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AN INITIAL ASSESSMENT OF A WETLAND-RESERVOIR WASTEWATER TREATMENT AND REUSE SYSTEM RECEIVING AGRICULTURAL DRAINAGE WATER IN NOVA SCOTIA

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ABSTRACT A wetland-reservoir wastewater treatment and reuse systems is an integrated water management system constructed on farms to conserve water and to help mitigate water pollution from agricultural drainage. This research assesses such a system in Nova Scotia and provides recommendations for adapting its location, design, construction, and operation to a cold climate. Water quality, hydraulic, and meteorological data was collected between November 2007 and January 2009. The system collected approximately 15500 m^3 (8700 m^3 ha^{-1} of drained land) annually, potentially enough water to irrigate more than the drained area. A tracer study was conducted in the constructed treatment wetland to assess residence time. Little difference was observed between the actual residence time (15.0 d) and the nominal residence time (14.5 d). This is attributed to a high length to width ratio (10:1). Annual nitrate-nitrogen and *E. coli* reductions by the constructed treatment wetland were 52% and 33%, respectively. Significant monthly variation was observed, and is attributed to the dynamic hydraulic and pollutant loading of tile drainage water. Total phosphorus and soluble reactive phosphorus concentrations were typically below detectable levels (0.10 mg L^{-1} and 0.05 mg L^{-1} respectively) at all sampling locations. Reservoir water quality exceeded irrigation water quality guidelines for *E. coli* (100 CFU 100 mL^{-1}) during summer months and is attributed to environmental factors. At a cost of approximately \$50,000 ha^{-1} the system may require economic incentives or drainage water disposal regulations before it can be adopted by farmers.

Keywords: Cold climate, Constructed treatment wetlands, Drainage water management, Drainage water quality, *E. coli*, Nitrate, Wastewater reuse, Water conservation.

INTRODUCTION Agricultural non-point source pollution, including subsurface drainage water, is a major source of surface and groundwater degradation (USEPA, 2007) as it may contain levels of nutrients, pathogens, pesticides, and sediment that exceed water quality guidelines. The export of these pollutants can have major ecological, health, and socio-economic effects. Waterborne illness, eutrophication, and toxicity to biota are among the most notable. 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 (Davis and Browne, 1996). 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 (Vasseur and Catto, 2008) and increased water demands (Nova Scotia Department of Environment and Labor, 2005).

Wastewater treatment and reuse systems have the potential to address both pollution from agricultural drainage water, and water supply issues. A Wetland-Reservoir Irrigation System (WRIS) is a type of wastewater treatment and reuse system that 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 (Allred et al., 2003; Baker et al., 2004; Tan et al., 2007). This water can be reused for irrigation, upon which the cycle of drainage, capture, and treatment may continue. Before these systems can be implemented in a cold climate, such as Nova Scotia, their location, design, construction, and operation need to be assessed in and adapted to local conditions. Specifically, a better understanding of system hydraulics and water quality, particularly with respect to pathogen management, is required.

OBJECTIVES The overall goal of this research is to assess and adapt a wetland – reservoir wastewater treatment and reuse system receiving agricultural drainage water to a cold climate, such as Nova Scotia. Specific project objectives are:

1) To design and construct a wastewater treatment and reuse system consisting of a tile drainage system, a CTW system, and an irrigation reservoir;
2) To assess system hydraulics;
3) To assess CTW treatment by determining seasonal and annual mass reductions of nitrate-nitrogen (NO_3^--N), total phosphorus (TP), soluble reactive phosphorus (SRP), and *Escherichia coli* (*E. coli*);
4) To assess reservoir water quality (NO_3^--N, TP, SRP, and *E. coli*).

DESIGN, CONSTRUCTION, AND OPERATION

Site Description The study site is located at the Bio-Environmental Engineering Center in Truro, Colchester County, Nova Scotia, Canada (N 45° 23’ and W 63° 15’) (Figures 1 and 2). 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). Conventional and no tillage practices were used on 43 and 57% of the drainage area, respectively. Liquid dairy manure was applied annually in the spring by a vacuum tanker. Manure was immediately incorporated into the conventional tillage plots and left on the surface of the no tillage plots.

