-02	.007	-.3041	-.2 96E-02
	3 00	-.2521*	4 850E-02	.000	-.3903	-.1139
	4 00	-.1356	4 816E-02	.055	-.2728	.1 675E-03
	5 00	-.6 724E-04	4 816E-02	1 000	-.1379	.1366

Based on observed means

* The mean difference is significant at the .05 level

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: LTNGRAMS

Std Residual

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Dependent Variable: LTNGRAMS

Predicted

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Total Phosphorus Content

Tests of Between-Subjects Effects

Dependent Variable: LTPGRAMS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	64.522 ^a	35	1.843	44.940	.000
Intercept	60.345	1	60.345	1471.074	.000
TISSUE	21.121	1	21.121	514.876	.000
LOCATION	1.358	5	.272	6.620	.000
DATE	10.405	2	5.203	126.829	.000
TISSUE * LOCATION	.459	5	9.183E-02	2.239	.052
TISSUE * DATE	30.002	2	15.001	365.688	.000
LOCATION * DATE	1.269	10	.127	3.093	.001
TISSUE * LOCATION * DATE	.507	105	0.0071E-02	1.236	.271
Error	7.302	178	4.102E-02		
Total	131.322	214			
Corrected Total	71.824	213			

^a R Squared = .898 (Adjusted R Squared = .878)

Multiple Comparisons

Dependent Variable: LTPGRAMS

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	.4738*	3.399E-02	.000	.3942	.5535
	o	3.909E-02	3.387E-02	.481	-4.03E-02	.1185
m	j	-.4738*	3.399E-02	.000	-.5535	-.3942
	o	-.4348*	3.387E-02	.000	-.5142	-.3554
o	j	-3.909E-02	3.387E-02	.481	-.1185	.4031E-02
	m	.4348*	3.387E-02	.000	.3554	.5142

Based on observed means

* The mean difference is significant at the .05 level

* The variable LTPGRAMS refers to the log-transformed total phosphorus content of plant tissues.

Multiple Comparisons

Dependent Variable: LTPGRAMS

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2 00	5 635E-02	4 808E-02	.850	-8.07E-02	.1934
	3.00	-2 727E-02	4 842E-02	.993	-.1652	.1107
	4 00	3 199E-02	4 808E-02	.986	-.1050	.1690
	5 00	.1657*	4 808E-02	.008	2 864E-02	.3027
	6 00	.1957*	4 808E-02	.001	5 865E-02	.3327
2 00	1 00	-5 635E-02	4 808E-02	.850	-.1934	8 066E-02
	3 00	-8 361E-02	4 808E-02	.506	-.2206	5 340E-02
	4 00	-2 436E-02	4 774E-02	.996	-.1604	.1117
	5.00	.1093	4 774E-02	.198	-2 67E-02	.2453
	6 00	.1393*	4 774E-02	.041	3 273E-03	.2754
3 00	1 00	2 727E-02	4 842E-02	.993	-.1107	.1652
	2 00	8 361E-02	4 808E-02	.506	-5 34E-02	.2206
	4 00	5 925E-02	4 808E-02	.821	-7 78E-02	.1963
	5 00	.1929*	4 808E-02	.001	5 591E-02	.3299
	6 00	.2229*	4 808E-02	.000	8 592E-02	.3599
4 00	1 00	-3 199E-02	4 808E-02	.986	-.1690	.1050
	2 00	2 436E-02	4 774E-02	.996	-.1117	.1604
	3 00	-5 925E-02	4 808E-02	.821	-.1963	7 775E-02
	5 00	.1337	4 774E-02	.057	-2.37E-03	.2697
	6 00	.1637*	4 774E-02	.008	2 763E-02	.2997
5 00	1 00	-.1657*	4 808E-02	.008	-.3027	-2 86E-02
	2 00	-.1093	4 774E-02	.198	-.2453	2 673E-02
	3 00	-.1929*	4 808E-02	.001	-.3299	-5 59E-02
	4 00	-.1337	4 774E-02	.057	-.2697	2 375E-03
	6 00	3 001E-02	4 774E-02	.989	-.1060	.1660
6 00	1 00	-.1957*	4 808E-02	.001	-.3327	-5 87E-02
	2 00	-.1393*	4 774E-02	.041	-.2754	-3 27E-03
	3.00	-.2229*	4 808E-02	.000	-.3599	-8.59E-02
	4 00	-.1637*	4 774E-02	.008	-.2997	-2 76E-02
	5 00	-3 001E-02	4 774E-02	.989	-.1660	.1060

Based on observed means

* The mean difference is significant at the .05 level

* Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent cell 2.

Dependent Variable: LTPGRAMS

Std Residual

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Dependent Variable: LTPGRAMS

Predicted

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Appendix F. Complete Results of 3-way ANOVAs for Nutrient Concentration

Total Nitrogen Concentration

Tests of Between-Subjects Effects

Dependent Variable: TN

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	74.389 ^a	35	2.125	25.415	.000
Intercept	822.964	1	822.964	9840.736	.000
DATE	21.723	2	10.861	129.877	.000
LOCATION	8.776	5	1.755	20.987	.000
TISSUE	8.799	1	8.799	105.210	.000
DATE * LOCATION	3.550	10	.355	4.245	.000
DATE * TISSUE	30.039	2	15.020	179.600	.000
LOCATION * TISSUE	.938	5	.188	2.244	.052
DATE * LOCATION * TISSUE	1.506	10	.151	1.801	.063
Error	14.886	178	8.363E-02		
Total	910.163	214			
Corrected Total	89.275	213			

^a R Squared = .833 (Adjusted R Squared = .800)

Multiple Comparisons

Dependent Variable: TN

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	-.4077*	4.854E-02	.000	-.5215	-.2940
	o	.3599*	4.837E-02	.000	.2466	.4733
m	j	.4077*	4.854E-02	.000	.2940	.5215
	o	.7677*	4.837E-02	.000	.6543	.8810
o	j	-.3599*	4.837E-02	.000	-.4733	-.2466
	m	-.7677*	4.837E-02	.000	-.8810	-.6543

Based on observed means

* The mean difference is significant at the .05 level.

Multiple Comparisons

Dependent Variable: TN
Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2.00	.1087	6.865E-02	.610	-8.70E-02	.3043
	3.00	.1106	6.913E-02	.599	-8.64E-02	.3076
	4.00	.3895*	6.865E-02	.000	.1939	.5851
	5.00	.4109*	6.865E-02	.000	.2153	.6065
	6.00	.5495*	6.865E-02	.000	.3539	.7451
2 00	1 00	-.1087	6.865E-02	.610	-.3043	8.696E-02
	3 00	1.905E-03	6.865E-02	1.000	-.1937	.1975
	4.00	.2808*	6.816E-02	.001	8.659E-02	.4751
	5.00	.3022*	6.816E-02	.000	.1080	.4965
	6.00	.4408*	6.816E-02	.000	.2466	.6351
3 00	1 00	-.1106	6.913E-02	.599	-.3076	8.642E-02
	2.00	-1.905E-03	6.865E-02	1.000	-.1975	.1937
	4.00	.2789*	6.865E-02	.001	8.331E-02	.4746
	5.00	.3003*	6.865E-02	.000	.1047	.4959
	6.00	.4389*	6.865E-02	.000	.2433	.6346
4.00	1 00	-.3895*	6.865E-02	.000	-.5851	-.1939
	2.00	-.2808*	6.816E-02	.001	-.4751	-8.66E-02
	3.00	-.2789*	6.865E-02	.001	-.4746	-8.33E-02
	5.00	2.139E-02	6.816E-02	1.000	-.1729	.2156
	6.00	.1600	6.816E-02	.175	-3.42E-02	.3542
5 00	1.00	-.4109*	6.865E-02	.000	-.6065	-.2153
	2.00	-.3022*	6.816E-02	.000	-.4965	-.1080
	3.00	-.3003*	6.865E-02	.000	-.4959	-.1047
	4.00	-2.139E-02	6.816E-02	1.000	-.2156	.1729
	6.00	.1386	6.816E-02	.323	-5.56E-02	.3329
6 00	1.00	-.5495*	6.865E-02	.000	-.7451	-.3539
	2.00	-.4408*	6.816E-02	.000	-.6351	-.2466
	3.00	-.4389*	6.865E-02	.000	-.6346	-.2433
	4.00	-.1600	6.816E-02	.175	-.3542	3.424E-02
	5.00	-.1386	6.816E-02	.323	-.3329	5.563E-02

Based on observed means.

*. The mean difference is significant at the .05 level

Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent FWS cell 2.

