PERFORMANCE ASSESSMENT OF AN OPEN AND COVERED STORMWATER WETLAND SYSTEM – AURORA, ONTARIO

a report prepared by:

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Great Lakes Sustainability Fund of the Government of Canada
Ontario Ministry of the Environment
Toronto and Region Conservation Authority
Lake Simcoe Region Conservation Authority
Municipal Engineers Association of Ontario
Town of Aurora

May 2003

NOTICE

The content of this report is the product of the SWAMP program and does not necessarily represent the policies of the supporting agencies. Although every reasonable effort has been made to ensure the integrity of the report, the supporting agencies do not make any warranty or representation, expressed or implied, with respect to the accuracy or completeness of the information contained herein. Mention of trade names or commercial products does not constitute endorsement or recommendation of those products. No financial support was received from developers, manufacturers or suppliers of technologies used or evaluated in this project.

PUBLICATION INFORMATION

Documents in this series are available from the Toronto and Region Conservation Authority:

Sonya Meek
Water Management Planner

Toronto and Region Conservation Authority

5 Shoreham Drive,
Downsview, Ontario
M3N 1S4

Tel: 416-661-6600, Ext. 5253
Fax: (416) 661-6898

E-mail: Sonya_Meek@trca.on.ca

THE SWAMP PROGRAM

The Stormwater Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, and the Municipal Engineer's Association. A number of individual municipalities and other owner/operator agencies have also participated in the SWAMP studies.

During the mid to late 1980s, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth is a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these environmental concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in southern Ontario. The SWAMP Program was designed to address this need.

The SWAMP Program's objectives are:

* to monitor and evaluate the effectiveness of new or innovative stormwater management technologies; and
* to disseminate study results and recommendations within the stormwater management industry.

For more information about the SWAMP Program, please contact:

Ms. Pat Lachmaniuk
Ministry of the Environment
Phone: 416-327-7480
Fax: 416-327-2936
Email: pat.lachmaniuk@ene.gov.on.ca

Additional information concerning SWAMP and the sponsoring agencies is included in Appendix A.

ACKNOWLEDGEMENTS

This report was prepared for the Steering Committee of the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The SWAMP Program Steering Committee is comprised of representatives from:

- the Government of Canada's Great Lakes Sustainability Fund,
- the Ontario Ministry of the Environment,
- the Toronto and Region Conservation Authority,
- the Municipal Engineers Association of Ontario.

Funding support for this project was provided by the Great Lakes 2000 Clean-up Fund (superseded by the Great Lakes Sustainability Fund) and The Ontario Ministry of the Environment (OMOE). The OMOE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOE provided laboratory analyses. The Lake Simcoe Region Conservation Authority and Town of Aurora provided some equipment and materials. Sheldon Smith conducted the first year of monitoring for this study as part of a Masters thesis at the University of Waterloo. Advice on monitoring and field installations during this phase of the study were provided by Mike Stone, Jonathan Price, Ian McKenzie and Carol Peterson from the University of Waterloo.

The following individuals provided additional technical advice and guidance:

- Dale Henry — Ontario Ministry of the Environment
- Pat Lachmaniuk — Ontario Ministry of the Environment
- Sonya Meek — Toronto and Region Conservation Authority
- Bill Snodgrass — City of Toronto, (formerly representing Ontario Ministry of Transportation)
- Sandra Kok — Great Lakes Sustainability Fund, Environment Canada
- Peter Seto — National Water Research Institute, Environment Canada
- John Shaw — Great Lakes Sustainability Fund, Environment Canada
- Michael D'Andrea — City of Toronto, Municipal Engineers Association of Ontario
- George Moolamootil — University of Waterloo

EXECUTIVE SUMMARY

Natural wetlands have long been viewed as providing important ecosystem functions in flood control and water quality enhancement. Recognition of these natural ecosystem services has led to the engineering and construction of wetlands to treat wastewater and stormwater. Although the idea of using natural systems for pollutant removal initially met with some resistance, constructed wetlands have now became recognized in Ontario as one of the most effective best management practices for stormwater treatment and runoff control.

Unfortunately, there is still a paucity of local monitoring data to support claims of effectiveness, and published information on the year-round performance of constructed wetlands in temperate climates is also very limited. This three year monitoring study of an extended detention wetland located in Aurora, Ontario was intended to help fill these knowledge gaps and provide a demonstration site against which other stormwater wetland designs could be evaluated. This goal was accomplished through analyses of system hydrology, water quality, temperature, vegetation dynamics, benthic invertebrates and sediment chemistry. Comparative evaluation of a heated greenhouse installed within the wetland offers additional insights into the role temperature plays in wetland treatment and the potential for enhancing performance during the cold season.

