PERFORMANCE ASSESSMENT OF A FLOW BALANCING AND WETLAND TREATMENT SYSTEM - TORONTO, ONTARIO

a report prepared by the

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
Municipal Engineers Association of Ontario
City of Toronto

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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 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 SWAMP studies.

During the mid to late 1980s, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these 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 intended to address this need.

The SWAMP Program's objectives are:

* to monitor and evaluate new and conventional 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 supporting agencies is included in Appendix A.

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- 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.

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EXECUTIVE SUMMARY

Background and Objectives

In 1990, the City of Scarborough (now part of the City of Toronto) undertook a feasibility study to examine the option of constructing a Dunkers Flow Balancing System (DFBS) at a storm sewer outfall discharging to Lake Ontario.[1] The Bluffers Park embayment, which receives stormwater and combined sewer overflows (CSOs) from the Brimley Road drainage area, was identified in the study as the most suitable of the six outfall sites for the DFBS. The study recommended that an Environmental Assessment (EA) be undertaken to determine the most appropriate strategy from a set of alternative options aimed at reducing the impacts of stormwater and CSO pollution to Lake Ontario.

An environmental assessment study was commissioned in 1993. The study reported on existing environmental conditions, identified potential impacts of stormwater and CSO discharges and evaluated alternative solutions and design concepts.[2] The preferred water quality enhancement strategies recommended for the Brimley Road Drainage area included pollution prevention (*e.g.*: water conservation, public education), roof downspout disconnection, and construction of a DFBS facility. One of the primary objectives of the flow balancing facility was to demonstrate the effectiveness of the technology in terms of contaminant reduction and habitat creation. Fulfilment of this objective was to be determined through an extensive post-construction monitoring program.

In 1999, the City of Toronto, the Ministry of the Environment and Environment Canada (Great Lakes 2000 Clean-up Fund) established a partnership to monitor the DFBS facility with respect to design and compliance parameters through the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The study was to assess the overall effectiveness of the facility in meeting its original design objectives through a detailed monitoring program conducted between May and November in 2000, 2001 and 2002. Specific objectives included:

(i) evaluating the water quality treatment efficiency of the system, with specific attention given to the concentrations of contaminants in water discharged from the facility;

(ii) assessing flow paths of stormwater discharge through the facility using dye tests; and

(iii) identifying predominant zones of settling through discrete monitoring of suspended solids and analysis of bottom sediments.

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[1] Paul Theil Associates Limited. 1991. *Feasibility Study of the Dunkers Flow Balancing System*. Prepared for the City of Scarborough.

[2] Aquafor Beech Limited. 1994. *Environmental Study Report, Brimley Road Drainage Area – Water Quality Enhancement Strategy*. Prepared for the City of Scarborough.

The water quality sampling and dye tests were to provide the basis for making recommendations on potential design improvements, operation and maintenance needs (*e.g.* dredging intervals) and transferability of the technology to other locations. These activities, together with a separate multi-year fisheries habitat and vegetation assessment currently being undertaken by the Ontario Ministry of Natural Resources, are aimed at providing a complete and balanced evaluation of the environmental performance of the technology.

Study Site

The facility treats runoff from a 171 hectare drainage area, of which 159.1 hectares are serviced by storm sewers and 11.9 hectares are serviced by combined sewers. Approximately 60% of land use within the catchment is residential, and the remaining 40% is a combination of industrial, institutional, commercial and open space. In a typical year, the combined sewers overflow roughly 15 times and comprise less than 5% of the total annual runoff.

