Monitoring anthropogenic nutrients in a modified natural wetland; Riding Mountain National Park, Manitoba

S. E. Belke and R. A. McGinn, Brandon University

Abstract: In recent years, extensive research has been conducted and several studies published detailing the ecology of wetlands, in particular the roles that wetland plants and soils serve in the removal of anthropogenic nutrients from wastewater. Ominnik Marsh is a natural wetland located in Riding Mountain National Park. A three-cell lagoon system discharges annually (single event flush) into the marsh. This study examines the impact of the spring melt, the single event lagoon discharge and the seasonal vegetation growth sequence on the phosphorus and nitrogen levels in Ominnik Marsh.

Seasonal observations of nutrient concentrations in the Ominnik Marsh wetland indicate that there is an uptake of nitrogen and phosphorus by the natural vegetation reducing these nutrient concentrations to background levels. Nutrient monitoring at points throughout the marsh supports the conclusion that the forcemain conduit leading into the sewage lagoons is leaking into the marsh. The data presented indicates that a significant area of the marsh is being "short-circuited" during the spring single event release from lagoon Cell 3.

Introduction

The role that wetlands play as natural water purifiers is an aspect of wetland ecology that has received considerable study in recent years (Mitsch and Gosselink 1993; Kadlec and Knight 1995; Kirby 2002). Wetlands have the capacity to receive, hold, and recycle potentially damaging nutrients washed from upstream and upland regions. In North America natural wetlands have been used as wastewater discharge sites as long as sewage has been collected (IWA Specialist Group 2000).

Ominnik Marsh is a natural wetland located within the Clear Lake watershed, in Riding Mountain National Park, Manitoba. The marsh receives an annual effluent flush from the Wasagaming sewage lagoons, and ultimately drains into the South Lake - Clear Lake complex. Clear

Lake is the focus of summer recreational activity in Riding Mountain National Park. Consequently, water quality throughout the Clear Lake watershed is a fundamental concern identified in both the Park Management Plan and the Ecosystem Conservation Plan (Dubois 1997).

The Study Area

Ominnik Marsh is a natural wetland system located within Riding Mountain National Park, about 100 km north of Brandon, Manitoba (Figure 1a). It is a part of the Octopus Creek - South Lake sub-basin of the Clear Lake watershed, which ultimately drains into Clear Lake. Ominnik Marsh is “Y” shaped. The trunk of the Y from sampling site O1 to O2 is approximately 440 m in length (Figure 1b). Two small beaver ponds (less than 0.25 ha) have been constructed at and near the Ominnik 2 sampling site. Vegetation common to the reach includes rooted willow (*Salix spp*.), reeds (*Phragmites spp*.), rushes (*Juncus spp*.) and sedges (*Carex spp*.); open water vegetation includes common reed (*Phragmites spp*.), duckweed (*Lemna minor*), water calla (*Calla palustris*), and cattail (*Typha spp*.)

The northeast branch of the “Y” (sampling sites O2-O5) is 760 m in length and approximately 160-250 m in width. This area of the marsh is the former course of Octopus Creek and during the spring freshet, flows can be measured at the O5 sampling site (Figure 1b). Since 1961, Octopus Creek flows have been diverted to the west, draining from the marsh into South Lake by way of a constructed channel (Figure 1b). The “old” Octopus Creek channel drops approximately 2.0 m from the O1 site at Provincial highway 10 to the outlet at the Boat Cove (O5). Channel slope is calculated to be 0.002 or 0.2%. Prominent vegetation common to this area of the marsh is rooted willow, (*Salix spp*.) alder (*Alnus spp*.), aspen (*Populus tremuloides*), sedges (*Carex spp*.) and blue joint grasses (*Calamagrostis canadensis*); open water vegetation includes *Lemna minor*, *Phragmites*, and *Typha*. Boat Cove Road provides access to the O5 sampling site.

