Evaluation of Design Criteria for Construction Sediment Control Ponds

Markham, Ontario

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Evaluation of Design Criteria for Construction Sediment Control Ponds – Markham, Ontario

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EXECUTIVE SUMMARY

Background and Objectives

Construction activities have been identified as a significant source of sediment to urban streams. Elevated levels of suspended sediment are a concern because of their detrimental impact on aquatic ecosystems. Effects on fish may include impairment to respiratory functions, lower tolerance to toxicants or disease, increased physiological stress, decreased reproductive success, and reduced vision, which inhibits their ability to find food.

Ponds are among the most effective structural practices for reducing the release of sediment from construction sites. However, there are currently no scientifically defensible standards for the design of these ponds in Ontario. As an interim measure, it has become common practice to use the ultimate (post-construction) stormwater management pond as a temporary sediment control pond. These ponds typically capture over 90% of construction site sediment, but due to extremely high influent concentrations, suspended solids in water discharged from the facilities rarely achieve levels necessary to protect downstream aquatic life.

This study evaluates a temporary sediment control pond in Markham as a basis for improving current guidelines for construction sediment ponds. Monitoring was undertaken from the stripping phase through to final construction and stabilization of the site to ensure that the full range of construction impacts was considered. Various pond design scenarios are simulated using a finite element hydrodynamic and sediment transport model to help determine how the design guideline should be modified to provide improved performance. Specific objectives of the study were to:

- monitor the performance of a construction sediment pond in terms of the quality and quantity of runoff;
- assess in-pond sediment accumulation rates and particle size distributions;
- evaluate pond effluent impacts on receiving waters;
- model the sediment settling dynamics in the pond under current and alternative pond design scenarios;
- provide recommendations on pond design for sediment control during the construction period; and
- update the *Erosion and Sediment Control Guidelines for Construction* (TRCA, 1994) based on the findings of the study.

The final objective of using study results to update the *TRCA Erosion and Sediment Control Guidelines for Construction* (April 1994) is a critical part of ensuring study outcomes are translated into practical effect through changes to how construction sites are managed from a sediment control perspective.

Study Site

The drainage area for the temporary construction sediment pond is located on predominately Peel clay soil in the Town of Markham near the intersection of Ninth Line and Major Mackenzie Drive. The pond has minor and major system drainage areas of 88.8 and 52.9 ha, respectively.

The temporary construction sediment pond was designed to meet OMOE ‘enhanced’ level guidelines for post-construction stormwater management ponds. The pond has a permanent pool volume of 127 m^3/ha, a large extended detention volume of 144 m^3/ha, and a length-to-width ratio of 8:1 (Figure 1). The extended detention volume accommodates runoff from a 4 hour 25 mm rainfall event and releases it over a minimum period of 48 hours. Average permanent pool and extended detention depths are 1.5 and 2.4 m, respectively.

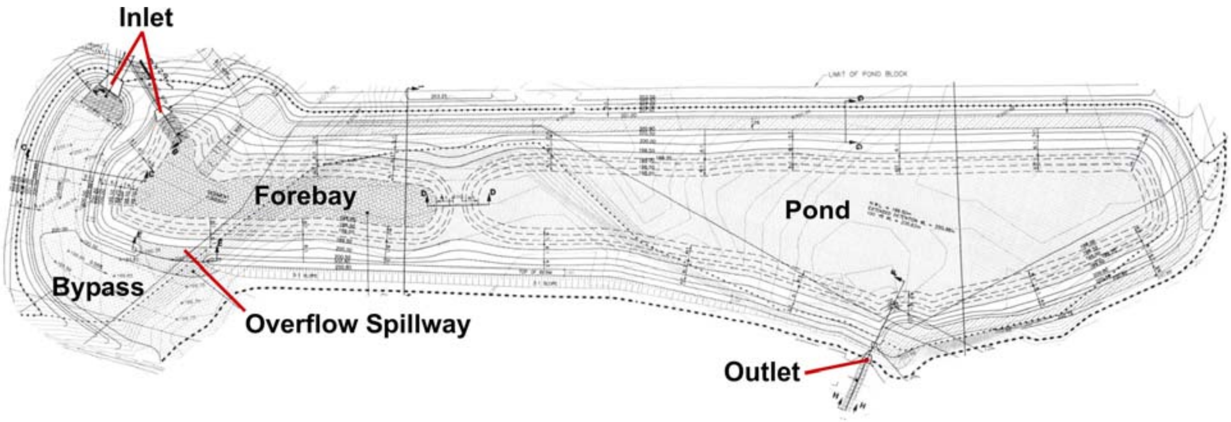

Figure 1: Schematic of the temporary construction sediment control pond

The pond outlet structure consists of a submerged perforated riser with a reverse slope pipe that draws water from below the permanent pool surface to help mitigate thermal impacts. Flows in excess of the 25 mm event (>2.9 m^3/s) pass over a control weir at the inlet and into the bypass channel, ultimately discharging to the Little Rouge Creek. Flows exceeding the pond capacity spill from the pond over a 20 m overflow weir into the Little Rouge Creek.

Methods

Monitoring

The water quantity monitoring program consisted of co-ordinated measurements of rainfall, flow at the inlet and outlet of the pond, and water levels. In 2004, receiving water levels and flow rates were also monitored. All stations were automated with recording intervals set at 5 minutes for rainfall, flow, sewer water level, and velocity. Pond and receiving water levels were measured hourly.

Water quality was monitored using automated water samplers installed at the inlet and outlet of the pond (2004 and 2005) and in the receiving water upstream and downstream from the pond outlet (2004 only). Up to 48 discrete water samples were collected during each event, depending on the duration of flow. Sample intakes were Teflon lined to prevent cross contamination. Pacing intervals for the inlet, outlet, and receiving waters were 10 minutes, 30 minutes and hourly, respectively.

Samples were analyzed primarily for suspended solids, particle size and turbidity. Other water quality groups were analyzed as single composites from each station during selected events to characterize the overall quality of construction site runoff and potential impacts on receiving waters. All samples were analyzed by the Ontario Ministry of the Environment laboratory in Etobicoke.

Samples of the bottom sediment were collected at 15 locations along 7 cross sections. These samples were analyzed for particle size to identify primary zones of deposition and assist in calibrating the hydrodynamic and sediment transport models.

The pond was surveyed four times during the various construction phases. The surveys were conducted at 16 cross sections and referenced to a common benchmark. The surveys were used to estimate the depth and rate of sediment accumulation, and to develop the finite element mesh for the model.

Modelling

The RMA suite of hydrodynamic and water quality models, developed by the US Army Corps of Engineers, was selected among several models as the best suited for this study. The finite element hydrodynamic model (RMA2) computes water surface elevations and velocity components for two-dimensional, depth averaged flow fields. The finite element solution is based on the Reynolds form of the Navier-Stokes equation for turbulent flow. Bed friction is accounted for using Manning's roughness equation. Turbulence is modelled via an eddy viscosity approach.

The finite element sediment transport model (SED2D) simulates two-dimensional, depth-averaged sediment transport in a water body. This model combines the basic processes of erosion, entrainment, transportation, and deposition to predict sediment concentration and bed change. SED2D can process both cohesive (silt and clay) and non-cohesive (sand) soil types; however, only a single effective grain size can be modelled during each simulation.

The finite element mesh for the pond was developed based on 2D drawings provided by the design engineers and bathymetry surveys conducted in September 2004, December 2004, and April 2005. The mesh is comprised of approximately 2000 elements and 5400 nodes. Element sizes range from 1 meter to 5 meters. Smaller elements are used for increased model accuracy in sections of the pond that are more complex, such as the inlet, outlet, and banks. Relatively flat sections of the pond are meshed with larger elements.

The model was calibrated to observed data through a lengthy process that involved determining the sensitive parameters and their effect on model output, then varying these parameters logically until the model solution approached the observed data. Three events were examined for calibration and validation purposes. Total rainfall for the October 22, 2005 event (24 mm) most closely matched the rainfall depth used in the design of the pond (25 mm). Hence, this event was used for all subsequent simulations.

Study Findings – Field Monitoring

Water Quantity

Between June 16th, 2004 and December 1st, 2005, 106 storm events were monitored, of which 68 had rainfall greater than 2.0 mm. A wide range of event sizes and intensities were captured over the study period.

The pond provided excellent flow control. The average reduction in peak flows for observed events was 83%. Detention times averaged 16.2 hours. Drawdown for the 25 mm event occurred over approximately 72 hours, which is much longer than the design drawdown time of 48 hours.

Runoff coefficients at the Greensborough site increased as the catchment was built-out. During early construction in 2004, events larger than 10 mm typically had runoff coefficients between 0.16 and 0.38. In 2005, as more and more area was developed and landscaped, the typical range was between 0.38 and 0.52.

Initially, the study aimed to examine impacts of the pond on receiving waters (Little Rouge River). However, flow monitoring indicated that receiving water impacts would be difficult to detect because outlet volumes represented only a small proportion (approx. 7%) of total flow in the Little Rouge River. Thus, the monitoring study objectives were limited to a detailed assessment of pond performance only.

Sediment Accumulation

Sediment survey results indicated that, as expected, the forebay filled up first, with sediment accumulation of up to 61% of the total permanent pool in this area by the 15th of April, 2005. Between April and November, 2005, some of the accumulated sediment in the forebay area was re-suspended and transported downstream. Over this period, sediment accumulation in the middle portion of the pond increased from 29 to 52% of the permanent pool volume, while forebay sediment accumulation decreased from 61 to 46% of the permanent pool. An unusually large and intense storm event on August 19th may have been partly responsible for this mass movement of sediment. Very little sediment accumulation occurred in the downstream third of the pond.

Water Quality

As indicated earlier, total suspended solids (TSS) was the primary water quality variable of interest in this study. A review of literature and guidelines on the receiving water impacts of TSS indicated that stream concentrations less than 25 mg/L provide a high level of protection to aquatic ecosystems. The impact of concentrations above 25 mg/L depends on the concentration and duration of exposure. The combined effects of these parameters on aquatic biota are evaluated in this study using a receiving water risk assessment framework originally developed by Newcombe (1986; as cited in Ward, 1992).

At the Greensborough pond, the average volume weighted event mean effluent TSS concentration (n=21) was 55.1 mg/L, ranging during individual events from 13 to 93 mg/L. Pollutograph analysis showed peak effluent TSS concentrations as high as 246 mg/L for discretely sampled events. By comparison, the average volume weighted influent event mean concentration was 3,362 mg/L (n=21), with short term peaks of up to 19,900 mg/L. Influent TSS concentrations dropped considerably as the area of exposed soils decreased from 2004 to 2005 (Table 1). On a load basis, 99% of incoming sediment was trapped inside the pond.

Table 1: Inlet and outlet TSS EMCs, loads and removal efficiencies for all events monitored for water quality (n=21)

Event Date	Rainfall (mm)	Influent TSS EMC (mg/L)	Influent Peak TSS Conc.	Mass In (kg)	Effluent TSS EMC (mg/L)	Effluent Peak TSS Conc.	Mass Out (kg)	Removal Efficiency (%)
2004 Season (n=7)								
Average	13.8	4933.1	8980.0	34372	33.9	97.3	238.0	97.6
Median	8.8	2607.0	5250.0	7080	22.9	60.6	44.0	99.3
Volume Weighted Avg		7375.8			55.1			99.3 *
2005 Season (n=14)								
Average	19.0	2879.2	7467.9	20321	41.3	97.8	406.3	97.6
Median	18.6	2517.0	7290.0	11122	43.5	82.7	363.6	98.4
Volume Weighted Avg		2302.6			50.7			98.0**
All Events (n=21)								
Average	17.2	3563.8	7734.7	25005	38.9	97.7	350.2	97.6
Median	15.4	2607.0	6580.0	10172	38.5	73.2	240.2	98.7
Volume weighted Avg		3362.3			51.6			98.6*

* based on sum of loads (not an average)

A receiving water impact analysis of effluent concentrations and durations showed that, assuming no dilution in the stream, most events would have a 'moderate impact' on downstream aquatic biota (Figure 2). If the duration of exposure is ignored and the risk assessment is based solely on effluent event mean concentrations, only one event falls within the 'moderate risk' category (80 to 400 mg/L), while 12 events are ranked as 'low risk' (25 – 80 mg/L) and 8 are in the 'very low risk' category (<25 mg/L).

Regression analysis showed that effluent quality is influenced more by flow volumes and peak outflow rates than by influent concentrations, influent loads and peak inflow rates. From a management perspective, this finding suggests that:

(i) upstream sediment control practices, such as construction phasing or infiltration techniques, that reduce flow volumes will lead to greater improvements in effluent quality than would practices that reduce influent TSS concentrations only;

(ii) limiting outflow rates by extending pond drawdown times will improve effluent quality; and

(iii) design features that minimize re-suspension of previously trapped sediments (*e.g.* submerged berms, permeable curtains) will improve overall pond performance.

Particle size analysis indicated that over 50% of the suspended particles entering the pond fell within the clay size fraction (< 4 µm). Despite the very fine influent particle size distribution, the facility was successful in further reducing the size of suspended particles from a median size of 3.8 µm at the inlet to a median size of 2.0 µm at the outlet.

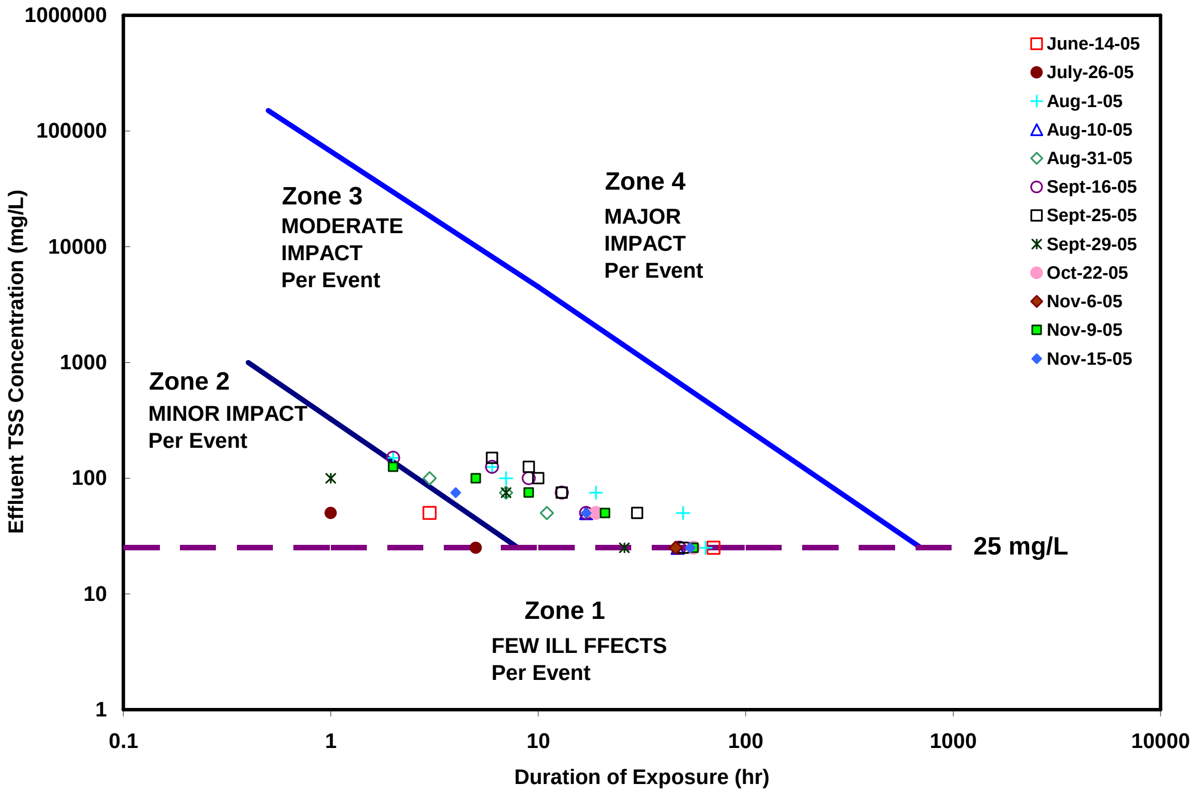

Figure 2: The concentrations and duration of effluent TSS for monitored events. Values represent the number of hours that specified concentrations were exceeded during an event. Impacts do not account for dilution of effluent in receiving waters. The fisheries impact framework is from Newcombe (1986; as cited in Ward, 1992).

A general analysis of influent, effluent and receiving water quality was undertaken to characterize the quality of construction site runoff. The results showed that, although construction site runoff contains high levels of suspended solids and phosphorus from eroded soils, it generally contains fewer metals, oils, chlorides and other pollutants than are typically found in stormwater runoff from stabilized urban sites. A comparison to guidelines showed that, despite significant removal of pollutants by the facility, effluent concentrations of copper, total phosphorus and *E.coli* most often exceeded provincial receiving water objectives.

Results from the Greensborough pond were compared to monitoring results from another construction sediment control pond monitored during 2002 in the community of Ballymore, Richmond Hill. The Ballymore pond had a larger permanent pool than the Greensborough pond (154 vs 127 m^3/ha), but shorter drawdown time (48 vs. 72 hours) and a much smaller length-to-width ratio (2:1 vs. 8:1). Drainage areas were 88 and 16 ha, respectively. Results showed significantly higher effluent event and peak TSS concentrations at Ballymore (Table 2). Effluent concentrations from 7 of 16 events monitored at Ballymore were considered to present a moderate or high risk to receiving waters (assuming no dilution and ignoring the duration of exposure), compared to only 1 of 21 events in a similar risk category at Greensborough. This analysis suggests that pond drawdown times and length-to-width ratios have a significant influence on the quality of effluent discharged from construction sediment ponds.

Table 2: Comparison of the Ballymore Pond in Richmond Hill to the Greensborough Pond in Markham.

	Ballymore Pond (n = 16)		**Greensborough Pond (n = 21)**	
	Average	**Median**	**Average**	**Median**
Rainfall (mm)	16.8	13.7	17.2	15.4
Influent Peak TSS Concentration (mg/L)	7,955	3,950	7,735	6,580
Influent TSS EMC (mg/L)	2,332	1,129	3,564	2,607
Effluent Peak TSS Concentration (mg/L)	318	167	98	73
Effluent TSS EMC (mg/L)	177	62	39	39
Rem. Efficiency (%)	91	96	98	99

Study Findings – Modelling

Nine scenarios were developed to examine the influence of various design parameters on pond performance. The following design parameters were selected for evaluation:

- Length-to-width ratio
- Presence or absence of submerged berms
- Drawdown time
- Outlet location
- Permanent Pool Volume

The scenario simulations involved varying one design parameter while keeping the other parameters constant. In each case, the results were compared to the base case, or existing pond model.

A summary of the scenarios and simulation results are presented in Table 3. Scenarios are arranged in ascending order of effluent event mean concentrations and loads. The base case scenario is highlighted in bold.

All simulations are based on the October 22nd event rainfall amount and distribution. This particular event had significant rainfall (24 mm) but it was distributed over three days. The majority of rain (18 mm) fell during the first 12 hours.

Table 3: Summary of scenarios and results

Scenario identifier	**L:W ratio**	**Number of berms**	**Drawdown time (hrs)**	**Permanent pool storage (m^3/ha)**	**Outlet location**	**TSS load in (kg)**	**TSS load out (kg)**	**Removal efficiency (%)**	**Peak outlet TSS concentration (mg/L)**	**Peak outlet load (kg/h)**	**EMC (mg/L)**
LW8:1 - B1 - D168 - P127 - O1	8:1	1	168	127	Existing	2,588	93	96.4	34.6	1.9	18.3
LW8:1 - B1 - D72 - P254 - O1	8:1	1	72	254	Existing	2,588	229	91.2	43.3	6.9	30.7
LW8:1 - B2 - D72 - P127 - O2	8:1	2	72	127	New	2,588	255	90.1	50.9	8.0	34.2
LW8:1 - B2 - D72 - P127 - O1	8:1	2	72	127	Existing	2,588	279	89.2	58.8	9.5	37.3
LW8:1 - B1 - D72 - P127 - O1	**8:1**	**1**	**72**	**127**	**Existing**	**2,588**	**299**	**88.5**	**68.8**	**11.2**	**39.9**
LW8:1 - B1 - D72 - P127 - O2	8:1	1	72	127	New	2,588	300	88.4	70.1	11.3	40.1
LW8:1 - B0 - D72 - P127 - O1	8:1	0	72	127	Existing	2,588	333	87.1	77.5	12.7	44.6
LW5:1 - B1 - D72 - P127 - O1	5:1	1	72	127	Existing	2,588	347	86.6	98.0	16.1	46.4
LW4:1 - B1 - D72 - P127 - O1	4:1	1	72	127	Existing	2,588	373	85.6	111.3	18.2	50.0
LW3:1 - B1 - D72 - P127 - O1	3:1	1	72	127	Existing	2,588	405	84.4	128.1	20.8	53.9

Scenario simulations showed that all pond design parameters selected for analysis had some impact on pond performance, with the magnitude dependent on the degree of variation. The following conclusions are based on results of the modelling study:

- Length to width ratio is one of the most important design parameters. Reducing the length-to-width ratio from 8:1 (existing) to 3:1 resulted in a 35% increase in the effluent suspended solids EMC and load.

- Submerged berms and forebays prevent short circuiting and enhance mixing. Scenario simulations showed that the addition of a second berm to the pond reduced the effluent EMC by 7% while removal of all berms increased the effluent EMC by 11%. Other barriers, such as perforated curtains or baffles, would likely have similar effects on effluent quality.

- Relocating the pond outlet from its current location near the end of the pond to the very end of the pond resulted in a 9% reduction in effluent EMC when implemented with the 2 berm scenario.

- Providing drawdown over a minimum of 48 hours, with preferred drawdown up to 72 hours, is recommended to provide enough time for complete mixing of runoff with the permanent pool.

Drawdown times longer than 72 hours are not recommended because rain events in Ontario occur, on average, every 72 hours during the growing season.

- Doubling of the permanent pool volume resulted in a 23% decrease in the effluent event mean concentration and load, and a 37% reduction in the peak effluent concentration. Clearly, storage volume is among the most important design parameters affecting overall pond performance, especially when the volume increase results in a much larger surface area. Adding volume by making the pond deeper was shown to produce only minor improvements in performance.

Conclusions and Recommendations

The target effluent event mean concentration for temporary sediment control ponds is 25 mg/L. Fisheries research has shown that suspended solids at or below this level will not harm downstream aquatic life or habitat. While ultimate (enhanced level) stormwater ponds typically achieve average event mean TSS concentrations of at least 25 mg/L (SWAMP, 2005; Strecker *et. al*., 2004; CWP, 2000), temporary sediment control ponds do not. This holds true even if the pond design exceeds existing criteria for sediment control ponds, as was shown in this study. The following recommendations on pond design and maintenance will help improve sediment capture. It should be recognized, however, that even if all of these recommendations are implemented, meeting the effluent suspended solids target of 25 mg/L will also require significantly improved management of sediment runoff upstream of the pond.

Table 4: Comparison of the current and recommended erosion and sediment control guideline for ponds.

Design or Maintenance Feature	Current Guideline (TRCA, 1994)	Recommended Guideline
Permanent Pool Volume (m^3/ha)	125	50% increase if either drawdown or length-to-width criteria can not be achieved
Extended Detention Volume (m^3/ha)	125	125
Drawdown Time (hours) (25 mm, 4 hr storm)	min 24	min 48 (72 preferred)
Length-to-Width Ratio	at least 3:1 (4:1 or 5:1 preferred)	at least 4:1 (5:1 or greater preferred)
Forebay/berm	none specified	two submerged berms or a forebay and a permeable curtain
Clean out frequency	when accumulated sediment reaches 50% of *pond* design capacity	when accumulated sediment reaches 50% of *forebay* design capacity

Table 4 compares the interim construction sediment pond guidelines to those recommended based on the results of the study. The main changes are: (i) an increase in the minimum length to width ratio from 3:1 to 4:1 ; (ii) the requirement for two submerged berms or curtains, dividing the pond into 3 roughly equal sized segments (iii) an increase in the minimum drawdown time from 24 to 48 hours, (iv) cleanout when the forebay (rather than pond) fills to 50% of its permanent pool depth; and (iv) a 25% increase in the surface area if one or more of the previous three criteria can not be met. All other aspects of the former pond guideline relating to minimum orifice size at the outlet, spillways, bank slopes, operational issues, etc. should remain the same.

Regarding sediment controls upstream of the pond, results of this study showed that practices which reduce flow volumes and TSS loads will likely be of greater benefit than practices which reduce TSS concentrations only. Phasing of development, such that only a portion of the total drainage area is stripped and built-out at any one time, is arguably the most effective way of achieving this flow volume reduction. Other site practices that encourage infiltration of runoff or minimize disturbance would also be beneficial. Filtration practices that reduce concentrations but not runoff volumes (*e.g.* silt fences) are the least effective because fine particles often bypass these practices. These practices do, however, keep sediment out of the pond, which helps prevent the need for costly dredging, and reduces re-suspension of previously trapped solids. Monitoring data suggest that re-suspension processes are probably an important, but often overlooked factor in overall pond performance.

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1.0 INTRODUCTION

1.1 Background

Construction activities have been identified as a significant source of sediment to urban streams (GLAB, 1998; Caltrans, 2002). Loss of topsoil from exposed areas in construction sites is often several times greater than from forest or agricultural areas (*e.g.* Wark and Keller, 1963). As the urban fringe in Canadian towns and cities expands into relatively undisturbed areas, concerns have been raised about the impact of sediment loading from construction sites on receiving water systems. In one study, monitoring of a channel reach upstream and downstream of a construction site showed an average increase in suspended solids concentration of 500%. This increase in stream sediment concentration occurred even though runoff volumes from the construction site comprised less than 25% of total stream flow and all of the required erosion and sediment controls had been implemented on the site (Greenland International and TRCA, 2001).

Elevated levels of suspended sediment are a concern because of their detrimental impact on aquatic ecosystems. Effects on fish may include impairment to respiratory functions, lower tolerance to toxicants or disease, increased physiological stress, decreased reproductive success, and reduced vision, which inhibits their ability to find food (Vondracek et al., 2003). Migrating fish will avoid rivers with high suspended solids concentrations. Reduced light transmission caused by increased turbidity can also reduce primary production (plant growth) in streams, which can have important repercussions on community dynamics (Waters, 1995). Spawning and egg incubation periods are particularly sensitive times because sediment (especially clay and silt) may attach to the adhesive surface of eggs resulting in increased egg mortality (Ward, 1992).

Several techniques have been developed to control erosion and sediment transport from construction sites. Simple prevention practices rank the highest in terms of effectiveness. These typically involve minimizing the extent of disturbed area at any one time by clearing only what needs to be cleared, conserving natural cover and immediately stabilizing disturbed areas. One of the simplest ways of doing this is to phase construction, such that only a portion of the land under development is exposed at any one time. Other structural erosion control methods, such as silt fences, rock dams, and straw bales are only moderately effective, especially for fine-grained soils and clays. An important reason for their lower level of effectiveness is their need for diligent maintenance, which is rarely done, and even more rarely enforced under existing regulations.

Ponds are among the most effective structural practices for reducing sediment release from construction sites. Located at the end of the treatment train, they provide the last and crucial line of defence in a multi-barrier approach that protects against excess sediment discharge to receiving waters. Unfortunately, there are no scientifically defensible standards for the design of these ponds in Ontario. As an interim measure, it has become common practice to use the ultimate (post-construction) stormwater management pond, designed to ‘enhanced’ level guidelines (OMOE, 1994, 2003), as a temporary sediment control pond (TRCA, 1994). These ponds typically capture over 90% of construction site sediment, but due to extremely high influent concentrations, the quality of effluent discharged from the facilities rarely meets levels necessary to protect aquatic life in downstream receiving waters (see guidelines below). This was demonstrated in a two-year study of a temporary construction sediment pond in Richmond Hill. Although the pond was designed to current standards, the average effluent event mean concentration over 16 events was 177 mg/L, with short term peaks of sediment concentration as high as 2,600 mg/L. A primary objective of the present study is to evaluate how these ponds can be redesigned to better protect of receiving waters.

1.2 Guidelines

1.2.1 Erosion and Sediment Control

Provincial guidelines on erosion and sediment control (ESC) were published by the Ministry of Natural Resources in 1989. These guidelines recommend a 90% trap efficiency for soil particles greater than 40 µm. Temporary sediment basins should have a minimum volume of $125m^3$/ha and be cleaned when this volume has been reduced by 60%. The pond need not include a permanent pool.

ESC guidelines for the Toronto and Region Conservation Authority (TRCA) jurisdiction were published in 1994. This document provides information on the purpose, installation and removal, maintenance, planning and design of ESC structures. Significant updates to this guideline have been completed and are expected to be finalized in the spring of 2006. Current draft guidelines recommend that the temporary sediment control pond have a permanent pool of at least 125 m^3/ha, a length-to-width ratio of 3:1 or greater, and drawdown over a minimum of 24 hours. The pond must be dredged when the storage volume has been reduced by 50%.

The Ontario Ministry of Transportation also devotes a chapter to temporary ESC in its Drainage Management Manual (1997). Like the TRCA guideline, descriptions and diagrams are provided for various ESC measures, and design guidelines are provided for a temporary sediment control pond. Design standards for sediment ponds in the manual are generally less stringent than recommended in the TRCA interim guideline.

1.2.2 Suspended Solids

Table 1.1 presents various receiving water guidelines or criteria for suspended solids and turbidity to protect aquatic organisms and their habitats. Further information on pertinent guidelines and recommendations, as well as a synopsis of research on the effects of sediment on fish and fish habitats is provided by the Department of Fisheries and Oceans (2000).

The Ontario PWQO for turbidity recommends that the natural Secchi disc reading not be changed by more than 10%. The Secchi disc is a circular metal disc with alternate black and white quadrants used to measure water clarity. The disc is lowered into the water while observing the depth at which it disappears. The instrument is usually applied to lakes where natural variations in turbidity are not significant, but it can be adapted to streams by using a graduated cylinder (‘turbidity tube’) with a Secchi disc at the bottom. In practice, this method of assessing impact is difficult to apply because the relationship between suspended particulate matter and Secchi disc readings is highly non-linear (Smith and Davies-Colley, 2002). A 10% reduction in disc visibility when the water is clear represents a very small increase in particulate matter, while the reverse is true when the water is turbid.

The Canadian Water Quality Guidelines recommend maximum allowable increases according to stream 'background' concentrations and duration of exposure. Background is here defined as the median concentration over several years of monitoring at a reference site with similar soil texture and geology. The maximum increase for long term exposures is considerably more stringent than for short term exposures. Since background concentrations in most streams in the Greater Toronto area are below 25 mg/L, this guideline suggests that under no conditions should the stream concentration exceed 50 mg/L. This value is almost the same as the six-day exposure threshold of 55 mg/L beyond which adult freshwater non-salmonids are at risk of mortality (Newcombe and Jensen, 1996).

Table 1.1: Suspended Solids Receiving Water Guidelines for the Protection of Aquatic Life

Organization	Guideline
Ontario Provincial Water Quality Objective (1999)	Suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%
Canadian Water Quality Guidelines (1999) *	*Clear flow*: maximum increase of 25 mg/L from background levels for any short-term exposure (e.g. 24 h period). Maximum increase of 5 mg/L from background levels for any long-term exposure (e.g. inputs lasting between 24 h and 30 days). *High flow*: maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is >250 mg/L
European Inland Fisheries Advisory Commission (1965)**	< 25 mg/L - no harmful effects 25 – 80 mg/L - moderate to good fisheries 80 – 400 mg/L - good fisheries unlikely >400 mg/L - poor fisheries

* Guideline is similar to the British Columbia and Manitoba (draft) guidelines
** Adopted by US Environmental Protection Agency (1973)

The federal guidance is consistent with criteria proposed earlier by a group of scientists for European freshwater fisheries in lakes and streams (EIFAC, 1965). Their criteria, which was later adopted by the USEPA (1973), was based on an extensive literature review of suspended sediment effects on fish growth, behaviour, food supply, reproductive success, mortality and disease. Their research indicated that concentrations of suspended solids below 25 mg/L would cause no harm to fish or fisheries. As concentrations rise to 80 mg/L, the quality of the fishery may be somewhat reduced, and above 80 mg/L a good fishery would be difficult to maintain (Table 1.1).

Newcombe (1986; as cited in Ward, 1992) suggests a framework for assessing impacts on aquatic biota based on the concentration of suspended solids and duration of exposure (Figure 1.1, also see Newcombe and MacDonald, 1991). The diagonal line between impact zone 2 and 3 was intentionally truncated to avoid extrapolation to very short duration – high concentration events and vice versa. This framework indicates the following:

- impacts of suspended solids concentrations on aquatic biota equal to or greater than 1000 mg/L lasting for 20 minutes or less are difficult to predict;
- suspended solids concentrations of 30 mg/L for over 8 hours but less than 700 hours (29 days) result in a moderate impact to aquatic life;
- suspended solids concentrations of 30 mg/L for over 700 hours (29 days) result in a major impact, and
- suspended solids concentrations of 100 mg/L begin to have moderate impacts on aquatic life at exposure durations above approximately 3 hours.

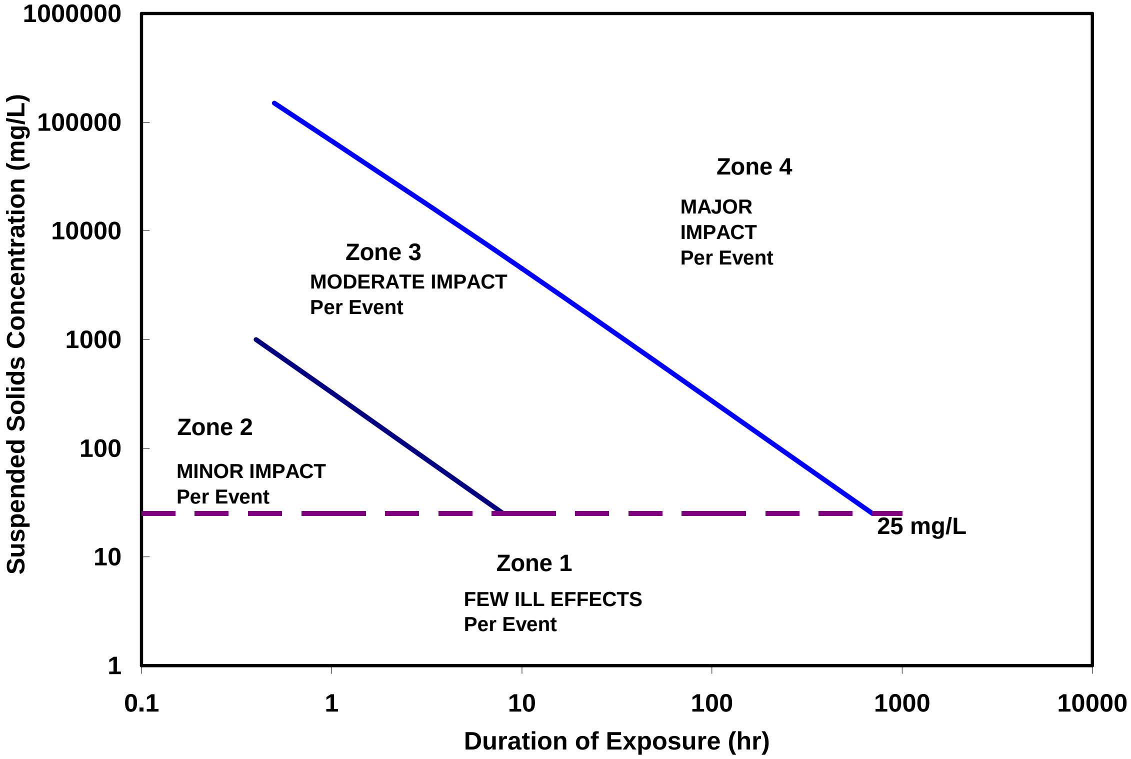


Figure 1.1: Impact of suspended solids on aquatic ecosystems as a function of concentration and duration of exposure.

Models based on these relationships have been successful in predicting impacts of suspended sediment on fish, life cycles and other aquatic organisms. In this study, the concentration-duration framework is used to evaluate the potential impact of pond effluent concentrations on downstream aquatic ecosystems. Plots of discrete suspended solids per event provide an easy method of assessing harm associated with events of various sizes and intensities, as well as with different modelling scenarios. It should be recognized, however, that an accurate assessment of potential effects on aquatic life must also consider effluent loads relative to suspended solids loads in the downstream channel itself (*i.e.* mixing and dilution effects).

1.3 Study Objectives

Field monitoring and modelling studies provide the basis for developing realistic and effective guidelines for sediment control practices on construction sites. This study evaluates a temporary sediment control pond in Markham that meets or exceeds all of the current design standards for ESC ponds. Monitoring was undertaken from the stripping phase through to final construction and stabilization of the site to ensure that the full range of construction impacts was considered. Modeling of the pond based on data collected during the monitoring period is used to assist in determining internal sediment removal dynamics and appropriate pond design guidelines for sizing and effluent water quality control. Specific objectives of the study were to:

- monitor the performance of a construction sediment pond in terms of the quality and quantity of runoff;
- assess in-pond sediment accumulation rates and particle size distributions;
- evaluate pond effluent impacts on receiving waters;
- model the sediment settling dynamics in the pond under current and alternative pond design scenarios;
- provide recommendations on pond design for sediment control during the construction period; and
- update the *Erosion and Sediment Control Guidelines for Construction* (TRCA, 1994) based on the findings of the study.

The final objective of using study results to update the *TRCA Erosion and Sediment Control Guidelines for Constructio*n (April 1994) is crucial to ensuring study outcomes are translated into practical effect through changes to how construction sites are managed from a sediment control perspective. The existing guidelines were originally established to assist contractors, consultants and municipalities in their efforts to develop a comprehensive approach to the control of erosion and sediment in land disturbing activities. It has been recognized that these guidelines should be updated to reflect new research findings and advancements that have been made in the area of erosion and sediment control. This study will assist in providing the basis for these updates.

