Evaluation of sediment control pond performance at construction sites in the Greater Toronto Area

B. Gharabaghi, A. Fata, T. Van Seters, R.P. Rudra, G. MacMillan, D. Smith, J.Y. Li, A. Bradford, and G. Tesa

Abstract: Receiving water quality concerns associated with increased construction activities in recent years in the Greater Toronto Area has prompted the Toronto and Region Conservation Authority (TRCA) to evaluate design criteria for sediment control ponds employed during the construction period. Stormwater management ponds located in the towns of Richmond Hill and Markham were monitored to obtain stormwater runoff quantity and influent–effluent quality data during site development. The ponds were designed and constructed in accordance with the Ontario Ministry of the Environment *Stormwater management planning and design manual 2003* for an enhanced level of protection (i.e., 80% total suspended solids removal). A hydrodynamic and sediment-transport model was used to examine the effect of pond geometry on sediment removal efficiency under varying storm events. The monitoring data and the modelling results clearly demonstrate the importance of proper pond size and geometry design. This paper focuses on the effect of the ratio of pond length to pond width in minimizing the short-circuiting effect and improvement of the sediment removal efficiency of stormwater management ponds. The results of this study will be useful in updating the design criteria for stormwater management ponds.

Key words: stormwater, management, pond, design, sediment.

Résumé : Après avoir reçu des messages de préoccupation concernant la qualité de l'eau dans la région du Grand Toronto suite à l'augmentation des activités de construction au cours des récentes années, l'Office de protection de la nature de Toronto et de la région (« TRCA »), a décidé d'évaluer les critères de conception des étangs de contrôle des sédiments utilisés durant la période de construction. Des étangs de gestion des eaux de ruissellement situés dans les villes de Richmond Hill et de Markham ont été suivis pour obtenir des donnés sur la quantité d'eaux de ruissellement et sur la qualité de l'influent/effluent durant l'aménagement des sites. Les étangs étaient conçus et construits selon le « *Stormwater management planning and design manual 2003* » (manuel de conception et de planification de la gestion des eaux de ruissellement du ministère de l'Environnement de l'Ontario) pour un niveau de protection accru (c.-à-d. élimination de total des solides en suspension à 80 %). Un modèle hydrodynamique et de transport des sédiments a été utilisé pour étudier l'effet de la géométrie des étangs sur l'efficacité d'élimination des sédiments lors de différents événements pluvio-hydrologiques. Les données de suivi et les résultats de la modélisation démontrent clairement l'importance d'avoir des étangs bien conçus et bien dimensionnés. Cet article met l'emphase sur l'effet du rapport longueur–largeur de l'étang à minimiser l'effet de court-circuitage et l'amélioration de l'efficacité de l'élimination des sédiments des étangs de gestion des eaux de ruissellement. Les résultats de cette étude seront utiles pour la mise à jour des critères de conception des étangs de gestion des eaux de ruissellement.

Mots clés : eaux de ruissellement, gestion, étang, conception, sédiment.

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Introduction

Urban centres in Ontario are undergoing rapid growth and development. Hundreds of active construction sites in the Greater Toronto Area are at risk of contributing to stormwater runoff pollution and receiving water quality concerns. In 2000, a workshop presented by the Great Lakes Science Advisory Board assessing the status of non-point source pollution control in the Great Lakes Basin identified that construction sites are significant sources of sediments to urban

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streams (Clarifica Inc. 2004). If left unchecked, runoff pollution from urbanizing watersheds, especially from construction sites, will increase sediment loads to receiving watercourses and ultimately Lake Ontario, resulting in degraded aquatic habitats, poor water quality, and higher risks to public health.

To develop a sustainable solution for this problem, industries, governments, and nongovernment organizations such as the Ontario Ministry of the Environment (OMOE) are in the process of evaluating and updating design criteria for controlling sediment transport in urban areas under development (Bradford and Gharabaghi 2004). Excessive turbidity blocks sunlight penetration, reducing photosynthesis by algae and aquatic plants and thus food production for aquatic life (Henley et al. 2000; Birtwell 1999). Suspended sediments provide surfaces upon which other contaminants such as heavy metals and chemicals can adsorb (Clark et al. 2003). Due to the close relationship between total suspended solids (TSS) and various stormwater pollutants, TSS concentrations are often used as an indicator of stream health (OMOE 2003).

The European Inland Fisheries Advisory Commission (1965) reported that TSS concentrations above 80 mg/L are harmful to fish, and concentrations below 25 mg/L are tolerable. Several options exist to remove suspended solids from runoff, but wet ponds are the most common type of stormwater management facility in Ontario (OMOE 2003). Settling is the primary mechanism for removal of TSS in construction sediment ponds, although physical and biochemical flocculation can be significant between rainfall events or during long residence times within ponds (OMOE 2003). According to the OMOE *Stormwater management planning and design manual 2003*, treatment targets typically range from a minimum 60% removal to 80% removal of suspended solids (OMOE 2003). The sizing and treatment criteria are not intended to apply to sediment control ponds servicing developing subdivisions, however, because of the increased sediment loads and finer particle sizes encountered in construction sites (Pitt et al. 1999).

Stormwater management ponds with an "enhanced" level of protection require at least 80% removal of suspended solids. The ponds are typically designed to store runoff from a 25 mm rainfall event over 24 h. Along with the active storage detention time of 24 h, current design criteria specify a pond length to pond width ratio of 4:1 to 5:1 and a forebay area of at most 33% of the permanent pool area. Suggestions for pond depth range between 1.0 and 2.5 m, including allowance for sediment accumulation; safety and aesthetic issues limit the depth (OMOE 2003).

This study expands upon earlier monitoring work at the Ballymore pond in Richmond Hill, Ontario. It was observed that the Ballymore pond exhibited a 95% TSS removal (greater than OMOE design criteria of 80%). Because of extremely high inlet concentrations (e.g., 34 000 mg/L), however, outlet concentrations were still as high as 2600 mg/L (Li et al. 2004).

