PERFORMANCE ASSESSMENT OF A POND-WETLAND STORMWATER MANAGEMENT FACILITY - MARKHAM, 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 Environment and Energy

Toronto and Region Conservation Authority

Municipal Engineers Association of Ontario

Town of Markham

June, 2002

NOTICE

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PUBLICATION INFORMATION

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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 Environment and Energy, 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.

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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 Environment and Energy,
- the Toronto and Region Conservation Authority,
- the Municipal Engineers Association of Ontario.

Funding support for this project was provided by the Great Lakes 2000 Cleanup Fund (superseded by the Great Lakes Sustainability Fund), the Ontario Ministry of Environment and Energy (OMOEE) and the Town of Markham. The OMOEE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOEE provided laboratory analyses. Administrative support to the SWAMP program was provided by the Toronto and Region Conservation Authority. Staff at the Town of Markham provided permission to conduct the monitoring study and assisted with the installation and operation of monitoring equipment.

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EXECUTIVE SUMMARY

Background and Objectives

In 1998, a multi-party agreement among the participating agencies of the Stormwater Assessment Monitoring and Performance (SWAMP) program[1] was established to monitor a stormwater pond-wetland demonstration facility located on the Upper Morningside Tributary of the Rouge River watershed in Markham, Ontario. The facility, known as the Markham Best Management Practice Demonstration Project (or Markham BMP), consists of a sediment forebay, wet pond and wetland that treats stormwater runoff from a 600 hectare, predominantly residential drainage basin. The pond-wetland system replaces a smaller water quantity stormwater dry pond. Selection of the BMP design was based on an ecosystem approach, with goals and objectives determined as an integrated subset of management plans for the Morningside Tributary sub-watershed and the Rouge River watershed. A twelve-month baseline monitoring program of environmental conditions prior to construction of the facility[2] forms the backdrop of this study.

The overall objective of this study was to assess the performance of the Markham BMP against the original design goals and targets identified for the facility. Within this general context, the specific aims were to:

- evaluate the function of the system in terms of contaminant removal, runoff control, temperature impacts, and sediment dynamics;
- assess seasonal variations in stormwater quality and facility function;
- assess potential impacts of the facility on channel morphology and, indirectly, on aquatic habitat within the Morningside Tributary;
- document aquatic plant regeneration patterns in the wetland;
- estimate sediment accumulation rates and dredging requirements for the facility, and
- suggest recommendations for system improvement and/or further research.

This study provides one of the first comprehensive assessments of pollutant removal and flow attenuation by a large, centralized multi-cell pond-wetland facility located within a temperate climate region. As a demonstration project, it is hoped that the results of this study will help guide the planning, design and retrofit of similar stormwater management facilities in Ontario.

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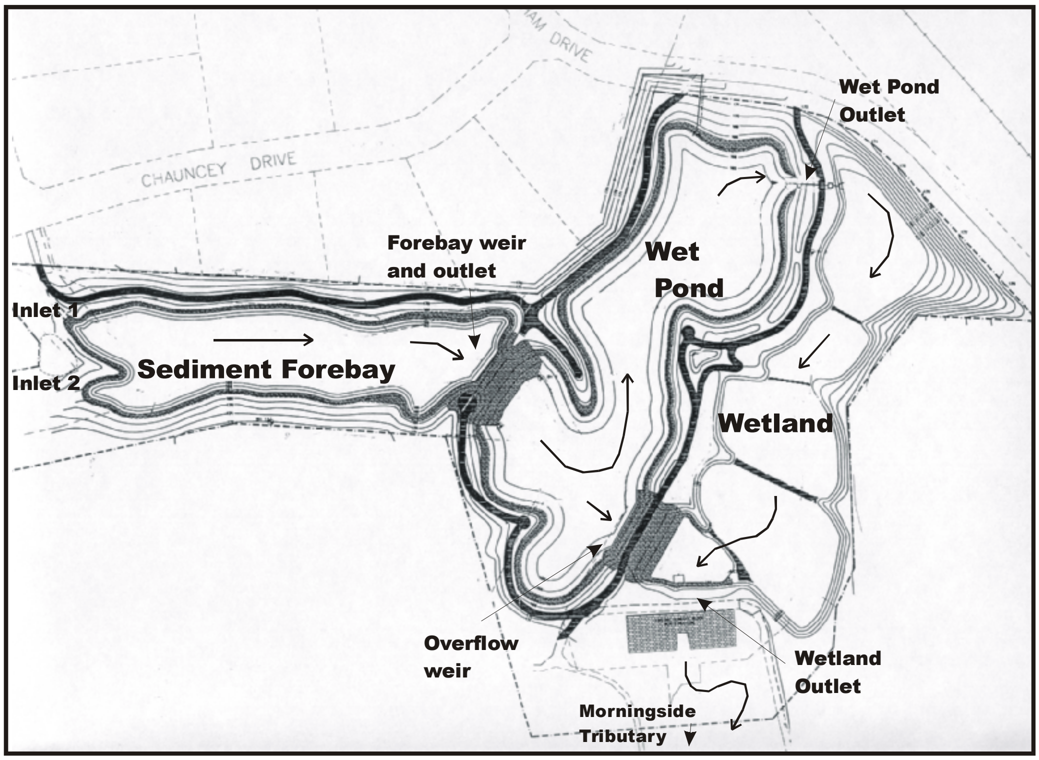
[1] The participating agencies are Government of Canada's Great Lakes Sustainability Fund, Ministry of Environment and Energy, Toronto and Region Conservation Authority, Municipal Engineer's Association and the Town of Markham.

