American Journal of Environmental Sciences 4 (2): 111-120, 2008
ISSN 1553-345X

Water Quality Assessment of A Constructed Wetland Treating Landfill Leachate and Industrial Park Runoff

[1]C. Galbrand, [2]I. G. Lemieux, [2]A. E. Ghaly, [1]R. Côté and [2]M. Verma
[1]School of Resources and Environmental Studies
[2]Department of Process Engineering and Applied Sciences, Dalhousie University, Halifax, Nova Scotia, Canada, B3J 2X4

Abstract: A surface flow constructed wetland was used for the treatment of landfill leachate and industrial park runoff. The wetland consisted of seven cells and was designed as a kidney shape to facilitate high retention time. The water quality was assessed for iron, manganese, phosphorus (orthophosphate), pH, dissolved oxygen (DO), nitrogen (ammonia, nitrate, nitrite and TKN), chemical oxygen demand (COD), total suspended solids (TSS) and total dissolved solids (TDS). The water quality parameters were measured at inlet, cell 1 (unvegetated area), cell 2, cell 3 and outlet to determine progress in treatment efficiency as water flow through the wetland. The reductions in iron, manganese, ammonia and TKN were 24.2 %, 6.7 %, 37 % and 5.9 %, respectively. The concentrations of nitrite, nitrate and DO were within the Canadian guidelines for the protection of aquatic animals. Increases in COD, TSS and TDS concentrations of 11.8 %, 5.2 % and 7.5 %, were observed at outlet mainly due to immature vegetation and underdeveloped biodiversity.

Keywords: Constructed wetland; Landfill leachate; Water quality; Iron; Manganese

INTRODUCTION

Approximately 14% of the world's wetlands are encountered in Canada where they occupy more than 1.2 million square kilometres[1]. It is difficult to provide a clear definition of a wetland as this unique ecosystem is extremely variable in nature and supports a wide range of hydrological and biological regimes[2]. However, wetlands can be broadly defined as aquatic ecosystems typically composed of a vegetation dominated by hydrophytes and characterized by shallow waters overlying saturated soils[3]. Through the interactions of the physical, biological and chemical functions unique to wetland ecosystems countless benefits are provided to both the human and natural world including: wildlife biodiversity, storm protection, water purification, commercial products, climate change control, recreation, education and culture[4]. In terms of both plant and animal wildlife, wetland ecosystems are among the top most productive environments on the planet[1,5]. They provide for the habitat needs of countless species of birds and mammals, as well as fish, amphibians, invertebrates, and microbial species that require aquatic environments for breeding, egg development, and larval growth[1,5,6].

Constructed wetlands are becoming increasingly common features emerging in landscapes across the globe. Although similar in appearance to natural wetland systems (especially marsh ecosystems), they are usually created in areas that would not naturally support such systems to facilitate contaminant or pollution removal from wastewater or runoff[5,7]. In essence, constructed wetlands are designed and constructed to capitalize on the intrinsic water quality amelioration functions of natural wetlands for human use and benefits. Fields[8] stated that constructed wetlands are built specifically for water quality improvement purposes, typically involving controlled outflow and a design that maximizes certain treatment functions. When designed properly, constructed wetlands are capable of effectively purifying wastewater using the same processes carried out in natural wetland habitats by vegetation, soils, and their associated microbial assemblages, but within a more controlled environment[6,7].

The exploitation of natural phytoremediation processes for the treatment of contaminants in constructed wetlands has become an increasingly popular practice in the last few decades and plants with significant phytoremediative capabilities are being increasingly utilized as remediative tools in constructed

Corresponding author: A. E. Ghaly, Professor, Department of Process Engineering and Applied Science, Dalhousie University, Halifax, Nova Scotia, Canada, B3J 2X4

wetlands for the treatment of wastewaters contaminated with nutrients (i.e. N, P, metals), pesticides, solvents, explosives, hydrocarbons, and radionuclides[9]. Many wetland plants are showing the capacity to withstand relatively high or toxic concentrations of contaminants[10]. It is often argued that one of the principal functions of vegetation in constructed wetland systems is to facilitate ideal environments for microbial populations which are primarily responsible for the breakdown of organic matter in wetland environments[11,12]. They do so by providing oxygenated zones around their roots and capillaries (rhizospheres) and by providing surface areas for microbial attachment for forming biofilms[7,13]. The aerobic microorganisms often in turn, enhance phytoremediation processes through symbiotic relationships which enhance metal uptake by roots[14]. Another important treatment process common to all wetland systems is the physical settling of suspended particulate matter such as silt or clay, or fine particles of organic and/or inorganic matter. Suspended matter can severely degrade water quality and habitat for a host of reasons. Pollutants such as hydrocarbons, fixed forms of nitrogen and phosphorus, heavy metals, bacteria and viruses often bind to these particulates. When effective particulate settling is facilitated, toxicity is reduced as the pollutants settle to the bottom of the wetland along with the suspended solids they are absorbed to[6]. The subsequent oxidation or reduction of these settled particulates then releases soluble forms of the pollutants to the wetland environment, which become available for adsorption or removal by soil, microbial populations and wetland plants[15].