Dependent Variable: TN

Std Residual

Model: Intercept + DATE + LOCATION + TISSUE + DATE*LOCATION + DATE*TISSUE
+ LOCATION*TISSUE + DATE*LOCATION*TISSUE

Dependent Variable: TN

Predicted

Model: Intercept + DATE + LOCATION + TISSUE + DATE*LOCATION + DATE*TISSUE
+ LOCATION*TISSUE + DATE*LOCATION*TISSUE

Total Phosphorus Concentration

Tests of Between-Subjects Effects

Dependent Variable: LTP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.060 ^a	35	.202	40.058	.000
Intercept	50.065	1	50.065	9941.855	.000
TISSUE	.525	1	.525	104.201	.000
LOCATION	.170	5	3.401E-02	6.754	.000
DATE	2.980	2	1.490	295.870	.000
TISSUE * LOCATION	2.247E-02	5	4.495E-03	.893	.487
TISSUE * DATE	3.121	2	1.560	309.848	.000
LOCATION * DATE	.198	10	1.982E-02	3.935	.000
TISSUE * LOCATION * DATE	3.511E-02	10	3.511E-03	.697	.726
Error	.896	178	5.036E-03		
Total	58.356	214			
Corrected Total	7.957	213			

^a R Squared = .887 (Adjusted R Squared = .865)

Multiple Comparisons

Dependent Variable: LTP

Tukey HSD

(I) DATE	(J) DATE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
j	m	3.275E-02*	1.191E-02	.016	4.840E-03	6.067E-02
	o	.2641*	1.187E-02	.000	.2363	.2919
m	j	-.0328*	1.191E-02	.016	-.0607	-.0048
	o	.2314*	1.187E-02	.000	.2035	.2592
o	j	-.2641*	1.187E-02	.000	-.2919	-.2363
	m	-.2314*	1.187E-02	.000	-.2592	-.2035

Based on observed means.

* The mean difference is significant at the .05 level

* The variable LTP refers to the log-transformed total phosphorus concentration of plant tissues.

Multiple Comparisons

Dependent Variable: LTP

Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 00	2 00	-.0112	1.685E-02	.986	-.0592	3.677E-02
	3.00	-.0115	1.696E-02	.984	-.0598	3.685E-02
	4 00	2.535E-03	1.685E-02	1.000	-.0455	5.054E-02
	5 00	1.615E-02	1.685E-02	.931	-.0319	6.416E-02
	6.00	6.869E-02*	1.685E-02	.001	2.069E-02	.1167
2 00	1 00	1.123E-02	1.685E-02	.986	-.0368	5.924E-02
	3 00	-.0003	1.685E-02	1.000	-.0483	4.774E-02
	4.00	1.377E-02	1.673E-02	.963	-.0339	6.143E-02
	5.00	2.738E-02	1.673E-02	.574	-.0203	7.505E-02
	6.00	7.992E-02*	1.673E-02	.000	3.226E-02	.1276
3 00	1.00	1.149E-02	1.696E-02	.984	-.0368	5.983E-02
	2.00	2.613E-04	1.685E-02	1.000	-.0477	4.827E-02
	4 00	1.403E-02	1.685E-02	.961	-.0340	6.203E-02
	5.00	2.765E-02	1.685E-02	.571	-.0204	7.565E-02
	6.00	8.018E-02*	1.685E-02	.000	3.218E-02	.1282
4 00	1.00	-.0025	1.685E-02	1.000	-.0505	4.547E-02
	2.00	-.0138	1.673E-02	.963	-.0614	3.390E-02
	3.00	-.0140	1.685E-02	.961	-.0620	3.398E-02
	5 00	1.362E-02	1.673E-02	.965	-.0340	6.128E-02
	6 00	6.615E-02*	1.673E-02	.001	1.849E-02	.1138
5 00	1 00	-.0162	1.685E-02	.931	-.0642	3.185E-02
	2.00	-.0274	1.673E-02	.574	-.0750	2.028E-02
	3 00	-.0276	1.685E-02	.571	-.0757	2.036E-02
	4 00	-.0136	1.673E-02	.965	-.0613	3.405E-02
	6 00	5.254E-02*	1.673E-02	.021	4.873E-03	.1002
6.00	1 00	-.0687*	1.685E-02	.001	-.1167	-.0207
	2.00	-.0799*	1.673E-02	.000	-.1276	-.0323
	3 00	-.0802*	1.685E-02	.000	-.1282	-.0322
	4.00	-.0662*	1.673E-02	.001	-.1138	-.0185
	5.00	-.0525*	1.673E-02	.021	-.1002	-.0049

Based on observed means

*. The mean difference is significant at the .05 level.

Locations 1 to 3 represent FWS vegetated cell 1 from inflow to outflow, while locations 4 to 6 represent FWS cell 2.

Dependent Variable: LTP

Std Residual

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE

ATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Dependent Variable: LTP

Predicted

Model Intercept + TISSUE + LOCATION + DATE + TISSUE*LOCATION + TISSUE*DATE

ATE + LOCATION*DATE + TISSUE*LOCATION*DATE

Appendix G. – Complete Results of Significant Regression Analyses

July

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605 ^a	.366	.303	.7819

a. Predictors: (Constant), LNH3

b. Dependent Variable: STNGRAMS

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.533	1	3.533	5.779	.037 ^a
	Residual	6.114	10	.611		
	Total	9.647	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.689	.455		5.915	.000
	LNH3	1.201	.500	.605	2.404	.037

a. Dependent Variable: STNGRAMS

Histogram

Dependent Variable: STNGRAMS

Scatterplot

Dependent Variable: STNGRAMS

* LNH3 refers to the log-transformed ammonia concentration of wastewater, while STNGRAMS refers to the total nitrogen content of aboveground biomass.

Model Summary^b

Model	R	R Square	Adjusted R Square	Std Error of the Estimate
1	.807 ^a	.651	.616	.1672

a. Predictors: (Constant), LNH3

b. Dependent Variable: SJTN

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.522	1	.522	18.663	.002 ^a
	Residual	.280	10	2.796E-02		
	Total	.801	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.008	.097		20.656	.000
	LNH3	.462	.107	.807	4.320	.002

a. Dependent Variable: SJTN

Histogram

Dependent Variable: SJTN

Scatterplot

Dependent Variable: SJTN

* SJTN refers to the total nitrogen concentration of aboveground biomass (in July).

October – Surface Water

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733 ^a	.538	.492	.6400

a. Predictors: (Constant), LNH3

b. Dependent Variable. STNGRAMS

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.768	1	4.768	11.639	.007 ^a
	Residual	4.096	10	.410		
	Total	8.864	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.550	.812		-.677	.514
	LNH3	2.066	.605	.733	3.412	.007

a. Dependent Variable STNGRAMS

Histogram

Dependent Variable STNGRAMS

Scatterplot

Dependent Variable STNGRAMS

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.779 ^a	.607	.568	1565

a. Predictors. (Constant), LNH3

b. Dependent Variable: ROTN

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.378	1	.378	15.443	.003 ^a
	Residual	.245	10	2.448E-02		
	Total	.623	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.149	.198		5.792	.000
	LNH3	.582	.148	.779	3.930	.003

a. Dependent Variable: ROTN

Histogram

Dependent Variable: ROTN

Scatterplot

Dependent Variable: ROTN

* ROTN refers to the total nitrogen concentration in below-ground biomass (in October).

Model Summary^b

Model	R	R Square	Adjusted R Square	Std Error of the Estimate
1	.669 ^a	.447	.392	2045

a. Predictors: (Constant), LNH3

b. Dependent Variable: SOTN

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	.338	1	.338	8.082	.017 ^a
	Residual	.418	10	4.182E-02		
	Total	.756	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig
		B	Std. Error	Beta		
1	(Constant)	.542	.259		2.089	.063
	LNH3	.550	.193	.669	2.843	.017

a. Dependent Variable: SOTN

Histogram

Dependent Variable: SOTN

Scatterplot

Dependent Variable: SOTN

* SOTN refers to the total nitrogen concentration in aboveground biomass (in October).