Figure 1. Map of Nova Scotia, Canada.

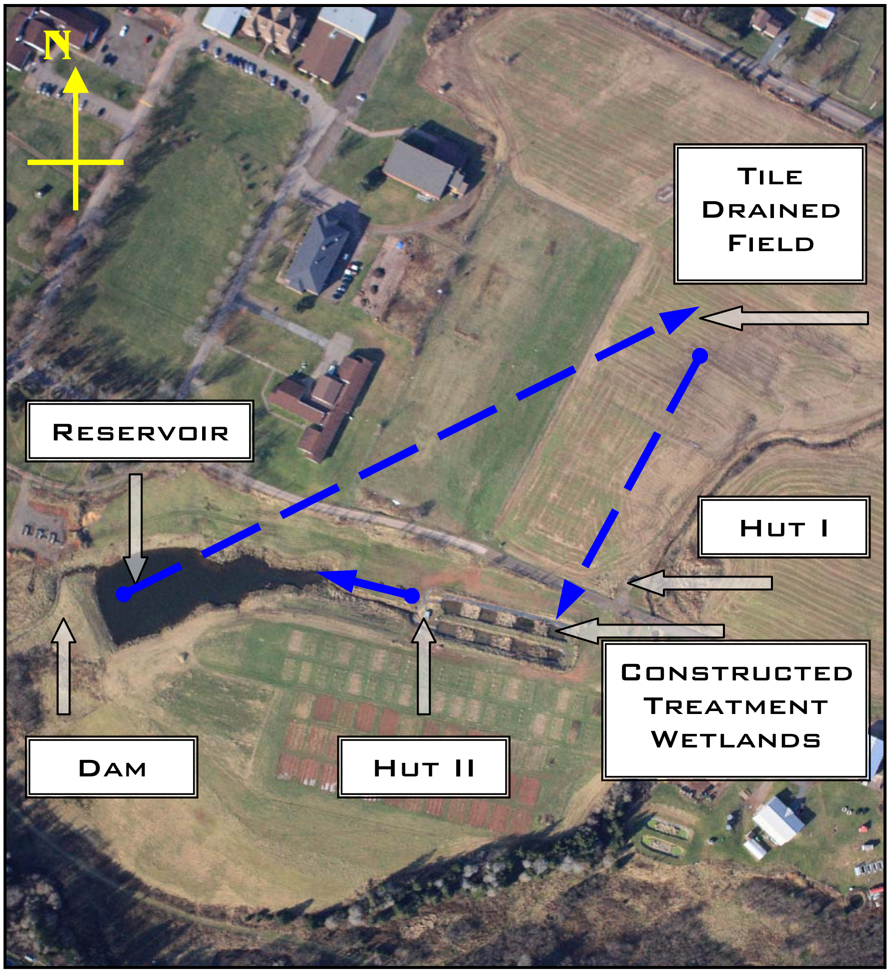

Figure 2. Plan view of the Wetland-Reservoir Irrigation System (1:4000).

Tile drainage system A 1.8 ha tile drainage system supplies the WRIS. It is comprised of 0.10 m diameter tile lines installed at a depth of 0.80 m and spaced every 12 m. These specifications are typical of systems in Nova Scotia (Gartley et al., 1987). The lines converge at monitoring Hut I where water quality and flow measurements were collected.

Constructed treatment wetland The function of the CTW as part of the WRIS is to improve drainage water quality so that it can be reused for irrigation or safely discharged into the environment. The main challenge of designing a CTW as part of a WRIS is to manage dynamic flow rates. The CTW was sized according to the k-C* model (Kadlec and Knight, 1996). Kadlec and Knight (1996) recommend applying the k-C* model seasonally for CTWs treating nutrients to account for dynamic pollutant loading. This also applies to the dynamic flow rates of CTWs receiving tile drainage water. The k-C* model was applied monthly using peak NO_3^--N, TP, and *E .coli* concentrations and monthly tile drainage flow extrapolated over 12 months from existing data. The wetland area to drained area ratio was comparable to those recommended by Kovacic et al. (2000) and Reinhardt et al. (2005). Constructed treatment wetland design specifications are listed in Table 1. Surface runoff was directed away from the CTW.