The western branch of the Ominnik Marsh “Y” includes a shallow pond (generally less than 1.5 m in depth), which can be subdivided into two areas; the open water pond and the floating vegetation with occasional open water (Figure 1b). This region of the marsh has an estimated length of 350 m from sampling sites O2 to O3 (the head of pond) and an additional 225 m across the pond to sampling site O4 (Figure 1b). The distance from sampling sites O2 to O4 is estimated to be 540 m. The region is approximately 125-250 m wide. The pond has an estimated elevation of 615.8 m above sea level. An upland ridge, rising approximately 3 m above

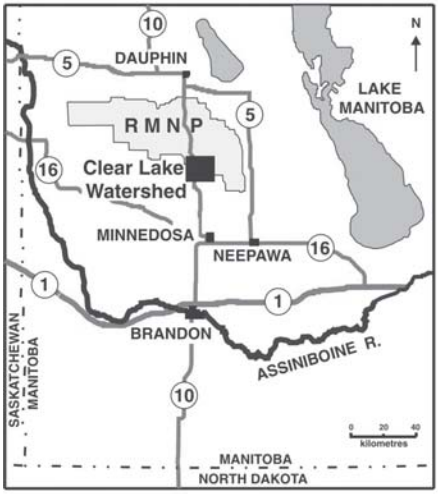

Figure 1a

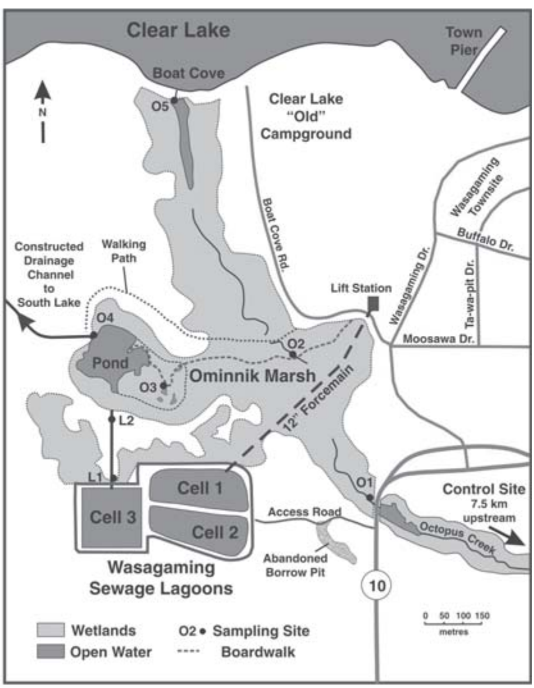

Figure 1b

Figure 1: a) *Location of the Study Area,* ***b)*** *Ominnik Marsh and the Wasagaming Sewage Lagoons, Clear Lake Watershed, Riding Mountain National Park.*

the marsh, bisects the western branch of the "Y," and separates the pond and marsh proper from a narrow wetland region adjacent the lagoon system (Figure 1b). White spruce (*Picea glauca*), alder (*Alnus spp*.), aspen (*Populus tremuloides*) and shrub species (hazel, *Corylus spp*.) are found on the uplands, willow (*Salix spp*.), sedges (*Carex spp*.), blue joint grasses (*Calamagrostis canadensis*), marsh marigold (*Caltha palustris L*.) and reeds (*Phragmites*), are common in the marsh. *Lemna minor*, *Calla palustris*, *Juncus* and floating mats of cattail (*Typha latifolia*) are common in the open water pond.

Wastewater Treatment in Wasagaming, Manitoba

In the early 1950's greywater waste from the old campground and the townsite was discharged directly into Ominnik Marsh (Rousseau 2002). A small earthen dam (the walking path on Figure 1b) held the wastewater discharge in the marsh throughout the summer. In the fall outflow conduits through the dam were opened and the following spring, the snowmelt freshet flushed the system directly into Clear Lake.

In the late 1950's and early 1960's a single cell lagoon (Cell 3) was constructed southwest of the town of Wasagaming within the Park boundaries (Figure 1b). Wastewater was pumped to the lagoon cell through a 12-inch (30 cm) diameter forcemain conduit buried beneath Ominnik Marsh. The lagoon cell was excavated out of in-situ coarse soils (sands, silty sands and clayey sands) and is approximately 168 m square (2.83 ha), 2 m deep, and unlined. At the time, it was believed that the settled solids would seal the pervious bottom of the lagoon in a few years. A concrete spillway and regulated outlet conduit, located on the north side of the lagoon cell, discharges into an excavated ditch which is approximately 75 m long, 4 m wide and up to 2.5 m deep. The ditch, designed to convey an annual spring release and accidental overflows from the lagoon cell into Ominnik Marsh, enters the marsh south of the pond (Figure 1b). This relatively straight man-made discharge channel contains four artificial dams, approximately 1.5 m in height that create temporary "holding ponds" in the ditch. The dams are easily overtopped, however, and during the annual spring release the channel flows continuously. It is speculated that the baffles or small dams were originally constructed in an effort to reduce flow velocities and/or to "hold" small accidental releases associated with overtopping of the lagoon cell during heavy rainfalls.