[2] Beak Consultants Ltd and Aquafor Beech, Ltd. 1997. *Best Management Practices Environmental Resource Management Demonstration Project, Town of Markham, Phase II and III report*. Brampton, Ontario.

Study Area and Facility Design

The 600 hectare drainage basin for the Markham BMP comprises 28% of the Morningside subwatershed. At the time of the study, approximately 67% of the drainage basin was developed (90% residential, 10% industrial). The catchment was expected to be fully developed within 5 to 10 years. The topography of the area is characterized by gently rolling hills with predominantly silty-sand soils. A fish and benthic invertebrate survey conducted by Beak and Aquafor Beech in 1992/3 in the Morningside Tributary downstream of the facility indicated generally degraded aquatic habitat consisting predominantly of tolerant warmwater communities with relatively low diversity.



Adapted from: Beak Consultants Ltd and Aquafor Beech, Ltd. 1997. *Best Management Practices Environmental Resource Management Demonstration Project, Town of Markham, Phase II and III Report.* Brampton, Ontario.

Figure 1: Markham BMP

The multi-cell on-line Markham BMP (Figure 1) was designed to perform several functions, including stormwater treatment, base-flow augmentation, flood protection and downstream erosion control. These functions are partly provided through extended detention storage above the 73,000 m^3 permanent pool for events with less than 25 mm of rain. By design, over three-quarters of the total extended detention volume for the 25 mm event was to drain within the first 24 hours, with the remainder draining over a period of 3 to 6 days. Total storage volume (permanent pool + extended detention) is 151,000 m^3, representing a volume-to-catchment area ratio of 252 m^3 per hectare, and a storage area-to-catchment ratio of 1.2%. Runoff volumes exceeding the extended storage capacity of the forebay and wet pond bypass the wetland and overflow directly from the wet pond to the wetland outlet.

A distributed runoff control structure at the wet pond outlet, consisting of a reverse slope feed pipe, inlet chamber and proportional weir, was designed to reduce the frequency of flows exceeding bankfull rates and augment flows during dry weather. The storage volume, length-to-width ratio, extended detention depth and drawdown time exceed the OMOEE's 'Level I' fisheries protection guidelines for this type of facility, but the maximum pond depth is 1.2 m deeper than the 3 m recommended limit.

Monitoring Program

Data were collected from November 1998 to December 1999 and from April to June 2000. The monitoring set-up consisted of continuous flow loggers, temperature probes and auto-samplers at the two inlets and at the outlets of the forebay, wet pond and wetland. Grab samples were taken at the inlets and wetland outlet during dry weather. Precipitation was determined using a tipping bucket rain gauge located within the drainage basin, approximately 1 km west of the facility. A total of 129 samples were collected, representing 30 rainfall events from November 1998 to December 1999. Water quality samples were preserved and submitted to the Ministry of Environment and Energy Lab in Toronto for analysis immediately following sample collection. Samples were analyzed for a wide range of chemical and physical parameters. Subsequent data analysis included calculations for flow balances, peak flow reduction, hydraulic detention times, flow duration, peak-to peak lag times, mean sample concentrations, contaminant loading rates and load-based removal efficiencies. Statistical analyses of water quality results were performed using a program developed by the OMOEE for stormwater constituent analysis.

Study Findings

Hydrology

At the level of development in 1999, the retrofitted Markham BMP met or exceeded the hydrologic design targets and objectives described in the environmental study report for the project[3]. Flood peaks were reduced by more than 80% for all storms, outlet peak flows were consistently below estimated bankfull rates (0.5 to 1.3 m^3/s) in the downstream tributary, storm flows were released gradually over a 3 to 10 day period, and hydraulic detention times (as calculated from inlet and outlet hydrograph centroids) averaged 31 hours. Peak

[3] Beak Consultants Ltd and Aquafor Beech, Ltd. 1997. *Best Management Practices Environmental Resource Management Demonstration Project, Town of Markham, Phase II and III Report*. Brampton, Ontario.

flows during large storms were also consistently less than the two-year pre-development rate, estimated at 4.9 m^3/s.

