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TECHNICAL REPORT ON THE EFFECTIVENESS OF THEHALTON WASTE MANAGEMENT SITE EAST STORMWATER POND TO REDUCE TSS AND ASSOCIATED CONTAMINANTS

Ian G. Droppo, Kirsten Exall and Cheng He

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TECHNICAL REPORT ON THE EFFECTIVENESS OF THE HALTON WASTE MANAGEMENT SITE EAST STORMWATER POND TO REDUCE TSS AND ASSOCIATED CONTAMINANTS

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Abstract

The three year project is designed to assess the existing performance of the East Stormwater Detention Pond (Halton Waste Management Site, Regional Road 25, Milton, Ontario) with respect to sediment and associated contaminant (metals) removal. The collaboration between the Halton Region and NWRI will help in the development of improved water management strategies and treatment technologies. The first year of the project (2005) was a feasibility study for the project with the results reported in the technical publication; NWRI Technical Note No.AEMRB-TN05-007. Following from this report the second year of the study has provided a better understanding of the flow and sediment dynamics of the pond during wet weather periods and will allowed for a more focused approach for the final year of the project. To date, field, laboratory physico-chemical analysis, hydrodynamic modeling and laboratory flume experiments have taken place. This report provides information on each of these areas and how they will direct the final year of the study.

RAPPORT TECHNIQUE SUR L'EFFICACITÉ DU BASSIN EST DE RETENUE DES EAUX PLUVIALES DU SITE DE GESTION DES DÉCHETS DE HALTON DANS LA RÉDUCTION DU TOTAL DES SOLIDES EN SUSPENSION ET DES CONTAMINANTS ASSOCIÉS

Ian G. Droppo, Kirsten Exall et Cheng He

Résumé

Ce projet de trois ans a pour objet d'évaluer la performance actuelle du bassin Est de retenue des eaux pluviales (site de gestion des déchets de Halton, route régionale 25, Milton, Ontario) dans l'élimination des sédiments et des contaminants associés (métaux). La collaboration entre la région de Halton et l'INRE facilitera l'élaboration de meilleures stratégies de gestion et technologies de traitement de l'eau. La première année du projet (2005) consistait en une étude de faisabilité du projet, dont les résultats ont été rapportés dans la note technique de l'INRE n° DRGEA-TN05-007. Découlant de ce rapport, la deuxième année de l'étude fournit une meilleure compréhension de la dynamique de l'écoulement et de la dynamique sédimentaire du bassin en périodes humides. Elle nous permettra aussi d'adopter une approche plus dirigée pour l'année finale du projet. Jusqu'à maintenant, des études de terrain, des analyses physicochimiques en laboratoire, des modélisations hydrodynamiques et des expériences de laboratoire menées sur des canaux ont été effectuées. Ce rapport présente de l'information sur chacun de ces aspects et la façon dont ils influeront sur la dernière année de l'étude.

Technical Report on the effectiveness of the Halton Waste Management Site East Stormwater Pond to reduce TSS and associated contaminants

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Introduction

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To date, field, laboratory physico-chemical analysis, hydrodynamic modelling and laboratory flume experiments have taken place. This report provides information on each of these areas and how they will direct the final year of the study.

2006 Field Station Set Up and Activity

The Halton East Pond is an open stormwater detention pond with the dimension of 120 m (L) x 50 m (W) and 2 m (D), there is one inlet (2 culverts) and one outlet in the pond as shown in Figure 1.

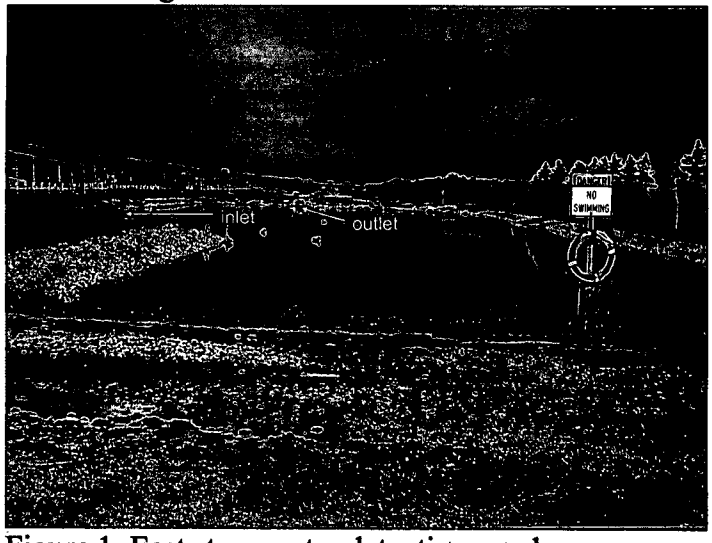

Figure 1. East stormwater detention pond.