Study Site

The study was conducted on a 1.2 hectare stormwater wetland in Aurora, Ontario (Figure 1). The drainage basin for the facility was 82.4 hectares, of which 30% was agricultural and the remainder was medium density residential. This facility was designed and constructed in 1988 as a dry pond, but it evolved into a wetland as moist conditions attracted aquatic plants. Modification to the outlet structure prior to the study created an extended detention capacity of 16 m^3/ha. This modification increased the stormwater residence time within the facility, maintaining a pool of standing water on an intermittent basis, and resulted in a drawdown period of 3 to 5 days after rain events.

The modified facility was unique in its combination of both pond and wetland features. It had no permanent pool, other than in the forebay (40 m^3), and would become dry during periods of infrequent rainfall. The facility did not meet the Ontario Ministry of the Environment (OMOE) stormwater wetland guidelines for permanent pool volume (23 m^3/ha), extended detention volume (40 m^3/ha) and length-to-width ratio (3:1). The length-to-width ratio of the wetland portion of the facility was only 2:1.

The greenhouse was constructed from December, 1995 to July, 1996. The greenhouse was located near the outlet of the facility, had a length-to-width ratio of 4.3:1, and covered 10% (or 210 m^2) of the wetland basin area. The greenhouse consisted of a structural base, upper frame and equipment shed and was

heated by a natural gas greenhouse furnace to maintain air temperatures at 10°C. Vegetation within the greenhouse was similar to that of the wetland.

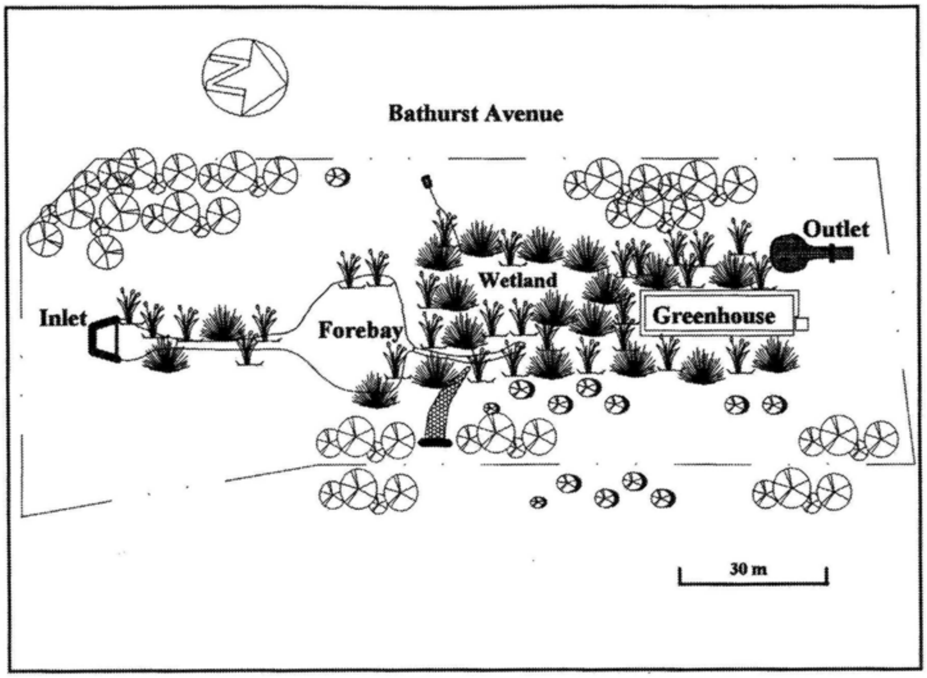

Figure 1: Aurora wetland facility

Study Methods

The water balance of the facility was estimated for 29 runoff events over the study period. Instruments employed for measurement of water balance components included area-velocity flow meters at the inlet and outlet, a water depth sensor in the wetland, groundwater piezometers, a class 'A' evaporation pan, and an automated rain gauge. Temperature of the water, soil substrate and air were recorded at six locations; three in the greenhouse and three in the wetland. Automated samplers at the inlet, outlet, greenhouse and wetland provided water quality data.