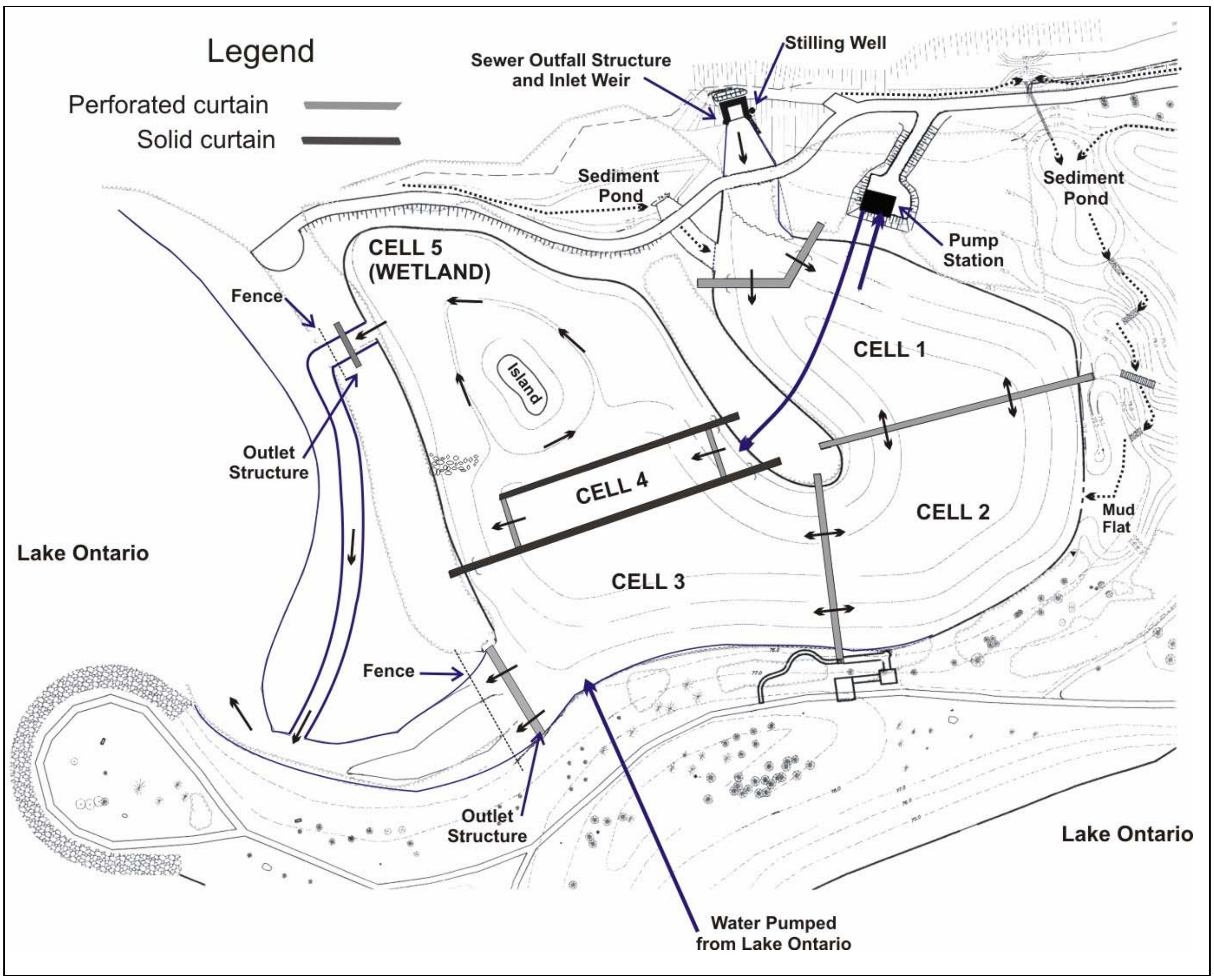

Figure 1: Flow balance and wetland treatment system schematic

The design of the City of Toronto facility was based on the Dunkers Flow Balancing System, developed in Sweden by Karl Dunkers. The facility consists of 5 cells built within a natural embayment and separated by pontoon-supported solid and perforated curtains anchored to the bottom with weights. The perforated curtains have variable width openings designed to promote plug flow conditions and minimize short-circuiting. During a rain event, stormwater enters the first cell, displacing the cleaner water into the second cell. Similarly, the remaining cells are filled in sequence before the polluted water can enter the lake. Retained water is pumped through a sedimentation cell (cell 4) and a wetland (cell 5) before being released to the lake. The volume pumped out of the storage cells is replaced by lake water that is pumped into cell 3.

