Assessment of Construction Sediment Control Ponds to Protect Receiving Waters

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EXECUTIVE SUMMARY

Background

Construction activities have been identified as one of the major sources of pollution to receiving waters. The Great Lakes Science Advisory Board Workshop (2000) on the status of non-point source pollution control in Great Lakes Basin identified construction sites as significant sources of sediment loads to urban streams and to Lake Ontario. High sediment loads result in degraded water quality and aquatic habitats.

Although Erosion and Sediment Control (ESC) measures reduce the amount of sediment exported from construction sites, there are still significant concerns regarding the sufficiency of current control measures to protect receiving waters. In particular, there are still questions regarding the suitability of storm water quality control ponds as the last 'line' of protection before receiving waters. In the Toronto and Region Conservation Authority (TRCA) jurisdiction, sediment control ponds are required in sites greater than 5 hectares. These ponds incorporate active and permanent pool storages to detain and discharge runoff over minimum 24 hours. Although these ponds are a significant improvement over the previous dry-only storage facilities (i.e., sediment control ponds), questions still remain as to their adequacy for treating stormwater prior to exiting the site and meeting receiving water targets.

This study documents the work completed to monitor and model the performance of a typical storm water management facility used for erosion and sediment control in an urban construction site. The monitoring program characterized the suspended solids generated from the construction site and entering and leaving the facility during various events in the fall of 2002 and summer and fall of 2003. The model supplemented the monitoring program to address additional questions associated with sediment removal performance. The model evaluates the current sediment control pond design standards in terms of meeting the downstream water quality objectives and to recommend measures for improving the effectiveness of the facility for further sediment removal.

Objectives

The main objective of this study is to provide background information regarding the performance of storm water management facilities for treating urban construction runoff prior to discharging to receiving water bodies. This document will provide input for further improvement of construction stormwater treatment and for revisions of current erosion and sediment control (ESC) guidelines.

Specific objectives include:

- Monitor runoff from a typical construction site and construction sediment control pond to obtain runoff quantity and quality data, sediment characteristics and sediment removal efficiency;
- Develop calibrated hydrologic and water quality model using monitored data to supplement measured data and assess sediment removal performance during monitoring period and long-term simulation;
- Conduct preliminary evaluation of receiving water quality impacts from sediment control pond outlet effluents by comparing sediment concentrations and durations with receiving water targets.

Study Area

The study area is referred to as the Ballymore construction sediment pond, located in the Town of Richmond Hill. The site was selected because this pond was designed using the standard wet pond criteria. The pond serves a drainage area of 15.3 hectares of residential lands. Two inlets convey the flow from two drainage areas of 12.9 and 2.4 hectares. The pond has a storage volume of 6071 m^3 which includes a permanent pool volume of approximately 2360 m^3. The extended detention outflow is controlled by a 112 mm diameter orifice resulting in a 48 hour drawdown time (runoff from a 25 mm storm). Two orifice plates within Ditch-Inlet-Catch-Basins (DICBs) (444 mm and 515 mm diameters) control the flow during 1:2 to 1:100 year storms. The outflow from the pond is discharged into a 42-m infiltration trench that provides phosphorus removal prior to discharge to a receiving storm sewer. Following figure shows the pond conditions during the study.

Ballymore sediment control pond

The pond was designed according to the MOEE Storm Water Management Practices Planning and Design Manual (1994) with the permanent pool volume sized for Level 1 (Enhanced Level of Protection).

Methodology

The monitoring program was designed to measure runoff quantity and quality (suspended solids concentration) at each inlet and at the outlet from the sediment control pond. The monitoring periods were from September to October of 2002 and May to November of 2003. Flow rates were monitored continuously at the two inlets and at the outlet. Water quality samples were collected using automatic samplers for up-to 6 hours from the start of each event. Samples were submitted to the Ontario Ministry of Environment (MOE) Laboratory for total suspended solids analysis (TSS), as well as other major constituent groups including nutrients, metals, and organics. Particle size distribution was also characterized. The watershed conditions were also monitored in terms of construction activities and soil exposure and disturbance. The sediment accumulation in the pond was measured during the monitoring period.

Data analysis included calculation of event flow volumes, runoff coefficients, hydraulic detention time, drawdown time, observed event mean concentrations, inlet and outlet sediment load and removal efficiencies.

The watershed area and sediment control pond were modeled using SWMM to predict event-based and long-term runoff, sediment generation, inlet and outlet TSS pollutographs. Concentration-duration curves were determined at the outlet to assess potential receiving water impacts. The model was calibrated using monitored quantity and quality data. Overall sediment removal performance for the pond was determined from simulated runoff hydrographs and pollutographs.

Since the watershed was undergoing housing construction during the monitoring period, the watershed condition changed during different periods. In response, models were developed for three sub-periods during the study representing the prevalent watershed conditions during the each period (i.e., September – October 2002, May – July 2003, and August – October 2003). These periodic models provided the ability to assess the effect of construction activities, especially soil exposure on watershed hydrology and water quality.

The calibrated model was useful for determining the long-term water quantity and quality parameters, sediment generation and receiving water impacts. The long-term model applied two sets of 3 years of hourly rainfall data from the Toronto Buttonville Airport. Each climate data set represented average and above average rainfall conditions.

Study Findings

Water Quantity Monitoring

A total of 15 storm events were monitored and analyzed during the study period:

- 4 large storms (greater than 20 mm);
- 8 medium sized storms (between 10 and 20 mm)
- 3 small storms (less than 10 mm).

As expected, runoff coefficients gradually increased from September 2002 to November 2003 as development proceeded. On average 35%, 51% , and 56% of rainfall appeared as surface runoff during storm events over the three periods (i.e., September – October 2002, May – July 2003, and August – October 2003). Storms less than 6 mm of rainfall produced negligible amount of runoff, probably due to initial abstraction losses and high infiltration due to soil exposure and construction conditions.

The hydraulic detention time, defined as the time difference between the observed inflow and outflow hydrograph centroids, provides a measure of average residence time before exiting the facility during a storm event. The hydraulic detention time averaged 12 hours and ranged from 8 to 20 hours during the monitored events.

The drawdown times, defined as the time between maximum and minimum water elevations during a storm, were also estimated from the observed hydrographs. On average the detention time was estimated at about 46 hours and it compares favorably with the designed drawdown of 48 hours.

Water Quality

Total suspended solids is the critical constituent in construction site runoff in terms of concentration and loading. Furthermore, suspended sediments act as carriers for other constituents of concern (phosphorus, metals and organics). Hence, SS serves as a direct and indirect measure of overall performance of the sediment control pond.

The following summarizes the water quality findings:

- The average observed TSS concentration at the inlet of the pond was 2,700 mg/L, ranging from 250 to 10,000 mg/L;
- The average TSS Event Mean Concentration (EMC) at the inlet of the pond was 2,200 mg/L, within a range of 200 mg/L to 7,800 mg/L.
- The average observed TSS concentration at the outlet of pond was 177 mg/L. The range was 7 mg/L to 1630 mg/L.
- The average observed TSS load removal efficiency during the sampling period was estimated to be 92%.

- The average TSS load removal efficiency was estimated from the simulation model using the entire pollutographs as 82%.
- The particle size distribution from the construction site was skewed towards the finer particles. At the inlet, about 99% of particle size of SS were smaller than 62 microns. Approximately 50% of particle size were smaller than 2.3 micron. Similar observations were made at the outlet.

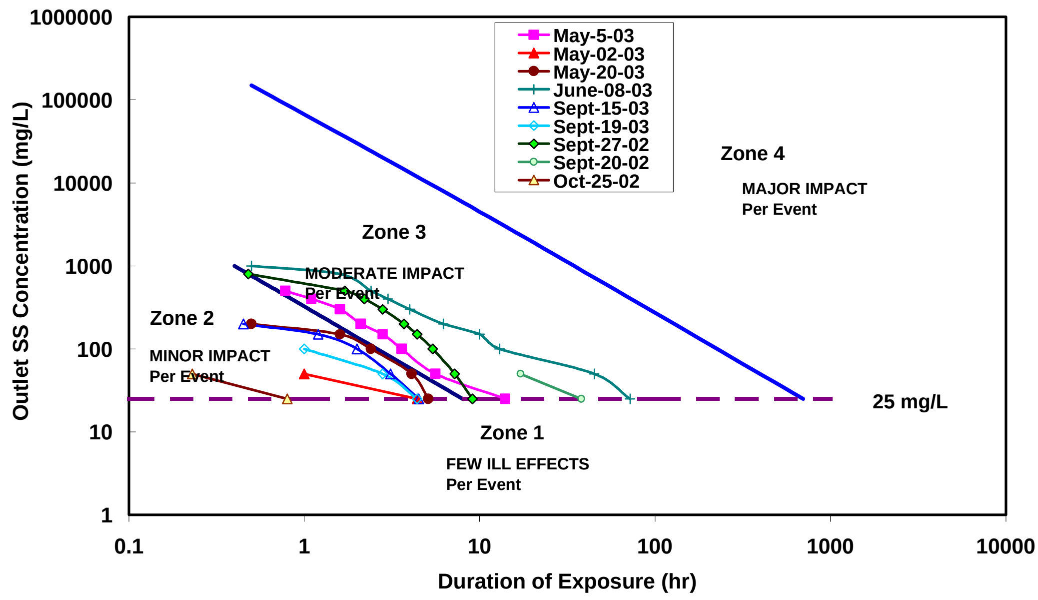
Long-term Simulation and Receiving Water Analysis

The model was used to determine the long-term performance of the pond in terms of SS removal and the receiving water impacts. Two sets of three-year hourly rainfall data corresponding to average and extreme wet year conditions were considered.

The annual sediment-loading rate from the construction site was estimated to be 3.2 and 3.4 m^3/ha for average and wet year conditions, respectively. This compares to 1.9 m^3/ha for stable watersheds with similar imperviousness.

The long-term SS removal efficiency for the pond was estimated as 91.0% and 90.0% for average and extreme wet year conditions respectively.

The results show that ponds designed under the current TRCA criteria, such as the Ballymore pond, provide significant benefits for removing SS from construction runoff. However, the SS concentrations in the effluent would lead to minor to moderate impacts on fish and fish habitat. Impacts are illustrated in following figure. However, this assumes no mixing/receiving water assimilation.



Severity of impacts by suspended sediments (Ward, 1992; MNR)

Conclusions and Recommendation

Sediment control ponds designed under the existing TRCA criteria (Enhanced Level of Protection and extended detention storage for the runoff from a 25 mm storm released over minimum 24 hours) will provide significant benefits for removing suspended solids from construction runoff. Total suspended solids removal of 90% can be expected from these facilities. The pond design criteria incorporates both active and permanent pool volumes for better TSS removal. However, suspended solids concentrations leaving the facility may still be high and, depending on receiving water conditions, could impact fish and fish habitat.

The following will improve the overall ESC effectiveness:

I. Implementation of the ultimate SWM facility as a sediment control pond during construction period should be considered.
II. The sizing criteria for sediment control ponds should be consistent with the ultimate SWM facility (MOE, 2003). This includes “Enhanced Level of Protection”.

This would bring the level of protection during construction to the highest standard presently practiced.

III. Ponds should be designed to facilitate accumulated sediment removal maintenance. This includes the means to drawdown the permanent pool or provide alternative means for sediment dewatering.

IV. Construction sediments should be removed before assumption.

V. The banks of the sediment control ponds can be significant sources of soil erosion and sediment contributions to the storage facility. Slope stabilization should be a high priority after pond construction.

VI. Particle size distribution analysis shows that construction sediment is comprised primarily of smaller particles. Low settling velocity of smaller particles yield lower treatment effectiveness as compared with stable urban sites and highlight the need for enhanced controls. Other measures, such as outflow polishing through vegetation filtering or sand filters should be considered.

VII. Large loads entering the ESC facility results in significant amounts of sediment leaving the facility, even with high removal effectiveness.

VIII. Receiving water impacts would best be determined through site-specific monitoring. This should include a comprehensive baseline monitoring before construction. Conditions at the outlet of the pond and downstream within the receiving stream should be included.

IX. The overall ESC effectiveness would be improved by reducing the amount of sediments reaching the ESC pond. Other 'at-source' ESC practices should continue to be implemented and other practices such as earlier re-vegetation could be enhanced. Effective use of ESC measures at the source, upstream of the pond, will reduce the incoming sediment load and improve the overall removal efficiency.

X. The owner should frequently inspect ESC controls to verify it's effectiveness. particularly after runoff events. Inspection records should be created to document the inspection and repairs.

XI. Stormwater management facilities used for ESC ponds should be surveyed annually to assess the sediment accumulation and maintenance requirements.

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1. Background

Without controls, construction activities in urban and urbanizing watersheds can cause severe detrimental impacts on receiving waters and aquatic systems (e.g., fish and fish habitats). Recently, a Great Lakes Science Advisory Board Workshop (2000) on the status of non-point source pollution control in Great Lakes Basin identified construction sites as significant sources of sediments to urban streams. Although sediment control measures have been required at construction sites for almost two decades, these have not proven to be adequate to protect receiving waters and meet the desired water quality and stream habitat targets. As many of municipalities are undergoing rapid expansion, runoff from urbanizing watersheds, especially from construction sites will increase sediment loads to receiving watercourses and ultimately to Lake Ontario resulting in degraded aquatic habitats and water quality.

In this regard, the Toronto and Region Conservation Authority (TRCA) and Fisheries and Oceans Canada have undertaken a number of steps collaborating with local, provincial and federal agencies to investigate the current state of ESC practices, assess receiving water impact targets and improve existing receiving water protection within its jurisdiction. Up to the current study, the TRCA initiatives include:

- Monitoring and collection of field data from construction sites;
- Assessment of the effectiveness of existing ESC practices;
- Preparation of draft model ESC by-law for municipalities; and
- Determination of relationship between construction phases and water quality.

The results from these studies will be used by the TRCA and other to update the current TRCA ESC guidelines.

Previous studies have indicated the need to implement ESC storage ponds at the on-set of urban development. The current design criteria for ESC ponds being considered is as follows:

Case 1: Use a temporary ESC pond for the period of construction only.

Case 2: Use the ultimate SWM pond for ESC during construction.

In case 1, the sizing criteria would be as follows:

- The permanent pool volume must be sized for a minimum of 125 m^3/ha or the volume required under the latest MOE Stormwater Management Planning and Design (SMPD) manual, whichever is greater.
- The active storage must be sized for a minimum of 125 m^3/ha, released over a minimum of 24 hours.

In case 2, when the ultimate facility is used for ESC, the sizing must meet the MOE SMPD manual (2003). As per TRCA requirements, an 'Enhanced Protection Level' will be required for sizing the permanent pool volume. In addition, the TRCA requires extended detention storage for the runoff from a 25 mm storm released over minimum 24 hours. The applicable design criteria for wet ponds is summarized in Table 1.

Table 1: ESC pond storage volume requirements (m^3/ha)

Protection Level	**Imperviousness**			
	35%	**55%**	**70%**	**85%**
Permanent Pool Volume[1]	100	150	185	210
Extended Detention Volume[2]	25 mm	25 mm	25 mm	25 mm

Note:
(1) MOE Enhanced Level of Protection sizing criteria – permanent pool only.
(2) Extended Detention Volume is the runoff from a 25 mm storm released over a minimum of 24 hours.

The implementation of either the ultimate pond or an interim pond designed according to the Enhanced Protection Level will provide better runoff treatment than the previous design criteria of 125 m^3/ha active storage (only). However, the question still remains as to whether the Enhanced Protection Level is sufficient to control the runoff from construction sites given the significantly different sediment characteristics and extreme suspended sediment concentration and loads as compared to stable urban areas. Furthermore, although new ponds may provide better treatment, there is still no data regarding the effectiveness for meeting the specific environmental quality objectives (e.g., targets for fish habitats). For example, the sizing does not relate the aquatic system sensitivity to suspended solids concentration and duration of exposures so as to limit the effects.

Therefore the TRCA recognized the need to evaluate the adequacy of SWM ponds designed according to MOE SMPD manual for construction sites and the performance of the ponds in meeting receiving water targets. This evaluation has been divided into two phases:

1. Phase I: Monitor a typical construction site and corresponding sediment control pond designed as per MOE SMPD manual and evaluate the pond performance; and
2. Phase II:: Monitor a typical construction site, sediment control pond and receiving water to evaluate the integrated performance.

