Design, construction, and operation of a wetland/reservoir system receiving agricultural drainage water

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Abstract
This study serves as a complete and detailed case study of the entire wetland reservoir system (WRS) design and construction process. Challenges presented by the cold climate and geology of Nova Scotia were identified and addressed during the design, construction, and operation of this WRS so that future systems can be optimized. The main challenge of integrating individual system components into the WRS were grade and land availability. A high water table impacted CTW construction and operation. A detailed field investigation should identify this challenge before construction, but limited land availability may force the CTW to be constructed in a less than ideal area. Installing tile drains around the perimeter of the CTW helped alleviate this challenge. Background hydraulic and water quality data was important for addressing episodic hydraulic and pollutant loading and localizing the design. Treatment is assessed and should help assess the design method, which used monthly data to determine the CTW area. Data from this study may contribute to the development of a design model specific to CTWs receiving drainage water. The WRS continued to operate without difficulty during the winter months. It is importance of establish vegetation cover immediately after construction to mitigate erosion, and to have emergency spillways to remove excess water during storm events.

Key Words
Subsurface drainage, water quality, constructed wetlands.

Introduction
Artificial subsurface or "tile" drainage is used to remove excess water from agricultural lands. Removing excess water lowers soil water content to field capacity, which permits earlier field trafficability and enhances growing conditions, and ultimately results in a more productive crop system. However, agricultural non-point source pollution, including subsurface drainage water, is a major source of surface and ground water degradation. Agricultural subsurface drainage water periodically contains concentrations of nutrients, pathogens, pesticides, and sediment that exceed water quality guidelines. The export of these contaminants can have major ecological, health, and socio-economic consequences. Tile drainage is used extensively throughout Nova Scotia and, in most cases, un-treated effluent is discharged directly into surface waterbodies.

Another water management issue affecting Nova Scotia is water availability during the growing season. Nova Scotia has endured droughts in recent years despite an abundance of groundwater, lakes, and rivers and receiving, depending on the region, annual precipitation of less than 1000 mm to more than 1600 mm (Environment Canada 2007). This is due to the timing of precipitation; there is often a surplus of precipitation during the non-growing season and a deficit during the growing season. Periods of water deficit in Atlantic Canada are projected to become more frequent and severe due to climate change and increased water demands (Nova Scotia Department of Environment and Labor 2005).

Treatment and reuse systems have the potential to address both pollution from agricultural drainage water, and water supply issues. One type of systems captures surface runoff and/or tile drainage water, uses a constructed treatment wetland (CTW) to improve water quality, and stores the treated water in a reservoir. This water can be reused for irrigation, upon which the cycle of drainage, capture, and treatment continues. These systems need to be assessed in a cold climate so that their location, design, construction, and operation can be optimized in Nova Scotia. Specifically, a better understanding of system hydraulics, CTW treatment efficiencies, and pathogen management is required. The purpose of this paper is to describe the design, construction, and a preliminary assessment of a drainage water treatment and reuse system that consists of a tile drainage system, a CTW system, and an irrigation reservoir.

Methods

Site Description

The study site is located at the Bio-Environmental Engineering Center in Truro, Nova Scotia, Canada (N 45E 23' and W 63E 15'). Truro has a daily average temperature of -6.6 ºC in January and 18.6 ºC in July and receives 1170 mm of annual precipitation, with peaks amounts during the fall (Environment Canada 2007; 2008). The tile drainage system that supplies the wetland-reservoir system (WRS) is underneath 1.8 ha of the field. It is comprised of 0.10 m diameter tile lines installed at a depth of 0.80 m and spaced every 12. The lines converge at a monitoring hut where water quality and flow measurements are collected. The tile drainage system design, manure type and spreader, and tillage systems are typical throughout Nova Scotia and therefore drainage water quality was expected to be representative of the region.

Constructed Treatment Wetland System

A surface flow wetland was selected because they have been successfully implemented in Nova Scotia (Smith *et al.* 2006; Wood *et al.* 2008). Steady state, first-order plug flow models, such as the k-C* model (Equation 1; Kadlec and Knight 1996), have been shown to adequately describe treatment in CTWs receiving episodic hydraulic and pollutant loading, such as that of drainage water (Carleton *et al.* 2001).

$$A = -\frac{Q}{k} * \ln(\frac{C_{out} - C^*}{C_{in} - C^*}) \qquad (1)$$

Where: A = Wetland area (m^2), Q = Annual inflow (m^3/yr), k = First order reaction or areal rate constant (m/yr), C_{out} = Outflow concentration (mg/L), C_{in} = Inflow concentration (mg/L), and C^* = Background concentration (mg/L). The k-C* model was applied monthly in 2005 to each contaminant. The maximum recorded C_{in} and the coinciding daily tile flow, extrapolated over 365 days to calculate Q, were used. C_{out} values were based on drinking water quality guidelines for NO_3^--N (FPTCDW 2008), irrigation water quality guidelines for *E. coli* (CCME, 2005). The k values used in this design were calculated by Jamieson *et al.* (2007) from a CTW receiving livestock wastewater in Nova Scotia. This yielded a maximum surface area (A) of 1025 m^2. Two independent CTW cells, were selected to allow (i) data replication, (ii) a higher length to width ratio while fitting within limited land availability and site topography, and (iii) flexibility to make repairs or modifications to one wetland while the other continues to operate. CTW specifications were based on several design manuals (NRCS 2002; USEPA 1988;1999). To address the concerns presented by a high water table a 12 mil woven polyethylene liner was installed. The wetland floors were sloped 0.2% and two 0.05 m perforated pipes, wrapped in filter fabric, were laid across the last two zones of each wetland to drain any water trapped beneath the liner. Tile drainage water is transported to the CTW by a 200 mm underground pipe. A vertical plastic fin glued inside a T splits flow to each cell. Knife valves allow flow to be shut-off to each cell. An in-line water level control structure at the outlet of each cell allows the water level to be controlled by adjusting plates. An emergency spillway at the outlet of each cell is used to safely discharge excess water if the control structure cannot. Water is then directed to the reservoir by a 30 m surface channel, which may provide additional treatment. Construction began in November 2006 and took approximately 14 days. Cattail (*typha spp.*) shoots were transplanted with a spacing of 1/m^2 into the shallow zones from a natural wetland in May 2007 and spread to cover the entire shallow zone by August 2007.