To remediate the effects of landfill leachate coming from the Burnside Drive landfill located in Burnside Industrial Park, Dartmouth, Nova Scotia and impacting the natural Wright's Brook ecosystem, a surface flow engineered treatment wetland was designed with the intended purpose of purifying the influent before discharging it back into the brook. The purpose of the present study was to use chemical water quality analyses to evaluate the efficiency of the Burnside constructed wetland in treating landfill leachate and runoff from Burnside Industrial Park.

BURNSIDE LANDFILL AND CONSTRUCTED WETLAND

The Burnside Drive landfill (now decommissioned and currently known as the Don Bayer Sports Field) is located near the northern boundary of the Burnside Industrial Park, at the corner of Akerley Boulevard and Burnside Drive (Fig. 1). This 13.4 acre open waste disposal site had accepted municipal, agricultural and industrial wastes, old tires, abandoned cars and demolition wastes (all of which were reportedly burned to reduce volume) from the Dartmouth Municipality. The dumpsite was graded, compacted and covered with two feet of soil upon closure, as was common in the day, with no regard to pollution control or aesthetics[16]. Since its closure in the 1970's, leachate from the decomposing waste beneath the sports field, as well as stormwater draining from a 55.1 hectare watershed surrounding the landfill ultimately discharge into Wright's Brook through stormwater ditches located on the western, northern and eastern borders of the sports field. Wright's Brook traverses 4.6 km, passing through Enchanted and Flat lakes before discharging into the Bedford Basin of the Halifax Harbour. Water quality analyses (Tables 1 and 2) indicated that the leachate wastewater contained elevated levels of iron, manganese, ammonia, and suspended solids. This wastewater discharge has had visible adverse effects on Wright's Brook and the associated ecosystems.

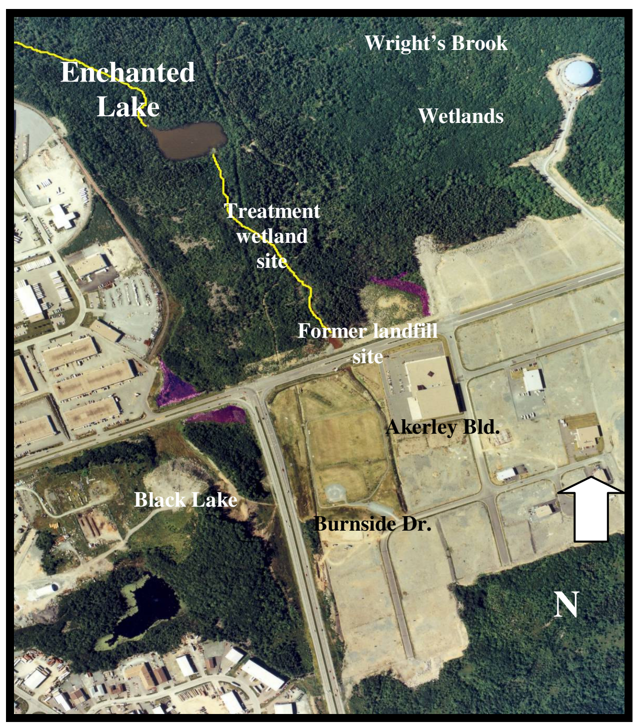

Fig. 1: Aerial photograph of the northern boundary of the Burnside Industrial Park (Scale 1:10000)[17]

Table 1: Elements and components in samples taken from the ditches adjacent to Don Bayer Sports Field[16,18-20]

Parameter	Concentration* (μg/L)	Guideline
Elements		
Aluminum	10.00	5-100[18]
Antimony	0.00	20[19]
Barium	0.00	1000[19]
Beryllium	0.00	11[20]
Bismuth	0.00	NGA
Boron	57.33	200[20]
Cadmium	0.00	0.012[18]
Calcium	43300.00	NGA
Chloride	75370.00	NGA
Chromium	0.67	1-8.9[18]
Cobalt	2.00	NGA
Copper	0.00	2-4[18]
Iron	6166.67	300[18]
Lead	0.00	1-7[18]
Magnesium	4000.00	NGA
Manganese	1800.00	1000-2000[19]
Molybdenum	0.00	73[18]
Nickel	0.00	25-150[18]
Phosphorus	0.00	NGA
Potassium	2100.00	NGA
Selenium	0.00	1[18]
Silver	0.00	0.1[18]
Sodium	41200.00	NGA
Strontium	190.00	NGA
Thallium	0.00	0.8[18]
Titanium	0.00	NGA
Uranium	0.00	NGA
Vanadium	0.00	NGA
Zinc	6.67	30[18]
Compounds		
Ammonia (as N)	1258.18	NGA
Bicarbonate (as $CaCO_3$)	94281.00	NGA
Carbonate (as $CaCO_3$)	181.00	NGA
Nitrate (as N)	0.00	0.6[18]
Nitrite	0.00	NGA
Nitrate + Nitrite (as N)	0.00	NGA
Ortho Phosphate (as P)	0.00	NGA
Sulfate	6330.00	NGA

*values are the average of four measurements.
NGA = No guideline available.