The two pumps discharging into cell 3 and cell 4 operate at a constant rate of 4 m^3/min. A third pump operating at the same rate transfers water from cell 1 to cell 4 during and after wet-weather events. The second pump is triggered if the peak inflow rate exceeds 4 m^3/s. The normal hydraulic load on cells 4 and 5 is thus doubled, and the chance of discharging untreated stormwater/CSO from cell 3 is reduced. Once triggered, the second pump remains on for 60 hours. The total volume of water pumped out of cell 1 at 8 m^3/min over this period is approximately equal to the total storage volume of cells 1 to 3 (28,500 m^3).

The total storage volume of the five cells is 39,200 m^3, representing a volume per catchment hectare of 229 m^3/ha (cells 1 to 3 = 167 m^3/ha), including the 11.9 hectare CSO area. Based on a design runoff coefficient of 0.39, cells 1 to 3 would capture flow from a one-year rain event, estimated at approximately 42 mm.

Monitoring Program

Intensive monitoring was undertaken from May to December in 2000, 2001 and 2002. The monitoring program included measurements of rainfall, flow, water quality, sediment quality, water temperature and two detailed dye tests.

Flow data used in the study were determined from continuous measurements taken at the inlet flow control structure. The cell 3 outlet was not conducive to flow monitoring. Hence, for the purpose of estimating removal efficiencies, the volume of water entering and exiting the facility during rain events was assumed to be equal. Comparative inlet and outlet measurements during low flow periods confirmed this assumption to be reasonable. Water levels were also monitored continuously at 5 minute recording intervals in several cells.

Based on flow measurements at the cell 5 control structure, it was determined that approximately 25% of the total flow volume entering the facility exited via cell 5, and 75% exited cell 3. These proportions were assumed to be constant over all rain events. Varying the proportions had little effect on load-based removal efficiency estimates because effluent concentrations at the two stations were similar.

The cell 5 outlet channel was blocked by beach sediment for most of the early part of the 2000 monitoring season when lake levels were high, and over most of the 2002 season. During this period, flow through the cell 5 outlet was assumed to be zero or negligible.

Wet weather flow entering the facility overland through the sediment ponds (dotted lines in Figure 1) was discounted as it was observed to be a negligible proportion of total flow.

Water quality samples were collected with automated samplers at the inlet, the outlets of cells 3 and 5, and the inlet and outlet of cell 4. In 2001 and 2002, samples were also collected at the downstream end of cells 1 and 2. Sampling was conducted during dry and wet weather, as well as during the 'post event' period as the contents of cells 1 to 3 were pumped to cell 4 and out to the lake. Analysis was conducted by the Ontario Ministry of the Environment laboratories following standard methods for general chemistry (e.g. pH, alkalinity, conductivity), metals, nutrients (P and N), bacteria, polynuclear aromatic hydrocarbons (PAHs), herbicides/pesticides, and toxicity.

Water temperature was monitored continuously every 30 minutes at the inlet and at the cell 3 and cell 5 outlets. In 2002, temperature was measured at 10 minute intervals near the outlet to cell 1 at 0.5, 1.5 and 2.5 m below the dry weather water surface. The depth integrated measurements indicated the degree of thermal stratification present in the pond during the summer, and provided insights into flow dynamics during storm events.

Bottom sediment samples were collected on November 16th, 2001 in cell 1, cell 3, cell 4, cell 5, and in Lake Ontario, both downstream of the outlet channels and at a control site on the south side of the embayment. All sites were sampled in triplicate using an Ekman Dredge and processed according to established protocols. Samples were analyzed for general chemistry, metals, nutrients, PAHs, PCBs and organochlorine pesticides.

Two dye tests were conducted during the 2001 monitoring season. The first test was conducted during a wet-weather event on October 23rd to measure flow paths of stormwater through the facility. The second test, conducted on November 21st, traced the flow path of lake water being pumped into cell 3 during dry weather.

Study Results

Water quantity

Flow was monitored for 110 rain and snowmelt events. Combined sewer overflows occurred during 32 of these events, but represented only 1.6% of the total runoff volume. Average runoff coefficients were relatively consistent over the three monitoring seasons, with seasonal averages ranging from 0.29 to 0.32.