The present study documents the findings of the recently completed first phase. This phase included a field monitoring and modeling program conducted from 2002 to 2003 at Ballymore Pond in Richmond Hill, Ontario. The study characterizes the hydrologic conditions within typical construction sites and sediment control ponds designed according the MOE manual. In addition, the study documents construction sediment characteristics, and the evaluation of pond performance and theoretical receiving water impact assessment.

1.1 Study Objectives

The main objective of this study is to document the performance of storm water management facilities designed according to the MOE SWMP manual for treating urban construction runoff prior to discharging to receiving water bodies. The study provides input for further improvement of construction stormwater treatment and will lead to future revisions of TRCA's ESC guidelines.

Specific objectives include:

- Monitor runoff from a typical construction site and construction sediment control pond to obtain runoff quantity and quality data, sediment characteristics and sediment removal efficiency;
- Develop calibrated hydrologic and water quality model using monitored data to supplement measured data and assess sediment removal performance during monitoring period and long-term simulation;
- Preliminary evaluation of receiving water quality impacts from pond outlet effluents by comparing sediment concentrations and durations with receiving water habitat targets.

This project is the first step towards linking stormwater runoff quality control best management practices and receiving water protection goals.

2. Study Site and Facility Description

2.1 Study Area

The study area is located south of Sunset Beach Drive and west of Bayview Avenue within Study Area B of the OPA 129 lands in the Town of Richmond Hill (see Figure 1). The development lands are surrounded by Sunset Beach Drive to the north, Bayview Avenue in the east and existing developments to the west and south. The site is known as Ballymore on Bayview Development Phase I and II (formerly known as the Longmoor lands).

The storm water management (SWM) facility, referred to as the Ballymore pond, was built in 2002 and is currently being used as a construction sediment control pond for the site is located in the north-west corner of the site. The facility was designed to service an area of approximately 15.1 hectares of mostly residential use. The storm runoff from the site is conveyed to the facility through major and minor systems. The outflow from the facility eventually enters into Lake Wilcox.

In addition to permanent pool volume, the SWM facility is designed to store the runoff from a 25-mm storm event for 48-hr (drawdown time), and 1:2 through 1:100 year peak flow control to a maximum outflow of 1.4 m^3/sec which is less than the capacity of a downstream receiving ditch (Sabourin Kimble & Associates Ltd., 2000).

The permanent pool volume is based on MOE Stormwater Management Practices Planning and Design Manual (Enhanced Level of Protection). The facility is designed with a shallow sediment forebay. Table 2 compares the MOE's SMPD manual wet pond guidelines for Enhanced Level of Protection (with 45% surface imperviousness) and the measured Ballymore pond as-built conditions. Other design parameters are shown for reference. As shown, the pond meets the MOE sizing requirements for maximum permanent pool volume, extended detention volume above permanent pool volume, and drawdown time.

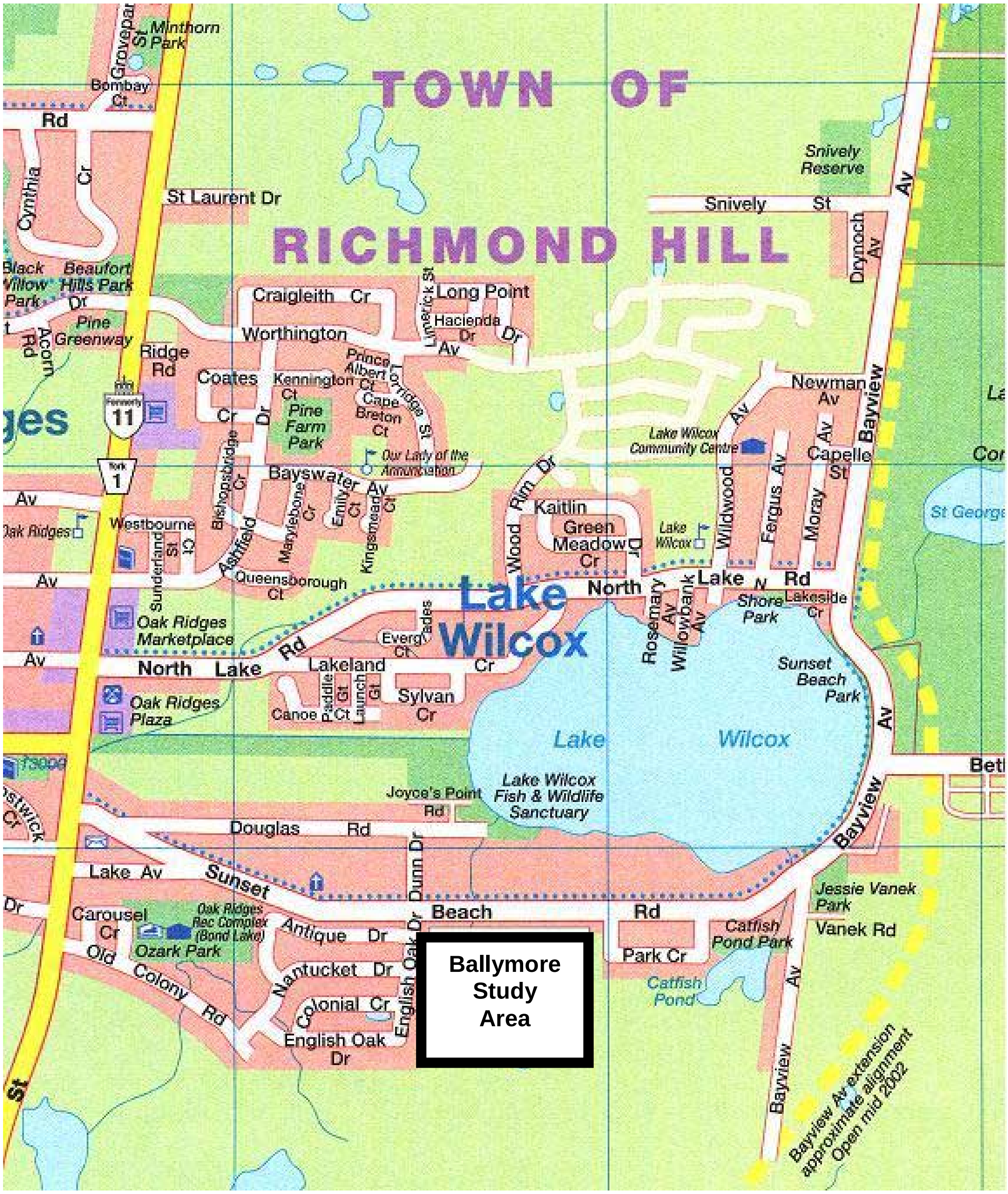

Figure 1: Ballymore study area

Table 2: Comparison pond design features

Design Parameter	Objective	MOE SMPD Manual	Ballymore Pond
Permanent pool volume (m^3/ha)	Enhanced Level of Protection	125*	154
Permanent pool depth (m)	Minimize resuspension	1-2 (mean); 3 max	2.4 max
Active storage depth (m)	Storage and flow control	1 to 1.5; max 2	1.6
Extended detention (m^3)	Runoff from 25 mm storm	40	110
Quantity control volume (m^3)	2-100 year water quantity control	N/A	242
Drawdown time (hours)	Suspended solids settling	24	48
Length to width ratio	Maximize flow path and minimize short-circuting	3:1	2:1

* Based on Enhanced Level of Protection and 45% surface imperviousness (MOE, 2003)

The pond receives runoff from two tributary areas through two inlets. Figure 2 shows the Ballymore pond inlets and the outlet locations. The southwest inlet is referred to as 'Inlet 1070' and corresponding drainage area is 'catchment 1070'. The second inlet, located on the northeast side is referred to as 'Inlet 510' and corresponding drainage area is 'catchment 510'. The outlet is located in the north side of the facility facing Sunset Beach Road.

The pond has a total storage volume of 6071 m^3, which includes a permanent pool volume of approximately 2360 m^3. The extended detention outflow is controlled by a 112 mm diameter orifice resulting in a 48 hour drawdown time (runoff from a 25 mm storm). Two orifice plates (444 mm and 515 mm diameters) situated within Ditch-Inlet-Catch-Basins (DICBs), control the flow during 1:2 to 1:100 year storms. The outflow from the pond currently discharges into an open 42-m ditch south of Sunset Beach Road.

Figure 2: Ballymore sediment control pond

2.2 Soil and Drainage

The soil within the study area primarily consists of about 1.5 meter of sandy silt till (or silt and sand till) over stone clayey silt till. Around the perimeter of the sandy silt area, the clayey silt till is closer to the surface and predominates (Sabourin Kimble & Associates Ltd., 2000).

In the pre-development scenario, the surface drainage from the study area was draining via overland sheet flow and ditch systems northward to lake Wilcox. Under post-development scenario, the drainage from the site is conveyed to the Ballymore SWM facility through curb, gutter, storm sewers and the discharge from the facility will be conveyed through a swale to the downstream storm sewer.

2.3 Construction Site Conditions

During the study, catchment 510 (2.4 hectares) was built-up and catchment 1070 (12.9 hectares) was undergoing development with active house construction.

When the monitoring program began in the fall of 2002, the catchment area upstream of inlet 510 was already stabilized and construction activities were completed. During this time, soil was exposed throughout catchment 1070 area and the roads were heavily covered with sediments. At the same time, although the pond was completed, significant erosion was present along the banks (Figure 3). No vegetation was present on the banks during the Fall 2002 sampling period.

Figure 3: Ballymore pond bank erosion

3. Monitoring Program

One of the main objectives of the field monitoring program was to collect water quantity and quality data representative of urban construction sites. The performance assessment required coordinated water quantity and quality measurements at the inlets and outlet of the pond. Sediment accumulation was also measured and construction activities noted. The monitoring periods were from August to October 2002 and May to October 2003. Details of instrumentation and statistical methods employed in collecting and analyzing data are provided in the following sections.

3.1 Instrumentation

Water Quality Samplers

The ISCO 6712 portable samplers were selected for water quality analysis. The samplers were chosen based on their ability to collect individual samples over specified time intervals to account for the variability in constituent concentration throughout the course of the runoff event. The samplers are equipped with 24 bottles. At the study site, the portable samplers are installed at the two inlets and one outlet of the pond.

Flow Logger

Flow data was collected using a flow logger, and an area velocity sensor. The data logger was calibrated and readings were retrieved to a laptop computer after every event.

Area Velocity Sensor

The Area Velocity Sensors (AV probes) are used at each inlet and outlet. The AV probes were programmed to trigger the samplers when there is an increase in water level.

3.3 Rainfall Data

Rainfall data used in this study was collected at a rain gauge located approximately 1 km from the site near the intersection of King Road and Young Street. This rain gauge is owned and operated by the Town of Richmond Hill. The rainfall was processed into 5 minutes and 15 minutes intervals for use in the analysis.

For the long-term simulation, hourly rainfall records were obtained from the Toronto Buttonville Airport station. The long-term rainfall record between 1973 to 2002 was used to assess the climate change analysis which is presented in Appendix A. From the analysis no trend was found for the rainfall volume for different return periods within last 30 years.

3.2 Sediment Accumulation

A significant amount of sediments accumulated within the facility during construction. Standard surveying techniques were used to measure accumulation within the pond. The results of the survey were used during modeling to calibrate the volume of sediment capture within the facility.

3.4 Sampling Program and Procedures

Samplers and flow measurement devices were installed and calibrated on-site. Initially, samplers were programmed in 2002 to sample 24 bottles at 5 min intervals. However, this proved to be insufficient to capture the entire events and the intervals were increased in 2003 to capture 6 hours. In both cases, sampling periods were still short and modeling was required to estimate the complete pollutographs.

An equipment maintenance protocol was developed immediately after the installation. This protocol included equipment cleaning, downloading, equipment tests, and equipment checks for damage.

3.5 Monitoring Construction Activities

Construction activities were monitored to characterize the construction phases and relate these to sediment generation. Housing construction was underway in catchment 1070 at the time of monitoring and the condition of lots and driveways was logged. A check list was developed that indicated the lot number and whether the lot was exposed, or sodded and whether the driveways were paved. In addition, notes were taken on the cleanliness of the roads, and if any soil piles were present. This was an important task as it provided an understanding of the sediment sources. For example, during the first sampling period in 2002, development in catchment 510 (2.4 ha) was complete and relatively little sediment was contributed from this area. However, catchment 1070 (12.9 ha) was not stabilized during the fall 2002 and spring 2003 sampling period.

Figure 4 demonstrates the observable difference in samples qualities collected from each inlet and at the outlet. In addition, these conditions were also apparent when comparing the conditions of the roads in both areas. The roads within the catchment 510 were clean. Figure 5 illustrates the road conditions in catchment 1070.

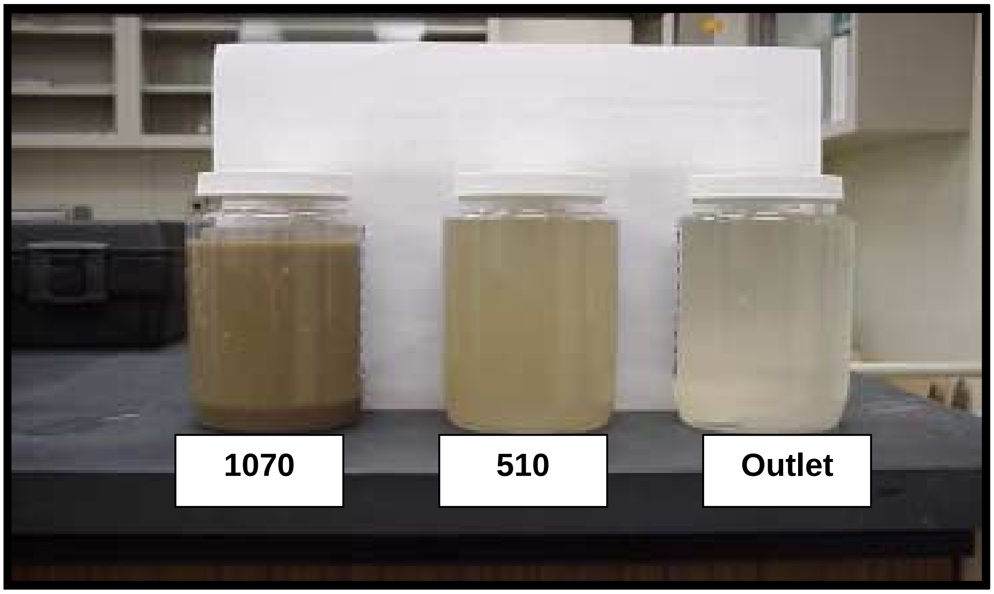

Figure 4: Water quality samples of each monitoring station

Figure 5: Road conditions in Catchment-1070 during construction

4. Water Quantity Analysis

This section presents the results of water quantity analysis. A total of 27 events were sampled during the monitoring period, 15 of these were available at the inlets and at the outlet and therefore these events were used for the analysis. A number of small size events for which the water quality samples either could not be collected or partially collected are not included in the analysis.

4.1 Rainfall-runoff

Table 3 presents the rainfall characteristics of monitored events for which water quantity and quality are analyzed. An inter-event time of 12 hours was selected to separate the individual rain events.

Table 3: Rainfall event characteristics

Event	Event Date	Total Rainfall (mm)	Rainfall Duration (hr)	Average Intensity (mm/hr)	Maximum Intensity (mm/hr)	Inter-Event Period (hr)
1	14-Sep-02	28.8	8.4	3.5	47.5	23.3
2	20-Sep-02	13.3	5.3	2.6	72.5	0.5
3	27-Sep-02	18.4	8.9	2.1	7.5	4.5
4	2-Oct-02	10.0	13.8	0.7	17.5	5
5	19-Oct-02	13.0	23.5	0.6	5	0.1
6	25-Oct-02	9.4	6.3	1.5	5	1.9
7	2-May-03	6.8	9.5	0.7	2.4	0.6
8	5-May-03	17.4	14.5	1.2	6.4	3.4
9	11-May-03	17.8	13.8	1.2	11.2	4.8
10	20-May-03	10.8	4.5	2.2	8.8	3.5
11	4-Jun-03	13.8	17.0	0.8	5.6	3.5
12	8-Jun-03	23.6	21.3	1.1	19.2	3.4
13	15-Sep-03	15.0	9.8	1.5	12.8	0.7
14	19-Sep-03	38.0	23.8	1.6	10.4	2.4
15	2-Nov-03	32.2	49.3	0.7	5.6	2.6

The events are classified based on the event volume: (i) large storms – greater than 20 mm, (ii) medium storms – between 10 mm and 20 mm, and small storms – less than 10 mm. Three small size storms, eight medium storms and four large storms were recorded.