Table 2: Water quality parameters of samples taken from the Don Bayer Sports Field stormwater ditches in October, 2000[16,18]

Parameter	Concentration* (μg/L)	Guideline
Water quality parameters		
Alkalinity (as $CaCO_3$) (mg/L)	95000.00	NGA
Color (TUC)	0.00	NGA
Conductance (μS/cm)	478.67	NGA
Dissolved Organic Carbon (mg/L)	2300.00	NGA
Hardness (as $CaCO_3$) (mg/L)	124670.00	NGA
pH	7.10	<6.5->9.0[19]
Reactive Silica (as SiO_2) (mg/L)	4330.00	NGA
Saturation pH @4 °C	8.25	NGA
Saturation pH @20 °C	7.85	NGA
TDS (Calculated) (mg/L)	235330.00	NGA
Turbidity (NTU)	3.30	NGA

* values are the average of four measurements.
NGA = No guideline available.

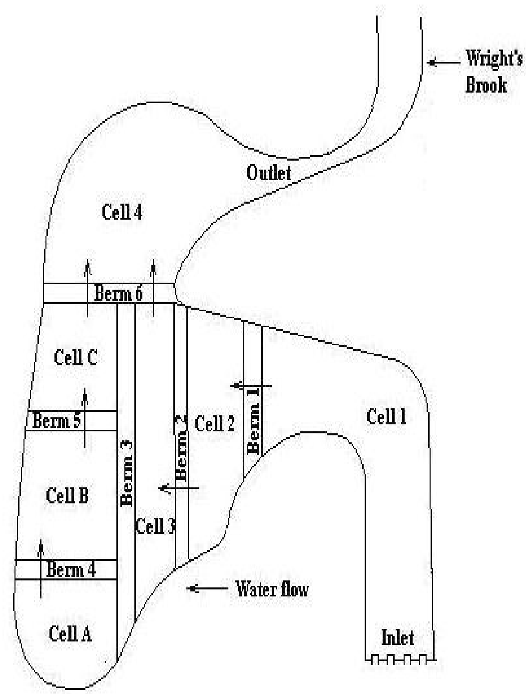

Fig. 2: Burnside treatment wetland diagram

To address the problem, a seven celled surface flow engineered treatment wetland (approximately 5000m^2 in area) was constructed in the late fall of 2001 and spring of 2002 (Fig. 2). The wetland consists of a deep-water (greater than 1m) system separated by shallow interior earth berms 2 m in width, which were constructed in the marshy area receiving the leachate wastewaters. The wetland was designed to curve in a kidney shape in order to increase the length to width ratio to about 5 to 1. The first wetland cell was deeper than the others (approximately 1.5 m) in order to facilitate the settling and accumulation of suspended solids. The till of the area was found to support 15 - 25% silt/clay with dense to very dense consistency and a permeability of 10^{-4} to 10^{-6} cm/sec[21]. Subsequently, it was concluded that compaction of the area substrates would provide adequate lining for the site. The natural gravitational flow facilitated by the site topography negated the need for any mechanical infrastructure such as pumps.

WATER SAMPLING PROCEDURE

Bi-weekly sampling of the water quality of the site commenced in May, 2003 and went on through September, 2003. Water quality samples were collected from Cell 2, 3 and the outlet and compared to baseline influent concentrations. The water quality between

Cells 2 and 3 were compared in order to gauge some semblance of purification progress from Cell 1 to Cell 3. The water quality of the outlet leading from Cell 4 was monitored and compared to influent concentrations to gauge the effectiveness of the entire system. Samples were collected on varying days to ensure samples taken were representative.

WATER QUALITY ANALYSES

Water samples collected from May to September 2003 were analyzed for iron, manganese, phosphorus (orthophosphate), pH, dissolved oxygen (DO), nitrogen (ammonia, nitrate, nitrite and TKN), chemical oxygen demand (COD), total suspended solids (TSS) and total dissolved solids (TDS). Nitrogen, pH, COD, TSS, TDS and orthophosphate were analyzed in the Biotechnology Laboratory at Dalhousie University according to the procedures described in Standard Methods for the Examination of Water and Wastewater[22]. Iron, manganese, and orthophosphate were analyzed in the Mineral Engineering Laboratory at Dalhousie University. Iron and manganese concentrations were determined using Flame Atomic Absorption (Varian SpectrAA, Model # 55B, Varian Inc., Mulgrave, Victoria, Australia) with a detection limit of 1 ppm. The accuracy of the analysis was verified using reference standards from CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL).

RESULTS AND DISCUSSION

The water quality analyses were conducted bi-weekly from May 24, 2003 to September 11, 2003. The iron, manganese, orthophosphate and nitrogen (nitrite, nitrate, ammonia and TKN) results are presented in Table 3. The total suspended solids (TSS), total disolved solids (TDS), chemical oxygen demand (COD), dissolved oxygen (DO) and pH are presented in Table 4.