Table 1. Constructed treatment wetland specifications.

Number of cells	2
Total area	1025 m^2
Wetland area to drained area ratio	5.70%
Length to width ratio	10:1
Length	72 m
Width	7 m
Freeboard	0.6 m
Number of deep zones	3 + forebay
Number of shallow zones	3
Percent of total wetland area occupied by shallow zones	43%
Forebay depth	1 m
Deep zone water depth	0.45 m
Shallow zone water depth	0.15 m
Soil depth	0.30 m
Primary vegetation	Cattail (*typha spp.*)
Inlet	150 mm pipe
Outlet	150 mm pipe into a 1.5 m high in-line control structure
Emergency spillway	Rock spillway, woven polyethylene liner
Liner	12 mil woven polyethylene

Reservoir and dam The function of the reservoir as part of the WRIS is to store the water treated by the CTW until it is used for irrigation. Reservoirs have also been shown to provide additional treatment (Gannon et al., 2005), which is important during high flow events if the CTW does not provide the desired treatment. An on-stream reservoir, 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 reservoir was sized to hold the annual tile drainage outflow and direct precipitation but its capacity was limited by land availability. Dam stability concerns due to less than ideal on-site fill material were addressed by an impervious upstream layer, a pea stone drain, toe drains and best compaction practices. Dam design specifications are listed in Table 2.

Table 2. Dam specifications.

Top width	5 m
Freeboard	1.2 m
Upstream slope	3:1
Downstream slope	3:1
Keyway depth	0.6 m
Maximum lift thickness	0.2 m
Compaction	100 % Standard Proctor
Optimum dry density	1850 kg m^{-3}
Optimum water content	15.5%
Seepage controls	12 kg m^{-2} Bentonite upstream layer, pea stone drain, toe drains
Spillway	< 0.2 m rock, 4 m wide control section

Irrigation system The function of an irrigation system as part of a WRIS is to use the water stored in the reservoir to irrigate crops, thereby increasing crop yield and quality. This increased productivity is the primary incentive for farmers to construct a WRIS. Existing WRISs have used controlled drainage/subirrigation systems (Allred et al., 2003; Baker et al., 2004; Tan et al., 2007), which utilize the tile drainage lines to distribute water to crops. However, an intermittent move sprinkler irrigation system was selected for this WRIS because of its widespread use in Nova Scotia.

The cost of the WRIS, \$50 000 ha^{-1}, was significant. Even with the benefits of increased crop productivity environmental regulations may be required to encourage farmers to adopt WRISs.

HYDRAULIC ASSESSMENT

Water budget A water budget of can help determine the amount of water available for irrigation and lead to designs that maximize available water. Meteorological parameters, tile drainage outflow rates (at Hut I), and CTW outflow rates (at Hut II) were continuously monitored between September 2007 to January 2009. Annual precipitation and annual temperature were greater than normal values for the region, 1170 mm and 6°C, respectively (Environment Canada, 2008). Precipitation was also significantly greater than amounts reported by similar studies in (Kovacic et al., 2000; 2006; Reinhardt et al., 2002; Tanner et al., 2005), illustrating the potential for greater hydraulic loading and a need to assess a WRIS in a cold climate, such as Nova Scotia.

The water budget imbalances are primarily attributed to groundwater intrusion, particularly in wetland 1 (Table 3). The CTW water budgets indicate a potential to treat alternative farm wastewater and supplement irrigation capacity during June and July, the months with the lowest flows (Figure 3). This is also the best time to perform maintenance.

Table 3. Summary of water budgets.