Comparison of continuous water level measurements on either side of the solid curtain separating cell 4/5 from cell 3 showed negligible differences in water level fluctuations during runoff events. If the pump station were the only source of flow into cell 4/5, a greater differential in water levels would have been expected. Dye tests in cell 4 later confirmed that flow around or under the curtain - and possibly flow through holes or tears in the curtain - were allowing significant runoff to enter cells 4 and 5 from cell 3.

Dye Tests

A wet weather dye test was conducted to assess the hydraulic efficiency of the system. This test was conducted during a relatively small but intense event (7.1 mm over 1.5 hours). Detailed sampling and volumetric calculations indicated that new influent water (represented by the dye) moved much further and over a shorter period of time than would be expected under plug flow conditions. Samples collected off two pontoons at various water depths revealed that the influent water was not vertically integrated. Instead of displacing water in the cells, the new influent water moves first across the surface and only later mixes with cell contents.

The purpose of the dry weather dye test was to chart the course of water pumped (at a rate of 4 m^3/min) into cell 3 from the lake. From cell 3 the water could either exit cell 3 or move back towards cell 1 where it would be pumped into cell 4 and flow through cell 5 out to the lake. Dry-weather test results demonstrated that, as intended, the majority of the lake water pumped into cell 3 moved toward cell 1 and was subsequently transferred to cells 4 and 5. However, residence time calculations indicated significant departure from plug flow conditions. Observations of dye patterns in cells 3 and 2 in particular revealed that the recirculation patterns are very complex and, at least at the surface, are strongly influenced by wind speed and direction.

Settling Dynamics

Discrete total suspended solids (TSS) monitoring during selected wet weather events at seven locations within the facility provided the basis for characterizing the movement of suspended solids through the facility, and identifying predominant zones of settling. Cell 1 was the major zone of deposition; at least 60% of the influent TSS load during wet weather events was removed in this cell. An additional 15-25% of the TSS load was removed in cells 2 and 3. Not all of the solid mass ‘removed’ in these cells was deposited there; a portion is pumped to cell 4 during and after the rain events.

As expected, mass peaks in TSS decreased with increasing distance from the inlet. During large events, a 15-20 minute time delay was typically observed between mass peaks at the inlet and cell 1, and between cell 1 and cell 2. Most events discretely sampled showed outlet suspended solids concentrations at or close to background levels over the duration of storm outflows, indicating that the facility was successful in storing and treating the majority of solids discharged into the facility.

Particle size analysis results demonstrated that the facility was effective in removing all particle sizes greater than 30 μm. The median suspended particle size of 7.5 μm in the influent was reduced to 3.5 μm at the pump intake to cell 4 and to 2 μm at the two outlet stations. Other studies of detention basins conducted by SWAMP suggest that even with larger permanent pools and longer settling times, it is not practical to expect reductions beyond a median effluent particle size of 2 μm.

Water Quality

The wet weather effluent water quality data set consisted of 52 and 38 samples collected at the cell 5 and 3 outlets, respectively. Water samples were analyzed for a wide range of water quality variables. As there are no effluent standards in Ontario, effluent concentrations were compared to provincial receiving water quality guidelines.

Only total phosphorus and *E.coli* had median effluent event mean concentrations (EMCs) above receiving water guidelines (Table 1). Concentrations of both constituents were at the low end of the range of effluent concentrations reported for other 'enhanced' protection level end of pipe facilities monitored in the GTA (see other SWAMP studies in this series).

Effluent concentrations of TSS were below levels considered detrimental to aquatic life. Average TSS event mean concentrations were 11 and 14 mg/L at the two outlets, with a range from 3 to 67 mg/L.

All samples tested for acute toxicity, including the facility influent, were found to be non-lethal to test organisms.