The hydraulic residence time was estimated to be 87 hours, or 3.6 days, based on plug flow conditions (*i.e.* no mixing, no short circuiting), the mean influent flow rate (0.27 m^3/s) and an estimate of the average pond volume during an event (85,000 m^3). Dead zones, short-circuiting, internal mixing and other factors would typically reduce this value. The hydraulic residence time was not measured by tracer tests as part of this study.

The runoff coefficient, or fraction of rainfall converted to storm runoff, averaged 0.16. This is slightly lower than expected for 1999 levels of catchment imperviousness (estimated at 24%), and may be attributed in part to mandatory roof drainage disconnection requirements for new development in Markham. Although several large rain events (> 25 mm) were recorded during the study period, few generated sufficient runoff volumes to cause overflow across the wet pond spillway. Hence, the hydrodynamics of this flow path could not be characterized.

During dry weather, the wet pond distributed runoff control structure helped to augment baseflow, but summer baseflow rates averaged only 6 L/s. During one long dry period, flow rates in the upper 100 m of the downstream tributary slowed to a trickle. As stormflow volumes increase with urbanization, higher average inter-event water levels are expected to further augment baseflow rates.

Water quality

Composite samples collected at five monitoring stations within the facility were analyzed for a large suite of parameters including suspended solids, metals, nutrients, chloride, herbicides, Polynuclear Aromatic Hydrocarbons (PAHs), phenols, bacteria and particle size. This report provides statistical summaries for individual parameters and assesses load and concentration-based contaminant removal efficiencies of the facility. Results are interpreted and discussed with reference to the original water quality targets for the facility, Provincial Water Quality Objectives (PWQOs), baseline conditions and other studies of stormwater ponds and wetlands.

Major conclusions from the analysis of the water quality data were as follows:

- Influent concentrations of several contaminants had very low detection frequencies, including arsenic, selenium, mercury, 9 herbicides, 7 phenols and 22 PAHs. Lead, cobalt and mercury were detected more frequently at the inlet, but were almost never detected at the outlet of the facility.

- Overall load-based removal efficiencies during the summer/fall period for selected constituents are presented in Table 1. Winter average concentration-based removal rates were less than summer removal rates for all constituents except TSS, total ammonia, *E.coli*, *F.streptococcus*, cadmium, nickel, lead, manganese, zinc and titanium.

- The majority of pollutants settled out in the forebay and wet pond (Table 1). The wetland showed slightly higher removal than the wet pond for several pollutants and was particularly effective in removing dissolved pollutants such as nitrate and phosphate.

Table 1: Overall load-based removal efficiencies (%) for selected constituents during the summer/fall period

	Forebay	**Wet pond**	**Wetland**
TSS	79	92	95
copper	75	84	85
zinc	83	87	87
chromium	63	80	84
nickel	67	65	62
ammonia (NH_3+NH_4)	28	44	22
TKN	53	48	55
total phosphorus	76	83	87
phosphate	61	76	89
E.coli	51	97	79
F. streptococcus	90	99	99

Note: Removal efficiencies represent cumulative load-based removal up to the outlet of each cell (forebay, wet pond and wetland). Thus, numbers in the wetland column represent overall removal for the entire facility.

- During wet weather, removal efficiencies for sand, silt and clay sized particles were estimated at 100%, 96% and 84%, respectively. Size selective removal of suspended particulates resulted in a decrease in the median particle size as water travelled through the facility. The median size of the average influent particle size distribution was 3.8 μm, compared to a median size of approximately 2.0 μm at the forebay, wet pond and wetland outlets. By volume, particles less than 4 μm (clay) accounted for 53% and 78% of the influent and wetland effluent particle size distributions, respectively.

- During the summer/fall monitoring period (May to November), mean wet weather effluent concentrations of copper, total phosphorus and *E.coli* were above Provincial Water Quality Objectives/Guidelines for these constituents. Based on limited sampling during dry weather, mean concentrations of chromium, iron and total phosphorus exceeded Ontario guidelines.

- The mean effluent temperature from May to July, 2000 was 4.1°C higher than the influent temperature. The maximum effluent temperature was 23.6°C, which is below the 26°C maximum target for the facility, but above the 21°C threshold for coldwater fisheries habitat.

- The retrofitted Markham BMP was significantly more effective than the original pond in terms of contaminant removal and peak flow attenuation, despite significantly increased catchment impervious cover in 1999.

