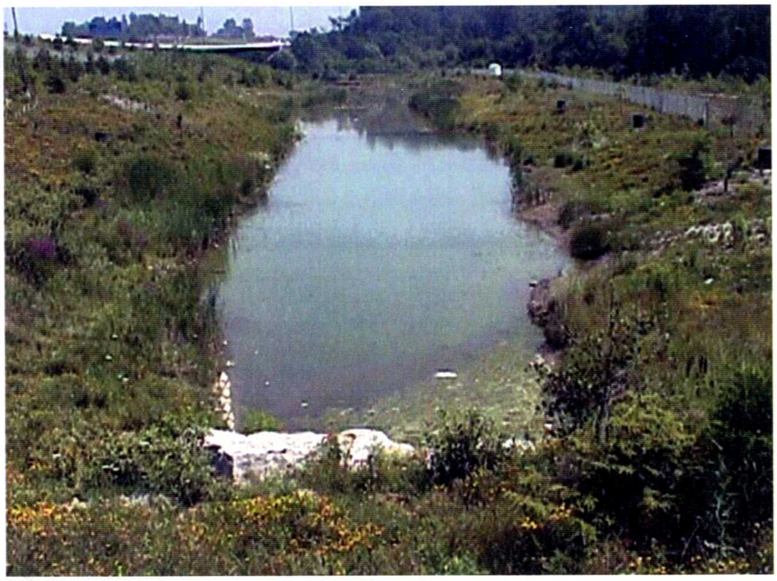
SWAMP

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

2003

Ministry of the Environment
Ontario

TORONTO AND REGION Conservation



Ministry of Transportation
Ontario

PERFORMANCE ASSESSMENT OF A HIGHWAY STORMWATER QUALITY RETENTION POND

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ROUGE RIVER, TORONTO, ONTARIO

a report prepared by the

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Great Lakes Sustainability Fund of the Government of Canada
Ontario Ministry of the Environment
Toronto and Region Conservation Authority
Municipal Engineers Association of Ontario
Ontario Ministry of Transportation

December, 2003

NOTICE

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

PUBLICATION INFORMATION

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THE SWAMP PROGRAM

The Stormwater Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, and the Municipal Engineer's Association. A number of individual municipalities and other owner/operator agencies have also participated in SWAMP studies.

Since the mid 1980s, the Great Lakes Basin has experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in southern Ontario. The SWAMP Program was intended to address this need.

The SWAMP Program's objectives are:

- to monitor and evaluate new and conventional stormwater management technologies; and
- to disseminate study results and recommendations within the stormwater management industry.

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Additional information concerning SWAMP and the supporting agencies is included in Appendix A.

ACKNOWLEDGEMENTS

This report was prepared for the Steering Committee of the Stormwater Assessment Monitoring and Performance (SWAMP) Program. The Steering Committee of the SWAMP Program is comprised of representatives from:

- the Government of Canada's Great Lakes Sustainability Fund,
- the Ontario Ministry of the Environment,
- the Toronto and Region Conservation Authority,
- the Municipal Engineers Association of Ontario.

This study was jointly funded by the Ontario Ministry of the Environment (OMOE), the Great Lakes Sustainability Fund (formerly the Great Lakes 2000 Clean-up Fund) and the Ontario Ministry of Transportation (MTO). The OMOE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOE provided laboratory analyses. MTO provided permission to conduct the monitoring study and assisted with the installation and operation of monitoring equipment. The Toronto and Region Conservation Authority (TRCA) provided administrative support for the SWAMP program. TRCA also conducted part of the study. The final editing of the report and some of the data analysis work were undertaken by Questor Veritas Inc. under contract to the SWAMP program.