Iron: Iron is an essential micronutrient element required by both plants and wildlife at significant concentrations, as it is a vital part of metabolic enzyme formation and the oxygen transport mechanism in the blood (haemoglobin) of all vertebrate and some invertebrate animals[23]. Iron occurs as one of the principle chemical constituents in water where it is present at concentrations typically less than 500 µg/L[24,25]. The iron concentrations observed in the treatment wetland decreased as the water flowed through the treatment wetland cells. However, in 6 of the sampling events, the iron concentration actually increased in Cell 3. The most significant factor which likely contributed to the increased iron concentrations observed in Cell 3 was inadequate settling occurring in Cells 1 and 2 due to significant breaks in the vegetated berms which reduced retention times. The lowest and highest iron effluent concentrations observed were 0.67 mg/L and 9.38 mg/L with an average of 5.17 mg/L. Although iron removal did occur (average of 24.2% reduction), the iron concentrations observed in the outlet effluent never dropped below the Canadian Council of Ministers of Environment (CCME) Guideline of 0.3 mg/L for the Protection of Freshwater Aquatic Life[18].

Manganese: Manganese is an essential micronutrient forming a vital part of the enzyme systems that metabolise proteins and energy in all animals. In surface water, natural levels are usually less than 0.2 mg/L and rarely exceed 1.0 mg/L, but it can be naturally present at levels as high as 40 mg/L[19]. In general, manganese is known to be lightly to

Table 3: Iron, manganese, orthophosphate and nitrogen compounds in the treatment wetland

Date	Location	Fe (mg/L)	Mn (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	NH_4^+ (mg/L)	TKN (mg/L)	PO_4 (mg/L)
May 24	Cell 1*	10.55	1.61	Nd	5.65	Nd	Nd	Nd
	Cell 2	5.62	1.42	Nd	2.39	0.50	4.00	Nd
	Cell 3	7.16	1.69	Nd	6.88	Nd	9.00	0.01
	Outlet	7.00	1.78	0.01	7.10	Nd	3.00	0.01
June 1	Cell 1*	11.05	1.48	0.02	4.49	0.50	7.50	Nd
	Cell 2	13.34	1.73	0.02	3.62	1.75	4.00	Nd
	Cell 3	7.37	1.76	0.01	2.46	0.25	9.25	Nd
	Outlet	9.38	1.78	0.01	6.74	Nd	4.25	Nd
June 18	Cell 1*	5.50	1.10	Nd	Nd	0.47	0.47	Nd
	Cell 2	5.73	1.18	0.02	7.03	Nd	4.25	Nd
	Cell 3	1.40	0.18	0.03	3.12	Nd	11.75	Nd
	Outlet	0.67	0.50	Nd	3.04	Nd	4.75	Nd
June 30	Cell 2	3.82	1.72	Nd	1.45	Nd	3.50	Nd
	Cell 3	5.96	1.50	Nd	2.10	Nd	19.00	Nd
	Outlet	3.75	1.76	0.02	2.90	Nd	5.25	Nd
July 21	Cell 2	7.69	1.45	Nd	5.73	3.00	4.25	0.03
	Cell 3	10.89	3.81	0.02	4.42	0.25	5.25	0.01
	Outlet	2.51	0.73	0.59	4.28	0.25	6.50	0.01
Aug. 6	Cell 2	1.05	0.44	0.24	2.46	0.25	1.25	Nd
	Cell 3	3.13	0.40	0.04	3.91	0.25	4.00	0.03
	Outlet	1.84	0.42	0.07	5.29	0.25	5.00	0.01
Aug. 25	Cell 2	8.68	2.12	Nd	1.88	2.00	7.00	Nd
	Cell 3	13.88	2.32	Nd	1.59	1.50	5.25	0.03
	Outlet	7.52	2.55	0.01	1.96	0.25	0.50	Nd
Sept. 11	Cell 2	10.43	1.37	0.03	1.38	0.25	2.00	0.01
	Cell 3	13.98	1.36	0.01	1.16	1.50	5.00	Nd
	Outlet	8.65	1.52	0.01	1.74	1.50	4.00	Nd

* Concentrations indicative of inlet concentrations as water sample taken in proximity to inlet in unvegetated area of Cell 1.
Nd = Not detected; TKN = Total Kjeldahl Nitrogen

moderately toxic to aquatic organisms in excessive amounts. Several factors such as salinity, pH, and the presence of other contaminants can affect the toxicity of manganese in waterbodies. However, water hardness appears to be the most influential factor affecting manganese toxicity. As hardness increases, manganese toxicity decreases[19,24]. The manganese concentrations in the wetland water generally did not decrease as the water flowed through the treatment wetland cells. However, the average reduction in manganese in the constructed wetland over the sampling period is slightly positive with a value of 6.7%. Although the CCME currently does not publish water quality guidelines for manganese, the British Columbian Ministry of Environment, Land and Parks (BCMELP)[19] have published acute and chronic manganese guidelines for the protection of freshwater aquatic life. The manganese concentrations observed in the outlet effluent exceeded the BCMELP acute guideline[19] of 1.914 mg/L on August 22nd and exceeded the BCMELP chronic guideline of 1.15 mg/L on May 23, June 1, June 30, August 25 and September 11.

NH_4^+: Ammonium is fairly harmless, whereas ammonia (the most toxic by-product of the nitrogen cycle) can be deadly at high levels, especially to fish. Ammonium and ammonia shift in equilibrium with each other according to pH. At the pH of 8.5 or greater, ammonia will be the more dominant form. Increased water temperatures also harbour the unionized form.

