SWAMP

Performance Assessment of a Highway Stormwater Quality Retention Pond - Rouge River, Toronto, Ontario

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Ministry of the Environment
Ontario

Toronto and Region Conservation

Ministry of Transportation
Ontario

PERFORMANCE ASSESSMENT OF A HIGHWAY STORMWATER QUALITY RETENTION POND

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ROUGE RIVER, 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
Ontario Ministry of Transportation

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NOTICE

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The initial version of this report was prepared by SWAMP. Additional data analysis and editing were undertaken by Questor Veritas Inc. under contract to the SWAMP program as represented by the Toronto and Region Conservation Authority. Questor Veritas did not have access to all of the original work, notably those portions of the work that were undertaken using statistical analysis software. Questor Veritas can not attest to the methodology or integrity of specific portions of the report.

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 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.

Since the mid 1980s, the Great Lakes Basin has 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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This report was prepared for the Steering Committee of the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The Steering Committee of the SWAMP Program 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.

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EXECUTIVE SUMMARY

Background

The Ontario Ministry of Transportation (MTO) has constructed a stormwater management pond for the control of runoff from a portion of Highway 401 in the vicinity of the Rouge River in Toronto. The Stormwater Assessment Monitoring and Performance (SWAMP) Program undertook a monitoring study at that pond site between 1995 and 1997. SWAMP examined the hydraulic and chemical characteristics of the facility. Other agencies examined aquatic vegetation, the algal community and runoff toxicity. This report presents the results of those studies.

Historically, highway runoff has been managed by draining it from the pavement as quickly as possible, minimizing the entry of water into the granular road base, and discharging the flow from the right-of-way at the nearest watercourse. More recently, studies have shown that runoff from various sources causes impairment of receiving waters. Consequently, many runoff management priorities are being re-examined and programs are being expanded.

Highway runoff contains a variety of contaminants including heavy metals and hydrocarbons. Specific materials include rubber residue from tire wear, auto body rust and eroded plating, spilled or leaked oil and fuel, hydrocarbons from exhaust, metal and other materials worn from bearings, bushings and brake linings, and hydrocarbons leached from asphaltic pavement. Other contaminants include chloride, sodium, and calcium from de-icing materials, nitrogen and phosphorus from roadside fertilizer applications, and pathogenic bacteria from animal waste. Recent studies have also shown that highway runoff can be toxic to aquatic organisms.

Objectives

The principal objective of the study was to evaluate the ability of the wet pond to mitigate both hydraulic and water quality impacts on the receiving stream. The monitoring program included an assessment of hydrology, water chemistry, thermal impacts, toxicity and the algal community in the pond. An additional objective was to monitor the growth of plants in and around the pond to examine the success of the planting program.

The Site

The stormwater facility at Highway 401 and the Rouge River (Figure 1) was constructed in 1995 by the Ontario Ministry of Transportation to address water quality and fishery concerns originating from highway runoff. Approximately 75% of the drainage area is used for transportation, while the remaining 25% is primarily residential. The pond is approximately 300 m long with a top width varying from 25 to 40 m. The sediment forebay is 80 m in length and 20 m to 40 m in width, and it makes up approximately 14% of the total permanent pool volume.