4.2 Runoff Coefficient

Volumetric runoff coefficient was determined by dividing the total rainfall volume by the total runoff volume for each event monitored, that is, fraction of rainfall volume converted to stormwater runoff during an event. Table 4 presents the volumetric runoff coefficient values for the constructed watershed catchment 1070.

Table 4: Rainfall-runoff coefficient

Event Date	Total Rainfall (mm)	Observed Runoff (mm)	Runoff Coefficient
14-Sep-02	28.8	7.1	0.25
20-Sep-02	13.3	2.8	0.21
27-Sep-02	18.4	9.2	0.50
2-Oct-02	10.0	3.2	0.32
19-Oct-02	13.0	4.1	0.32
25-Oct-02	9.4	4.6	0.49
2-May-03	6.8	3.4	0.50
5-May-03	17.4	8.5	0.49
11-May-03	17.8	7.5	0.42
20-May-03	10.8	5.5	0.51
4-Jun-03	13.8	5.0	0.36
8-Jun-03	23.6	18.7	0.79
15-Sep-03	15.0	6.3	0.42
19-Sep-03	38.0	25.6	0.67
2-Nov-03	32.2	19.2	0.60

As expected, the volumetric runoff coefficients varies between events. The coefficient ranges from 0.21 to 0.79. As expected, the runoff coefficient trend gradually increases from the fall 2002 to fall 2003, as construction in catchment 1070 proceeds.

A sample rainfall and observed hydrographs at both the inlets and hydrograph at the outlet of the pond is presented in the Figure 6. Figure 7 presents the rainfall-runoff relationship in the watershed. The figure shows that surface runoff volume increases with the rainfall volume.

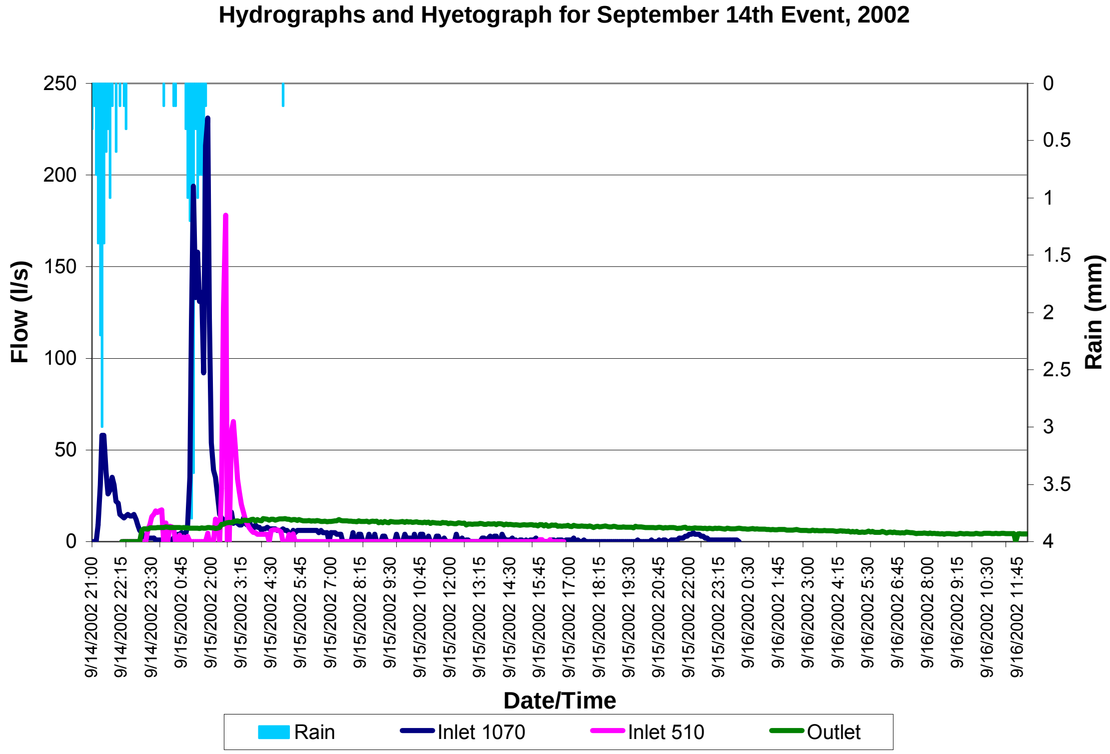

Figure 6: Sample observed hydrographs at the inlets and outlet

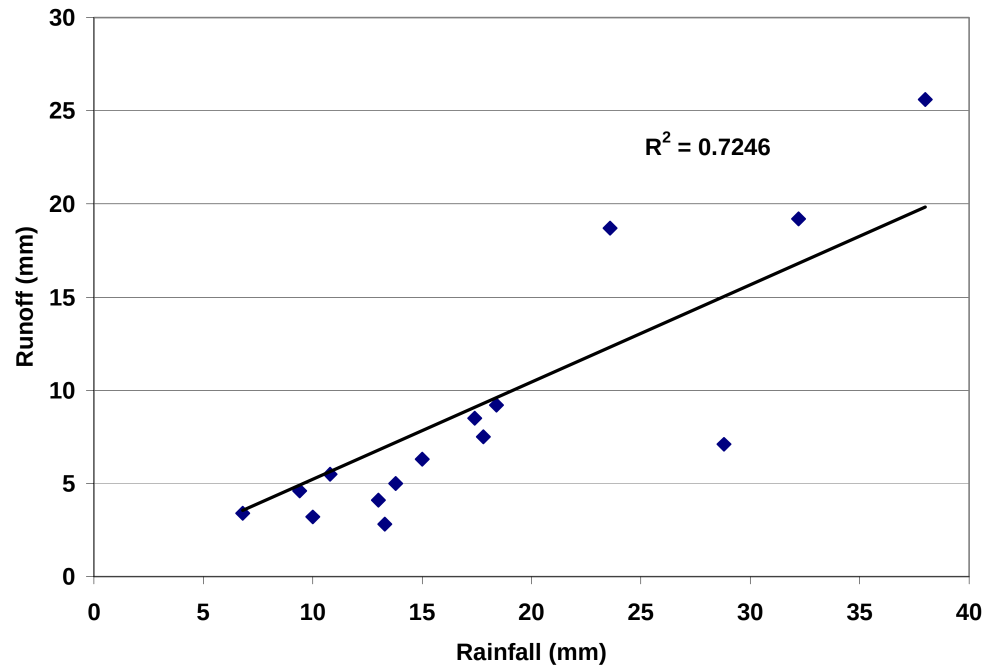

Figure 7: Rainfall-runoff relationship for Ballymore study site

4.3 Hydraulic Detention Times and Drawdown Times

The hydraulic detention time, defined as the time difference between inlet and outlet hydrograph centroids, provides a measure of detention of inlet hydrograph within the facility during the storm event. Detention time is a function of the water volume in the pond and the outflow rate. Typically longer detention times are required for greater pollution removal efficiencies.

Table 5 presents the estimated hydraulic detention times from the observed inflow and outflows for the Ballymore pond. In this case, the inlet hydrograph to the pond constitute the combined hydrographs from catchment 510 and catchment 1070. The average hydraulic detention time was estimated as 12 hours.

Table 5: Hydraulic Detention Time

Event Date	**Hydraulic Detention Time (hr)**
14-Sep-02	11.4
20-Sep-02	10.1
27-Sep-02	13.4
2-Oct-02	8.1
19-Oct-02	9.9
25-Oct-02	15.4
2-May-03	7.8
5-May-03	19.9
11-May-03	5.7
20-May-03	16.6
4-Jun-03	10.6
8-Jun-03	14.4
15-Sep-03	19.8
19-Sep-03	15.3
Average	**12.0**

The drawdown time, defined as the time from maximum and minimum active storage volume. Drawdown will vary depending on the active storage volume captured during the event. The larger the event, the longer the drawdown time.

Table 6 presents the drawdown times during each event. The average drawdown time is 46.0 hours. For some events the estimated drawdown time was very high because of lager size of storm, large flow duration, longer duration of storm and probably contribution from the base flow. The estimated average drawdown favorably matches with the designed drawdown of 48 hours. Higher drawdown times than design occur due to prolonged inflow after the end of the storm events (hydrograph recession). Figure 8 presents the sample drawdown versus time. The combined inlet hydrographs to the pond and pond outflow hydrographs were used for the drawdown time estimation.

Table 6: Estimated Drawdown Time

Event Date	Drawdown Time (hr)
14-Sep-02	25.8
20-Sep-02	51.5
27-Sep-02	80.0
2-Oct-02	36.5
19-Oct-02	39.0
25-Oct-02	94.3
2-May-03	24.3
5-May-03	27.3
11-May-03	29.0
20-May-03	16.0
4-Jun-03	14.5
8-Jun-03	21.8
15-Sep-03	86.5
19-Sep-03	101.0
Average	**46.0**

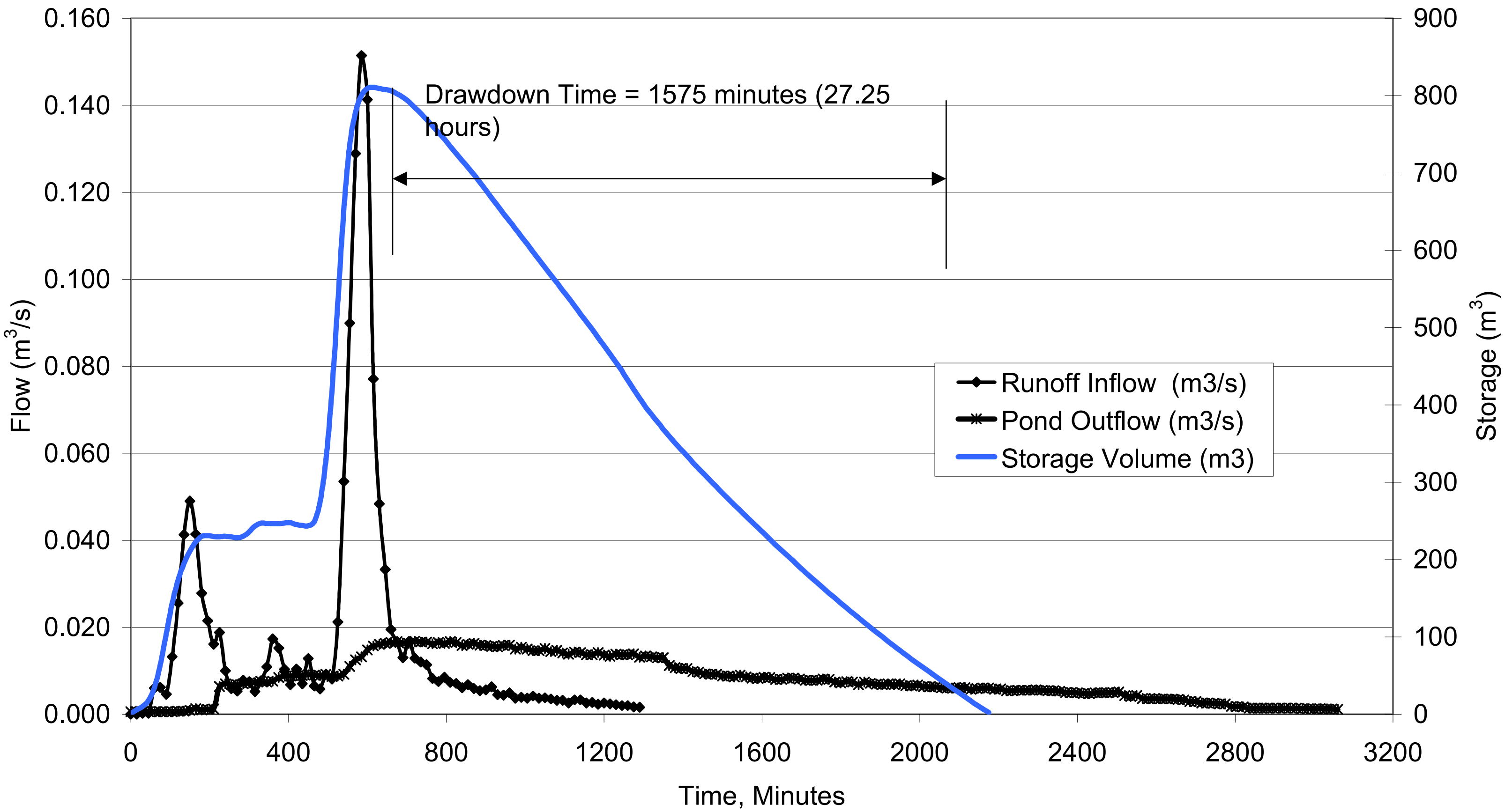

Figure 8: Drawdown estimation for May 5th 2003 event

5. Water Quality Analysis

This section presents the results of water quality analysis. Similar to the quantity analysis, the water quality analysis was conducted for 15 events for which complete inflow and outflow data was available.

The water quality analysis includes results from both discrete and composite samples. Discrete samples were analyzed for suspended solids and pollutographs were developed for each of the events. Composite samples were used to determine average particle size distributions and to determine other constituents.

Figures 9 and 10 present suspended solid concentrations from two different events (October 2nd 2002, and May 20th 2003) sampled in two different seasons, fall and spring. Maximum concentration in Inlet 1070 on October 2nd reached over 10,000 mg/L, while for Inlet 510 concentration reached approximately 1,000 mg/L during the first two hours of the event. It is also evident that the concentration at the outlet was significantly reduced to a maximum of 10 mg/L. Although both events received similar rainfall volumes (approximately 10 mm), the outlet concentration was significantly higher during the event May 20th as compared to the October 2nd event. This shows the potential variability of TSS effluent concentration between the events.

Other factors influence the suspended solid load. The use of bulkheads in the sewers is one factor. At the end of the fall 2002 sampling period visual observations revealed that a significant amount of sediment had accumulated upstream of the bulkheads with sediments almost reaching the top of the bulkhead. Other factors include rainfall depth, intensity, duration, and inter-event dry period.