Dog houses were set up over the inlet and outlet to house electronic and sampling equipment. An electrical line was run from the Halton Region's pumping station to power the inlet site while a solar panel was used to power the outlet site.

Area Flow Velocity Meters (Sigma 950) were installed within the 200 mm diameter pipe at the outlet of the pond and in the north inlet culvert. The south inlet culvert was blocked off at the up stream end to force all stormwater through the north culvert and allow for an accurate measurement of flow velocity and volume. Observations, however, revealed that the culverts have substantially decayed with water circumventing the blocked end of the south culvert by seeping in through the bottom at a significant rate. As such, inflows for this year are only estimates. Corrective measures will be taken in 2007 to collect accurate flows and will be described below.

An automated sampler (Sigma 900) was also installed within the outlet pipe and north inlet culvert to collect 1 L water samples at equal time intervals. The Sigma water samplers were triggered to initiate sampling once a water level threshold was surpassed. Up to 24 1L samples can be collected for each round of sampling. These samples were analyzed discreetly or in composite as described below.

Laboratory Physico-Chemical Analysis

As the majority of metals will be associated with particulate matter (Horowitz, 1991), sampling focused on the assessment of suspended solids (SS) concentrations over storm events. The rationale for this focus is that if the pond reduces SS concentration from the inlet to the outlet there will be a corresponding reduction in the loading of metals. Total suspended solids (TSS) was measured in discrete one litre samples collected by the autosamplers during rain events.

An initial assessment of a small suite of metals (Cd, Cu, Fe, Mn, Pb and Zn) on a small number of composite samples was carried out in association with SS. Atomic absorption spectroscopy (AAS) was used as the analytical method for the determination of total metals concentration.

Hydrodynamic Modelling

A three dimensional hydrodynamic numerical model (Star CD) was used to simulate flow conditions in the pond under various flow rates and macrophyte placement scenarios. Upon completion this model will be able to assess residency times, and the fate of sediment within the pond.

Laboratory Flume Experiments (Polymer Application Effects)

In the summer of 2006, the Halton Region applied a polymer (United 228 - United Laboratories) to the pond in an attempt to remove solids from the water column. The application of the liquefied polymer was through a surficial broadcasting from the shore line. Given sufficient time the polymer will react with suspended solids and be delivered to the bed of the pond either in association with created flocs, individual particles or on its own. Once delivered to the bed, this polymer may influence the stability of the bed sediment. In the first report by Droppo and Exall (2005), it was hypothesized that wind resuspension may be an issue with the East Stormwater Pond. Mobilization of bed sediment from the pond would be detrimental to its effective operation. Any method that will increase bed sediment stability and thereby minimize erosion and migration of sediments and associated contaminants out of the pond is desirable. As such, the purpose of the laboratory flume experiment was to assess if polymer application can influence bed sediment stability. Three methods of polymer application were examined; 1) broadcasting over the water surface (to simulate the Halton Region protocol), 2) mixing (water column, suspended sediment and polymer are all mixed prior to settling) and 3) injection (deposited bed sediment was injected directly with a polymer). As the properties of the United 228 could not be determined, chitosan was used as a surrogate to investigate these different polymer application techniques and their influence on the stability of the bed.

The flume geometry and operation is described in Lau (1994) and is illustrated in Figure 2a. In short, the bed sediment from the East Stormwater Pond was placed into the flume (Figuer 2b) and water was added. The polymer was added via one of the application methods and then the stability of the bed sediment was evaluated. Stability was assessed by imparting a known shear (via the rotation of the annular flume lid on the surface of the water) onto the bed sediment and determining the point or erosion (critical bed shear stress for erosion). Comparison between polymer applications were assessed as to their ability to stabilize the bed from erosion.