In 1961, as part of this free water surface wetland system, a 390 m drainage channel, connecting the pond in Ominnik Marsh to South Lake, was excavated. This and the original "walking path" dam effectively diverted the Octopus Creek flows to South Lake and only peak flow events were able to overtop the "walking path" dam and flow directly into Clear Lake. The constructed channel drops approximately 1.0 m over the 390 m length. The slope is calculated to be 0.002 or 0.2%.

The primary treatment single cell lagoon system of the early 1960's allowed "a considerable amount of pollution" to be released into Ominnik Marsh (Bazillion et al., 1992). In drier years, significant exfiltration and evaporation losses often obviated the necessity for a release into Ominnik Marsh. The lagoon, however, was hydraulically overloaded in the summer, could not store the annual volume of wastewater generated, and during heavy rainfall events overflowed into the marsh (Rousseau 2002 and Wruth 2002).

Two additional cells, Cell 1 and Cell 2, were constructed in the early 1970's to the east of the original lagoon cell (Figure 1b). The expanded system (three cells) covers 7.25 ha (17.9 acres), and has a potential storage capacity of 97,284 dam^3 (21.4 million imperial gallons) of wastewater (MacLaren 1979). The additional cells were excavated out of the in-situ coarse soils. The banks and bottom were lined (Pratt 1991). Valve controlled conduits connect the three lagoon cells in series. Generally the conduits, positioned 1.5 m (5 feet) above the bottom of the lagoons, drain surface waters from Cell 1 to Cell 2 and from Cell 2 to Cell 3. Cell 1 is anaerobic and the primary settling cell. Cell 2 is anaerobic in the spring and aerobic throughout the summer and Cell 3, the finishing cell, is aerobic throughout the year (Paton 2002). Submerged and floating aquatic vegetation was sampled near the shores of Cells 1 and 2 using a long handle rake and grab samples taken from a boat. *Ceratophyllum demersum* (Coontail) was practically a monoculture, very abundant forming thick submerged mats (Rogosin 2002). *Lemna minor* (Duckweed) and *Zannichellia palustris* (Horned-Pondweed) were present but relatively sparse. *Ceratophyllum demersum L.* present in Cell 2 appeared to be less vigorous and bushy and generally a paler green than those present in lagoon Cell 3 (Rogosin 2002). Emergent plants growing along the borders of the lagoon cells 1 and 2 consist of *Typha spp.* (Cattails) grasses and sedges (mostly *Carex spp.*) (Rogosin 2002).

Wastewater is pumped to lagoon Cell 1 through the existing 30 cm (12 inch) diameter forcemain conduit buried beneath Ominnik Marsh. There is a suspicion that this conduit was not properly installed and leaks (MacLaren 1979). Pressure testing in 1991 supports this hypothesis (Pratt 1991). However, the most recent pressure test (summer 2002) indicates that the line is not leaking (Wruth 2002).

Wruth (2002) describes the operational procedures for the Wasagaming three-cell lagoon wastewater treatment system. While the system operates throughout the year, discharges during October through to late May are minimal, effectively shutting down the system for a seven-month period. Consequently, the three-cell lagoon wastewater treatment system operates from late May to mid-October**.** Peak wastewater volumes occur in July and August when the population of the resort town is estimated to average 8,000 (Huissman 2002)**.** Untreated wastewater is pumped into lagoon Cell 1. During the summer recreational season the valves controlling the conduits which link the three cells remain open allowing transfer of surface wastewater from Cell 1 to Cell 2 and finally to Cell 3. In the spring the three cells are isolated for a short period (usually May) and the effluent in Cell 3 is tested for total and fecal coliform bacteria count, biochemical oxygen demand and other water quality parameters. Once the fecal coliform counts and the five-day BOD meets the provincial public health standards there is a release of approximately 36,350 dam^3 (8 million imperial gallons) from Cell 3. This effluent release normally occurs in mid to late June. Following the spring release the valves are reopened and remain open for the remainder of the summer. Occasionally, following a rainy summer or autumn, there is a mid-October drawdown release of approximately 18,000 dam^3 in preparation for the following spring operations. Operational procedures similar to those followed in the spring are employed; the cells are isolated, effluent in Cell 3 is tested and then released into the marsh as a single one-day event.