2.0 STUDY AREA AND FACILITY DESIGN

2.1 Drainage area

The drainage area for the temporary construction sediment pond is located on predominately Peel clay soil in the Town of Markham near the intersection of Ninth Line and Major Mackenzie Drive, within the new Greensborough community development (Figure 2.1). The pond has minor and major system drainage areas of 88.8 and 52.9 ha, respectively. Monitoring was undertaken from the land stripping stage through to full construction. Details on the progress of construction activities over the two year study period are provided in chapter four.

2.2 Pond design

The temporary construction sediment pond (Pond "B") has a permanent pool volume of 127 m^3/ha, a large extended detention volume of 144 m^3/ha and a length-to-width ratio of 8:1 (Figure 2.2). The extended detention volume accommodates runoff from a 4 hour 25 mm rainfall event and releases it over a minimum period of 48 hours. The average permanent pool and extended detention depths are 1.5 and 2.4 m, respectively. As shown in Table 2.1, the pond design meets OMOE enhanced level ultimate pond guidelines for the protection of receiving waters.

Table 2.1: Greensborough pond design features compared to OMOE ultimate (post-construction) stormwater pond guidelines

Design Feature	Design Objective	OMOE (2003) Guidelines for Ponds	Greensborough Pond, Markham, Ontario
Permanent Pool Depth (m)	minimize re-suspension; avoid anoxic conditions	1-2 average; 3 max.	1.5
Permanent Pool Volume (m^3/ha)	protection of aquatic habitat	60 (normal) 125 (enhanced)[1]	127
Extended Detention Depth (m)	storage and flow control	1 to 1.5	2.4
Extended Detention Volume (m^3/ha)	protection of aquatic habitat	40	144
Drawdown Time (hours) (25 mm, 4 hr storm)	suspended solids settling	24	48 (minimum)
Length-to-Width Ratio	minimize short circuiting	at least 3:1 (4:1 or 5:1 preferred)	8:1

1. Based on 45% surface imperviousness.

The pond outlet structure consists of a submerged perforated riser with a reverse slope pipe that draws water from below the permanent pool surface to help mitigate thermal impacts. Flows in excess of the 25 mm event (>2.9 m^3/s) pass over a control weir at the inlet and into the bypass channel, ultimately discharging to the Little Rouge Creek (Figure 2.2). Flows exceeding the pond capacity spill from the pond over a 20 m overflow weir into the Little Rouge Creek.

Figure 2.1: Study area in the Town of Markham, Greensborough Community, Pond B.

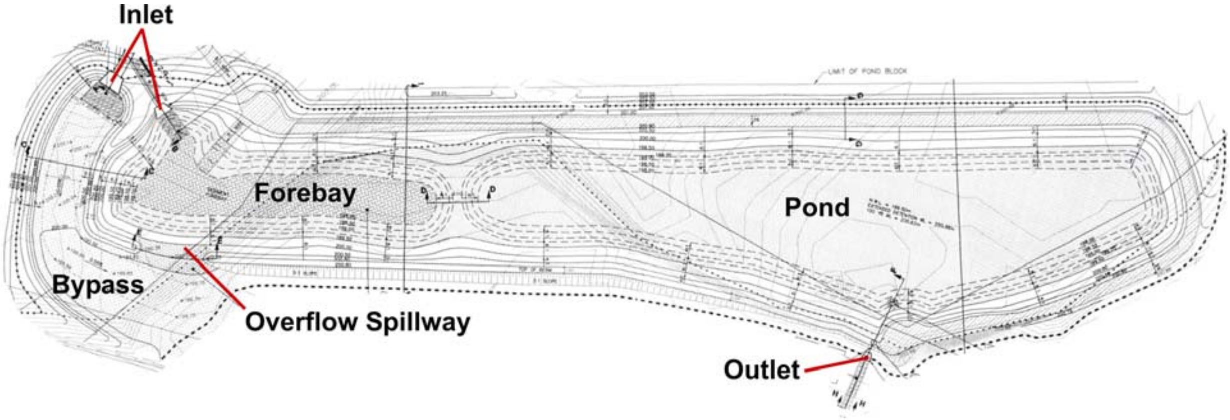


Figure 2.2: Pond B schematic.

2.3 Receiving waters

The pond drains to the Little Rouge River. Upstream land use is predominantly rural. Fish communities in the Creek adjacent to the pond are comprised of a diverse but largely warm water community. This stretch of the upper Little Rouge River is not suitable for cold water fish species.

3.0 STUDY APPROACH

3.1 Monitoring Program

Table 3.1 provides a summary of monitoring activities in 2004 and 2005. Table 3.2 lists the type and location of water samples collected over the study period. Figure 3.1 depicts the location of all monitoring equipment in 2005.

Table 3.1: Monitoring program summary for 2004/2005

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2004 Season												
Flow	na	na	na	na	na	x	x	x	x	x	x	x
Water Level	na	na	na	na	na	na	x	x	x●	x●	x●	x●
Velocity	na	na	na	na	na	x	x	x	x	x	x	x
Water Quality	x	na	na	na	na	na	x	na	x	x	x	na
Water and Air Temperature	na	na	na	na	na	x○	x○	x○	x	x	x	x
Rainfall	na	na	na	na	na	na	x	x	x	x	x	x
Sediment Accumulation Survey	na	na	na	na	na	■	na	na	x	na	x	na
Catchment Survey	na	na	na	na	na	x	x	x	x	x	x	x
2005 Season												
Flow	na	na	na	na	x	x	x	x	x	x	x	na
Water Level	na	na	na	na	x	x	x	x	x	x	x	na
Velocity	na	na	na	na	x	x	x	x	x	x	x	na
Water Quality	na	na	na	na	na	x	x	x	x	x	x	na
Rainfall	na	na	na	na	x	x	x	x	x	x	x	x
Sediment Accumulation Survey	na	na	na	x	na	na	na	na	na	na	x	na
Catchment Survey	na	na	na	na	na	na	x	x	na	x	x	na
Sediment Quality	na	na	na	na	na	na	na	na	na	x	na	x

x●: Level measurements at pond outlet and receiving water (upstream and downstream).

■: Baseline survey, engineered drawing. Drawing confirmed by consultant survey.

x○: Inlet data not available

The terms ‘discrete’ and ‘composite’ in Table 3.2 refer to the type of sample that was submitted to the laboratory for analysis. Discrete samples typically consist of 24 or more individual samples collected over the duration of the event. Discrete samples were analyzed only for suspended solids, dissolved solids and total solids. Composite samples were formed by combining all of the 24 discrete samples into a single bottle, and submitting water from this composite bottle to the laboratory for analysis. Composite samples were usually analyzed for a wide range of water quality variables, including nutrients, metals, general chemistry, bacteria and hydrocarbons. Grab samples are collected at a single point in time, rather than over the duration of the event.

Table 3.2: Water quality sample history for the 2004/2005 season

Sample Date	Automated Sampling				Grab Sampling		
	Inlet	Outlet	Upstream	Downstream	Markham Road	Major Mackenzie Drive	Ninth Line
January 14, 2004	na	na	na	na	DWG	DWG	DWG
January 20, 2004	na	na	na	na	na	na	DWG
June 28, 2004	na	na	na	na	DWG	DWG	DWG
July 7, 2004	C	C	C	C	na	na	na
July 14, 2004	na	na	na	na	DWG	DWG	DWG
July 19, 2004	C, D	C, D	C, D	C, D	na	na	na
July 27, 2004	na	na	na	na	WWG	WWG	WWG
September 9, 2004	C, D	C, D	C, D	C, D	na	na	na
October 15, 2004	C	C	C	C	na	na	na
October 30, 2004	C	C, D	C, D	C, D	na	na	na
November 2, 2004	C, D	C, D	C, D	C, D	na	na	na
November 4, 2004	C	C	C	C	na	na	na
November 4, 2004	na	na	na	na	WWG	WWG	WWG
November 24, 2004	C	C	C	C	na	na	na
June 14, 2005	C,D	C,D	na	na	na	na	na
July 17, 2005	C,D	C,D	na	na	na	na	na
July 26, 2005	C,D	C,D	na	na	na	na	na
August 1, 2005	C,D	C,D	na	na	na	na	na
August 2, 2005	C,D	na	na	na	na	na	na
August 10, 2005	C,D	C,D	na	na	na	na	na
August 19, 2005	na	na	na	na	na	na	na
August 31, 2005	C,D	C,D	na	na	na	na	na
September 8, 2005	C,D	C,D	na	na	na	na	na
September 16, 2005	C,D	C,D	na	na	na	na	na
September 25, 2005	C,D	C,D	na	na	na	na	na
September 29, 2005	C,D	C,D	na	na	na	na	na
October 22, 2005	C,D	C,D	na	na	na	na	na
October 28, 2005	na	na	na	na	na	na	na
November 6, 2005	D	C,D	na	na	na	na	na
November 9, 2005	C,D	C,D	na	na	na	na	na
November 15, 2005	C,D	C,D	na	na	na	na	na

WWG: Wet Weather Grab, DWG: Dry Weather Grab

C: Composite, D: Discrete, na: not available

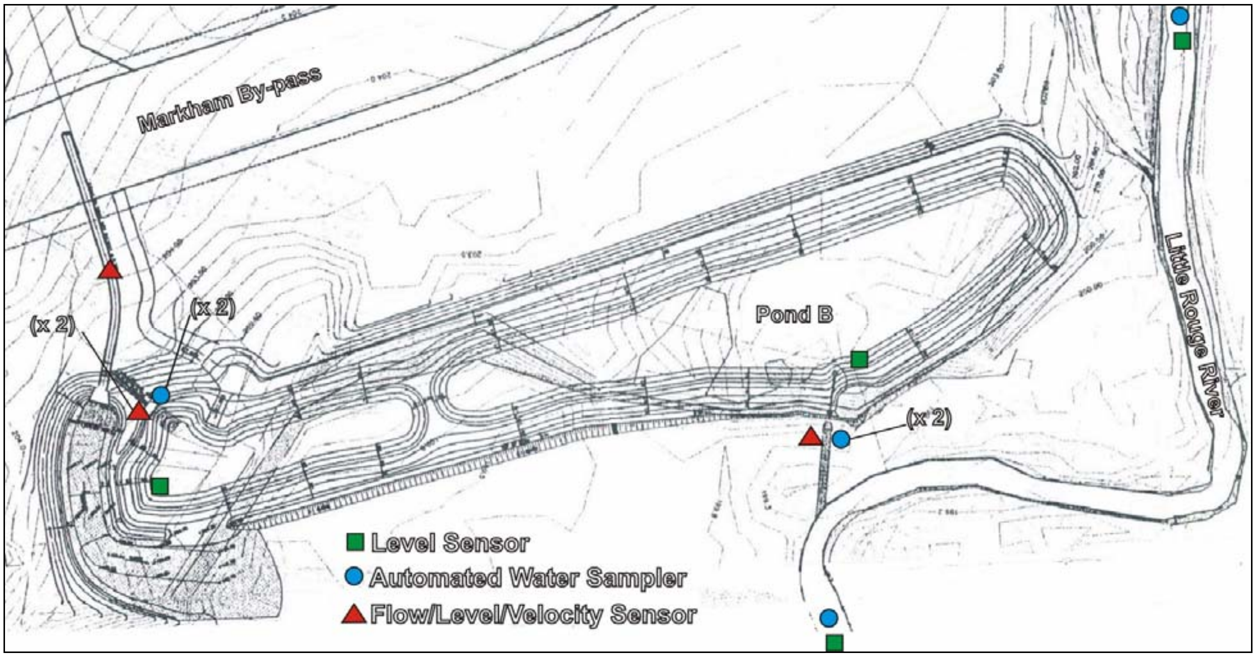


Figure 3.1: Location of monitoring equipment. Note that water sampling and level measurements in the Little Rouge River were conducted only during the first year of monitoring (2004).

3.2 Water Quantity

The water quantity monitoring program consisted of co-ordinated measurements of rainfall, flow at the inlet and outlet of the pond, and water levels. In 2004, receiving water levels and flow rates were also monitored. All stations were automated with recording intervals set at 5 minutes for flow, sewer water level, rainfall, and velocity. Pond and receiving water levels were measured hourly.

3.2.1 Precipitation

The primary rain gauge used for estimating precipitation depths was installed approximately 500 m north of the pond on the Ham Farm property. The gauge was a 1 mm tipping bucket recording cumulative rainfall at 5 minute intervals using an Onset MicroStation logger. Two permanent TRCA rain gauges (TRCA Claremont Conservation Area and Rouge River at 14th Avenue) were also located within 10 kilometres of the pond and were used as back-up measurements when the on-site gauge was not functioning.

3.2.2 Flow

Inlet and outlet flow was monitored using two ISCO area-velocity sensors programmed to record flow at 5 minute intervals. The inlet sensor was installed upstream from the inlet structure in the sewer and was permanently positioned under a constant dry weather flow to avoid sediment accumulation on top of the sensor.

Outlet flow measurements were taken downstream of the Hickenbottom outlet structure in a circular pipe where flow was constant, even during dry weather. Figure 3.2 shows the outlet channel and energy dissipaters, approximately 20 m upstream of the Little Rouge River.

Figure 3.2: Pond outfall after an event.

3.2.3 Level

Water levels were measured at hourly recording intervals using 4 Telog 2100 level loggers in the pond near the inlet and outlet, and both upstream and downstream from the outlet structure in the Little Rouge Creek (2004 only). Levels were also measured at 5 minute recording intervals behind the inlet grate using an area-velocity probe. This sensor was primarily used to trigger the sampler during rain events.

3.3 Water Quality

3.3.1 Automated Water Sampling

ISCO 6700 automated water samplers were installed at the inlet and outlet of the pond (2004 and 2005) and in the receiving water upstream and downstream from the pond outlet (2004 only). Twenty-four discrete water samples were collected and later proportioned according to flow. Sample intakes were Teflon lined to prevent cross contamination. Pacing intervals for the inlet, outlet, and receiving waters were 10 minutes, 30 minutes and hourly, respectively. Both the inlet and outlet samplers were triggered at water levels ≥50 mm. The upstream and downstream samplers were triggered by rain gauges when total precipitation increased above 1 mm in depth.

3.3.2 Composite and Discrete Sampling

Samples were analysed both discretely and as a composite. Composite samples combined 500mL from all 24 ISCO 1L bottles into a single 20L Teflon bottle. The combined samples were mixed and poured into the appropriate laboratory bottles and submitted for various parameters. Discrete samples were submitted to the laboratory and analyzed for suspended solids, total solids, dissolved solids, turbidity, and conductivity. In this case, the remaining 500 mL in each 1L bottle was rebottled and submitted individually to the laboratory.

3.3.3 Grab Sampling

Wet and dry weather grab samples were collected at three different locations along the Little Rouge Creek in 2004. Two stations were located upstream from the study area (Markham Road and north of Major Mackenzie Drive), and one was located downstream from the study area (Ninth Line). Samples were collected manually from the centre of flow using a single 10L Teflon bottle.

3.3.4 Laboratory Analyses

Although the focus of the analyses was on suspended solids, turbidity and particle size distributions, other general variable groups were also infrequently analyzed to characterize the overall quality of water being discharged from construction sites. The follow water quality groups were analyzed by the Ontario Ministry of the Environment laboratory in Etobicoke:

- Suspended Solids
- Particle size
- Turbidity
- Nutrients
- Metals
- General Chemistry
- PAHs
- Bacteria
- Bacteria

3.3.5 Water Temperature

Water and air temperature was continuously monitored at one hour intervals using Onset Hobo temperature loggers. Water temperature sensors were located in the inlet sewer, pond outlet, upstream, and downstream in the Little Rouge Creek.

3.4 Pond Bathymetric Data

The pond was surveyed four times during the various construction phases to estimate the depth and rate of sediment accumulation. The surveys were conducted at 16 cross sections (Figure 3.3) and all measurements were referenced to a common benchmark.

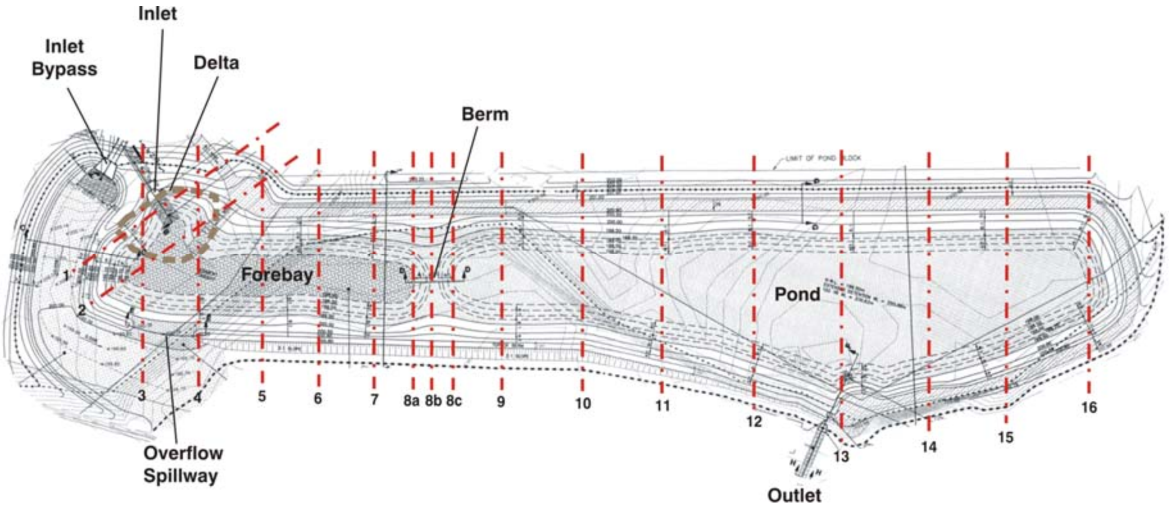


Figure 3.3: Sediment accumulation survey cross section locations

3.5 Statistical Analysis

3.5.1 Water Quality

The total volume and total pollutant mass in any runoff was determined by summation over the appropriate time intervals. The influent volume (V_i) and influent pollutant mass (M_i) are calculated as:

$$V_i = \sum_{k=T1}^{T3} Q_{i_k} \, \Delta t_k \qquad (1)$$

$$M_i = \sum_{k=T1}^{T3} C_{i_k} \, Q_{i_k} \, \Delta t_k \qquad (2)$$

where: Q = flow measured over finite time interval, Δt

C = concentration of a specified pollutant measured over finite time interval, Δt

$T1$ represents the start of the runoff (influent) flow

$T3$ represents the end of the runoff (influent) flow

Volume weighted mean concentration was calculated as:

$$MC_{VW} = \sum_{i=1}^{i=n} (V_i \times EMC_i) \; / \; \sum_{i=1}^{i=n} V_i \qquad (3)$$

where MC_{VW} = volume weighted mean concentration for all events sampled.

Load-based efficiency was calculated as:

$$LE = \frac{SOL_{in} - SOL_{out}}{SOL_{in}} \tag{4}$$

where SOL is the sum of all mass loads entering and leaving the pond.

3.5.2 Baseflow, Catchment Lag, and Detention Time

The pond had continuous baseflow from groundwater seepage through sewer joints. Baseflow was separated from event runoff to calculate removal efficiencies.

Stormwater ponds are typically designed in accordance with runoff quantity, quality and erosion control objectives. Various event characteristics related to time and intensity can be extracted from a simple hydrograph and hyetograph. Detention times were calculated based on the time delay between the inlet and outlet hydrograph centroids. Similarly, catchment lag time represents the time delay between the centroids of the hyetograph and inlet hydrograph. Baseflow is not included in the calculation of the runoff hydrograph centroid. Thus, the centroid represents the average runoff conditions independent of dry-weather flow.

4.0 STUDY FINDINGS: FIELD MONITORING

4.1 Catchment Construction Activity

Catchment construction activity was recorded monthly from June 2004 to December 2005. Figure 4.1 presents the observed extent of construction from June to September and from October to December in each year of the study. Storm sewers were installed on roughly half of the catchment in 2004 and over most of the catchment in 2005.

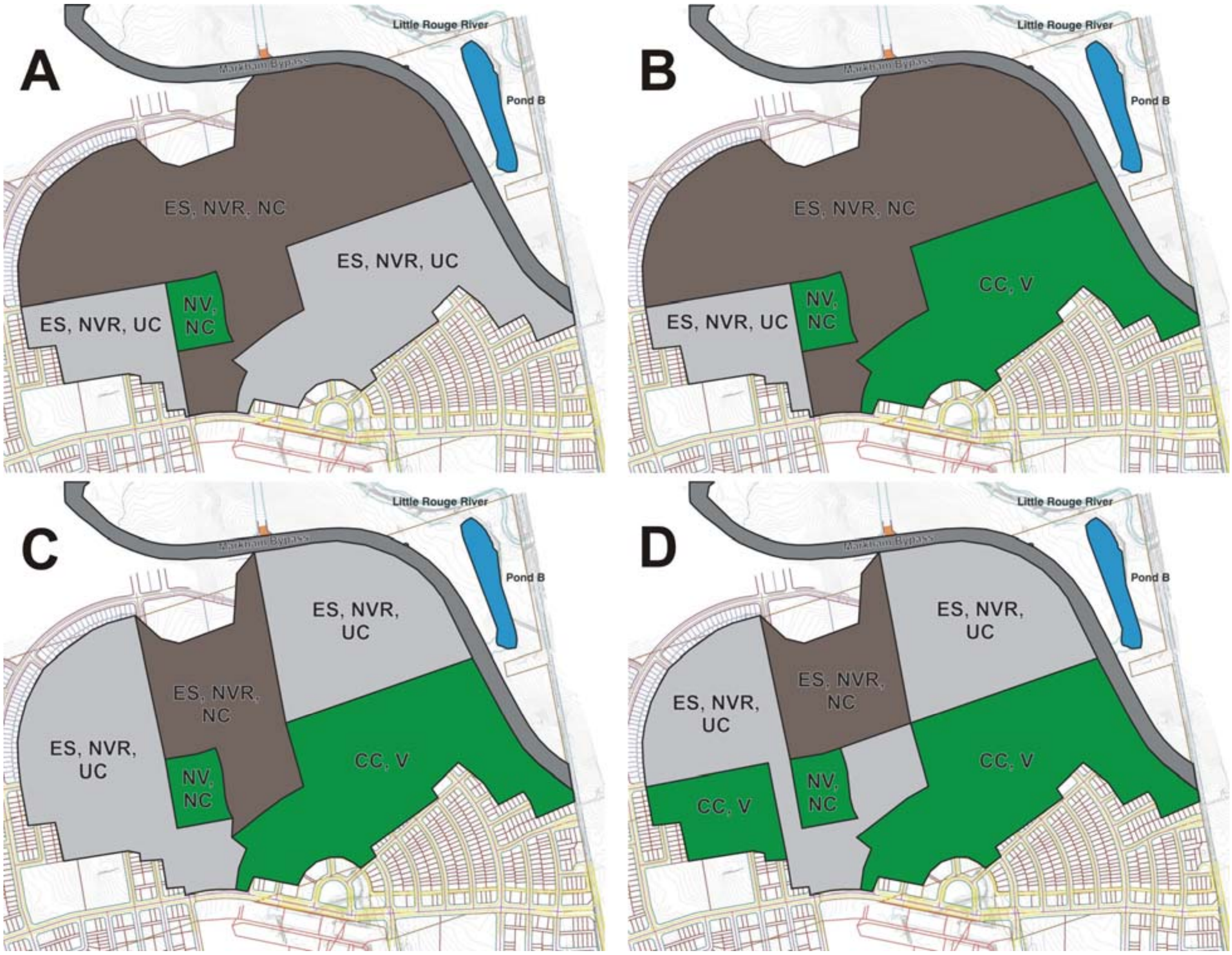
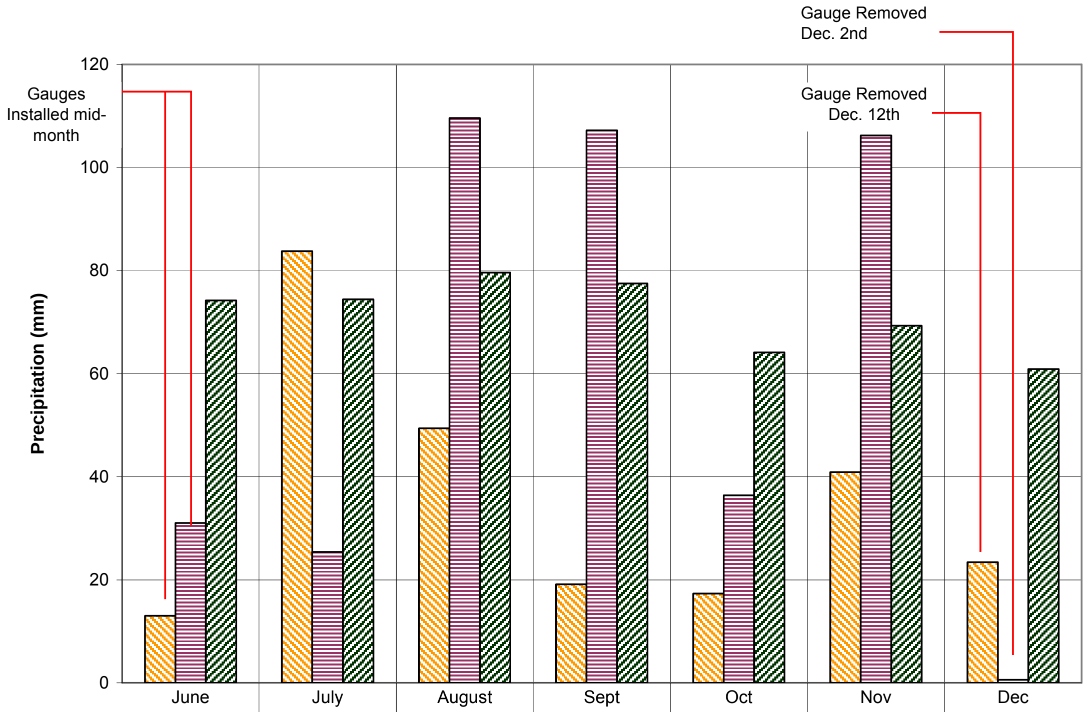


Figure 4.1: Observed average construction activity during the study period from June 2004 to December 2005. Image A: June to September 2004; Image B: October to December 2004; Image C: May to August 2005; and Image D: September to December 2005. Image codes are as follows: ES exposed soil, NV natural vegetation, NVR natural vegetation removed, NC no construction, UC under construction, CC construction complete, and V vegetated (properties landscaped).

4.2 Water Quantity

4.2.1 Rainfall

Figure 4.2 presents total rainfall measured on site (at Lloyd Ham farm) in 2004 and 2005 relative to Toronto area precipitation normals (1971-2000). The 2004 monitoring season was relatively dry, with only 220 mm of rainfall from July to November. In 2005, 385 mm of rain fell over the same period, which was similar to the regional precipitation normals of 365 mm. In both years, the distribution of rainfall over the growing season deviated significantly from normals. Very wet and very dry months were not uncommon. In both years, there was a good correlation ($R^2 > 0.9$) between the on site rain gauge and two other nearby gauges (Rouge River at 14th Avenue and Claremont Conservation Area).



	June	July	August	Sept	Oct	Nov	Dec
▧ Lloyd Ham Farm 2004	13	83.8	49.4	19.1	17.3	40.9	23.4
▤ Lloyd Ham Farm 2005	31	25.4	109.6	107.2	36.4	106.2	0.6
▨ Pearson Airport (normals)	74.2	74.4	79.6	77.5	64.1	69.3	60.9

Figure 4.2: Total monthly precipitation for on-site gauge (Ham Farm) and Pearson International Airport normals from 1971-2000.

Between June 16th, 2004 and December 1st, 2005, 106 storm events were monitored, of which 68 had rainfall greater than 2.0 mm. A wide range of event sizes and intensities were captured over the study period (Table 4.1). As expected, most storm events were ≥0.5 and ≤10 mm, but 17 larger events (>10 mm) were also observed. The largest event occurred on August 19th, 2005 (37.8 mm). The maximum sustained rainfall intensity over a 5 minute period was observed during the July 19th 2004 storm, when the rainfall intensity peaked at 95 mm/hr.

Table 4.1: Rainfall event summary. Events less than 2 mm were not included.

Range	Start Date	Rain (mm)	Duration (hrs)	Max. Rainfall Intensity (mm/hr)**	Range	Start Date	Rain (mm)	Duration (hrs)	Max. Rainfall Intensity (mm/hr)**
2 to 5 mm	7/14/2004	2.6	1:45	7.2	6 - 10 mm con't	11/4/2004	8.8	21:45	7.2
	7/22/2004*	2.1	0:45	20.4		11/24/2004	8.2	14:15	6.0
	8/13/2004	2.4	3:15	2.4		11/28/2004	9.0	7:30	7.2
	8/26/2004	2.9	12:15	12.0		11/30/2004	7.8	13:00	3.6
	8/28/2004	5.0	3:30	36.0		5/14/2005	6.8	6:25	12.0
	10/15/2004	4.1	4:15	9.6		6/13/2005	6.2	2:05	24.0
	6/16/2005	3.4	5:15	4.8		7/17/2005	10.0	3:55	21.6
	6/28/2005	4.0	3:35	24.0		8/2/2005	6.2	0:40	31.2
	7/26/2005	4.8	1:45	12.0		8/5/2005	7.0	1:30	40.8
	8/1/2005	2.2	2:30	4.8		8/19/2005	8.8	2:40	12.0
	8/10/2005	3.6	2:30	16.8		9/25/2005	8.8	6:55	28.8
	8/10/2005*	3.4	0:20	14.4		9/29/2005	9.4	3:05	38.4
	8/12/2005	3.2	5:40	14.4		11/27/2005	9.8	3:50	4.8
	8/27/2005	2.0	3:55	4.8	11 to 15 mm	7/14/2004*	11.4	7:00	28.8
	9/14/2005	2.2	2:10	7.2		8/29/2004*	15.9	7:00	36.0
	9/22/2005	2.8	2:55	4.8		5/13/2005	14.6	1:05	24.0
	10/7/2005	3.8	3:15	4.8		6/14/2005	15.0	3:15	48.0
	10/15/2005	2.8	1:30	4.8		8/1/2005*	11.6	0:40	36.0
	10/17/2005	2.0	0:45	4.8		9/8/2005	15.4	4:15	43.2
	10/23/2005	3.0	5:40	4.8		11/28/2005	12.2	6:25	9.6
	11/5/2005	2.4	2:40	7.2	16 to 20 mm	9/9/2004	17.2	9:45	4.8
	11/6/2005*	4.2	3:50	14.4		10/22/2005$^+$	18.0	14:10	7.2
6 to 10 mm	7/20/2004	7.3	4:15	27.6		11/9/2005	19.2	13:50	40.8
	7/22/2004	6.7	1:00	20.4	21+ mm	7/19/2004	28.8	4:30	94.8
	7/27/2004	7.3	6:45	7.2		8/19/2005*	37.8	3:05	67.2
	7/31/2004	9.9	8:00	6.0		8/30/2005	21.6	7:50	9.6
	8/10/2004	9.0	1:45	32.4		9/16/2005	32.3	11:25	60.0
	8/27/2004	7.0	1:15	27.6		9/25/2005*	34.8	17:50	21.6
	10/30/2004	8.8	11:00	14.4		11/15/2005	25.6	20:50	12.0
	11/2/2004	8.2	12:00	7.2		11/29/2005	26.6	10:50	9.6

* Days on which there were two or more discrete events
** Maximum sustained rainfall over a 5 minute period
$^+$ First two days only – total rainfall over 3 days was 23.8 mm.

4.2.2 Runoff Statistics

A summary of hydrologic statistics for selected events is presented in Table 4.2. Event hydrographs and hyetographs for selected events are presented in Appendix A with TSS pollutographs.

Runoff coefficients at the Greensborough site increased as the catchment was built-out. During early construction in 2004, events larger than 10 mm typically had runoff coefficients between 0.16 and 0.38. In 2005, as more and more area was developed and landscaped, the typical range increased to between 0.38 and 0.52 (Table 4.2).

The mean peak flow reduction for observed events was 83%. The mean outflow duration for events monitored was 95 hours. In some cases, outflow durations encompass two events because the pond did not fully drawdown before another rain event started. Drawdown times for the 25 mm event occurred over approximately 72 hours, which is much longer than the design drawdown time of 48 hours.

During most events, more stormwater entered the facility than exited it, suggesting that some water may be exfiltrating during the 72 hour drawdown period. The average difference between inflow and outflow volumes (*i.e.* the volumetric balance) for events in Table 4.2 was 15.6%. Large imbalances occurred when evaporation over long dry periods caused pond water levels to fall below the permanent pool elevation (*e.g.* June 28th and August 10th, 2005). In these instances, the initial period of runoff produced no outflow, and thus total event inflow volumes were much greater than outflow volumes. Removing these events from the volumetric balance calculation reduces the average from 15.6 to 11.0%. Errors in flow measurement were estimated to be approximately ±20%.

Centroids were calculated for several events in order to determine the average and median catchment lag and pond detention times (Table 4.3). An event was defined as the start of inflow to the point at which outflows returned to pre-event baseflow. The mean catchment lag time and pond hydraulic detention time was 10.2 and 16.2 hours respectively. Lag times and detention times varied according to antecedent conditions and rainfall intensity.

Table 4.2: Hydrologic Summary

Event Start	Rainfall	Maximum Rainfall	Inlet Volume	Outlet Volume	Volume Difference	Runoff Volume (no baseflow)	Peak Flow In	Peak Flow Out	Peak Flow Reduction	Outflow Duration	Runoff Coef.+
2004 Season	**(mm)**	**(mm/5 min)**	**(m3)**	**(m3)**	**(%)**	**(m3)**	**(m3/s)**	**(m3/s)**	**(%)**	**Hours**	
7/4/04 8:00	11	5.1	2500.0	2154.5	13.8	472.8	0.128	0.021	83.5	75	0.05
7/7/04 2:00	13.2	2.7	2116.8	1857.2	12.3	459.7	0.071	0.012	83.8	83	0.04
7/19/04 11:00	36.2	7.9	13286.1	12762.2	3.9	5115.3	0.420	0.071	83.2	64	0.16
7/27/04 3:00	8.5	0.6	7587.9	6972.7	8.1	1837.8	0.098	0.026	73.3	86	0.24
7/30/04 17:00	12.4	0.7	7718.3	7065.6	8.5	2531.0	0.124	0.036	71.3	112	0.23
8/10/2004 15:00	9	2.7	3899.1	3266.9	16.2	1790.6	0.127	0.017	86.8	70	0.22
8/27/04 13:00	7	2.3	2163.0	1576.8	27.1	1351.6	0.097	0.016	83.9	-	0.22
9/9/2004 0:00	17.2	0.4	7225.8	6902.8	4.5	3485.7	0.117	0.031	73.8	125	0.23
10/15/04 9:00	4.1	0.8	1262	949	24.8	847.4	0.038	0.015	60.8	-	0.23
10/30/04 4:00	8.8	1.2	3401.4	2801.1	17.6	2548.4	0.111	0.015	86.4	71	0.33
11/2/2004 3:00	8.2	0.6	2391.3	2290	4.2	1546	0.072	0.015	79.5	55	0.21
11/4/04 7:00	8.8	0.6	3744.8	3198.4	14.6	1805.3	0.086	0.020	77.3	96	0.23
11/23/04 20:00	8.7	0.5	2937.7	2658.3	9.5	1209.6	0.043	0.016	63.8	87	0.16
11/28/04 1:00	10.1	0.6	4735.6	4292.4	9.4	3427.8	0.095	0.023	76.2	70	0.38
11/30/2004 22:00	7.8	0.3	4742.7	4390	7.4	2540.8	0.067	0.022	67.2	87	0.37
6/13/2005 17:45	25.8	4	8694.0*	8848.9	-1.8	4400.9	0.563	0.046	91.8	141	0.19
6/28/2005 15:55	4.2	2	521.1	40.4*	92.2*	337.8	0.120	0.001	99.3	35	0.09
8/10/2005 6:25	10.4	1.4	5450.9	2838.9*	47.9*	3481.2	0.923	0.020	97.9	96	0.38
8/30/2005 23:20	21.8	0.8	8213.0	6545.0	20.0	8213.0	0.359	0.057*	84.0	106	0.42
9/8/2005 5:30	15.4	3.6	2497.0	2371.4	5.0	1298.0	0.474	0.020*	95.7	58	0.09
9/16/2005 7:25	33.2	5	16183.7	15071.4	6.9	9345.2	0.617	0.059	90.4	154	0.32
9/25/2005 3:40	53	3.2	28893.5†	23410.8	19.0	24235.3	0.801	0.069	91.4	223	0.51
10/7/2005 9:00	5	0.4	907.9	674.3	25.7	295.1	0.036	0.007	82.1	48	0.07
10/22/2005 12:05	23.8	0.6	9562.8†	10543.3	-10.3	7955.1	0.305	0.038	87.5	124	0.38
11/9/2005 6:20	19.2	3.4	8858.1	8267.0	6.7	7525.0	0.847	0.037	95.6	130	0.44
11/15/2005 4:00	26.6	1	12444.4	10976.9**	11.8	12192.7	0.852	0.059	93.0	76	0.52
Average	**15.7**	**2.0**			**15.6**		**0.3**	**0.029**	**83.1**	**94.7**	**0.26**
Median	**10.7**	**1.1**			**10.7**		**0.1**	**0.022**	**83.8**	**86.5**	**0.23**

*On June 28th and August 10th, antecedent pond water levels were below the permanent pool elevation. Hence, there was no outflow during the initial period of runoff.

**Outlet removed before pond returned to Baseflow, outlet flow partially predicted.

†Inlet data is not complete for the time period

+ Runoff coefficients are based on a drainage area of 88.8 hectares. Lower runoff coefficients in 2004 are a result of fewer storm sewers in this year.