	October 2007 to October 2008		
	Wetland 1	**Wetland 2**	**Reservoir**
Gains			
Inflow from tile drainage (m^3)	1538 (3.00)[A]	4822 (9.41)[A]	
Inflow from constructed treatment wetlands (m^3)			12080
Direct precipitation (m^3)	725 (1.41)	725 (1.41)	3701
Losses			
Outflow (m^3)	9074 (17.70)	3873 (7.56)	
Evapotranspiration (m^3)	30 (0.06)	30 (0.06)	174
Change in volume (m^3)	-6841 (-13.35)	1644 (3.21)	

[A] All tile drainage flow was directed to W2 at the start of August 2008
Volumes are reported as depths (m) inside brackets

A complete reservoir water budget could not be conducted because spillway outflow was not monitored. The reservoir water budget indicates that the system can collect approximately 15500 m^3 (8700 m^3 ha^{-1} of drained land) annually. This volume is significantly greater than the projected annual volume of available water, 8500 m^3 (4700 m^3 ha^{-1}), although it does include groundwater intrusion into the CTW. This indicates a potential to irrigate a greater area if the reservoir was enlarged to maximize available water, which may make the WRIS more cost effective and attractive to farmers. Other studies on CTWs receiving solely tile drainage water have reported available water volumes ranging from 900 to 3900 m^3 ha^{-1} (Kovacic et al., 2000; 2006; Tanner et al., 2005). There is also the potential to increase capacity by incorporating surface runoff.

Residence time Residence time (RT) can help characterize how water moves through a CTW and explain differences between actual and design treatment, ultimately leading to

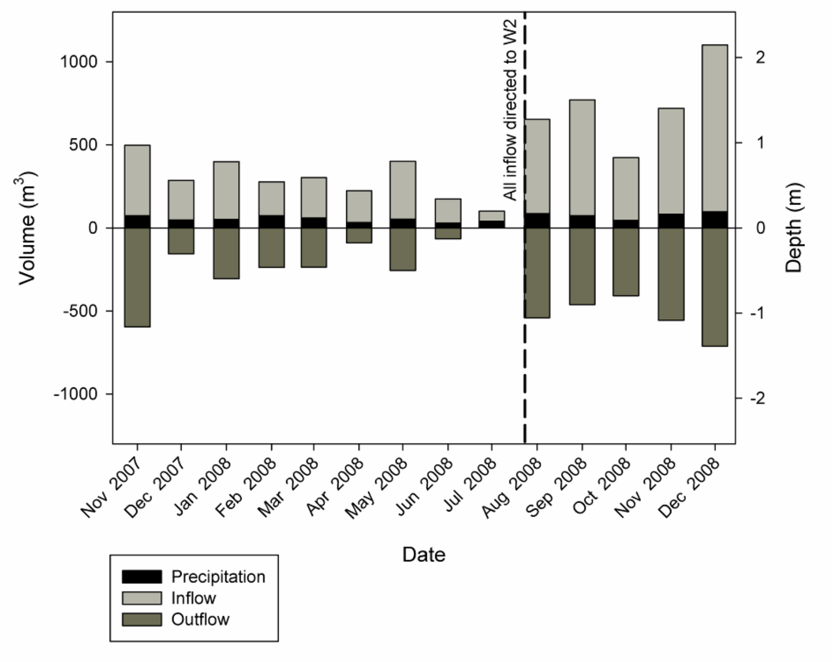

Figure 3. Wetland 2 water budget.

improved designs and management. A tracer study was conducted using potassium bromide, an ion tracer that has been used in similar cold climate tracer studies in Nova Scotia (Jamieson et al., 2001; Miles, 2008; Smith et al., 2005). Little difference was observed between the actual RT (15.0 d) and the nominal RT (14.5 d). This is attributed to a high length to width ratio (10:1), which is recommended for future systems.