Federal and provincial guidelines for the design of standard lagoons require that stabilization ponds have a one year storage capacity and a maximum organic load on the primary cell of 50 lb per acre per day (Pratt 1991). In 1976 the three-cell lagoon system was hydraulically and organically overloaded (MacLaren 1979). Organic loads exceeded the provincial standard and the three lagoons could not meet the federal storage requirements (MacLaren 1979). Following the implementation of recommendations in the MacLaren Study (1979), the average seasonal sewage flow from April to October was reduced from 200,000-225,000 imperial gallons per day (approximately 100 dam^3 day^{-1}) to approximately 150,000 imperial gallons per day (68 dam^3 day^{-1}) (Pratt 1991). Since the three-cell lagoon storage is 97,284 dam^3 (21.4 million imperial gallons) and the annual volume is estimated to be 145,927 dam^3 (32.1 million imperial gallons) the present system fails to meet the federal storage requirements. Exfiltration, the water losses through the base and sides of the Wasagaming lagoon cells, is considered to be significant and probably accounts for the fact that the annual sewage volume can be stored in the three cells.

In 1976, lagoon exfiltration losses including leakage from the forcemain conduit were estimated to be approximately 50 million imperial gallons (227,300 dam^3) annually, a volume that was approximately 80% of 1976 influent flow (MacLaren 1979). This volume may be an overestimate as it does not include summer evaporation losses which can be significant. Pratt's (1991) estimate of exfiltration losses considers seasonal evaporation losses. Pratt estimates a conservative evaporative loss of one-foot (30 cm) depth from the three lagoon cells (18 acres surface area) or approximately 5 million imperial gallons (22,730 dam^3) (Pratt 1991). Sewage volume for the April to October period was estimated to be 20 million imperial gallons (90,920 dam^3) and the combination of exfiltration and evaporation losses accounted for 15 million imperial gallons (68,190 dam^3) or 75% of influent volume (Pratt 1991).

Pratt (1991) estimated the organic loading for the three-cell system. Organic loading is evaluated by the five day BOD per acre and total coliform count. Assuming a mean BOD loading of 150 mg L^{-1} in the sewage and a mean daily flow of 150,000 imperial gallons per day, organic loading on the system was less than the 50 lb per acre per day. Pratt concluded that the wastewater treatment system was, on average, functional throughout the operation period (April to October). During the summer months, however, the system is overloaded.

Objective of the Study

The general objective of this study is to assess the efficiency of Ominnik Marsh, a modified natural wetland, to sequester anthropogenic nutrients from agricultural runoff and municipal wastewater. Specifically, efficiency will be assessed by sampling marsh waters at a series of strategic points for soluble orthophosphate, total ammonia, nitrate, and nitrite ion concentrations. The study will examine the nutrient concentrations associated with the spring freshet and the sewage lagoon single event discharge release. Attempts at resolving the "leaking forcemain" issue will be addressed.

Theoretical Considerations

Nitrogen and Phosphorus:

In the majority of aquatic systems, either nitrogen or phosphorus is the nutrient that limits aquatic plant production (Hammer and MacKichan 1981). The accumulation of nitrogen and phosphorus will contribute to the eutrophication of lakes and reservoirs (Hammer and Knight 1992).

The main subenvironments to which nitrogen and phosphorus can be transferred from wetland surface waters are the atmosphere, sediment-interstitial water, and living and dead biomass (Neely and Baker 1989). In turn, each of these subenvironments can also serve as the source of nutrients to surface waters. Since the concentrations of these elements in natural environments are usually low (Calow and Petts 1996), they are considered good indicators of anthropogenic nutrient loading. Consequently, the water quality analyses focuses on the concentrations of nitrogen and phosphorus in the water samples.

Ammonia:

Ammonia is a colourless gaseous alkaline compound of nitrogen and hydrogen. It is an inorganic form of nitrogen that is very soluble in water and can be used directly by plants. Natural sources of ammonia in surface waters include the decomposition of plant material and animal waste, weathering of clays, nitrogen fixation by clays and gas exchange with the atmosphere (pure ammonia being a gas present in air). Ammonia is found in water as NH_3 (free ammonia or dissolved un-ionized ammonia gas), and as NH_4^+ (ammonium ions). In water the two forms (NH_3 and NH_4^+) exist in equilibrium and their combined concentration is referred to as total ammonia. Analytical methods are not readily available for the measurement of free ammonia. Consequently, measures of ammonium ion concentration and equilibrium relationships are used to determine total ammonia (NH_3 + NH_4^+) concentration. Ammonium is a major component in fertilizers manures and sewage and significant amounts can enter water bodies in runoff from cultivated fields, rural residences and cottages. During application and post application, under the right conditions, volatilization significantly increases the ammonia concentration in the atmosphere.