Table 1: Wet weather effluent quality and performance summary for selected constituents

Variable	**Receiving Water Guideline**	**Median Effluent Concentrations[1]**		**Overall % removal[2]**
		Cell 3	**Cell 5**	
Total suspended solids	n/a	11.2 mg/L	13.8 mg/L	81
Total phosphorus	0.03 mg/L	0.07 mg/L	0.06 mg/L	77
Lead	5 µg/L	< RMDL[3]	< RMDL[3]	73
Copper	5 µg/L	4.1 µg/L	3.4 µg/L	85
Zinc	20 µg/L	10 µg/L	7 µg/L	89
E. coli	100 CFU/100 mL	240 CFU/100 mL	60 CFU/100 ml	75

Notes: 1. n = 52 and 38 at the cell 3 and 5 outlets, respectively. The *E. coli* data set was smaller: n = 10 and 7, respectively.
2. Values represent load based removal efficiencies. n = 30 for TSS, n = 11 for all other variables except *E.coli* (n = 4).
3. RMDL = reporting method detection limit.

Although effluent concentrations of indicator bacteria were within the expected range, there was some concern that *E.coli* inputs to the lake from the facility could contribute to poor water quality at Bluffers Park beach, which is located less than half a kilometre east of the site. Comparison of *E.coli* levels in facility effluents with daily sampling results at the beach and grab samples collected in the lake downstream of the outlets did not suggest any connection between facility effluents and beach concentrations of *E.coli*.

Pollutant Removal

Total suspended solids removal efficiencies were calculated for 30 rain events, of which 14 were classified as small (<10 mm), 6 as mid sized (10 – 20 mm) and 10 as large (>20 mm). The average size of the 30 storm events was 14 mm, with a range between 3 and 31 mm.

The overall load based TSS removal efficiency for these storm events was 81% (Table 1). This rate compares favourably to the 60% design target for the facility. Storms with more than 20 mm of rain tended to have lower removal efficiencies (74%) and higher effluent TSS event mean concentrations (24 mg/L) than events with less than 20 mm (91% and 12 mg/L respectively).

The facility was designed to store and treat runoff from storms as large as 42 mm in size. A storm as large as 42 mm was not observed during the study period, however two back-to-back events, each with approximately 25 mm of rainfall, had removal efficiencies of 72 and 80%, indicating that if 50 mm falls over a 48 hour period, the facility would be reasonably effective in treating most of the volume discharged.

Sediment Quality

Sediment chemistry samples collected at various locations both in and downstream of the facility showed progressively better sediment quality with distance from the inlet. Among the samples collected within the facility, cell 5 sediment was the cleanest, and was the only cell where sediment quality met the MOE's 'lowest effect level' guidelines for the protection of aquatic life.

Average sediment particle size distributions (PSD) at the chemistry sampling sites indicated that influent sediment loads are settling out primarily in cells 1 to 4, and that only a small proportion of the very fine suspended solids entering cell 5 are being deposited in this cell.

Operation and Maintenance

Functional components in the Dunkers facility requiring on-going maintenance include the pontoons, cell divider curtains, recirculation pumps, weirs and outlet channels. The life expectancy for these components ranges from 15 years for the pumps to 35 years for pontoons if they are maintained appropriately.

The cell 5 outlet channel was originally designed to discharge to the lake westward via a short and straight channel section. However, natural coastal geomorphic processes resulted in beach sand being pushed or carried into the channel when lake levels were high, causing flow through this outlet to be blocked. The channel eventually formed its own channel parallel to the beach such that it discharges in a location sheltered from the waves (Figure 1). This longer, naturally formed channel has required less frequent maintenance and dredging than the original channel.

Other operational issues included holes and tears in the solid curtains caused by beavers, and damage to the lake inlet pipe from shore currents. These components of the Dunkers system must be carefully designed to avoid frequent and expensive repairs.

Periodic removal of contaminated sediments deposited in the facility is crucial to ensure the facility continues to function effectively. Based on measured sediment loads and removal rates, it was estimated that clean-out of deposited solids in cells 1 and 4 would be required after 32 and 22 years following construction, respectively. Other cells would need dredging less frequently.

Conclusions and Recommendations

The primary goal of the three year monitoring study was to evaluate the effectiveness of the Toronto Dunkers Flow Balancing System in reducing influent concentrations of suspended solids and associated contaminants from storm and combined sewage discharge. Fulfilment of this objective was achieved through co-ordinated monitoring of rainfall, flow and water quality, dye tests, sediment sampling, and discrete suspended solids monitoring at multiple locations within the facility. Although the pumps were not operating as designed for the entire study period, and the smaller of the two outlets was intermittently blocked with beach sediment, the system nevertheless performed exceptionally well, exceeding the original design targets with respect to water quality treatment.