Objectives and scope of study

The goal of this study is to evaluate the performance of sediment control ponds in construction sites and update current design criteria, if necessary, to ensure adequate suspended sediment removal efficiency of these ponds during catchment development. The scope of the field study was limited to monitoring the sediment control pond in the developing Greensborough subdivision in Markham, Ontario. A numerical model was utilized to assist in examining the effects of various pond geometries on sediment removal efficiency. The monitoring results from both the Ballymore and Greensborough ponds were compared with the modelling results to observe trends. Additional scenarios such as changing the pond outlet location, varying the permanent pool depth, or adding a sediment curtain (baffle) will be tested during the second year of the study. Insight provided by these simulations will aid in evaluating and updating design criteria for new ponds and testing the effectiveness of various alternatives for improving the performance of existing ponds.

Study area

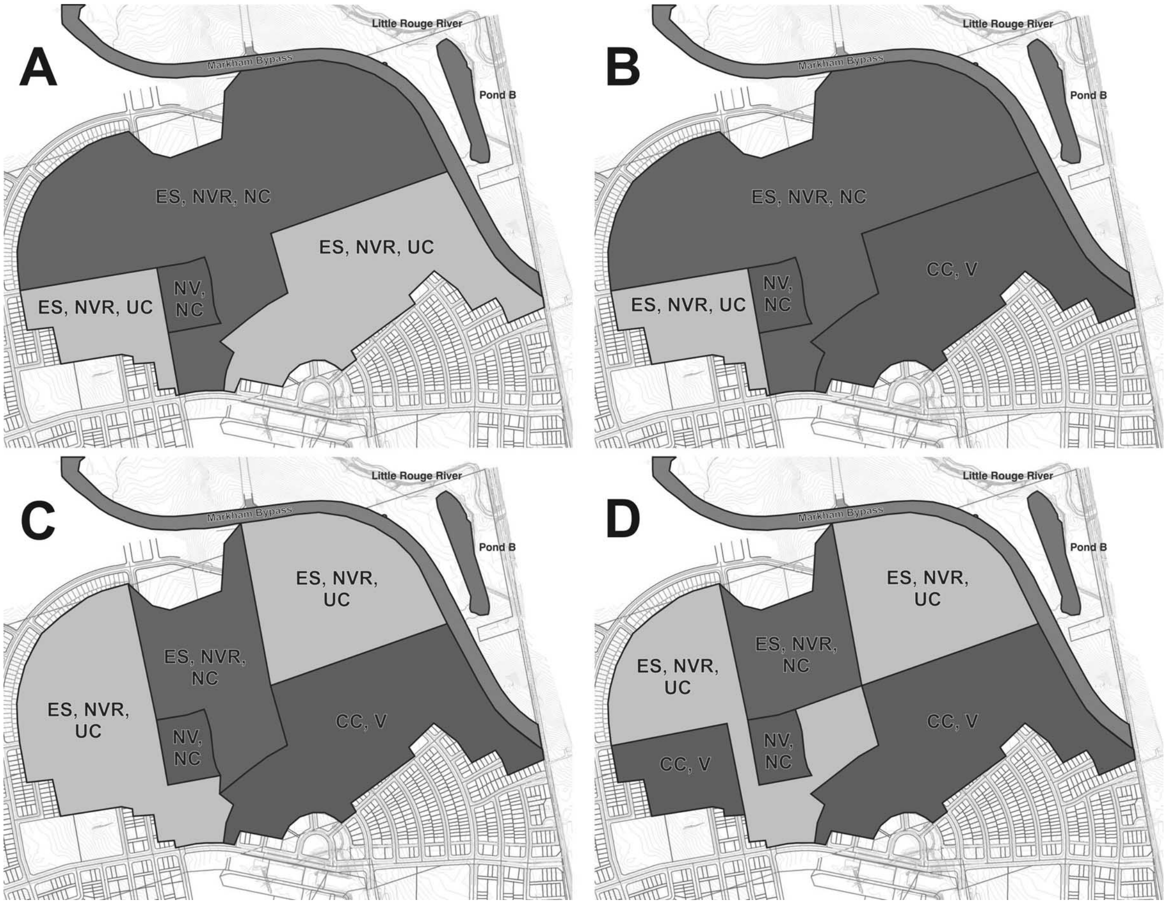
The Greensborough pond is located in the Town of Markham near the intersection of Ninth Line and Major Mackenzie Drive, within the developing Greensborough community. Development has been staged to reduce erosion as required by the erosion and sediment control plan being followed by the developer. Various sections of the subdivision have become directly connected to the storm sewer following their completion. At the beginning of the monitoring season, approximately 43.6 ha of the catchment were directly connected to the pond. Presently, 100% of the drainage area has become connected to a sewer, which discharges directly into the stormwater pond. In total, the pond is designated to receive runoff from a minor system drainage area of 88.8 ha. Figure 1 illustrates the development of the catchment area from June 2004 to December 2005 (TRCA and University of Guelph 2005).

To provide OMOE level 1 protection of effluent (minimum 80% suspended solids removal efficiency), the pond was designed as an extended detention facility with a length-to-width ratio of 8:1 and a permanent pool volume of approximately 11 360 m^3. The OMOE *Stormwater management planning and design manual 2003* suggests a permanent pool storage volume to drainage area ratio of 125 m^3/ha for the soil imperviousness level at this particular site (OMOE 2003). When the monitoring season commenced, the pond volume was such that it provided a storage to drainage area ratio of 261 m^3/ha. As the remainder of the catchment became connected to the pond via storm sewer, however, the storage volume to drainage area was reduced to 128 m^3/ha, still above the value suggested in the *Stormwater management planning and design manual 2003*. The pond was designed with a sediment forebay that has shown significant accumulation of sediment, as indicated by a recent survey of the pond bathymetry. To date, three surveys of the pond bottom have been conducted. The pond outlet pipe discharges to the Little Rouge Creek.