Water quality samples were collected at the inlet, outlet, greenhouse and wetland to identify temporal and spatial trends as stormwater passed through the facility, as well as to assess relative differences in water quality among the wetland, greenhouse and outlet monitoring stations. Samples at the inlet were flow-proportioned over the duration of each runoff event, except during the winter, when a single set of 3 grab samples was collected at the inlet near the end of the runoff event. Outlet samples were collected once every hour over a period of 24 hours, then combined into a single composite sample for each day of the drawdown period. Pollutant concentrations of these daily composite samples were later proportioned by daily flow to approximate the effluent event mean concentration. Wetland and greenhouse samples were also collected after each day of the drawdown period, but consisted of a single grab sample, rather than a composite of 24 samples collected at one hour intervals. Since flow was not measured in the greenhouse or wetland, water quality analysis at these locations was based solely on constituent concentrations. All samples were submitted for analysis to the OMOE laboratory in Toronto immediately following collection. Analysis included all the major pollutant groups, including nutrients (N and P), metals, general chemistry, *E.coli*, TSS and phenolics.

Vegetation samples were collected from ten plots within the vegetated portion of the facility; four in the greenhouse and six in the wetland and forebay. Vegetation growth and density were monitored at these locations from April to November, 1997. In June and September, 1997 vegetation samples were collected from locations adjacent to the ten plots. Samples were weighed, dried and submitted as separate above-ground and below-ground samples for lab analysis. Vitality testing was performed on plant rhizomes collected from the greenhouse in January 1997.

Sediment samples were collected from a total of four plots in the greenhouse, wetland (2 plots) and forebay. A control location on the upper southern bank of the facility, above the high water mark, was also sampled. In December, 1996 and June, 1997, sediment samples collected from these plots were submitted for geochemical analysis. In August, 1997, samples from adjacent locations were submitted for bioassessment of toxicity and bioaccumulative potential.

Study Findings

Water Quantity

The Aurora wetland provided a level of runoff control intended to prevent erosion and protect aquatic habitat downstream of the facility. Peak flows were reduced by over 80% during most events. Stormwater drawdown extended over a period of 3 to 5 days and the mean hydraulic detention time was estimated to be 36 hours. Discharge rates in the downstream channel did not exceed 58 L/s, which was sufficient to contain flow within the banks of the channel.

Although the facility was originally designed based on a runoff coefficient of 0.41 (*i.e.* 41% of rainfall within the catchment enters the facility as runoff), flow data for 29 events indicated a mean runoff coefficient of only 0.21. A runoff coefficient of this magnitude is not atypical for a drainage basin with 30% agricultural land use.

Over the study period, water losses to groundwater during wet and dry weather accounted for approximately 13% of the total influent runoff. By comparison, evaporation over the same period accounted for only 0.7% of influent runoff. These quantities are based on the assumption that evaporation and water losses to groundwater are negligible during the winter. For the 29 rainfall events monitored over the study period, inputs (runoff, rain, groundwater discharge) to the wetland system were greater than outputs (outflow, evaporation, groundwater recharge) from the system by an average of 4.7%, which is within the expected error range of the monitoring instruments.

Water Quality

Effluent average event mean concentrations (AEMCs) and load-based removal efficiencies are summarized by season and for the entire study period in Table 1. The major findings regarding water quality were as follows.

Table 1: Summary of wet weather average effluent event mean concentrations (AEMC) and load-based removal efficiencies (R.E.) for selected parameters.

Parameter	Winter[1]		Spring		Summer		Fall		Study Period		PWQOs[2]
	Eff. AEMC	R.E. (%)	Eff. AEMC	R.E. (%)	Eff. AEMC	R.E. (%)	Eff. AEMC	R.E. (%)	Eff. AEMC	R.E. (%)	
General Chemistry											
TSS (mg/L)	28.7	46	16.8	90	25.6	91	26.0	87	23.8	86	
BOD (mg/L)	1.6	7	3.1	55	3.1	34	2.1	22	2.5	32	
COD (mg/L)	29.3	6	30.6	51	31.4	36	22.6	39	28.4	33	
Oil/Grease (mg/L)	1.5	25	1.4	82	1.4	44	0.7	78	1.2	61	
Chloride (mg/L)	429	-15	34	69	105	-51	56	24	45	-1	
Phenolics (µg/L)	1.4	21	1.3	48	1.8	-6	1.1	55	1.5	26	1
E. Coli (c./100ml)	252	42	319	68	475	94	1107	55	464	84	100
Nutrients											
TP (mg/L)	0.16	8	0.16	56	0.10	83	0.18	64	0.14	58	0.03
PO_4 (mg/L)	0.07	26	0.06	14	0.02	86	0.09	31	0.05	44	
TKN (mg/L)	0.88	36	1.19	52	0.81	63	0.79	51	0.90	49	
NH_3+NH_4 (mg/L)	0.05	50	0.17	79	0.03	52	0.05	40	0.06	63	
NO_3 (mg/L)	0.63	27	0.36	26	0.08	82	0.50	11	0.28	41	
Metals											
Copper (µg/L)	5.8	37	5.7	66	4.8	69	5.0	57	5.3	58	5
Zinc (µg/L)	63.8	-87	30.4	59	24.0	53	26.3	58	31.8	17	20
Chromium (µg/L)	2.5	20	1.2	50	1.0	58	1.8	32	1.5	36	8.9[3]
Iron (µg/L)	470	6	353	65	386	52	481	31	415	41	300