a b

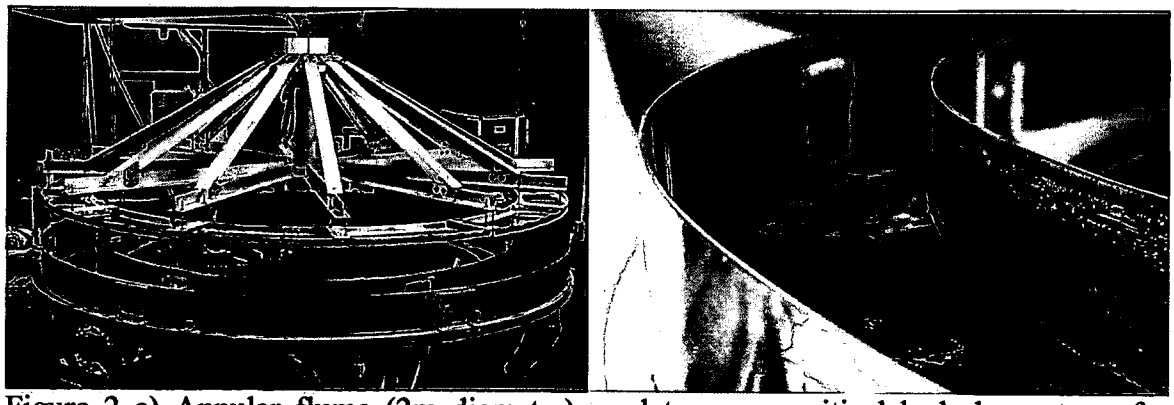

Figure 2 a) Annular flume (2m diameter) used to assess critical bed shear stress for erosion. b) Bed sediment within the flume prior to the addition of water.

Results and Discussion

Pond Efficiency as it relates to Suspended Solid Concentration Removal – Samples were collected from the inlet on five dates between September 19 and October 12. Figure 3 shows an example of the data from samples collected from the inlet pipe during an event in the morning of October 4. As discussed above, the flow values are uncertain due to issues with the equipment and the pipes. For this event, the inlet sampler was programmed to collect one litre every 10 minutes after the threshold level (2 cm) had been reached in the pipe. While TSS concentrations were initially low, an apparent spike in flow resulted in higher TSS values, which tapered off slowly with time.

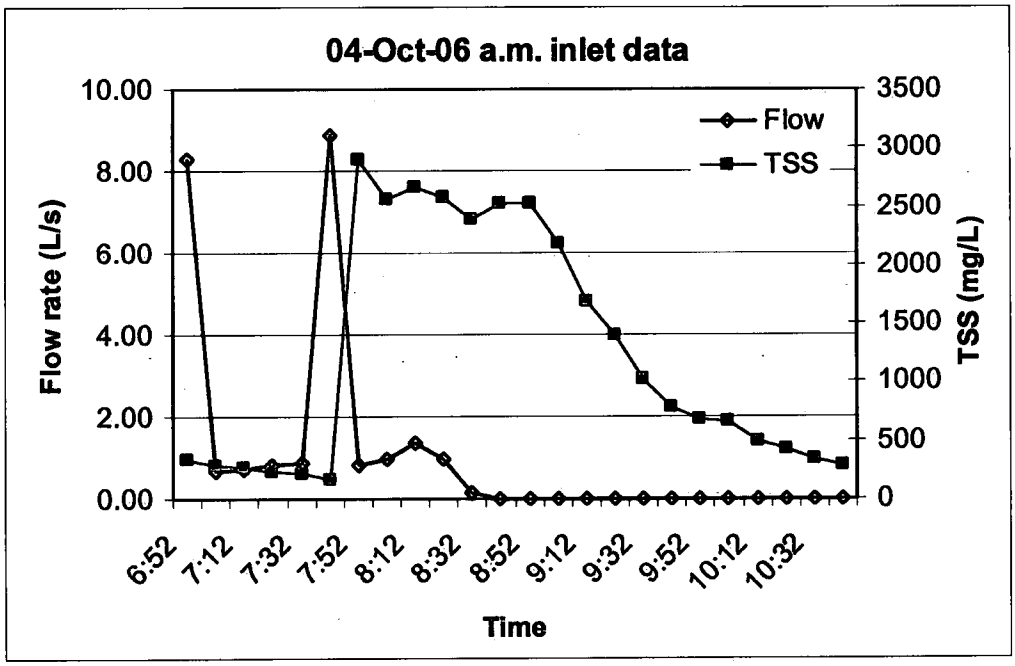

Figure 3. Monitoring data from East Pond inlet during a high solids rain event.