Field monitoring

The field monitoring program at the Greensborough pond commenced in June 2004 prior to development and will con-

Fig. 1. Observed average construction activity during the study period from June 2004 to December 2005: (A) June–September 2004; (B) October–December 2004; (C) May–August 2005; (D) September–December 2005. CC, construction complete; ES, exposed soil; NC, no construction; NV, natural vegetation; NVR, natural vegetation removed; UC, under construction; V, vegetated (properties landscaped).



tinue for several years to the end of the construction period to ensure that the full range of construction impacts is adequately considered. Several surface water quantity and quality monitoring stations were set up at the pond inlet and outlet and in the Little Rouge Creek upstream and downstream of the pond (Fig. 2).

A 1 mm tipping-bucket rain gauge was installed within 500 m of the site, and an Onset MicroStation datalogger (Onset Computer, Bourne, Massachusetts) recorded precipitation at 5 min intervals. Two additional rain gauges were installed within 10 km of the pond in the event that the main rain gauge was damaged or offline. A secondary rain gauge was installed on site for triggering the automatic water quality samplers.

Runoff flow entering the sewer culvert upstream of the pond was measured using an Isco area–velocity meter (Teledyne Isco, Inc., Lincoln, Nebraska). Data were logged every 5 min with an Isco 4150 logger. Additional velocity and level readings were measured at the inlet structure with an Isco area–velocity meter coupled with a pressure transducer. A 5 psi (1 psi = 6.895 kPa) Telog 2100 level logger (Telog Instruments, Inc., Victor, New York) recorded water levels in the pond. Pond discharge was monitored with an Isco area–velocity meter. Both upstream and downstream monitoring stations on the Little Rouge Creek were equipped with 10 psi Telog 2100 level loggers. Hourly temperature of the air, influent, effluent, and receiving waters was recorded with Onset Hobo® temperature loggers.

Water samples were taken at the pond inlet every 10 min and at the pond outlet every 30 min. Collection of volume-weighted water samples was accomplished using automated Isco 6700 water samplers triggered by a signal from a secondary rain gauge during storm events greater than 1 mm. The stations upstream and downstream of the pond were also equipped with automated water samplers and logged data at hourly intervals. Wet- and dry-weather grab samples were collected from stations located upstream of the study area (Markham Road and north of Major Mackenzie Drive) and downstream from the study area (Ninth Line). All water quality samples were analyzed for suspended solids, turbidity, metals, nutrients, biological oxygen demand (BOD), chemical oxygen demand (COD), bacteria, conductivity, pH, alkalinity, chloride, polycyclic aromatic hydrocarbons (PAHs), and phenolics.

There were several storm events (Table 1) during the monitoring period (July to end of November 2004). Comparing the precipitation results with standard intensity–duration–frequency (IDF) for the Toronto area revealed that none of the monitored rainfall events exceeded the 2 year return storm (Doherty and Shah 1990).

Fig. 2. Monitoring locations.

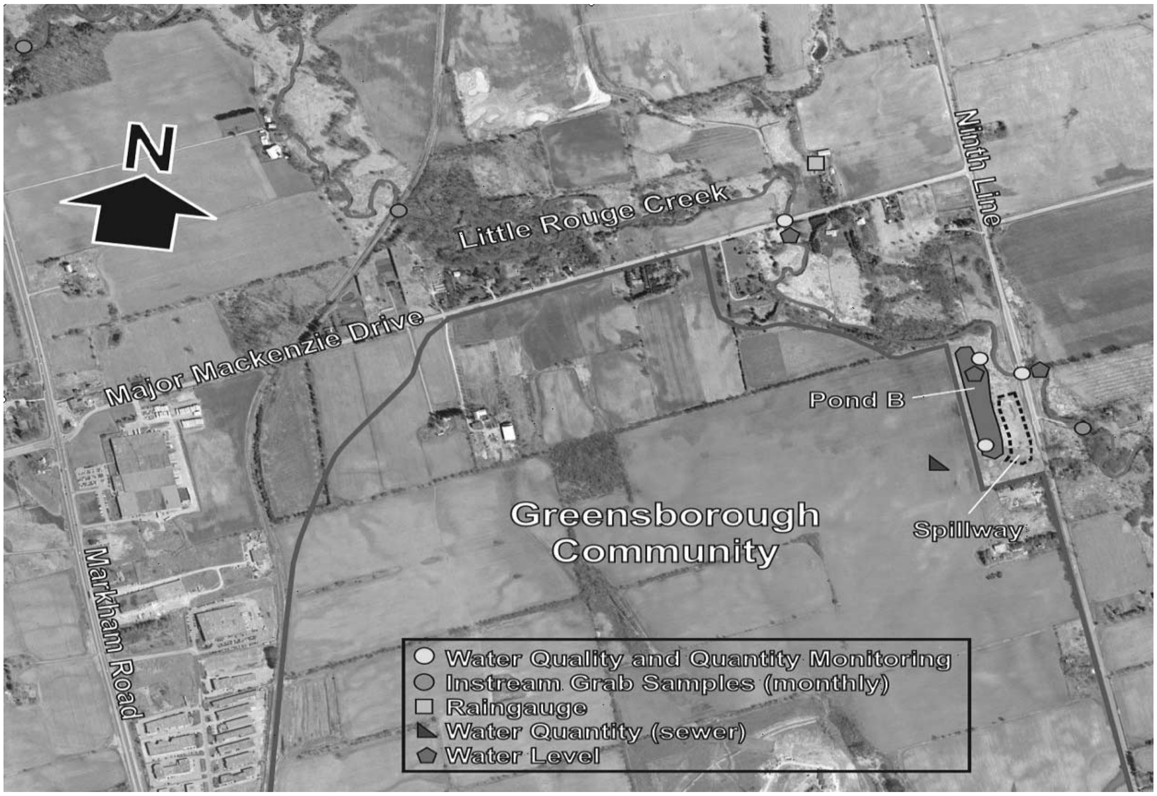


Table 1. Event summary for the 2004 monitoring season.