1) Mean concentrations and removal efficiencies over the winter period are based on grab samples collected near the end of the runoff event and, therefore, should be interpreted with caution. 2) Underlining indicates concentrations greater than Provincial Water Quality Objectives/Guidelines for receiving waters. 3) 1 µg/L in its less common hexavalent form (Cr VI).

- The load-based TSS removal efficiency was 86% over the study period, ranging seasonally from 46% during the winter to 91% during the summer. The poor removal efficiencies calculated for TSS and other pollutants during the winter may have been a result of low influent concentrations (average = 43 mg/L). Those concentrations may have been partly a consequence of grab sample collection, which would have missed high solids loading associated with the 'first flush' of runoff. Consequently, poor efficiency in winter should not be attributed exclusively to cold weather effects on removal mechanisms.

- Removal efficiencies for most other constituents were considerably less than that of TSS (Table 1). Nutrient removal ranged from 41% for nitrate to 63% for total ammonia, and metal efficiencies were mostly less than 60%. In general, removal efficiencies were greatest during warm weather conditions. However, part of this difference may simply reflect differences in the method of inlet sample collection during the summer and winter (*i.e* composite vs grab).). The effluent concentrations were similar during warm and cold weather.

- Detection frequencies were low in the effluent for several metals, including lead, cadmium, cobalt, nickel and molybdenum. Others such as zinc, copper and iron were often observed at concentrations exceeding receiving water standards (Provincial Water Quality Objectives/Guidelines - PWQOs).

- *E.coli*, TP and phenolics had average effluent concentrations above PWQOs.

- The average particle size distribution (PSD) of suspended particles over the study period indicated a substantial shift to finer particle sizes after the first day of treatment. Based on the samples analyzed, the average particle size of the influent was 3.4 μm (average of PSD medians), compared to the average effluent particle size of 1.7 μm on day 1, and 1.4 μm on day 4.

- Daily constituent concentration data over the treatment period indicated that TSS concentrations decreased substantially after the first day of treatment, but that daily average concentrations of most metals and nutrients displayed a more gradual decline. This gradual decline for the majority of pollutants highlights the importance of residence time in treatment performance. The results are also consistent with the hypothesis that the pollutants are either in dissolved form or associated with the finer suspended particles.

- The maximum water temperature in the wetland (24°C) during the summer was above the 21°C maximum recommended for cold water fisheries habitat. Unlike most wet ponds, the water temperature in the Aurora wetland increased only slightly from the inlet to the outlet, probably due to the small permanent pool and shading of the water column by a dense assemblage of plants.

- Greenhouse air temperatures were higher than the wetland by an average of 5°C, and the growing season in the greenhouse was 12 to 14 weeks longer than the wetland. However, substrate and water temperatures were similar, and the greenhouse failed to provide improved treatment relative to external wetland. This finding is likely explained by the strong influence of soil and water temperatures on root-zone biological removal processes. Also, physical and chemical mechanisms of removal are influenced by temperature and water viscosity.

Vegetation and Sediment Analysis

- The wetland was dominated by *Typha latifolia* (common cattail) and *Scirpus dominus* (bulrush). Vitality testing on both plants indicated that, during the winter, active metabolic functioning was occurring in the below-ground rhizomes, even though the above-ground tissues were dead. In the greenhouse, these plants started growing and reached their maximum height approximately six weeks earlier than in the external wetland.

- Biomass analysis of above and below-ground tissues for the entire wetland indicated a decrease in the below-ground to above-ground dry weight ratio from 1.3 in June to 0.5 in September. The greenhouse and wetland plants were similar, except that the greenhouse above-ground tissues had slightly higher moisture contents.