The toxicity to aquatic organisms of ammonia in an aqueous solution is attributed to the un-ionized NH_3 component of total ammonia (Williamson 2001). Since it is difficult to measure free (un-ionized) ammonia concentrations in a solution, equilibrium relationships are used to estimate the free ammonia concentration from total ammonia measurements. Water temperature and pH regulate this equilibrium. As temperature and/or pH increases the percentage of free ammonia in total ammonia increases.

In unpolluted waters free ammonia and ammonium occur in small quantities usually less than 1.0 mg L^{-1} (Reid and Wood 1976) and pose little or no risk to aquatic organisms. Health Canada's maximum allowable concentration (MAC) of ammonia for drinking water is 2.0 mg L^{-1}. The Water Encyclopedia, page 472 'Guidelines for Evaluating Quality for

Aquatic Life', recommends that free ammonia (NH_3) should not exceed 0.5 mg L^{-1} (Van der Leeden *et al*. 1990).

Nitrates and Nitrites:

Nitrate (NO_3^-) and nitrite (NO_2^-) are two inorganic forms of nitrogen found in water. Along with ammonia they are an important sources of nitrogen for aquatic plants. Nitrates are used extensively as an ingredient in nitrogen fertilizers; thus runoff from cultivated land is a common source of anthropogenic nitrate. Nitrates can also form from sewage, animal waste, plant and animal decay, as well as leachate from igneous rock.

Nitrate ion concentrations in water bodies in western Canada rarely exceed 5.0 mg L^{-1} of nitrogen in nitrate form and are usually below 1.0 mg L^{-1} of nitrate nitrogen (Williamson 1988 and Van der Leeden *et al*. 1990, 422-423). Nitrate nitrogen ($N0_3^-$-N) refers to the mass of nitrogen in the nitrate form. According to Health Canada the maximum allowable concentration (MAC) for nitrates should not exceed 45.0 mg L^{-1} (Health Canada 1996). This corresponds to maximum allowable nitrate nitrogen ($N0_3^-$-N) concentration of 10.0 mg L^{-1} (Williamson 2001 and Van der Leeden *et al*., 443). The nitrate nitrogen concentration in unpolluted waters rarely exceeds 0.300 mg L^{-1} (Reid and Wood 1976).

Nitrite nitrogen ($N0_2^-$-N) is found at lower concentrations than nitrate nitrogen, approximately 0.001 mg L^{-1} in unpolluted waters (Reid and Wood 1976). Sources for nitrite include industrial effluent, sewage and animal waste. The MAC for nitrite is 3.2 mg L^{-1} of $N0_3^-$ or 1.0 mg L^{-1} for nitrite nitrogen (Williamson 2001 and Van der Leeden *et al*. 1990, 443).

Phosphorus:

Phosphorus is an essential nutrient for plant and animal life, and in many systems functions as the growth-limiting nutrient. Plants will readily utilize phosphorus; usually ninety percent or more of total phosphorus in impounded waters is organically bound (Hammer and MacKichan 1981). Phosphorus in natural waters commonly occurs as phosphate, which is classified as orthophosphate (PO_4^{-3}), polyphosphates (polymers of phosphoric acid), and organically bound phosphates, each existing in either a filterable (dissolved) or non-filterable (particulate) form. Filterable orthophosphate concentrations tend to be low in natural water bodies because living organisms assimilate phosphorus. Sources for phosphorous include agricultural run-off from fertilizers and animal feeds, and municipal wastewaters containing detergents and other commercial products. Total mean phosphorus concentration of most lakes ranges from 0.010 - 0.030 mg L^{-1} (Reid and Wood 1976). Total phosphorus (soluble phosphate phosphorus) concentration should not exceed 0.025 mg L^{-1} in any reservoir, lake or pond, or in any tributary at the point where it enters such bodies of water (Williamson 2001).