Consequently, as pH and/or temperature increase, the proportion of un-ionized ammonia increases, resulting in increased toxicity[26]. Chronic effects of exposure to ammonia include damage to gill membranes, preventing fish from carrying on normal respiration, alteration of metabolisms or increases in body pH. Ammonia can cause osmoregulatory damage and is an irritant to delicate tissues such as the internal organs. Even trace amounts of ammonia can stress fish, suppressing the immune system[27]. In most sampling events ammonia decreased as the water flowed through the constructed wetland (average reduction of 37.0%) and was actually not detected in 37% of the samples analysed.

NO_2^-: In aerobic conditions, most ammonium is oxidized to nitrite by *Nitrosomonas* bacteria[24]. Nitrite is very unstable and is oxidized to nitrate by *Nitrobacter* bacteria. It has been termed an invisible killer as it has no visible affect on the water column, but is often toxic to fish at low concentrations. The presence of excessive nitrite also depletes dissolved oxygen in the water column as the oxidation of nitrite to nitrate consumes oxygen[25]. The nitrite water quality guideline established by CCME for the protection of freshwater life is 0.06 mg/L[18]. Overall, the nitrite levels observed in the treatment wetland were minimal until the July 21st sampling date, where the nitrite concentration in the outlet was 0.59 mg/L, which exceeds the CCME Guidelines[18]. The high nitrite levels observed in the outlet on the July 21st sampling date may be correlated with the stagnation observed in the site that day as nitrite can persist in waters which suffer from oxygen depletion[25].

NO_3^-: Nitrate is an inorganic compound of nitrogen which is bioavailable for plant uptake and is essential to plant growth[24,28]. Natural levels of nitrate in waterbodies are typically lower than 1 mg/L. Where nitrite and ammonia are toxic, nitrate is virtually harmless, with direct toxic effects typically not observed until concentrations greater than 1000 mg/L[25]. However, if phosphorus concentrations are sufficient, high nitrate content in waters can increase the severity of eutrophication, which can have chronic effects on aquatic life. The nitrate water quality guideline established by CCME for the protection of aquatic life[18] is 13 mg/L. Overall, the nitrate levels observed in the treatment wetland were minimal. In seven out of the eight sampling events there was an increase in the nitrate concentration as water flowed through the constructed wetland.

TKN: Total Kjeldahl Nitrogen (TKN) is the sum of both ammonia and organic nitrogen. The combination of the organic nitrogen and all forms of inorganic nitrogen (NH_4, NO_3 and NO_2) make up total nitrogen. Natural levels of TKN in waterbodies are typically less than 2.0 mg/L. There are no specific TKN water quality guidelines for the protection of aquatic life. However, concentrations above 3 mg/L are considered excessive in natural waters[29].

Table 4: Dissolved oxygen, chemical oxygen demand, total suspended solids, total dissolved solids and pH in the treatment wetland

Date	Location	TSS (mg/L)	TDS (mg/L)	COD (mg/L)	DO (mg/L)	pH
May 24	Cell 1*	365	305	689	6.2	7.2
	Cell 2	390	376	546	6.1	7.3
	Cell 3	615	611	754	6.2	7.1
	Outlet	490	236	650	5.7	7.6
June 1	Cell 1*	460	247	351	4.3	7.5
	Cell 2	405	395	728	4.7	7.5
	Cell 3	410	388	676	4.3	7.6
	Outlet	513	462	884	4.0	7.6
June 18	Cell 1*	NA	255	NA	NA	6.7
	Cell 2	845	762	741	5.0	7.2
	Cell 3	970	883	806	6.4	7.5
	Outlet	893	871	676	4.5	7.6
June 30	Cell 2	400	345	637	4.2	7.6
	Cell 3	758	500	858	2.5	6.9
	Outlet	518	493	1027	3.9	7.5
July 21	Cell 2	523	509	1092	4.1	7.2
	Cell 3	605	576	1079	3.5	6.9
	Outlet	513	276	1001	4.4	7.19
Aug. 6	Cell 2	375	115	897	4.1	7.1
	Cell 3	365	124	1131	4.3	6.8
	Outlet	370	136	1066	4.4	6.8
Aug. 25	Cell 2	525	440	1209	4.1	6.8
	Cell 3	515	383	1053	4.4	6.7
	Outlet	550	356	858	3.7	7.7
Sept. 11	Cell 2	535	407	741	4.6	7.4
	Cell 3	410	306	1053	4.4	7.0
	Outlet	410	334	1092	4.6	6.7

*Concentrations indicative of inlet concentrations as water sample taken in proximity to inlet in unvegetated area of Cell 1.
NA = Not analysed
DO = Dissolved Oxygen
COD = Chemical Oxygen Demand
TDS = Total Dissolved Solids
TSS = Total Suspended Solids

The TKN concentrations observed in the treatment site ranged from 0.0 to 19.0 mg/L, with an average of 4.98 mg/L. The TKN did not decrease as the waters moved through the cells (average reduction of 5.9%). Concentrations were notably high in Cell 3 for the May 24th to June 30th sampling dates. The organic forms of nitrogen measured in TKN analyses include nitrogen that is bound to algae. Commonly, sites which support prolific algae contain elevated levels of TKN[24,25]. Algal blooms were developing and decaying in the treatment site during the period when TKN levels in the water samples appeared exceptionally high.