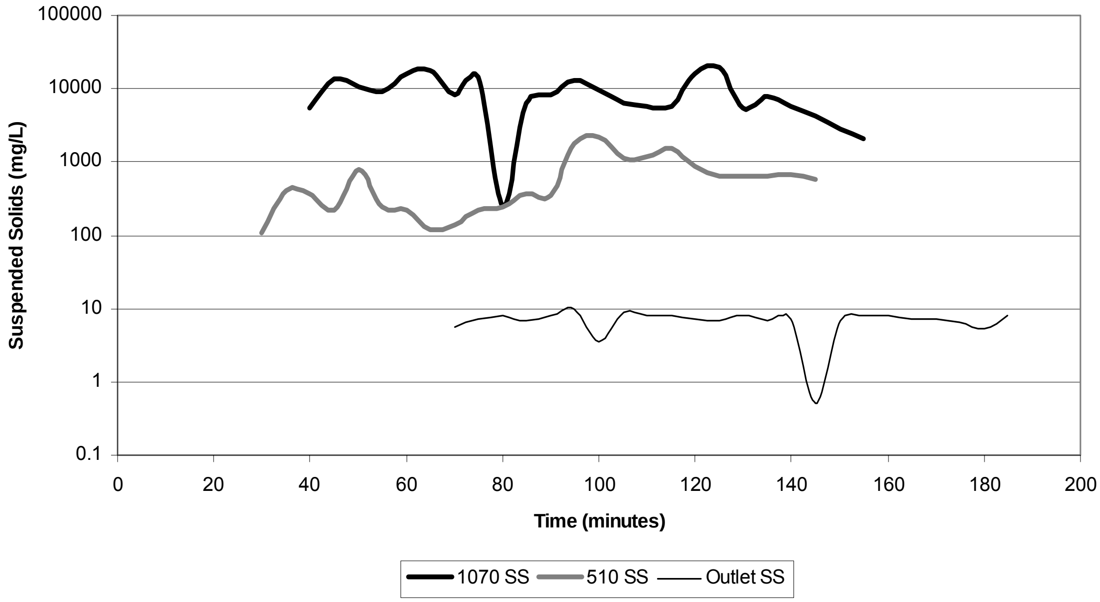

Figure 9: Suspended solids concentration for October 2, 2002 event

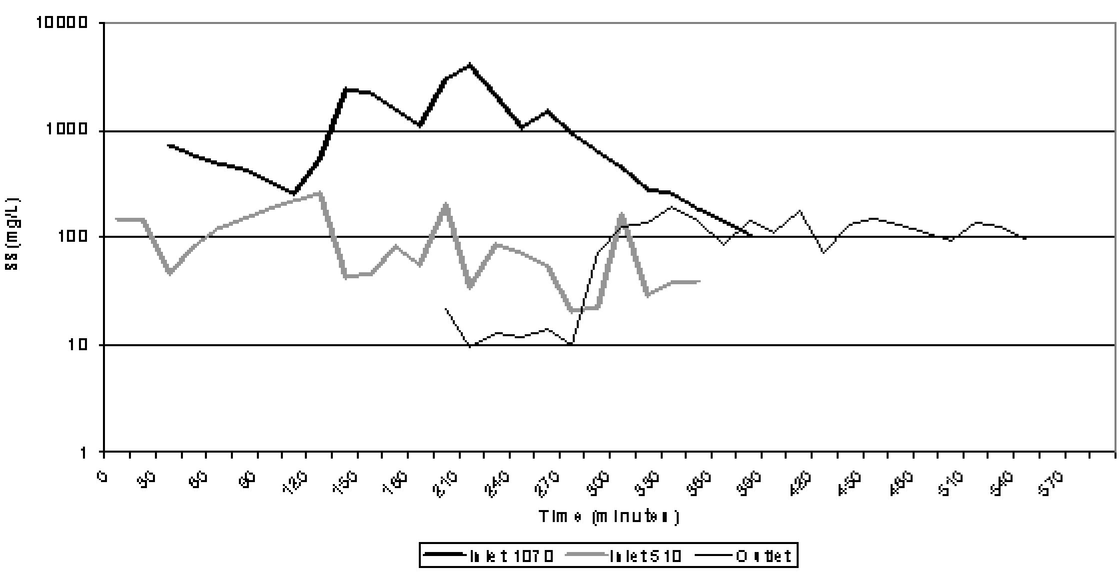

Figure 10: Suspended solids concentration for May 20, 2003 event

Table 7 presents the summary of TSS concentrations at the inlets and outlet of the Ballymore Pond. The average concentration during the sampling period and maximum concentration during the event are presented. The average TSS concentration from catchment 1070 during the sampling period was 2,700 mg/L, within a range of 250 to 10,000 mg/L. The maximum concentration was 34,000 mg/L. This occurred in September 20, 2002. The average TSS concentration from the catchment 510 during the sampling period was 150 mg/L, within a range of 10 to 800 mg/L. The difference is a clear example of the impacts construction on TSS generation.

The Event Mean Concentration (EMC) for each event was also determined. Table 7 presents the estimated inlet and outlet loading and removal efficiencies for each event. The average removal efficiency during the early stages of treatment (6 hour) is estimated to be about 92%. The removal efficiency for the entire event is estimated to be about 82%. This is further explained in Section 6.

Table 7: Observed SS Concentration from Inlets and Outlet of Ballymore Pond

Event Date	**Sample Period (hr)**	**Rainfall (mm)**	**Construction Watershed Inlet 1070**		**Stable Watershed Inlet 510**		**Out flow from the Pond**	
			SS average Concentration (mg/L)	**Max. SS Concentration (mg/L)***	**SS average Concentration (mg/L)**	**Max. SS Concentration (mg/L)***	**SS average Concentration (mg/L)**	**Max. SS Concentration (mg/L)***
14-Sep-02	2 hr	28.8	8726	20050	297	450	277	415
20-Sep-02		13.3	1690	34000	13	36	27	59
27-Sep-02		18.4	5494	12200	143	429	75	189
02-Oct-02		10.0	9999	19100	806	2190	7	10
19-Oct-02		13.0	1228	3800	151	385	29	67
25-Oct-02		9.4	1322	3800	92	188	17	62
02-May-03	6 hr	6.8	423	979	22	49	30	52
05-May-03		17.4	1033	2350	53	214	36	60
11-May-03		17.8	2650	6110	NA	NA	224	470
20-May-03		10.8	1763	4100	83	252	100	192
04-Jun-03		13.8	1493	3380	258	327	49	202
08-Jun-03		23.6	5368	8560	136	1320	1630	2640
13-Jun-03		14.0	1199	4190	55	160	82	144
15-Sep-03		9.8	699	3030	58	120	121	213
22-Sep-03		25.0	263	538	46	46	28	46
19-Sep-03	12 hr	38.0	367	1100	47	47	93	259

*Max. TSS Concentration – Maximum TSS Concentration recorded during the event
NA – Not Available

Table 8: Observed SS Loads from inlets and outlet and removal efficiency

Event Date	Sample Period (hr)	Rainfall (mm)	SS Load (Kg)		SS Load from Outlet	Load based Removal Efficiency (%)
			Construction Catchment (Inlet 1070)	Stable Catchment (Inlet 510)		
14-Sep-02	2 hr	28.8	126	10	13.5	90
20-Sep-02		13.3	396	0.3	1.5	100
27-Sep-02		18.4	1379	42	3.5	100
02-Oct-02		10.0	1712	499	0.4	100
19-Oct-02		13.0	80	11	1.5	98
25-Oct-02		9.4	226	13	0.5	100
02-May-03	6 hr	6.8	89	3	2.7	97
05-May-03		17.4	258	5	5.8	98
11-May-03		17.8	1497	NA	596.3	60
20-May-03		10.8	585	32	32.4	95
04-Jun-03		13.4	317	5	2	99
08-Jun-03		23.6	7741	46	1108	86
13-Jun-03		14.0	695	14	14	98
15-Sep-03		9.8	441	8	31	93
22-Sep-03		25.0	386	1	6	97
19-Sep-03	12 hr	38.0	750	7	22	98

Please Note: The removal efficiency shown in the last column corresponding only to sampling period (i.e., 2 hr or 6 hr or 12 hr). The removal efficiency for the entire event includes the period after the sampling was completed and this was accomplished through the calibrated model The high removal efficiency during the sampling period of the event is attributed to:

- The outflow from the pond at the beginning of the event primarily constitute the standing clear water within the pond (i.e., solids are settled during the previous interevent time);
- Flocculation processes enhance the sedimentation by agglomeration of primary particles into larger particles and corresponding higher settling velocity.

5.1 Particle Size Distribution

The particle size distributions were determined to understand the nature of construction sediments and to establish settling characteristics used for further modeling and to assist with interpretation of performance monitoring results. These are obtained from the composite water quality samples. Figure 11 shows the average cumulative particle size distributions for the fall sampling season of 2002.

The results show that particle size distribution of incoming sediments is extremely fine-grained, primarily consisting of fine silts, clays and colloidal materials.

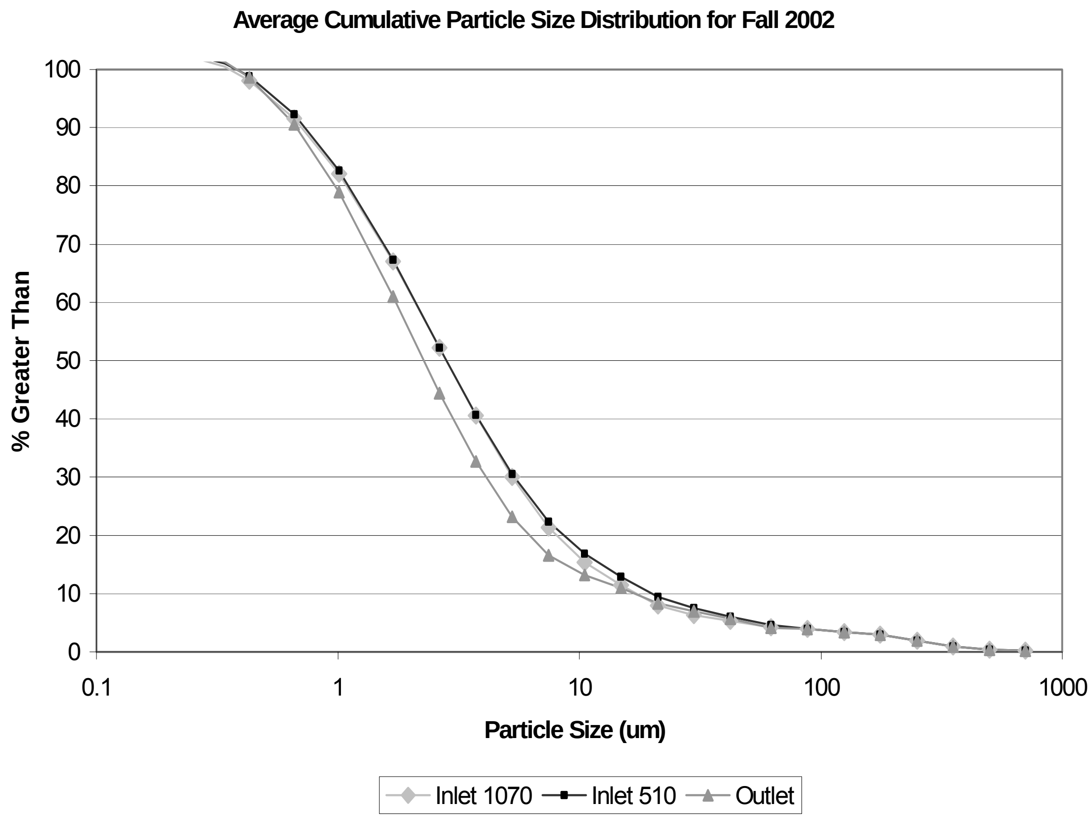

Figure 11: Average Particle Size distribution

Table 8 shows that the average D_{10} value for Inlet 1070, 510, and outlet is 23.6, 23.7, and 16.8 respectively.

Table 9: D_{10} and D_{50} Particle Size for Fall 2002 and Spring 2003

	Inlet 1070	**Inlet 510**	**Outlet**	**Inlet 1070**	**Inlet 510**	**Outlet**
Event	**D_{10}**			**D_{50}**		
14-Sep	20.985	41.5	14.42	7.067	3.15	2.23
20-Sep	-	19.28	-	-	3.45	-
27-Sep	13.47	15.68	19.3	2.57	2.86	2.41
02-Oct	20.1	-	-	3.6	-	-
19-Oct	39.9	18.5	-	5.6	2.32	-
25-Oct	-	-	-	-	-	-
02-May	10.72	24.8	6.086	2.17	4.26	1
05-May	14.208	47.95	16.94	2.59	6.34	2.17
11-May	14.79	-	7.25	2.98	-	2.16
12-May	16.84	31.8	14.14	2.39	2.98	1.99
20-May	19.7	76.44	7.41	3.35	8.86	2.43
Average:	18.97	27.95	16.86	3.59	3.73	2.32

Most of the particles (99%) are smaller than 62 micron and 50% are smaller than 2.3 micron. This observation is consistent with other studies in the United States ("Performance of current sediment control measures at Maryland construction sites by Schueler and Lugbill (1990)").

6. Ballymore Construction Site and Pond Modeling

The purpose of the modeling exercise was three fold:

(1) to assess the TSS EMC and loading for the monitored events,

(2) to quantify the long-term sediment generation from the construction watershed, and

(3) to determine the long-term solid removal performance of the construction sediment control pond.

The details of the modeling methodology are presented in Appendix C. This section summarizes the results of the model

6.1 Model Calibration

The measured flow and TSS concentrations were used to calibrate the model. As expected differences between observed and monitored conditions do occur. Calibration minimized the error.

Water Quantity Calibration

Table 10 presents the comparison of observed and simulation water quantity results. The difference in runoff volume between observed and simulated events range between 0 to 8.3% and difference in peak flow range between 0.17 to 5.9%.

Figure 12 illustrates the observed and simulated flow during May 5, 2003 event.

Table 10: Comparison of observed and simulated water quantity results

Event Date	Rainfall (mm)	Comparison of Runoff Volume			Comparison of Peak Flow		
		Observed (mm)	Simulated (mm)	% Difference	Observed (l/s)	Simulated (l/s)	% Difference
14-Sep-02	28.2	6.80	6.80	0.00	231.0	231.4	0.17
20-Sep-02	13.3	1.70	1.80	5.56	99.4	101.0	1.58
27-Sep-02	18.4	6.90	7.00	1.43	70.9	71.9	1.39
02-Oct-02	10.0	2.20	2.40	8.33	72.4	72.8	0.55
19-Oct-02	13.0	3.00	3.20	6.25	24.0	25.5	5.88
25-Oct-02	9.4	3.02	3.10	3.23	29.0	30.5	4.92
02-May-03	6.8	2.90	3.00	3.33	16.7	17.5	4.57
05-May-03	17.4	7.00	7.10	1.41	97.9	99.4	1.51
11-May-03	17.8	5.10	5.30	3.77	63.7	65.0	2.00
20-May-03	10.8	2.90	3.00	3.33	66.8	68.3	2.20
04-Jun-03	13.8	5.30	5.30	0.00	49.5	50.4	1.79
08-Jun-03	23.6	15.90	16.20	1.85	375.7	377.4	0.45
15-Sep-03	15.0	6.00	6.10	1.64	106.7	108.0	1.20
19-Sep-03	38.0	25.30	25.90	2.32	222.6	223.0	0.18
02-Nov-03	32.2	19.00	19.20	1.04	77.7	78.5	1.02

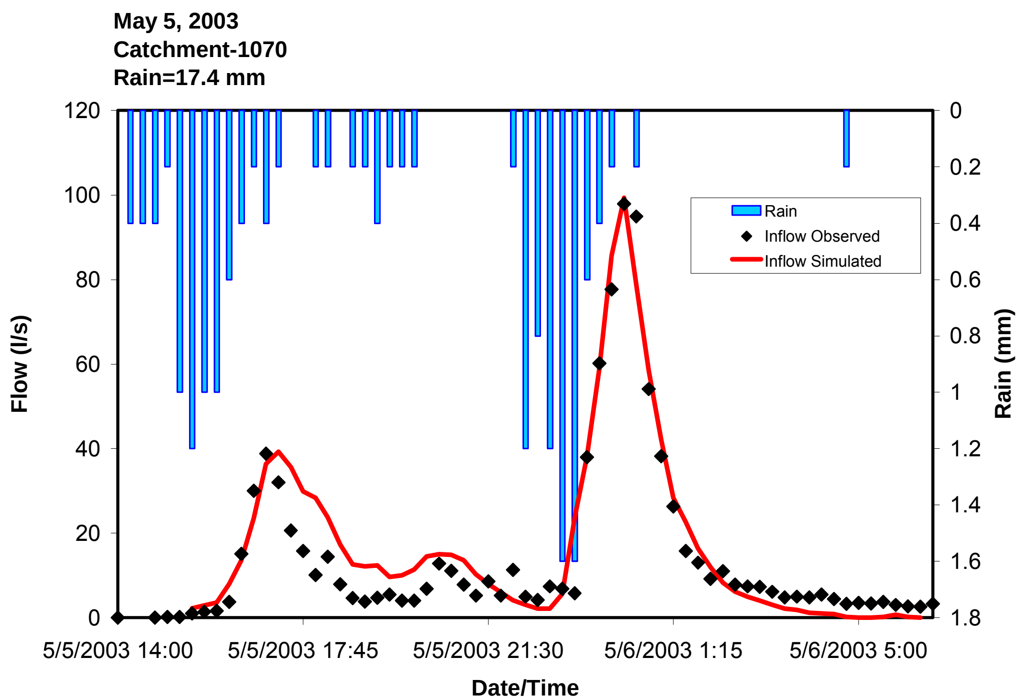

Figure 12: Comparison of observed and simulated hydrographs for May 5th 2003

Water Quality Calibration

Table 11 presents the comparison of observed and simulated water quality results. The difference in observed and simulated SS load during the sampling period was averaged 17% within a range between 2% to 90%. This range of error is typical of water quality simulation.

The average TSS EMC from the Ballymore construction watershed and entering the pond during each monitored event was estimated to be 2,200 mg/L within a range of 200 mg/L to 7,800 mg/L.

Figure 13 illustrates the calibration of the observed and simulated TSS concentration during May 5, 2003 event.