Methodology

Eight point-sampling sites were identified throughout the Octopus Creek-Ominnik Marsh sub-basin (Figure 1b), including a control site. The control site is located 7.5 km upstream (east) of Figure 1b, near the headwaters of Octopus Creek. The site receives drainage from wetlands, natural meadows, woodlots, and a few small agricultural fields. At the control site there is no recognized point sources of pollution or anthropogenic nutrients (Moore and McGinn 1997). Consequently, the control site is believed to represent natural background concentrations for ammonium, nitrate, nitrite, and soluble phosphate (Moore and McGinn 1997).

Ominnik Marsh 1 (O1) is a point-sampling site located just west of Highway 10, outside the Park gate but inside the Park boundary (Figure 1b). At this site Octopus Creek drainage enters Ominnik Marsh and nutrient concentrations are considered to represent the background values entering Ominnik Marsh. During the spring freshet in 1997, Moore and McGinn (1997) observed ammonia and soluble phosphate concentrations at this site that were an order of magnitude greater than those recorded at the control site. Point sources of anthropogenic nutrients to Octopus Creek include the Elkhorn Resort and the Triangle Riding Stables.

Ominnik Marsh 2 (O2) is located in Ominnik Marsh approximately 440 m further along the drainage path from O1 (Figure 1b). The site happens to be situated downstream from 12-inch diameter forcemain conduit conveying waste from the town of Wasagaming into the lagoon cell 1 (Figure 1b). The O2 site is accessed from the boardwalk and samples Octopus Creek flows distributed through the trunk region of Ominnik Marsh. It was hypothesized that the suspected leakage from the forcemain might augment the ammonia, nitrite and soluble orthophosphate concentrations in the O2 samples compared to the O1 concentrations. In addition it was postulated that lagoon discharge flows and associated nutrient concentrations would not show up in the O2 samples.

Ominnik Marsh 3 (O3) is located in a small open water area of floating vegetation, accessible by the Ominnik Marsh boardwalk (Figure 1b). It is positioned slightly to the north and east (upflow) of the locale where the lagoon discharge channel enters the marsh. This sampling site was selected to monitor the dispersion of lagoon releases and associated nutrient concentrations within the marsh.

Ominnik Marsh 4 (O4) is located at the exit point of the pond-marsh at metre 1 of the constructed channel that drains Ominnik Marsh westward into South Lake (Figure 1b). This sampling site monitors the dispersion of lagoon release flows and associated nutrient concentrations and could be used to compare influent nutrient concentrations with outflow concentrations (O1 versus O4). The same site was used by Moore and McGinn (1997) for monitoring nutrient uptake and sorption through the marsh in their 1996 study.

Ominnik Marsh 5 (O5) is located at the site that originally received the drainage from Octopus Creek prior to the construction of the western drainage channel (Figure 1b). Since the diversion of Octopus Creek, this locale serves as a boat marina and launch. A small bar has ponded the natural drainage from the marsh which now enters Clear Lake by way of a small channel. Near the bar the pond is approximately 1.0 m deep. The O5 site samples the flow through the outflow channel. It was anticipated that freshet overflows and nutrient concentrations moving through the system in the spring might appear in the O5 samples.

The Lagoon 1 (L1) sampling site is located at the head of the constructed ditch a few meters downstream of the concrete spillway and outlet where treated wastewater effluent is released from lagoon Cell 3 (Figure 1b).

The Lagoon 2 (L2) sampling site is located at the north end of the lagoon discharge ditch. The site is just upstream of the last “holding” dam in the excavated ditch which discharges into the marsh (Figure 1b).

Sampling and Analyses

Sampling began on May 6, 2002, although overnight temperatures frequently dropped to below zero degrees Celsius up until the end of the month. Point water samples were collected once every four days during the spring freshet (May 6 - May 20) and approximately once a week throughout June and July. Samples were taken near the surface. Following the single event lagoon discharge (June 20), point sampling occurred once every 24 hours for a seven-day period. As the nutrient levels declined in the late summer and fall, samples were routinely collected once a week.

Samples are analyzed on site for temperature, pH, conductivity, total dissolved solids and dissolved oxygen. Ammonium, nitrate, nitrite and soluble orthophosphate ion concentrations were measured in the laboratory within 24 hours of sampling. Portable ion specific colourmetric meters (Hach and Hanna Instruments) were used. Observations and results of total ammonia and soluble orthophosphate analyses are presented in this paper.