October – Sediment Water

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.739 ^a	.545	.500	.6347

a. Predictors. (Constant), LNH3

b. Dependent Variable: STNGRAMS

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4.835	1	4.835	12.001	.006 ^a
	Residual	4.029	10	.403		
	Total	8.864	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.535	.500		1.070	.310
	LNH3	1.354	.391	.739	3.464	.006

a. Dependent Variable: STNGRAMS

Scatterplot

Dependent Variable: STNGRAMS

Scatterplot

Dependent Variable: STNGRAMS

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.760 ^a	.577	.535	.1622

a. Predictors: (Constant), LNH3

b. Dependent Variable: ROTN

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.360	1	.360	13.664	.004 ^a
	Residual	.263	10	2.632E-02		
	Total	.623	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.469	.128		11.495	.000
	LNH3	.369	.100	.760	3.696	.004

a. Dependent Variable: ROTN

Scatterplot

Dependent Variable: ROTN

Scatterplot

Dependent Variable: ROTN

Model Summary^b

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.627 ^a	.393	.332	2142

a. Predictors: (Constant), LNH3

b. Dependent Variable: SOTN

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	297	1	297	6.479	.029 ^a
	Residual	.459	10	4.589E-02		
	Total	.756	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.860	.169		5.097	.000
	LNH3	.336	.132	.627	2.545	.029

a. Dependent Variable: SOTN

Scatterplot

Dependent Variable: SOTN

Scatterplot

Dependent Variable: SOTN

Model Summary^b

Model	R	R Square	Adjusted R Square	Std Error of the Estimate
1	.582 ^a	.339	.273	7.087E-02

a. Predictors: (Constant), LDP

b. Dependent Variable: STPGRAMS

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.572E-02	1	2.572E-02	5.121	.047 ^a
	Residual	5.022E-02	10	5.022E-03		
	Total	7.594E-02	11			

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.243	.021		11.655	.000
	LDP	-.921E-02	.041	-.582	-2.263	.047

a. Dependent Variable: STPGRAMS

Histogram

Dependent Variable: STPGRAMS

Regression Standardized Residual

Scatterplot

Dependent Variable: STPGRAMS

* LDP refers to the log-transformed dissolved phosphorus concentration of wastewater (sampled from sediment), while STPGRAMS refers to the total phosphorus content of aboveground biomass.

Appendix H. – Raw Water Quality Data (2003)

Oxidation Reduction Potential

Sample point	Jun-03	Jul-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	4-Nov	average	std dev
Lagoon	60.3	-93.3	-91.1	-138.5	-112.3	-104.3	-17.8	-116.6	-83	-65.3	10.2	-68.33636	60.92069
Exercise runoff	-66.4	370.7	290.2	282.3	266.6	228.1	281.3	52.6	99.5	124.1	114.8	431.7273	748.244
Facultative Pond	310.6	348.3	288.6	232.5	266.6	228.1	330.2	173	123.7	238.4	133.6	261.03	96.94271
Cell 1 Influent	340.1	385.1	361.3	311.1	213.8		304.1	110.6	126.4	244.5	139.1	260.64	104.6687
Cell 2 Influent	356.4	383.3	387.5	289.2	265.3		361.1	179.1	104.7	252.4	122.9	265.1364	107.8834
Cell 3 Influent	361.4	376.6	385.8	354.2	249.1	169.2	366.8	177.8	92.4	264.8	83.5	255.2889	135.4385
Cell 3 Effluent	423.2	382		371.7	135.4		350.9	178.2	182.6	274.8	201.7	264.5125	103.7432
Filter Strip Run off	418			368.8	141.1		306.6	62.7	138.7			285.725	114.9538
1w	397.7	333.5	355	307.6	224		319	168.3	122			270.6	88.63756
2w	373.8	337.1	315	303.5	226.1		324.1	208.4	99.4			285.7875	94.55111
3w	410.3	334.9	328.8	307.2	273.2		325.3	208.4	124.5			271.075	72.1489
4w	332.7	263.9	315.7	317.5	280.6		319.6	196.3	112.7			255.2275	86.21872
5w	339.1	164.72	337	297.9	274.5		323.8	36.8	123.2			244.0875	105.7031
6w	316.2	272.1	307	305.3	268.3		323.9	184.5	119.5			271.875	78.10019
7w	305.3	332.4	330.2	305.9	275.4		323.8	-46	91.6			207.625	138.5695
8w	288	106.1	322.9	300.8	273.7		323.8	7.4	101			225.1714	131.9978
9w	367.4	186.8		311.4	278.4		366.7	157.8	390.2	325.3		341.1375	77.46931
1w	363.9	392.5		384.5	348.2		368.4	241.6	395	317.3		347.5625	50.54706
1w	346.6	386		386.4	339.2		300.6	243.3		302.4		321.5571	55.24584
1w	393.1	391		285.9	334.6		334.7	21		309.1		290.3714	128.3264
1w	252.8	402		382.1	330.9		337.4	143.6	399.1	315.8		331.0625	81.72994
1w	381	390.1		358.8	328.7		337.3	173.3	393.6	319.8		322.0125	80.93446
1w	363.2	400.4		360.6	227.2		308.2	197.2	148.5	325.9		301.525	90.41987
1w	379.7	412.1		361.7	280		311.6	250	146.6	356.9		303.9125	75.99685
1w	336.1	377.2		336.9	333.5		353	312.5	263			326.1833	34.90544
1s				347.1	362.6	358.2	347.5	309.1	415.4			356.34	38.47766
2s				338.6	333.3	363.1	350.2	306.4	406.9			349.75	33.81921
3s				339.4	329.6		354.7	313	341			335.54	15.45277
4s				329.7		366.5	253.6	311	370.2			326.2	47.62914
5s				323	322.5	364.5	323.7	312.4	385.1			338.5333	29.13436
6s				321.6	326	360.7	330.4	317.5	394.2			341.7333	29.93684
7s				315.9	321.6	320.7	300.7	316	392.7			327.9333	32.60679
8s				332.9	318.7	338.2	330.2	312.6	391.8			337.4	28.27303
9s				276.4	352	383.9	380	356.6	408.8	361.2		359.8429	41.67021
1s				320.7	320.9	344.9	297.7	325.9		367.5		323.9333	28.25468
1s				298.3	320.8	344.9	315.1	321.9		371.1		328.6833	25.60456
1s				295.8	313.5	355.7	314.3	322.4		244.1		307.6333	36.83431
1s				296.6	309.4	354	320.1	249.3		244.5		295.65	42.32525
1s				304.6	314.8	356.2	323.7	305.6		216.28		303.53	46.74604
1s				316.3	320.2	360.3	322.2	317		236		312	40.80113
1s				310.2	300	367.5	322.7	306.5		351		324.65	24.1789
1s				308.6	154.3	366.5	244.6	305.7		355.1		289.1333	78.93523

11 Total Phosphorus

Sample point	May-03	Jun-03	Jun-03	Jul-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	4-Nov	avg	stdev
Lagoon	121 561														
Exercise runoff	13 125	16 09	75 009	120 974	110 716	115 994	88 461	96 559	451 029	79 5283	614 336	31 1136	0 5277	162 2043	190 2207
Facultative Pond	16 731	25 88	66 396	17 751	20 205	18 652								27 6188	21 17057
Cell 1 Influent	15 829	15 48	26 921	24 122	22 367	19 021	24 072	31 962	38 904	38 2547	42 4551	11 7366	0 127	25 4852	11 91903
Cell 2 Influent	20 337	18 54	11 531	11 255	17 64	19 695	25 582		33 697	32 9481	36 0724	10 1423	0 2133	19 47783	11 42244
Cell 3 Influent	16 216	15 36	8 808	13 629	16 62	21 789	28 35		34 193	34 1274	32 5543	20 6892	1 4507	20 97733	10 70051
Cell 3 Effluent	12 461	13 64	12 123	11 63	13 716	14 561	21 052	19 649	18 691	20 9764	24 1764	20 4489	0 8434	15 97401	6 348454
Filter Strip Runoff	9 647			6 758		10 808	18 2836		17 451	18 1368	20 0302	11 9868	0 9527	13 07101	5 91275
1w		12 596	9 046	15 003	14 488	18 098	28 17		15 715	20 9764	17 8942	13 5811	0 637	7 78216	6 26967
2w		43 25	7 287	14 878	17 084	20 712	27 512		26 63	29 4104	34 1877			20 8617	8 728863
3w			16 585	12 754	19 587	12 992	26 853		26 506	28 2311	32 3031			24 55012	10 8474
4w		26 49	9 675	28 869	17 115	13 484	27 018		26 258	38 8443	33 5595			21 9764	7 470026
5w		32 24	12 062	8 881	22 676	21 02	31 125		30 226	38 2547	51 7779			24 59031	9 459852
6w		46 56	8 167	16 377	20 297	15 637	29 816		26 506	42 9717	35 4442			27 58473	13 22079
7w		30 77	14 7	9 506	19 061	20 712	34 425		35 805	33 5377	34 1877			26 86399	13 03159
8w		23 92	10 805	32 367	13 901	20 251	32 121		27 746	39 4339	49 265			25 85604	9 933408
9w		17 44	10 679	13 878			23 726		25 886	42 3821	38 5852			27 75666	12 19458
1w		4 1	11 308	6 133		12 562	21 271		18 443	19 6792		19 8357		24 65376	12 07068
1w		9 48	8 418	7 882		12 808	19 01		18 939	19 7972	23 1713	17 5055		14 16649	6 63227
1w		9 6	9 925	7 507		12 069	20 632		17 327	18 6179		19 8357		15 22344	5 662058
1w		8 99	12 313	4 509		11 793	23 825		18 691	18 0283		14 3169		14 6097	5 348549
1w		8 5	11 811	8 007		10 101	18 557		15 219	18 0283		17 3829		13 88778	5 936839
1w		7 4	7 79	5 259		14 007	22 187		17 575	20 9764		18 9772		13 45078	4 369868
1w		5 81	10 805	7 507		13 3	20 92		15 467	16 2594		17 0149		14 2727	6 669209
1w		6 67	18 218	12 879		7 763	18 397		19 931	7 0613		17 2602		13 38641	5 08702
1s						5 456	0 78	1 9	3 571	7 0613	0 239			4 21506	3 092851
2s						10 901	1 109	1 1	2 207	0 0936				4 21506	3 092851
3s						8 809	14 311	1 644	5 43	3 7504	7 9684			1 81912	2 200493
4s						12 992			4 314	1 8726				5 1353	3 785498
5s						3 58	5 578	5 578	11 629	16 4387	0 2566			7 32665	5 471174
6s						6 102	4 589	0 461	2 703	0 4946				11 65943	4 531441
7s						12 408	17 669	1 676	4 314	14 3726	1 7364			1 49904	1 533786
8s						17 913		31 323	14 107	11 7217	19 1104			5 468667	4 692224
9s						5 18		17 731	30 102	22 9245				17 72318	7 269499
1s						11 22	15 331	10 247	28 738	93 0866		12 6		22 16763	5 811272
1s							2 788	20 609	17 203	12 9575		15 298		29 97092	36 36915
1s								1 004	1 954	0 942		1 3944		15 43642	3 281155
1s								5 354	7 409	9 8915		2 1756		1 61648	0 76905
1s								13 221	12 938			6 836		5 03242	3 860621
1s								0 103	1 612	2 1085		3 0341		9 89725	3 677669
1s								2 258	8 649	12 7689		5 4623		2 514767	2 313217
1s							3 544	2 188	4 259	11 0708		2 5435		6 03484	4 769627
1s														4 038717	3 661806