Table 11: Comparison of observed and simulated water quality results

Event Date	**Rainfall (mm)**	**Comparison of SS Loads for sampling period (Catchment-1070)**		**Simulated SS EMC for the Entire Event (mg/L)**	**Simulated SS load for the Entire Event (Kg)**
		Observed (kg)	**Simulated (kg)**		
14-Sep-02	28.2	1364	957	874	2577
20-Sep-02	13.3	396	154	1548	1252
27-Sep-02	18.4	1379	1228	2177	5929
02-Oct-02	10.0	1712	1834	7817	7228
19-Oct-02	13.0	74	63	365	452
25-Oct-02	9.4	2227	3436	6838	8244
02-May-03	6.8	88	156	456	416
05-May-03	17.4	276	282	2924	2862
11-May-03	17.8	1205	1043	2455	1941
20-May-03	10.8	614	765	2114	1097
08-Jun-03	23.6	7254	6707	2057	4093
15-Sep-03	15.0	432	642	1364	1118
19-Sep-03	38.0	745	1328	575	1929
22-Sep-03	25.0	415	787	449	1020
02-Nov-03	32.2	122	149	429	959

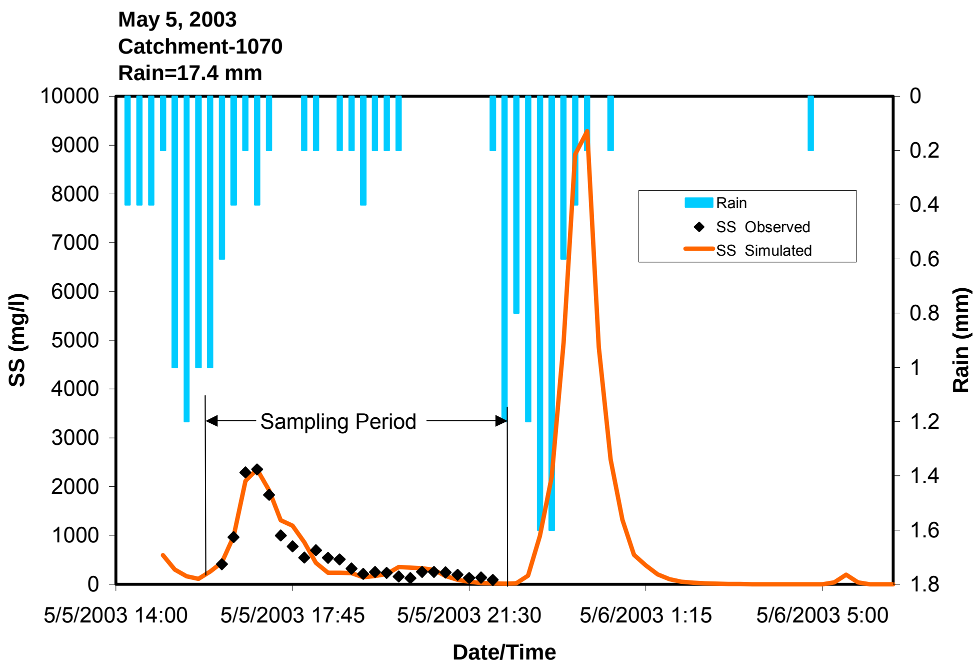

Figure 13: Comparison of observed and simulated pollutographs for May 5th 2003

6.2 Sediment Load Generation

In order to assess the sediment load generation from construction watersheds with active housing construction condition, long-term simulation of Catchment-1070 model was conducted. The long-term simulation was conducted for two scenarios: (i) average rainfall (ii) extreme rainfall conditions using Toronto Buttonville Airport rainfall record. Average rainfall year condition was assessed using the 1978 to 1980 rainfall record and extreme rainfall year condition was assessed using the 1990 to 1992 rainfall record.

Table 12 presents the annual average sediments generation rates.

Table 12: Annual sediment loading rates

Rainfall Condition	Annual Average Sediment Generation Rate (Kg/ha)	Wet Density* (kg/m^3)	Sediment Loading (m^3/ha)
Average Wet Year	3920	1230	3.2
Extreme Wet Year	4205	1230	3.4

*Greenland International Consulting Inc. 1999.

The annual sediment loading information is useful to size ESC facilities and to estimate operation and maintenance requirements. It is noted that for a stable watershed with 55% imperviousness cover, the annual sediment loading rate is about 1.9 m^3/ha (Greenland International Consulting Inc., 1999).

6.3 Pond Performance

Pond Calibration

The pond treatment performance calibration results are presented in Table . Figure 14 illustrates the model results during May 5, 2003 event. The details are presented in the Appendix – B.

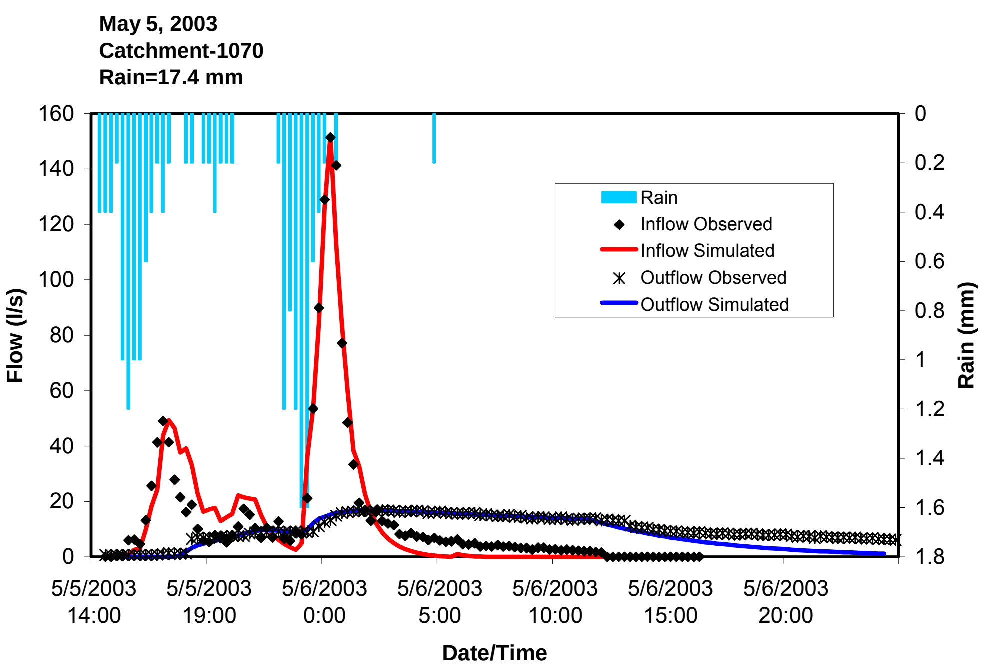

Figure 14: Pond model water quantity calibration results

Removal Efficiency

The average TSS removal efficiency is estimated to be 82% within a range of 54% to 99.8%. (Refer to Appendix – B for details).

6.4 Long-term Performance

Long-term continuous simulation was conducted to estimate the cumulative construction sediment loads leaving the site. The continuous simulation model was based 3 years hourly rainfall data from Toronto Buttonville Airport for average and extreme wet year conditions. Average rainfall year condition was assessed using the 1978 to 1980 rainfall record and extreme rainfall year condition was assessed using the 1990 to 1992 rainfall record. May 2003 watershed condition which represents the active building construction scenario was used for the continuous simulation.

Tables 13 and 14 present the water quantity and quality results of continuous simulation of pond model.

Table 13: Long-term simulation results

Parameter	**Average Wet Year Condition (April 1978 – November 1998)**	**Extreme Wet Year Condition (April 1990 – November 1992)**
Total precipitation (mm)	554	620
SS inflow load (kg)	62,120	69,667
SS outflow load (kg)	5,591	6,817
Removal efficiency	91.0	90.0
Error (%)	1.0	1.1

The long-term TSS removal efficiency during construction was estimated as 91.0% and 90.0% for average and extreme wet year conditions. This removal performance meets the highest criteria under the MOE SMPD manual ("Enhanced Protection"). However, the overall system performance depends on the receiving water impacts due to actual flow rates and concentration discharged into receiving waters. The following section describes the preliminary receiving water impacts assessment.

7. Receiving Water Analysis

This section presents a preliminary receiving water impacts assessment due to effluent discharge from construction sediment control facilities. The receiving water analysis accounts for concentration and duration of exposure in the receiving water body. Figure 15 presents conceptually the receiving water impact assessment approach.

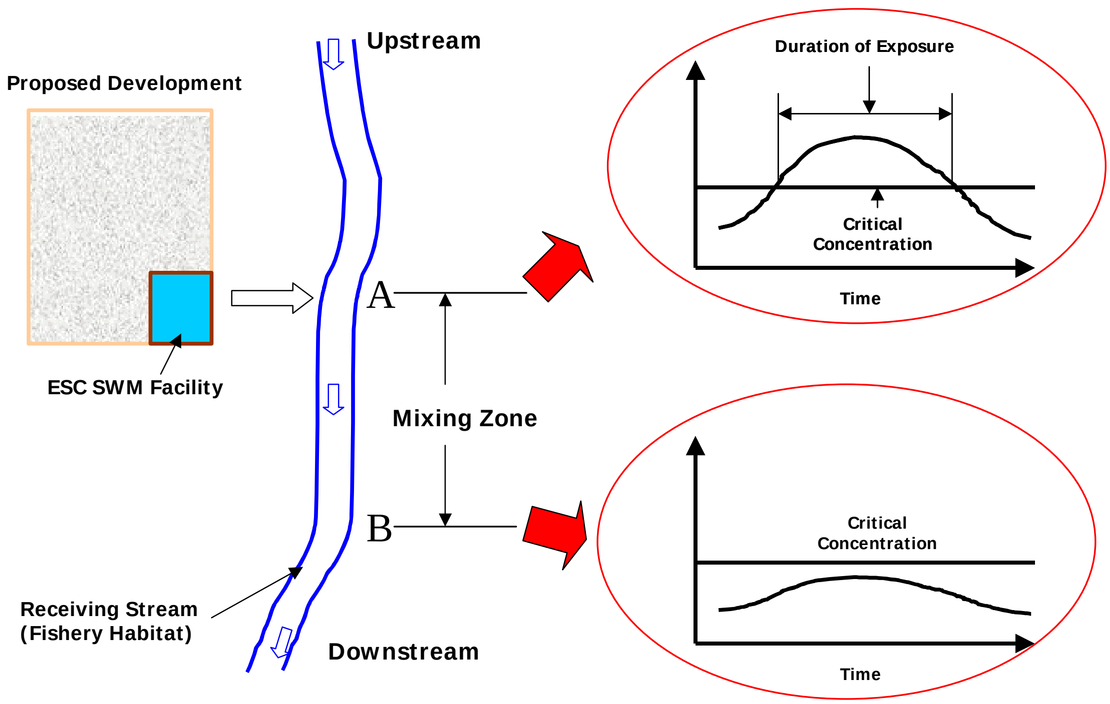

Figure 15: Receiving water impacts assessment approach

During runoff events the effluent from the facility enters the watercourse and mixing occurs in the stream. The concentration in the mixing zone depends on:

- Effluent concentration from the ESC facility
- Background concentration in the stream
- Stream flow and pond outflow rates.

Two methods are used in a preliminary manner to assess the receiving water impacts without mixing and dilution in the receiving stream:

1. Risk on fish habitat due to increase in TSS concentration – relative changes in instream concentration (GOC, 1993) ;
2. Severity of impacts due to TSS concentration and duration of exposure (Ward, 1992, MNR).

These two methods are discussed in the study entitled "Investigation to Develop an Improved Sizing Approach for Construction Sediment Control Facilities" by Clarifica Inc. (2001).

The first method quantifies the risk to fish and fish habitat based on the increases in suspended solids concentration above the background levels. Observed pond effluent TSS concentrations are used to evaluate the risks. Table 14 summarizes the results and shows the number of events that would impact fish and fish habitat.

Table 14: Receiving water impacts due to increses in TSS concentration

Sediment Concentration Increase (mg/L)	Risk to Fish and Fish Habitat[1]	Number of events during 2002-03 monitoring period
0	No risk	
< 25	Very low risk	2 events
25 –100	Low risk	9 events
100 – 200	Moderate risk	2 events
200 – 400	High Risk	2 events
> 400	Unacceptable risk	1 event

[1] GOC, 1993. "The Yukon Placer Authorization". Government of Canada. Authorization and supporting documents applicable to placer mining in the Yukon Territory. Pg 36. Ottawa, Canada.

The second impact assessment methodology considers both concentration and duration of exposure in the effluent from the pond. Concentration and the duration of exposure curves for the Ballymore pond outlet during monitored events were estimated using the model. Figure 16 illustrates concentration and duration of exposure. Points of this curve represent number of hours when the concentration is exceeded during each event.

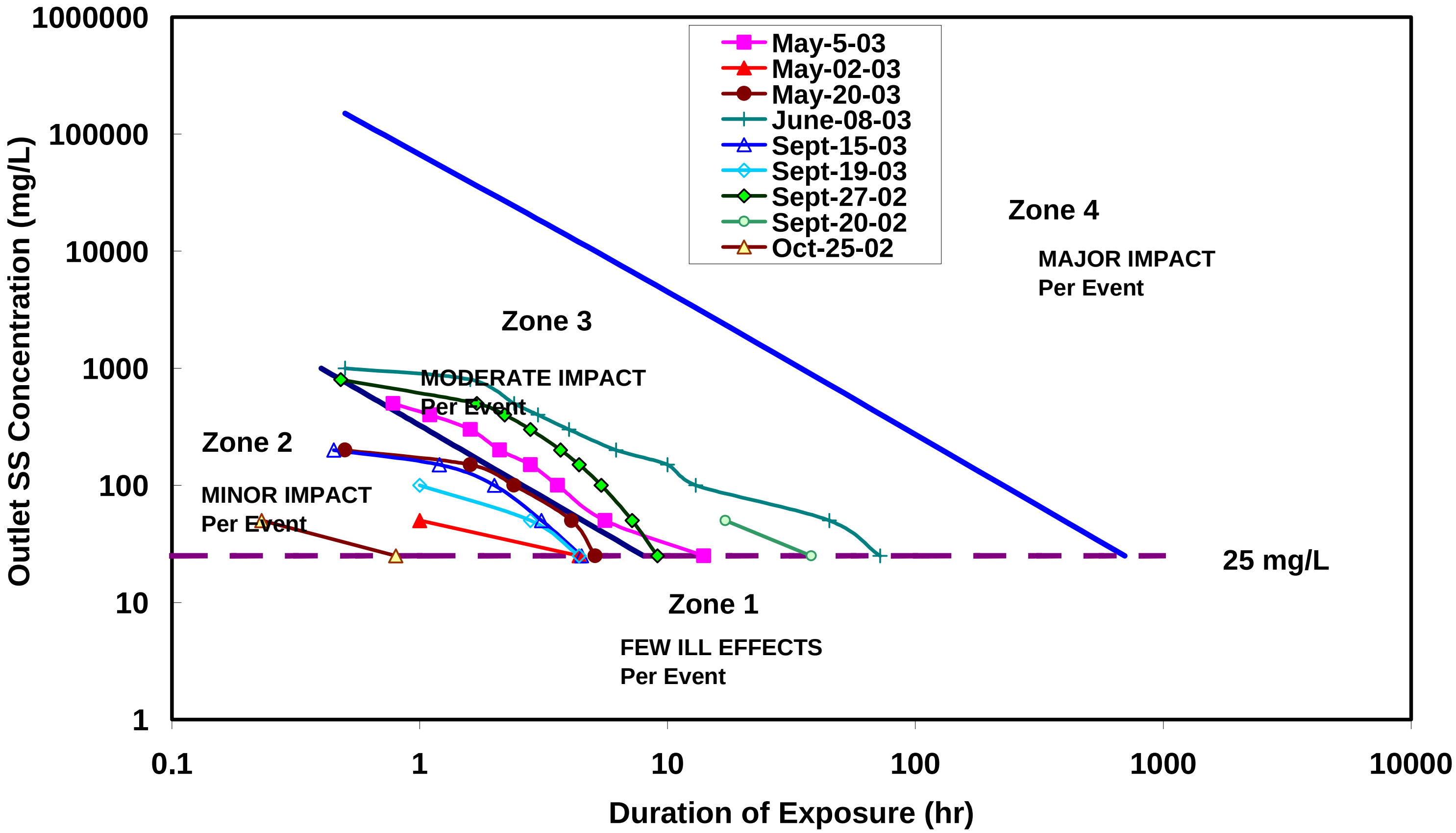

Figure 16: Preliminary evaluation of severity of impacts by suspended sediments

Ref: Ward, N. 1992. "The Problem of Sediment in Water for Fish". Northwester Ontario Boreal Forest Management Technical Notes. Ontario Ministry of Natural Resources.