Table 4.3: Catchment lags and detention times

Date	Total Rainfall (mm)	Rainfall Centroid (mins)	Inlet Centroid (mins)	Outlet Centroid (mins)	Catchment Lag (hrs)	Detention Time (hrs)
07/14/04	14.2	1368.6	1739.7	2827.1	6.2	18.1
07/19/04	36.2	460.4	866.9	1936.0	6.8	17.8
07/22/04	8.8	274.8	1107.6	1881.8	13.9	12.9
07/30/04	11.3	807.1	1152.0	1920.9	5.7	12.8
08/10/04	9.0	70.7	434.8	2074.8	6.1	27.3
08/29/04	20.9	790.9	1526.5	2294.1	12.3	12.8
09/09/04	17.2	319.5	519.1	1569.7	3.3	17.5
10/30/04	8.8	497.0	988.0	2136.8	8.2	19.1
11/02/04	8.3	336.1	662.4	1301.7	5.4	10.7
11/24/04	8.2	531.2	641.8	1548.5	1.8	15.1
11/28/04	9.0	230.0	635.0	1743.1	6.8	18.5
11/30/04	7.8	465.4	1157.4	1938.0	11.5	13.0
6/14/2005	19.2	651.4	855.5	2008.2	3.4	19.2
7/17/2005	10.8	126.8	398.3	1165.9	4.5	12.8
8/10/2005	10.4	1001.9	1020.7	1741.2	0.3	12.0
8/31/2005	21.8	284.3	1822.0	1956.2	25.6	2.2
9/8/2005	15.4	72.3	1077.4	1701.4	16.8	10.4
9/16/2005	36.4	1170.3	2883.5	3061.0	28.6	3.0
9/25/2005	53	2029.0	2110.3	4782.4	1.4	44.5
10/22/2005	23.8	983.8	2235.0	3298.4	20.9	17.7
11/6/2005	5.6	443.0	1499.6	2420.3	17.6	15.3
11/9/2005	19.2	333.7	1160.6	2796.0	13.8	27.3
11/15/2005	22.4	540.1	1424.0	2200.3	14.7	12.9
Average		**599.5**	**1213.8**	**2187.1**	**10.2**	**16.2**
Median		**465.4**	**1107.6**	**1956.2**	**6.8**	**15.1**

Outflow volumes were a small fraction of receiving water flow volumes. For events summarized in Table 4.4, the average contribution of facility discharge to receiving water discharge was only 6.8%. Thus, the impact of effluent water quality on Little Rouge Creek would likely be small unless concentrations of water quality constituents were substantially different than those observed in the Creek.

Table 4.4: Outflow volume contributions to receiving water

	Outlet Volume (m^3)	Downstream Volume (m^3)	% of Downstream Volume
July 7, 2004	1857.2	34658.1	5.4
July 19, 2004	12762.2	156832.7	8.1
September 9, 2004	6902.8	66051.6	10.5
October 15, 2004	949.0	13740	6.9
October 30, 2004	2801.1	27361.6	10.2
November 2, 2004	2290.0	44631.4	5.1
November 24, 2004	2658.3	56652.1	4.7
June 13, 2005	8848.9	115598.6	7.7
June 28, 2005	40.4	10815.4	0.4
August 10, 2005	2838.9	36549.8	7.8
August 30, 2005	7553.2	82629.9	9.1
September 8, 2005	2371.4	66719.8	3.6
September 16, 2005	15071.4	121290.2	12.4
September 25, 2005	23410.8	258211.5	9.1
October 7, 2005	674.3	19395.2	3.5
October 22, 2005	10543.3	109485.2	9.6
November 9, 2005	8267.0	199572.6	4.1
November 15, 2005	10976.9	305160.0	3.6
Mean			**6.8**
Median			**7.3**

4.3 Sediment Accumulation Surveys

The pond was re-graded on June 29th to meet the original design specifications. Four surveys of the pond were subsequently conducted to determine the volume and rate of sediment accumulation. Results presented in Table 4.5 show the bulk of sediment accumulation occurring in the forebay (zone 1 from 0 to 100 m from the inlet) and middle portion of the pond (zone 2 from 100 to 170 m from the inlet). The downstream end of the pond (zone 3 from 170 to 310 m from the inlet) experienced very little sediment accumulation (see also Figure 5.2 in section 5.3.3 later in the report).

Survey results indicate that the forebay filled up first, with sediment accumulation of up to 61% of the total permanent pool in this area by the 15th of April, 2005. Between April and November, 2005, some of the accumulated sediment in the forebay area was re-suspended and transported downstream to zone 2. Over this period, the decrease in sediment accumulation in zone 1 corresponded to a large increase in sediment accumulation in zone 2 from 29 to 52% of the permanent pool volume. An unusually large and intense storm event on August 19th may have been partly responsible for this mass movement of sediment.

Table 4.5: Cumulative changes in sediment depth, volume and accumulation as a percent of the permanent pool volume.

		Baseline 29-Jun-04	1st survey 19-Sep-04	2nd survey 15-Dec-04	3rd survey 15-Apr-05	4th survey 16-Nov-05
Zone 1	Depth Change (m)	0	0.20	0.30	0.69	0.52
(2600 m^2)	Volume (m^3)	0	520	780	1794	1352
	Accumulation (% of perm. pool)	0	18	27	61	46
Zone 2	Depth Change (m)	0	0.09	0.27	0.33	0.59
(1050 m^2)	Volume (m^3)	0	95	283	346	620
	Accumulation (% of perm. pool)	0	8	24	29	52
Zone 3	Depth Change (m)	0	0.01	0.01	0.01	0.01
(6400 m^2)	Volume (m^3)	0	64	64	64	64
	Accumulation (% of perm. pool)	0	1	1	1	1
Total Area	Volume (m^3)	0	678	1127	2204	2035
(10050 m^2)	Accumulation (% of perm. pool)	0	6	10	19	18

Notes: 1. The baseline elevations were estimated from the average monthly depth change between survey 1 and survey 3. 2. The first three surveys were conducted using a total station, the fourth survey was conducted using sonar. All surveys were referenced to a common benchmark. 3. See Figure 3.3 for survey transect locations. Zone 1 is the forebay area (transect 1 to 8b). Zone 2 is the middle area (transect 8c to 12). Zone 3 is the end of the pond (transect 13 to 16)

Over the entire pond, sediment deposition resulted in a decrease of only 18 to 19% in permanent pool storage. The forebay and middle portion of the pond, however, were about 50% full by November 16th, 2005. This accumulation in the upstream portions of the pond significantly increases the potential for scour and re-suspension of previously trapped sediment. The influent and effluent data presented in the next section provides further evidence of these processes.

4.4 Water Quality

4.4.1 Total Suspended Solids

4.4.1.1 Event Mean Concentrations and Removal Efficiencies

Figure 4.3 shows the average event mean concentrations (AEMC), weighted according to event flow volumes, for suspended solids at the pond and river monitoring stations. The figure indicates that, as expected, construction site runoff entering the pond contained much higher concentrations of suspended solids than was observed both in pond effluent and in the river upstream and downstream of the discharge point. Since facility effluent TSS concentrations were roughly 40 mg/L lower than the receiving waters, the increase from upstream to downstream must be attributed to in-stream erosion, rather than the quality of pond discharges. Indeed, the upstream and downstream sampling stations were located on a sharp bend in the river where some erosion would be expected to occur.

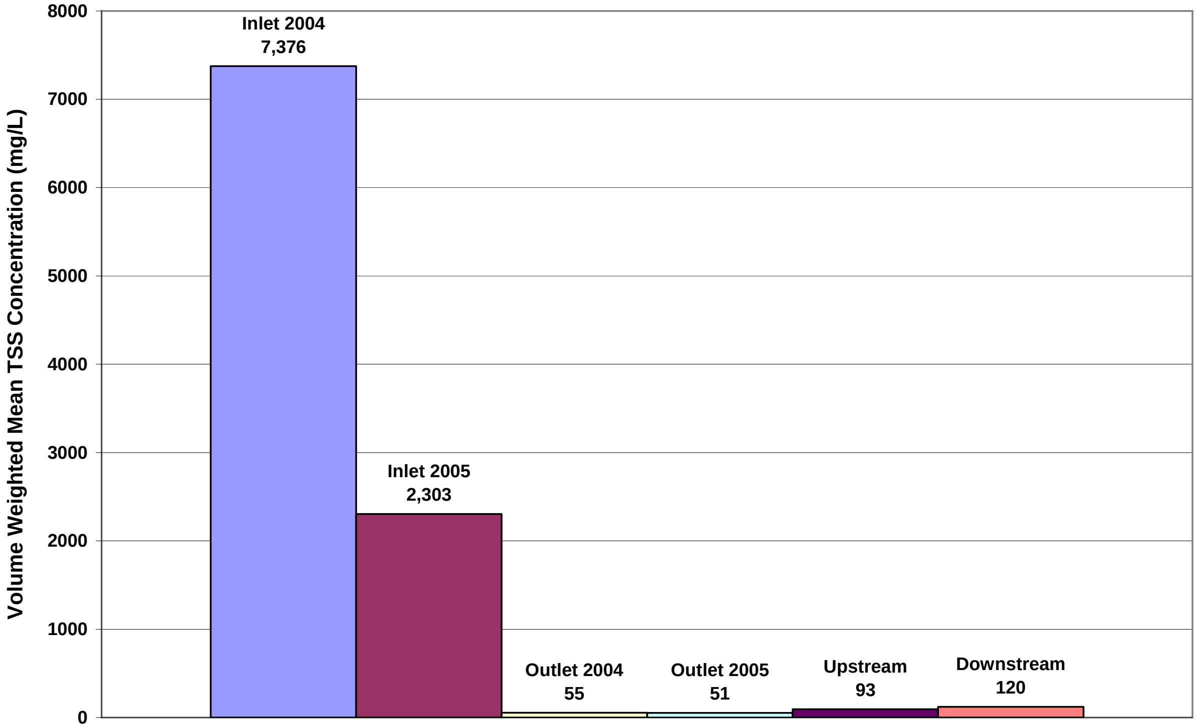


Figure 4.3: Volume weighted average event mean concentrations for suspended solids at the inlet and outlet of the facility (2004 and 2005) and upstream and downstream of the discharge point in the river (2004 only).

Table 4.6 summarizes TSS EMCs, loads, and removal efficiencies for all events monitored for suspended solids. As phases of the construction site were completed and more and more areas were stabilized, influent concentrations appeared to decline, although the trend is not statistically significant. By contrast, Effluent quality did not appear to be affected by the more stabilized catchment; possibly because more sediment had accumulated in the pond, some of which may have been re-suspended during storm events. The average volume weighted EMC for events in 2004 and 2005 was 55 and 52 mg/L, ranging over the entire study period from 15 to 93 mg/L. The largest TSS concentration was 246 mg/L, observed on July 19th, 2004, when influent concentrations peaked at 19,900 mg/L.

Table 4.6: Inlet and outlet TSS EMCs, loads and removal efficiencies for all events monitored for water quality

Event Date	Rainfall (mm)	Influent TSS EMC (mg/L)	Influent Peak TSS Conc.	Mass In (kg)	Effluent TSS EMC (mg/L)	Effluent Peak TSS Conc.	Mass Out (kg)	Removal Efficiency (%)
July 7, 2004	13.2	1880*	-	3980*	12.8*	-	24*	99.4
July 19, 2004	36.2	13028	19900	173089	92.8	246	1184	99.3
September 9, 2004	17.2	2607	5250	18837	34.8	45.2	240	98.7
October 15, 2004	4.1	5610*	-	7080*	22.9*	-	22*	99.7
October 30, 2004	8.8	9920*	-	33742*	38.5	76.0	108	99.7
November 2, 2004	8.2	892	1790	2132	19.2	21.8	44	97.9
November 24, 2004	8.7	595*	-	1748*	16.5*	-	44*	88.7
June 14, 2005	19.2	9308	12500	60817	30.5	63.7	254	99.6
July 17, 2005	10.8	2401*	6580	2963*	16.9	23.0	26	99.1
July 26, 2005	9	2633	2930	2300	24.1	68.3	21	99.1
August 1, 2005	18	5490	14500	54982	71.6	196	717	98.7
August 10, 2005	11.2	3692	6380	20123	48.5	61.8	137	99.3
August 31, 2005	21.8	854	2160	10172	48.5	120.0	366	96.4
September 8, 2005	15.4	3580	10200	8940	14.5	23.3	34	99.6
September 16, 2005	32.8	2897	11700	46880	57.2	163.0	862	98.2
September 25, 2005	43.6	971	8040	28044	63.0	191.0	1476	94.7
September 29, 2005	9.4	962	3310	6860	39.9	102.0	361	94.7
October 22, 2005	23.8	830	5890	7937	42.8	70.3	451	94.3
November 6, 2005	5.6	3797	8000	5353	20.5*	41.4	29*	99.8
November 9, 2005	19.2	1925	9480	17055	56.7	150.0	469	97.3
November 15, 2005	25.6	970	2880	12072	44.2	95.0	485	96.0
2004 Season								
Average	13.8	4933.1	8980.0	34372	33.9	97.3	238.0	97.6
Median	8.8	2607.0	5250.0	7080	22.9	60.6	44.0	99.3
Volume Weighted Avg		7375.8			55.1			99.3 **
2005 Season								
Average	19.0	2879.2	7467.9	20321	41.3	97.8	406.3	97.6
Median	18.6	2517.0	7290.0	11122	43.5	82.7	363.6	98.4
Volume Weighted Avg		2302.6			50.7			98.0**
All Events								
Average	17.2	3563.8	7734.7	25005	38.9	97.7	350.2	97.6
Median	15.4	2607.0	6580.0	10172	38.5	73.2	240.2	98.7
Volume weighted Avg		3362.3			51.6			98.6**

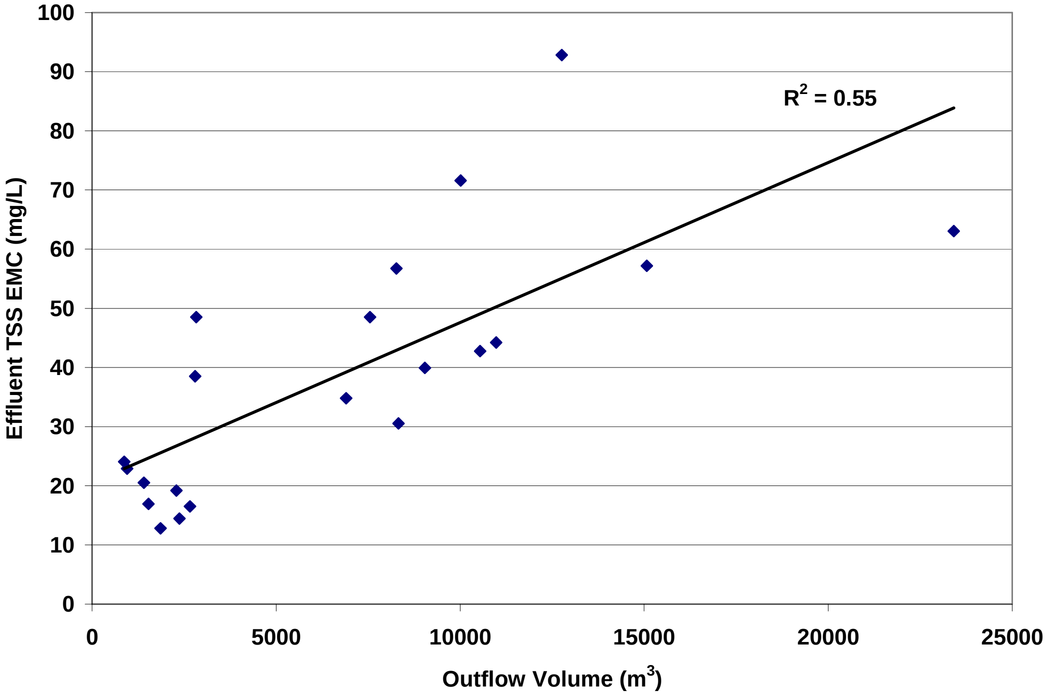
* time weighted composite samples. All other EMCs are flow proportioned based on multiple discrete samples.
** based on sum of loads (not an average)

Although effluent concentrations often exceeded levels typically observed in ponds draining stabilized catchments (SWAMP, 2004), the pond was nevertheless very effective in trapping sediments. On a seasonal load basis, 99% of suspended solids were removed. For individual events, removal efficiencies never fell below 88%. With such high sediment removal rates, one may expect pond effluents to be relatively clear. That this was not the case underscores the misleading nature of removal efficiencies when applied to construction site runoff. Several studies have shown that removal efficiency is a biased indicator of performance because it is directly correlated with influent concentrations (*e.g.* SWAMP, 2005). Effluent EMCs and loads are a more meaningful indicator of pond impacts on receiving waters.

Regression analysis was conducted to determine causal relationships among flow and water quality parameters. Results indicated that effluent quality is influenced more by inflow/outflow volumes and peak flow rates than by influent concentrations, loads or peak influent flow rates. As shown in Figure 4.4, outflow volumes explain 55% of the variation in TSS EMCs ($R^2 = 0.55$, $P<0.01$) and peak outflow rates explain 61% of the variation in effluent TSS EMCs ($R^2 = 0.61$, $P<0.01$). Peak outflow rates were also correlated with peak effluent TSS concentrations ($R^2 = 0.52$, $P<0.01$). By contrast, there were either weak or no correlations between influent and effluent TSS EMCs or loads, peak influent and effluent TSS concentrations, or peak inflow rates and peak influent concentrations. These results suggest the following:

- reducing influent sediment loads through upstream controls would not necessarily lead to corresponding reductions in effluent loads unless the upstream loading reduction was also associated with a reduction in the volume of inflows (*i.e.* with enhanced infiltration);
- increasing outflow rates by reducing draining water more quickly out of the facility (*i.e.* by reducing drawdown times) would likely produce dirtier effluents;
- re-suspension of previously trapped sediment in the pond during storm events may be as important or more important than influent concentrations in explaining variations in effluent concentrations.

Thus, from a management perspective, ponds should be designed to minimize the potential for re-suspension of trapped solids and maximize the time over which active storage drains from the facility. Upstream controls, on the other hand, should be focused on reducing both the volume and concentration of TSS in water entering the pond through, for instance, phasing of construction activities and implementation of stormwater infiltration practices.



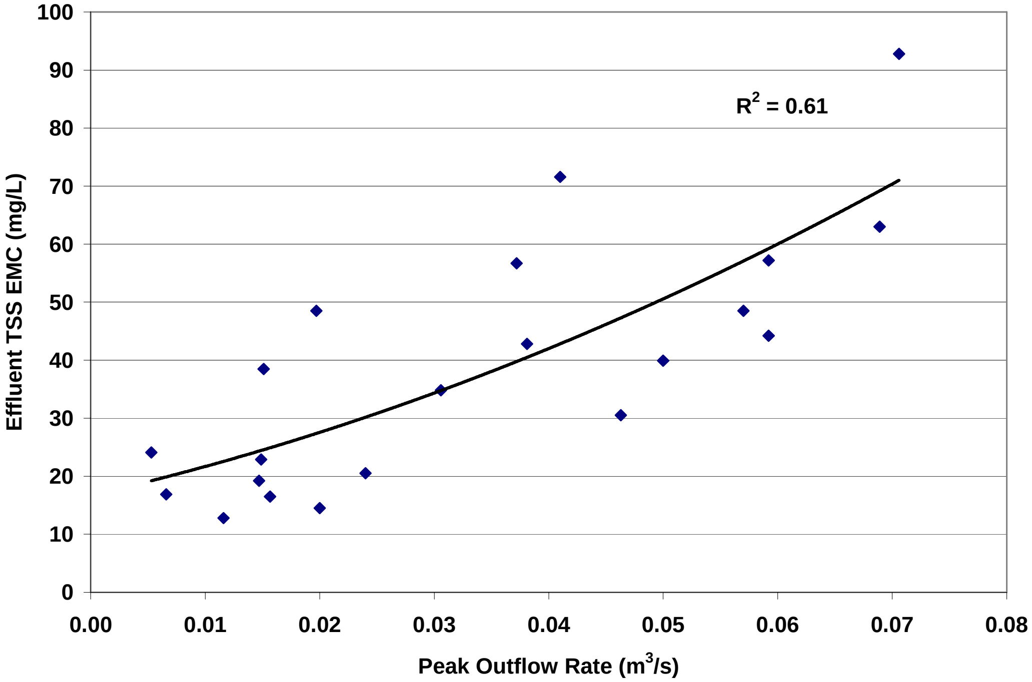


Figure 4.4: Relationship between outflow volumes and effluent TSS event mean concentrations (top) and between peak outflow rates and effluent TSS event mean concentrations (bottom).

4.4.2 Particle Size Distribution

Table 4.7 presents average percent distributions of sand, silt and clay sized particles at the inlet and outlet of the facility and in the receiving waters. Average cumulative particle size distributions (PSDs) are displayed graphically in Figure 4.5. In 2005, samples' collected within the facility were divided into 'early' and 'late' periods in order to assess changes in size distributions over time. The 2004 samples were only collected during the 'early' period, which typically includes the hydrograph rise, peak and a portion of the run.

The influent and river suspended solids were significantly coarser (95% confidence level) than those sampled at the outlet of the facility, indicating that facility was effective in removing larger particles (Figure 4.5). The median particle size dropped from 3.8 μm to 2.0 μm at the outlet. The percentage of clay sized particles at the inlet, outlet and river stations was 52, 66 and 46%, respectively (Table 4.7). The late effluent PSDs were slightly finer than the earlier ones (*i.e.* higher percentage of clay). All stations had very low sand fractions, reflecting the catchment soils, which are comprised predominantly of silt and clay. Such fine effluent particle sizes raises the question of whether there are limits to what can be expected from a technology that treats construction runoff primarily through passive settling. Evaluating this hypothesis was an important objective of the pond modelling exercise presented in chapter 5.

Table 4.7: Percent distribution of sand, silt and clay particles

Class	**Inlet**		**Outlet**		**Receiving Waters**	
	Early	**Late**	**Early**	**Late**	**Upstream**	**Downstream**
Sand (>62μm)	1.5	1.6	0.06	0.03	1.2	0.6
Silt (<62μm,>3.73μm)	46.8	50.4	33.6	28.1	53.1	53.3
Clay (<3.73μm)	51.7	48.0	66.4	71.9	45.6	46.2

Note: 'early' samples typically include the rise and peak of the hydrograph; 'late' samples are usually collected on the hydrograph run.

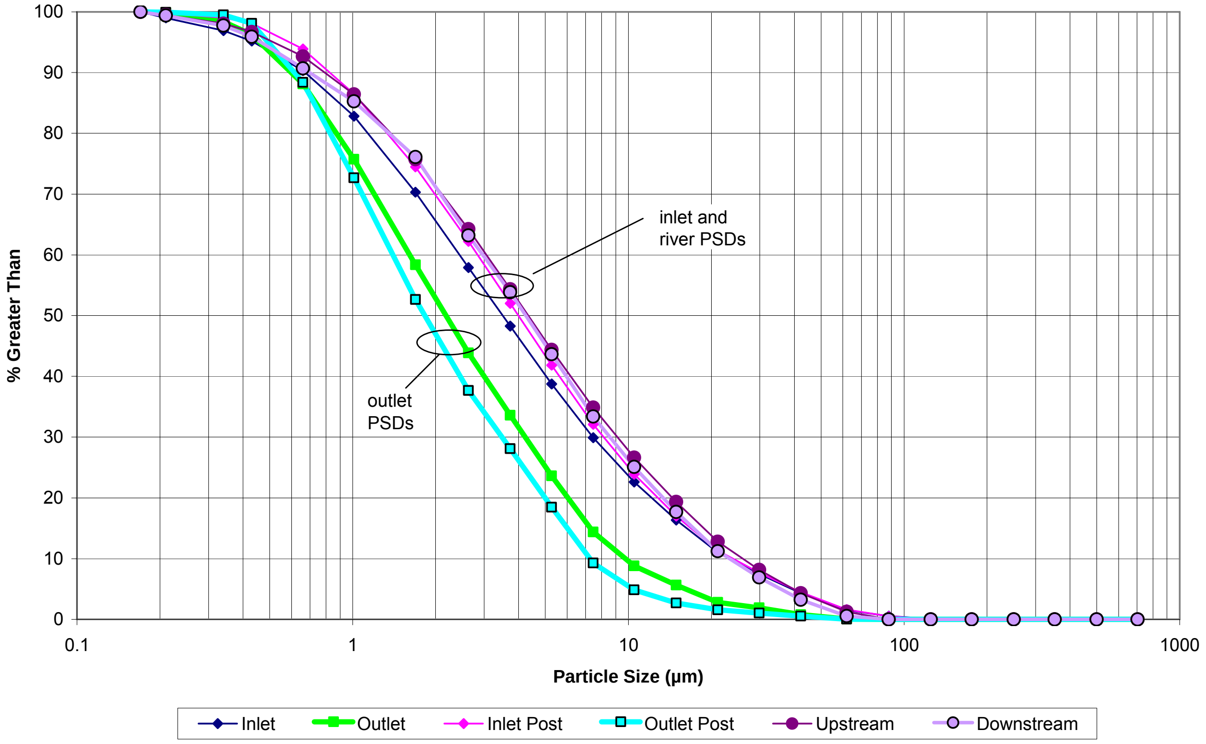


Figure 4.5: Average particle size distributions at the inlet, outlet and river stations. 'Post' samples are collected later in the event, typically on the run of the hydrograph.

4.4.3 Pollutographs

In 2004 and 2005, several events were analyzed discretely for suspended solids. Figures 4.6 and 4.7 show sample hydrographs, hyetographs, and pollutographs for the September 16th and November 9th events. (see Appendix A for hydrographs and pollutographs for other events). The September and November events were both relatively large events, with total rainfall of 32.8 and 19.2 mm, and average rainfall intensities of approximately 2.8 and 1.4 mm/hr, respectively. Although the November event had a lower average rainfall intensity, influent peak flow was higher during this event because of a short burst of rainfall near the end of the event.

During both events, the influent pollutograph closely matches the influent hydrograph. Effluent pollutographs and hydrographs peaked at roughly the same time, but concentrations declined more rapidly than flows, reflecting a process of mixing and dilution within the pond. The larger event had a higher peak influent TSS concentration (11,700 vs. 9,480 mg/L) but peak effluent TSS concentrations (163 and 150 mg/L) during the two events were similar. Flow weighted influent and effluent event mean concentrations were 2896 and 57 mg/L for the September event and 1925 and 56 mg/L for the November event, respectively.

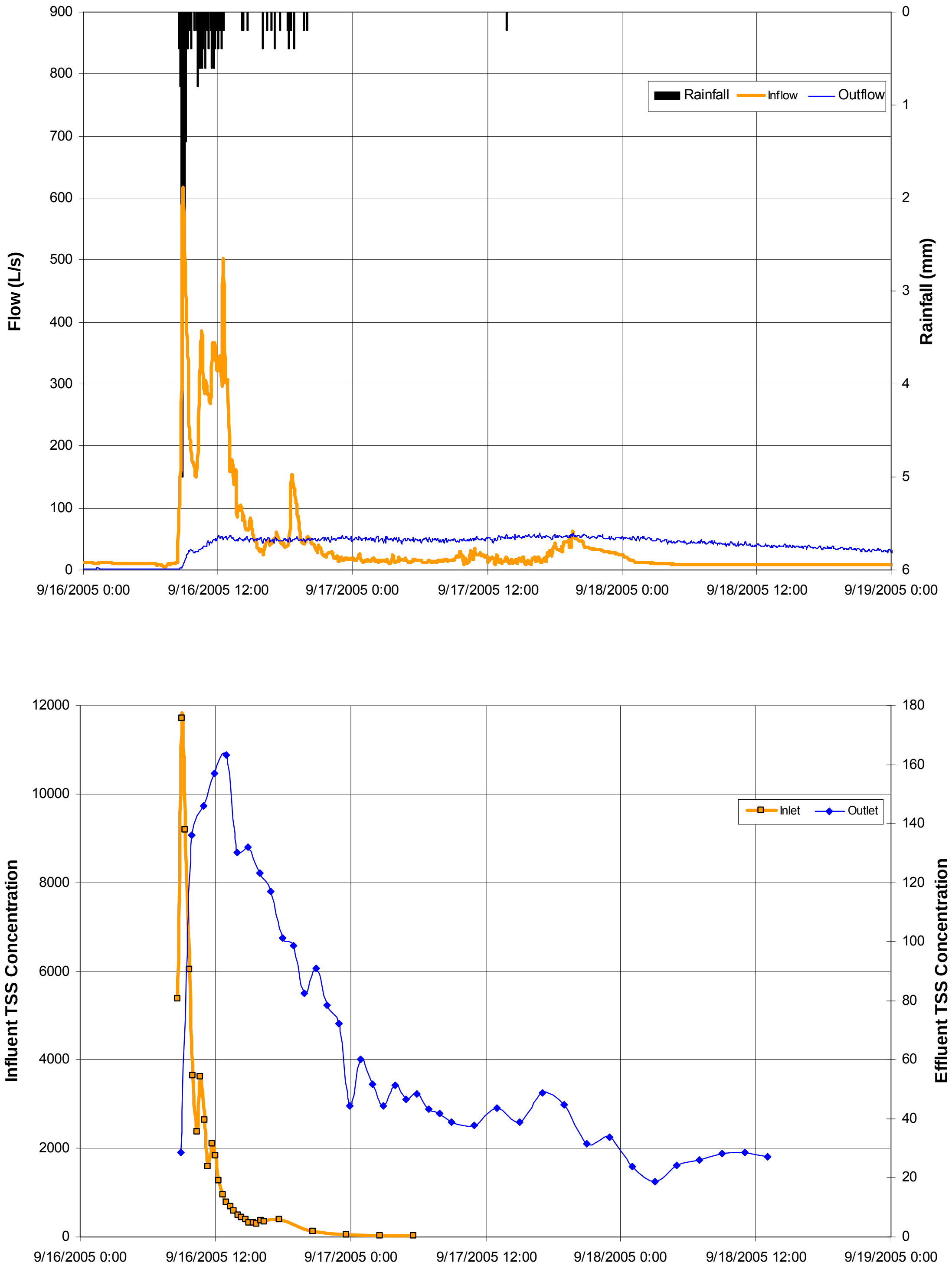


Figure 4.6: Hyetograph, hydrograph and TSS pollutograph for 32.8 mm event on September 16th, 2005.

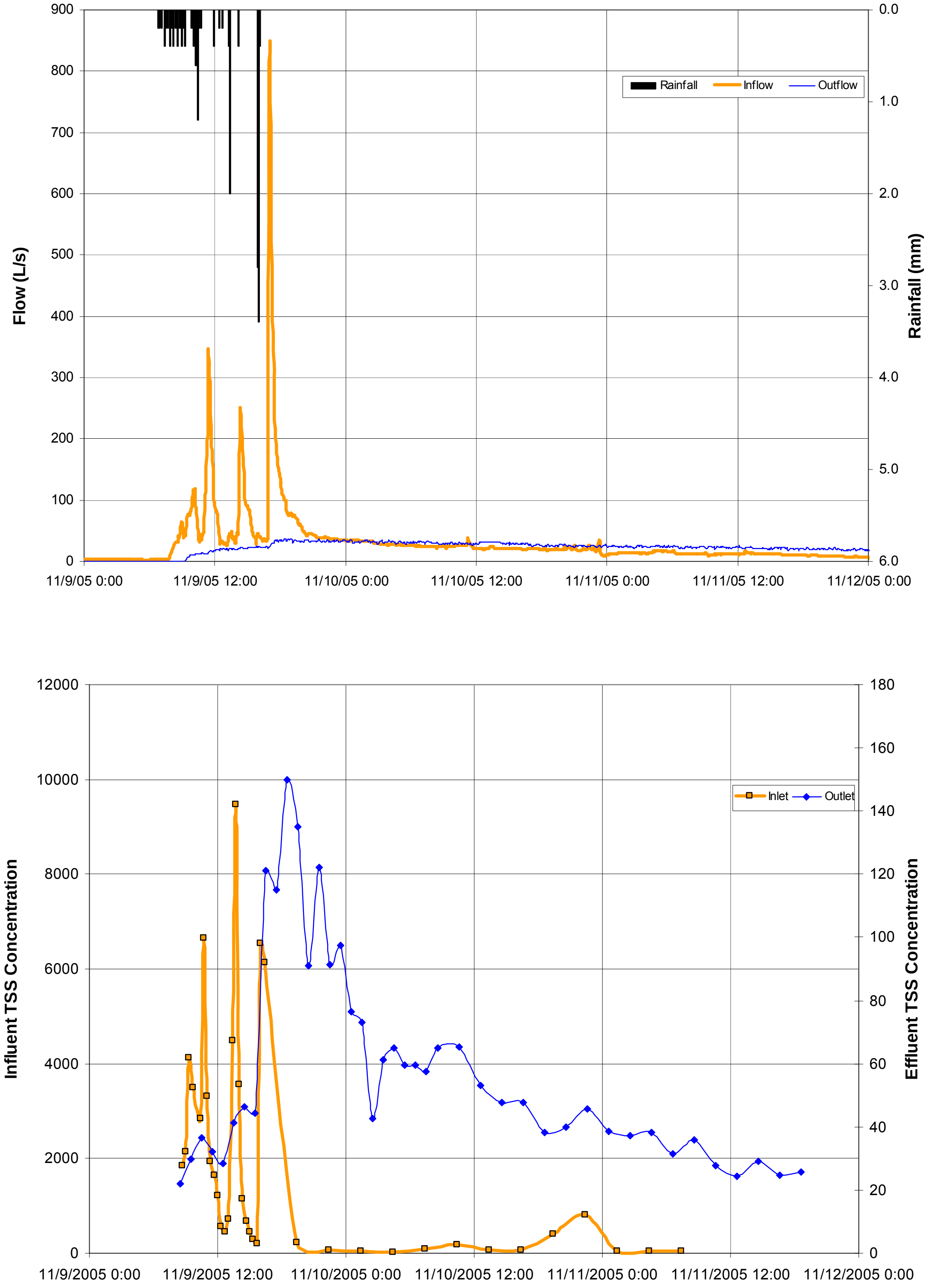


Figure 4.7: Hyetograph, hydrograph and TSS pollutograph for a 19.2 mm event on November 9th, 2005.

4.4.4 Receiving Water Impacts

The impact of suspended particulate matter on receiving waters is typically measured as a concentration and duration of exposure. A framework developed by Newcombe (1986; as cited by Ward, 1992) depicts the relationship between these variables and predicted levels of impact on the aquatic system (Figure 4.8). This framework is used in this report to evaluate the potential effect of discrete suspended solids concentrations on receiving waters for events monitored over the study period. Use of the framework here does not account for dilution caused by mixing with receiving waters. If the receiving body provides some dilution capacity, the impact on aquatic life downstream of the mixing zone would, of course, be less severe than the plots in Figure 4.8 suggest. At this particular study site, facility effluents would have, in fact, reduced downstream concentrations of suspended solids because upstream concentrations were greater than those measured in pond effluents during most rain events.

Recognizing the limitations of this analysis, the sampling data indicate that effluent quality falls mostly in the minor and moderate impact zones. Most of the ‘moderate’ impacts consisted of TSS concentrations between 25 and 75 mg/L that persisted over long periods. Less than 20% of observations were above 75 mg/L.

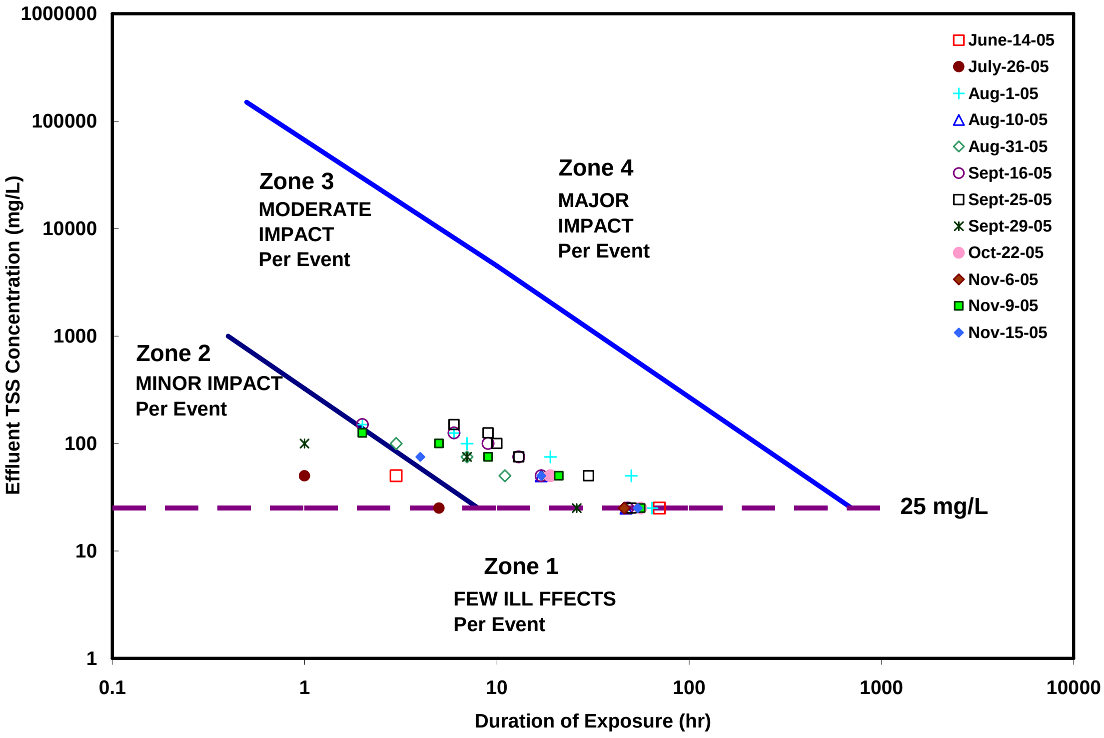


Figure 4.8: The concentrations and duration of effluent TSS for monitored events. Values represent the number of hours that specified concentrations were exceeded during an event. Impacts do not account for dilution of effluent in receiving waters. The fisheries impact framework is from Newcombe (1986, as cited in Ward, 1992).

Another method of assessing potential receiving water impacts associated with pond effluent quality uses receiving water risk thresholds established by the European Inland Fisheries Advisory Commission (1965) (see discussion in chapter 1). Again, this analysis assumes no dilution in the receiving water system. By this method, most of the events fall in the 'very low' and 'low risk' categories. Only one event could be considered to pose a 'moderate risk' to downstream fish and fish habitat (Table 4.8).

Table 4.8: Downstream risk to fish and fish habitat associated with effluent suspended solids concentrations.