Dissolved Phosphorus

	2-Jul	15-Jul	29-Jul	12-Aug	26-Aug	9-Sep	7-Oct	avg	stdev
1w	9.18	4.0167	5.37	14.5		16.74	24.6	12.40112	7.773733
2w	0.086	4.75	1.31	16.74		16.74	23.48	10.51767	9.719298
3w	4.39	2.54	3.03	14.16		17.87	22.36	10.725	8.538887
4w	8.44	0.33	6.84	14.16		16.52	22.92	11.535	7.981643
5w	6.23	4.02	3.16	14.16		16.63	26.63	11.805	9.110765
6w	0.7	0.33	1.31	19.55		15.62	27.07	10.76333	11.54288
7w	6.84	5.74	2.91	23.48		12.81	22.36	12.35667	8.802887
8w	3.16	2.42	12.37	17.48		15.96	31.45	13.80667	10.71904
9w			3.77	10.57		14.95	25.73	13.755	9.213633
iw			2.54	12.14		21.35	15.06	12.7725	7.82965
iiw	0.086		1.44	10.01		13.26	11.91	7.3412	6.133733
iiiw	5		1.56	9.89		13.94		7.5975	5.43695
ivw			1.93	16.46		11.02		9.803333	7.34101
viv	1.07		3.03	10.34		16.07	18.43	9.788	7.683204
viw	0.33		1.81	10.45		10	15.62	9.47	5.707872
viiw	5.98			10.45		14.27	24.83	12.47	10.12373
1s			1.63	13.37		9.89	12.48	10.43	3.313618
2s				1.78		0.48		1.025	0.795257
3s			0.045	0.18		0.12		0.155	0.049497
4s			1.09	6.84		0.72		0.39875	0.336313
5s			5.54			0.23		2.72	3.593842
6s				0.15		0.14		1.956667	3.103358
7s				1.25		0.08		0.336667	0.38553
8s			7.62	8.13		0.17		0.583333	0.582866
9s			2.34	9.2		0.19		6.06	3.923986
is			5.04	9.54		10.55		8.3225	4.074395
iis			6.76	7.96		11.22		7.8375	3.022056
iiis			0.365	1.17		10.32		8.645	1.594689
ivis			0.868	5.16		0.55		0.65125	0.355208
vis			2.28	5.72		2.46		2.5745	1.843414
vvis			1.42	1.23		5.27		5.28	2.29482
viiis			0.193	2.1		1.48		1.229333	0.251001
				0.55		5.83		2.615	2.18285
						0.37		0.43825	0.198324

Total Kjeldahl Nitrogen

Sample point	Jun-03	Jun-03	Jul-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	4-Nov	avg	stdev
Lagoon		1749.85	707.23	876.42	571.2	547.33	743.12	1940.9	1350.38	1929.12	491.02	478.1	1034.97	592.228
Exercise runoff	40.12	68.72	50.86	73.37	61.52								58.918	13.50931
Facultative Pond	45.02	60.63	50.48	115.94	62.22	8.06	123.28	260.58	308.92	381.38	130.41	97.57	137.0408	117.0765
Cell 1 Influent	9.49	61.42	40.11	37.02	34.58	34.96		167.08	180.04	66.65	19.23	45.28	63.26	56.94916
Cell 2 Influent	31.93	44.7	23.38	29.46	53.11	53.8		125.35	161.1	50.82	36.86	29.51	58.18364	44.03017
Cell 3 Influent	10.09	23.11	16.42	55.44	27.88	24.57	23.53	48.76	167.84	73.99	42.81	30.06	45.375	42.60353
Cell 3 Effluent	1.62	28.16	21.82		25.72	18.3		38.29	91.56	35.63	20.34	28.82	31.026	23.5824
Filter Strip Runoff		16			30.67	24.56		30.53	87.07	20.66	29.56	17.13	32.0225	23.00202
1w	22.18	43.21	53.63	35.28	44.24	37.6		70.74	47.22	71.93			47.33667	16.17023
2w	26.45	28.08	53.6	47.52	50.88	50.19		94.99	59.6	131.04			60.26111	33.14954
3w		46.36	43.96	42.65	36.42	50.49		77.37	64.63	114.18			59.5075	25.7668
4w	35.84	27.43	106.89	37.72	48.08	44.06		67.11	64.81	90.32			58.02889	26.67811
5w	35.57	25.47	18.95	66.85	64.32	60.56		74.34	86.48	193.35			69.54333	51.7319
6w	14.5	14.53	55.95	28.53	54.85	53.4		75.89	93.12	113.03			55.97778	33.96804
7w	25.77	21.59	17.89	55.8	66.54	58.76		63.8	100.68	127.18			59.77889	36.51068
8w	44.41	96.38	99.28	36.48	56.77	61.89		73.35	95.36	134.86			77.64222	31.44043
9w	27.62	19	19.57		36.23	29.45		59.36		83.77			39.28571	23.88938
1w	16.36	15.8	4.07		26.61	13.26		35	33.47		45.24		23.75125	13.66634
11w	25.53	15.43	19.64		10.35	33.85		42.25	32.35	82.44	47.58		34.38	21.74418
111w	23.99	10.93	11.85		19.39	40.59		44.04	34.07		55.83		30.08625	16.1897
11w	15.13	35.48	27.93		27.32	26.09		41.34	28.58		44.42		30.78625	9.346547
11w	14.71	12.17	18.67		21.46	4.48		44.34	27.21		49.1		24.0175	15.56632
11w	11.55	54.08	17.44		20.22	20.27		49.55	35.45		42.03		31.32375	16.08429
111w	27.07	13.07	25.11		28.95	28.77		24.95	31.13		42.38		27.67875	8.094756
12	12.18	20.84	10.83		27.08	25.31		26.25	26.53		43.52		24.0675	10.18968
1s					62.04	60.56		75.62		87.71			72.956	11.53621
2s					71.58			78.85		72.15			71.72	5.759358
3s					79.6			78.62		71.91			79.2325	6.659957
4s					65.93			77.46		83.42			75.2725	9.841397
5s					36.62			87.13	68.56	79.47			69.135	22.18006
6s					80.19			83.17		71.92			77.24667	4.621519
7s					70.29	92.46			125.43	81.64			89.804	21.42521
8s					51.3	79.25		76.63	138.68	114.86			104.695	43.54909
9s					51.87			60.15	99.34	89.37			71.412	21.43975
1s					14.92			30.46	41.47		24.08		26.75	9.911675
11s					20.41	22.6		30.72	39.21		23.17		25.99	7.558674
111s					16.02	20.57		26.59	36.55		35.03		28.32167	8.648987
11s					17.02			29.88	29.05		20.26		23.116	5.922722
11s					23.64			22.42	25.24		24.58		23.318	1.80267
11s					38.56	16.75		22.36	17.87		14.53		20.18833	9.74478
11s					14.5			20.33	15.2		14.03		16.015	2.916556
11s					15.86	8.13		15.57	24.03		20.28		15.51333	6.158307