Paired inlet-outlet samples were collected for two events in October 2006. Figure 4a and 4b show an example of the paired data. For this event, both inlet and outlet samplers were programmed to collect one litre every half hour after the level sensor indicated that the threshold level (5 cm) had been reached in the pipe. In spite of apparently wide fluctuations in the flow, TSS values at the inlet remained quite low throughout this event increasing from approximately 50 to 80 mg/L. The data from the outlet also showed low TSS values over the entire sampling period remaining between 50 and 60 mg/L. Over the storm event there is a slight decreasing trend in the TSS data suggesting a removal of TSS by the pond prior to discharge. The increase in TSS observed in the final sample of the outlet (Figure 4b), however, suggests that a longer sampling period may have been more appropriate for this event.

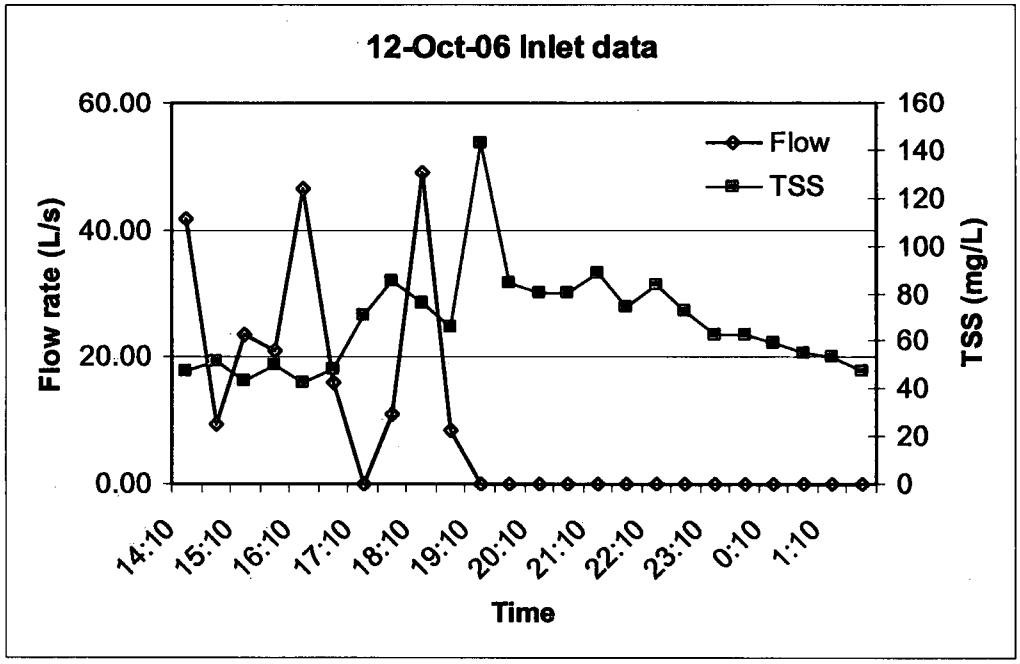

Figure 4a. Monitoring data from East Pond inlet during a high flow, low solids rain event.