Concentration Ranges*	Risk to Fish and Fish Habitat*	# of Events with Effluent EMCs within specified Range**
<25 mg/L	Very Low Risk	8
25 – 80 mg/L	Low Risk	12
80 – 400 mg/L	Moderate Risk	1
> 400 mg/L	High Risk	0

* based on EIFAC guidelines (1965)

** indicated risk assumes no dilution of effluent in receiving waters.

4.4.5 General Water Quality

Water samples were analyzed for major groups of pollutants in order to characterize the quality of water entering and exiting the facility relative to the quality of the Little Rouge Creek receiving water. A statistical summary of the results is presented in Appendix B. Results of continuous water temperature monitoring are provided in Appendix C. The main findings were as follows:

- Concentrations of most pollutants of concern were lower in facility effluents than in the receiving waters;

- Downstream concentrations of some pollutants were higher than upstream concentrations, but as there were several instances in which effluent concentrations were lower than upstream concentrations, this upstream-to-downstream increase can not be attributed to the poor quality of facility effluents.

- Facility influent concentrations of common stormwater contaminants, such as copper, lead and zinc, were considerably lower than observed in stormwater pond influents from fully developed urban sites (SWAMP 2005);

- Effluent concentrations of total phosphorus, *E. coli*, cadmium, copper and iron exceeded receiving water objectives, but the volume weighted mean concentrations of all these constituents were either lower than or not significantly different than levels observed in receiving waters;

- Resident waterfowl frequently observed in the pond may be a potential source of *E. coli* and phosphorus from the facility;

- Eroded sediments in runoff, both in the pond and receiving waters, contained high concentrations of phosphorus, probably from current and historical farming practices in the region.

- Polycyclic Aromatic Hydrocarbons (PAH) and all but three herbicides/pesticides (2, 4-D, MCPP and Pentachlorophenol) were observed at concentrations below laboratory analytical detection limits (although many of the limits for PAHs well exceed the provincial receiving water guideline). Dicamba was also found above detection limits in the Little Rouge Creek.

From this analysis, it may be concluded that construction site runoff contains relatively low levels of pollutants (*e.g.* metals, PAHs) typical of fully developed urban sites. Hence, total suspended solids and associated pollutants, such as total phosphorus, should continue to be the primary focus of concern at construction sites for the protection of aquatic habitat.

The removal efficiencies for selected water quality variables analyzed in this study are presented in Appendix D. Significant reduction was noted for suspended solids, total phosphorus, TKN, nitrates and bacteria. Heavy metals such as lead, zinc, and copper had lower removal efficiencies because influent concentrations were very low (*i.e.* close to background levels), making further reductions difficult to achieve. Several studies have shown strong direct relationships between removal efficiencies and influent concentrations. Constituents observed primarily in dissolved form, such as chloride and cadmium, would not be expected to be removed since the pond functions based on settling processes.

4.4.6 Dry Weather Sampling

In 2004, sampling was conducted during dry weather in order to characterize the quality of the receiving water. Samples were collected at three stations. Two were located upstream near Markham Road and north of Major Mackenzie Drive and one was located downstream east of Ninth Line. Dry weather results are provided in Appendix E.

As expected, concentrations were much lower than observed during wet weather. Only *E. coli* exceeded the provincial guideline, which is designated for bathing areas, not rivers. Cadmium was above the guideline only because the detection limit was greater than the objective. Among the 9 samples collected only one exceeded the detection limit for cadmium.

Dry weather discharges from the pond were not expected to have a significant impact on the river because pond discharge volumes are small relative to river discharge and effluent concentrations during dry weather are generally quite low. However, as sediment accumulated in the pond, a visible plume of fine clay particles was frequently observed in the outlet channel. Samples of the effluent and river water upstream and downstream of the discharge location were collected to determine whether or not dry weather discharges were affecting receiving water quality.

Results presented in Table 4.9 show that effluent suspended solids and turbidity were indeed higher than receiving water concentrations, as expected from the visible difference in water clarity, but that the effect on downstream concentrations after mixing was not significant. On other streams where the pond discharge volume comprises a larger proportion of total flow in the river, or where there are several sediment control ponds discharging to the same stream, the dry weather impact of pond effluents may be a greater concern. Sand or compost filters installed between the outlet and receiving stream are proposed as a means of improving the clarity of effluent discharges.

Table 4.9: Concentrations of solids and turbidity at the outlet and in receiving waters immediately upstream and downstream of the outfall.

Variable	Outlet	Upstream	Downstream
Total suspended solids (mg/L)	20.1	5.3	5.7
Total dissolved solids (mg/L)	291	430	419
Total solids (mg/L)	311	436	425
Turbidity (FTU)	35.4	3.2	4.8

4.5 Greensborough Pond vs. Ballymore Pond

In this section, the Greensborough pond monitoring results are compared to those from an earlier monitoring study of a construction sediment control pond (referred to as the Ballymore pond) in Richmond Hill, Ontario (Clarifica Inc., 2004; Ryerson University, 2001). The comparison is an apt one because both ponds drained construction catchments consisting primarily of silt and clay materials, and the size of particles entering the facilities had similar distributions (D_{50} between 3 and 4 μm).

Table 4.10: Greensborough and Ballymore pond design features compared to OMOE ultimate (post-construction) stormwater pond guidelines

Design Feature	Design Objective	OMOE (2003) Guidelines for Ponds	Greensborough Pond, Markham, Ontario	Ballymore Pond, Richmond Hill, Ontario
Permanent Pool Depth (m)	minimize re-suspension; avoid anoxic conditions	1-2 average; 3 max.	1.5	2.4 max.
Permanent Pool Volume (m^3/ha)	protection of aquatic habitat	60 (normal) 125 (enhanced)[1]	127	154
Extended Detention Depth (m)	storage and flow control	1 to 1.5	2.4	1.6
Extended Detention Volume (m^3/ha)	protection of aquatic habitat	40	144	110
Drawdown Time (hours) (25 mm, 4 hr storm)	suspended solids settling	24	Approx. 72[2]	48
Detention Time (hours)[3]	suspended solids settling	n/a	16.2	12.0
Length-to-Width Ratio	minimize short circuiting	at least 3:1 (4:1 or 5:1 preferred)	8:1	2:1
Design Protection Level		--	Level 1 (enhanced)	Level 1 (enhanced)
Drainage Area (ha)		--	88.8	15.3

1. Based on 45% surface imperviousness.
2. Approximate value based on observed outflow duration (design drawdown is minimum 48 hours)
3. Average measured values calculated as the time delay between inlet and outlet hydrograph centroids

From a design perspective, however, the Greensborough and Ballymore ponds differed in several important ways, even though both were designed to OMOE 'enhanced level' standards for ultimate ponds (2003). The key design differences relate to storage volumes, length to width ratios and drawdown times. While the Ballymore pond has a larger permanent pool, the Greensborough pond has more extended detention, longer drawdown and detention times, and a significantly larger length-to-width ratio (8:1 vs. 2:1) (Table 4.10). The Ballymore pond banks were also less well stabilized than the Greensborough pond, although the slopes were similar.

Table 4.11 compares rainfall, TSS concentrations and removal efficiencies at the two sites. The Greensborough pond emerges from the comparison as the more effective of the two ponds, even though influent concentrations and loads were, on average, higher at the Greensborough site. The average peak TSS effluent concentration at Ballymore was over three times greater than observed at the Greensborough pond. Mean effluent EMCs were also considerably higher. Note, however, that removal efficiencies were impressive at both sites, which highlights the misleading nature of this statistic when applied to construction site runoff.

Effluent impacts to downstream aquatic life are assessed using the concentration-duration (Figure 4.9) and concentration (Table 4.8) evaluation frameworks presented earlier. Based on the concentration-duration framework, effluent impacts of the two ponds appear to be similar, with effluent concentration-durations falling mostly within the 'moderate impact' zone. However, Ballymore 'moderate impacts' (based on model simulations of effluent pollutographs) occur both at higher concentrations (Figure 4.9) and higher flow rates because for a given event, outflows are released over a shorter time period (see differences in drawdown times in Table 4.10). Consequently, for the same size event, Ballymore will have higher suspended solids loads per unit drainage area than Greensborough, thereby rendering it less likely that downstream mixing in receiving waters will reduce concentrations to levels required for the protection of aquatic life.

Basing the risk assessment strictly on event concentrations presents a different perspective. At Ballymore, 7 of the 16 events monitored fell within the moderate and high risk categories, compared to only 1 at Greensborough (Table 4.12). Unfortunately, the Ballymore data used in this analysis are not the same as used in Figure 4.9, although they should be comparable. The latter are model simulations for the entire drawdown period, whereas data in Table 4.12 are monitored values, collected over only a portion of the event (simulated EMCs were not available). The use of different data sets makes it difficult to compare the two Ballymore risk assessments, but the overall conclusion that Ballymore poses a greater risk to receiving waters than Greensborough still holds true.

Table 4.11: Comparison of outlet suspended solid concentrations and loadings for the Ballymore and Greensborough ponds.

Ballymore Pond, Richmond Hill							Greensborough Pond, Markham						
Event Date	**Rainfall (mm)**	**Inlfuent Peak TSS Conc.**	**Influent TSS Conc. (mg/L)[+]**	**Effluent Peak TSS Conc.**	**Effluent TSS Conc. (mg/L)[§]**	**Rem. Eff. (%)**	**Event Date**	**Rainfall (mm)**	**Influent Peak TSS Conc.**	**Influent TSS EMC (mg/L)**	**Effluent Peak TSS Conc.**	**Effluent TSS EMC (mg/L)**	**Rem. Eff. (%)**
14-Sep-02	28.8	20050	7404	415	277	96.3	7-Jul-04	13.2	-	1880*	-	12.8*	99.4
20-Sep-02	13.3	34000	1427	59	27	98.1	19-Jul-04	36.2	19900	13028	246	92.8	99.3
27-Sep-02	18.4	12200	4655	189	75	98.4	9-Sep-04	17.2	5250	2607	45	34.8	98.7
2-Oct-02	10	19100	8557	10	7	99.9	15-Oct-04	4.1	-	5610*	-	22.9*	99.7
19-Oct-02	13	3800	1059	67	29	97.3	30-Oct-04	8.8	-	9920*	76	38.5	99.7
25-Oct-02	9.4	3800	1129	62	17	98.5	2-Nov-04	8.2	1790	892	22	19.2	97.8
2-May-03	6.8	979	360	52	30	91.7	24-Nov-04	8.7	-	595*	-	16.5*	88.7
5-May-03	17.4	2350	879	60	36	95.9	14-Jun-05	19.2	12500	9308	64	30.5	99.7
11-May-03	17.8	6110	-	470	224	-	17-Jul-05	10.8	6580	2401*	20	16.9	99.3
20-May-03	10.8	4100	1499	192	100	93.3	26-Jul-05	9	2930	2633	68	24.1	99.1
4-Jun-03	13.4	3380	1299	202	49	96.2	1-Aug-05	18	14500	5490	196	71.6	98.7
8-Jun-03	23.6	8560	4547	2640	1630	64.2	10-Aug-05	11.2	6380	3692	62	48.5	98.7
13-Jun-03	14	4190	1020	144	82	92.0	31-Aug-05	21.8	2160	854	120	48.5	94.3
15-Sep-03	9.8	3030	598	213	121	79.8	8-Sep-05	15.4	10200	3580	23	14.5	99.6
19-Sep-03	38	538	317	259	93	70.6	16-Sep-05	32.8	11700	2897	163	57.2	98.0
22-Sep-03	25	1100	229	46	28	87.8	25-Sep-05	43.6	8040	971	191	63.0	93.5
-	-	-	-	-	-	-	29-Sep-05	9.4	3310	962	102	39.9	95.9
-	-	-	-	-	-	-	22-Oct-05	23.8	5890	830	70	42.8	94.8
-	-	-	-	-	-	-	6-Nov-05	5.6	8000	3797	41	20.5*	99.5
-	-	-	-	-	-	-	9-Nov-05	19.2	9480	1925	150	56.7	97.1
-	-	-	-	-	-	-	15-Nov-05	25.6	2880	970	95	44.2	95.4
Average	**16.8**	**7955**	**2332**	**318**	**177**	**91**		**17.2**	**7735**	**3564**	**98**	**39**	**98**
Median	**13.7**	**3950**	**1129**	**167**	**62**	**96**		**15.4**	**6580**	**2607**	**73**	**39**	**99**

[§] Ballymore samples were collected over a relatively short duration (usually < 6 hours; drawdown is approx. 48 hours) and, therefore, may not represent the true event mean.

[+] Weighted average of two influent measurements based on the relative size of the contributing drainage areas.

* Time integrated composite samples (not flow proportioned).

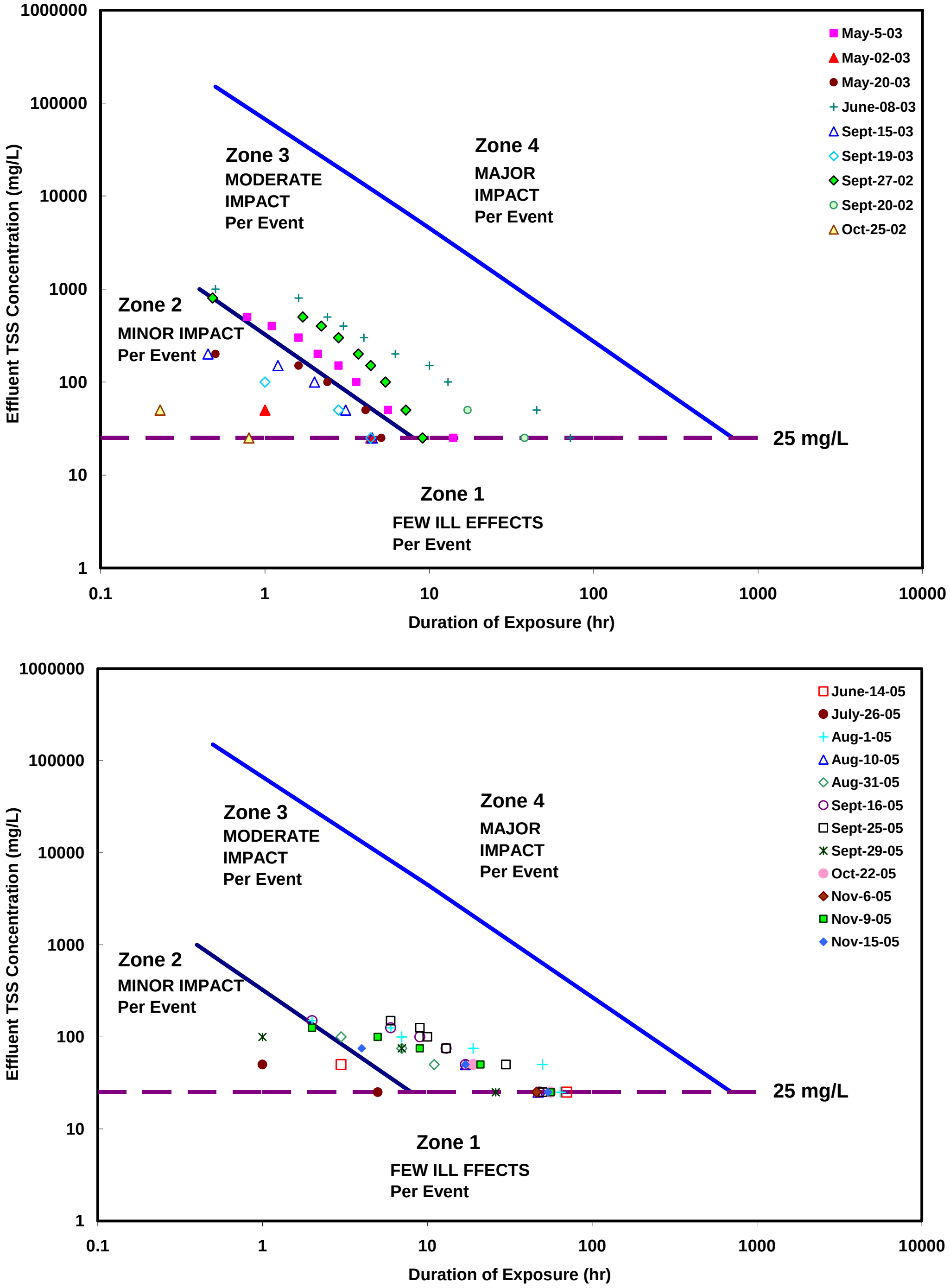


Figure 4.9: The concentrations and duration of effluent TSS for rain events monitored at the Ballymore and Greensborough ponds. Values represent the number of hours that specified concentrations were exceeded during an event. Impacts do not account for dilution of effluent in receiving waters. Ballymore data are model simulations; Greensborough data are actual observations. The fisheries impact framework is from Newcombe (1986, as cited in Ward, 1992).

Table 4.12: Downstream risk to fish and fish habitat associated with effluent suspended solid concentrations at the Ballymore and Greensborough ponds.

Concentration Ranges*	Risk to Fish and Fish Habitat*	# of Events with Effluent EMCs within Specified Range**	
		Ballymore[+]	Greensborough
<25 mg/L	Very Low Risk	2	8
25 – 80 mg/L	Low Risk	7	12
80 – 400 mg/L	Moderate Risk	6	1
> 400 mg/L	High Risk	1	0

* Based on EIFAC 1965; USEPA, 1973

** Indicated risk assumes no dilution of effluent in receiving waters.

[+] Ballymore effluent concentrations are not, strictly speaking, event mean concentrations because they were collected over a relatively short time period (usually < 6 hours; drawdown time is approx. 48 hours).

5.0 STUDY FINDINGS: MODELLING

5.1 Modelling Objectives

A numerical model was developed to simulate the Greensborough stormwater management pond. The primary goal of this task was to demonstrate the relative impact of key pond design parameters on the quality of water being discharged from temporary construction sediment ponds. These data were subsequently used to re-evaluate and revise the existing guideline for the design of these ponds.

The design parameters selected for analysis include:

- length to width ratio;
- presence or absence of submerged berms;
- location of the outlet relative to the inlet,
- permanent pool; and
- drawdown time.

The following sections describe the model selected for this study, input parameters, calibration, scenarios and simulation results. Simulation movie clips can be viewed in Appendix F.

5.2 Model Selection

Following a review of numerical models for surface water environments (MIKE21; PHOENICS; PCSWMM), the RMA suite of hydrodynamic and water quality models (developed by the US Army Corps of Engineers) was selected as the best suited to fulfilling the study objectives.

5.2.1 RMA2 Hydrodynamic Model

The finite element hydrodynamic model (RMA2) computes water surface elevations and velocity components for two-dimensional, depth-averaged flow fields. The finite element solution is based on the Reynolds form of the Navier-Stokes equation for turbulent flow. Bed friction is accounted for using Manning's roughness equation. Turbulence is modelled via an eddy viscosity approach. The model can process both dynamic and steady-state solutions. RMA2 is suitable for shallow water problems, such as a stormwater pond, in which vertical accelerations are negligible and flow is unstratified (King et al, 2003).

5.2.2 SED2D Sediment Transport Model

The finite element sediment transport model (SED2D) simulates two-dimensional, depth-averaged sediment transport in a water body. This model combines the basic processes of erosion, entrainment, transportation, and deposition to predict sediment concentration and bed change. SED2D can process both cohesive (silt and clay) and non-cohesive (sand) soil types; however, only a single effective grain size can be modelled during each simulation.

5.3 Model Input

5.3.1 Pond bathymetry / finite element mesh

The RMA2 hydrodynamic model requires a finite element mesh of the Greensborough pond in order to determine a solution. A finite element mesh was developed based on 2D drawings dated June 29, 2004 provided by the design engineers (Cosburn Patterson Mather Limited, 2002) and bathymetry surveys conducted in September 2004, December 2004, and April 2005. The finite element mesh is a close approximation to the pond geometry and takes into account the most recent bathymetry survey (April 15, 2005) to represent the sediment accumulation to date. The mesh is comprised of approximately 2000 elements and 5400 nodes (Figure 5.1). Element sizes range from 1 meter to 5 meters. Smaller elements are used for increased model accuracy in sections of the pond that are more complex, such as the inlet, outlet, and banks. Relatively flat sections of the pond are meshed with larger elements.

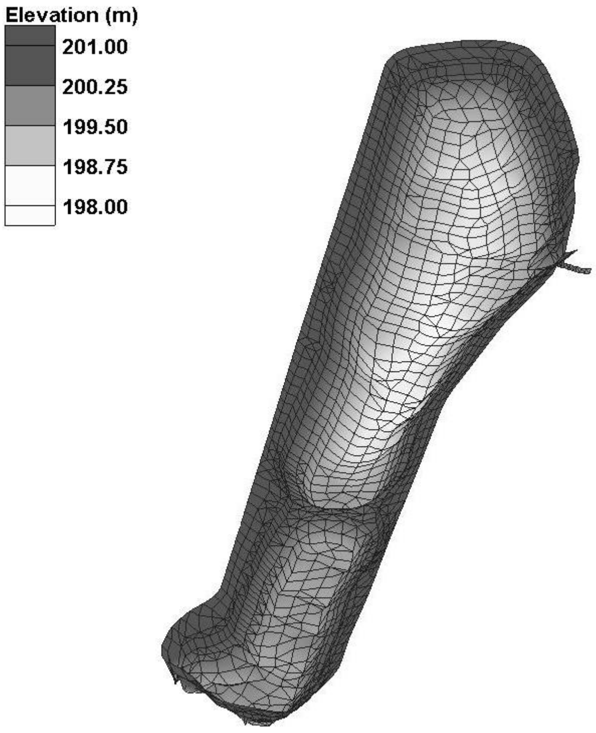


Figure 5.1: Finite element mesh for existing Greensborough pond.

5.3.2 RMA2 Boundary and initial conditions

Two boundary conditions were required for the hydrodynamic model; both consisted of observed field data. Measured inflows and water levels were entered directly into the model as boundary conditions. The primary initial condition for all simulations was the initial pond water level. It was assumed that only the permanent pool volume of the pond was full and that the active storage was completely drawn down, resulting in a starting water level of 198.75 meters.

5.3.3 SED2D Boundary and initial conditions

The initial condition for the SED2D model was the total suspended sediment concentration in the pond at the start of the simulation. This was assumed to be zero in order to observe the effect of fresh sediment entering the pond.

The SED2D model boundary condition was based on the observed data. Inlet pollutographs were used to introduce the sediment load into the pond. Special consideration was given in selecting the boundary condition, as outlined below.

Bathymetry surveys conducted in 2004 and 2005 indicated that no sediment had accumulated in the outlet area and the far end of the pond (Figure 5.2), which suggests that suspended sediments arriving in the vicinity of the outlet consist of fine particles (i.e. clay) that do not settle.

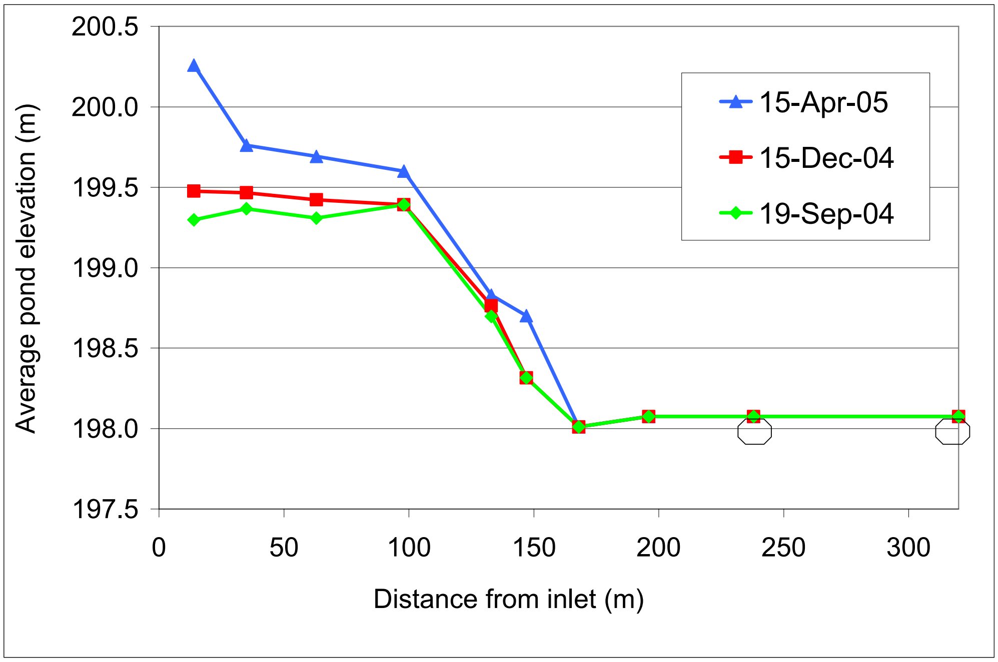


Figure 5.2: Bathymetry survey results.

The mass balance of inlet TSS load and outlet TSS load, as well as the particle size analysis of sediment samples from the bed material near the inlet (Figure 5.3) indicate that the clay fraction of inlet TSS is approximately 20% to 30%, depending on the size of the event. Thus, the inlet pollutograph was scaled to reflect the clay fraction, or non-settling particles. Cross sections 1 and 2 in Figure 5.3 illustrate that the proportion of clay size particles in the inlet area is roughly 30%.

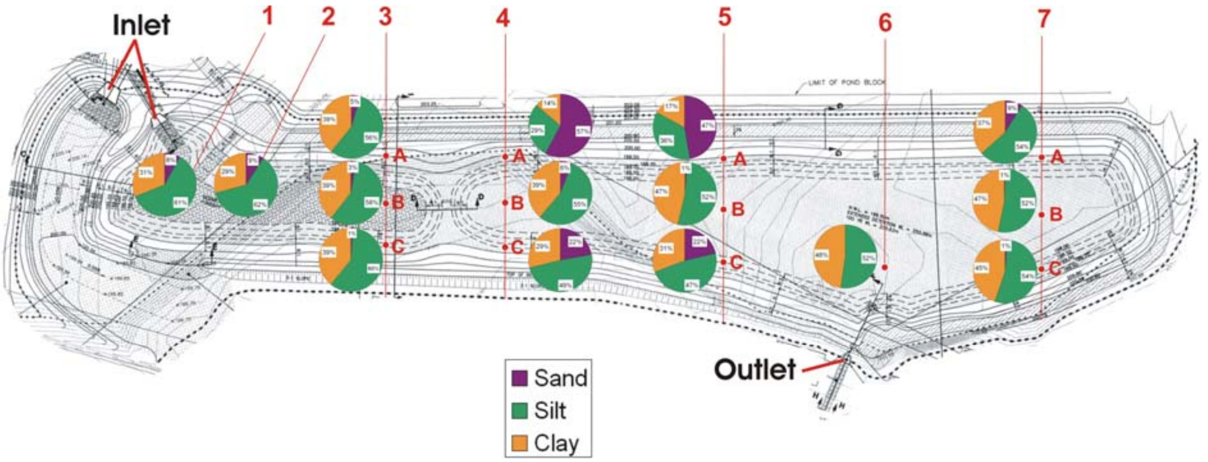


Figure 5.3: Particle size distributions for multiple pond cross sections.

5.4 Model calibration

Proper calibration ensures that the results generated by the model are consistent with observed data. Calibration is a lengthy process that involves determining the sensitive parameters and their effect on model output; these parameters are logically changed until the model solution approaches the observed data. Assigning model parameter values is a critical step in the modelling process. This section describes the sensitivity analysis process and considerations and estimates of the various model parameters of RMA2 and SED2D.

5.4.1 Hydrodynamic model

As mentioned earlier, the Greensborough pond model boundary conditions and geometry of the finite element mesh are based on observed field data. The Manning's bed roughness coefficient (*n*) is a model parameter which requires calibration because bed roughness significantly affects the magnitude of simulated current speeds. The value of *n* for natural soft clay bed materials varies between 0.02 to 0.03 (Barnes, 1967). The roughness of the pond bed could be accurately determined using a flume. However, for the purposes of this study, the value of *n* for modelling the bed roughness conditions was estimated to be 0.025, reflecting a relatively smooth bed boundary consisting of fine sediments.

The eddy viscosity coefficient controls the level of turbulence mixing in the RMA2 model. Literature values of eddy viscosity were used in this study. The eddy viscosity coefficients generally vary between 100 and 10,000 N-Sec/m^2 depending on flow situations (Nezu et al., 1993). This coefficient is affected by the size of the water body, including flow depth and horizontal dimension. The eddy viscosity coefficient for the Greensborough pond was estimated to be 5000 N-Sec/m^2, based on the published values and guidelines for other water bodies with a similar size (Rodi, 1993).

Since the RMA2 model operates on mass conservation principles, inlet volume and outlet volume checks were conducted to ensure that the model was computing the numerical solution correctly. Observed data was used for the inflow and water level boundary conditions; therefore the pond model performed as the monitoring results indicated.

5.4.2 Sediment transport model sensitivity analysis

A sensitivity analysis was conducted on the four major calibration parameters that influence the output of the SED2D sediment transport model, including clay fraction of inlet sediment load, settling velocity of the fine sediments, and effective diffusion coefficient in the longitudinal and transverse directions. During the sensitivity analysis, three out of the four parameters were held constant while the remaining parameter was varied. This method revealed the effect of each parameter in isolation.

The first parameter to be examined was the estimated clay fraction of the influent TSS pollutograph, represented in the model by a single 'representative' particle size. Results of the analysis are provided in Table 5.1. Peak effluent TSS concentrations (and subsequent outlet loads) increased as influent TSS increased (Figure 5.4, 5.5 and 5.6).

Table 5.1: Sensitivity results for influent TSS clay fraction.

Parameter	Parameter value	Peak outlet TSS concentration (mg/L)	%change from control
Clay fraction (% of influent TSS pollutograph)	15	63	-32%
	17	68	-26%
	19	**92**	**0%**
	21	101	10%

Particle settling velocity, based on Stoke's Law, represents the rate at which a single grain of sediment falls towards the pond bed. This parameter enables the model to decide, based on the velocity and turbulence in the flow field, whether or not a particle settles or remains suspended in the water. High settling velocities cause particles to drop out of suspension quickly and accumulate on the bed. As the settling velocity approaches zero, particles tend to stay in suspension. Turbulent energy caused by wind and small eddies can keep clay size material (<2 μm) in suspension indefinitely. Several settling velocities were tested in the sensitivity analysis, ranging from 0 m/s (no settling) to 3.27×10^{-7} m/s. The method used assumes no enhanced settling due to particle flocculation (Table 5.2).

Table 5.2: Sensitivity results for particle settling velocity.

Parameter	Parameter value	Peak outlet TSS concentration (mg/L)	%change from control
Settling velocity (m/s)	**0**	**92**	**0%**
	3.27×10^{-9}	73	-21%
	6.05×10^{-8}	63	-32%
	3.27×10^{-7}	57	-38%

Diffusion of suspended sediment occurs mainly due to turbulence mixing in the flow field. When the transport equation is simplified by averaging in time and space, the combined effect is known as dispersion or effective diffusion. Lam and Jacquet (1976) and Lick (1982) reported a range of values for effective diffusion in lake environments from 10^3 to 10^6 cm^2/s (0.1 to 100 m^2/s). A sensitivity analysis on this parameter was conducted for the range of 0.1 to 10 m^2/s (Table 5.3).

Table 5.3: Sensitivity results for effective diffusion coefficient.

Parameter	Parameter value	Peak outlet TSS concentration (mg/L)	%change from control
Effective diffusion coefficient (m^2/s)	0.1	48	-48%
	0.5	82	-10%
	1	**92**	**0%**
	5	102	11%
	10	104	13%

The sensitivity analysis revealed the following trends:

- Increasing the clay fraction entering the pond increases outlet TSS concentrations
- Reducing the settling velocity causes more particles to remain in suspension, thus increasing the outlet TSS concentrations
- Decreasing the effective diffusion coefficient reduces the peak outlet TSS concentrations and reduces the slope of the outlet pollutograph tail

Based on these results, a settling velocity representing a typical clay particle (~2 µm) was selected for the simulations. Monitoring data showed that over 50% of the effluent particle sizes were less than 3.73 µm (clay). Since the modelling study is concerned with the effluent TSS concentrations and loads, it is these small, non-settling clay particles that are of most interest.

Three events were examined for calibration and validation purposes. Total rainfall for the October 22, 2005 event (24 mm) most closely matched the rainfall depth used in the design of the pond (25 mm). Hence, this event was used for all subsequent simulations. For all three storms, the observed outlet concentration, clay fraction percentage and diffusion coefficient increased with event size. However, each individual event required a slightly different set of calibration parameters. This was attributed to, among other factors, differences in antecedent water levels, depth of sediment accumulation (and solids re-suspension), antecedent suspended solids concentrations, wind-induced turbulence and changes in the extent of exposed soils in the catchment.

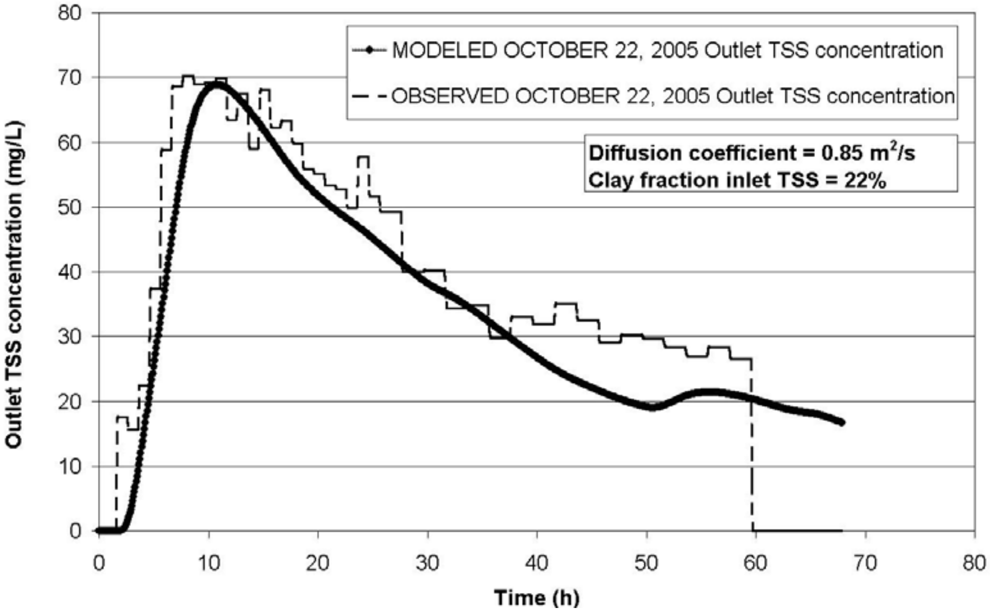


Figure 5.4: Calibration of the model for diffusion coefficient and clay fraction of inlet TSS for the October 22, 2005 event.

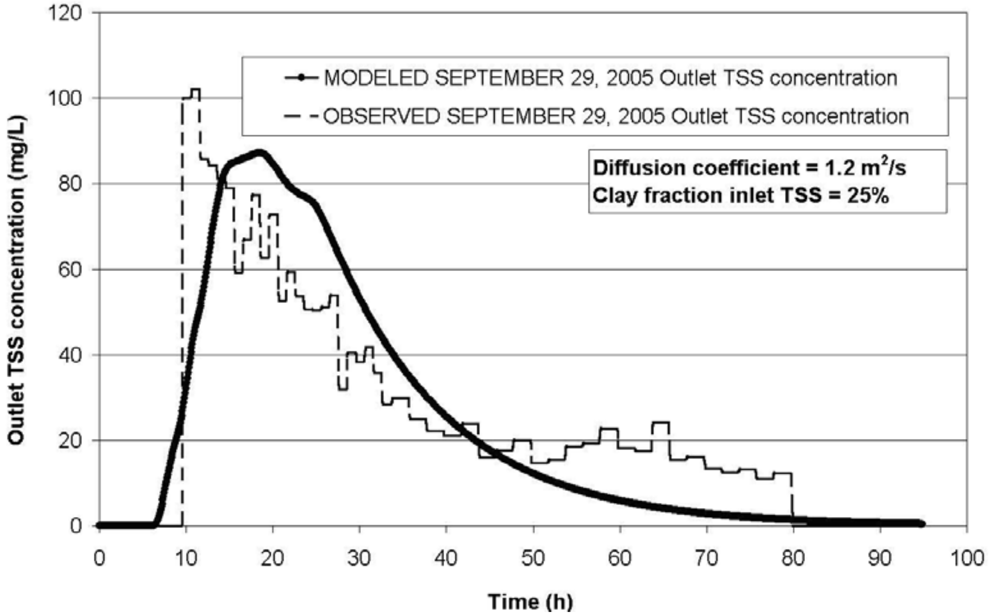


Figure 5.5: Calibration of the model for diffusion coefficient and clay fraction of inlet TSS for the September 29th, 2005 event.

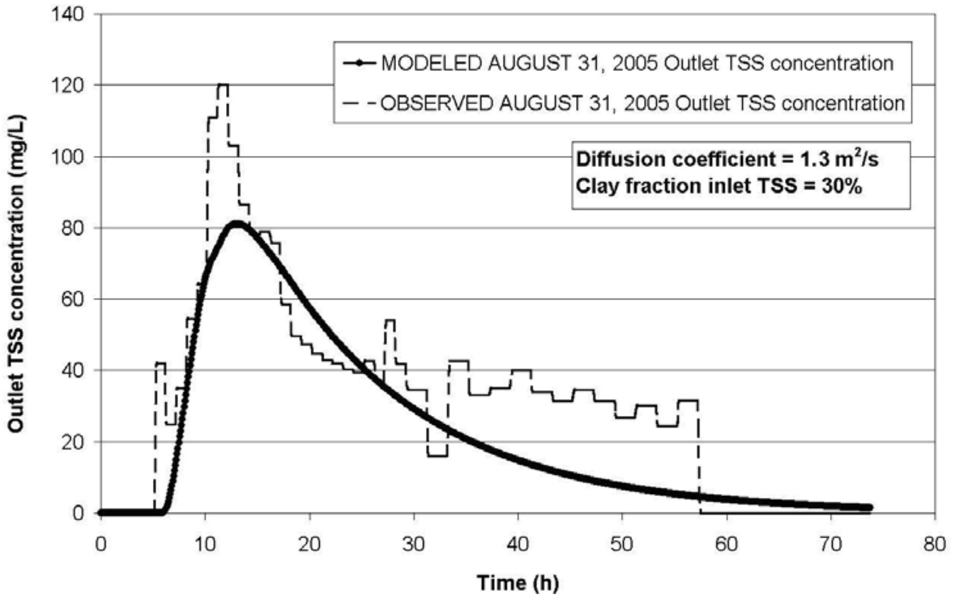


Figure 5.6: Calibration of the model for diffusion coefficient and clay fraction of inlet TSS for the August 31st, 2005 event.