It may be seen that the pond effluent concentration can induce minor to moderate impacts. This evaluation should be treated as preliminary because no mixing or dilution is considered in the analysis.

Although the design standard of Ballymore pond met the requirements of MOE Stormwater Management Planning and Design Manual criteria, the effluent TSS concentration can impact on fish and fish habitat.

7. Conclusions and Recommendations

7.1 General Performance

The main objective of this study was to assess the performance of storm water management facilities designed according to the MOE Stomwater Management Planning and Design manual for treating urban construction storm runoff prior to discharging to receiving water bodies. The scope included assessment of typical hydrologic conditions of a construction site, sediment characteristics and performance of sediment control pond in terms of water quantity and quality.

This study demonstrates that significant water quality improvement can be achieved through implementation of ultimate SWM facility as a sediment control pond during construction activities. The field data collection and analysis shows that the Ballymore pond meets the target in terms of suspended solids removal efficiency (> 80%). However, effluent suspended solids concentration remain elevated and receiving water impacts to fish and fish habitats can be expected.

7.1.1 Water Quantity

A total of 15 storm events were captured and analyzed during the study period:

- 4 large storms (greater than 20 mm);
- 8 medium sized storms (between 10 and 20 mm)
- 3 small storms (less than 10 mm).

As expected, runoff coefficients gradually increase as development proceeded. On average 35%, 51%, and 56% of rainfall appeared as surface runoff during storm events over the three monitoring period (i.e., September – October 2002, May – July 2003, and August – October 2003). Storms less than 6 mm of rainfall produced negligible amount of runoff, probably due to initial abstraction losses and high infiltration due to soil exposure and construction conditions.

The drawdown times, defined as the time between maximum and minimum water elevations during a storm, were also estimated from the observed hydrographs. On average the detention time was estimated at about 46 hours with a range from 14 to 101 hours. Longer drawdown times occurred during larger events due to hydrograph recession. Shorter times occurred due to smaller inflow volumes.

7.1.2 Water Quality

Total Suspended Solids (TSS) is the critical constituent in construction site runoff in terms of concentration and loading. Furthermore, suspended sediments act as carriers for other constituents (phosphorus, metals and organics). Hence, TSS serves as a direct and indirect measure of overall performance of the sediment control pond.

The following summarizes the water quality findings:

- The average observed TSS concentration at the inlet of the pond was 2,700 mg/L, ranging from 250 to 10,000 mg/L;
- The average TSS Event Mean Concentration (EMC) at the inlet of the pond was 2,200 mg/L, within a range of 200 mg/L to 7,800 mg/L.
- The average observed TSS concentration at the outlet of pond was 177 mg/L. The range was 7 mg/L to 1630 mg/L.
- The average observed TSS load removal efficiency during the sampling period was estimated to be 92%.
- The average TSS load removal efficiency was estimated from the simulation model using the entire pollutographs as 82%.

The particle size distribution from the construction site was skewed towards the finer particles. At the inlet, about 99% of particle size of suspended solids were smaller than 62 microns. Approximately 50% of particle size were smaller than 2.3 micron. Similar observations were made at the outlet.

The particle size distribution from the construction site was skewed towards the finer particles. At the inlet, about 99% of particle size of SS were smaller than 62 microns. Approximately 50% of particle size were smaller than 2.3 micron. Similar observations were made at the outlet.

7.1.3 Long-term simulation and receiving water analysis

The model was used to determine the long-term performance of the pond in terms of SS removal and the receiving water impacts. Two sets of three-year hourly rainfall data corresponding to average and extreme wet year conditions were considered.

The annual sediment-loading rate from the construction site was estimated to be 3.2 and 3.4 m^3/ha for average and wet year conditions, respectively. This compares to 1.9 m^3/ha for stable watersheds with similar imperviousness.

The long-term SS removal efficiency for the pond was estimated as 91.0% and 90.0% for average and extreme wet year conditions respectively.

The results show that ponds designed under the current TRCA criteria, such as the Ballymore pond, provide significant benefits for removing SS from construction runoff. However, the TSS concentrations in the effluent would lead to minor to moderate impacts on fish and fish habitat. However, this assumes no mixing/receiving water assimilation.

7.2 Recommendations

Sediment control ponds designed under the existing TRCA criteria (Enhanced Level of Protection and extended detention storage for the runoff from a 25 mm storm released over minimum 24 hours) will provide significant benefits for removing suspended solids from construction runoff. Suspended solids removal of 90% can be expected from these facilities. The existing pond design criteria incorporates both active and permanent pool volumes for better TSS removal. However, suspended solids concentrations leaving the facility may still be high and, depending on receiving water conditions, could impact the fish and fish habitat.

The following will improve the overall ESC effectiveness:

I. Implementation of the ultimate SWM facility as a sediment control pond during construction period should be considered.

II. The sizing criteria for sediment control ponds should be consistent with the ultimate SWM facility (MOE, 2003). This includes "Enhanced Level of Protection". This would bring the level of protection during construction to the highest standard presently practiced.

III. Ponds should be designed to facilitate accumulated sediment removal maintenance. This includes the means to drawdown the permanent pool or provide alternative means for sediment dewatering.

IV. Construction sediments should be removed before assumption.

V. The banks of the sediment control ponds can be significant sources of soil erosion and sediment contributions to the storage facility. Slope stabilization should be a high priority after pond construction.

VI. Particle size distribution analysis shows that construction sediment is comprised primarily of smaller particles. Low settling velocity of smaller particles yield lower treatment effectiveness as compared with stable urban sites and highlight the need for enhanced controls. Other measures, such as outflow polishing through vegetation filtering or sand filters should be considered.

VII. Large loads entering the ESC facility results in significant amounts of sediment leaving the facility, even with high removal effectiveness.

VIII. Receiving water impacts would best be determined through site-specific monitoring. This should include a comprehensive baseline monitoring before construction. Conditions at the outlet of the pond and downstream within the receiving stream should be included.

IX. The overall ESC effectiveness would be improved by reducing the amount of sediments reaching the ESC pond. Other 'at-source' ESC practices should continue to be implemented and other practices such as earlier re-vegetation could be enhanced. Effective use of ESC measures at the source, upstream of the pond, will reduce the incoming sediment load and improve the overall removal efficiency.

X. The owner should frequently inspect ESC controls to verify it's effectiveness. particularly after runoff events. Inspection records should be created to document the inspection and repairs.

XI. Stormwater management facilities used for ESC ponds should be surveyed annually to assess the sediment accumulation and maintenance requirements.

8. References

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Appendix A – Climate Change Analysis

Climate Change Analysis

To assess the variation of rainfall over a long-term period a climate change analysis was conducted. The hourly rainfall data from the Toronto Buttonville Airport station from 1973 to 2002 was included in the analysis. Rainfall data for the months April to November for each year were included analysis as rainfall data for winter months for a number of years were not available. Using probabilistic approach the climate change analysis was conducted. The objective of the analysis was to determine any trend over the 30 years. Following procedure was adapted to conduct the climate change analysis:

1. The 30-year long-term rainfall record was divided into six periods each having five years of record chronologically staring from 1973 to 2002 (e.g., 1973-77, 1978-82, 1983-88, 1989-92, 1993-97, 1998-02).
2. For each period, the 5-year rainfall record was discretized into individual storm events using an interevent time of 1 hour. It is assumed that the rainfall volumes of all discretized storm events can be described by an exponential probability density function (PDF) and such assumptions are verified for Canadian climate in many earlier studies (Adams and Papa, 2000). The parameter of the exponential PDF can be obtained by taking the inverse of the average runoff volume. Using these step the parameter values of rainfall volume for each period was calculated.
3. The return period (in years), T_R, of a rainfall event can be given by following equation

$$T_R = \frac{1}{\theta \cdot \Pr ob[V \geq v_t]} \qquad \text{(A-1)}$$

where θ is the number of events per year, Prob[V ≥ v_t] is the probability per rainfall event of any rainfall event volume equalling or exceeding v_t and is given by

$$\Pr ob[V \geq v_t] = \int_{v=v_t}^{\infty} \zeta\, e^{-\zeta v} dv = e^{-\zeta v_t} \qquad \text{(A-2)}$$

The parameter of exponential PDF, ζ is given by the $\frac{1}{\bar{v}}$

Substituting Equation (A-2) in Equation (A-1)

$$T_R = \frac{1}{\theta e^{-\zeta v_t}} \quad \text{or}$$

$$v_t = \frac{1}{\zeta}\ln\left(\frac{1}{\theta T_R}\right) \qquad \text{(A-3)}$$

v_t provides the rainfall volume for the return period of t years.

4. Using Equation, the rainfall event volume for various return periods can be obtained for each of the time period. By comparing the event volumes between the periods, the trend can be assessed.

Table A-1 presents the estimation of rainfall volume for various return periods over the 30 years.

Table A1: Estimation of rainfall volumes for various return periods

Period	Rainfall Volume	Rainfall Events	Average Rainfall Volume	Exponential PDF Parameter ζ	Annual No of Events	2-Yr Rainfall Volume (mm)	5-Yr Rainfall Volume (mm)	10-Yr Rainfall Volume (mm)
1973-77	2702.7	519	5.21	0.19	104	27.8	32.6	36.2
1978-82	2881.6	560	5.15	0.19	112	27.8	32.6	36.1
1983-87	2791	513	5.44	0.18	103	29.0	34.0	37.7
1988-92	2797.3	515	5.43	0.18	103	28.9	33.9	37.7
1993-97	2569.2	514	5.00	0.20	103	26.6	31.2	34.7
1998-02	2290	444	5.16	0.19	111	27.9	32.6	36.2

From the Table A-1 it is apparent that there is no trend exists between the periods for various return period events. Such analysis should be conducted for long-term rainfall record, for example more than 100 years to verify any trend. Since the available rainfall record is only 30 years, the results should be interpreted with caution.

Ref: Adams, B. J. and F. Papa: “Urban Storm Water Planning and Management with Analytical Probabilistic Models”, John Wiley & Sons Inc. New York, 2000

Appendix B – Summary of Hydrologic Characteristics

Ballymore Pond

September 2002-November 2003 Events

Summary of Hydrologic Statistics

	Event Date		Rain					Inlet Combined				Outlet				Runoff Coefficient	Hydraulic Detention Time (hr)	Drawdown Time (hr)
			Total Rainfall (mm)	Duration (h)	Mean Intensity (mm/hr)	Maximum Intensity (mm/hr)	Interevent Period (days)	Total Runoff (mm)	Flow Duration (hr)	Average Flow (l/s)	Peak Flow (l/s)	Total Runoff (mm)	Flow Duration (hr)	Average Flow (l/s)	Peak Flow (l/s)			
1	2002	14-Sep	28.8	8.4	3.5	47.5	23.3	7.1	11.0	26.6	321	6.8	37	7.8	12.6	0.25	11.4	25.8
2		20-Sep	13.3	5.3	2.6	72.5	0.5	2.82	22	5.2	120.4	3.9	42	3.9	8.6	0.21	10.1	51.5
3		27-Sep	18.4	8.9	2.1	7.5	4.5	9.2	36	11.2	144.9	9.8	72	5.8	16.3	0.50	13.4	107.8
4		02-Oct	10	13.8	0.7	17.5	5	3.2	19.6	6.9	99.4	2.2	19.5	4.1	72.4	0.32	8.1	36.5
5		19-Oct	13	23.5	0.6	5	0.1	4.1	23.2	7.5	57.9	5.2	26	7.7	10.4	0.32	9.9	39
6		25-Oct	9.4	6.3	1.5	5	1.9	4.6	32	6.1	48.9	6	44.8	4.7	7.4	0.49	15.4	94.3
7	2003	02-May	6.8	9.5	0.7	2.4	0.6	3.4	34.8	3.9	24.9	3.3	37.3	3.8	8.4	0.50	7.8	24.3
8		05-May	17.4	14.5	1.2	6.4	3.4	8.5	21.5	16.6	151.4	10.9	112.5	4.1	16.8	0.49	19.9	27.3
9		11-May	17.8	13.8	1.2	11.2	4.8	7.5	28	10.9	100.1	17	95.2	7.7	16.6	0.42	5.66	29
10		20-May	10.8	4.5	2.2	8.8	3.5	5.5	34.5	6.6	94.7	8.4	79.8	4.5	17.9	0.51	16.6	16
11		04-Jun	13.8	17	0.8	5.6	3.5	5	26.8	7.8	49.5	6.4	73.5	3.7	10.6	0.36	10.6	14.5
12		08-Jun	23.6	21.3	1.1	19.2	3.4	18.7	40.25	19.7	385.7	26.2	65.5	17	54.1	0.79	14.4	21.8
13		15-Sep	15	9.8	1.5	12.8	0.7	6.3	33	7.6	136.5	6.2	58.3	4.5	14.4	0.42	9.8	86.5
14		19-Sep	38	23.8	1.6	10.4	2.4	25.6	80.5	19.1	243.1	12.1	79	6.5	16.3	0.67	15.3	179
15		02-Nov	32.2	49.3	0.7	5.6	2.6	19.2	75.8	10.8	85.3	10.7	129.5	3.5	7.5	0.60	NA	NA

Appendix C – Ballymore Construction Site and Pond Modeling

B. Ballymore Construction Site and Pond Modeling

The purpose of the modeling exercise was three fold: (1) to assess the SS EMC and load for the monitored events, (2) to assess the long-term sediment generation from the construction watershed, and (3) to assess the long-term solid removal performance of the construction sediment control pond. The model is developed based on PC-SWMM (US EPA SWMM ver. 4.4.h engine), which is a parametric, deterministic simulation model that uses rainfall data to simulate runoff, pollutant load from a user defined watershed condition. The SWWM simulation model comprising of two components such as construction watershed model and pond model used the observed runoff quantity and quality data for calibration. While it is impossible to develop the construction watershed model and pond simulation model that will simulate observed conditions with 100% accuracy, the models with reasonable accuracy were developed for the assessment of construction site and pond performance. As a result, the model outputs are viewed as a reasonable estimate of field condition within an assumed range of possible conditions.

B.1 Construction Watershed Model Set-up

To simulate the typical construction watershed condition, a representative construction watershed model was developed for the Catchment-1070. The model was calibrated and verified with the field data that include watershed condition especially construction activities, measured runoff quantity and quality at the inlets.

The construction activities make the watershed very dynamic in terms of hydrology. The standard hydrologic calibration procedure typically used for stable catchments was not applicable in this case because of variable watershed conditions over the simulation period. Therefore following methodology was adopted to develop the construction watershed model which is as follows:

1. The entire monitoring period was divided into three separate periods for which three individual construction watershed models were developed. The three periods include: (i) September to October 2002, (ii) May to July 2003, and (iii) August to November 2003. It is assumed that during these periods the watershed conditions, particularly imperviousness and construction activities and corresponding soil exposure are reasonably constant.

2. The construction watershed model was calibrated with available observed runoff quantity data (i.e., runoff volume, and flow) for each of the periods. The hydrologic model parameter values that produced simulated runoff hydrographs closely matches with the observed runoff hydrographs were identified.

3. The calibrated runoff quantity models for each of the periods were further used for the calibration of runoff quality using the SS concentration data. Since observed SS data is partial (i.e., first 2 to 6 hrs), the calibration procedure was limited to matching portions of observed and simulated pollutographs. In other words, if first 2 to 6 hours of simulated pollutograph was reasonably matched with observed data, the model was selected for the generation of entire pollutographs of the event.

4. A continuous simulation model for the construction watershed was developed to assess the long-term sediment generation conditions. In this case May 2003 watershed condition was used to represent active housing construction condition.

B.2 Construction Watershed Model Calibration Results

Using the methodology described in the previous section, construction watershed model for Catchment-1070 provided the simulated runoff hydrographs and SS pollutographs for the monitored events.

Water Quantity

Table B1 presents the comparison of observed and simulation water quantity results. The difference in runoff volume between observed and simulated events range between 0 to 8.3% and difference in peak flow range between 0.17 to 5.9%.

Figures B1 to B3 presents the comparison of observed and simulated hydrographs for few events.