Phosphorus: Phosphorus is an essential macronutrient that is a limiting factor to plant growth. It is essential to all life as a component of nucleic acids and a universal energy molecule[30]. In excess, phosphorus triggers eutrophic conditions which involve the prolific growth of algal and other aquatic plants. Algal growths can have lethal impacts on aquatic life and, at high concentrations, can be toxic. The absorption of sunlight by algal blooms reduces the amount of light reaching aquatic plants in sediment. If an algal bloom is prolonged, aquatic plants will die. Large amounts of decaying algae result in the consummation of large quantities of oxygen by the bacteria and fungi that break it down. This results in the dramatic reduction of oxygen concentrations in the water column, particularly at night. This reduction affects invertebrate predators with high oxygen requirements. The subsequent lack of predators results in critical disruptions in the food chain and increases of nuisance species such as mosquitoes. Algal blooms can also contain toxic strains of blue-green algae which may kill birds, domestic animals, aquatic macroinvertebrates and even humans if consumed[30-32]. In waters, phosphorus is often biologically unavailable as it binds readily to particles. Soluble phosphorus which is available for uptake is called orthophosphate. The orthophosphate concentrations in the waters of Cell 1, 2, 3, and the outlet were minimal, fluctuating between undetectable levels to 0.03 mg/L.

TSS: Total suspended solids (TSS) include all particles suspended in water that will not pass through a filter. Abundant suspended solids such as clay and silt, fine particles of organic matter, inorganic particulates (such as iron), soluble coloured compounds and phytoplankton can result in: (a) decreased light penetration in water reducing photosynthesis of aqwatic plants, (b) decreased water depth due to sediment build-up, (c) smothering of aquatic vegetation, habitat and food, (d) smothering of macro and micro-organisms, larva, eggs and the clogging of fish gills, (e) reduced efficiency of predation by visual hunters, and (f) increased absorbed heat by the water which results in lowering dissolved oxygen, facilitating parasite and disease growth and increasing the toxicity of ammonia[24,25]. There are no specific CCME Water Quality Guidelines for TSS. The TSS concentrations in Cell 2, Cell 3 and the outlet remained relatively stable over the course of the sampling season, showing no improvement as the site vegetation matured and as the water flowed through the constructed wetland (average increase of 5,2%). The most likely explanation for this result is the ineffective settling due to the breaks in the wetland berms which caused dramatic reductions in retention times.

TDS: Total dissolved solids (TDS) is a measure of the concentration of dissolved constituents in water, which commonly include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is essential nutrients for aquatic life. Changes in TDS concentrations can be harmful to aquatic organisms by affecting the density of water. Excessive TDS can reduce water clarity, hinder photosynthesis, and lead to increased water temperatures[24,25]. There are no specific CCME Water Quality Guidelines for TDS. The TDS concentrations in Cell 2, Cell 3 and the outlet remained relatively stable over the course of the sampling season, showing no improvement as water went from the inlet to the outlet (average increase of 7.5%), and as site vegetation matured. The most likely explanation for this result is reductions in retention times experienced by the site as a result of breaks in the berms.

COD: Chemical oxygen demand (COD) is a measure of the amount of oxygen required to chemically oxidize reduced minerals and organic matter. In general, the greater the COD value in water, the more oxygen the influent demands from the waterbody, thus resulting in depleted dissolved oxygen which is essential to the metabolism of all aerobic aquatic organisms[33-35]. There are no COD guidelines established by CCME for the protection of aquatic life. However, the COD concentrations observed in the site are notably higher (averaging about 857.5 mg/L) than the COD concentrations of domestic sewage. COD concentrations did not appear to decrease as the water flowed through the site (average increase of 11.8%).

DO: Dissolved oxygen (DO) is one of the most fundamental parameters in water, as it is essential to the metabolism of all aerobic aquatic organisms. It is added to the water column via photosynthesizing plants and stream flow aeration, and is consumed from the waterbody by bacterial, plant and animal respiration, decaying plants and organisms, and chemical oxidation[35]. The CCME guideline for dissolved oxygen for the protection of freshwater aquatic life is between 5.5 and 6.0 mg/L for warm water ecosystems such as the treatment wetland[18]. With the exception of the May 24th sampling date, virtually all samples analysed were below the minimum guideline of 5.5 mg/L. The dissolved oxygen concentrations in the treatment wetland water generally decreased as the water flowed through the treatment wetland cells until late June when the concentrations appeared to drop slightly and level off. This was unexpected as it had been assumed that as the water flowed through the cells it would become more oxygenated as a result of the growing vegetation and water purification. Low dissolved oxygen levels are often the result of organic pollution[25]. In seeing that colder waters have greater oxygen capacity, the decreasing dissolved oxygen concentrations may be correlated with water temperatures which were greater than 15°C for the June 30 to September sampling dates. The low dissolved oxygen concentrations may also be explained by the abundant iron ochre observed in the site as the physical oxidation of iron consumes oxygen[30-36].

pH: Exceedances of pH guidelines have been associated with many adverse effects. However, one of the most significant impacts of pH in waterbodies is the effect that it has on the solubility and thus the bioavailability of other substances such as iron, manganese and ammonia[37]. The pH of the treatment wetland remained relatively neutral, fluctuating between 6.7 and 7.7 with an average of 7.0. No pH levels were observed above or bellow the CCME pH guidelines for the protection of freshwater aquatic life of less than 6.5 and greater than 9.0[18]. No change of the pH was observed as the waters flowed through the site (average increase of 1.9%), although a general decrease in pH appears to have occurred over the course of the summer as the system matured. No correlation was observed between the metal levels and pH levels, rain events, or any other constituent.