Downstream channel adjustments

The Markham BMP was intended to prevent channel enlargement and erosion by attenuating peak flows and extending stormflow drawdown times. To evaluate progress towards this goal, morphological changes within the Morningside tributary north of Steeles Avenue were assessed through erosion pin measurements and channel cross section surveys in 1996, 1998/1999 and, as part of this study, in August 2000. In general, changes in channel morphology since 1996 were modest relative to urban streams without stormwater control. A small decrease in channel area due to sediment deposition (up to 20 cm) was observed at cross sections 100 and 160 m downstream of the facility. Further downstream, at 250 and 500 m, the channel was slightly larger relative to 1996 elevations due to bed erosion of up to 25 cm. Changes since 1999 were more significant than between 1998 and 1999, probably due to a series of large storms in April and May 2000, two of which overtopped the spillway, causing major erosion of the overflow berm between the pond and wetland, and considerable sediment transport downstream. Unlike other large storms, the volume and force of the overflows were sufficient to remove armour stones (approximately 10-40 cm in diameter) and erosion cloth installed to prevent scour of the overflow channel.

Wetland Vegetation Assessment

The sediments and associated seedbank from the former marsh were used in the construction of the new wetland as a means of promoting rapid post-construction establishment of plants. A survey of wetland plants indicated that this strategy was reasonably successful. A community of plants very similar to what previously existed at the former marsh had naturally re-established itself only two years after construction. The species composition was dominated by common cattails (85-90%) and reed canary grass (8-13%), with several other wetland plants forming a minor part of the vegetation community.

Operation and Maintenance

Acceptable performance levels at the Markham BMP can only be sustained if the facility is adequately maintained. Regular inspections are required for sediment accumulation, weir blockage, bank and spillway erosion, vegetation health and the occurrence of industrial spills. Sediment removal is the most costly maintenance activity. Sediment accumulation rates were estimated from flow volume and TSS data collected in 1999, and were based on the assumption that the catchment will be fully developed in 2005. At ultimate development levels, sediment accumulation rates are estimated at 15.2, 5.5 and 0.2 mm/yr in the forebay, wet pond and wetland, respectively. At these rates, the forebay, wet pond and wetland will require sediment removal roughly 21, 54 and 193 years from the time the facility became operational in 1997.

Conclusions and Recommendations

The facility met or exceeded most of the original design targets and objectives, demonstrating that significant improvement in performance can be achieved by retrofitting small single-subdivision catchment water quantity stormwater ponds to much larger and more cost-effective centralized pond-wetland treatment systems as development within the catchment increases. Observed improvements in performance can be mostly attributed to an increased storage area-to-catchment ratio and the innovative distributed runoff control structure at the wet pond outlet, which minimized the frequency of bankfull flow rates in the downstream channel and prolonged the release of stored water after an event. The wetland on the end of the treatment train also contributed to the success of the facility by improving system performance, particularly with respect to dissolved constituents.

Recommendations for system improvement, maintenance and further research are as follows.

- Erosion cloth lining the spillway was seriously damaged during a large storm event in April 2000. The cloth protects underlying soils from transport downstream during overflow events, and should be repaired so as not to endanger the health of aquatic communities within the downstream tributary.

- Bypass flow from the wetpond was discharged to the downstream portion of the wetland. As indicated above, this geometry can lead to erosion within the wetland. Future designs should, therefore, allow bypass flow around the wetland directly into the downstream channel.

- The drawdown time of the wetpond runoff control structure often exceeded the average interevent period (approximately 72 hours in Ontario). Thus, the active storage capacity available for a subsequent event would have been limited, increasing the likelihood of bypass flow. To enhance the design of future facilities, further consideration should be given to weir designs and pond hydraulics such that an optimum balance is achieved among storage, detention time, and baseflow augmentation in the downstream channel.

- The wetland outlet structure accumulated coarse bedload sediment during low flow periods. A low concrete barrier elevating the outlet structure above the wetland bed would help to trap the sediment, while sustaining a permanent pool of water in the upstream wetland cells. The permanent pool would enhance water quality functions of the wetland by increasing the bottom-to-water contact ratio.

- Estimates of sediment accumulation rates provided in this report were based on several assumptions and should not be relied upon to determine dredging requirements. For this reason, direct measurements of sediment accumulation in each of the cells and around outfalls and intake pipes are recommended at 5-year intervals.

- Drawing upon earlier studies, this report documents changes in performance of the Markham pond/wetland at different stages of development. As the catchment becomes increasingly urbanised, continued monitoring will be required to verify whether the hydrological and water quality performance of the facility continue to meet the original design targets and objectives.

- Direct assessment of urban runoff impacts on aquatic biota was beyond the scope of this study. Shifts in aquatic health often occur very gradually and therefore require long term monitoring of appropriate biological and habitat indicators. The existence of this and earlier studies on the water quality, geomorphology and health of the Morningside tributary make the Markham site well suited for long-term aquatic habitat monitoring.

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