Table B1: Comparison of observed and simulated water quantity results

Event Date	Rainfall (mm)	Comparison of Runoff Volume			Comparison of Peak Flow		
		Observed (mm)	Simulated (mm)	% Difference	Observed (l/s)	Simulated (l/s)	% Difference
14-Sep-02	28.2	6.80	6.80	0.00	231.0	231.4	0.17
20-Sep-02	13.3	1.70	1.80	5.56	99.4	101.0	1.58
27-Sep-02	18.4	6.90	7.00	1.43	70.9	71.9	1.39
02-Oct-02	10.0	2.20	2.40	8.33	72.4	72.8	0.55
19-Oct-02	13.0	3.00	3.20	6.25	24.0	25.5	5.88
25-Oct-02	9.4	3.02	3.10	3.23	29.0	30.5	4.92
02-May-03	6.8	2.90	3.00	3.33	16.7	17.5	4.57
05-May-03	17.4	7.00	7.10	1.41	97.9	99.4	1.51
11-May-03	17.8	5.10	5.30	3.77	63.7	65.0	2.00
20-May-03	10.8	2.90	3.00	3.33	66.8	68.3	2.20
04-Jun-03	13.8	5.30	5.30	0.00	49.5	50.4	1.79
08-Jun-03	23.6	15.90	16.20	1.85	375.7	377.4	0.45
15-Sep-03	15.0	6.00	6.10	1.64	106.7	108.0	1.20
19-Sep-03	38.0	25.30	25.90	2.32	222.6	223.0	0.18
02-Nov-03	32.2	19.00	19.20	1.04	77.7	78.5	1.02

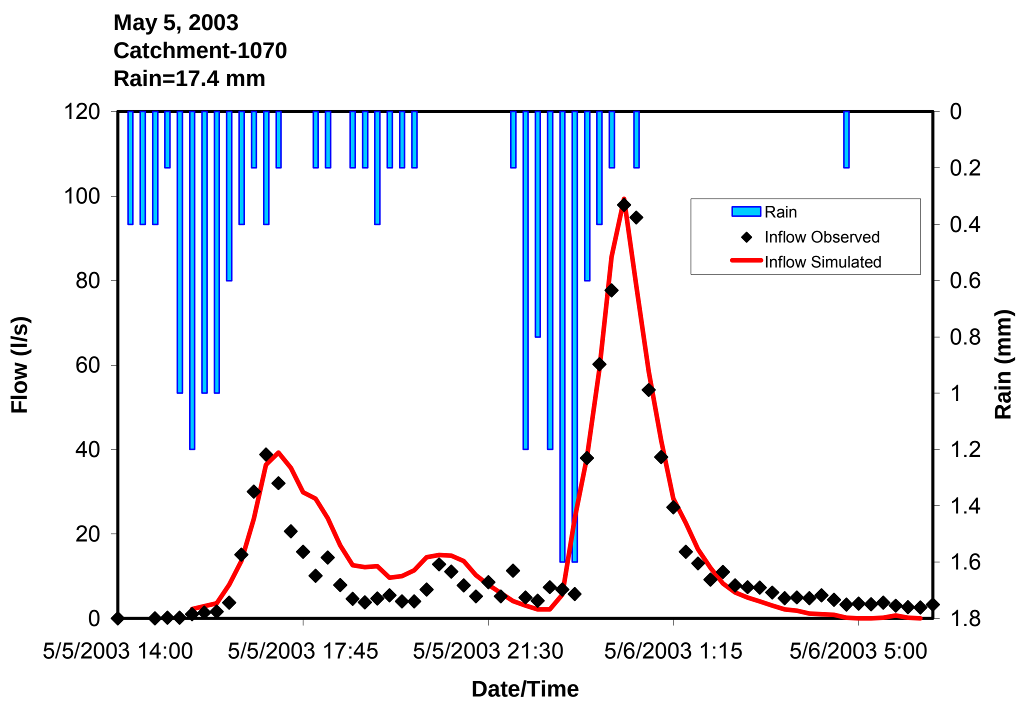

Figure B1: Comparison of observed and simulated hydrographs for May 5th 2003

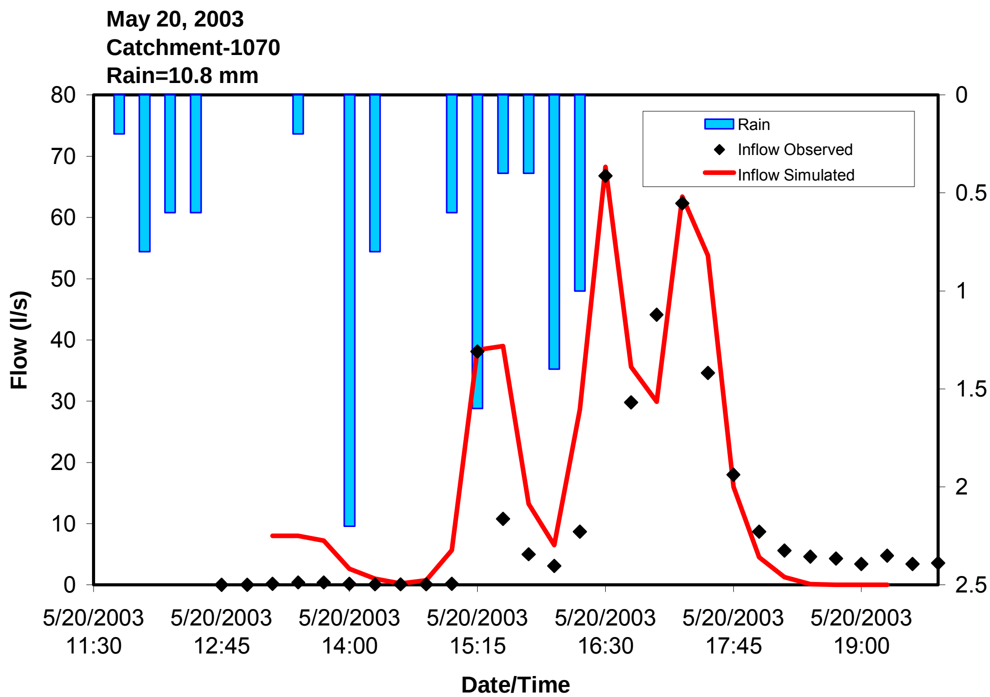

Figure B3: Comparison of observed and simulated hydrographs for May 20th 2003

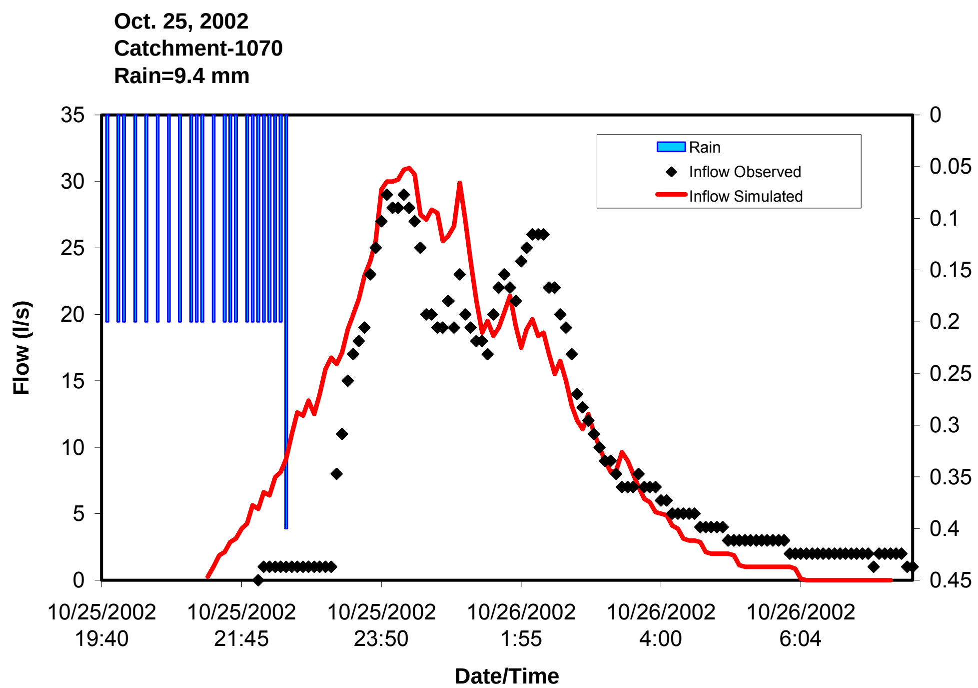

Figure B4: Comparison of observed and simulated hydrographs for Oct. 25th 2000

Water Quality Results

The runoff sediment load from a construction site yields from two sources: (i) buildup and washoff of sediments from the watershed surface, and (ii) soil erosion from the exposed pervious area. SWMM also uses two routines for sediment generation during a runoff event. First, buildup and washoff routine which is typically used for simulating SS load from stable catchments. Second, soil erosion routine, which uses Universal Soil Loss Equation to model sediment loads from soil erosion. The simulated sediment load for the event is the combination of both the sources.

The modeled exposed soil area for the construction watershed which was subjected to erosion comprising of two sources: (i) monitored soil exposure in the individual lots, and (ii) soil exposure from the bank of the construction sediment control pond. In the runoff quality calibration, the model parameter values of buildup and washoff processes and erosion processes were obtained such that the model predicted pollutograph closely matches with the observed pollutograph.

The calibrated watershed model provided entire pollutographs for the events. Table B1 presents the comparison of observed and simulation water quality results. The difference in observed and simulated SS load during the sampling period was averaged 17% within a range between 2% to 90%. This is typical in case of water quality simulation.

The average SS event mean concentration (EMC) from the Ballymore construction watershed was estimated as 2,200 mg/L within a range of 200 mg/L to 7,800 mg/L.

Figures B5 to B7 presents the comparison of observed and simulated pollutographs for few events. Figure 15 shows the observed and simulated SS during the sampling period portion of the entire event.

Table B1: Comparison of observed and simulated water quality results

Event Date	Rainfall (mm)	Comparison of SS Loads for sampling period (Catchment-1070)		Simulated SS EMC for the Entire Event (mg/L)	Simulated SS load for the Entire Event (Kg)
		Observed (kg)	Simulated (kg)		
14-Sep-02	28.2	1364	957	874	2577
20-Sep-02	13.3	396	154	1548	1252
27-Sep-02	18.4	1379	1228	2177	5929
02-Oct-02	10.0	1712	1834	7817	7228
19-Oct-02	13.0	74	63	365	452
25-Oct-02	9.4	2227	3436	6838	8244
02-May-03	6.8	88	156	456	416
05-May-03	17.4	276	282	2924	2862
11-May-03	17.8	1205	1043	2455	1941
20-May-03	10.8	614	765	2114	1097
08-Jun-03	23.6	7254	6707	2057	4093
15-Sep-03	15.0	432	642	1364	1118
19-Sep-03	38.0	745	1328	575	1929
22-Sep-03	25.0	415	787	449	1020
02-Nov-03	32.2	122	149	429	959

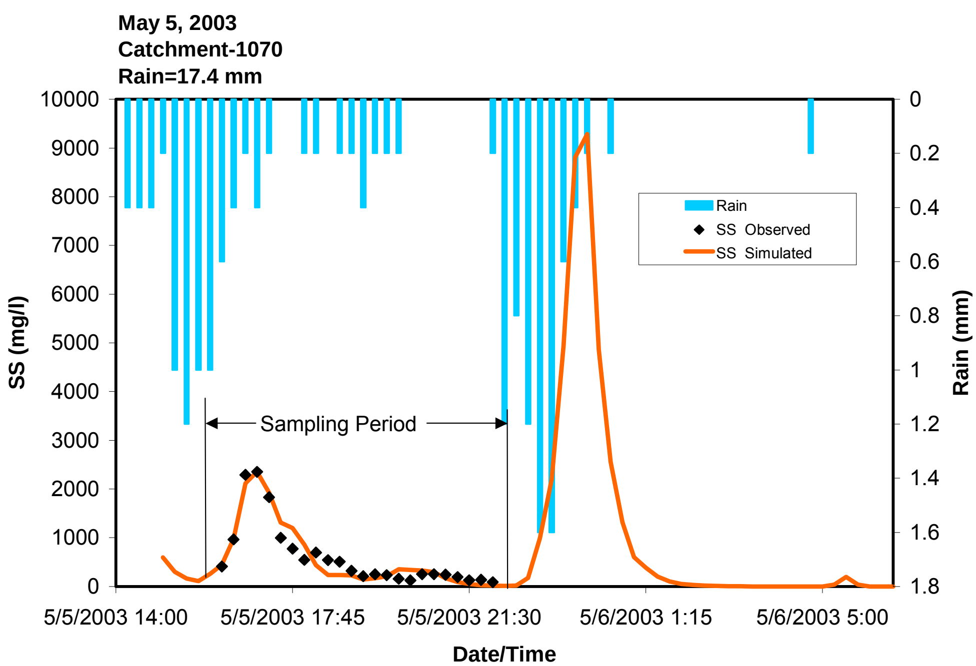

Figure B5: Comparison of observed and simulated pollutographs for May 5th 2003

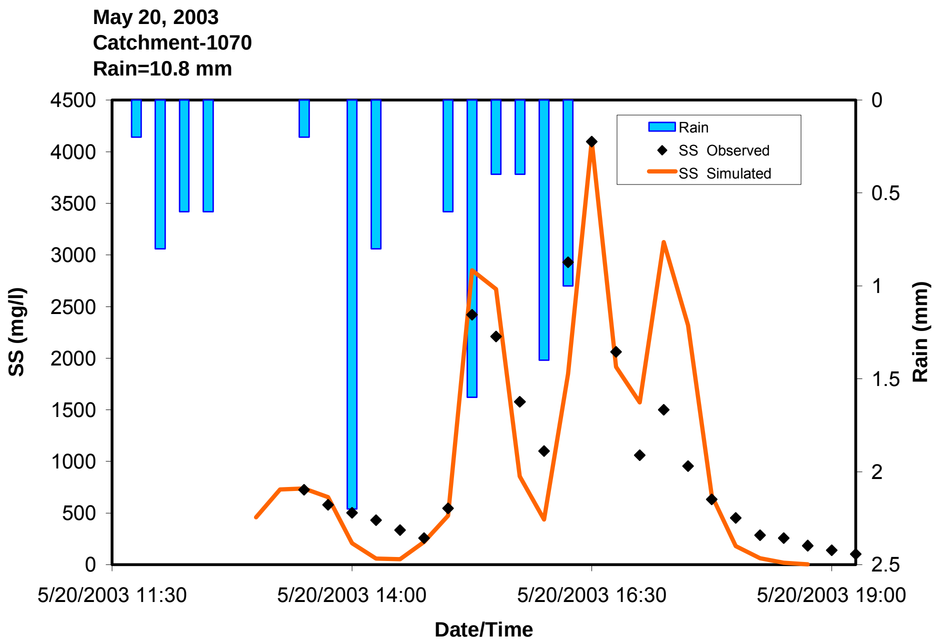

Figure B6: Comparison of observed and simulated pollutographs for May 20th 2003

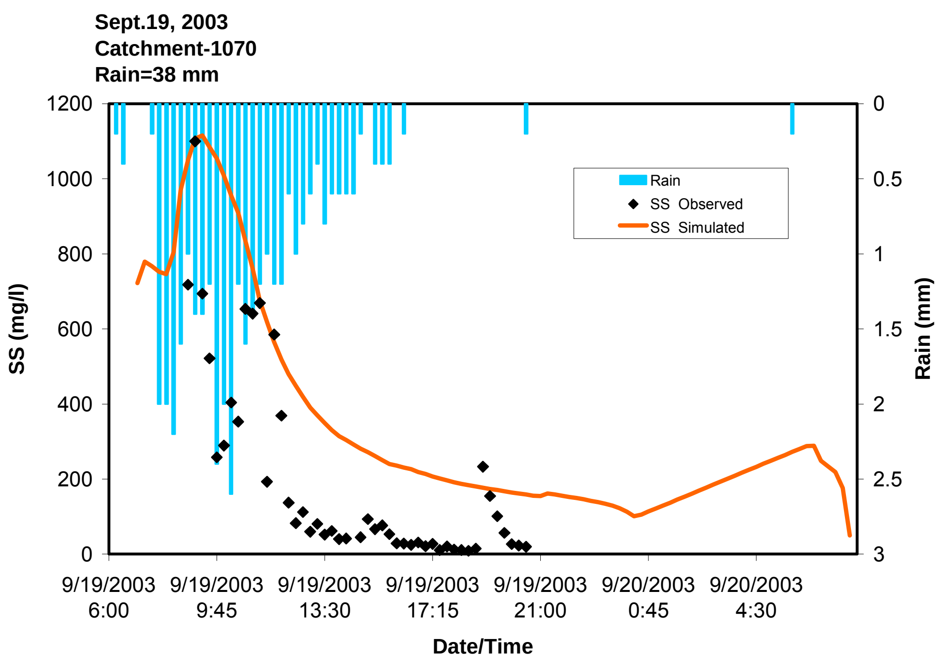

Figure B7: Comparison of observed and simulated SS pollutograpgs for September 19th 2003

B.3 Sediment Load Generation from Constructions Watersheds

In order to assess the sediment load generation from construction watersheds with active housing construction condition, long-term simulation of Catchment-1070 model was conducted. The long-term simulation was conducted for two scenarios: (i) average rainfall (ii) extreme rainfall conditions using Toronto Buttonville Airport rainfall record. Average rainfall year condition was assessed using the 1978 to 1980 rainfall record and extreme rainfall year condition was assessed using the 1990 to 1992 rainfall record. A three-year simulation period was selected because typically construction activities for a subdivision development span between two to three years. Furthermore, the rainfall period between April to November for each year is considered to reflect the monitoring period condition (i.e., water quantity and quality was not monitored during winter).