Precipitation range (mm)	Date	Rainfall (mm)	Duration (h:min)	Max. 5 min rainfall intensity (mm)	Avg. rainfall intensity (mm/h)	Rainfall volume (m^3)
2–5	14 July	2.6	1:45	7.2	1.5	1 134
	26 Aug.	2.9	12:15	12.0	0.2	1 264
	15 Oct.	4.1	4:15	9.6	1.0	1 788
6–10	20 July	7.3	4:15	27.6	1.7	3 184
	22 July	6.7	1:00	20.4	6.7	2 922
	27 July	7.3	6:45	7.2	1.1	3 184
	31 July	9.9	8:00	6.0	1.2	4 318
	10 Aug.	9.0	1:45	32.4	5.1	3 925
	27 Aug.	7.0	1:15	27.6	5.6	3 053
	30 Oct.	8.8	11:00	14.4	0.8	3 838
	2 Nov.	8.2	12:00	7.2	0.7	3 576
	4 Nov.	8.8	21:45	7.2	0.4	3 838
	24 Nov.	8.2	14:15	6.0	0.6	3 576
	28 Nov.	9.0	7:30	7.2	1.2	3 925
	30 Nov.	7.8	13:00	3.6	0.6	3 402
11–15	14 July	11.4	7:00	28.8	1.6	4 972
	29 Aug.	15.9	7:00	36.0	2.3	6 935
16–20	9 Sept.	17.2	9:45	4.8	1.8	7 502
21+	19 July	28.8	4:30	94.8	6.4	12 562

The extended storage capacity of the Greensborough pond was designed to maintain a drawdown time of 48 h for a 25 mm over 4 h rainfall event (Cosburn Patterson Mather Ltd. 2002). Based on observed data, however, the actual drawdown time of the pond was approximately 83 h. The Ballymore pond had a 48 h drawdown time, although the volumes of the two ponds were almost identical (TRCA and University of Guelph 2005). Based on observed data (Table 2) it was apparent that the detention time of the Greensborough pond was greater than that of the Ballymore pond

Table 2. Hydraulic detention time comparison between Ballymore pond and Greensborough pond.

Ballymore pond			Greensborough pond		
Event date	Rainfall (mm)	Hydraulic detention time (h)	Event date	Rainfall (mm)	Hydraulic detention time (h)
14 Sept. 2002	28.8	11.4	14 July 2004	14.2	18.1
20 Sept. 2002	13.3	10.1	19 July 2004	36.2	17.8
27 Sept. 2002	18.4	13.4	22 July 2004	8.8	12.9
2 Oct. 2002	10.0	8.1	30 July 2004	11.3	12.8
19 Oct. 2002	13.0	9.9	10 Aug. 2004	9.0	27.3
25 Oct. 2002	9.4	15.4	28 Aug. 2004	20.9	12.8
2 May 2003	6.8	7.8	9 Sept. 2004	17.2	17.5
5 May 2003	17.4	19.9	30 Oct. 2004	8.8	19.1
11 May 2003	17.8	5.7	2 Nov. 2004	8.3	10.7
20 May 2003	10.8	16.6	24 Nov. 2004	8.2	15.1
4 June 2003	13.8	10.6	28 Nov. 2004	9.0	18.5
8 June 2003	23.6	14.4	30 Nov. 2004	7.8	13.0
15 Sept. 2003	15.0	19.8	—	—	—
19 Sept. 2003	38.0	15.3	—	—	—
Avg.	16.9	12.7		13.3	16.3

Fig. 3. Hyetograph and hydrographs for the 19 July 2004 event.

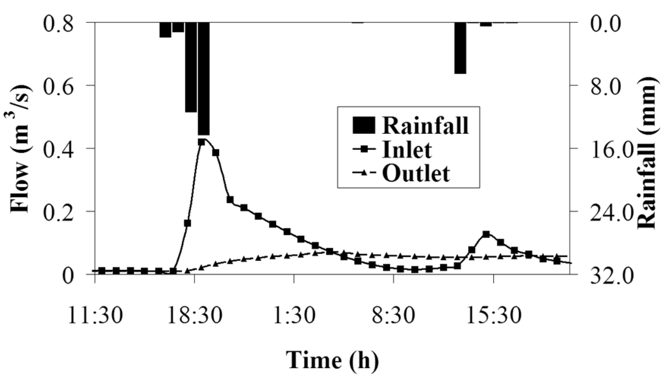


Fig. 4. Total suspended solids pollutographs for the 19 July 2004 event.

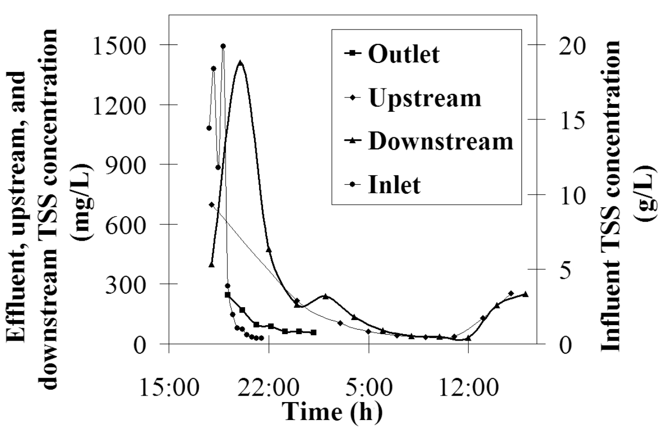


Fig. 5. Hyetograph and hydrographs for the 9 September 2004 event.