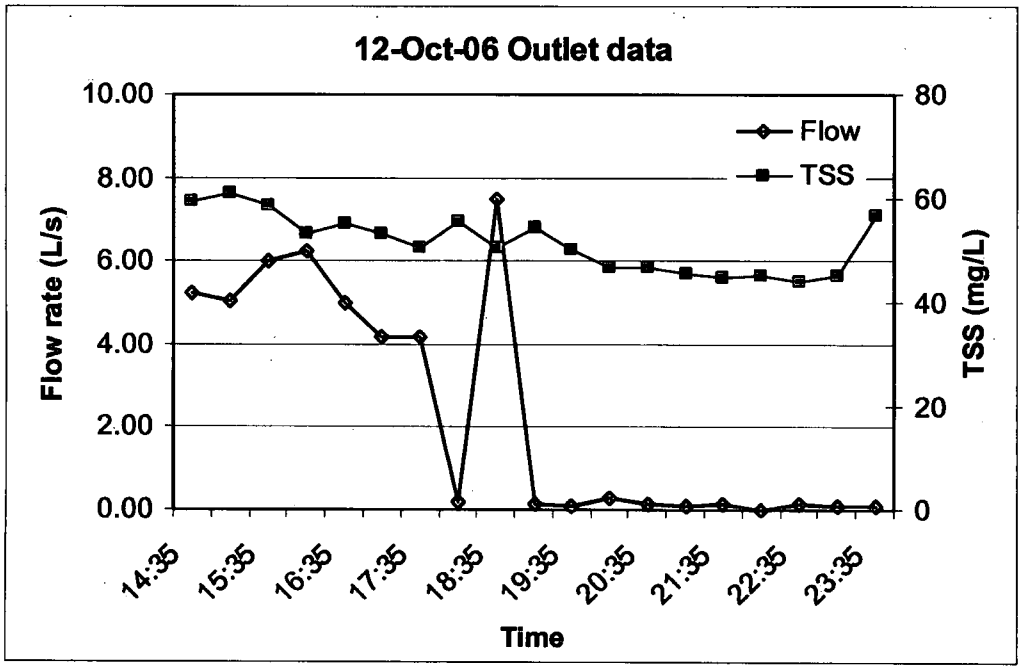

Figure 4b. Monitoring data from East Pond outlet during a high flow, low solids rain event.

Equipment and sampling protocol challenges that arose during the 2006 season will be resolved for monitoring in the 2007 season. The sampling and analysis protocols have been established, faulty equipment has been repaired and recalibrated, and the timing and

frequency for inlet and outlet samplers will be further refined to better understand the solids removal efficiency of the pond.

Pond Metal (Cd, Cu, Fe, Mn, Pb, Zn) Concentrations with Inlet Suspended Solids - Metal analysis was carried out on three composite samples collected over two storm events for the inlet sample location only. Unfortunately the outlet sampling system experienced errors which did not allow us to collect a sufficient volume of sample for suspended solid metal concentration analysis. This will be rectified for the following year.

In order to assess the potential impact of the metals entering the detention pond and/or leaving the detention pond on aquatic life, the concentrations were compared to the Guidelines for the Protection and Management of Aquatic Sediment Quality (MOEE, 1993). The guidelines as outlined in Table 1 reflect a gradient of ecotoxic effects and are based on the chronic, long term effects of contaminants on benthic organisms.

Table 1. MOEE Guidelines for the Protection and Management of Aquatic Sediment Quality (MOEE, 1993).

Pollutant Categories	Sediment Quality	Potential Impact
> SEL	Grossly Polluted	Will significantly affect use of sediment by benthic organisms.
> LEL	Marginally-Significantly Polluted	Will affect sediment use by some benthic organisms.
> NEL	Clean-Marginally Polluted	Potential to affect some sensitive use.
< NEL	Clean	No impact on water quality water or benthic organisms anticipated.

SEL = severe effect level, LEL = lowest effect level, and NEL = no effect level.

Four of six suspended sediment metals (Cd, Fe, Pb and Mn) exhibited concentrations that were below the LEL (i.e. considered clean to marginally polluted), suggesting minimal impact on the organisms which live in a sediment environment with these metal concentrations (Table 2). Copper and Zn were between the SEL and the LEL (i.e. marginally to significantly polluted), suggesting a possible chronic effect on organisms (Table 2). The majority of metal levels in Table 2 are within the range or below the levels found for natural rivers and lakes as summarized by Stone and Droppo (1996). Caution must be taken, however, when comparing the results of different studies due to the operationally defined nature of metal extraction. In addition, as with this initial study, metals are expressed as total concentration and do not take into account the binding phase of the metal to the sediment particles. Metals are generally associated with sediments through 1) an exchangeable fraction, 2) bound to carbonates, 3) bound to Fe/Mn oxides,

4) bound to organics and 5) a residual phase. Generally the sequence of extraction (fraction 1 to fraction 4) can be viewed as an inverse scale of the relative availability of metals (i.e. bioavailability) (fraction 5 is considered not available) (Stone and Droppo, 1996). Generally fraction 5 represents a significant proportion of the metal concentration and thus can not pose any significant impact on biota. For example in a study by Droppo et al (2006) on street sediments the total iron concentration was reduced by an order of magnitude from 40,000 μg/g to 4,000 μg/g when only fractions 1 to 4 were accounted for. As such, for the preliminary metals examined in this study, it would appear that there is a limited risk of suspended solid associated metals having a significant impact on biota. Further assessment of this issue, however, is warranted.

Table 2. Mean total metals concentrations compared to MOEE guidelines (n=3).