Ammonia

Sample point	May-03	Jun-03	Jun-03	Jul-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	4-Nov avg	std dev
Lagoon	170 698		239 54	441 35	511 97	457 6	292 56	288 77	475	437	396 23	294.11	250 12	371 2955 99 42294
Exercise runoff	5 874	31 92	16 24	9.32	7.32	7 26	4 78	22 58	46 4	93 4	174 87	85 01	50 49	44 19333 51 35236
Facultative Pond	16 348	17 26	4 66	5.37	11 01	14 49	12 83		33 3	51 7	21 21	10	5 81	15 01273 15 19811
Cell 1 Influent	4 547	2 14	2 92	4.24	12 45	8 54	21 9		34 8	49	0 77	25 64	19 49	16 80364 15 38288
Cell 2 Influent	10 671	7 61	7 16	2.01	1 37	15 09	3 17	10 97	23 4	38 3	31 25	24 57	18 67	13 59583 13 34299
Cell 3 Influent	1 438	0 4	0 59	0.64	1 12	3 22	10 02		9 2	24 5	10 65	14 08	8 21	7 205 7 862559
Cell 3 Effluent	0 178	0 49	0 29	0 51		0 95	3 17		7 2	19 8	0 55	17 45	7 21	7 1975 7 579104
Filter Strip Runoff	0 194		0 27			1 37	3 73		26 9	28 5	42 24			19 99222 10 46721
1w		14 06	10 94	16 82	12 45	15 71	12 31		25 7	46 9	70 81			27 09625 21 17359
2w		11	11 39	20 48	14 07	14 49	16 42		42 7	41 2	84 11			32 00625 24 12434
3w		12 84	12 84	26 97	17 98	16 36	15 76		43 1	51 7	57 09			31 62566 16 77757
4w		20 34	13 36	39 99	28 18	21 75	14 51		39 8	62 3	108 9			36 60111 31 1496
5w		16 57	11 36	26 97	23 93	12 82	20 17		40 4	73 2	73 92			30 40333 26 19108
6w		8 26	10 51	19 69	14 66	17 75	19 36		44	66 4	87 81			31 72667 28 35589
7w		7 92	9 33	11 8	21 17	10 9	19 36		49 1	72 5	91 68			33 62 30 29431
8w		12 96	13 36	22 15	10 57	9 27	10 02		39 1	76 1	44 1			27 05875 24 20636
9w		8 27	8 27	15 55		1 9	2 92		17 8	16 5	21 21	22 55		9 857778 9 34375
1w		14 06	0 78	2 64		2 85	7 51		21 4	17 1	38 75	31 76		14 59566 13 50113
1w		2 42	3 87	5 16		2 83	10 88		34 2	20 2		41 06		14 88875 15 48336
1w		2 96	1 96	7 65		1 75	8 5		15 2	14 5		27 94		9 465 9 323635
1w		0 53	2 04	4 77		1 83	7 51		10 4	10 4		24 57		8 3 7 560709
1w		1 02	2 13	7 96		1 75	6 12		8 93	16 5		25 64		7 7525 9 046789
1w		1 6	0 88	1 65		1 55	4 8		8	15 2		20 7		6 78 7 454435
1w		0 55	1 08	2 54		3 36	7 83		7 24	9 75		23 54		7 6575 7 082154
1w		0 37	3 05	6 04		39 99	24 78	37 59	45 6	38 7	73 92			43 43 16 43462
1s						55 35		33 09	54	57	67 82			53 452 12 62479
2s						55 35		19 88	47 1	60 2	42 24			42 135 15 61792
3s						55 35	28 04			58 2	38 75			36 505 16 33382
4s						12 31	20 17			69	59 6			40 212 25 961
5s						35 41		14 15	46	65 1	48 06			48 464 10 7609
6s						51 03	33 05	44 55	49 2	57 9	59 6			50 16667 10 93127
7s						32 64	34 44	40 92	58 5	57 9	59 6			52 82167 18 30182
8s						30 1	20 17	62 58	47 7	59	80 57			34 625 12 43468
9s						2 9	2 47	21 64	40 8	49	46 04			7 165 4 694832
1s						1 7	1 57	5 56	7 78	15 1		9 18		7 608333 6 133376
1s						2 46	1 71	7 81	12 1	17 1		8 07		9 563333 7 233363
1s						1 77	0 92	0 97	14 2	10 5		20 7		4 915 4 26942
1s						1 55		4 49	8 4	7 73		7 1		6 604 3 752317
1s						0 91	1	5 33	9 5	6 22		11 37		4 703333 3 289631
1s						1 22	0 5	0 79	9 65	7 3		5 26		4 12 3 862543
1s						1 03	1 45	3 48	7 38	7 49		8 43		4 876667 3 292778

Nitrate													
Sample point	Jun-03	Jun-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	4-Nov	avg	stdev
Lagoon		729.67	1.452	2.49							27.84	74.28564	217.5154
Exercise runoff	0.99	0.65		1.02							2.2562	2.93727	
Facultative Pond	0.82	1.09	2.214	1.16							4.16	1.68325	1.25683
Cell 1 Influent	0.78	0.45	1.878	1.46	1.34		0.209	0.701	0.673	3.23	1.98	1.284636	0.86591
Cell 2 Influent	0.68	0.48	1.878	1.46	1.32		1.05	0.739	1.55	1.88	2.74	1.360636	0.651019
Cell 3 Influent	0.75	0.41	1.505	1.27	0.84	1.69	0.568	0.345	0.126	2.29	3.3	1.210333	0.915913
Cell 3 Effluent	0.9	0.43	2.925		0.89		0.209	0.412	0.117	1.71	3.15	1.2173	1.087456
Filter Strip Runoff		0.88			1		0.39	0.537	0.03	2.08		1.260875	1.203603
1w	0.71	0.98	2.098	1.52	1.51		0.042	0.873	0.34			1.043667	0.639857
2w	0.86	0.53	3.092	1.9			0.047	0.635	0.522			1.1195	0.979762
3w		0.68	2.034	1.27	1		0.218	0.592	0.939			1.035375	0.575531
4w	1.36	1.33	4.816	0.89	1.6		0.334	0.477	0.564			1.474444	1.32206
5w	0.9	0.88	2.478	1.74	0.84		0.914	0.957	0.47			1.123667	0.634218
6w	0.86	0.62	1.777	1.16	1.51		0.023	0.987	1.3			1.090778	0.547465
7w	0.9	0.65	3.454	1.11	1.42		1	0.635	0			1.177667	0.960283
8w	0.71	1.09	2.098	1.33	1.7		1.12	0.89	0			1.158667	0.60588
9w	0.94	0.68	3.859		1.42		0.375	0.865	0.717			1.272	1.099074
1w	0.82	0.62	2.098		0.88		0.047	0.635	1.58	1.98		1.127778	0.691754
1lw	0.68	0.72	3.092		0.95		0.161	0.477	1.39	2.19		1.197778	0.919767
2lw	0.86	0.59	2.344		4.29		0.626	0.45		2.41		1.58625	1.337028
3lw	0.75	0.65	2.098		3.8		0.065	0.694		1.71		1.339625	1.182147
4lw	0.86	0.62	2.478		1.98		7.8	1.75		2.08		2.34725	2.292884
5lw	0.9	0.65	2.344		0.81		0.151	0.778		2.08		1.104125	0.740568
6lw	0.86	0.62	2.478		1.07		0.066	0.621		1.88		1.20325	0.822615
7lw	0.9	0.72	2.619		1.82		0.536	0.94		2.41		1.535625	1.213312
8lw	0.82	0.56	4.079		1.82		0.94	2.21	2.53			2.162	0.875483
1s					0.72	3.31	0.94	2.15	1.27			1.8766	1.435423
2s					1.56	4.26	0.993	2.74	4.72			2.759	1.415253
3s					0.84	3.91	0.914	5.18	3.82			3.508	2.38459
4s					0.75	2.47	1.35	16.2	1.73			4.3198	6.689442
5s					10.49	10.29	0.449	7.87	6.62			6.51	3.926153
6s					2.62	4.26	3.01	4.88	4.16			2.996667	1.704731
7s					3	10.29	1.07	3.15	2.13			3.468333	3.454889
8s					2.81	13.8	0.675	1.33	1.8			3.5325	5.089945
9s					4.46	2.47	0.523	1.5		3.08		2.17767	1.457601
1s					0.8	1.76	0.358	1.04		2.53		1.411333	0.814554
2s					1.98	2.8	0.36	1.49		2.29		1.658	0.936947
3s					5.56	2.47	0.33	1.12		3.08		2.481667	1.807821
4s					1.32	3.17	0.431	1.26		2.93		1.8222	1.177656
5s					1.36	5.48	1.66	0.967		2.18		2.147833	1.684353
6s					0.95	14.39	0.523	1.1		2.79		3.9506	5.89928
7s					0.64	2.57	0.363	0.94		2.18		1.267167	0.891751
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Biochemical Oxygen Demand