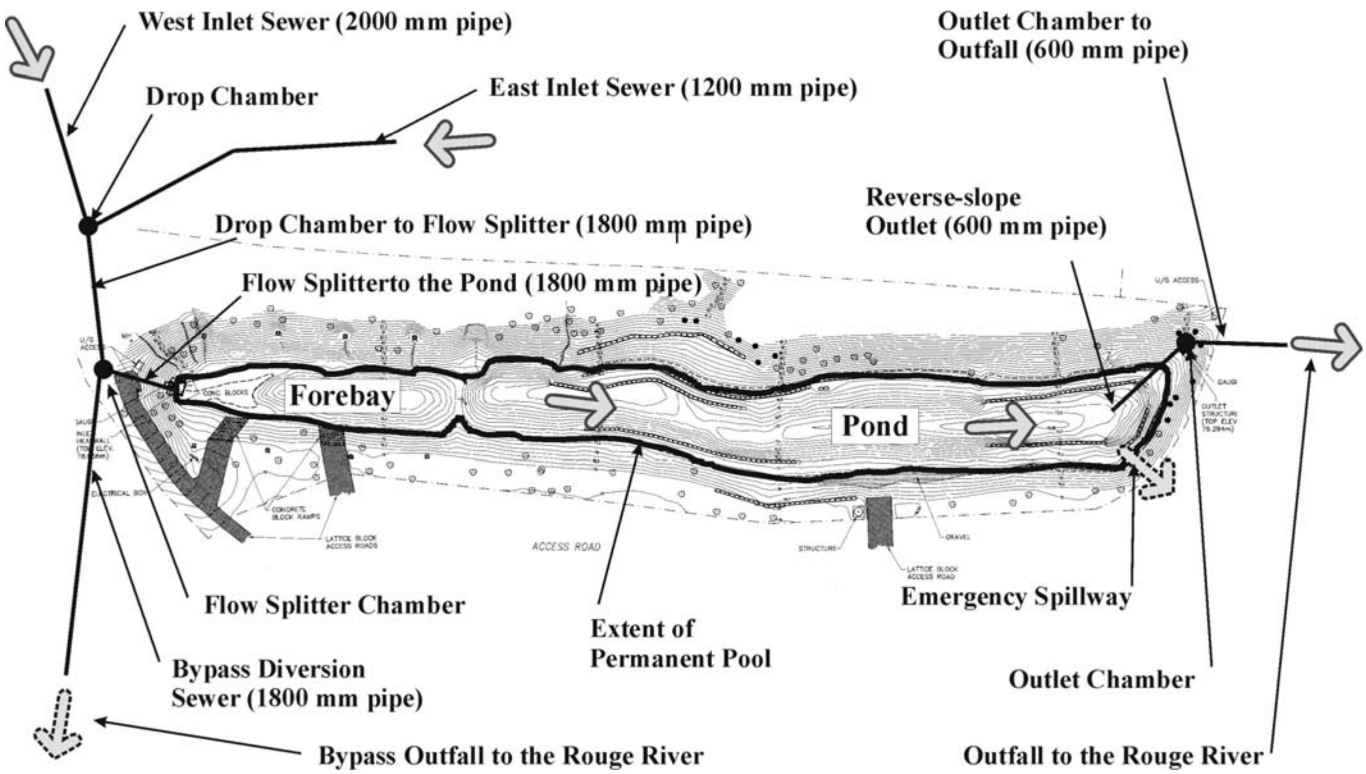

Figure 1: Rouge stormwater management pond

The pond discharges its outlet flow to the Rouge River through a reverse-slope pipe that traps floating matter and warm surface water in the pond. An overflow weir in the storm sewer upstream of the pond diverts flows greater than those of a two-year return period event directly to the river.

Study Methods

Assessment of the stormwater pond was based on coordinated measurements of runoff volume, water quality and water temperature at the inlet and outlet during the summer/fall periods (May to November) and on grab samples for water quality during the winter/spring periods (December to April) from 1995 to 1997. During the summer/fall period, separate assessments of wetland vegetation and the pond algal community were undertaken to provide additional insights into the effectiveness of the planting program and the ecological status of the pond.

Flows were measured using area-velocity probes in the inlet and outlet pipes. A level sensor was also installed in the overflow (splitter) chamber for much of the study period. Rain was measured either on site or at the adjacent park. Inlet samples were collected automatically using a time-based composite sampler. Outlet samples were collected automatically using a flow-proportioned composite sampler. Grab samples were collected to characterize the inlet and outlet during the winter. All samples were analyzed by the Ontario Ministry of the Environment.

The aquatic vegetation monitoring component was conducted by the Toronto and Region Conservation Authority during 1996 and 1997. The goal of the study was to develop a list of recommended vascular wetland plant species and recommended planting strategies for stormwater management pond projects in the Greater Toronto Area.

The algal community assessment component was conducted by Daniel D. Olding, Consulting Biologist, under contract to the Toronto and Region Conservation Authority during 1996 and 1997. Algae were used as an indicator of ecological and water quality conditions of the forebay and wet pond.

Toxicity tests were undertaken by the Ontario Ministry of the Environment.

Study Findings

Monitoring began during the reconstruction of the highway and before the landscape contractor had completed the planting work in the pond. Consequently, the initial water quality data were atypical of normal operation (May 1995 to August 1996). The volumetric balance measured across the pond was poor during the construction period as a result of flow diversions and pond draining operations. However, data obtained from the post-construction period (September 1996 to September 1997) provided reasonable volumetric balances and good water quality data.