5.5 'What If' Scenarios

Ten scenarios were developed to examine the influence of length-to-width ratio, number of berms, permanent pool storage, drawdown time and outlet location on pond performance. The results of each scenario were compared to the tenth scenario; the base case, or existing pond model. Table 5.4 summarizes the scenarios and the identifier by which they are referred to in subsequent graphs. The individual scenarios are described in the following sections. The base case is highlighted in bold.

Table 5.4: Scenario description summary.

Scenario identifier	L:W ratio	Number of berms	Drawdown time (hr)	Permanent pool storage (m^3/ha)	Outlet location
LW8:1 - B1 - D168 - P125 - O1	8:1	1	168	127	Existing
LW8:1 - B2 - D72 - P125 - O2	8:1	2	72	127	New
LW8:1 - B2 - D72 - P125 - O1	8:1	2	72	127	Existing
LW8:1 - B1 - D72 - P125 - O1	**8:1**	**1**	**72**	**127**	**Existing**
LW8:1 - B1 - D72 - P125 - O2	8:1	1	72	127	New
LW8:1 - B0 - D72 - P125 - O1	8:1	0	72	127	Existing
LW5:1 - B1 - D72 - P125 - O1	5:1	1	72	127	Existing
LW4:1 - B1 - D72 - P125 - O1	4:1	1	72	127	Existing
LW3:1 - B1 - D72 - P125 - O1	3:1	1	72	127	Existing
LW8:1 - B1 - D72 - P254 - O1	8:1	1	72	254	Existing

5.5.1 L:W ratio

A major design parameter of ponds is the geometry or shape, which is represented using a length to width ratio (L:W). The Ontario Ministry of Environment Stormwater Management Planning and Design Manual (OMOE 2003) suggest a minimum L:W of 4:1 to 5:1 for ultimate stormwater ponds, including the forebay. The interim guideline for temporary construction sediment ponds recommends a minimum L:W ratio of 3:1. The existing pond had an exceptionally long L:W ratio of 8:1.

The purpose of the L:W ratio simulations were to determine the effect that pond geometry plays in the performance of the pond. Four L:W ratio scenarios were simulated -- 3:1, 4:1, 5:1 and 8:1 (existing pond) (figures 5.7, 5.8, and 5.9). In each of these simulations, only the L:W ratio was varied; *i.e.,* the volume, depth and surface area were identical for all three scenarios.

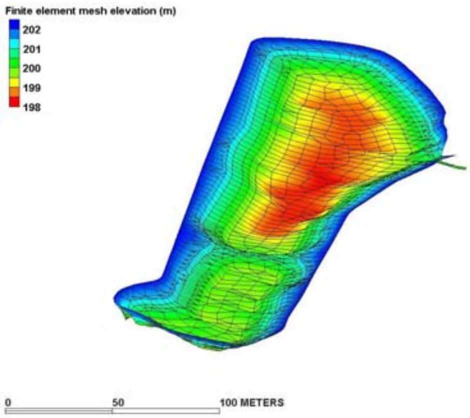


Figure 5.7: Finite element mesh for 3:1 L:W ratio.

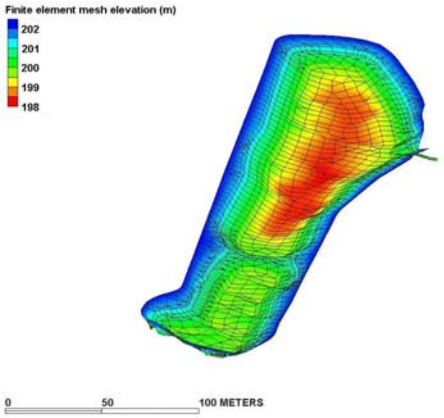


Figure 5.8: Finite element mesh for 4:1 L:W ratio

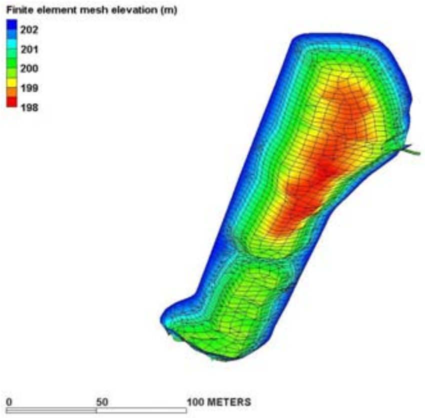


Figure 5.9: Finite element mesh for 5:1 L:W ratio.

5.5.2 Drawdown time

Extending the period over which water is discharged from the facility (*i.e.* the drawdown time) promotes settling by reducing flow velocities and providing better mixing of influent runoff with the permanent pool. A scenario was developed to evaluate the effect of drawdown on effluent quality.

5.5.3 Outlet location

Stormwater pond design guidelines indicate that the distance between the inlet and outlet be maximized. The outlet of the Greensborough pond was located at roughly 70% of the pond length to accommodate connection with the Little Rouge Creek. In order to identify the impact of outlet location, the finite element mesh was altered so that the existing outlet was removed and a new outlet was constructed at the far end of the pond (Figure 5.10).

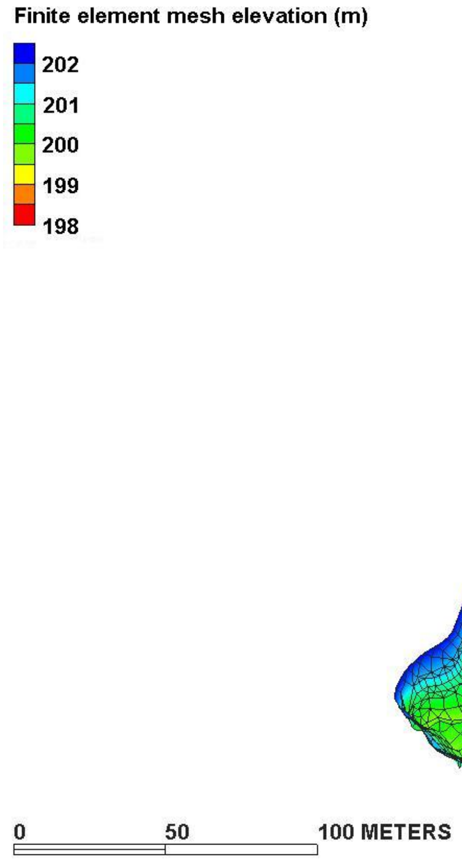


Figure 5.10: Finite element mesh for relocated outlet.

5.5.4 Forebay berms

Stormwater ponds, especially those involved in sediment control, are often designed with a sediment forebay, used to trap larger sediment particles. A berm typically separates the forebay area from the rest of the pond. The influence of berms is examined in three scenarios; no berms (Figure 5.11), 1 berm (existing), and two berms (5.12).

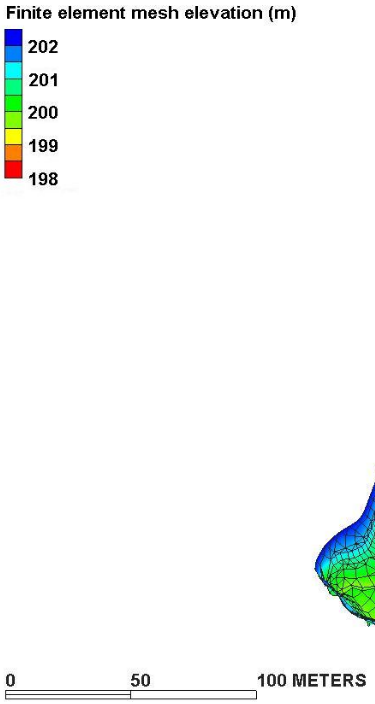


Figure 5.11: Finite element mesh for no berm scenario.

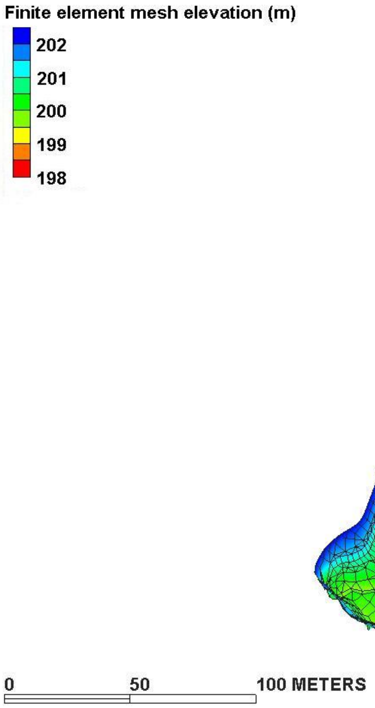


Figure 5.12: Finite element mesh for 2 berm scenario.

5.5.5 Permanent pool

The permanent pool scenario involved doubling the size of the permanent pool from 127 m^3/ha to 254 m^3/ha. Since this is a 2D model that is relatively insensitive to changes in depth, the increase in permanent pool volume was simulated by increasing the surface area but maintaining depths the same as the base case. The length-to-width ratio was not affected by this change.

5.6 Simulation results

A summary of simulation results is presented in Table 5.5. Scenarios are arranged in ascending order of effluent event mean concentrations and loads. The base case scenario (*i.e.* the existing pond) is highlighted in bold.

All simulations are based on the October 22nd event rainfall amount and distribution. This particular event had significant rainfall (24 mm) but it was distributed over three days. The majority of rain (18 mm) fell during the first 12 hours. The following sections provide a discussion of each scenario.

Table 5.5: Summary of scenarios and results

Scenario identifier	L:W ratio	Number of berms	Drawdown time (hrs)	Permanent pool storage (m^3/ha)	Outlet location	TSS load in (kg)	TSS load out (kg)	Removal efficiency (%)	Peak outlet TSS concentration (mg/L)	Peak outlet load (kg/h)	EMC (mg/L)
LW8:1 - B1 - D168 - P127 - O1	8:1	1	168	127	Existing	2,588	93	96.4	34.6	1.9	18.3
LW8:1 - B1 - D72 - P254 - O1	8:1	1	72	254	Existing	2,588	229	91.2	43.3	6.9	30.7
LW8:1 - B2 - D72 - P127 - O2	8:1	2	72	127	New	2,588	255	90.1	50.9	8.0	34.2
LW8:1 - B2 - D72 - P127 - O1	8:1	2	72	127	Existing	2,588	279	89.2	58.8	9.5	37.3
LW8:1 - B1 - D72 - P127 **- O1**	**8:1**	**1**	**72**	**127**	**Existing**	**2,588**	**299**	**88.5**	**68.8**	**11.2**	**39.9**
LW8:1 - B1 - D72 - P127 - O2	8:1	1	72	127	New	2,588	300	88.4	70.1	11.3	40.1
LW8:1 - B0 - D72 - P127 - O1	8:1	0	72	127	Existing	2,588	333	87.1	77.5	12.7	44.6
LW5:1 - B1 - D72 - P127 - O1	5:1	1	72	127	Existing	2,588	347	86.6	98.0	16.1	46.4
LW4:1 - B1 - D72 - P127 - O1	4:1	1	72	127	Existing	2,588	373	85.6	111.3	18.2	50.0
LW3:1 - B1 - D72 - P127 - O1	3:1	1	72	127	Existing	2,588	405	84.4	128.1	20.8	53.9

5.6.1 L:W ratio

Pond geometry has a significant effect on effluent TSS concentrations and loads. As the L:W ratio decreased from 8:1 to 3:1, effluent EMC and total loads increased from 40 to 54 mg/L and 299 to 405 kg, respectively (Table 5.5 and Figure 5.13).

This result is generally consistent with the finding in section 4.6 that, for similar sized events, the Ballymore pond (L:W ratio of 2:1) had considerably higher effluent TSS concentrations than the Greensborough pond (L:W ratio of 8:1) (see section 4.6). As the L:W ratio was the primary physical difference between the ponds, this design element was likely an important factor in observed differences in pond performance.

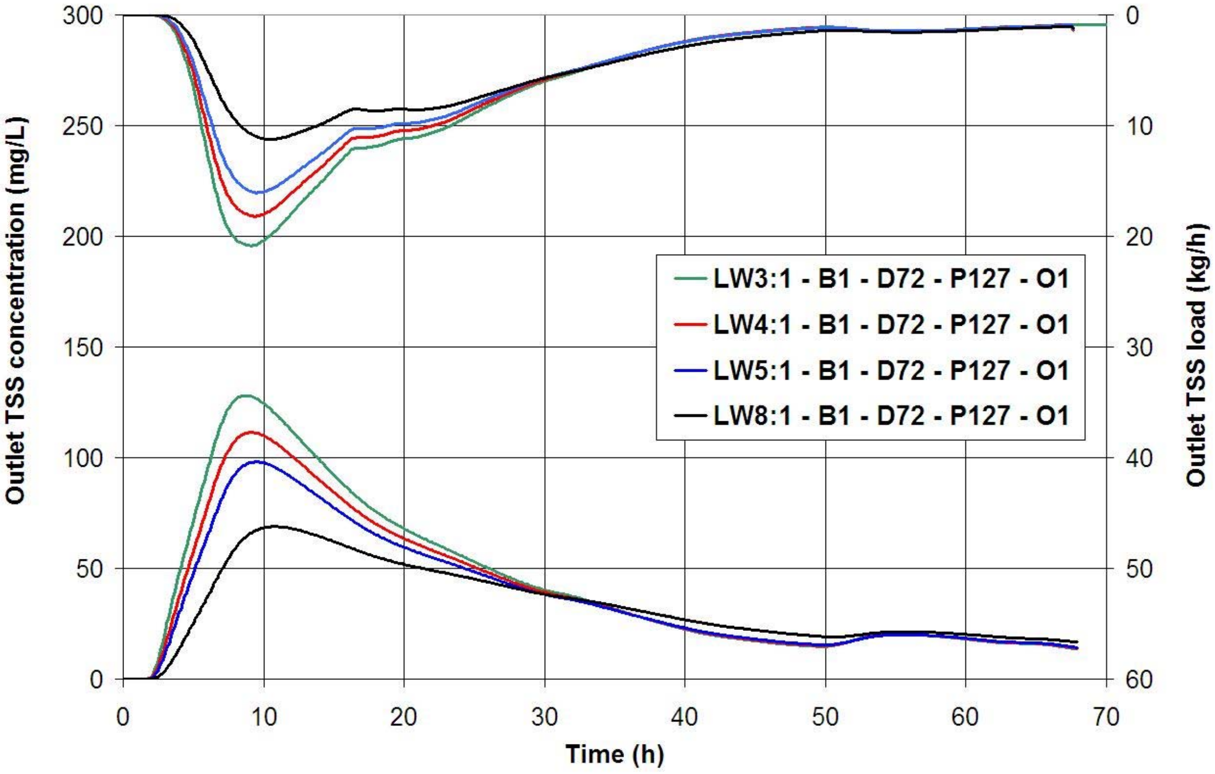


Figure 5.13: Effect of L: W ratio on outlet TSS concentration and load.

5.6.2 Drawdown time

Current stormwater pond guidelines suggest a permanent pool storage of 125 m^3/ha of drainage area to enhance settling of suspended solids. The amount of mixing of permanent pool volume and influent runoff is influenced by the time over which runoff is drained from the facility (i.e. the drawdown time). The drawdown time also influences flow velocities, which can have an important effect on settling and re-suspension of previously trapped solids.

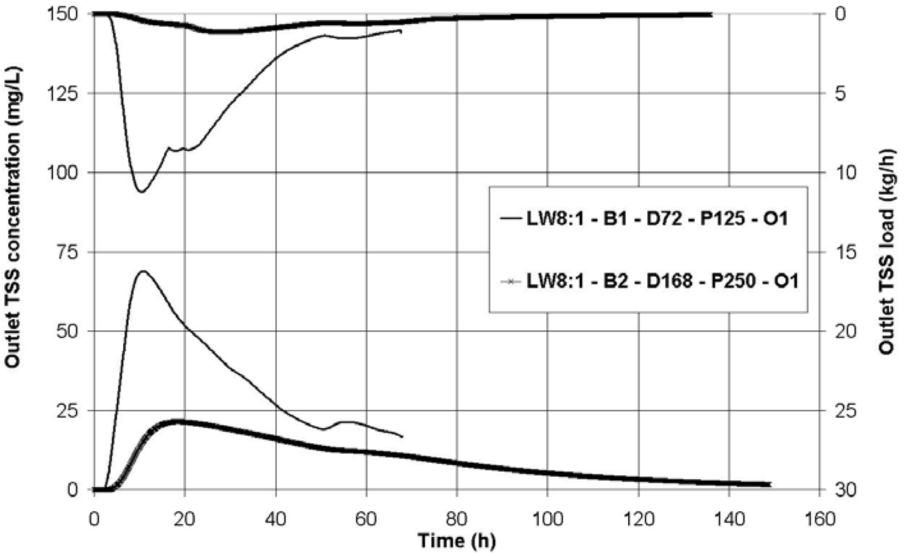


Figure 5.14: Effect of drawdown time on outlet TSS concentration and load.

Increasing drawdown times from 72 hours to 168 hours resulted in a dramatic reduction in effluent TSS peak concentrations and loads, as well as in effluent EMCs and loads. Similarly, reducing drawdown below 72 hours would likely have an adverse effect on effluent quality. Unfortunately drawdown times greater than 48 hours are not feasible for most developments because of the requirement that the outlet structure orifice be no smaller than 75 mm. The 168 hour drawdown scenario was included merely to illustrate the effects of drawdown on pond performance (Figure 5.14).

5.6.3 Outlet location

Relocating the outlet to the far end of the pond had a negligible effect on pond performance, save for lagging the outlet hydrograph slightly. Flow trace diagrams for the existing pond scenario and the relocated outlet scenario indicated that a short circuiting effect was evident when the outlet was located at the far end of the pond. To counter this, a second berm was added to the pond in order to increase mixing, resulting in the highest pond performance of all scenarios (not counting the 168 hour drawdown scenario, which was modelled to illustrate the effects of drawdown only) (Figure 5.15).

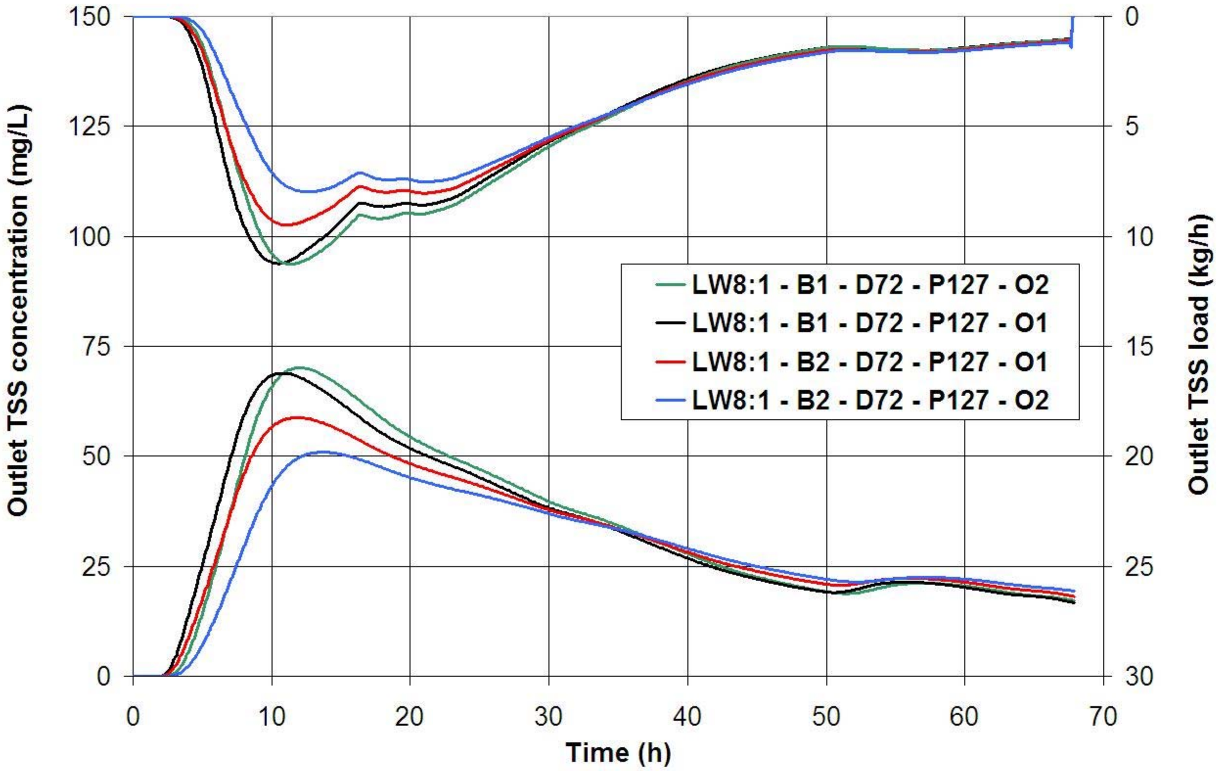


Figure 5.15: Effect of outlet location on outlet TSS concentration and load.

5.6.4 Submerged berms

Removal of the forebay berm increased effluent TSS concentrations and loads. The effluent TSS concentrations are strongly influenced by the presence (or absence) of berms. It appears that by promoting circulation in the areas between the berms, suspended sediment has more time to mix before reaching the outlet (Figure 5.16).

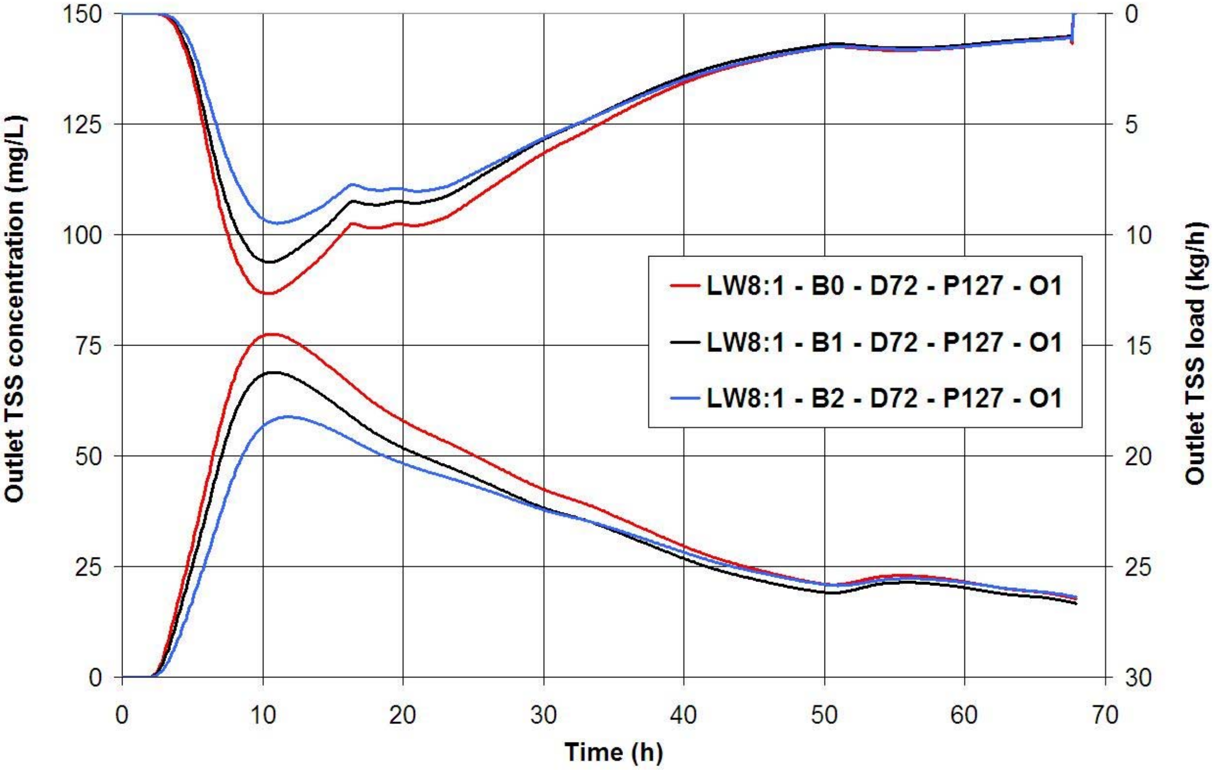


Figure 5.16: Effect of berms on outlet TSS concentration and load.

5.6.5 Permanent pool volume

Doubling of the permanent pool volume from 127 m^3/ha to 254 m^3/ha resulted in a 23% decrease in the effluent event mean concentration and load, and a 37% reduction in the peak effluent concentration. Clearly, storage volume is among the most important design parameters affecting overall pond performance, especially when the volume increase results in a much larger surface area. Adding volume by making the pond deeper was shown to produce only minor improvements in performance.

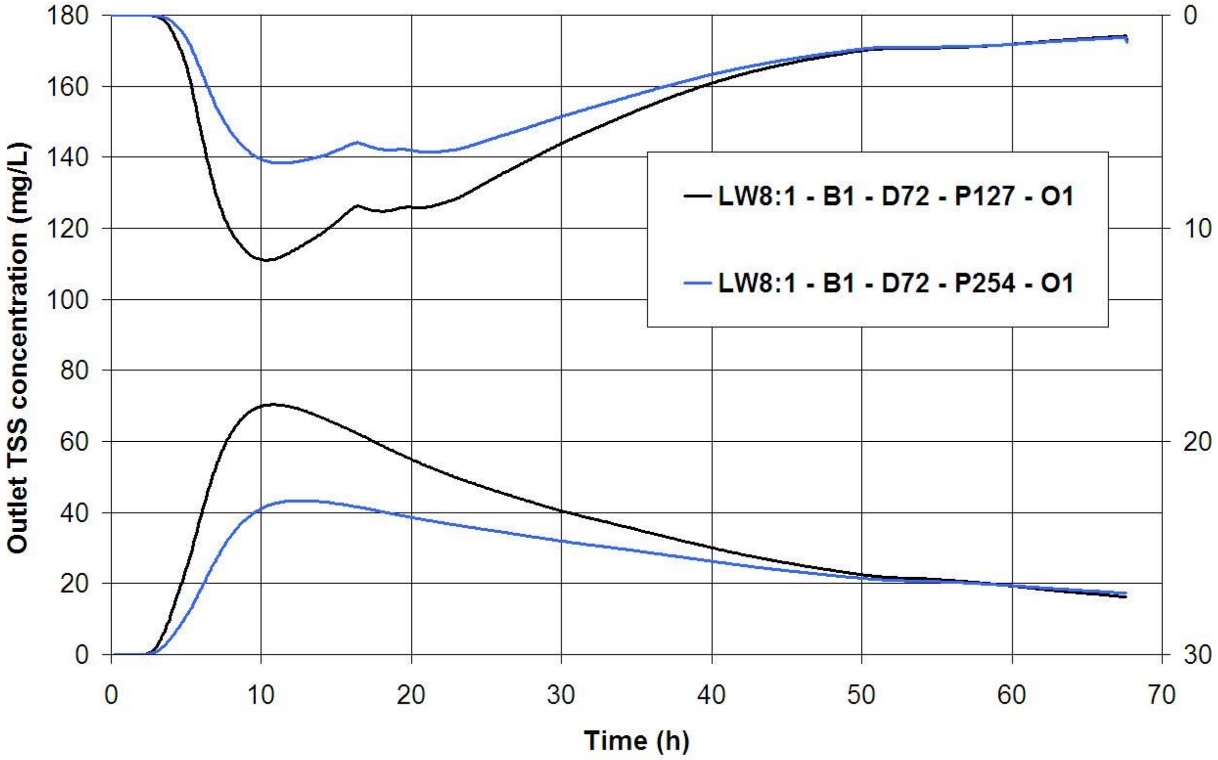


Figure 5.17: Effect of an increase in permanent pool volume (*i.e.* increase in surface area) on outlet TSS concentration and load.

5.7 Model limitations

Like any modelling exercise that attempts to simulate complex environmental processes, this one too has its limitations. Most of these relate to simplifications introduced either because the scope of work needed to be contained within manageable limits, or because sufficient data were not available for calibration. Detailed wind data, for instance, were not available at the site, and therefore, although the model is capable of simulating wind-driven circulation, this input parameter could not be included.

In terms of scope, the modelling was done in two rather than three dimensions, requiring that vertical effects be depth averaged. This decision limited the model's capacity to estimate vertical effects and mixing in the pond. Pond simulations using complex 3-D models are generally not recommended unless detailed turbulent flow velocity and in-pond water quality data are available (Dr. A. McCorquodale, pers. comm.). The model also only considers fine particles; *i.e.*, the clay fraction that remains in suspension, rather than the larger grain sizes. Using this approach, the accumulation and scour of larger grain size sediment from the pond bed could not be simulated. Settling caused by flocculation of particles within the pond is also not explicitly considered by the model. The same is true for sediment re-suspension processes. Simulation of re-suspension would require in-pond monitoring data at the sediment-water interface, which were not available.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Although sediment control measures have been required at construction sites in Ontario for almost two decades, receiving waters continue to suffer from elevated discharges of sediment (Greenland, 2001). This study evaluates design criteria for sediment control ponds as one step towards addressing this deficiency. The evaluation consists of two components: (i) a two year monitoring study of a construction sediment pond designed to current standards; and (ii) development of a hydrodynamic model, calibrated to field monitoring data, and run for various alternative particle size and pond design scenarios. Revisions to the existing design guideline for construction sediment ponds are recommended based on results of this study.

Key conclusions for each of the study components are as follows:

6.1 Pond Monitoring

Monitoring results indicate that construction sediment ponds result in significant water quality improvements, but even with high sediment capture rates, effluent quality from ponds does not meet levels required for the protection of downstream aquatic communities.

6.1.1 Water Quantity

Between June, 2004 and December, 2005, over 60 storm events were monitored, ranging in size between 0.5 to 38 mm. The mean runoff coefficient for the pond drainage area was 0.26, with lower values during the early period of development, and higher values as the catchment was built out.

The pond provided good flow control. Peak flows were reduced by an average of 83% and storm volumes were drained slowly over a period of 72 hours or more. Detention times, based on bulk fluid centroid analysis, averaged 16.2 hours.

Initially, the study was to examine impacts of the pond on receiving waters (Little Rouge River). However, flow monitoring indicated that receiving water impacts would be difficult to detect because outlet volumes represented only a small proportion (approx. 7%) of total flow in the Little Rouge River. Thus, the monitoring study objectives were limited to a detailed assessment of pond performance only.

6.1.2 Water Quality

Total suspended solids (TSS) was the primary water quality variable of interest both because sediment loads from construction sites are typically elevated and other pollutants of concern readily bind to suspended solids. In general, receiving water suspended solids concentrations of less than 25 mg/L provide a high level of protection to aquatic ecosystems (*e.g.* USEPA, 1973, EIFAC, 1965; Newcombe and MacDonald, 1991).

At the Greensborough pond, the average volume weighted event mean effluent TSS concentration (n=21) was 55.1 mg/L, ranging during individual events from 13 to 93 mg/L. Pollutograph analysis showed peak effluent TSS concentrations as high as 246 mg/L for discretely sampled events. By comparison, the average volume weighted influent event mean concentration was 3,362 mg/L (n=21), with short term peaks of up to 19,900 mg/L. On a load basis, 99% of incoming sediment was trapped inside the pond.

A receiving water impact analysis of effluent concentrations and durations showed that, assuming no dilution in the stream, most events would have a ‘moderate impact’ on downstream aquatic biota. If the duration of exposure is ignored and the risk assessment is based solely on effluent event mean concentrations, only one event falls within the ‘moderate risk’ category (80 to 400 mg/L), while 12 events are ranked as ‘low risk’ (25 – 80 mg/L) and 8 are in the ‘very low risk’ category (<25 mg/L).

Regression analysis showed that effluent quality is influenced more by flow volumes and peak outflow rates than by influent concentrations, influent loads and peak inflow rates. From a management perspective, these analyses suggest that: (i) upstream sediment control practices, such as construction phasing or infiltration techniques, that reduce flow volumes will lead to greater improvements in effluent quality than would practices that reduce influent TSS concentrations only; (ii) limiting outflow rates by extending pond drawdown times will improve effluent quality; and (iii) design features that minimize re-suspension of previously trapped sediments (*e.g.* submerged berms) will improve overall pond performance.

Particle size analysis indicated that over 50% of the suspended particles entering the pond fell within the clay size fraction (< 4 um). Despite the very fine influent particle size distribution, the facility was successful in further reducing the size of suspended particles from a median size of 3.8 to 2.0 at the inlet and outlet, respectively.

A general analysis of influent, effluent and receiving water quality was undertaken to characterize the quality of construction site runoff. The results showed that, although construction site runoff contains high levels of suspended solids and phosphorus from eroded soils, it generally contains fewer metals, oils, chlorides and other pollutants than are typically found in stormwater runoff from stabilized urban sites. A comparison to guidelines showed that, despite significant removal of pollutants by the facility, effluent concentrations of copper, total phosphorus and *E.coli* most often exceeded provincial receiving water objectives.

Results from the Greensborough pond were compared to monitoring results from another construction sediment control pond monitored in the community of Ballymore, Richmond Hill. The Ballymore pond had a larger permanent pool than the Greensborough pond (154 vs 127 m^3/ha), but shorter drawdown time (48 vs. 72 hours) and a much smaller length-to-width ratio (2:1 vs. 8:1). Results showed significantly higher effluent event and peak TSS concentrations at Ballymore. Effluent concentrations from 7 of 16 events monitored at Ballymore were considered to present a moderate or high risk to receiving waters (assuming no dilution), compared to only 1 of 21 events monitored at Greensborough. This analysis shows that pond drawdown times and length-to-width ratios have a significant influence on the quality of effluent discharged from construction sediment ponds.

At the Greensborough site, TSS concentrations in the receiving water system upstream and downstream of the pond discharge location were consistently elevated above levels observed in pond effluent runoff. Pond discharges appeared to have little influence on receiving water sediment levels, in part because, as indicated earlier, the volume of water discharged from the pond represents only a small fraction of stream flow volumes.

6.2 Hydrodynamic Model

Modelling was undertaken to assist in evaluating pond design guidelines for sizing and effluent water quality control. The following conclusions are based on results of the modelling study:

- Length to width ratio is among the most important design parameters. Reducing the length-to-width ratio from 8:1 (existing) to 3:1 resulted in 35% increase in the effluent suspended solids EMC and load.

- Submerged berms and forebays prevent short circuiting and enhance mixing. Scenario simulations showed that the addition of a second berm to the pond reduced the effluent EMC by 7% while removal of all berms increased the effluent EMC by 11%. At least two berms or other options that help improve hydraulic efficiencies, such as perforated curtains or baffles, should be provided in all temporary sediment control ponds.

- Maximizing the distance between the pond inlet and outlet improves pond performance and should be considered to be a high priority criterion in selection of the pond inlet and outlet locations. Relocating the pond outlet from its current location near the end of the pond to the very end of the pond resulted in a 9% reduction in effluent EMC when implemented with the 2 berm scenario.

- Model simulations and monitoring data indicated that drawdown time was an important design parameter. Providing drawdown over a minimum of 48 hours, with preferred drawdown up to 72 hours, is recommended to provide enough time for complete mixing of runoff with the permanent pool. Drawdown times longer than 72 hours are not recommended because rain events in Ontario occur, on average, every 72 hours during the growing season.

- Doubling the permanent pool volume reduced the effluent suspended solids EMC and load by 23%. Unfortunately, increasing the size of the pond can also result in much higher costs. Therefore, an increase in permanent pool volume (while maintaining existing permanent pool depths) is only recommended when the specified drawdown time and/or length-to-width ratio can not be met.

6.3 Recommended Design Criteria for Construction Sediment Control Ponds

The target effluent event mean concentration for temporary sediment control ponds is 25 mg/L. Fisheries research has shown that suspended solids at or below this level will not harm downstream aquatic life or habitat. While ultimate (enhanced level) stormwater ponds typically achieve average event mean TSS concentrations of at least 25 mg/L (SWAMP, 2005; Strecker *et. al*., 2004; CWP, 2000), temporary sediment control ponds do not. This holds true even if the pond design exceeds existing criteria for sediment control ponds. The following recommendations on pond design and maintenance will help improve sediment capture. It should be recognized, however, that even if all of these recommendations are put into effect, meeting the effluent suspended solids target of 25 mg/L will also require significantly improved management of sediment runoff upstream of the pond.

Table 6.1 compares the interim construction sediment pond guidelines to those recommended based on the results of the study. The main changes are: (i) an increase in the minimum length to width ratio from 3:1 to 4:1 ; (ii) the requirement for two submerged berms or permeable curtains dividing the pond into 3 roughly equal sized segments (iii) an increase in the minimum drawdown time from 24 to 48 hours, (iv) cleanout when the forebay (rather than pond) fills to 50% of its permanent pool depth; and (iv) a 25% increase in the surface area if one or more of the previous three criteria can not be met. All other aspects of the former pond guideline relating to minimum orifice size at the outlet, spillways, bank slopes, operational issues, etc. should remain the same.

Table 6.1: Comparison of the current and recommended erosion and sediment control guideline for ponds.

Design or Maintenance Feature	**Current Guideline (TRCA, 1994)**	**Recommended Guideline**
Permanent Pool Volume (m^3/ha)	125	50% increase if either drawdown or length-to-width criteria can not be achieved
Extended Detention Volume (m^3/ha)	125	125
Drawdown Time (hours) (25 mm, 4 hr storm)	min 24	min 48 (72 preferred)
Length-to-Width Ratio	at least 3:1 (4:1 or 5:1 preferred)	at least 4:1 (5:1 or greater preferred)
Forebay/berm	none specified	two submerged berms
Clean out frequency	when accumulated sediment reaches 50% of *pond* design capacity	when accumulated sediment reaches 50% of *forebay* design capacity

Regarding sediment controls upstream of the pond, results of this study showed that practices which reduce flow volumes and TSS loads will likely be of greater benefit than practices which reduce TSS concentrations only. Phasing of development, such that only a portion of the total drainage area is stripped and built-out at any one time, is arguably the most effective way of achieving this flow volume reduction. Other site practices that encourage infiltration of runoff or minimize disturbance would also be beneficial. Filtration practices that reduce concentrations but not runoff volumes (*e.g.* silt fences) are the least effective because fine particles often bypass these practices. These practices do, however, keep sediment out of the pond, which helps prevent the need for costly dredging, and reduces re-suspension of previously trapped solids. Monitoring data suggest that re-suspension processes are probably an important, but often overlooked factor in overall pond performance.