Observations and Results

Recorded seasonal nutrient concentrations support Moore and McGinn (1997) observation that high ammonium ion and soluble orthophosphate concentrations progress through the lower reaches of Octopus Creek and enter Ominnik Marsh during the spring freshet and following heavy rainfalls. The total ammonia concentrations recorded during the 2001 freshet (May 6-May 20) never exceeded 0.29 mg L^{-1}; soluble orthophosphate concentrations exceed the 0.025 mg L^{-1} Manitoba Surface Water Quality objective for waters in reservoirs, lakes, and ponds (Table 1).

A comparison of the O1 and O4 data (Figures 2a and 2b) indicate that excess runoff nutrients are taken up into the wetland system and/or are diluted to background levels by the end of May and that there is a successful uptake and reduction in nutrients with renewed vegetal growth in June and July.

The one notable exception to this trend is the nutrient concentrations measured at O2, which show a dramatic rise in ammonium ion and soluble orthophosphate concentrations as the recreational season progresses (Figures 2a and 2b). The O2 sampling site is located downstream of the forcemain that conveys wastewater from the townsite across the marsh into the lagoon Cell 1 (Figure 2a). Park managers (Rousseau, 2002) and consultants (MacLaren 1979 and Pratt 1991) had speculated that the pipe was leaking at some point. The nutrient concentration data recorded at the O2 sampling site support the hypothesis that the influent conduit is leaking. The seasonal over all mean soluble orthophosphate concentration (1. 03 mg L^{-1}) at the O2 site is at least twice the recorded concentration measured at the O1 site (0.43 mg L^{-1}) immediately upstream and at least three times the concentrations recorded downstream at sites O3 and O5 (0.29 and 0.18 mg L^{-1}, respectively)(Table 1). During the peak operational months (July and August) soluble orthophosphate concentrations exceeded 1.47 mg L^{-1}, recording a mean value of 1.65 mg L^{-1} (Table 1).

Total ammonia concentrations measured at O2 also support the leaking conduit theory. The seasonal mean ammonium ion concentration (0.33 mg L^{-1}) and the July-August mean (0.54 mg L^{-1}) measured at O2 was at least twice the value recorded at O1, O3 and O5 (Table 1).

It was expected that Ominnik Marsh 3 and 4 would reflect the elevated nutrient concentrations (ammonium ion and soluble orthophosphate)

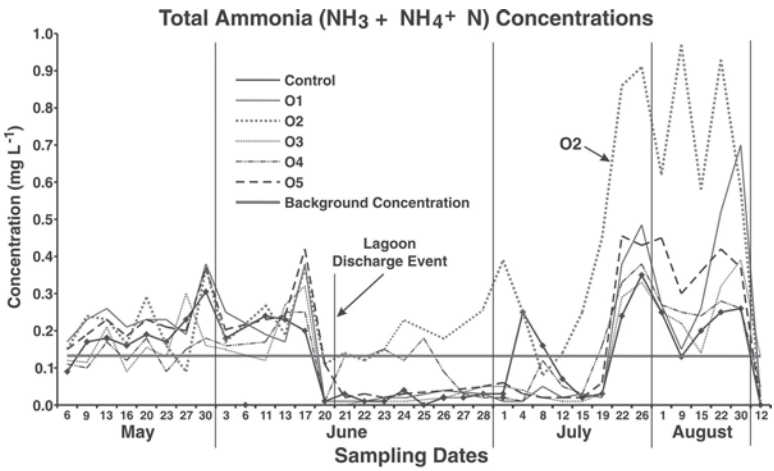

Figure 2a

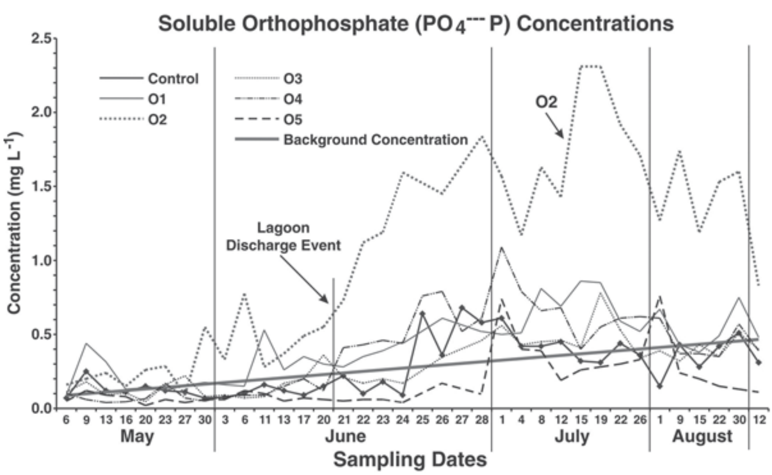

Figure 2b

Figure 2: a) *Total ammonia and* ***b)*** *soluble orthophosphate concentrations recorded at the Ominnik Marsh sampling sites, May-September 2002.*