WATER QUALITY ASSESSMENT Weekly water samples were collected from the tile drainage outlet (Hut I), CTW outlet (Hut II), and reservoir spillway. Sample frequency increased during high flow periods. Annual NO_3^--N (Figure 4) and *E. coli* (Figure 5) mass reductions by the CTW were 52% and 33%, respectively, and concentrations at the CTW outlets were typically below drinking water guidelines (FPTCDW, 2008). Significant monthly variation was observed, and is attributed to the dynamic hydraulic and pollutant loading of tile drainage water, specifically the trend of increasing pollutant concentrations during high flow periods when RT was not long enough to allow biogeochemical cycling to adequately improve water quality. This highlights the need for design and management considerations that can help mitigate the pollution potential of high flow periods. Possible design considerations include sizing the wetlands based on peak episode flows, incorporating high-flow diversions, or constructing a holding pond before or combined with the CTW. One possible management option is to lower the wetland water level before an event and raise the water level during the event. This will enable the wetland to temporarily serve as a detention pond.

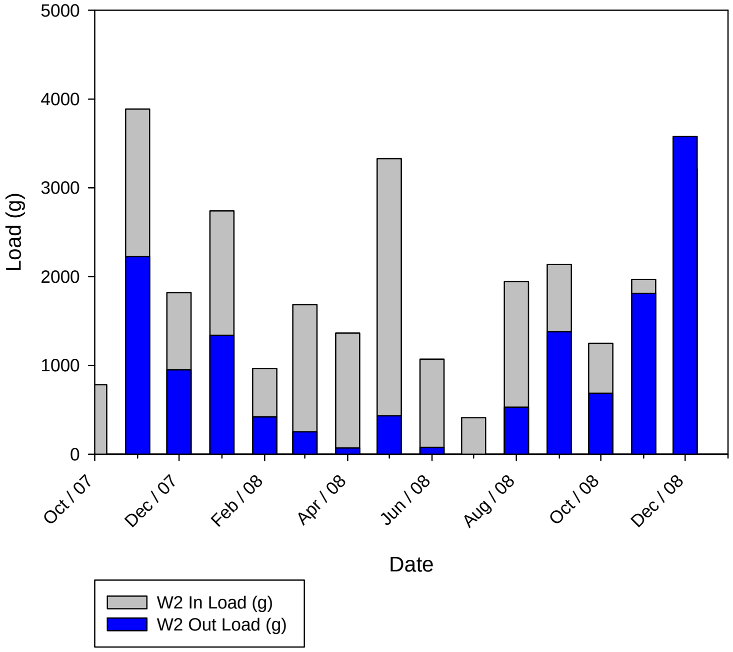

Figure 4. Nitrate-nitrogen loads in wetland 2.

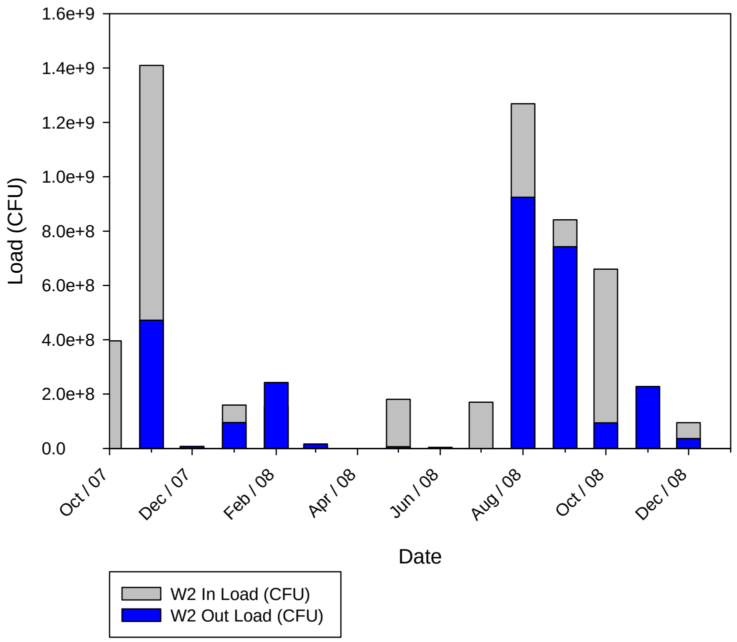

Figure 5. *E. coli* loads in wetland 2.