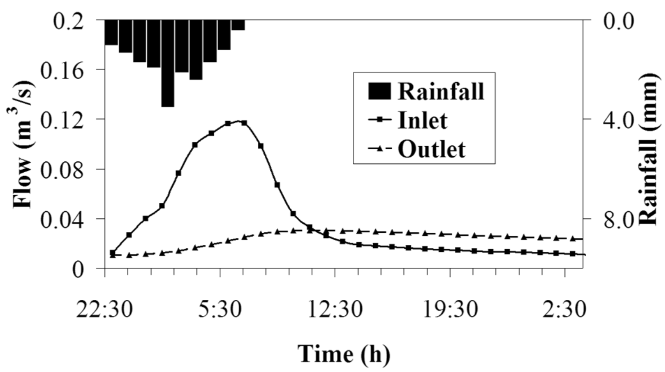
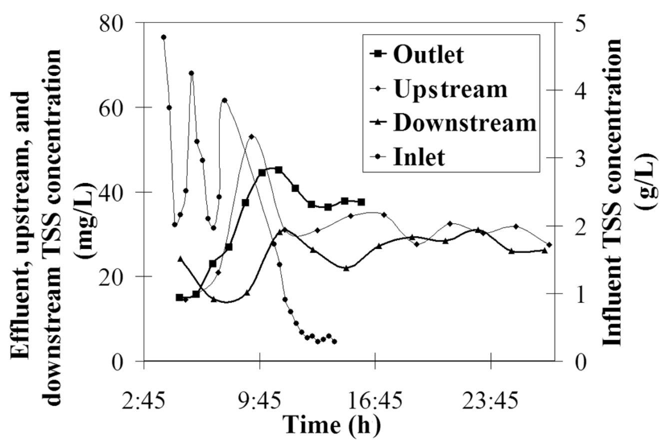


Fig. 6. Total suspended solids pollutographs for the 9 September 2004 event.



(16.3 h versus 12.7 h). The TRCA and University of Guelph (2005) attributed these differences to the disparity in length-to-width ratios (8:1 versus 2:1).

Total suspended solids concentration data were collected for several major events. Figures 3–6 depict the hyetographs, hydrographs, and pollutographs for the 19 July 2004 and 9 September 2004 events. The July and September events had very different storm characteristics. For example, total rainfall and rainfall intensities for the 19 July 2004 and 9 September 2004 events were 36.2 and 17.2 mm and 6.4

and 1.8 mm/h, respectively. Concentrations at the inlet for both events were over 100 times greater than the TSS concentrations at the outlet and receiving water stations.

Similarly, because of the higher rainfall volume and higher rainfall intensity on 19 July 2004, inlet concentrations were 10 times greater than those for the 9 September 2004 event. In both cases, concentrations reflect the rise and run of inlet and outlet flows, where peak concentrations occur during peak flows and lower concentrations during low flows. The pond effluent concentrations had lower TSS concentrations than the receiving water and therefore did not contribute significantly to raising the concentrations downstream, although they added to the already high loads in the creek.

Numerical simulation technique

A finite element hydrodynamic and sediment transport model of the Greensborough pond was used to aid in visualizing trends, flow patterns, and sediment scour–deposition areas and estimating sediment removal efficiency for alternative pond length to pond width ratios. Additional scenarios such as changing the pond outlet location, varying permanent pool depth, or adding a sediment curtain are considered for the second year of the study. These numerical simulations provide a basis for identification of the range of conditions under which sediment control ponds may perform effectively.

Model description

The RMA suite of hydrodynamic and water quality models developed by the Coastal and Hydraulics Laboratory, US Army Corps of Engineers (available from http://chl.erdc.usace.army.mil/software), was selected as the best tool suited to fulfilling the study objectives. Since the pond is relatively shallow (less than 2 m deep), the two-dimensional, depth-averaged version of the RMA modelling system was used in this study. This included RMA2 for hydrodynamic modelling and SED2D for sediment transport modelling.

RMA2 is a finite element model that computes water surface elevations and velocity components at each node in the finite element mesh using a numerical solution of the Reynolds form of the Navier–Stokes equation for turbulent flows. Inputs to the RMA2 model include bed elevation (bathymetry), bed roughness, pond inflow rate, water surface elevations, dynamic eddy viscosity coefficients, and water temperature. Friction is calculated using the Manning or Chezy equations. Eddy viscosity coefficients are used to model turbulence. Both steady-state and dynamic problems can be analyzed (King et al. 2003*a*). The software provides visual results such as velocity vector plots, contour lines, and flow trace animations.

SED2D is a generalized model for simulating two-dimensional, depth-averaged sediment transport in a water body and is capable of modelling and providing visualization of sediment entrainment, transportation, and deposition in the pond water and bed. The model is limited in that only a single sediment particle size can be modelled for each simulation (King et al. 2003*b*). The SED2D model requires water surfaces elevations and velocities (calculated by RMA2), water temperature, sediment particle size – settling velocity, influent sediment concentration, initial sediment concentration, deposition characteristics of the sediment, and sediment diffusion coefficients.

Model development

A finite element mesh was developed for the pond based on the bathymetry data (Fig. 7). Initially, the forebay and permanent pool bed depths were equal (i.e., elevation 198 m). Observations at the site and plots of the most recent bathymetry survey in three dimensions (Fig. 7) illustrate how the depth of the forebay has decreased due to sediment accumulation.

Dynamic boundary conditions for flow and water surface elevation were obtained directly from the 22 October 2005 monitored data. Model simulations were carried out using a 5 min time step to capture the fluctuations represented by the available 5 min data. Calibration of the RMA2 model involved choosing a value of Manning's bed roughness; it was estimated to be 0.025, reflecting a relatively smooth bed boundary consisting of fine sediments (Barnes 1967). The dynamic eddy viscosity coefficient for the pond was estimated to be 5000 $N{\cdot}s{\cdot}m^{-2}$ ($1\ N{\cdot}s{\cdot}m^{-2} = 0.1 \times 10^5\ Pa{\cdot}s$), based on the published values and guidelines for other water bodies with a similar size (Rodi 1993). Calibration criteria involved ensuring that the resulting water surface elevations calculated by the model matched the monitored data.