Metal	LEL ($\mu g\ g^{-1}$)	SEL ($\mu g\ g^{-1}$)	Mean Total Concentration ($\mu g\ g^{-1}$)
Cd	0.6	10	0.4
Cu	16	110	38.5
Fe	20000	40000	19258
Mn	460	1100	391
Pb	31	250	18.0
Zn	120	820	160.7

Hydrodynamic Model - Prior to the modelling exercise a bathometric survey was carried out. The results of this survey are presented in Figure 5. The three dimensional hydrodynamic numerical model was applied to simulate flow conditions in the pond under various flow rates and geometries for exploring possible ways to improve the performance of the stormwater pond. While a very high flow has been modeled below (1 m^3/s), it does provide an indication of the flow patterns of the pond as it currently exists (Figure 6). In addition, an important aspect assessed by this model was the influence of the macrophyte bed directly in front of the inlet culverts. These macrophytes may play a negative or positive role in the performance of the pond by either 1) short circuiting the flow by deflecting it towards the outlet and/or 2) slowing down flow with the beneficial result of settling out sediment. To simulate the macrophyte bed, a porous block with the similar size and shape was built into the model domain as shown in Figure 7.

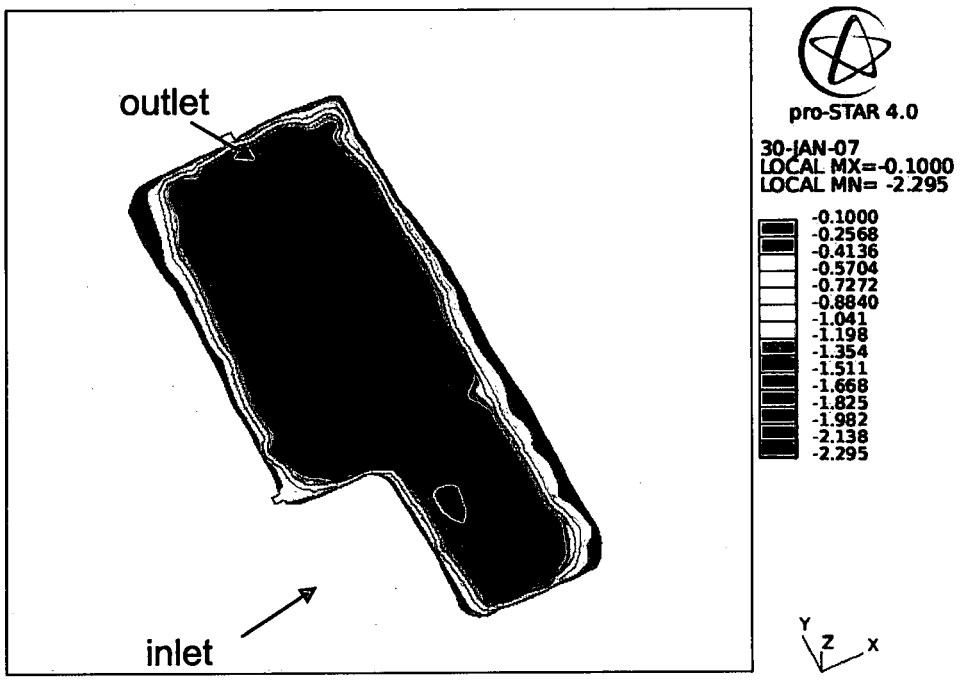

Figure 5. Depth contour of the Halton East Pond. Note that negative numbers can be taken as absolute depths.