Reservoir outlet water quality exceeds water quality guidelines for *E. coli*, 100 CFU 100 mL^{-1} (CCME, 2005), during the summer months when it would be used for irrigation. This is a potential safety issue if the water is used to irrigate crops eaten raw and detracts from the attractiveness the WRIS. Contamination may be attributed to increased wildlife activity during the summer months or from surface runoff.

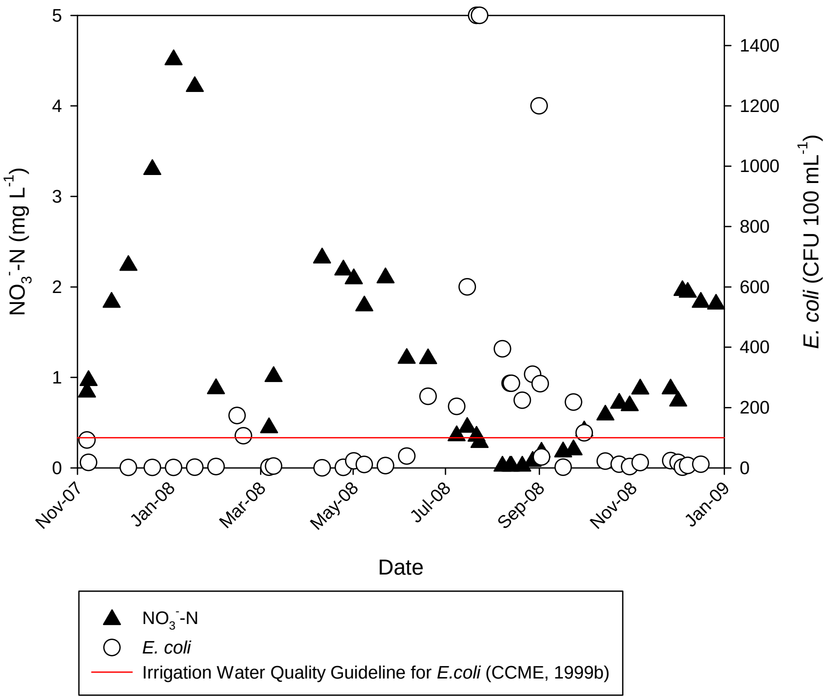

Figure 6. Reservoir outlet water quality.

Total phosphorus and SRP concentrations throughout the system were consistently below detection limits (0.05 mg L^{-1} and 0.1 mg L^{-1} respectively). Therefore eutrophication due to excess phosphorus, particularly in freshwater where it is often the limiting nutrient, does not appear to be a significant concern from this site.

CONCLUSIONS Wetland-reservoir irrigation systems can be a functional alternative used to address pollution from agricultural drainage water and water supply issues. Local conditions, particularly the resulting hydraulics, must be considered during the design process so that WRISs can be adapted to the region. The CTW should have a high (10:1) length to width ratio to ensure plug flow hydraulics and be sized by applying the k-C* model using at least monthly peak pollutant concentrations and average monthly flow rates for optimized treatment. The reservoir capacity should be large enough to retain peak annual tile drainage outflows, direct precipitation, and unaccounted for inputs for maximum irrigation benefits.

However, the implementation of the WRIS will be site specific, mainly because of their high cost and land area / topography requirements. Only on farms that experience water shortages or irrigation water quality problems for crops eaten raw would these systems be viable.

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REFERENCES

Allred, B.J., Brown, L.C., Fausey, N.R., Cooper, R.L., Clevenger, W.B., Prill, G.L., La Barge, G.A., Thornton, C., Riethman, D.T., Chester, P.W. and Czartoski, B.J. 2003. Water table management to enhance crop yields in a wetland reservoir subirrigation system. Appl. Eng. Agric. 19(4):407-421.

Baker, B.J., Allred, B.J., Luckeydoo, L.M., Fausey, N.R., Clevenger, W.B., Brown, L.C., and Hamsher, S.E. 2004. Ohio Wetland Reservoir Subirrigation System (WRSIS) - Preliminary results. Proc. of the 8th International Drainage Symposium. p. 89-98. ASABE, St. Joseph, MI.