Calibration of the SED2D model was based on a sensitivity analysis that resulted in selecting a particle settling velocity corresponding to a particle size of 2 μm according to Stoke's law. Due to the aforementioned limitations of the SED2D model, only one particle size can be modelled per simulation. Based on suspended sediment sample analysis, over 50% of the suspended particles are less than 3 μm in size. Further studies will include the full range of particle sizes, however. A dispersion coefficient of 1 m^2/s was selected based on a sensitivity analysis. The model was calibrated to observed effluent TSS concentrations for 22 October 2005; observed and modelled data are compared in Fig. 8.

Flow, level, and TSS concentration boundary conditions based on monitored data were used for subsequent simulations. The original finite element mesh was scaled down to a length-to-width ratio of 2:1 to simulate the geometry of the Ballymore pond. All other parameters, including permanent pool volume, were held constant for both ponds. The drawdown time for the 2:1 pond, governed by the pond water level boundary condition, was identical to that for the 8:1 pond. Similarly, the same inflow boundary conditions used for the 8:1 pond were also used for the 2:1 pond. Trends in sediment removal efficiency for both ponds were examined to assess the impact of reducing pond length-to-width ratio.

Results and discussion

Analysis of the Greensborough pond monitoring data included a comparison in the design and performance of the Ballymore and Greensborough ponds in terms of sediment removal efficiency. Model results concerning the effect of changing the pond length to pond width ratio on sediment

Fig. 7. Finite element mesh illustrating pond bathymetry.

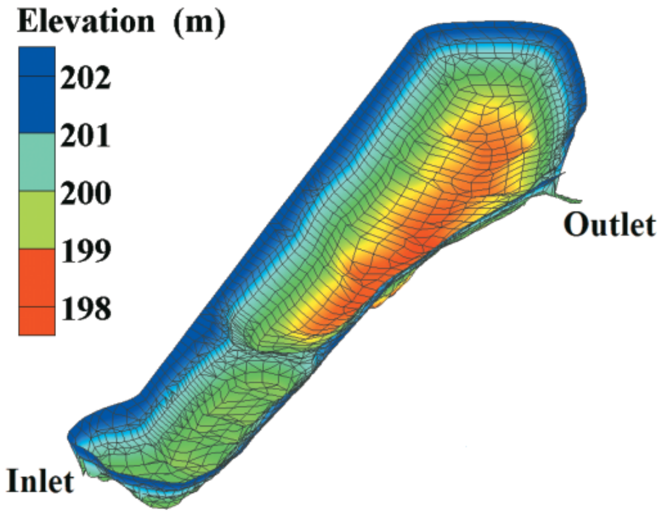
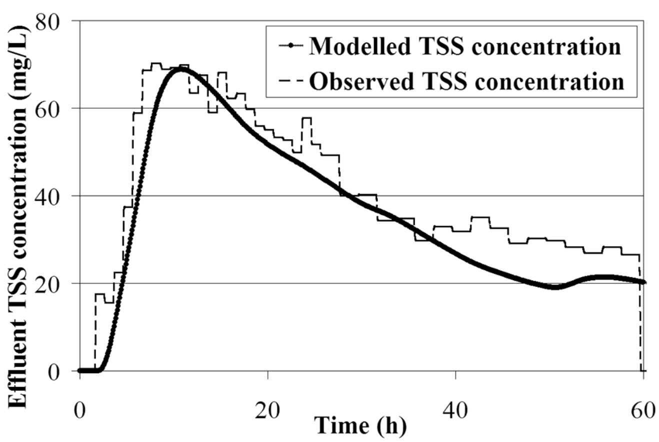


Fig. 8. Observed and modelled TSS concentrations for the 22 October 2005 event.



removal efficiency are presented as well as a discussion of flow trace circulation, TSS concentration profiles, and sediment deposition areas.

Ballymore pond versus Greensborough pond

The TRCA, Ryerson University, and Clarifica Inc. conducted the Ballymore pond study in 2003. From a design perspective, the Ballymore and Greensborough ponds were very different, but both were engineered based on OMOE design criteria (Table 3). The key design difference was the length-to-width ratio. The Greensborough pond had a length-to-width ratio of 8:1, whereas the Ballymore pond had a length-to-width ratio of 2:1. As a result, significant differences were observed in pond performance with regard to the treatment of suspend solids.

Total suspended solids

The seasonal load based removal efficiency for TSS was 99.0%. This impressive measure of system performance has little meaning at a construction site, however, because of the extremely high influent TSS concentrations.

Although catchment sizes differed, particle-size tests indicated that grain-size distributions at both sites were very similar. Both sites consisted primarily of silt and clay materials and consistently had particle sizes less than 62 µm. Over 50% of effluent suspended sediment sizes were less than 3.73 µm (clay).

Despite these very fine influent grain-size distributions, both ponds removed over 90% of the suspended solids discharged to the pond. The differences lay primarily in the TSS concentration of the effluent. The average effluent concentrations for the Ballymore and Greensborough ponds were 176.6 and 37.2 mg/L, respectively. Further analysis showed that the Ballymore pond failed to meet Department of Fisheries and Oceans (DFO) – TRCA sediment control objectives of maintaining effluent TSS concentrations less than 80 mg/L more often than the Greensborough pond, although further monitoring is required to confirm this conclusion. Table 4 highlights the effluent concentrations from the Ballymore and Greensborough ponds for several events. Effluent concentrations exceeding the DFO–TRCA limit of 80 mg/L are in bold typeface.

Despite the large loadings, outlet effluent concentrations appeared to have little or no effect on receiving water TSS concentrations (Fig. 6). The background flow rates and TSS levels in the Little Rouge Creek are higher than any effluent discharge to this date. Further monitoring is required to determine whether events larger than those monitored would produce downstream effects.

Effluent total suspended solids concentration profiles

Total suspended solids concentration profiles were developed following the numerical simulations of the two different pond geometries. Figure 9 depicts the effluent TSS concentration versus time for each length-to-width ratio simulation. The peak concentration for the 2:1 length-to-width ratio pond was considerably higher than that for the 8:1 length-to-width ratio pond. The effluent event mean concentrations were higher in the 2:1 length-to-width ratio pond than in the 8:1 length-to-width ratio pond.