From the perspective of hydraulic performance, the principal function of a stormwater pond is to reduce the impact of elevated storm flows on downstream areas. This task is accomplished by detaining, or holding back, some of the flow to distribute the runoff over a longer time period.

The amount by which the runoff peak was reduced by the pond is quantified as the ratio of the outlet peak flow to the inlet peak flow, expressed as a percentage. For those events reporting both influent and effluent flows, the average peak ratio was 47%, with a range of 20% to 81%.

Another parameter commonly used to quantify pond performance is the drawdown time, the time between the attainment of the maximum storage volume and the end of flow or re-establishment of baseflow. A lengthy drawdown time promotes more uniform flow and healthy downstream environmental conditions. However, an excessive drawdown time would reduce the storage volume available for subsequent events. The range of operational drawdown times was 11.5 to 95.6 hours, with an average value of 33.9 hours. Operational drawdown times may be influenced by runoff occurring after the maximum storage volume has been reached. The observations should not be confused with theoretical values calculated in the absence of continuing inflow.

The hydraulic detention time is the time interval between the centroids of the influent and effluent hydrographs. It is the average time by which the flow is detained by the facility. The average detention time was 1.9 hours. The maximum detention time was 5.3 hours. The minimum value was affected by poor data quality and was reported as a negative number.

Table 1 summarizes the influent and effluent concentrations for selected stormwater constituents and the respective removal efficiencies as determined for the summer/fall post-construction monitoring period. Removal efficiency was computed as seasonal load-based values; event concentrations were volume-weighted in this procedure. Average concentrations were calculated using a statistical procedure that accommodates the characteristics of laboratory results; they were not volume-weighted. Twenty-one of the twenty-eight post-construction events were sampled for water quality. Overall, the removal of suspended material and related pollutants was very good.

There were very large increases in the chloride concentration and conductivity across the pond during the summer/fall monitoring period. Deicing salt is applied to the highway in winter. Because salt water is more dense than fresh water, the salt tends to sink to the bottom of pond. The typically slow melting and runoff rates in winter, coupled with ice cover that protects the pond contents from wind-driven mixing, permit the formation of density stratification in the pond. During the summer and fall, when little residual salt is entering the pond, molecular diffusion and turbulence caused by storm flows and wind tend to disperse some of the stored salt and cause it to be discharged in the effluent.

The pond was responsible for a modest average increase in runoff temperature. The effect was more pronounced in July and August, with increases of about 6 to 7 degrees Celsius. In October and November there was essentially no change in the water temperature across the pond. Average outlet temperatures of 20 to 22 degrees Celsius in the summer months would be expected to stress cold-water organisms. However, the temperature of the Rouge River was generally greater than that of the pond outflow during the summer.

A total of nine influent and nine effluent samples were submitted for toxicity testing using two single-species bioassays, the *Daphnia magna* 48-hour acute lethality test and the rainbow trout 96-hour acute lethality test. Based on these samples, the runoff was found to be occasionally toxic for *Daphnia magna* and non-lethal for rainbow trout. One of the nine samples from the inlet, and three samples from the outlet, were toxic to *Daphnia magna*. Chloride compounds might have caused the toxicity to *Daphnia magna*, for the samples found to be toxic were all collected during the winter when the chloride concentrations were at their highest. Chloride concentrations above 3,000 mg/l are known to be toxic to *Daphnia magna*.

Table 1: Performance summary -- summer/fall post-construction period

Parameter	Units	RMDL[1]	Summer/Fall Post-Construction		
			In[2]	Out[2]	% Removal[3]
Suspended Solids	mg/l	2.5	331	37	90
Turbidity	FTU	0.01	209.92	33.82	83
Aluminum	mg/l	0.011	0.945	0.263	73
Chromium	mg/l	0.0014	0.0085	0.0020	79
Copper	mg/l	0.0016	0.0521	0.0102	85
Iron	mg/l	0.0008	1.4666	0.4707	72
Lead	mg/l	0.01	0.03	0.01	88
Mercury	µg/l	0.02	0.02	0.01	44
Nickel	mg/l	0.0013	0.0068	0.0024	75
Zinc	mg/l	0.0006	0.3021	0.0672	84
Nitrogen, Total Kjeldahl	mg/l	0.02	2.00	0.75	70
Phosphorus , Total	mg/l	0.002	0.393	0.060	85
Phosphate	mg/l	0.0005	0.0309	0.0067	78
Dissolved Carbon , Organic	mg/l	0.1	9.3	3.1	73
Oil and Grease	mg/l	1	9	1	87
Pentachlorophenol	ng/l	10	69	41	58
Chloride	mg/l	0.2	205.7	579.5	-86
Conductivity	µS/cm	1	949	2269	-58
Dissolved Carbon , Inorganic	mg/l	0.2	23.6	47.7	-35
pH	nil	0.1	7.9	8.2	-3.8
Alkalinity	mg/l	0.2	103.4	205.0	-29
E. Coli	# / 100 mL	4	3071	356	83
Fecal Coliforms	# / 100 mL	4	6517	783	73