May 2003 watershed condition was used to assess the sediment load from construction sites during active housing construction. Table B2 presents the annual average sediments generation rates for active housing construction stage from construction sites.

Table B2: Annual sediment loading rates

Rainfall Condition	Annual Average Sediment Generation Rate (Kg/ha)	Wet Density (kg/m^3)	Sediment Loading (m^3/ha)
Average Wet Year	3920	1230	3.2
Extreme Wet Year	4205	1230	3.4

The annual sediment loading information is very useful not only for sizing the erosion and control measures but also help to estimate the sediment removal requirements for operation and maintenance of the construction sediment control ponds. It is noted that for a stable watershed with 55% imperviousness cover, the annual sediment loading rate is 1.9 m^3/ha (Greenland International Consulting Inc., 1999) compared to 3.2 m^3/ha from construction sites with active housing construction condition for an average wet year condition. Such information for different construction conditions would be very useful.

B.4 Sediment Control Pond Model Calibration Results

This section presents the model set-up and calibration results for the Ballymore construction sediment control pond.

B.4.1 Pond Model Set-up and Calibration

To assess the sediment removal performance and to assess the possible receiving water impacts from the pond outlet SS concentration, a storage-treatment pond model for the Ballymore pond was developed in conjunction with watershed model. The integrated watershed model and pond model was calibrated with pond inlets and outlet water quantity and quality data. The calibration exercise provided the determination of treatment pond model parameter values (e.g., storage-discharge relationship, initial storage volume and SS concentration etc.) such that the simulated inlet and out flows matched with the observed combined flow from two sub-catchments (i.e., Catchment-1070 and Catchment-510) and outlet flow from the pond.

The water quantity calibration for the Ballymore pond are presented in Figures B8 and 9. The SWMM models a detention unit as either as a plug flow system or completely mixed system. In this study, the SS treatment was simulated as the completely mixing reactor because of (i) the construction pond permanent pool volume was generally large compared to the average event runoff volume, (ii) high concentration of inflow SS, and (iii) mixing was facilitated by the presence of two inlets located opposite to each other. In this mode, the incoming sediments was instantly distributed uniformly throughout the facility resulting in uniform pollutant concentration throughout the facility. The removal efficiency was obtained as a function of pollutant decay coefficient, which in conjunction with simulation time-step determines the decay rate. The results of water quality calibration are presented in Table .

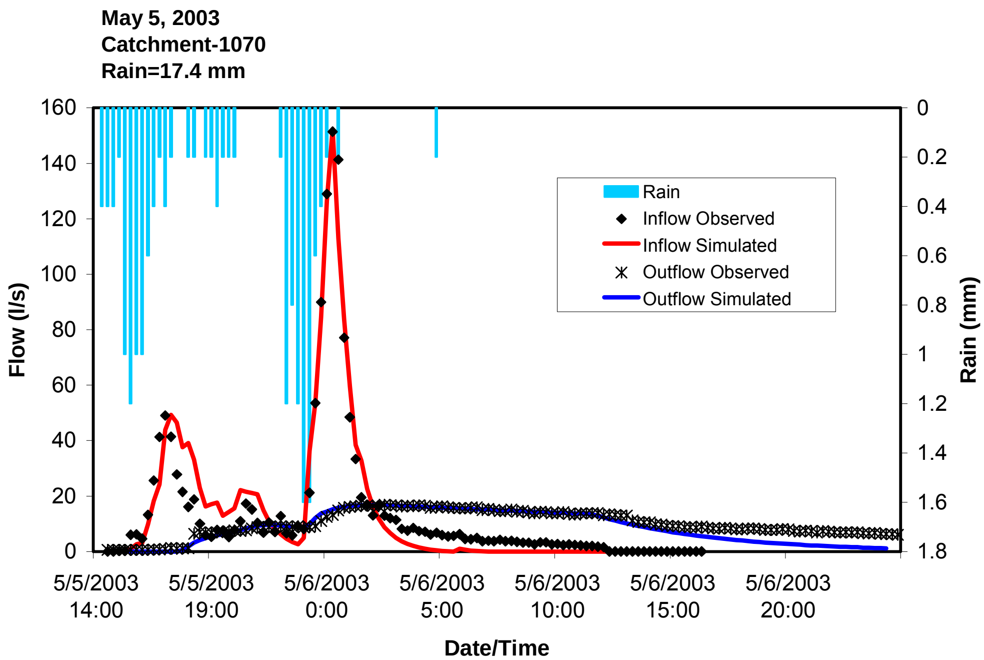

Figure B8: Pond model water quantity calibration results

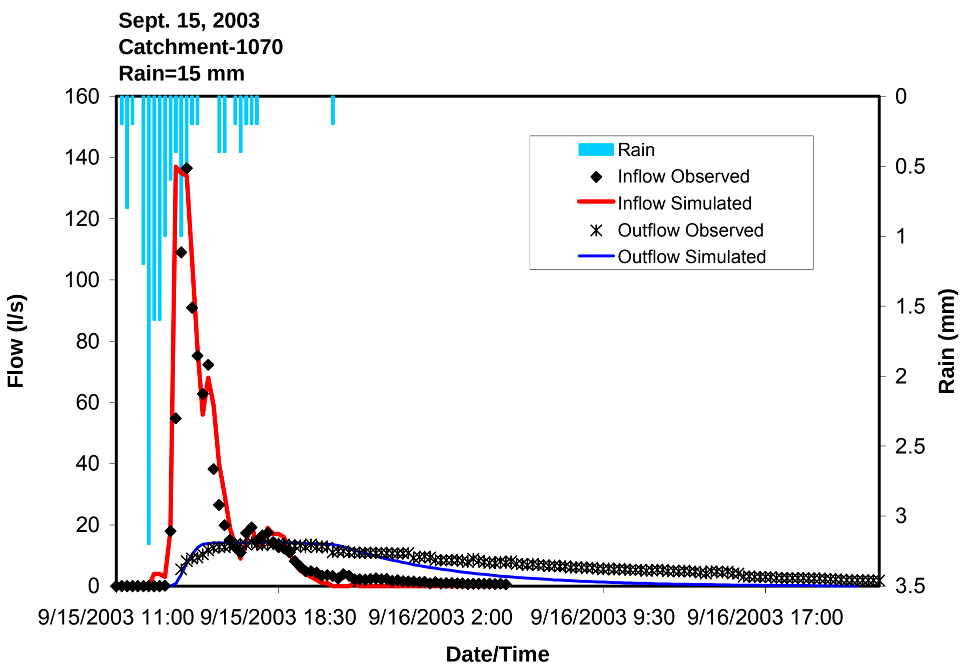

Figure B9: Pond model water quantity calibration results

B.4.2 TSS Removal Effciency

After calibrating the pond model with water quantity, that is, matching with observed combined inflow and out flows, the water quality calibration was conducted for each of the events. In this case, the observed SS load was compared for the simulated load for the sampling period during the event. If the runoff event duration is smaller than sampling period then the complete calibration for the event was obtained, otherwise a partial calibration was obtained. The parameter values which provided reasonable matching of observed SS load, the simulation load for the entire event was obtained. The SS load based removal efficiency for each sampled event is defined as follows:

$$RE = \left[\frac{\left[(V_i \times EMC_i) - (V_o \times EMC_o) \right]}{(V_i \times EMC_i)} \right] \times 100\%$$

where V_i is inflow volume, EMC_i is inflow concentration, V_o is outflow volume and EMC_o is outflow concentration and RE is removal efficiency.

Table B3 presents the load based SS removal efficiency for the monitored events.

Table B3: Inflow and outflow SS load and removal efficincy

Event Date	Rainfall (mm)	Inflow SS Load (kg)	Comparison of outlet SS Loads during sampling period		Outlet SS Load (kg)	Removal Efficiency
			Observed (kg)	Simulated (kg)		
14-Sep-02	28.2	850	11.0	20	304	64.3
20-Sep-02	13.3	111	1.4	2.7	17.1	84.6
27-Sep-02	18.4	2807	3.6	5.6	90.0	96.8
02-Oct-02	10.0	3074	0.5	0.6	3.4	99.8
19-Oct-02	13.0	226	2	2.7	40.3	82.2
25-Oct-02	9.4	779	0.5	0.7	3.5	99.5
02-May-03	6.8	448	2.5	2.7	5.4	98.5
05-May-03	17.4	4687	4.3	4.4	71.0	98.5
20-May-03	10.8	1842	20.4	19.4	35.0	98.1
08-Jun-03	23.6	2984	268.5	354.4	4599	-54.1
15-Sep-03	15.0	1346	19.7	16.0	18.1	98.7
19-Sep-03	38.0	2256	16.2	14.8	15.8	99.3
02-Nov-03	32.2	1104	19.2	22.3	53.4	95.2

The difference in observed and simulated SS load during the sampling period was averaged 16% within a range between 2% to 92%.

The average SS removal efficiency based on the entire pollutograph was estimated as 82% within a range of 54% to 100%.

From the Table B3 it is apparent that the general SS removal efficiency for most of the events were more than 90%. The high removal efficiency is attributed to higher concentration, and particle sizes of influent solids are finer, flocculation processes enhance the sedimentation by agglomeration of primary particles into larger particles and corresponding higher settling velocity.

B.4.3 SS Removal Efficiency for Design Storms

The calibrated pond model was used to simulate the pond performance for design storm events. The design storm events for 1:2 to 1:100 year for the Richmond Hill were used as the input to the model. May 2003 watershed condition which represent the active housing construction condition was used to simulate construction scenario. Table B4 present the simulation results for design storms.

Table B4: SS removal efficiency for design storms

Design Storm	Rainfall (mm)	Runoff (mm)	SS Load In (kg)	SS Load Out (Kg)	% Removal
1:2	34.7	22.4	3256	250	92.3
1:5	46.5	33.9	3752	267	92.9
1:10	54.3	41.5	3806	251	93.4
1:25	64.0	52	3724	240	93.6
1:50	71.3	59.5	3578	220	93.7
1:100	78.7	67.2	3442	199	93.9

From the Table B4 it is clear that the SS removal for all of the design storm is above 90%. Most of the monitored storms are smaller than 1:2 year design storm.

B.4.4 Continuous Simulation of Ballymore Pond

Long-term continuous simulation of integrated watershed model and pond model was conducted to estimate the cumulative loads exited from the Ballymore pond. The continuous simulation model was based 3 years hourly rainfall data from Toronto

Buttonville Airport for average and extreme wet year conditions. Average rainfall year condition was assessed using the 1978 to 1980 rainfall record and extreme rainfall year condition was assessed using the 1990 to 1992 rainfall record. May 2003 watershed condition which represents the active building construction scenario was used for the continuous simulation. Figure B9 presents the sample continuous simulation results in the form of outlet flow and SS concentration between May 1 to 26th 2003.

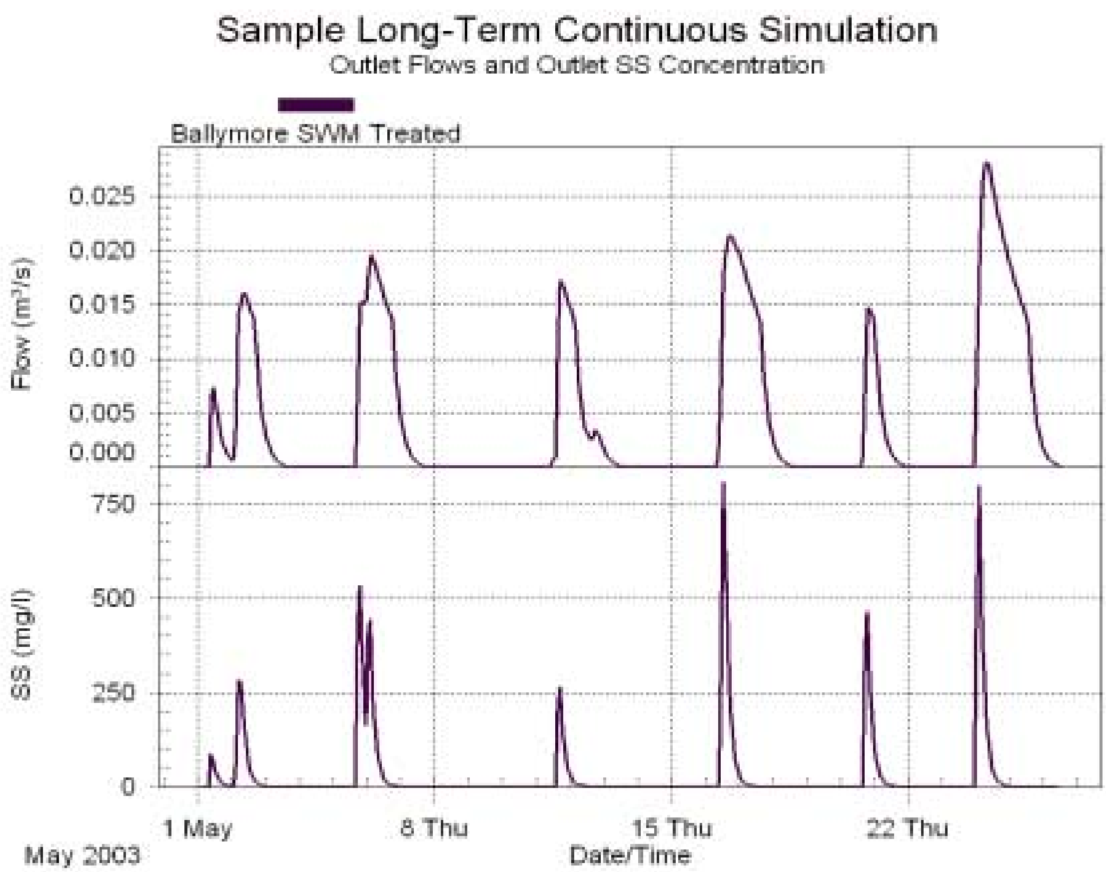

Figure B9: Sample long-term continuos simulation results

Tables B5 and B6 present the water quantity and quality results of continuous simulation of pond model.

Table B5: Long-term simualtion of water quantity

Parameter	Average Wet Year Condition (April 1978 – November 1998)		Extreme Wet Year Condition (April 1990 – November 1992)	
	(mm)	(m^3)	(mm)	(m^3)
Total precipitation	1,662	255,250	1,860	285,610
Total infiltration	438	67,260	490	75,250
Total evaporation	390	59,880	434	66,700
Surface runoff	874	134,210	983	151,000
Error (%)	2.5		2.7	

Table B6: Long-term simulation water quality

Parameter	Average Wet Year Condition (April 1978 – November 1998)	Extreme Wet Year Condition (April 1990 – November 1992)
	(kg)	(kg)
Total inflow load	186,360	209,000
Total outflow load	16,772	20,450
Removal efficiency	91.0	90.0
Error (%)	1.0	1.1

The long-term SS removal efficiency for the Ballymore Pond was estimated as 91.0% and 90.0% for average and extreme wet year conditions which satisfies the Level 1, Enhanced receiving water protection.