Sediment removal efficiencies

Ultimately, the model results for each simulation were used to generate removal efficiencies based on pond geometry. The ability of the pond to settle suspended solids was largely influenced by the length-to-width ratio. Removal efficiency increased with an increase in the length-to-width ratio. The simulated 2:1 length-to-width ratio pond exhibited an 82% sediment removal efficiency, and the simulated 8:1 length-to-width ratio pond attained 89% removal.

Sediment deposition–scour areas

Sediment deposition and bed elevation change were calculated using the RMA2 and SED2D models. The patterns in which material was deposited agree with the observed change in pond bathymetry. The bed profile, as designed, was initially flat; however, several months of deposition and scour have caused changes as shown in the most recent bathymetry survey (Fig. 7). Formation of a sediment delta in the forebay was observed at the site; model results of bed change also predicted a build-up of sediments in this area (Fig. 10).

Table 3. Ontario Ministry of the Environment (OMOE) design guidelines and pond characteristics for the Ballymore and Greensborough ponds.

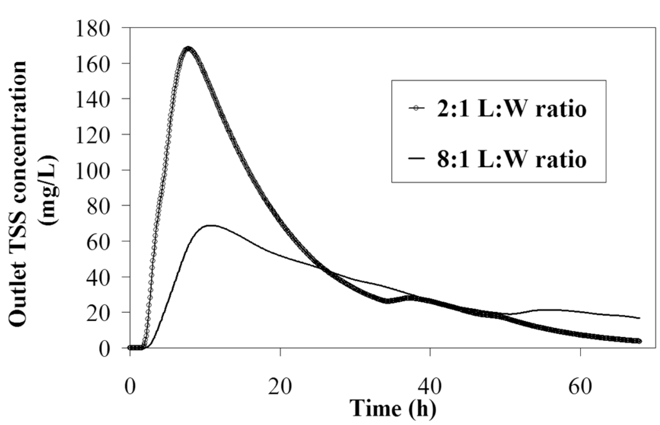
Design feature	Design objective	OMOE (2003) guidelines	Ballymore pond	Greensborough pond
Permanent pool depth (m)	Minimize resuspension	1–2 (avg.); 3 (max.)	2.4 (max.)	1.5
Permanent pool volume (m^3/ha)	Protection of aquatic habitat	60 (normal); 125 (enhanced)[a]	154	128
Extended detention depth (m)	Storage and flow control	1.0–1.5	1.6	2.4
Extended detention volume (m^3/ha)	Protection of aquatic habitat	40	110	144
Drawdown time (h)[b]	Suspended solids settling	24	48	83
Detention time[c]	Suspended solids settling	—	12.7	16.3
Length-to-width ratio	Minimize short-circuiting	At least 3:1 (4:1 or 5:1 preferred)	2:1	8:1
Design protection level			1	1

[a]Based on 45% surface imperviousness.
[b]The *Stormwater management planning and design manual 2003* (OMOE 2003) refers to drawdown as active storage detention.
[c]Calculated values based on time delay between inlet and outlet hydrograph centroids.

Table 4. Comparison of outlet suspended solid (SS) event mean concentrations (EMC) and loadings for Ballymore and Greensborough ponds.

Ballymore pond			Greensborough pond		
Event date	Rainfall (mm)	Outlet SS EMC (mg/L)	Event date	Rainfall (mm)	Outlet SS EMC (mg/L)
14 Sept. 2002	28.8	**277.0**	7 July 2004	13.2	12.8
20 Sept. 2002	13.3	27.0	19 July 2004	36.2	**109.0**
27 Sept. 2002	18.4	75.0	9 Sept. 2004	17.2	34.4
2 Oct. 2002	10.0	7.0	15 Oct. 2004	4.1	22.9
19 Oct. 2002	13.0	29.0	30 Oct. 2004	8.8	42.8
25 Oct. 2002	9.4	17.0	2 Nov. 2004	8.2	21.9
2 May 2003	6.8	30.0	24 Nov. 2004	8.2	16.5
5 May 2003	17.4	36.0	—	—	—
11 May 2003	17.8	**224.0**	—	—	—
20 May 2003	10.8	**100.0**	—	—	—
4 June 2003	13.8	49.0	—	—	—
8 June 2003	23.6	**1630.0**	—	—	—
13 June 2003	—	**82.0**	—	—	—
15 Sept. 2003	15.0	**121.0**	—	—	—
22 Sept. 2003	—	28.0	—	—	—
19 Sept. 2003	38.0	**93.0**	—	—	—
Avg.	16.9	176.6		13.7	37.2
Median	15.0	75.0		11.0	28.7

Fig. 9. Calculated effluent TSS concentrations for 8:1 and 2:1 length (*L*) to width (*W*) ratios.



In agreement with the observed deposition patterns, the model indicated that most of the suspended solids did not travel beyond the forebay, as shown in Fig. 11, but some particles remaining in suspension continued through the outlet.

Flow circulation patterns

The flow trace feature of the RMA model introduces random particles to the flow field and tracks their motion. Flow trace visualization is a very useful and effective tool for recognition of vortices, dead zones, and short-circuiting problems in a pond. A flow trace analysis identified that the location of the pond outlet has created a sizable dead zone in the Greensborough pond (Fig. 12) and may contribute to a short-circuiting problem in the actual pond (i.e., ineffective use of the entire pond volume).

Fig. 10. Sediment deposition areas.