	Jun-03	Jun-03	Jul-03	Jul-03	Jul-03	Aug-03	26-Aug	9-Sep	23-Sep	7-Oct	21-Oct	avg	stdev
1w	82.4	59.4	47.8	54.9	114	158.3		170	141.3	171		111.0111	51.07268
2w	60.6	69.6	23.4	154	39.7	102.5		42.75	56.8	99.7		72.11667	40.38717
3w		41.6	10	39.4	10.4	151.6		41.3	65.4	101.3		57.625	48.03727
4w	63.8	70	27.8	43.7	56.53	44.33		56.35	65.2	78.2		56.21222	15.47997
5w	71.6	83	17.2	68.9	21.3	171.5		107.4	135	172.4		94.25556	57.499
6w	52	65.6	35.8	38.3	109	98.4		94.1	214	116.3		91.5	54.93826
7w	52.6	48.8		63.4	27.03	161.1		155	72.95	70.5		81.4225	49.47085
8w	70	69.4	78.5	68.1		99.6		107.2	188	142.4		102.9	42.83306
9w	38	17.8	9.9		121	191		110.5	135.6	89		89.1	63.23311
lw	52.85	83.9	23.1	50	18.45	55.1		24	48.75	62.3	35.85	45.43	20.33765
lw	42.35	45.95	8.2		50.45	60.2		23.45	45.85	43.4	35.7	39.50556	15.43285
liw	47	60.25	8		29	40.85		26.35	38.05	40.35	31.55	35.71111	14.58117
liiw	69.1	32.65	5.5		7.9	63.3		23.4	38.45		33.9	34.275	23.04452
ivw	64.8	38.95	11.4		14.55	55		10.5	52.5		31.4	34.8875	21.37476
vw	52.5	30.1	20.25		35	49.65		30	38.35	40.45	42.3	37.62222	10.12284
viw	26.95	54.8	30.5		56.3	98.9		34.65	53.45	50.75	51	50.81111	21.2387
viiw	41.65	25.54	5.4		27.9	26.95		14.9	25.7	54.05	44.95	29.67111	15.09105
viiiw	57.2	66.7	26.3		57.5	87.6		62.3	29.6	44.1	95.4	58.52222	23.37786

* "w" denotes surface water samples, while "s" denotes sediment water samples. All concentrations are in mg/L.

Appendix I. – Raw Plant Data (2003/2004)

Sample	UGcode	stems	DW	TN	TP	tissue	location	date	TN (g)	TP (g)
C1-1R		1		271.45	2 19	0.311 r		1 m	5 944755	0.84421
C1-2R		2		191.97	3 09	0.374 r		1 m	5.931873	0 717968
C1-2S		3	10	3	3 56	0 570 s		1 m	0 1068	0.0171
C1-3R		4		673 13	2 02	0 318 r		1 m	13 59723	2.140553
C1-3S		5	22	13.2	2 86	0.386 s		1 m	0 37752	0.050952
C1-4R		6		393.82	2 26	0 397 r		1 m	8.900332	1 563465
C1-4S		7	10	1.7	3 61	0 519 s		1 m	0.06137	0 008823
C1-5R		8		75.76	3 20	0 501 r		1 m	2.42432	0.379558
C1-5S		9	4	3 64	3 37	0 622 s		1 m	0 122668	0.022641
C1-6R		10		99 24	2 59	0 468 r		1 m	2 570316	0.464443
C1-6S		11	5	4 212	2.52	0.310 s		1 m	0.106142	0.013057
C1-7R		12		215.81	2 17	0.359 r		2 m	4.683077	0 774758
C1-7S		13	11	5 746	2 79	0 470 s		2 m	0.160313	0.027006
C1-8R		14		105 051	2 34	0 444 r		2 m	2.458193	0.466426
C1-8S		15	6	6.54	2.57	0.404 s		2 m	0.168078	0 026422
C1-9R		16		222.45	2 45	0 395 r		2 m	5.450025	0 878678
C1-9S		17	15	4.89	3 14	0.508 s		2 m	0.153546	0 024841
C1-10R		18		580.68	2.07	0 353 r		3 m	12.02008	2.0498
C1-10S		19	18	9 94	2.82	0 420 s		3 m	0.280308	0.041748
C1-11R		20		237.25	2.54	0 335 r		3 m	6.02615	0.794788
C1-11S		21	7	2 94	3 43	0 579 s		3 m	0 100842	0.017023
C1-12R		22		463.41	2 00	0.333 r		3 m	9 2682	1 543155
C1-12S		23	6	5	2 92	0.406 s		3 m	0.146	0.0203
C1-13R		24		406 73	2 00	0 337 r		2 m	8 1346	1.37068
C1-13S		25	9	4 68	3 13	0 494 s		2 m	0.146484	0 023119
C1-14R		26		899.25	1 70	0.284 r		2 m	15.28725	2.55387
C1-14S		27	20	8 84	2.68	0.400 s		2 m	0.236912	0 03536
C1-15R		28		368.03	1 71	0 331 r		2 m	6 293313	1.218179
C1-15S		29	12	8.42	2 92	0 476 s		2 m	0 245864	0.040079
C1-16R		30		656 72	1 40	0.299 r		3 m	9.19408	1 963593
C1-16S		31	7	4 46	2 66	0 472 s		3 m	0.118636	0 021051
C1-17R		32		285.49	2 19	0 410 r		3 m	6 252231	1.170509

C1-17S	33	8	4 06	2 78	0 442 s	3 m	0 112868	0 017945
C1-18R	34		226 45	2 26	0 413 r	3 m	5 11777	0.935239
C1-18S	35	13	12.04	2 31	0 355 s	3 m	0.278124	0 042742
C2-1R	36		248.12	1 32	0 249 r	6 m	3.275184	0 617819
C2-1S	37	8	4 1	2.48	0 351 s	6 m	0.10168	0.014391
C2-2R	38		137 63	1.39	0 206 r	6 m	1.913057	0.283518
C2-2S	39	4	3 28	1 97	0.242 s	6 m	0 064616	0.007938
C2-3R	40		581 88	1 24	0 274 r	6 m	7.215312	1 594351
C2-3S	41	17	4 71	2.54	0 325 s	6 m	0.119634	0.015308
C2-4R	42		316.9	1 57	0 273 r	6 m	4 97533	0 865137
C2-4S	43	19	6 34	2.45	0 335 s	6 m	0.15533	0.021239
C2-5R	44		135 32	1.48	0 228 r	6 m	2.002736	0.30853
C2-5S	45	12	3 76	2.58	0 331 s	6 m	0.097008	0.012446
C2-6R	46		338.88	1.25	0 269 r	6 m	4.236	0.911587
C2-6S	47	9	1 9	2 98	0.456 s	6 m	0.05662	0 008664
C2-7R	48		348.73	0.92	0.245 r	5 m	3 208316	0.854389
C2-7S	49	9	2.3	2 61	0.436 s	5 m	0 06003	0 010028
C2-8R	50		149 56	1 19	0 350 r	5 m	1.779764	0 52346
C2-8S	51	6	3 31	2.85	0 478 s	5 m	0.094335	0 015822
C2-9R	52		186.54	1 26	0.313 r	5 m	2.350404	0 58387
C2-9S	53	7	3.51	2 67	0 436 s	5 m	0.093717	0 015304
C2-10R	54		160.56	1 42	0 358 r	5 m	2 279952	0 574805
C2-10S	55	5	2.78	3 22	0.602 s	5 m	0 089516	0.016736
C2-11R	56		298 59	1 65	0.368 r	5 m	4 926735	1.098811
C2-11S	57	11	8 61	2 83	0 506 s	5 m	0 243663	0.043567
C2-12R	58		157 01	1 54	0 326 r	5 m	2.417954	0.511853
C2-12S	59	5	2.29	3.22	0 542 s	5 m	0.073738	0 012412
C2-13R	60		447.48	1.76	0 289 r	4 m	7 875648	1 293217
C2-13S	61	40	28 26	2 44	0.359 s	4 m	0 689544	0.101453
C2-14R	62		459.45	1 70	0 337 r	4 m	7 81065	1.548347
C2-14S	63	37	19	2 82	0.425 s	4 m	0.5358	0 08075
C2-15R	64		223 91	1 98	0.401 r	4 m	4 433418	0 897879