1 Reporting Method Detection Limit, as reported by the analytical laboratory

2 Average event mean concentrations (AEMC) as determined by a statistical routine that accommodates left-censored data and uses log-normal distributions. The inlet samples were time-proportioned composites. The outlet samples were flow-proportioned composites. The seasonal mean values are not proportioned to event volumes.

3 Seasonal removal efficiency is load-based, calculated using event volume weighting except for pH and conductivity which are simple averages.

The vegetation monitoring study determined that all the introduced plant species were still present in the facility after three growing seasons. All the areas planted, except one, had thrived and expanded. A grouping of 44 soft-stem bulrush was planted adjacent to the submerged weir in the main pond. These plants had survived along the pond edges but did not expand out into the pond, presumably because currents in that area impeded the growth of the plant. Seventy-six aquatic and meadow marsh plant species naturally colonized the main pond area within two growing seasons. During the same period, 50 aquatic and meadow marsh plant species had naturally colonized the sediment forebay. The natural colonization was probably brought about through wind, water and animal transportation. Vegetation communities at this site showed a tendency to evolve toward a common group of dominant species.

The algae found in the Rouge Pond, while having some ubiquitous taxa and some representatives indicative of nutrient rich conditions, showed an exceptional number of salt tolerant marine or brackish water diatoms. The quality of incoming stormwater had a strong impact on the algal composition present in the sediment forebay. The degraded algal communities at this location suggested that poor runoff quality had been experienced. The periphyton in the forebay was characterized as being extremely species poor, with only four taxa recorded. The impact was likely caused by the quality of the sediments since the phytoplankton community, which uptake their nutrients from the water column, did not seem to be affected in the same manner. The bio-volume of the phytoplankton community was sparse, and the periphyton communities were impaired. Toward the quiescent treatment zone of the pond, the number of species in both the phytoplankton and periphyton community increased, and the impairment of the periphyton diminished.

Design Guidelines

The Stormwater Management Planning and Design (SWMPD) Manual issued by the Ontario Ministry of the Environment refers to three protection levels. The highest level, "enhanced", is equated to 80% long-term TSS removal. The "normal" level is associated with 70% long-term TSS removal.

The preliminary design report indicates that two simulation programs, SWMM and POND, were used to design the facility. The expected TSS removal efficiency was approximately 70% based on the models used. The selected size was an optimum point on the performance versus size curve.

The SWMPD Manual provides sizing guidelines for wet ponds, expressing pond size in cubic metres per hectare of drainage basin for the three protection levels and for various levels of catchment imperviousness. The Rouge Pond has a volume of 21,000 m^3 and a tributary area of 129 ha, resulting in a design size of 163 m^3/ha. For that size of pond, and for an average level of imperviousness of 45%, an enhanced level of performance would be expected according to the manual. The actual performance of the facility exceeded the enhanced level. The Rouge Pond had a seasonal average TSS removal efficiency of 90%. The excellent performance of the facility may be attributed to its large length-to-width ratio, which tends to promote plug-flow conditions and minimizes short-circuiting of flow through the pond.