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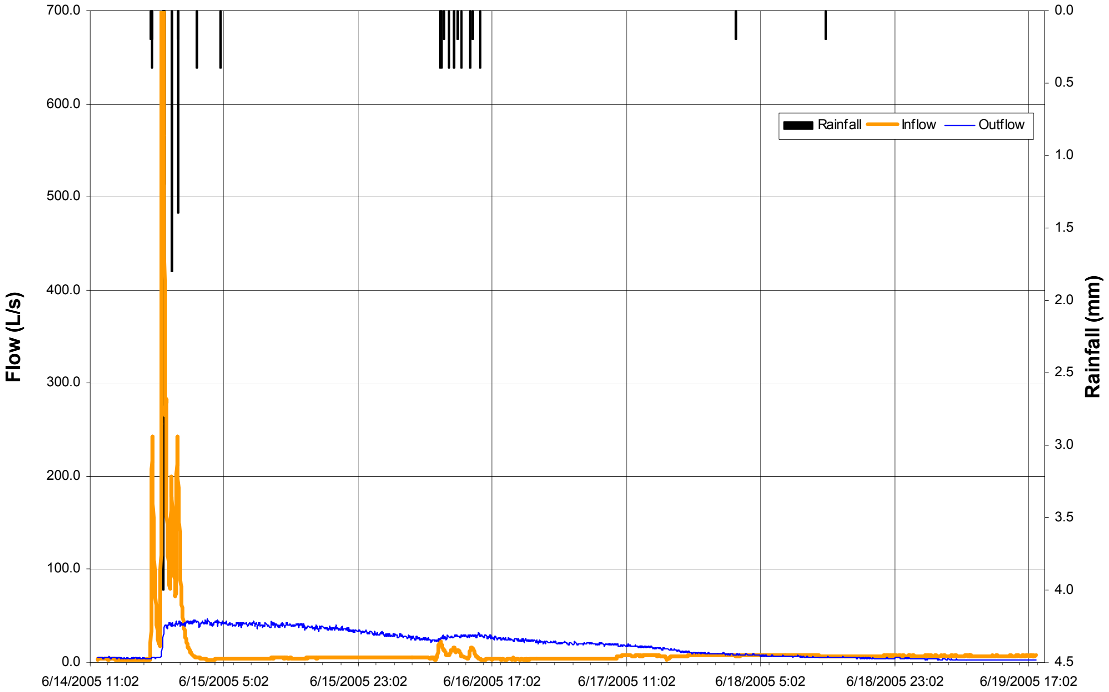
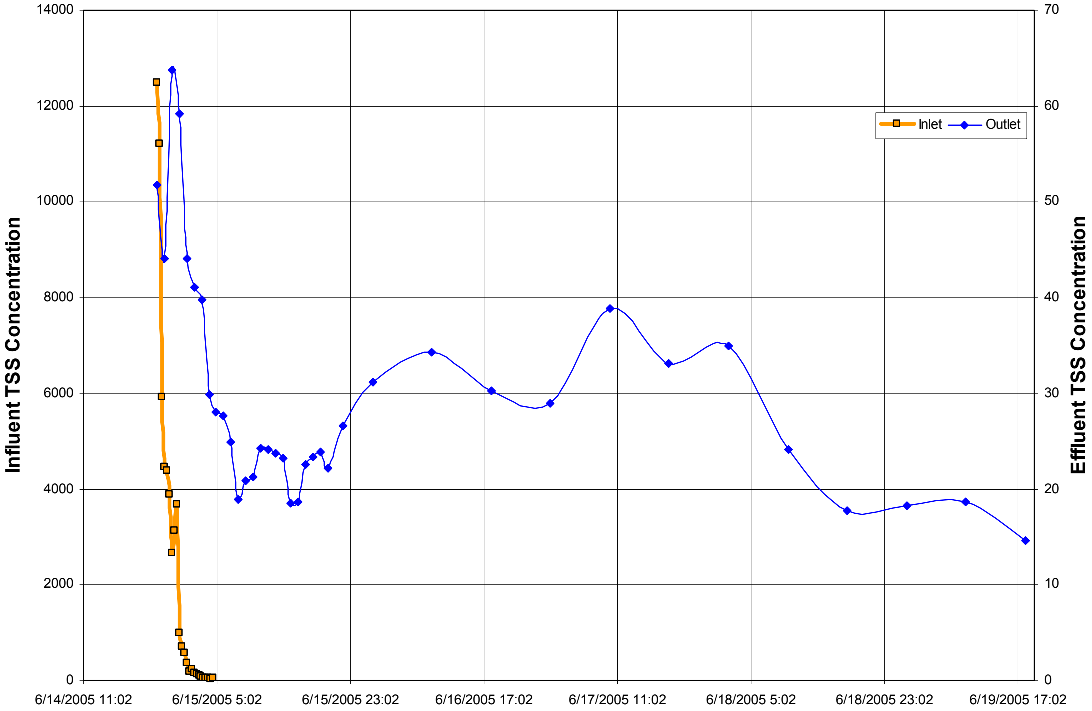
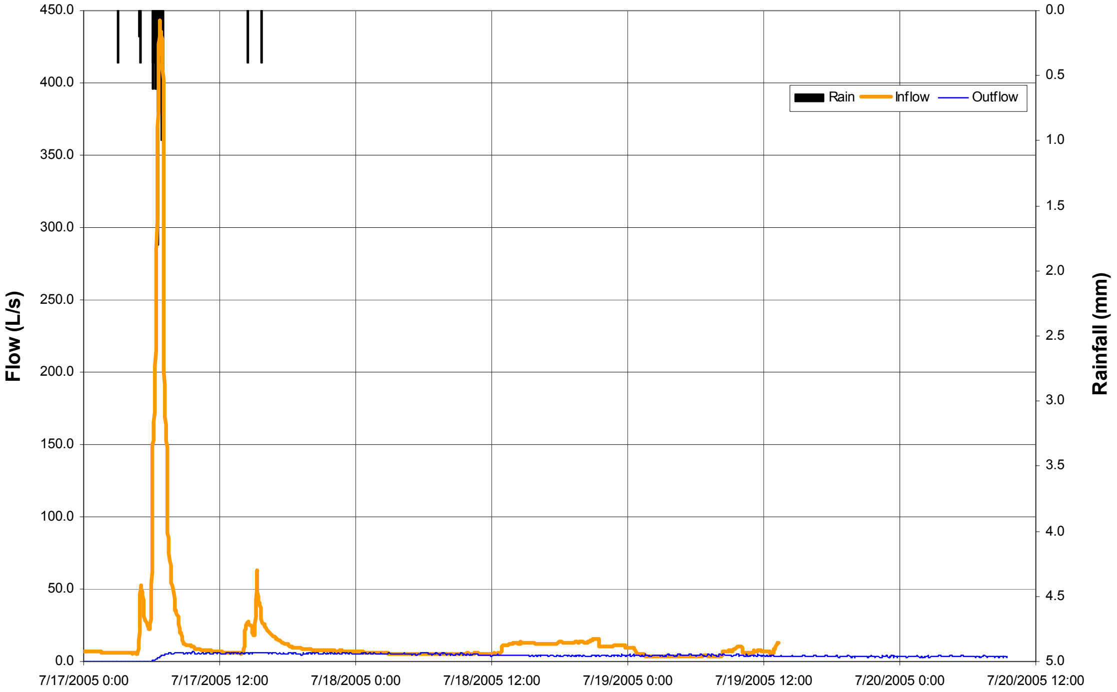
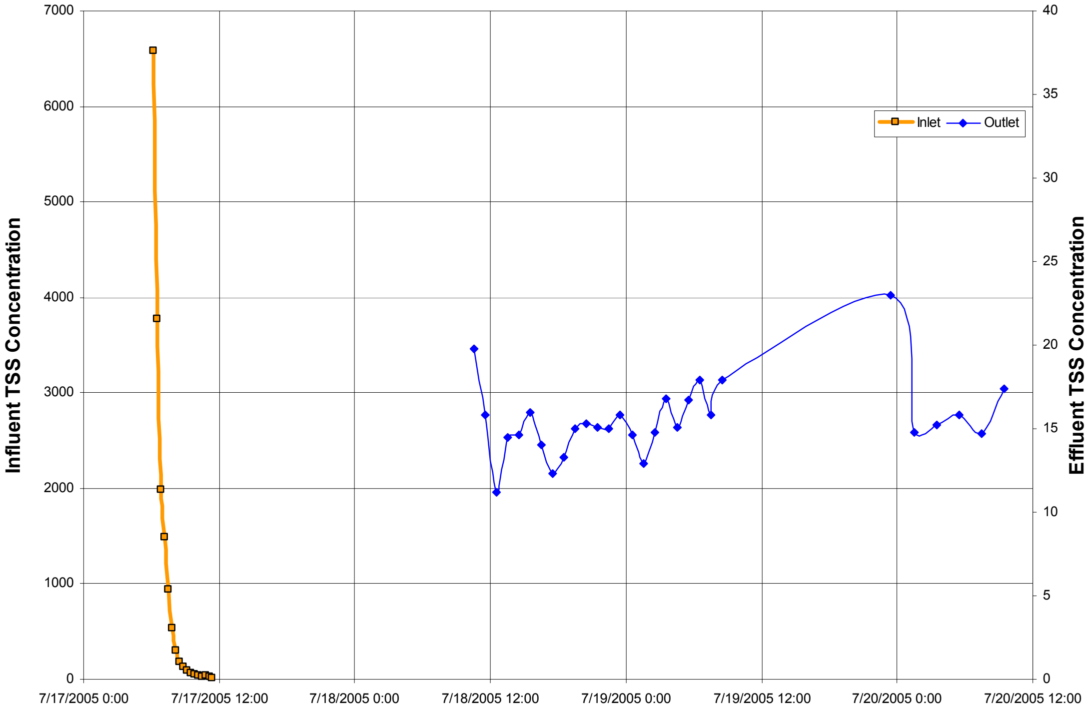
APPENDIX A

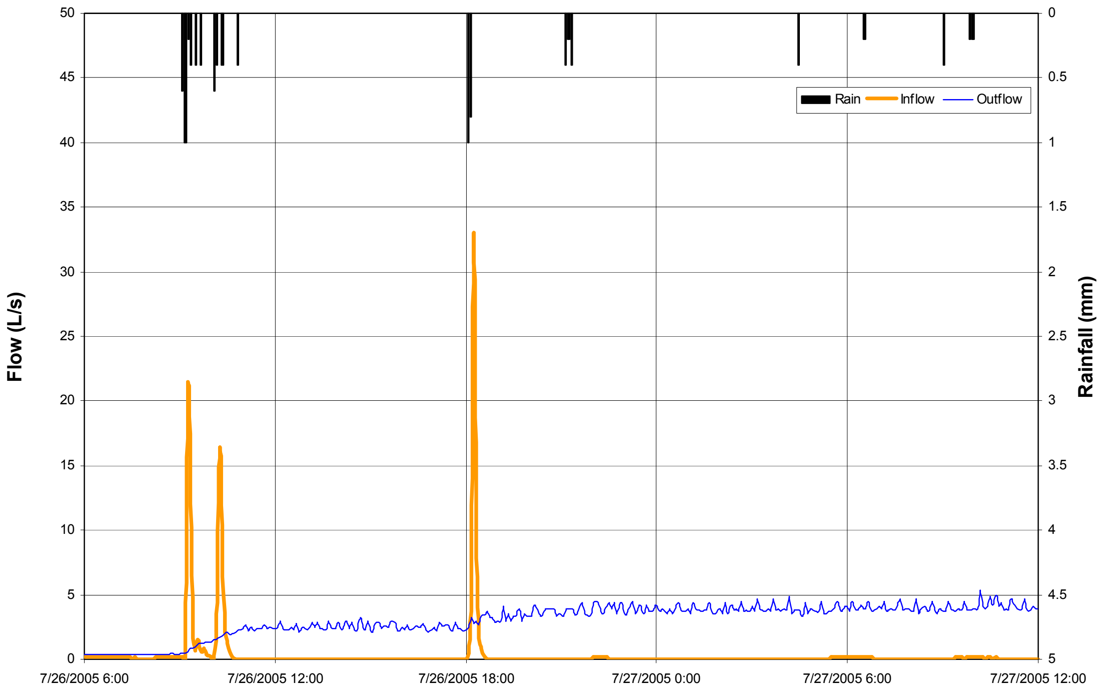
Hydrographs, Hyteographs and Pollutographs for Selected Event

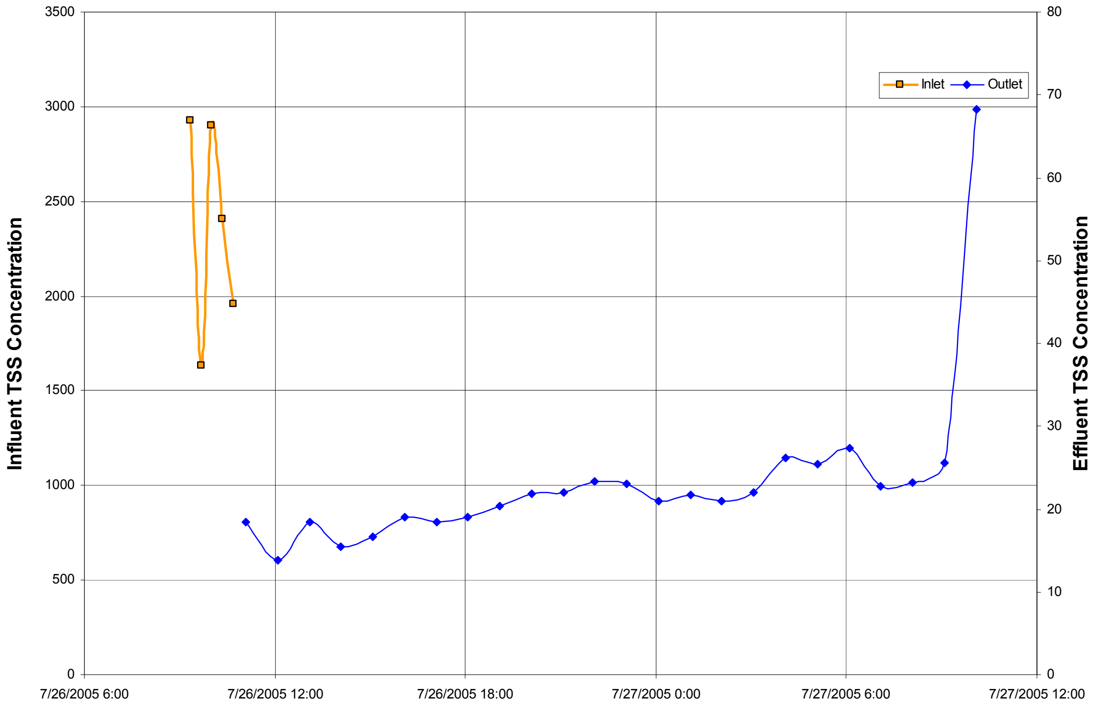

Flow (L/s)
Rainfall (mm)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Rainfall
Inflow
Outflow
6/14/2005 11:02
6/15/2005 5:02
6/15/2005 23:02
6/16/2005 17:02
6/17/2005 11:02
6/18/2005 5:02
6/18/2005 23:02
6/19/2005 17:02

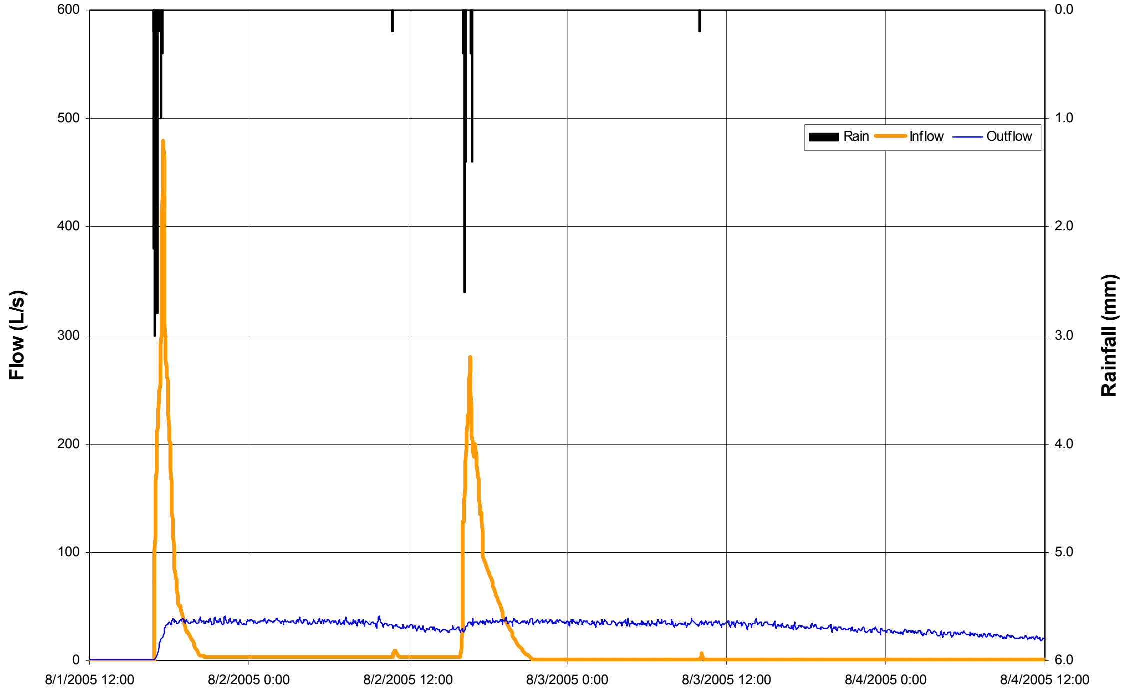

Influent TSS Concentration
Effluent TSS Concentration
14000
12000
10000
8000
6000
4000
2000
0
70
60
50
40
30
20
10
0
Inlet
Outlet
6/14/2005 11:02
6/15/2005 5:02
6/15/2005 23:02
6/16/2005 17:02
6/17/2005 11:02
6/18/2005 5:02
6/18/2005 23:02
6/19/2005 17:02

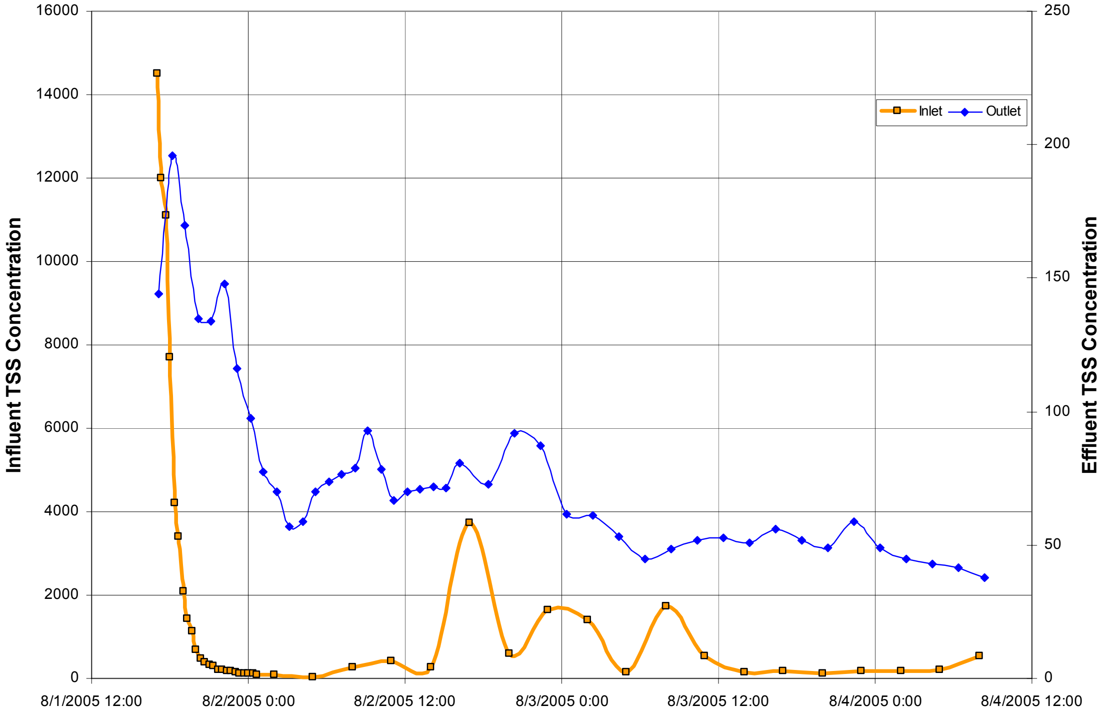

Flow (L/s)
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Rain
Inflow
Outflow
7/17/2005 0:00
7/17/2005 12:00
7/18/2005 0:00
7/18/2005 12:00
7/19/2005 0:00
7/19/2005 12:00
7/20/2005 0:00
7/20/2005 12:00

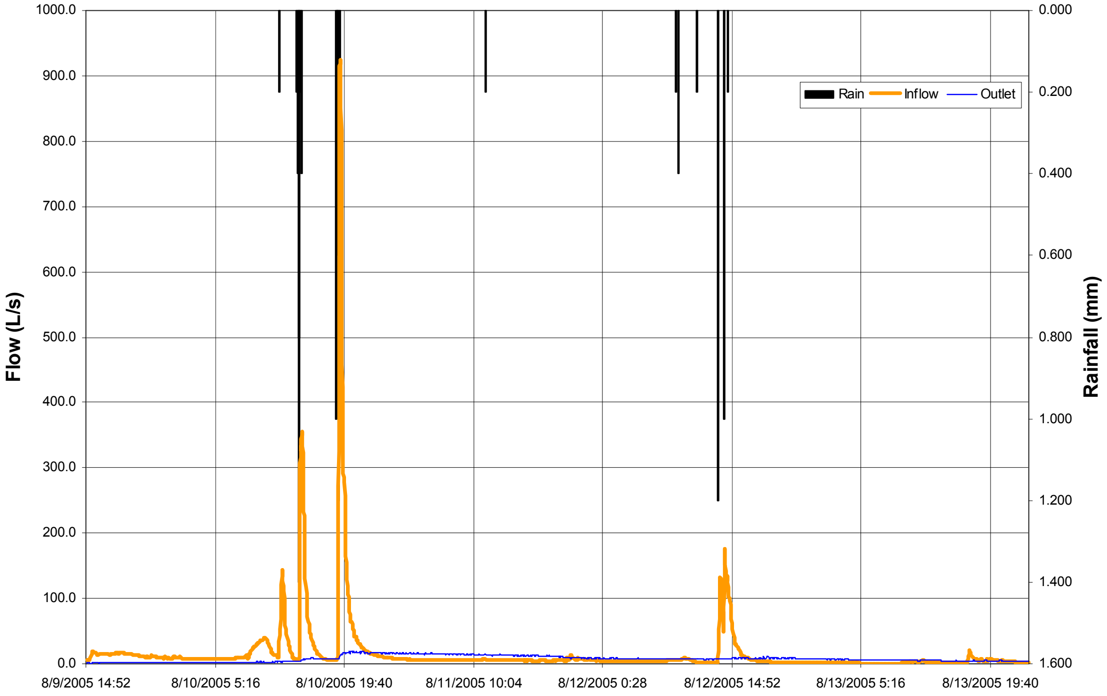

Influent TSS Concentration
7000
6000
5000
4000
3000
2000
1000
0
Effluent TSS Concentration
40
35
30
25
20
15
10
5
0
Inlet
Outlet
7/17/2005 0:00
7/17/2005 12:00
7/18/2005 0:00
7/18/2005 12:00
7/19/2005 0:00
7/19/2005 12:00
7/20/2005 0:00
7/20/2005 12:00

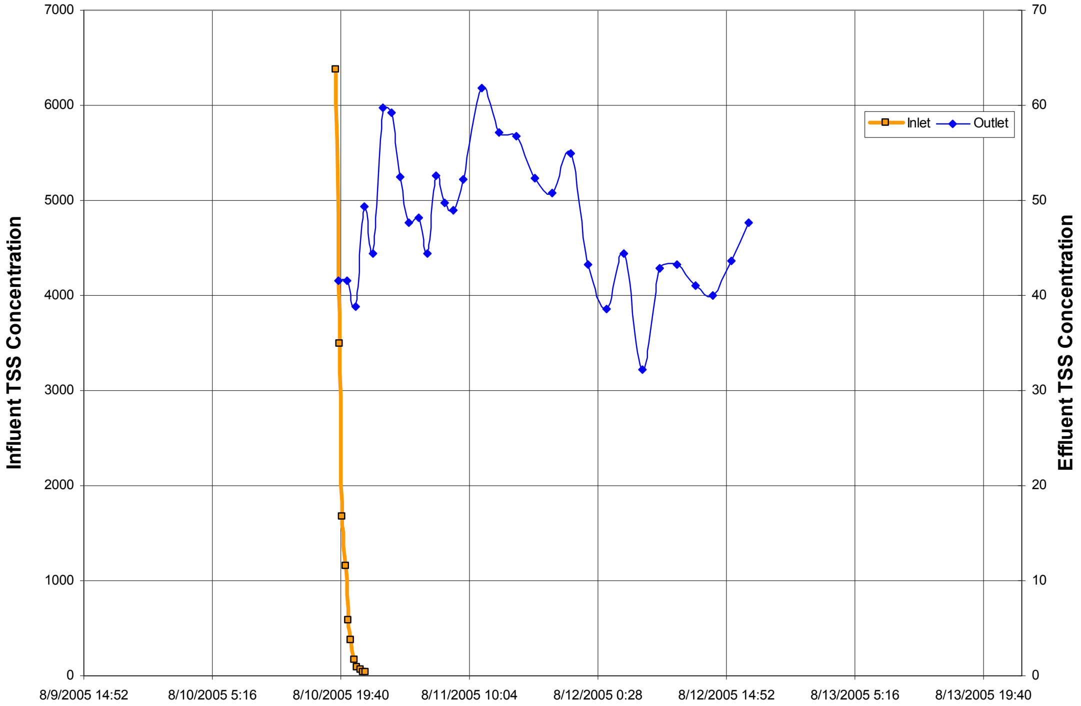

Flow (L/s)
Rainfall (mm)
Rain
Inflow
Outflow
50
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
7/26/2005 6:00
7/26/2005 12:00
7/26/2005 18:00
7/27/2005 0:00
7/27/2005 6:00
7/27/2005 12:00

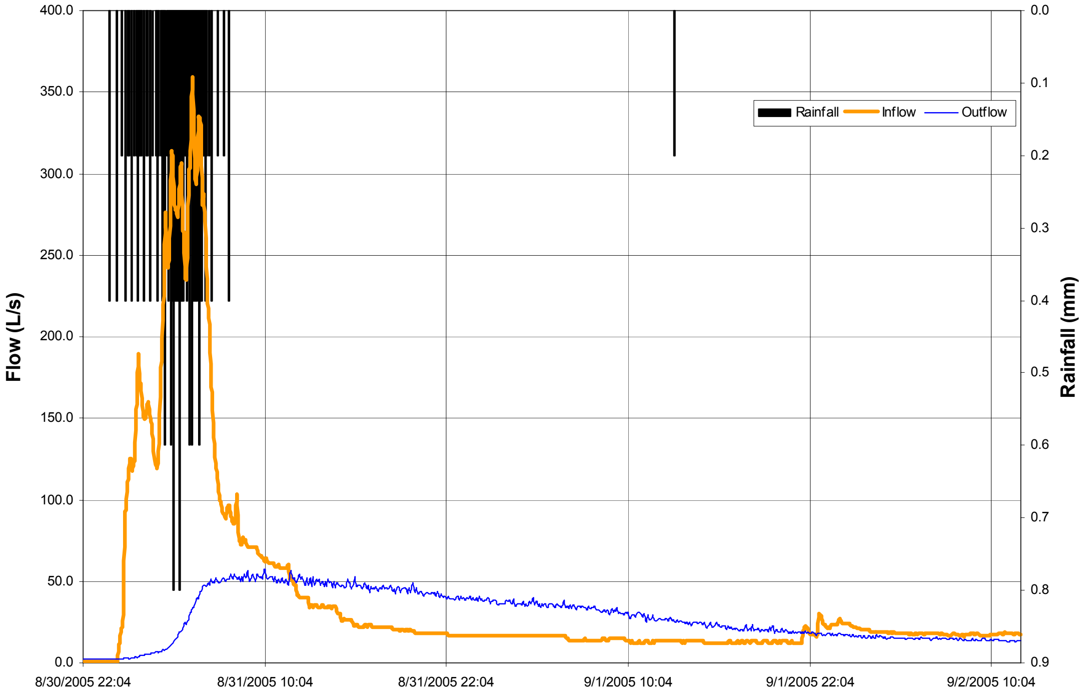

Influent TSS Concentration
Effluent TSS Concentration
Inlet
Outlet
3500
3000
2500
2000
1500
1000
500
0
80
70
60
50
40
30
20
10
0
7/26/2005 6:00
7/26/2005 12:00
7/26/2005 18:00
7/27/2005 0:00
7/27/2005 6:00
7/27/2005 12:00

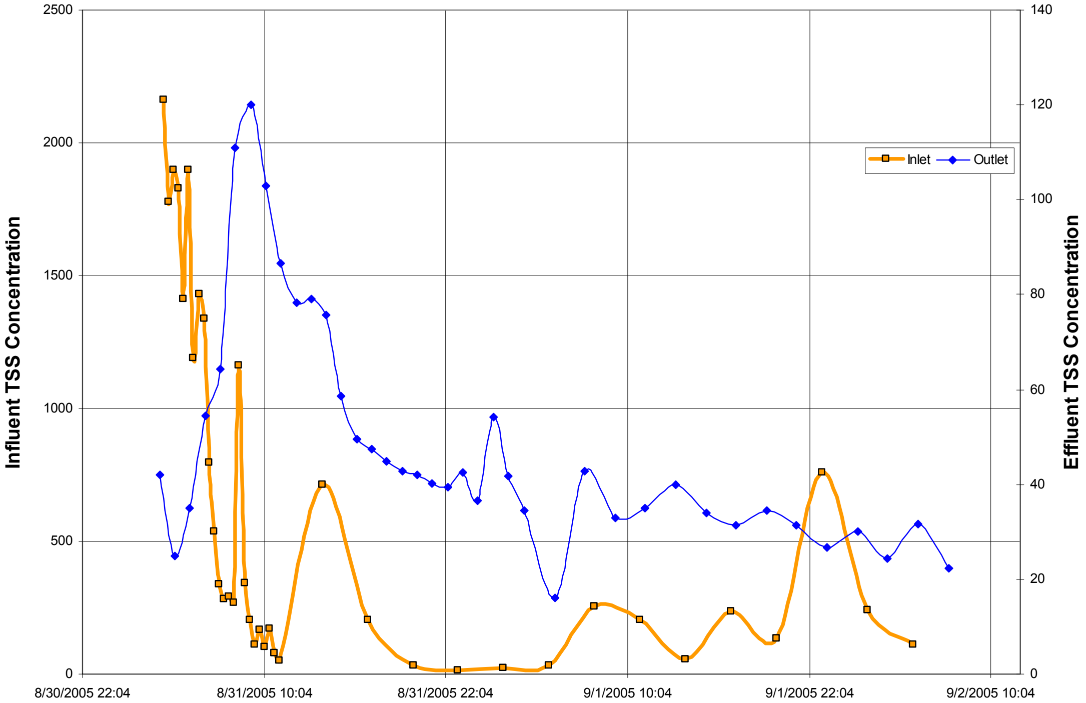

600
500
400
300
200
100
0
Flow (L/s)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
Rainfall (mm)
Rain
Inflow
Outflow
8/1/2005 12:00
8/2/2005 0:00
8/2/2005 12:00
8/3/2005 0:00
8/3/2005 12:00
8/4/2005 0:00
8/4/2005 12:00

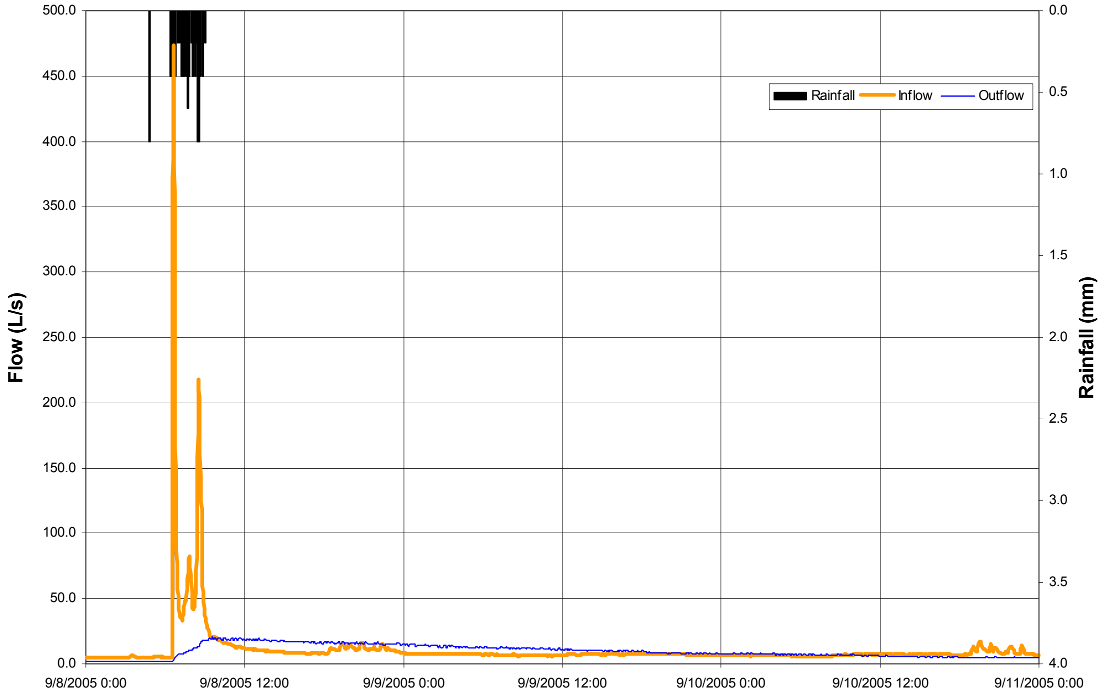

16000
14000
12000
10000
8000
6000
4000
2000
0
Influent TSS Concentration
250
200
150
100
50
0
Effluent TSS Concentration
Inlet
Outlet
8/1/2005 12:00
8/2/2005 0:00
8/2/2005 12:00
8/3/2005 0:00
8/3/2005 12:00
8/4/2005 0:00
8/4/2005 12:00

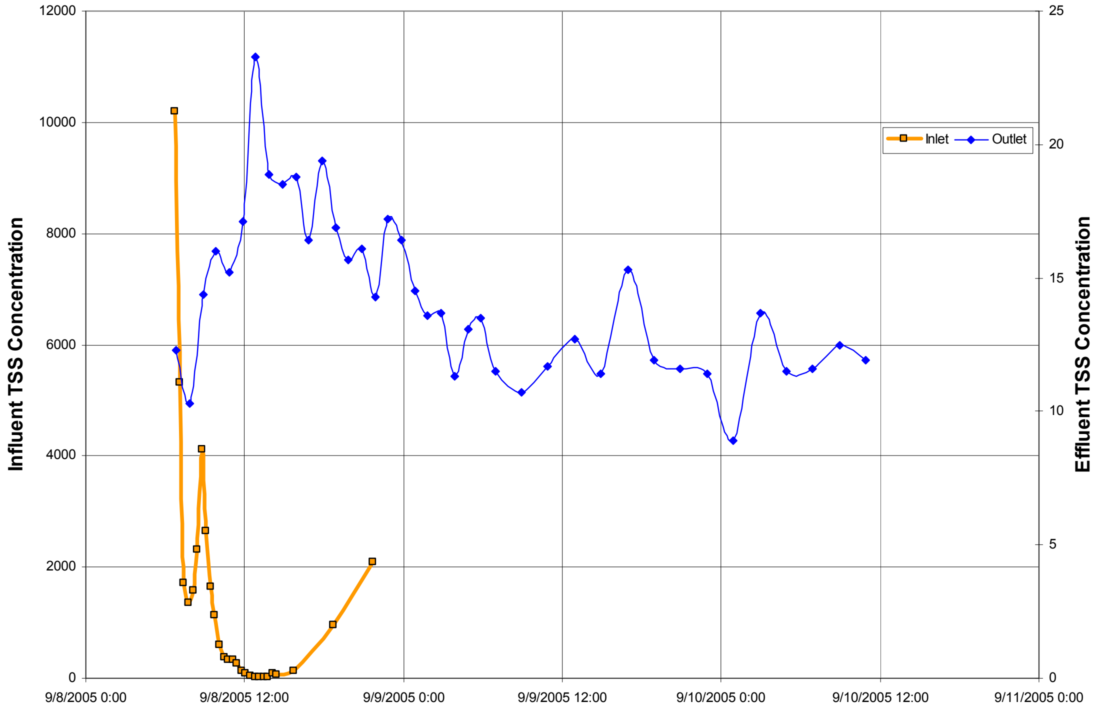

Flow (L/s)
Rainfall (mm)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
8/9/2005 14:52
8/10/2005 5:16
8/10/2005 19:40
8/11/2005 10:04
8/12/2005 0:28
8/12/2005 14:52
8/13/2005 5:16
8/13/2005 19:40
Rain
Inflow
Outlet