CONCLUSIONS

The water quality of the constructed wetland was poor due to immature ecosystem. The reduced water retention experienced by the system which resulted from breaks in the berms destabilized the flora and fauna of individual cells. The high iron and manganese contents adversely affected the trophic structure and had cascading effects on the overall system. The constructed wetland was inefficient in limiting iron, manganese and nitrogen levels in the present state. Meanwhile, increases in COD, TSS and TDS concentrations were an indicator of partial degradation of particulate and dissolved organic matter and would require either higher retention time or higher density of vegetation. It is expected that as the vegetation will mature and spread, removal efficiency will increase due to enhanced biological activity. Furthermore, dissolved oxygen levels will increase and more contaminants can be absorbed through phytoremediative processes.

ACKNOWLEDGEMENTS

This study was made possible through the financial support of the ELJB Foundation of Montréal and the TD Bank Friends of the Environment Foundation of Toronto.

REFERENCES

1. NRC. 2004. The Atlas of Canada: Wetlands. Natural Resources Canada [online] Available: http://atlas.nrcan.gc.ca/site/english/learningresources/theme_modules/wetlands/index.html#facts [2007, June 12]
2. Rader, R. B., D. P. Batzer and S. A. Wissinger. 2001. Bioassessment and Management of North American Freshwater Wetlands. John Wiley & Sons, New York, New York
3. Batzer, D. P., R. B. Rader and S. A. Wissinger. 1999. Invertebrates in Freshwater Wetlands of North America : Ecology and Management. John Wiley & Sons, New York, New York
4. RCW. 2002. Background papers on wetland values and functions: Reservoirs of biodiversity. Ramsar Convention on Wetlands, Gland, Switzerland [online] Available: http://www.ramsar.org/info/values_biodiversity_e.htm [2007, 24 July]
5. Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands, third edition. John Wiley & Sons, New York Osmond, D. L., D. E. Line, J. A. Gale, R. W. Gannon, C. B. Knott, K. A. Bartenhagen,, M. H. Turner, S. W. Coffey, J. Spooner, J. Wells, J. C. Walker, L. L. Hargrove, M. A. Foster, P. D. Robillard, and D. W. Lehning. 1995. WATERSHEDSS: Water, Soil and Hydro-Environmental Decision Support System [online]Available: http://www.water.ncsu.edu/watershedss/ [2007, 24 July]