The following recommendations are provided based on study results and observations made during the course of the monitoring study.

1. The outlet channel to cell 5 was periodically blocked with sediment throughout the study period, especially when lake water levels were high. Dredging the channel parallel to the beach appears to have been an effective and relatively low cost solution to this problem for the past two years. However, if the problem persists in future high lake water level years, consideration should be given to other alternatives, such as a buried pipe where the current channel lies, to ensure uninterrupted conveyance of cell 5 flows to the lake.

2. Bottom sediments should be removed every 4 to 6 years from the cell 1 and cell 4 forebays to avoid re-suspension and distribution of this sediment over the remaining cells, and to extend the period over which dredging of the entire facility would be required. The precise interval of sediment removal should be determined from direct measurements of sediment accumulation in these areas.

3. Sediment sampling results and dye test residence time calculations suggested that flow in cell 5 was short circuiting along the west side of the island. Extending the cobblestone spit immediately downstream of the cell 4 outlet would help to improve residence time by diverting flow around the east side of the island.

4. As mentioned earlier, there was significant flow across the solid curtain separating cell 3 from cells 4 and 5, even after the City repaired and re-anchored the curtain to the bottom in November, 2001. Despite the relatively pervious nature of the curtain, however, the facility provided excellent water quality treatment. Further, the quality of wetland sediments met provincial sediment quality standards, suggesting that the water that is entering from cell 3 (probably from the bottom of the cell) is relatively free of contaminated sediment. It is recommended, therefore, that no further attempts be made to repair the curtain, and that the facility continue to operate as a more connected unit than was intended in the original design.

5. Residence times in the original design brief for the facility were calculated on the assumption of plug-flow conditions (no mixing of the influent flow and facility contents). Dye tests and suspended solids monitoring demonstrated that the plug flow assumption is not valid, even as an approximation of actual conditions. In reality, considerable mixing occurs and influent sediment plumes travel much further than would be anticipated under strict plug flow conditions. Future flow balancing systems of a similar design should be based on conceptual and physical models that better represent the underlying complexity of the system and processes involved.

6. In the initial planning stages of the project, there was some discussion about whether the treatment effectiveness of the facility would be significantly compromised if cell 5 was entirely isolated from the system by impermeable barriers and functioned solely as wetland habitat. In this scenario, all stormwater flows would pass through cells 1 to 3 before exiting to the lake and the recirculation pumps would be removed or relocated. The findings of this study suggest that this change in design would likely reduce the capacity of the facility to treat flows. Cell 5 provides an important polishing function to flows that are pumped through cell 4. If flows were restricted entirely to cells 1 to 3, flow rates and volumes exiting cell 3 would increase, resulting in shorter residence times and poorer overall removal. The current design has been shown to provide reasonably good quality habitat for aquatic life while providing ancillary benefits in terms of treatment. Changes to the existing design are, therefore, not recommended.

7. Further study is required to determine whether the pumps provide an indispensable benefit to the system both in terms of increased residence times and better circulation during dry weather. The results collected thus far appear to suggest that the pumps are dispensable. There was, for instance, no difference in the quality of effluent or efficiency of removal when the lake pump was shut down for extended periods. Continuous influent baseflow of between 5 and 15 L/s provides a recirculation function, similar to that of the pumps (albeit at a considerably lower rate). If the cell 1 pumps were shutdown, flow would still enter cells 4 and 5 via cell 3 through the curtain; this flow path could be opened up further if necessary, preferably at the downstream end. Water entering cell 5 from cell 3 is relatively clean, since most of the treatment occurs in the first two cells. Hence, shut-down of the pumps would not jeopardize the function of the wetland as habitat for waterfowl and aquatic life. Further consideration of the utility of 'pump-back' in flow balancing systems should consider

monitoring results from the flow-balancing system in Etobicoke, which provides passive treatment through a series of interconnected cells separated by solid and perforated curtains attached to pontoons.

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