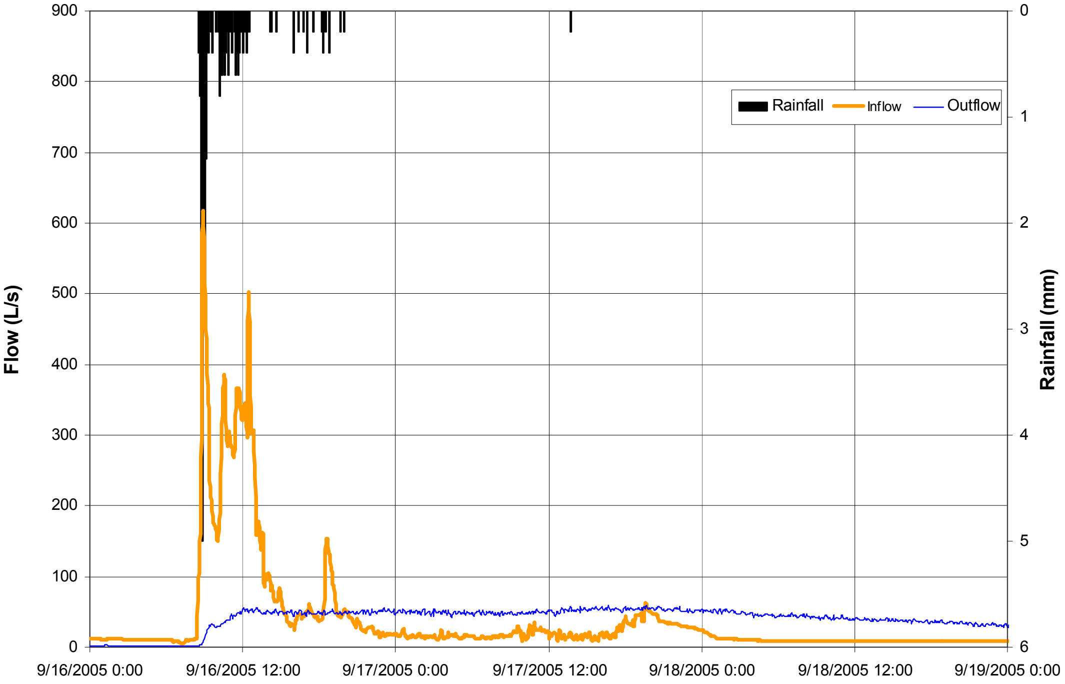

Influent TSS Concentration
Effluent TSS Concentration
7000
6000
5000
4000
3000
2000
1000
0
70
60
50
40
30
20
10
0
8/9/2005 14:52
8/10/2005 5:16
8/10/2005 19:40
8/11/2005 10:04
8/12/2005 0:28
8/12/2005 14:52
8/13/2005 5:16
8/13/2005 19:40
Inlet
Outlet


400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Flow (L/s)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Rainfall (mm)
Rainfall
Inflow
Outflow
8/30/2005 22:04
8/31/2005 10:04
8/31/2005 22:04
9/1/2005 10:04
9/1/2005 22:04
9/2/2005 10:04


2500
2000
1500
1000
500
0
Influent TSS Concentration
140
120
100
80
60
40
20
0
Effluent TSS Concentration
Inlet
Outlet
8/30/2005 22:04
8/31/2005 10:04
8/31/2005 22:04
9/1/2005 10:04
9/1/2005 22:04
9/2/2005 10:04


Flow (L/s)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Rainfall (mm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Rainfall
Inflow
Outflow
9/8/2005 0:00
9/8/2005 12:00
9/9/2005 0:00
9/9/2005 12:00
9/10/2005 0:00
9/10/2005 12:00
9/11/2005 0:00


Influent TSS Concentration
12000
10000
8000
6000
4000
2000
0
Effluent TSS Concentration
25
20
15
10
5
0
Inlet
Outlet
9/8/2005 0:00
9/8/2005 12:00
9/9/2005 0:00
9/9/2005 12:00
9/10/2005 0:00
9/10/2005 12:00
9/11/2005 0:00


900
800
700
600
500
400
300
200
100
0
Flow (L/s)
0
1
2
3
4
5
6
Rainfall (mm)
Rainfall
Inflow
Outflow
9/16/2005 0:00
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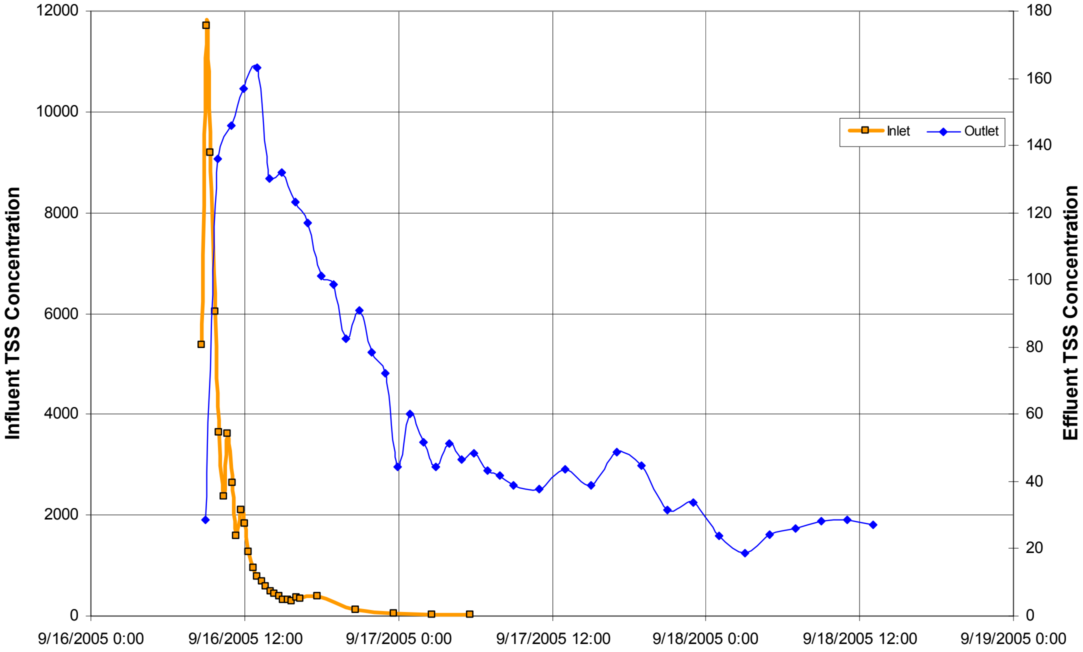
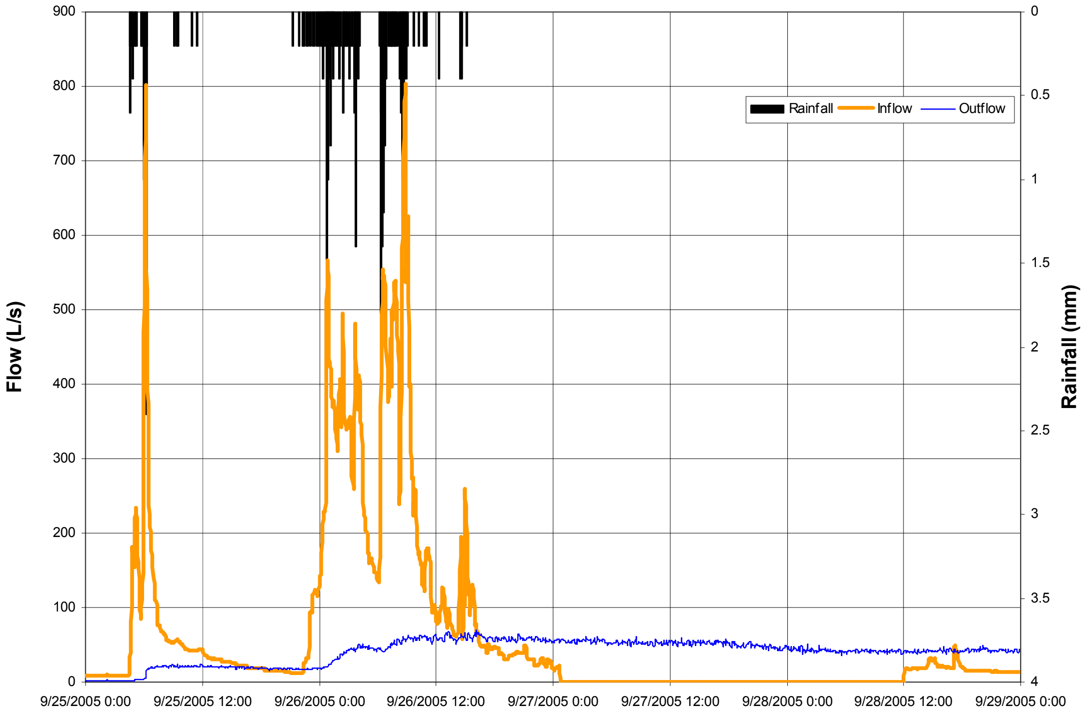
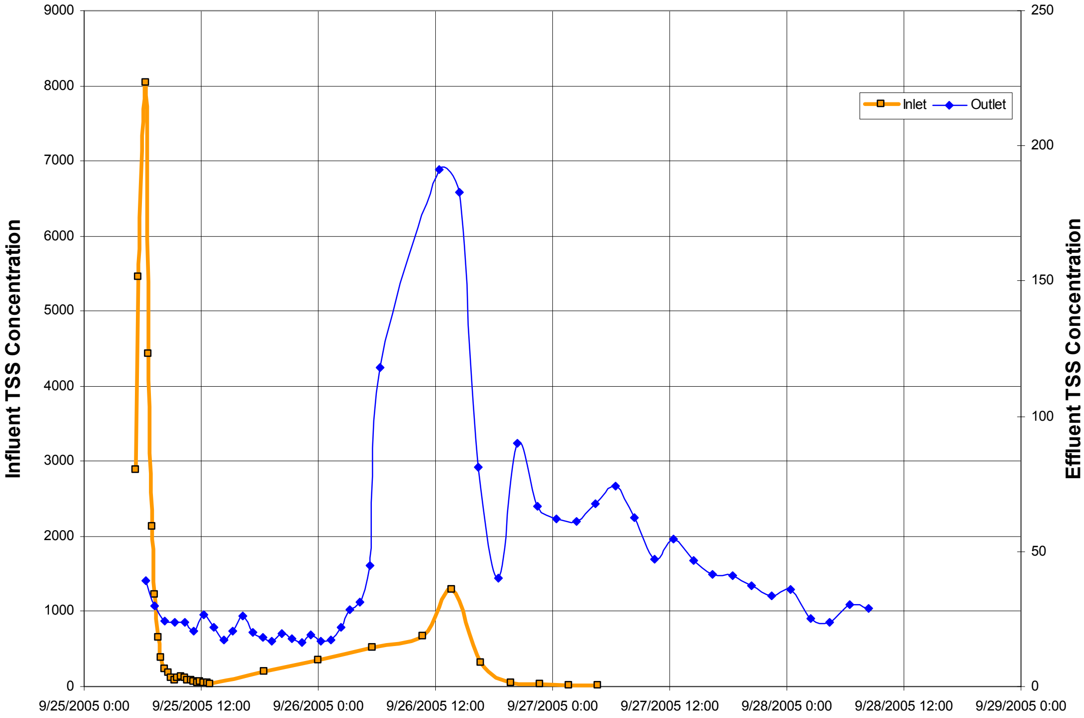
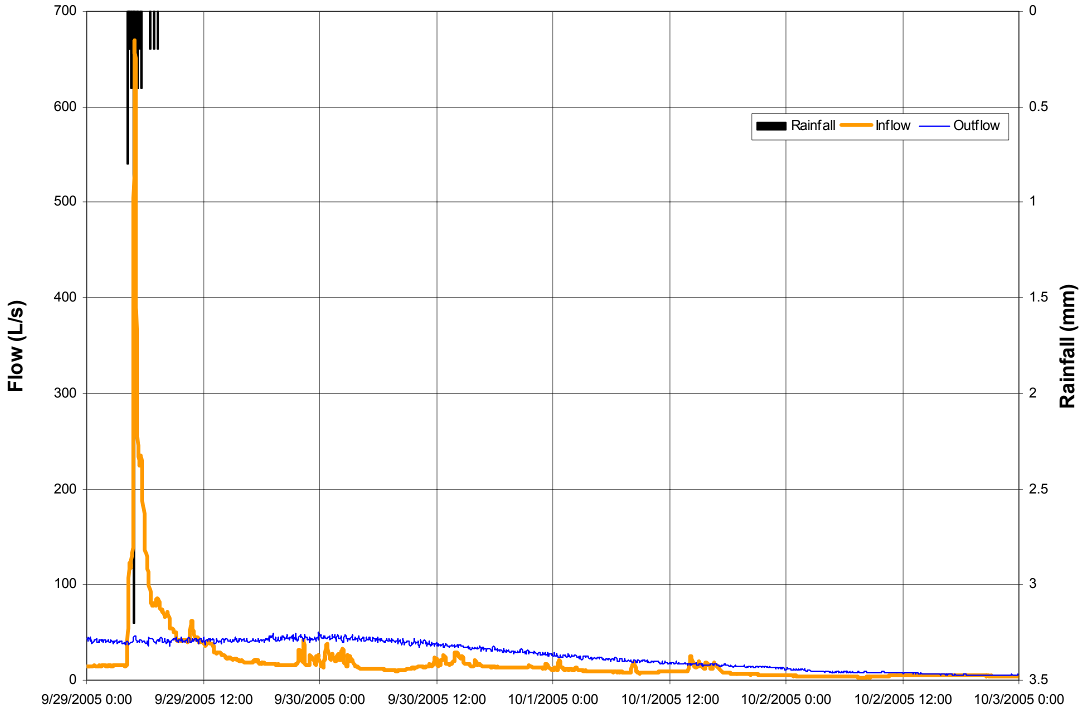
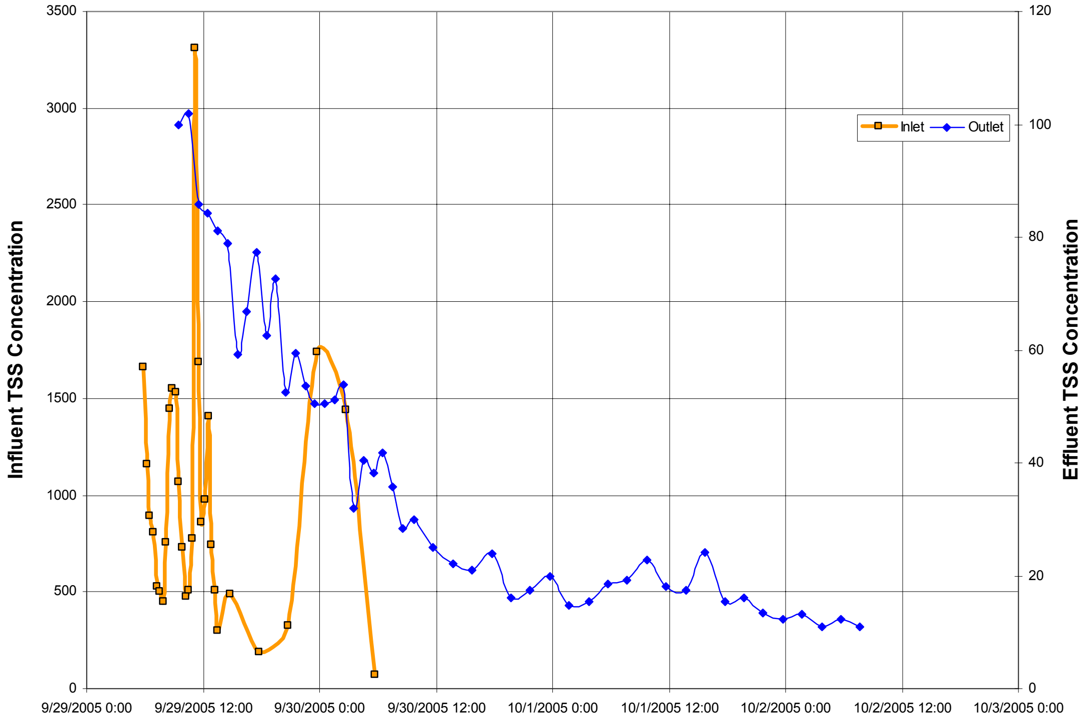
9/18/2005 12:00
9/19/2005 0:00

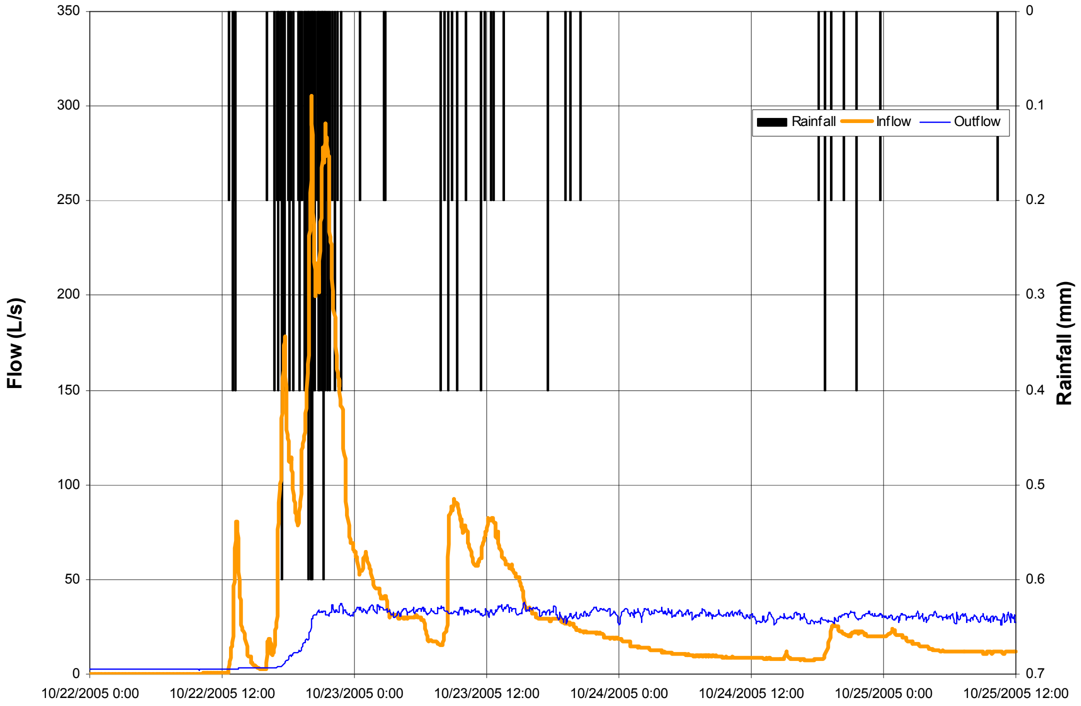

12000
10000
8000
6000
4000
2000
0
Influent TSS Concentration
180
160
140
120
100
80
60
40
20
0
Effluent TSS Concentration
Inlet
Outlet
9/16/2005 0:00
9/16/2005 12:00
9/17/2005 0:00
9/17/2005 12:00
9/18/2005 0:00
9/18/2005 12:00
9/19/2005 0:00

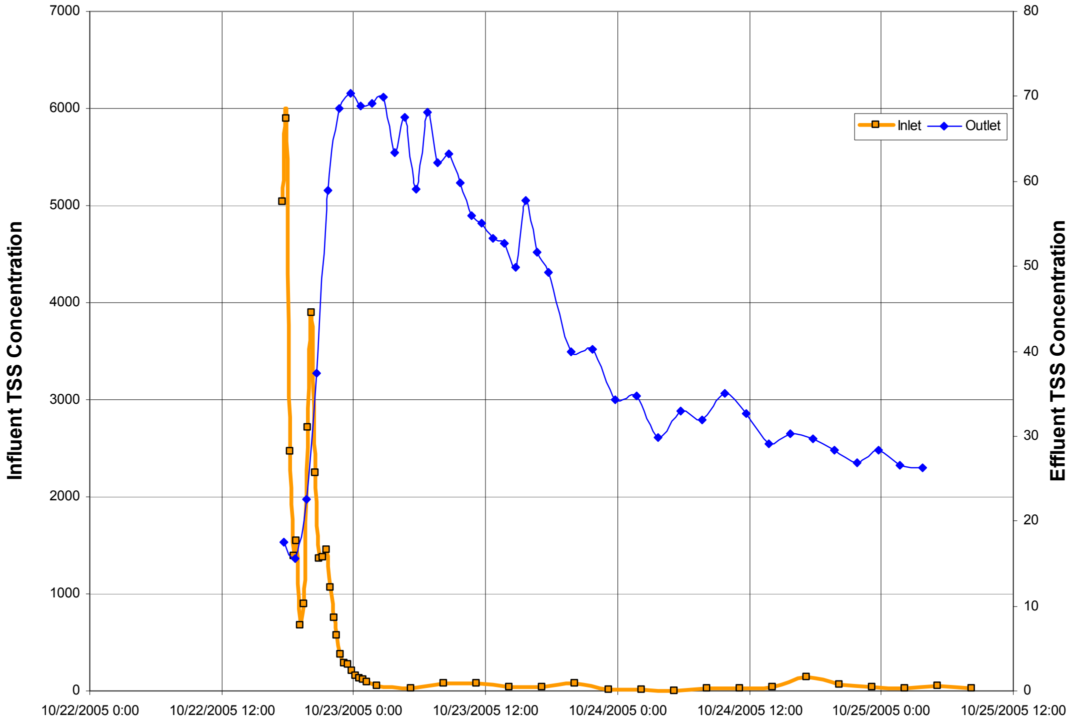

Flow (L/s)
Rainfall (mm)
Rainfall
Inflow
Outflow
900
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
9/25/2005 0:00
9/25/2005 12:00
9/26/2005 0:00
9/26/2005 12:00
9/27/2005 0:00
9/27/2005 12:00
9/28/2005 0:00
9/28/2005 12:00
9/29/2005 0:00

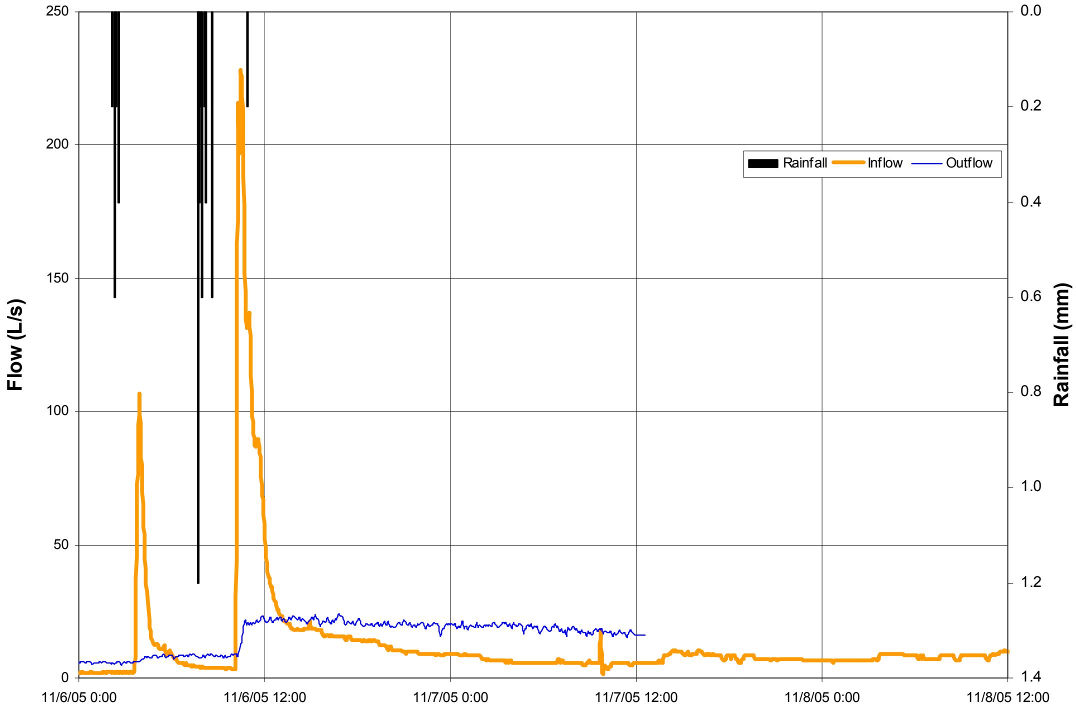

Influent TSS Concentration
Effluent TSS Concentration
Inlet
Outlet
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
250
200
150
100
50
0
9/25/2005 0:00
9/25/2005 12:00
9/26/2005 0:00
9/26/2005 12:00
9/27/2005 0:00
9/27/2005 12:00
9/28/2005 0:00
9/28/2005 12:00
9/29/2005 0:00

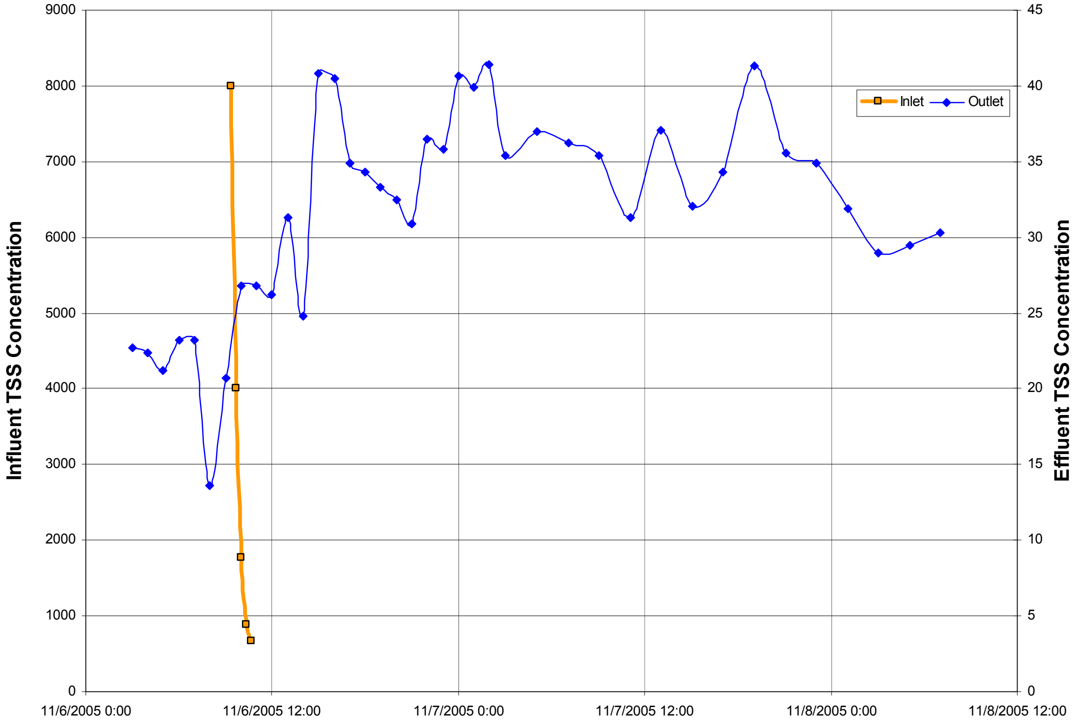

700
600
500
400
300
200
100
0
Flow (L/s)
0
0.5
1
1.5
2
2.5
3
3.5
Rainfall (mm)
Rainfall
Inflow
Outflow
9/29/2005 0:00
9/29/2005 12:00
9/30/2005 0:00
9/30/2005 12:00
10/1/2005 0:00
10/1/2005 12:00
10/2/2005 0:00
10/2/2005 12:00
10/3/2005 0:00

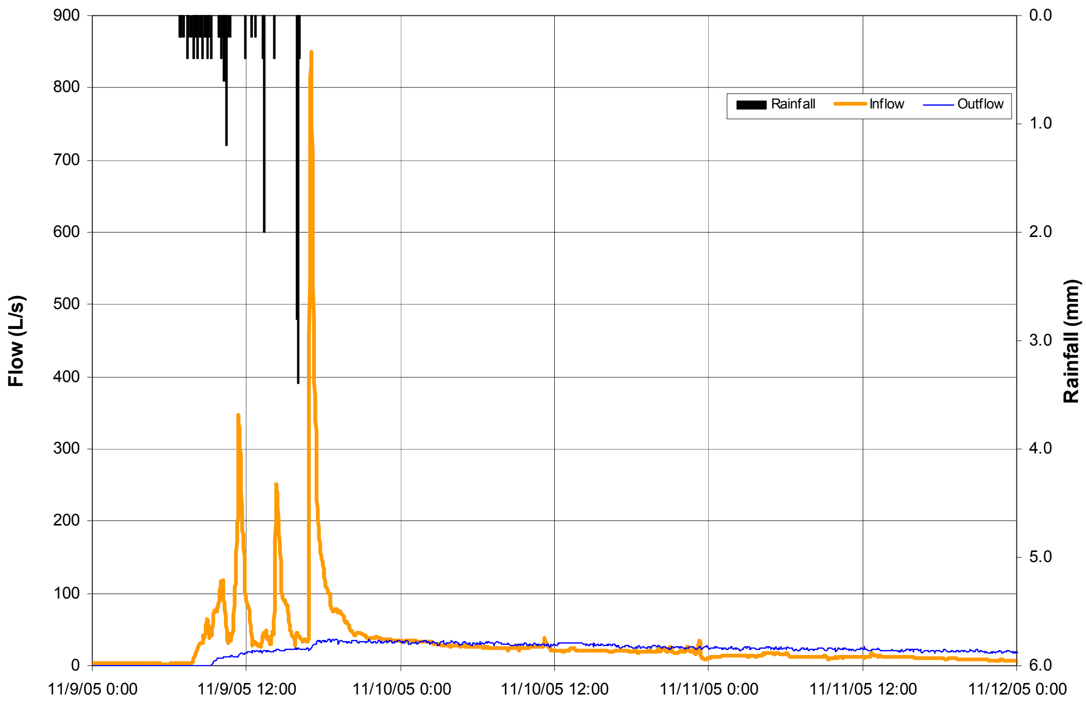

3500
3000
2500
2000
1500
1000
500
0
Influent TSS Concentration
120
100
80
60
40
20
0
Effluent TSS Concentration
Inlet
Outlet
9/29/2005 0:00
9/29/2005 12:00
9/30/2005 0:00
9/30/2005 12:00
10/1/2005 0:00
10/1/2005 12:00
10/2/2005 0:00
10/2/2005 12:00
10/3/2005 0:00

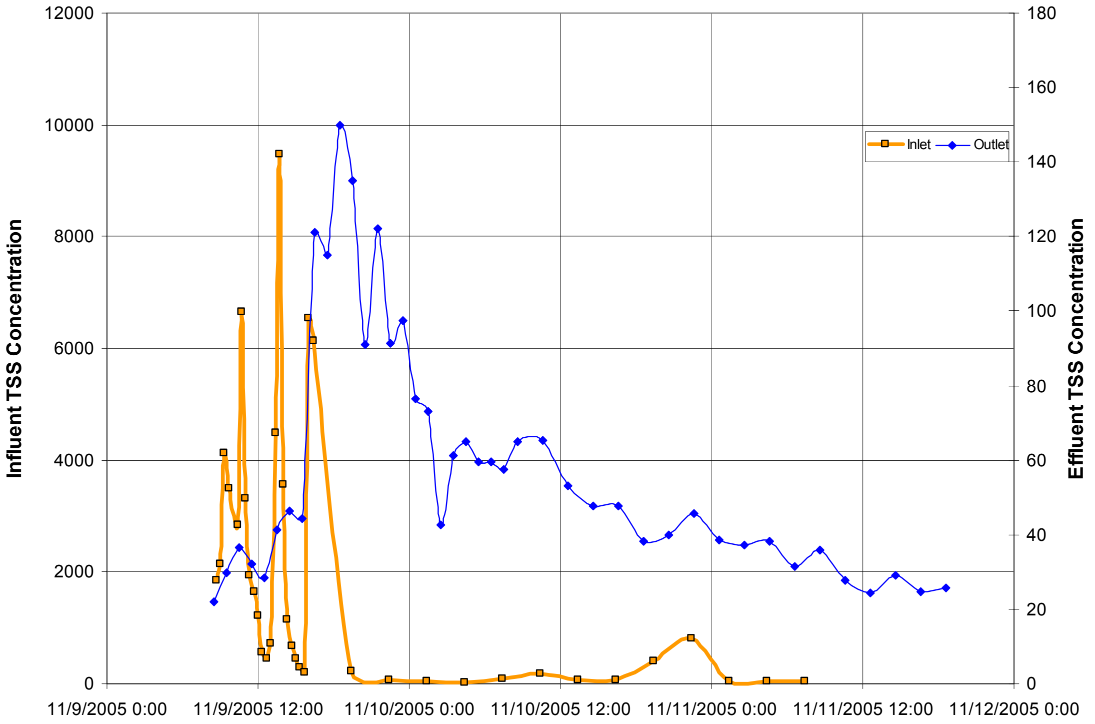

Flow (L/s)
Rainfall (mm)
Rainfall
Inflow
Outflow
350
300
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
10/22/2005 0:00
10/22/2005 12:00
10/23/2005 0:00
10/23/2005 12:00
10/24/2005 0:00
10/24/2005 12:00
10/25/2005 0:00
10/25/2005 12:00

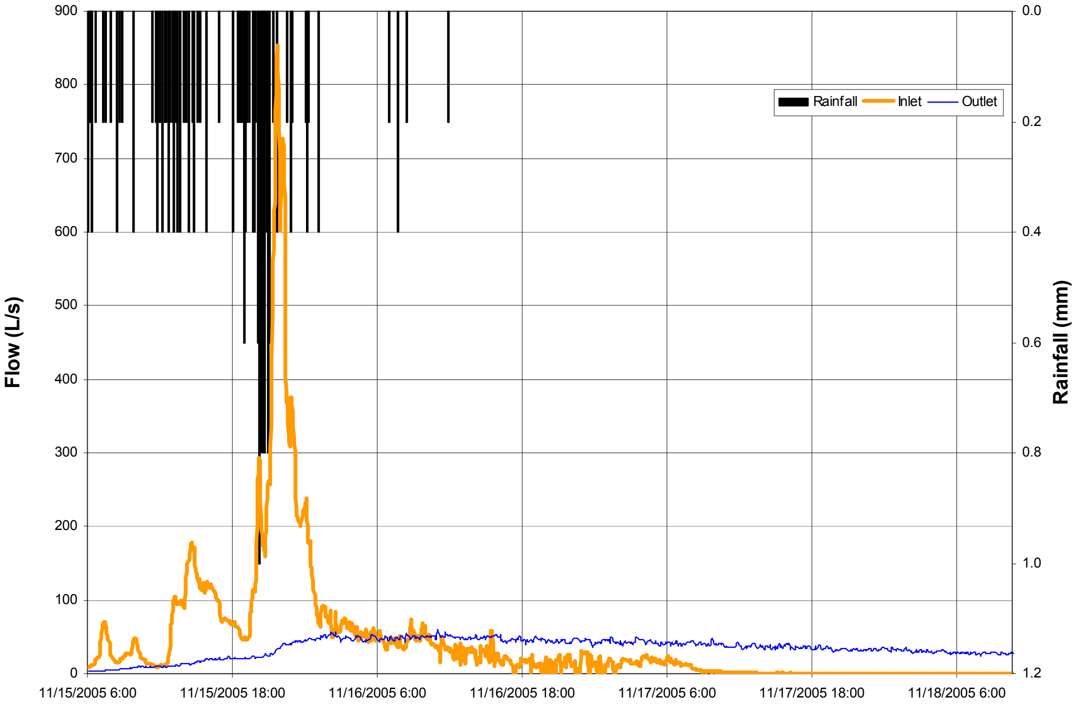

Influent TSS Concentration
Effluent TSS Concentration
Inlet
Outlet
7000
6000
5000
4000
3000
2000
1000
0
80
70
60
50
40
30
20
10
0
10/22/2005 0:00
10/22/2005 12:00
10/23/2005 0:00
10/23/2005 12:00
10/24/2005 0:00
10/24/2005 12:00
10/25/2005 0:00
10/25/2005 12:00

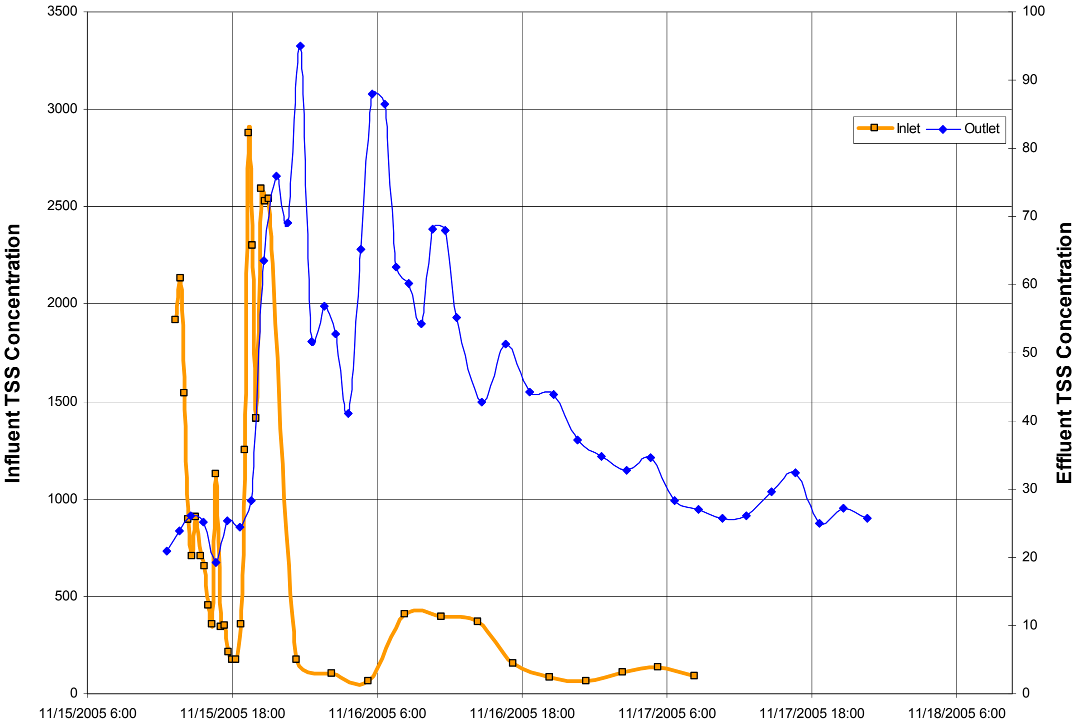

Flow (L/s)
Rainfall (mm)
250
200
150
100
50
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Rainfall
Inflow
Outflow
11/6/05 0:00
11/6/05 12:00
11/7/05 0:00
11/7/05 12:00
11/8/05 0:00
11/8/05 12:00