C2-15S	65	14	9 12	3 37	0.512 s	4 m	0 307344	0.046694
C2-16R	66		108 35	1.99	0.420 r	4 m	2 156165	0.45507
C2-16S	67	15	9 25	3.25	0.545 s	4 m	0 300625	0.050413
C2-17R	68		258 27	1.64	0.342 r	4 m	4 235628	0.883283
C2-17S	69	7	7 52	2.87	0.438 s	4 m	0.215624	0.032938
C2-18R	70		273 82	1.58	0.358 r	4 m	4.326356	0.980276
C2-18S	71	19	12 11	2.72	0.468 s	4 m	0.329392	0.056675
C1-1R	72		21.5	1.91	0.502 r	1 j	0.41065	0.10793
C1-1S	73	13	176.1	2.75	0.441 s	1 j	4.84275	0.776601
C1-2R	74		58 7	1.38	0.399 r	1 j	0.81006	0.234213
C1-2S	75	12	128 3	2.78	0.459 s	1 j	3.56674	0.588897
C1-3R	76		128.5	1.43	0.352 r	1 j	1.83755	0.45232
C1-3S	77	7	140.3	2.26	0.41 s	1 j	3 17078	0.57523
C1-4R	78		182	1.76	0.387 r	1 j	3.2032	0.70434
C1-4S	79	5	83 1	2.13	0.311 s	1 j	1.77003	0.258441
C1-5R	80		213 1	2.35	0.397 r	1 j	5 00785	0.846007
C1-5S	81	15	128 9	2.57	0.442 s	1 j	3 31273	0.569738
C1-6R	82		330 9	2.2	0.394 r	1 j	7.2798	1.303746
C1-6S	83	8	175 2	2.41	0.417 s	1 j	4 22232	0.730584
C1-7R	84		63 9	1.67	0.475 r	2 j	1.06713	0.303525
C1-7S	85	18	134.8	2.8	0.43 s	2 j	3.7744	0.57964
C1-8R	86		46 9	1.67	0.436 r	2 j	0.78323	0.204484
C1-8S	87	14	156 4	2.72	0.465 s	2 j	4.25408	0.72726
C1-9R	88		61 3	1.87	0.528 r	2 j	1.14631	0.323664
C1-9S	89	18	163 4	2.72	0.471 s	2 j	4.44448	0.769614
C1-10R	90		438 1	1.39	0.312 r	3 j	6.08959	1.366872
C1-10S	91	14	241	2.31	0.412 s	3 j	5.5671	0.99292
C1-11R	92		136 5	2.07	0.499 r	3 j	2.82555	0.681135
C1-11S	93	15	302 4	2.59	0.433 s	3 j	7 83216	1.309392
C1-12R	94		223.1	1.44	0.326 r	3 j	3 21264	0.727306
C1-12S	95	11	150 1	2.46	0.423 s	3 j	3 69246	0.634923
C1-13S	96	14	215 5	2.37	0.487 s	3 j	5.10735	1.049485

C1-14R	97		46.8	1.82	0.614 r	3 j	0.85176	0.287352
C1-14S	98	9	156	2.44	0.497 s	3 j	3.8064	0.77532
C1-15R	99		89	1.47	0.396 r	3 j	1.3083	0.35244
C1-15S	100	10	157.5	2.58	0.488 s	3 j	4.0635	0.7686
C1-16R	101		42.1	1.25	0.386 r	2 j	0.52625	0.162506
C1-16S	102	7	72.6	2.85	0.521 s	2 j	2.0691	0.378246
C1-17R	103		39.6	1.7	0.468 r	2 j	0.6732	0.185328
C1-17S	104	11	102.7	2.99	0.507 s	2 j	3.07073	0.520689
C1-18R	105		126	1.37	0.386 r	2 j	1.7262	0.48636
C1-18S	106	13	226.7	2.55	0.494 s	2 j	5.78085	1.119898
C2-1R	107		61.9	1.1	0.292 r	6 j	0.6809	0.180748
C2-1S	108	6	133.6	2.23	0.41 s	6 j	2.97928	0.54776
C2-2R	109		78.1	0.99	0.358 r	6 j	0.77319	0.279598
C2-2S	110	8	86.6	1.98	0.397 s	6 j	1.71468	0.343802
C2-3R	111		73.5	0.94	0.311 r	6 j	0.6909	0.228585
C2-3S	112	9	165	2.08	0.382 s	6 j	3.432	0.6303
C2-4R	113		27.2	1.9	0.46 r	6 j	0.5168	0.12512
C2-4S	114	6	76.8	2.17	0.488 s	6 j	1.66656	0.374784
C2-5R	115		45.6	1.15	0.373 r	6 j	0.5244	0.170088
C2-5S	116	7	157.7	1.93	0.376 s	6 j	3.04361	0.592952
C2-6R	117		110.6	0.9	0.269 r	6 j	0.9954	0.297514
C2-6S	118	12	203.1	2.05	0.396 s	6 j	4.16355	0.804276
C2-7R	119		55	2.23	0.506 r	5 j	1.2265	0.2783
C2-7S	120	4	71.3	2.64	0.497 s	5 j	1.88232	0.354361
C2-8R	121		55.8	2.08	0.474 r	5 j	1.16064	0.264492
C2-8S	122	11	117.9	2.52	0.494 s	5 j	2.97108	0.582426
C2-9R	123		86.8	2.13	0.489 r	5 j	1.84884	0.424452
C2-9S	124	15	212.3	2.33	0.461 s	5 j	4.94659	0.978703
C2-10R	125		81.1	1.23	0.438 r	5 j	0.99753	0.355218
C2-10S	126	13	101.8	2.16	0.357 s	5 j	2.19888	0.363426
C2-11R	127		95.5	1.08	0.349 r	5 j	1.0314	0.333295
C2-11S	128	9	62.6	2.55	0.366 s	5 j	1.5963	0.229116

C2-12R	129		61.2	1 33	0 391 r	5 j	0.81396	0 239292
C2-12S	130	9	96 3	2 09	0 331 s	5 j	2.01267	0 318753
C2-13R	131		68.3	1.1	0 42 r	4 j	0.7513	0.28686
C2-13S	132	6	113 2	1 78	0.36 s	4 j	2.01496	0.40752
C2-14R	133		29.8	1.47	0 548 r	4 j	0 43806	0 163304
C2-14S	134	10	152.8	2.37	0 392 s	4 j	3.62136	0 598976
C2-15R	135		97 1	0 88	0 345 r	4 j	0.85448	0.334995
C2-15S	136	11	345 4	1 73	0.371 s	4 j	5 97542	1 281434
C2-16R	137		121.1	1.03	0.307 r	4 j	1.24733	0.371777
C2-16S	138	6	90.3	2.2	0 354 s	4 j	1.9866	0 319662
C2-17R	139		67 5	1 2	0 321 r	4 j	0.81	0 216675
C2-17S	140	18	245 9	2 14	0.393 s	4 j	5.26226	0 966387
C2-18R	141		92.6	1 15	0 406 r	4 j	1.0649	0 375956
C2-18S	142	11	192.1	2.18	0.374 s	4 j	4.18778	0.718454
C1-1R	143		216 7	1 93	0.341 r	1 o	4.18231	0 738947
C1-1S	144	10	246.8	1.32	0.098 s	1 o	3.25776	0 241864
C1-2R	145		435.7	2.13	0 376 r	1 o	9 28041	1.638232
C1-2S	146	18	420.9	1 29	0.128 s	1 o	5.42961	0.538752
C1-3R	147		154	2.49	0 447 r	1 o	3 8346	0.68838
C1-3S	148	12	270 2	1 48	0 205 s	1 o	3 99896	0.55391
C1-4R	149		406 4	2 03	0.401 r	1 o	8 24992	1.629664
C1-4S	150	17	272	1 18	0 121 s	1 o	3.2096	0.32912
C1-5R	151		129.1	1.69	0.323 r	1 o	2.18179	0.416993
C1-5S	152	7	138.3	1.26	0.135 s	1 o	1.74258	0.186705
C1-6R	153		217.2	2 28	0.400 r	1 o	4 95216	0 8688
C1-6S	154	12	187 6	1.49	0.130 s	1 o	2 79524	0.24388
C1-7R	155		124 3	2 19	0 390 r	2 o	2 72217	0.48477
C1-7S	156	14	121.8	1 78	0 159 s	2 o	2 16804	0.193662
C1-8R	157		264 7	1.73	0 355 r	2 o	4 57931	0 939685
C1-8S	158	11	246 2	1 52	0 124 s	2 o	3 74224	0 305288
C1-9R	159		227	2 06	0 398 r	2 o	4.6762	0 90346
C1-9S	160	14	197 7	1 86	0 173 s	2 o	3.67722	0 342021