Conclusions

- The highway stormwater management pond was monitored during and after highway reconstruction. Flow balances could not be achieved during the construction period (prior to September, 1996) but the water quality data are considered to be of value in characterizing construction period conditions. The post-construction period (September, 1996 to September 1997) produced data that are considered to be representative of the normal performance of this facility.
- The average peak ratio, measured as the ratio of the outlet peak flow to the inlet peak flow, was 47% with a range of 20 to 81%. The hydraulic detention time, measured as the time lag between the inlet and outlet hydrograph centroids, was approximately 2 hours. The operational drawdown time, measured as the time lag from the maximum storage volume to the re-attainment of baseflow conditions, was approximately 34 hours. This performance is considered to provide a significant reduction in the hydraulic impact of runoff on the receiving stream. However, a detention time of 24 hours is generally recommended as a design parameter. Hydraulic residence time was not measured in this study.
- During the post-construction summer/fall monitoring period the pond achieved an average TSS removal efficiency of 90%. The mean inlet TSS concentration was 331 mg/L, and the mean outlet concentration was 37 mg/L. Turbidity and particle size measurements also indicated a substantial reduction in the amount of suspended material.
- Substantial removals were also observed for metals. Greater than 80% removal was achieved for copper, lead and zinc. Removals of chromium, nickel, aluminum and iron were between 70 and 80%.
- The total phosphorus concentration was reduced 85% and the total Kjeldahl nitrogen concentration was reduced 70%.
- Among the 41 organic parameters (herbicides, pesticides and PAH's) analyzed in this study, only pentachlorophenol was found at concentrations consistently above laboratory detection limit; its removal efficiency was 58%. A second compound, 2,3,4,6 tetrachlorophenol, was measured at concentrations close to the detection limit; the estimated removal efficiency was 26%.
- On average, the outlet water temperature was only 3^{o} C warmer than the pond influent. In summer, the temperature increase across the facility was approximately 6 to 7^{o} C resulting in effluent temperatures generally ranging from 20 to 22 degrees (peak temperature observation = 27^{o} C). The temperature of water in the Rouge River tended to be greater than that of the pond effluent.
- Chemo-stratification was found to occur in the pond, with significant increases in conductivity observed within approximately 1 m of the bottom of the pond. Salt applied to the highway in winter was found to be exported from the pond during the summer/fall monitoring period, resulting in negative removals of chloride and conductivity. Although most of the stratified salt water was apparently below the inlet of the reversed-slope discharge pipe, the design of the outlet may have contributed to the release of the salt.
- The runoff was found to be predominantly non-lethal. However, acute toxicity was occasionally detected. Chloride was considered to be the probably cause of occasional toxicity detected for *Daphnia magna*.

- Vegetation monitoring results indicated that diversity of native plants increased from 13 to 81 within a period of two years. The communities tended to evolve towards a common group of dominant species. These observations suggested that natural colonization could be adopted as an effective planting strategy. In a situation when a head start in vegetation is required, a reduced diversity of planting species and materials in the initial planting plan can be considered.
- The algae found in the Rouge Pond, while having some ubiquitous taxa and some representatives indicative of nutrient rich conditions, showed an exceptional number of salt tolerant marine or brackish water diatoms.

Recommendations

Regarding facility design and operation:

- The detention time measured in this facility was less than the 24 hours generally recommended for stormwater ponds. The outlet throttling gate was fully open during the study. Consideration should be given to operating the facility with the gate partially closed to increase the detention time, providing that overflows through the grating at the top of the outlet structure are held to a minimum number and volume. Specific recommendations can not be made at this time because of uncertainty related to the water levels in the pond during the study period. The installation of a water level monitor in the pond would facilitate appropriate adjustment for optimum pond performance.
- The geometry of the pond was very effective. The 10:1 length to width ratio promotes plug flow conditions. Future pond designs would benefit from similar geometry. Where land of an appropriate shape is not available, the use of berms and baffles to promote plug-flow conditions should be considered.
- Further consideration should be given to the design of outlet structures of the type used in this facility. The low-level intake was presumably successful in reducing the discharge of floating material and in controlling the thermal impact of the pond on the receiving water. However, the geometry of the system reduces the sediment storage capacity of the pond and shortens the sediment clean out interval. The low-level intake also promotes the release of accumulated salt. This latter consideration will remain academic until some possible future time when mobile desalination facilities may be considered as feasible components of pond maintenance programs.

Regarding monitoring programs:

- Monitoring programs intended to provide data on normal operating conditions should be started after all construction activity has ceased and after environmental factors such as vegetation have stabilized to at least some extent. Those programs designed to monitor sediment removal during construction should select sites where the inlet sewers and the pond contents will not be changed while the study is under way.

- Future pond monitoring programs should make use of back-up flow sensors, and combine flow measurement with pond surface level measurement, to ensure that throughput and storage volumes are adequately quantified.
- Further consideration should be given to road salt management programs, to studies of the presence of salt in stormwater management facilities and to potential desalting operations.

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