Influent TSS Concentration
Effluent TSS Concentration
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
45
40
35
30
25
20
15
10
5
0
Inlet
Outlet
11/6/2005 0:00
11/6/2005 12:00
11/7/2005 0:00
11/7/2005 12:00
11/8/2005 0:00
11/8/2005 12:00


Flow (L/s)
Rainfall (mm)
900
800
700
600
500
400
300
200
100
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
11/9/05 0:00
11/9/05 12:00
11/10/05 0:00
11/10/05 12:00
11/11/05 0:00
11/11/05 12:00
11/12/05 0:00
Rainfall
Inflow
Outflow


Influent TSS Concentration
Effluent TSS Concentration
12000
10000
8000
6000
4000
2000
0
180
160
140
120
100
80
60
40
20
0
11/9/2005 0:00
11/9/2005 12:00
11/10/2005 0:00
11/10/2005 12:00
11/11/2005 0:00
11/11/2005 12:00
11/12/2005 0:00
Inlet
Outlet


Flow (L/s)
Rainfall (mm)
900
800
700
600
500
400
300
200
100
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Rainfall
Inlet
Outlet
11/15/2005 6:00
11/15/2005 18:00
11/16/2005 6:00
11/16/2005 18:00
11/17/2005 6:00
11/17/2005 18:00
11/18/2005 6:00


Influent TSS Concentration
Effluent TSS Concentration
3500
3000
2500
2000
1500
1000
500
0
100
90
80
70
60
50
40
30
20
10
0
Inlet
Outlet
11/15/2005 6:00
11/15/2005 18:00
11/16/2005 6:00
11/16/2005 18:00
11/17/2005 6:00
11/17/2005 18:00
11/18/2005 6:00

APPENDIX B

Water Quality

Table B-1: Summary of EMCs, event median concentrations, and volume-weighted mean concentrations

				Inlet			Inlet Post			Outlet			Outlet Post			Upstream			Downstream		
Parameter	**Units**	**DL**	**GL**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**
General Chemistry																					
Chloride	mg/L	0.2	250	33.4	27.1	29.4	47.3	47.5	41.4	34.4	28.5	30.4	29.3	28.3	24.8	52.8	46.2	52.5	51.0	44.9	50.2
Oxygen demand; chemical	mg/L as O2			45.7	26.0	10.7				25.6	24.0	6.1									
Oxygen demand; biochemical	mg/L as O2	0.2		2.75	2.75	2.1	2.3	2.3	0.03	2.7	2.7	1.4	1.4	1.4	0.04	1.2	1.1	1.2	1.2	1.4	1.2
Solids; suspended	mg/L	2.5		2437.94	1562.5	2855.9	680.2	477.0	402.3	94.2	39.4	65.7	42.4	39.1	46.2	50.9	34.0	92.8	54.9	14.6	120.0
Solids; total	mg/L	10		2749	1850	3152	1097	898	793	375	315	341	313	311	314	434	421	462	431	407	478
Solids; dissolved	mg/L	10		313	295	297	414	409	400	281	280	275	270	275	268	383	385	369	376	379	358
Solvent extractable	mg/L	1		2	1	1	2	1	1	12	1	11	1	1	1	1	1	1	1	1	1
Conductivity	uS/cm	1		481	454		636	628		433	431		404	388		589	592		578	583	
pH	none		6.5-9.5	8.1	8.1		8.22	8.23		8.15	8.1575		8.1	8.1		8.4	8.4		8.3	8.4	
Alkalinity; total fixed endpt	mg/L CaCO3	2.5		83.5	82.0		114.3	114.5		78.8	79.8		76.1	74.6		206.0	217.0		200.0	210.0	
Turbidity	FTU	0.01	5	**1633.10**	**2000**		**859.00**	**646.00**		**79.25**	**74.45**		**83.06**	**93.95**		**42.91**	**17.20**		**57.76**	**11.70**	
Oxygen demand; chemical	mg/L as O2			168.6	111.0	14.8				46.0	45.0	6.3	0.7	0.2	0.1						
Carbon; dissolved organic	mg/L	0.1		4.9	4.4	4.5	3.9	3.6	3.4	4.5	4.1	4.1	4.0	3.7	3.5	4.1	3.7	4.1	4.3	3.9	4.7
Carbon; dissolved inorganic	mg/L	0.2		19.5	19.5	18.5	26.0	26.0	25.5	17.8	18.6	17.7	16.8	16.8	15	42.5	50.8	31.2	45.9	48.9	42.8
Silicon; reactive silicate	mg/L	0.02		3.14	3.15	3.07	3.96	4.01	3.64	1.685	1.85	1.95	2.46	2.46	2.09	9.35	4.42	18.43	4.01	4.06	3.81
Hardness	mg/L	1		220	215	219				168	170	168				264	260	266	200	254	182
Calcium	mg/L	0.25		66.10	63.85	65.87				51.20	51.50	51.21				80.63	78.20	81.61	56.43	76.90	49.79
Magnesium	mg/L	0.1		13.3	13.4	13.3				9.8	9.7	9.8				15.4	15.8	15.2	20.3	15.7	22.0
Sodium	mg/L	0.1		27.9	26.5	27.8				16.1	15.8	16.1				24.5	21.6	25.7	15.3	21.2	13.3
Potassium	mg/L	0.05		8.22	6.91	8.00				6.08	6.22	6.04				3.22	3.16	3.23	3.21	3.33	3.15
Sulphate	mg/L	0.5		143.3	128.5	141.7				78.3	78.8	78.1				32.6	32.2	33.2	34.5	33.8	34.8
Pesticides and Herbicides																					
2,4-dichlorophenol	ng/L	2000	200	1000	1000	829	1000	1000	882	1000	1000	919	1000	1000	622	1000	1000	1000	1000	1000	1000
2,4,6-trichlorophenol	ng/L	20	18000	10	10	8	10	10	9	10	10	9	10	10	6	10	10	10	10	10	10
2,4,5-trichlorophenol	ng/L	100	18000	50	50	41	50	50	44	50	50	46	50	50	31	50	50	50	50	50	50
2,3,4-trichlorophenol	ng/L	100	18000	50	50	41	50	50	44	50	50	46	50	50	31	50	50	50	50	50	50
2,3,4,5-tetrachlorophenol	ng/L	20	1000	10	10	8	10	10	9	10	10	9	10	10	6	10	10	10	10	10	10
2,3,4,6-tetrachlorophenol	ng/L	20	1000	10	10	8	10	10	9	10	10	9	10	10	6	10	10	10	10	10	10
Pentachlorophenol	ng/L	10	500	52	43	53	18	12	32	9	5	11	18	5	15	16	5	32	15	5	30
Dicamba	ng/L	50	200000	55	25	23	61	25	49	25	25	23	29	25	19	115	25	173	102	25	147
Bromoxynil	ng/L	50	5000	25	25	21	25	25	22	25	25	23	25	25	16	25	25	25	25	25	25
2,4-D-propionic acid	ng/L	100		50	50	41	50	50	44	50	50	46	50	50	31	50	50	50	50	50	50
2,4-D	ng/L	100	4000	1341	415	869	786	740	649	266	123	439	651	440	419	240	50	311	233	50	262
Silvex	ng/L	20		10	10	8	10	10	9	10	10	9	10	10	6	10	10	10	10	10	10
2,4,5-T	ng/L	50		25	25	21	25	25	22	25	25	23	25	25	16	25	25	25	25	25	25
2,4-DB	ng/L	200		100	100	83	100	100	88	100	100	92	100	100	62	100	100	100	100	100	100
Dinoseb	ng/L	20	50	10	10	8	10	10	9	10	10	9	10	10	6	10	10	10	10	10	10
Picloram	ng/L	100	29000	50	50	41	50	50	44	50	50	46	50	50	31	50	50	50	50	50	50
Diclofop-methyl	ng/L	100	6100	50	50	41	50	50	44	50	50	46	50	50	31	50	50	50	50	50	50
MCPP,2-4Cl2MePhenoxy-PropAcid	ng/L			1214	380	704	919	790	787	304	222	481	657	775	439	187	20	222	178	28	188
MCPA,4Cl2MePhenoxy-AceticAcid	ng/L		2600	20	20	17	20	20	17.6	20	20	18	20	20	12	20	20	20	20	20	20
MCPB,4Cl2MePhenoxy-ButyricAcid	ng/L			20	20	17	20	20	17.6	20	20	18	20	20	12	20	20	20	20	20	20
Polycyclic Aromatic Hydrocarbons																					
Naphthalene	ug/L	0.2	7	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2-methylnaphthalene	ug/L	0.2	2	0.1	0.1	0.1	1.3	0.1	0.5	0.1	0.1	0.1	0.25	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1-methylnaphthalene	ug/L	0.5	2	0.25	0.25	0.2	2.0	0.3	0.8	0.25	0.25	0.2	0.25	0.25	0.2	0.25	0.25	0.25	0.25	0.25	0.25
2-chloronaphthalene	ug/L	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Acenaphthene	ug/L	0.2	5.8	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Acenaphthylene	ug/L	0.2		0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fluorene	ug/L	0.2	0.2	0.1	0.1	0.1	0.5	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Phenanthrene	ug/L	0.2	30	0.1	0.1	0.1	0.6	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

				Inlet			Inlet Post			Outlet			Outlet Post			Upstream			Downstream		
Parameter	**Units**	**DL**	**GL**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**	**Mean**	**Median**	**VWAC**
Anthracene	ug/L	0.2	0.8	0.1	0.1	0.1	0.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fluoranthene	ug/L	0.2	0.8	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pyrene	ug/L	0.2	0.025	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Benzo(a)anthracene	ug/L	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Chrysene	ug/L	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Benzo(b)fluoranthene	ug/L	0.2		0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Benzo(k)fluoranthene	ug/L	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Benzo(a)pyrene	ug/L	0.2	0.015	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Indeno(1,2,3-c,d)pyrene	ug/L	0.5		0.25	0.25	0.2	0.25	0.25	0.1	0.25	0.25	0.2	0.25	0.25	0.2	0.25	0.25	0.25	0.25	0.25	0.25
Dibenzo(a,h)anthracene	ug/L	0.5	2	0.25	0.25	0.2	0.25	0.25	0.1	0.25	0.25	0.2	0.25	0.25	0.2	0.25	0.25	0.25	0.25	0.25	0.25
Benzo(g,h,i)perylene	ug/L	0.2	0.02	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1-chloronaphthalene	ug/L	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Perylene	ug/L	0.5	0.07	0.25	0.25	0.2	0.25	0.25	0.1	0.25	0.25	0.2	0.25	0.25	0.2	0.25	0.25	0.25	0.25	0.25	0.25
Indole	ug/L	0.2		0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
5-nitroacenaphthene	ug/L	1		1	1	0.4	1	1	0.1	0.5	0.5	0.4	0.5	0.5	0.3	1	1	1	1	1	1
Biphenyl	ug/L	0.2	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Nutrients																					
Nitrogen; ammonia+ammonium	mg/L	0.002	1.4	0.053	0.026	0.044	0.040	0.021	0.046	0.111	0.108	0.101	0.1	0.1	0.068	0.031	0.019	0.032	0.020	0.014	0.023
Nitrogen; nitrite	mg/L	0.001	0.06	0.045	0.039	0.039	0.039	0.037	0.036	0.023	0.025	0.026	0.028	0.031	0.023	0.014	0.013	0.018	0.016	0.011	0.018
Nitrogen; nitrate+nitrite	mg/L	0.005		1.409	1.553	1.336	1.889	1.910	2.034	0.481	0.436	0.627	0.553	0.598	0.452	0.889	0.628	1.145	0.850	0.632	1.067
Phosphorus; phosphate	mg/L	0.005		0.046	0.018	0.025	0.035	0.006	0.032	0.010	0.005	0.010	0.011	0.009	0.009	0.010	0.003	0.020	0.008	0.003	0.016
Phosphorus; total	mg/L	0.002	0.03	**2.308**	**1.483**	**2.725**	**0.504**	**0.410**	**0.398**	**0.097**	**0.091**	**0.117**	**0.106**	**0.107**	**0.101**	**0.094**	**0.055**	**0.171**	**0.106**	**0.040**	**0.211**
Nitrogen; total Kjeldahl	mg/L	0.02	3.2	3.60	2.23	**3.54**	1.06	1.04	0.98	0.85	0.87	0.82	0.82	0.86	0.73	0.67	0.51	0.96	0.64	0.45	0.93
Bacteria																					
Escherichia coli	c/100mL		100	**8285**	**4275**	**4881.3**	**11000**	**11000**		**629**	**495**	**798**				**1383**	**445**	**1705**	**998**	**305**	**1212**
Fecal streptococcus	c/100mL			23795	20825	18711.7	24500	24500		1061	665	871				2063	1105	2423	2175	1045	2541
Pseudomonas aeruginosa	c/100mL			4247	1510	403.5	9350	9350		1550	22	26				12	10	13	11	6	9
Metals																					
Aluminum	ug/L	11	75	**1102**	**511**	**815**	**1331**	**1500**	**1543**	**546**	**553**	**597**	**638**	**599**	**608**	**357**	**236**	**617**	**387**	**188**	**728**
Arsenic	mg/L	0.001	0.1	**0.390**	0.001	**0.201**	0.001	0.001	0.001	0.001	0.001	0.0005	0.001	0.001	0.0004	0.001	0.001	0.001	0.001	0.001	0.001
Barium	ug/L	0.2		97.2	94.8	97.0	91.0	89.8	85.3	43.0	43.5	43.4	42.0	42.2	38.0	55.5	58.3	57.4	55.3	55.5	60.2
Beryllium	ug/L	0.2	11	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calcium	mg/L	0.005		247.024	218.250	248.809	159.250	142.500	138.056	48.636	48.725	51.452	48.608	48.950	44.122	63.543	65.700	64.459	62.443	63.000	65.166
Cadmium	ug/L	0.6	0.1	**0.5**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**	**0.5**	**0.3**	**0.3**	**0.3**	**0.5**	**0.3**	**0.4**	**0.5**	**0.3**	**0.4**
Cobalt	ug/L	1.3	0.9	**2.1**	**1.8**	**1.8**	**1.7**	**1.7**	**1.8**	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.7	**1.2**	0.7	**1.7**
Chromium	ug/L	1.4	8.9	3.1	1.3	1.8	6.8	3.4	4.7	1.6	1.2	1.3	6.0	0.7	4.4	0.9	0.7	0.8	0.7	0.7	0.7
Copper	ug/L	1.6	5	**5.3**	3.4	4.5	**8.3**	**9.1**	**8.4**	**7.9**	**5.4**	**7.7**	**5.9**	**5.9**	**5.4**	**6.2**	**5.5**	**6.2**	**8.1**	4.1	**11.6**
Iron	ug/L	0.8	300	**777.4**	**315.3**	**548.8**	**1146.5**	**927.5**	**1353.7**	**520.8**	**506.8**	**580.0**	**671.1**	**664.0**	**657.9**	**349.3**	**342.0**	**510.8**	**343.9**	**210.0**	**549.8**
Magnesium	mg/L	0.008		10.297	10.895	9.474	15.708	15.400	15.609	8.994	9.230	8.737	8.410	8.210	7.350	11.847	12.000	10.822	11.526	11.900	10.633
Manganese	ug/L	0.2		374.1	389.5	354.9	231.3	225.0	213.6	50.9	53.5	58.8	48.3	48.3	46.6	41.3	29.3	69.1	47.0	22.7	87.7
Mercury	ug/L	0.02	0.2	0.04	0.03	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Molybdenum	ug/L	1.6	10	0.9	0.8	0.9	1.0	0.8	0.9	0.9	0.8	0.8	1.2	0.8	1.0	0.8	0.8	0.8	0.8	0.8	0.8
Nickel	ug/L	1.3	25	3.3	2.8	2.6	3.9	4.0	4.0	1.6	1.7	1.7	1.7	1.9	1.6	1.1	0.7	1.5	2.0	1.8	2.7
Lead	ug/L	10	5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5
Selenium	mg/L	0.001	0.1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.0005	0.001	0.001	0.0004	0.001	0.001	0.001	0.001	0.001	0.001
Strontium	ug/L	0.1		752.4	745.0	722.7	856.3	850.0	811.2	389.1	387.3	393.1	383.1	362.0	339.6	179.4	178.0	178.1	184.4	182.0	185.0
Titanium	ug/L	0.5		15.2	2.4	9.4	6.1	4.1	4.3	11.1	9.9	10.3	12.7	12.5	11.1	5.2	5.3	6.3	4.7	4.8	5.4
Vanadium	ug/L	1.5	7	3.0	1.8	2.2	3.6	3.7	3.5	1.9	1.8	1.9	3.0	2.8	2.8	1.4	0.8	2.2	1.2	0.8	1.9
Zinc	ug/L	0.6	20	8.6	4.7	6.9	13.7	15.7	15.4	5.1	4.6	5.4	5.5	5.5	5.2	5.0	4.3	7.1	6.0	3.3	9.9

DL: Detection Limit; GL: Guideline; VWAC: Volume weighted average concentration; Inlet and inlet post refer to composites collected during the 'early' (usually rise and peak) and 'late' (usually hydrograph run) periods of runoff.

Values above guidelines.

Trace herbicides and pesticides detected. In each case, half the detection limit was used for statistics. Values deferred from guideline exceedence

Trace polycyclic aromatic hydrocarbons detected. In each case, half the detection limit was used for statistics. Values deferred from guideline exceedence

APPENDIX C

Water Temperature

Temperature

Water temperatures were continuously monitored in 2004 to assess potential thermal impacts of the pond on receiving waters. The bottom draw outlet combined with an unusually cool summer air temperatures helped to minimize thermal impacts. Throughout the summer, maximum effluent water temperatures never exceeded 22°C. Maximum temperatures in the Little Rouge River were higher than effluent water temperatures throughout the summer (Table C-1). Average receiving water temperatures, by contrast, were higher than effluent temperatures only during July (Figure C-1).

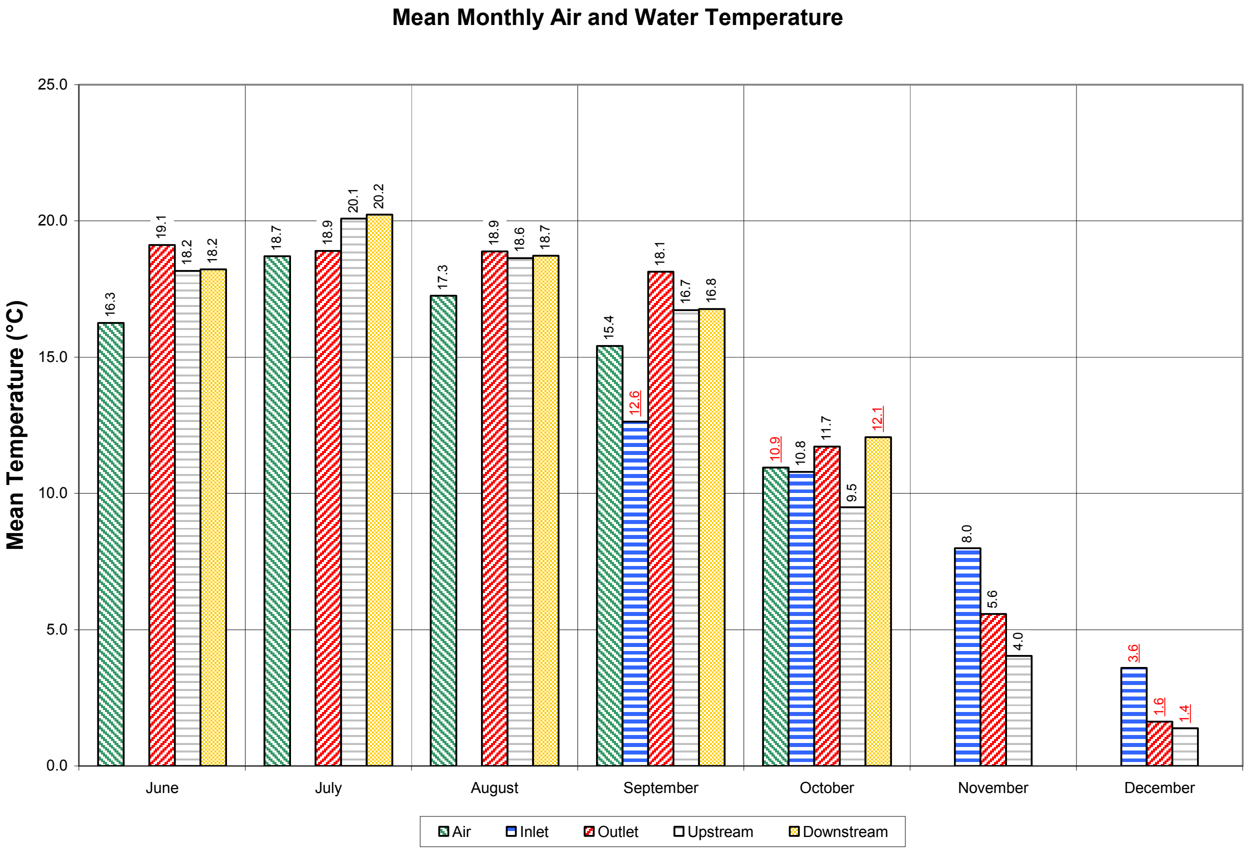


Figure C-1: Mean monthly air and water temperature. Several stations in September, October, and December did not have a full data set (red underlined text).

Figure C-2 shows the temperature fluctuations at the various stations. The difference between inlet and outlet temperatures is roughly 3°C. Daily temperature at all stations varied with diurnal changes in air temperature.

Table C-1: Summary of the maximum, minimum, mean, and median air and water temperature

	Air			Inlet			Outlet			Upstream			Downstream		
	Max	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
June	29.5	4.6	16.4	na	na	na	21.8	17.8	19.1	25.1	14.0	18.2	25.6	14.1	18.3
July	27.9	9.0	18.7	na	na	na	20.0	17.8	18.9	25.4	16.5	20.1	25.7	16.7	20.3
August	26.1	4.6	17.2	na	na	na	19.7	18.3	18.9	23.5	13.4	18.6	23.5	13.4	18.7
September	25.2	1.6	15.3	**15.9**	**9.8**	**12.4**	19.0	16.8	18.1	21.6	11.5	16.6	21.8	11.0	16.7
October	**18.5**	**-0.8**	**11.3**	13.3	6.6	10.7	16.9	8.2	11.6	14.2	5.8	9.4	**14.6**	**9.3**	**12.1**
November	na	Na	na	10.9	4.1	7.9	10.2	2.8	5.4	9.0	-0.1	3.9	na	na	na
December	na	Na	na	**7.4**	**-1.9**	**3.5**	**4.1**	**-2.4**	**1.5**	**3.7**	**-0.1**	**1.3**	na	na	na

Underlined values indicate that the month did not have a complete data set.

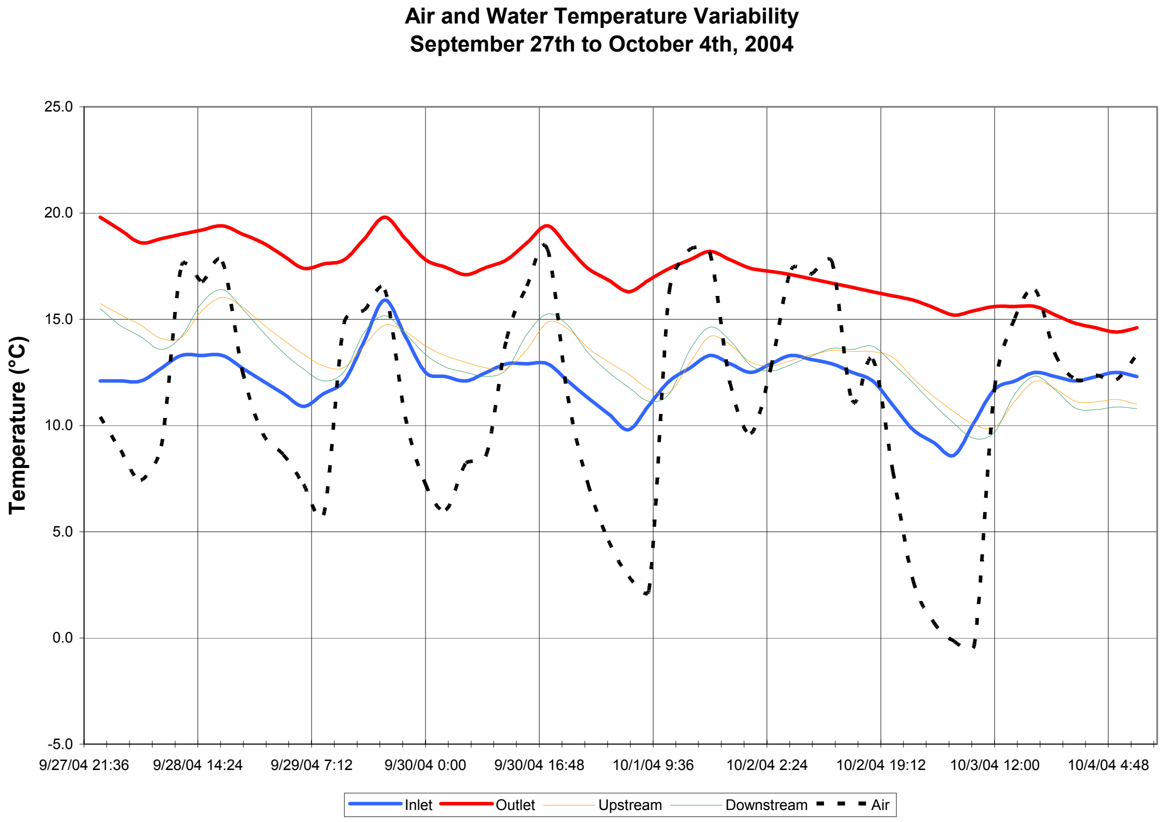
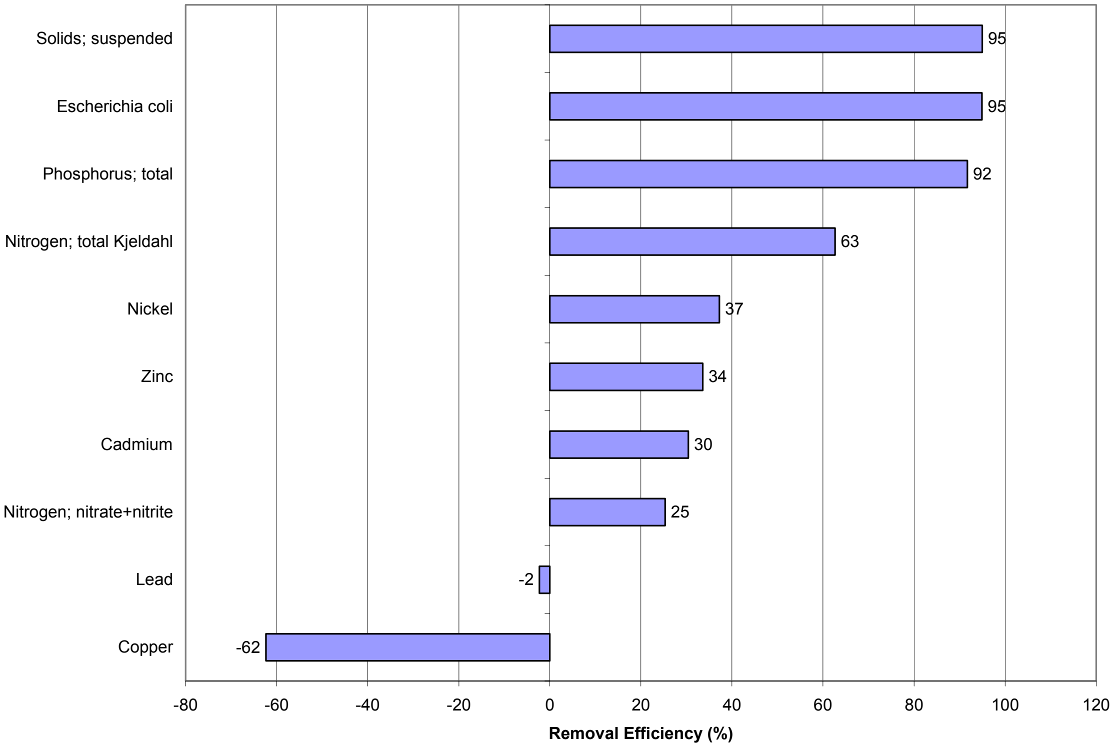


Figure C-2: Air and water temperature variability

APPENDIX D

Selected Removal Efficiencies


Solids; suspended
Escherichia coli
Phosphorus; total
Nitrogen; total Kjeldahl
Nickel
Zinc
Cadmium
Nitrogen; nitrate+nitrite
Lead
Copper
95
95
92
63
37
34
30
25
-2
-62
-80
-60
-40
-20
0
20
40
60
80
100
120
Removal Efficiency (%)

APPENDIX E
Dry Weather Water Quality

Table E-1*:* Dry weather sampling event concentrations

				Dry Weather																	
				Major Mackenzie Drive						Markham Road						Ninth Line					
	Units	DL	GL*	# > dl	# of Samples	Min	Max	Mean	Median	# > dl	# of Samples	Min	Max	Mean	Median	# > dl	# of Samples	Min	Max	Mean	Median
General Chemistry																					
Chloride	mg/L	0.2	250	3	3	56.5	65.5	60.6	59.7	3	3	55.3	66.0	60.2	59.2	3	3	57.5	68.8	61.9	59.5
Mercury	ug/L	0.02	0.2	2	3	0.01	0.02	0.02	0.02	2	3	0.01	0.02	0.02	0.02	2	3	0.01	0.02	0.02	0.02
Arsenic	mg/L	0.001	0.1	0	3	0.0005	0.0005	0.0005	0.0005	0	3	0.0005	0.0005	0.0005	0.0005	0	3	0.0005	0.0005	0.0005	0.0005
Selenium	mg/L	0.001	0.1	0	3	0.0005	0.0005	0.0005	0.0005	0	3	0.0005	0.0005	0.0005	0.0005	0	3	0.0005	0.0005	0.0005	0.0005
Calcium	mg/L	0.25		2	3	0.13	71.80	46.34	67.10	2	3	0.13	70.00	45.91	67.60	2	3	0.13	69.30	45.21	66.20
Magnesium	mg/L	0.1		2	3	0.1	14.6	9.6	14.2	2	3	0.1	14.4	9.5	14.1	2	3	0.1	14.2	9.4	13.9
Sodium	mg/L	0.1		2	3	0.1	31.6	20.5	29.9	2	3	0.1	30.8	20.3	30.1	2	3	0.1	31.4	20.8	30.8
Potassium	mg/L	0.05		2	3	0.03	2.02	1.30	1.84	2	3	0.03	1.98	1.30	1.89	2	3	0.03	2.10	1.34	1.89
Hardness	mg/L	1		2	3	0.5	239.0	155.2	226.0	2	3	0.5	234.0	153.8	227.0	2	3	0.5	232.0	151.5	222.0
Sulphate	mg/L	0.5		2	3	0.3	29.0	18.5	26.2	2	3	0.3	29.3	18.6	26.3	2	3	0.3	29.8	19.0	27.0
Oxygen demand; biochemical	mg/L as O2	0.2		2	3	0.1	1.0	0.6	0.8	2	3	0.1	0.9	0.6	0.8	2	3	0.1	1.3	0.8	0.9
Solids; suspended	mg/L	2.5		2	3	1.3	5.4	3.2	3.0	1	3	1.3	6.2	2.9	1.3	2	3	1.3	8.9	4.7	3.8
Solids; total	mg/L	10		3	3	375	403	391	395	3	3	373	397	382	377	3	3	373	402	391	398
Solids; dissolved	mg/L	10		3	3	372	402	388	389	3	3	367	397	379	374	3	3	369	396	386	393
Solvent extractable	mg/L			2	3	1	3	2	3	2	3	1	3	2	2	2	3	1	2	2	2
Conductivity	uS/cm			3	3	572	618	596	599	3	3	565	610	584	576	3	3	567	609	594	605
pH	none		6.5-9.5		3	8.3	8.5	8.4	8.4		3	8.3	8.5	8.4	8.4		3	8.3	8.5	8.4	8.4
Alkalinity; total fixed endpt	mg/L CaCO3			3	3	191.0	206.0	198.3	198.0	3	3	183.0	197.0	190.3	191.0	3	3	187.0	200.0	194.3	196.0
Turbidity	FTU		5	3	3	2.02	5.40	3.21	2.22	3	3	1.86	7.01	3.74	2.34	3	3	3.25	8.12	5.31	4.57
Carbon; dissolved organic	mg/L			3	3	4.0	4.7	4.3	4.2	3	3	3.9	5.3	4.4	4.1	3	3	4.2	4.5	4.4	4.4
Carbon; dissolved inorganic	mg/L			3	3	43.9	46.7	45.3	45.3	3	3	41.9	44.5	43.4	43.9	3	3	43.0	45.8	44.7	45.3
Silicon; reactive silicate	mg/L			3	3	2.04	3.08	2.64	2.80	3	3	2.26	3.34	2.79	2.78	3	3	1.86	2.48	2.25	2.40
Nutrients																					
Nitrogen; ammonia+ammonium	mg/L		1.4	3	3	0.004	0.031	0.014	0.007	3	3	0.003	0.030	0.015	0.011	3	3	0.002	0.034	0.021	0.028
Nitrogen; nitrite	mg/L	1	0.06	3	3	0.008	0.021	0.013	0.009	3	3	0.008	0.023	0.013	0.009	3	3	0.009	0.015	0.011	0.010
Nitrogen; nitrate+nitrite	mg/L	1		3	3	0.426	0.958	0.654	0.577	3	3	0.533	1.020	0.721	0.609	3	3	0.360	0.830	0.564	0.502
Phosphorus; phosphate	mg/L			0	3	0.003	0.003	0.003	0.003	0	3	0.003	0.003	0.003	0.003	0	3	0.003	0.003	0.003	0.003
Phosphorus; total	mg/L	2.5	0.03	3	3	0.020	0.035	0.025	0.021	3	3	0.016	0.039	0.025	0.021	3	3	0.019	0.033	0.025	0.024
Nitrogen; total Kjeldahl	mg/L			3	3	0.41	0.51	0.45	0.43	3	3	0.38	0.62	0.47	0.41	3	3	0.39	0.53	0.45	0.44
Bacteria																					
Escherichia coli	c/100mL		100		3	150.0	1400.0	686.7	510.0		3	120.0	4400.0	1570.0	190.0		3	160.0	1300.0	556.7	210.0
Fecal streptococcus	c/100mL				3	200.0	2000.0	820.0	260.0		3	250.0	4900.0	1820.0	310.0		3	180.0	2600.0	1043.3	350.0
Pseudomonas aeruginosa	c/100mL	0.01			3	2.0	10.0	4.7	2.0		3	2.0	46.0	16.7	2.0		3	2.0	8.0	4.0	2.0
Metals																					
Aluminum	ug/L		75	3	3	48	143	82	56	3	3	49	147	83	54	3	3	78	162	110	91
Barium	ug/L	1		3	3	44.7	53.9	48.9	48.0	3	3	45.0	49.2	47.1	47.1	3	3	44.4	53.8	48.4	47.0
Beryllium	ug/L	1	11	0	3	0.1	0.1	0.1	0.1	0	3	0.1	0.1	0.1	0.1	0	3	0.1	0.1	0.1	0.1
Calcium	mg/L	0.2		3	3	55.5	64.9	59.2	57.2	3	3	55.4	57.0	56.0	55.6	3	3	56.6	65.1	59.6	57.0
Cadmium	ug/L	0.6	0.1	1	3	0.3	0.8	0.5	0.3	0	3	0.3	0.3	0.3	0.3	0	3	0.3	0.3	0.3	0.3
Cobalt	ug/L	0.5	0.9	0	3	0.7	0.7	0.7	0.7	0	3	0.7	0.7	0.7	0.7	1	3	0.7	1.4	0.9	0.7
Chromium	ug/L	1	8.9	0	3	0.7	0.7	0.7	0.7	0	3	0.7	0.7	0.7	0.7	0	3	0.7	0.7	0.7	0.7
Copper	ug/L	1	5	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8
Iron	ug/L	0.5	300	3	3	90.0	190.0	127.3	102.0	3	3	93.2	196.0	130.1	101.0	3	3	117.0	194.0	147.3	131.0
Magnesium	mg/L	0.5		3	3	12.4	13.4	12.7	12.4	3	3	10.9	12.9	12.1	12.6	3	3	12.5	13.2	12.8	12.8
Manganese	ug/L	0.2		3	3	18.0	25.9	21.1	19.4	3	3	17.6	26.0	20.9	19.0	3	3	20.6	31.1	25.0	23.2
Molybdenum	ug/L	0.2	10	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8
Nickel	ug/L	0.2	25	1	3	0.7	1.4	0.9	0.7	0	3	0.7	0.7	0.7	0.7	1	3	0.7	2.0	1.1	0.7
Lead	ug/L	0.2	5	0	3	5	5	5	5	0	3	5	5	5	5	0	3	5	5	5	5
Strontium	ug/L	0.2		3	3	178.0	191.0	185.7	188.0	3	3	169.0	183.0	176.0	176.0	3	3	184.0	195.0	191.0	194.0
Titanium	ug/L	0.2		3	3	0.8	3.8	1.9	1.2	3	3	0.8	3.9	1.9	1.0	3	3	1.8	4.5	2.9	2.5
Vanadium	ug/L	0.2	7	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8	0	3	0.8	0.8	0.8	0.8
Zinc	ug/L	0.2	20	2	3	0.3	2.0	1.1	1.1	3	3	1.0	1.8	1.5	1.6	3	3	0.7	1.7	1.1	0.9

Notes: GL: Guideline; DL: Detection Limit
*Provincial Water Quality Objectives (PWQO) used where applicable. Other values are Canadian Water Quality Guidelines or derived from the literature.
Value above guideline.