Table 1: *Mean total ammonia and soluble orthophosphate concentrations recorded at the Ominnik Marsh sampling sites, May-September 2002.*

MEAN TOTAL AMMONIA CONCENTRATIONS

$NH_3 + NH_4^+$ N mg L^{-1}	MEAN mg L^{-1}	SD mg L^{-1}	May mg L^{-1}	June mg L^{-1}	July mg L^{-1}	Aug mg L^{-1}	Jul-Aug Mean mg L^{-1}
Control	0.136	0.105	0.187	0.078	0.144	0.218	0.172
OM 1	0.180	0.176	0.238	0.103	0.126	0.380	0.223
OM 2	0.330	0.265	0.212	0.199	0.416	0.736	0.539
OM 3	0.135	0.118	0.160	0.087	0.098	0.264	0.162
OM 4	0.150	0.095	0.138	0.130	0.138	0.260	0.185
OM 5	0.186	0.154	0.221	0.126	0.137	0.380	0.230
L1	0.264	0.196	0.201	0.411	0.185	0.100	0.152
L2	0.600	0.237	0.000	0.540	0.607	0.712	0.601

MEAN SOLUBLE ORTHOPHOSPHATE CONCENTRATIONS

PO_4^{---} P mg L^{-1}	MEAN mg L^{-1}	SD mg L^{-1}	May mg L^{-1}	June mg L^{-1}	July mg L^{-1}	Aug mg L^{-1}	Jul-Aug Mean mg L^{-1}
Control	0.277	0.183	0.125	0.253	0.416	0.358	0.394
OM 1	0.425	0.435	0.196	0.363	0.666	0.544	0.619
OM 2	1.026	1.051	0.242	0.894	1.756	1.466	1.645
OM 3	0.291	0.297	0.124	0.213	0.495	0.400	0.458
OM 4	0.384	0.391	0.075	0.368	0.675	0.454	0.590
OM 5	0.175	0.179	0.065	0.079	0.361	0.296	0.336
L1	1.953	1.953	0.501	2.485	1.819	1.068	1.530
L2	0.720	0.720	0.000	0.800	0.731	0.546	0.604

associated with the single event lagoon discharge on June 20, 2002. Flow patterns suggested that the discharge from the lagoon outlet channel would fan into the marsh and raise the nutrient concentrations at O3 and O4 (Figure 1b). While this appears to be the case at the O4 site, O3 does not record similar elevated nutrient concentrations.

Ammonia ion concentrations recorded at the O3 site remained at the relatively undetectable background level of 0.01 mg L^{-1} following the June 20 discharge (Figure 2a). Samples taken at the O4 site, however, recorded a tenfold increase in the ammonia ion concentration (0.12 mg L^{-1}) following the discharge event (Figure 2a).

Soluble orthophosphate ion concentration illustrates a similar pattern. At the O3 sampling site, soluble phosphate concentrations rose sharply from the background level of 0.20 mg L^{-1} to 0.36 mg L^{-1} on June 20, 2002 (Figure 2b). During the next four days, the soluble orthophosphate ion concentrations decreased to background levels. Similarly, soluble phosphate concentrations recorded at the O4 site doubled during the release. Concentrations, however, increased during the following week, recording a maximum concentration on June 26 of 0.79 mg L^{-1} (Figure 2b).

The nutrient concentration pattern illustrated during the lagoon discharge release suggests that the lagoon discharge does not fan out into the marsh but effectively short-circuits a large segment of the marsh system and flows directly from the lagoon channel exit point to the South Lake outlet channel (Figure 1b).

Conclusions and Recommendations

The objective of this study was to assess the efficiency of Ominnik Marsh, a natural wetland, in the uptake of nutrients from agricultural runoff and municipal wastewater. Seasonal observations in the Ominnik Marsh wetland indicate that there is a successful uptake and reduction in nutrients during the spring freshet; that the conduit leading into the sewage lagoons is leaking; and that a significant area of the marsh is being "short-circuited" during the annual lagoon discharge release. It is suggested that the leaking inflow forcemain be replaced and that the lagoon discharge channel be re-engineered to enter the marsh at least 150 m east of the present locale.

References

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