- Tissue chemistry analysis showed that, as biomass increased from June to September, the concentrations of most pollutants in the tissues decreased. In terms of mass, however, all nutrients and metals showed significant increases in both above and below-ground tissues over the summer. TKN and TP masses tripled from June to September. The nutrient masses in the plants represented a much greater proportion of influent loads to the wetland than did the metals.

- With the exception of TP, arsenic and chromium, concentrations of pollutants in wetland sediments were greater than concentrations at a nearby control site. However, among pollutants analyzed, only copper had concentrations that exceeded the lowest effect tolerance level for benthic invertebrates.

- Wetland sediments were found to be of good quality based on mayfly, midge and minnow lethal and sublethal endpoints, chemical uptake and bulk sediment chemistry. Forebay sediments showed moderate to severe levels of growth reduction to mayfly nymphs and midge larvae, probably due to high concentrations of PAHs (11 μg/g) in the sediments.

Conclusions and Recommendations

The Aurora facility is unique among stormwater treatment wetlands in that it did not support a substantial permanent pool and would drain dry during periods of infrequent rainfall. As such, the Aurora wetland design did not meet with provincial criteria for this type of facility. Nevertheless, study results indicate that the facility provided good hydraulic control of peak flows and adequate levels of treatment for most pollutants. Extending the time over which stormwater was detained within the facility through modification of the outlet structure was considered to be a key factor in pollutant removal.

The greenhouse did not provide improved cold season performance relative to the wetland, probably because water and substrate temperatures in the greenhouse and wetland were similar. Higher greenhouse air temperatures and a significantly extended growing season were not, by themselves, sufficient to enhance greenhouse treatment capacity. This result is attributed to the key role of root-zone biota in plant removal processes, and the close dependence of root-zone biota on water and soil temperatures, as well as the effect of water temperature on physical and chemical mechanisms of pollutant removal.

Recommendations for facility improvement, maintenance and future research are as follows.

Maintenance and Safety Issues

A considerable amount of trash and debris was carried into the facility during the study period. This trash and debris should be cleaned out at least once a year.

Signs were placed in the facility during the study period warning of human hazards related to fluctuating water levels. Further restrictions on human access to the flooding zone could be achieved by the use of dense perimeter vegetation or fencing with natural materials. Well defined trail grids outside of the flooding zone would help to retain the public amenity function of the facility.

Facility Improvement

Runoff events during the winter are less frequent and intense compared to the summer, but can be large and extend over long periods of time. Treatment of stormwater under this type of runoff regime can be improved by lengthening the cold season detention period through temporary alterations to the outlet control structure. Due to the longer interevent periods and slower release of runoff during the winter, longer extended detention periods may be possible without compromising the water quantity control function of the facility.

If development expands beyond the 58 hectare area documented in this study, some modifications may be warranted such that the facility more closely approximates OMOE design criteria for constructed wetlands. These modifications may include the following: (i) deepening the forebay to the 1 m depth recommended in the SWMP manual; (ii) increasing the length-to-width ratio from 2:1 to 3:1 by moving the forebay closer to the inlet; (iii) reconfiguring the basin such that it retains a 35 cm permanent pool; and (iv) increasing the total depth of extended detention to 1 m, or up to the bottom of the existing outlet weir through installation of a Hickenbottom riser device similar to that installed as part of the study.

Wetlands provide food for several species of mammals and water fowl as well as habitat for amphibians. It was often observed during periods of flooding that waterfowl used the wetland area to forage. Since waterfowl can contribute significantly to the fecal matter in the facility, in addition to stirring up bottom sediments, waterfowl use should be restricted by, for example, providing dense vegetation in open areas.

Future Considerations

Once plant uptake and sediment adsorption pools in the Aurora wetland approach a limit (as defined by site specific environmental conditions and loading regime), removal rates may suffer substantial declines. Deterioration of performance in this regard may indicate the need for dredging, especially in the forebay, and natural or artificial re-establishment of vegetation cover. Short-term monitoring of system performance should be conducted every 3 to 5 years to determine whether maintenance for this purpose is warranted.

The Aurora facility was a dry pond converted to a wetland, but also functioned partly as an infiltration basin, with average water losses to groundwater accounting for 16% of influent runoff during the summer. These losses helped to further reduce pollutant loading to receiving waters. Enhancing the infiltration component of stormwater wetland facilities should be considered when meeting OMOE permanent pool volume guidelines is not practical, and the potential for contamination of groundwater resources is low.

TABLE OF CONTENTS

List of Figures

List of Tables