C1-10R	161		240.1	1.94	0.364 r	2 0	4.65794	0.873964
C1-10S	162	8	175.8	1.01	0.098 s	2 0	1.77558	0.172284
C1-11R	163		162.4	1.99	0.386 r	2 0	3.23176	0.626864
C1-11S	164	9	118.5	1.38	0.127 s	2 0	1.6353	0.150495
C1-12R	165		243	1.76	0.363 r	2 0	4.2768	0.88209
C1-12S	166	9	196.5	1.10	0.105 s	2 0	2.1615	0.206325
C1-13R	167		280.3	2.31	0.466 r	3 0	6.47493	1.306198
C1-13S	168	20	285.2	1.99	0.182 s	3 0	5.67548	0.519064
C1-14R	169		131.3	2.05	0.388 r	3 0	2.69165	0.509444
C1-14S	170	5	47.8	1.64	0.152 s	3 0	0.78392	0.072656
C1-15R	171		129.2	2.06	0.395 r	3 0	2.66152	0.51034
C1-15S	172	12	58.9	1.54	0.138 s	3 0	0.90706	0.081282
C1-16R	173		387.7	1.90	0.334 r	3 0	7.3663	1.294918
C1-16S	174	12	225.5	0.93	0.154 s	3 0	2.09715	0.34727
C1-17R	175		186.1	2.28	0.376 r	3 0	4.24308	0.699736
C1-17S	176	16	196.7	1.19	0.147 s	3 0	2.34073	0.289149
C1-18R	177		238.8	2.32	0.390 r	3 0	5.54016	0.93132
C1-18S	178	17	191.5	1.37	0.130 s	3 0	2.62355	0.24895
C2-1R	179		85.4	1.91	0.443 r	4 0	1.63114	0.378322
C2-1S	180	11	87.1	1.31	0.139 s	4 0	1.14101	0.121069
C2-2R	181		288.4	1.95	0.421 r	4 0	5.6238	1.214164
C2-2S	182	26	248	1.22	0.153 s	4 0	3.0256	0.37944
C2-3R	183		82	1.93	0.344 r	4 0	1.5826	0.28208
C2-3S	184	10	133.1	1.37	0.173 s	4 0	1.82347	0.230263
C2-4R	185		174.4	2.04	0.442 r	4 0	3.55776	0.770848
C2-4S	186	24	110.1	1.51	0.219 s	4 0	1.66251	0.241119
C2-5R	187		226.3	1.90	0.374 r	4 0	4.2997	0.846362
C2-5S	188	17	177.8	1.03	0.122 s	4 0	1.83134	0.216916
C2-6R	189		173.3	1.59	0.401 r	4 0	2.75547	0.694933
C2-6S	190	6	91.7	0.86	0.107 s	4 0	0.78862	0.098119
C2-7R	191		209.2	2.16	0.400 r	5 0	4.51872	0.8368
C2-7S	192	15	142.5	1.33	0.172 s	5 0	1.89525	0.2451

C2-8R	193		307.7	1 69	0.349 r	5 o	5.20013	1 073873
C2-8S	194	21	143.8	0 93	0.111 s	5 o	1.33734	0 159618
C2-9R	195		226.8	1.81	0 382 r	5 o	4.10508	0 866376
C2-9S	196	13	132.7	1 12	0.132 s	5 o	1.48624	0 175164
C2-10R	197		362.9	1 15	0 291 r	5 o	4.17335	1.056039
C2-10S	198	20	177.4	0 74	0.080 s	5 o	1.31276	0 14192
C2-11R	199		157.5	1 33	0.297 r	5 o	2 09475	0.467775
C2-11S	200	9	126	0 99	0.115 s	5 o	1 2474	0.1449
C2-12R	201		205.4	1 41	0 309 r	5 o	2.89614	0.634686
C2-12S	202	16	122	0 79	0.112 s	5 o	0.9638	0 13664
C2-13R	203		288.2	1 63	0.320 r	6 o	4.69766	0.92224
C2-13S	204	25	139.7	0 77	0.099 s	6 o	1.07569	0 138303
C2-14R	205		247.5	1 88	0.361 r	6 o	4 653	0.893475
C2-14S	206	25	145.5	0.98	0.120 s	6 o	1.4259	0.1746
C2-15R	207		168.3	1.92	0.351 r	6 o	3.23136	0 590733
C2-15S	208	9	93.6	1.16	0.137 s	6 o	1.08576	0 128232
C2-16R	209		182.5	1.97	0 354 r	6 o	3.59525	0.64605
C2-16S	210	16	120.5	1 38	0.163 s	6 o	1.6629	0.196415
C2-17R	211		460.1	1.59	0.316 r	6 o	7.31559	1.453916
C2-17S	212	22	129.2	1.19	0.180 s	6 o	1.53748	0.23256
C2-18R	213		162.8	1.72	0.352 r	6 o	2.80016	0.573056
C2-18S	214	14	132.4	1 35	0.166 s	6 o	1 7874	0 219784

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Sample	UGcode	stems	DW	TN	TP	tissue	location	TNgrams	TPgrams
C1-1R	215	355.5	2.43	0.438 r	1	8.63865	1.55709		
C1-2R	216	224	2.12	0.406 r	1	4.7488	0.90944		
C1-3R	217	351.5	2.10	0.356 r	1	7.3815	1.25134		
C1-4R	218	165.5	2.84	0.489 r	1	4.7002	0.809295		
C1-5R	219	362.5	2.10	0.350 r	1	7.6125	1.26875		
C1-6R	220	278.2	2.15	0.341 r	1	5.9813	0.948662		
C1-7R	221	218.2	2.44	0.442 r	2	5.32408	0.964444		
C1-8R	222	160.3	2.39	0.482 r	2	3.83117	0.772646		
C1-9R	223	288.5	2.98	0.476 r	2	8.5973	1.37326		
C1-10R	224	453.3	1.78	0.417 r	2	8.06874	1.890261		
C1-11R	225	188.5	3.12	0.467 r	2	5.8812	0.880295		
C1-12R	226	259.5	1.81	0.316 r	2	4.69695	0.820022		
C1-13R	227	304.9	2.13	0.446 r	3	6.49437	1.359854		
C1-14R	228	223.8	2.13	0.397 r	3	4.76694	0.888486		
C1-15R	229	119.8	2.24	0.386 r	3	2.68352	0.462428		
C1-16R	230	301.3	2.18	0.395 r	3	6.56834	1.190135		
C1-17R	231	336.6	2.53	0.431 r	3	8.51598	1.450746		
C1-18R	232	383.2	2.21	0.373 r	3	8.46872	1.429336		
C2-1R	233	155.4	1.70	0.353 r	4	2.6418	0.548562		
C2-2R	234	140.4	2.10	0.383 r	4	2.9484	0.537732		
C2-3R	235	158.3	2.10	0.382 r	4	3.3243	0.604706		
C2-4R	236	209.4	2.36	0.426 r	4	4.94184	0.892044		
C2-5R	237	135.1	2.16	0.363 r	4	2.91816	0.490413		
C2-6R	238	86.6	2.37	0.410 r	4	2.05242	0.35506		
C2-7R	239	220.9	1.85	0.354 r	5	4.08665	0.781986		
C2-8R	240	222.8	1.49	0.303 r	5	3.31972	0.675084		
C2-9R	241	211.4	1.47	0.266 r	5	3.10758	0.562324		
C2-10R	242	212.8	1.68	0.305 r	5	3.57504	0.64904		
C2-11R	243	235.8	1.55	0.341 r	5	3.6549	0.804078		
C2-12R	244	356.8	1.38	0.269 r	5	4.92384	0.959792		
C2-13R	245	118.6	1.83	0.318 r	6	2.17038	0.377148		
C2-14R	246	220.3	1.43	0.221 r	6	3.15029	0.486863		
C2-15R	247	102.5	1.75	0.273 r	6	1.79375	0.279825		
C2-16R	248	140.3	1.96	0.335 r	6	2.74988	0.470005		
C2-17R	249	51.7	2.51	0.398 r	6	1.29767	0.205766		
C2-18R	250	113.5	2.43	0.372 r	6	2.75805	0.422222		