Reservoir/Dam Design and Construction

The function of the reservoir as part of the WRS is to store the water treated by the CTW until it is used for irrigation. An on-stream reservoir, which is formed by constructing a dam across the downstream end of a gully, was selected rather than a dugout reservoir primarily because of land availability and cost. The proximity of the gully to the field is close enough to allow for a reasonable length of irrigation main pipe. A field investigation consisting of test pits, permeability tests, and a review of soil maps was conducted to assess seepage potential of the reservoir and the suitability of site soil for use as dam fill. In-situ and Guelph permeability tests indicated that the site is characterized as slowly permeable, raising a concern about water retention by the reservoir. Test pits dug at the dam foundation site revealed a sandstone layer below the topsoil, capable of bearing the dam load. A contour survey of the gully was conducted and reservoir volumes were calculated for various dam locations. A maximum volume of 5000 m^3 was calculated when the dam was situated at the downstream limit of the gully. The reservoir has a surface area of 0.3 ha and a maximum depth of 4.5 m, deep enough to provide fish habitat and limit aquatic plant growth. This volume is less than the potential volume of 8500 m^3 but was limited by land availability, topography, and cost, as experience by Allred *et al.* (2003).

System Costs
A major obstacle in the adoption of the WRS is cost. Cost depends on factors such as existing components, irrigation requirements, drainage area, water quality, topography, and site geology. System costs for our system are listed in Table 1.

Table 1. System costs

	Cost ($CAD)
Irrigation System	
Pump	4800
Pipes	9000
Sprinklers	2400
Fittings	2400
Constructed Treatment Wetland	
Excavation	10000
Synthetic liner	5700
Control structures	2000
Pipes	2500
Valves	600
Spillway construction	400
Spillway rock	400
Reservoir	
Soil tests	1500
Engineering fees	4700
Grubbing and stump disposal	10400
Dam construction	40000
Compaction monitoring	600
Bentonite	3000
Spillway geotextile	800
Spillway rock	2400
Site seeding	2200
Total	105800

Cost should be lowered as recommendations for optimizing WRS location, design, construction, and operation are implemented. It is also difficult to put a financial value on the environmental benefits. Wichelns (2005) investigated the economic feasibility of an integrated on-farm drainage management system in California and concluded that economic incentives and drainage water disposal regulations may be required to encourage farmers to bear the significant cost of the system. Operational challenges generally occurred during high flow events. During a few storm events, before vegetation was established, erosion caused significant damage to instrumentation, CTW berms and dykes, unknown hydraulic and pollutant loading, and sedimentation in the ditch between the CTW and reservoir. This challenge was addressed once vegetation was established. Vegetation debris, transported during fall high flow events, frequently obstructed control structures. This could be addressed through the use of larger control structures or intake screens.

Preliminary water quality results
Water quality, hydrological, and meteorological data were collected since November 2007. Preliminary data indicate that annual nitrate-nitrogen (NO_3^--N) and *E .coli* reductions were 52% and 33%, respectively. Significant monthly variation was observed, and is attributed to the episodic hydrologic and pollutant loading of drainage water. Total phosphorus and soluble reactive phosphorus concentrations were typically below detectable levels (0.10 mg/L and 0.05 mg/L, respectively) at all sampling locations. Reservoir water quality exceeded irrigation water quality for *E. coli* guidelines (100 CFU/100 mL) during summer months and is attributed to environmental factors. This project provides a detailed case study of the design and construction process of a wetland-reservoir treatment and reuse system. Recommendations focusing on managing episodic hydrologic and pollutant loading are also made to optimize future systems in Nova Scotia.

Conclusion
Nutrient and pathogen loading from the disposal of agricultural drainage water is a major source of surface water quality degradation. Common effects of this type of degradation include eutrophication, and the contamination of drinking and irrigation water supplies. Climate change and increasing water demands also

threaten the availability of good quality water. Integrated water management systems have been used to address these challenges by treating and reusing drainage water. Before these systems can be implemented in Nova Scotia their location, design, construction, and operation need to be optimized to the cold climate and geology of the region. This project provides a detailed case study of the design and construction process of a wetland-reservoir treatment and reuse system. Recommendations focusing on managing episodic hydrologic and pollutant loading are also made to optimize future systems in Nova Scotia. The most likely implementation of wetland-reservoir drainage water treatment and reuse systems in Nova Scotia is on farms that do not have access to enough water. The benefits of creating an irrigation water source may help offset the capital costs of constructing the system. The system did supply more than enough water to irrigate the drainage area and it does significantly improve water quality. However it may not be able to consistently supply water that meets the irrigation water quality guidelines for *E. coli*. This is still an improvement over the typical case where no irrigation water treatment occurs. Regulations for discharging drainage water into the environment may be necessary to encourage farmers to adopt this type of system for the protection of the environment.

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