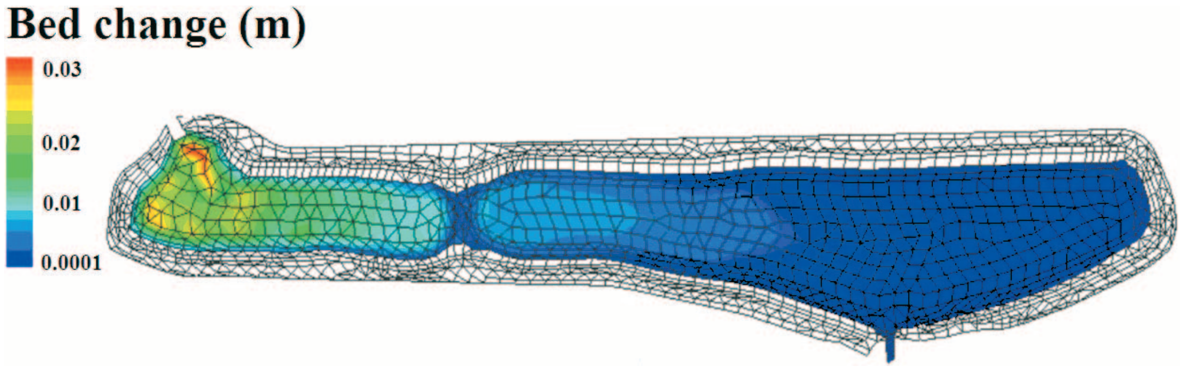


Fig. 11. TSS concentrations during peak inflow.

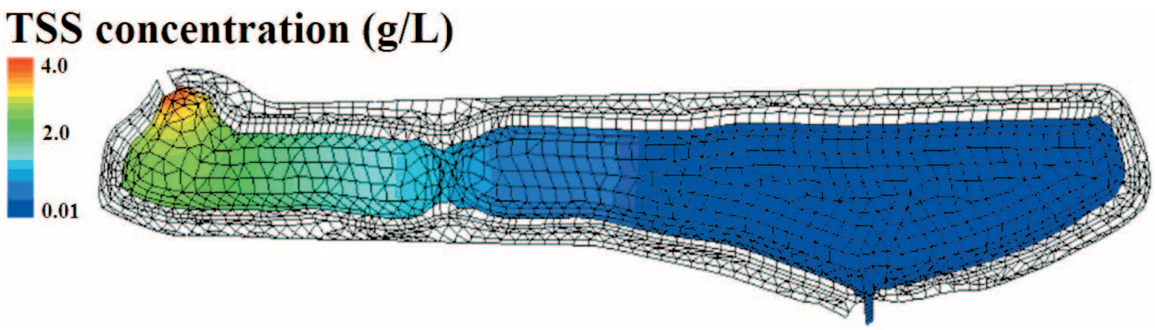
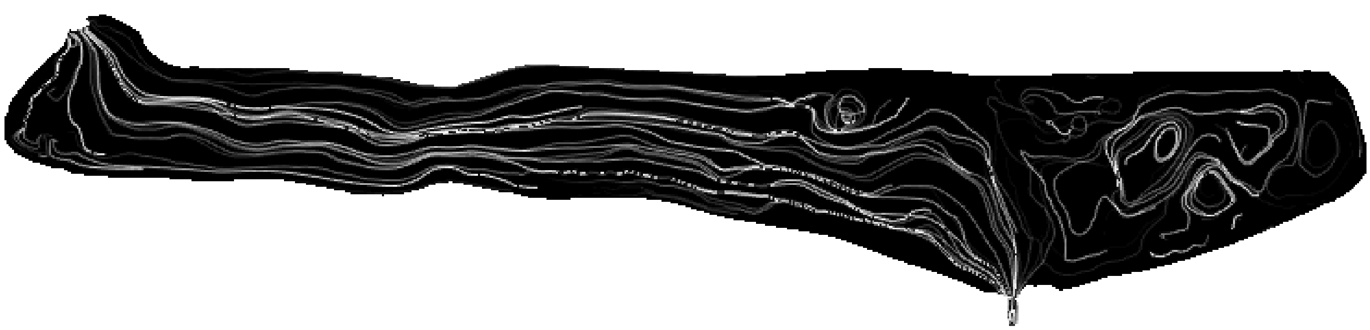


Fig. 12. Flow trace.



Conclusions

It is widely acknowledged that construction site runoff can significantly affect receiving water quality. Although sediment control measures have been required at construction sites for almost two decades, the controls have proven insufficient to protect receiving waters and meet the desired targets (Clarifica Inc. 2004). This comparison of the sediment control ponds in Richmond Hill and Markham was undertaken to help address this deficiency. The study expands on earlier monitoring work conducted on the Ballymore construction sediment pond in Richmond Hill. Data collected thus far show that, although both ponds were designed according to Ontario Ministry of the Environment (OMOE) enhanced level 1 guidelines for ultimate stormwater ponds, the Greensborough pond performed significantly better than the Ballymore pond. Both ponds exceeded the OMOE 80% TSS removal target. Numerical simulation using finite element analysis is a powerful and effective technique for examining the effect of changes in the pond design on its sediment removal efficiency. The following conclusions were drawn from this study:

- Although the Ballymore and Greensborough ponds were both engineered based on the same OMOE design criteria, significant differences in pond performance with regard to the treatment of suspend solids were observed.
- Comparison of the Ballymore pond and the Greensborough pond illustrated that the Greensborough pond had higher sediment removal efficiency than the Ballymore pond. The main difference between the two ponds is that the Greensborough pond has a length-to-width ratio of 8:1, whereas the Ballymore pond has a length-to-width ratio of 2:1.

- Modelling results support the hypothesis that a reduction in length-to-width ratio increases short-circuiting, leading to diminished removal efficiency.
- The sediment transport model and the three bathymetric surveys identified the areas of sediment accumulation in the pond. The sediment forebay was the primary site of sediment accumulation.
- A large dead zone exists at the far end of the Greensborough pond due to the location of the outlet structure. A substantial section of the permanent pool volume is not effectively used (due to short-circuiting) for dilution of suspended solids.
- Numerical modelling techniques compliment and enhance the value of monitoring data by helping to explain and visualize flow circulation patterns. Using numerical models can aid in performing "what-if" scenarios to help with improvements in the design of the stormwater management facilities.

Acknowledgments

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