Canadian Council of Ministers of the Environment (CCME). 2005. Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses: Summary Table. Updated October 2005. *In* Canadian Environmental Quality Guidelines. 1999. CCME, Winnipeg, MB.

Davis, D.S., and Browne, S. 1996. Nova Scotia's Climate. p. 97-103 *In* Davis D. S., Browne S. (eds.), Natural History of Nova Scotia. Natural History Museum / Nimbus, Halifax, NS.

Environment Canada. 2008. The Canadian Climate Normals 1971-2000. The Green Lane,Environment Canada. Available at: www.climate.weatheroffice.ec.gc.ca /climate_normals/. Accessed: 1 May, 2008.

Federal-Provincial-Territorial Committee on Drinking Water (FPTCDW). (2008). Guidelines for Canadian Drinking Water Quality Summary Table. Health Canada, Canada.

Gannon, V.P.J., Duke, G.D., Thomas, J.E., VanLeeuwen, J., Byrne, J., Johnson, D., Kienzle, S.W.; Little, J.; Graham, T.; Selinger, B. 2005. Use of in-stream reservoirs to reduce bacterial contamination of rural watersheds. Sci. Total Environ. 348:19-31.

Gartley, C., Cochrane, L., DeHaan, R., and Madani, A. 1986. Farm Drainage in the Atlantic Provinces. Authority of the Atlantic Provinces Agricultural Services Co-ordinating Committee. ACAE Publication No. 3.

Jamieson R.C., Jamieson T.S., Gordon R.J., Stratton G.W. and Madani A. 2001. Influence of ionic tracer selection on wetland mixing characterization studies. p. 295-302. *In* Influence of ionic tracer selection on wetland mixing characterization studies. Wetlands & remediation II: Second conference on wetlands & remediation, Salt Lake City, UT. 16-17 Nov. 1999 2001.

Kadlec, R.H., and Knight, R.L. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, FL.

Kovacic, D.A., David, M.B., Gentry, L.E., Starks, K.M., and Cooke, R.A. 2000. Effectiveness of constructed wetlands in reducing nitrogen and phosphorus export form agricultural tile drainage. J. Environ. Qual. 29(4):1262-1274.

Kovacic, D.A., Twait, R.M., Wallace, M.P., and Bowling, J.M. 2006. Use of created wetlands to improve water quality in the midwest - Lake Bloomington case study. Ecol. Eng. 28:258-270.

Miles M.E. 2008. Assessing residence time in constructed treatment wetlands receiving agricultural wastewater. M. Sc. Dalhousie University in co-operation with Nova Scotia Agricultural College, Halifax, Nova Scotia

Nova Scotia Department of Environment and Labour (NSDEL). 2005. A Drinking Water Strategy for Nova Scotia. NSDEL, NS.

Reinhardt, M., Gachter, R., Wehrli, B., and Muller, B. 2005. Phosphorus retention in small constructed wetlands treating agricultural drainage water. J. Environ. Qual. 34:1251-1259.

Smith, E., Gordon, R., Madani, A. and Stratton, G.W. 2005. Cold climate hydrological flow characteristics of constructed wetlands. Can. Biosys. Eng. 47:1.1-1.7.

Tan, C.S., Zhang, T.Q., Drury, C.F., Reynolds, W.D., Oloya, D., and Gaynor, J.D. 2007. Water quality and crop production improvements using a wetland-reservoir and drainage/subsurface irrigation system. Can. Water Res. J. 32(2):129-136.

Tanner, C.C., Nguyen, M.L., and Sukias, J.P.S. 2005. Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. Agr. Ecosyst. Environ. 105:145-162.

U.S. Environmental Protection Agency (USEPA). 2007. National Water Quality Inventory: Report to Congress – 2002. Report Cycling No. EPA 841-R-07-001. USEPA Office of Water, Washington, D.C.

Vasseur, L., and Catto, N. 2008. Atlantic Canada. p.162 to 220 *In* Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E. (eds.) From Impacts to Adaptation: Canada in a Changing Climate. 2007. Government of Canada, Ottawa, ON.