6. Hammer, D. A. 1992. Creating Freshwater Wetlands. Lewis Publishers, London
7. Fields, S. 1993. Regulations and policies relating to the use of wetlands for nonpoint source pollution control. Created and Natural Wetlands for Controlling Nonpoint Source Pollution, R.K. Olson (ed.), CRC Press, Boca Raton, Florida. Pp. 151-158
8. Schnoor, J. L. 2002. Phytoremediation of soil and groundwater. Evaluation Report # TE-02-01. Center for Global and Regional Environmental Research and the Department of Civil and Environmental Engineering, University of Iowa for the Ground-Water Remediation Technologies Analysis Center Technology, Iowa City, Iowa
9. USEPA. 2000. Introduction to phytoremediation. Technical Report # EPA/600/R-99/107. United States Environmental Protection Agency, Washington, D.C. [online]Available: http://www.clu-in.org/download/remed/introphyto.pdf [2002, 28 October].
10. FRTR. 1998. Remediation technologies screening matrix and reference guide version 3.0. Federal Remediation Technologies Roundtable, Aberdeen Proving Ground, Maryland [online].Available:http://www.frtr.gov/matrix2 [2002, 4 December]
11. USEPA. 1996. A citizen's guide to bioremediation. Techinical Report # EPA 542-F-01-001. United States Environmental Protection Agency, Washington, D.C. [online] Available: http://www.epa.gov./swertio1/download/citizens/bioremediation.pdf [2002, 28 October]
12. Tousignant, E., O. Fankhauser and S. Hurd. 1999. Guidance manual for the construction and operations of constructed wetlands for rural applications in Ontario. Stantec Consulting Ltd, R&TT, Alfred College, University of Guelph, Guelph, Ontario [online]. Available: http://res2.agr.ca/initiatives/manurenet/download/wetlands_manual.pdf [2002, 8 November]
13. Lasat, M. 2000. The use of plants for the removal of toxic metals from contaminated soil. American Association for the Advancement of Science [online].Available: http://www.clu-in.org/download/remed/lasat.pdf [2002, 3 March].
14. USEPA. 2000. Wastewater technology fact sheet: Subsurface flow wetlands. Technical Report # EPA 832-F-00-023. United States Environmental Protection Agency, Washington, D.C. [online] Available: http://www.epa.gov/npdes/pubs/wetlands-subsurface_flow.pdf [2002, 19 October].
15. Ghaly, A. E. and R. Côté. 2001. Engineered wetland technology for treatment of industrial park contaminants: Technical report. Dalhousie University, Halifax, Nova Scotia.
16. HLIS. 1992. Aerial photograph 183, 92329-7. 92-07-16, 11D-12, 111-65. Halifax Land Information Services, Government of Nova Scotia, Halifax, Nova Scotia.
17. CCME. 2006. Canadian water quality guidelines for the protection of aquatic life: summary table. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba [online].Available: http://www.ccme.ca/assets/pdf/ceqg_aql_smrytbl_e_6.0.1.pdf [2007, 24 July].
18. BCMELP. 2001. Ambient water quality guidelines for manganese. Overview Report. Prepared pursuant to Section 2(e) of the Environment Management Act, 1981. British Columbian Ministry of Environment, Land and Parks, Vancouver, British Columbia [online]. Available: http://www.env.gov.bc.ca/wat/wq/BCguidelines/manganese/manganese.html [2007, 24 July]
19. OMEE. 1994. Water management: Policies, guidelines and provincial water quality objectives. Technical Report # 3303e, Ontario Ministry of Environment and Energy, Toronto, Ontario [online].Available: http://www.ene.gov.on.ca/envision/gp/3303e.pdf [2007, August 16].
20. Lewis, M. C. F., B. B. Taylor, R. R. Stea, G. G. J. Fader, R. J. Horme, S. G. MacNeil and J. G. Moore. 1998. Earth science and engineering: Urban development in the metropolitan Halifax region. Minerals and Energy Branch, Nova Scotia Department of Natural Ressources, Halifax, Nova Scotia.
21. APHA. 2002. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Baltimore, Maryland.
22. King, B. R., G. M. Long, and J. K. Sheldon. 1992. Practical Environmental Bioremediation. Lewis Publishers, Boca Raton, Florida
23. Boulton, A. J. and M. A. Brock. 1999. Australian Freshwater Ecology: Processes and Management. Cooperative Research Centre for Freshwater Ecology and Gleneagles Publishing, Canberra, Australia

24. Mason, C. F. 1998. Biology of Freshwater Pollution, third edition. Addison Wesley Longman Limited, London, England
25. USEPA. 1995. Ecological restoration: Linking restoration practices to water quality parameters. Technical Report # EPA 841-F-95-007. United States Environmental Protection Agency, Washington, D.C. [online]. Available:http://www.epa.gov/OWOW/NPS/Ecology/chap3.html [2002, 19 September].
26. USEPA. 1998. Update of ambient water quality criteria for ammonia. Technical Report # EPA 822-R-98-008. United States Environmental Protection Agency, Washington, D.C. [online].Available: http://www.epa.gov/ost/standards/nh3_rpt.pdf [2001, 29 October].
27. Freedman, B. 2001. Agriculture and environment. In: B. Freedman (ed). Environmental Science: A Canadian Perspective, second edition. Pearson Education Canada Inc., Toronto, Ontario.
28. Cameron, K, C. Madramootoo, A. Crolla, and C. Kinsley. 2003. Pollutant removal from municipal sewage lagoon effluents with a free-surface wetland. Water Research, 37: 2803–2812.
29. Lee, G. F. and A. Jones-Lee. 2001.Assessing the water quality impacts of phosphorus in runoff from agricultural land. Proceedings of American Chemical Society Agro Division Symposium: Environmental Impact of Fertilizer Products in Soil, Air and Water. American Chemical Society, Chicago, Illinois.
30. Sharpley, A. N., S. C. Chapra, and R. Wedepohl. 1994. Managing agricultural phosphorus for protection of surface waters: Issues and options. Journal of Environmental Quality, 23: 437-451.
31. Vollenweider, R. A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Technical Report # DAS/CSI/68.27. Organization for Economic Cooperation and Development, Paris, France
32. Silva, A. C., M. Dezotti, G. L. Sant'Anna Jr. 2004. Treatment and detoxication of a sanitary landfill leachate. Chemosphere, 55(2): 207-214
33. Cusso, R., K. Haarstad, M. C. Lavagnolo and P. Littarru. 2001. Removal of municipal solid waste COD and NH4–N byphyto-reduction: A laboratory–scale comparison of terrestrial and aquatic species at different organic loads. Chemosphere, 16: 459-470
34. CCME. 1999. Canadian water quality guidelines for the protection of aquatic life: Dissolved oxygen (Freshwater). In: Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba
35. Fripp, J., P. F. Ziemkiewicz and H. Charkavorki. 2000. Acid mine drainage treatment. Technical Report # ERDC TN-EMRRPSR-14. EMRRP Technical Notes Collection [online].Available: http://el.erdc.usace.army.mil/elpubs/pdf/sr14.pdf [2007, 24 July]
36. CCME. 1999. Canadian water quality guidelines for the protection of aquatic life: pH (Marine). In: Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.