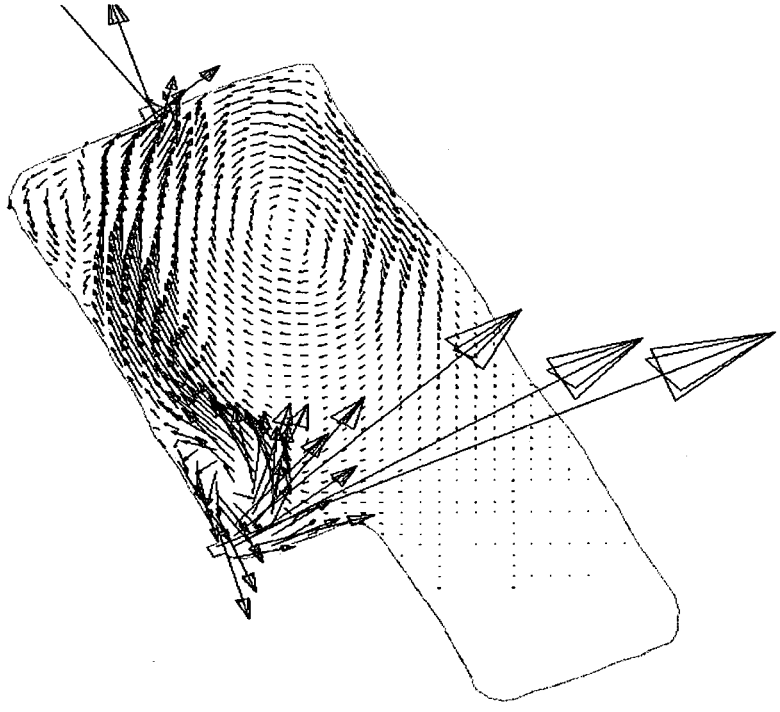

Fig. 6: The simulated velocity field in the Halton East Pond with plants right in front of the inlet pipe (flow velocity = 1 m/s; flow rate = 1.2 m^3/s).

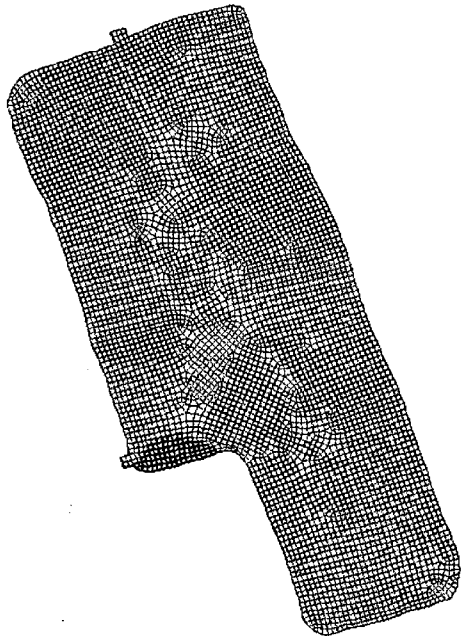

Figure 7. A mesh used for numerical modelling, the green area represents the location of the living plant in the Halton East Pond.

As the pond currently exists, while flow does enter into the macrophyte bed, likely resulting in some beneficial sediment removal, the majority of flow is diverted by this barrier (Figure 8). Figure 6 illustrates that the inflow currently takes the path of least hydraulic resistance directly to the outlet. The south end of the pond provides little beneficial use with the current situation. This shortcut flow pattern will reduce the flow resident time and the area of the pond which currently is active in particle removal.

Figure 8. Inlet flow is diverted towards the outlet due to macrophyte location.

While only preliminary at this time, an effective option for enhancing the performance of the pond would be to remove the macrophyte bed at the inlet. By removing the inlet macrophyte bed, the entire pond is involved in the circulation pattern thus resulting in a longer hydraulic residence time and a more effective sediment removal (Figure 9). Of particular interest in this scenario is that the currently inactive south portion of the pond would now be integrated into the flow pattern (evidenced by a clockwise circulation in the zone – Figure 9), extending the active area for sediment removal greatly.

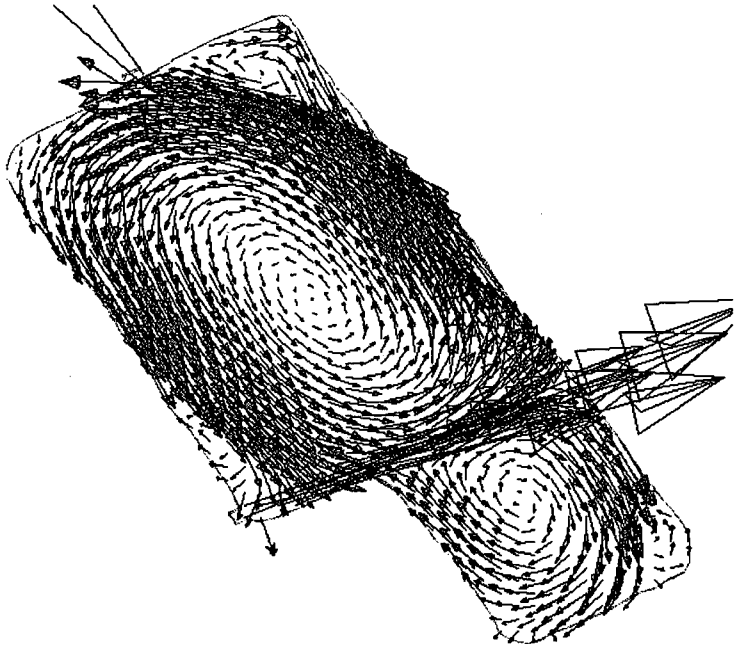

Figure 9. The simulated velocity field in the Halton East Pond with plants being removed from front of the inlet pipe (flow velocity = 1 m/s; flow rate = 1.2 m^3/s).

A more effective use of macrophytes for sediment control would be to populate the north end of the pond in front of the outlet. This would act as a filter of sediments and would increase the hydraulic residence time of the pond.

Laboratory Flume Experiments (Polymer Application Effects) – The flume study on the application of chitosan to stabilize pond bed sediment was carried out by a fourth year undergraduate thesis student (Maricris Marinas). Experiments were initially performed using kaolinite clay, then repeated with sediment collected from the HWMS East Pond using a ponar sampler in July and August 2006. The three polymer application methods described above (broadcast, mixing and injection) were applied and the sediment bed was evaluated for resistance to shear. Additionally, the flocs formed were evaluated for size and speed of settling after re-suspension. Data from the experiments are currently being analyzed; results will be made available to Halton Region when the report is complete. The results will be of value in planning the most effective use of chemical additives in the pond.

2007 Study Plan

Equipment – All equipment will be reinstalled with the following additions for 2007:

Two flow meters will be installed in each inlet pipe to better characterize the flow regime entering the pond. If the flow are such that they are not effectively measured by the electronic equipment then it is proposed that a weir box be integrated into the inlets for a more accurate assessment of input dynamics.

Two logging optical backscatter probes will be installed within the pond to continuously monitor turbidity (a surrogate of TSS) over time. One will be place close to the inlet while the other will be placed close to the outlet.

An acoustic doppler velocity meter (ADV) will be deployed within the pond in a down wind location for a period of one month. This instrument will log the velocity profile within the near bed region and will allow for the calculation of bed shear stress values. These values can then be compared to the flume experiments which provide the critical bed shear stress for erosion for the pond bed sediment. This information will provide evidence as to if resuspension is an issue for the east stormwater detention pond.

Sampling - Multiple storm inlet and outlet samples collected and analyzed for:

TSS
Volatile suspended solids (VSS)
Whole water samples for a suite of metal concentration analysis
Suspended sediment samples for a suite of metal concentration analysis
Sequential extraction AA analysis for suspended solid associated metals (sample volume dependent)

Modelling - Next step is to study the sediment dynamics within the pond under various hydraulic conditions using Lagrangian particle tracking model.

Experimentation/Research – It is proposed that a sediment tracing study be undertaken in the late summer, early fall, in order to validate the numerical model and to further determine the efficiency of the pond to remove sediment from suspension prior to its discharge. A rare-earth element (Holmium- Ho) labelled clay will be injected as a slurry into the inflow of the pond (either during a natural storm event or during a simulated storm event) and the plume traced as it dispersed within the pond. Following settling of the tracer, sediment cores will be collected and analyzed for Ho concentration. This information can then be plotted in a GIS application and overlaid with the model predicted flow patterns. The result will be a conclusive evaluation of the pond's current condition to remove fine-grained cohesive sediments (i.e. those that contain the majority of the pollution) and will lead to strategies for improving the performance further.

Toxicological analysis of Ho is currently underway in order to determine if any negative effects can result from this experimentation.

The report on the flume study carried out by M. Marinas on the application of polymers to stabilize pond bed sediment will be completed and a copy provided to the Halton Region. An executive summary of this thesis will provide the Region with possible options as to the application of the polymer currently in use for the control of suspended solids within the East stormwater detention pond.

Summary

In the 2006 season, NWRI efforts focused on the monitoring, modelling and polymer application studies. Sampling and flow measurement equipment were installed in the inlet and outlet of the East Pond at the Halton Waste Management Site. Preliminary samples were collected to evaluate the sampling and analysis protocols, which will be further refined for the 2007 monitoring season. A bathometric survey of the pond was carried out and a three dimensional hydrodynamic numerical model was applied to simulate flow conditions in the pond under various flow rates and geometries. Based on the preliminary results, possible ways to improve the performance of the Halton East Pond are discussed. A laboratory study of three polymer application methods was completed; the report will be provided to Halton Region when available.

In 2007, NWRI plans to continue and refine its efforts in monitoring and modelling. A novel method of tracing sediment behaviour has also been proposed for discussion between NWRI and Halton Region.

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