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EXECUTIVE SUMMARY

Background

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

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

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

Objectives

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

The Site

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

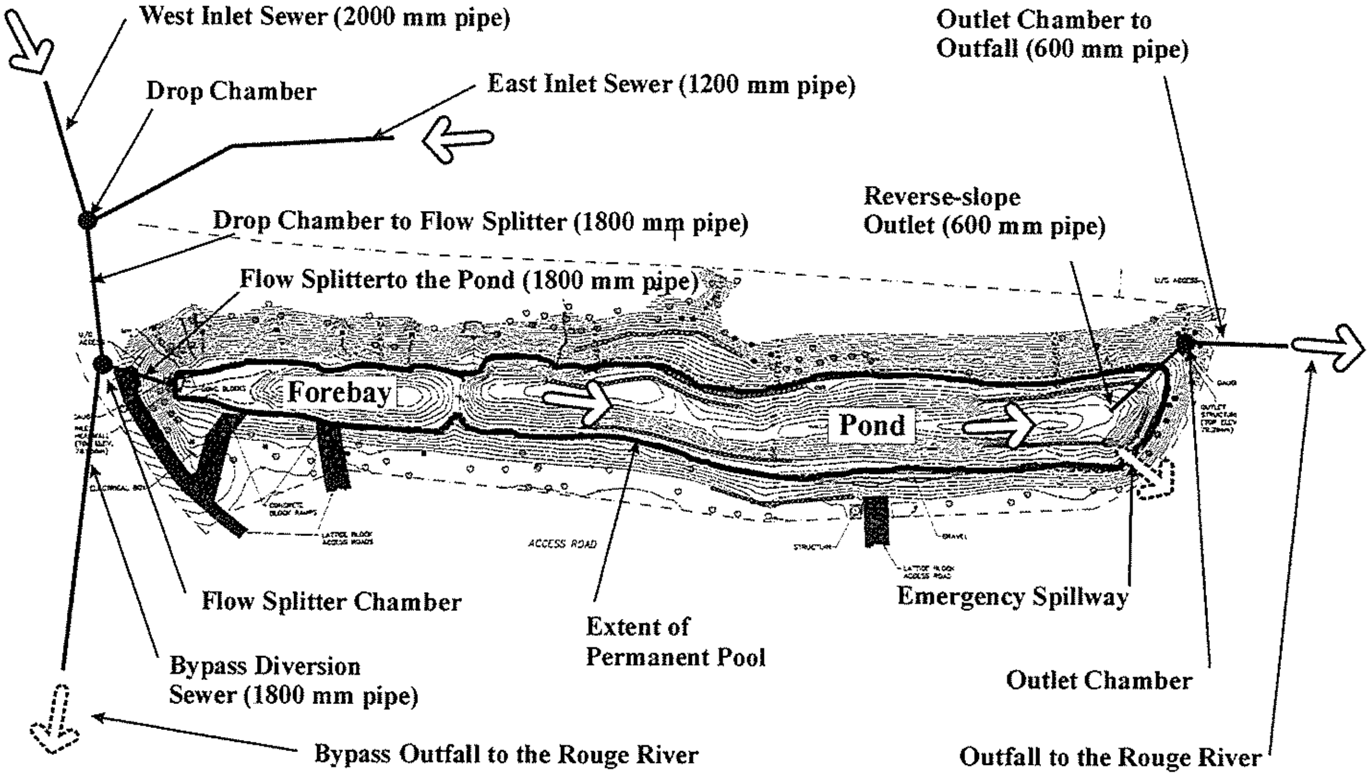

Figure 1: Rouge stormwater management pond

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

Study Methods

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

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

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

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

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

Study Findings

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Design Guidelines

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

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

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

Conclusions

- The highway stormwater management pond was monitored during and after highway reconstruction. Flow balances could not be achieved during the construction period (prior to September, 1996) but the water quality data are considered to be of value in characterizing construction period conditions. The post-construction period (September, 1996 to September 1997) produced data that are considered to be representative of the normal performance of this facility.

- The average peak ratio, measured as the ratio of the outlet peak flow to the inlet peak flow, was 47% with a range of 20 to 81%. The hydraulic detention time, measured as the time lag between the inlet and outlet hydrograph centroids, was approximately 2 hours. The operational drawdown time, measured as the time lag from the maximum storage volume to the re-attainment of baseflow conditions, was approximately 34 hours. This performance is considered to provide a significant reduction in the hydraulic impact of runoff on the receiving stream. However, a detention time of 24 hours is generally recommended as a design parameter. Hydraulic residence time was not measured in this study.

- During the post-construction summer/fall monitoring period the pond achieved an average TSS removal efficiency of 90%. The mean inlet TSS concentration was 331 mg/L, and the mean outlet concentration was 37 mg/L. Turbidity and particle size measurements also indicated a substantial reduction in the amount of suspended material.

- Substantial removals were also observed for metals. Greater than 80% removal was achieved for copper, lead and zinc. Removals of chromium, nickel, aluminum and iron were between 70 and 80%.

- The total phosphorus concentration was reduced 85% and the total Kjeldahl nitrogen concentration was reduced 70%.

- Among the 41 organic parameters (herbicides, pesticides and PAH's) analyzed in this study, only pentachlorophenol was found at concentrations consistently above laboratory detection limit; its removal efficiency was 58%. A second compound, 2,3,4,6 tetrachlorophenol, was measured at concentrations close to the detection limit; the estimated removal efficiency was 26%.

- On average, the outlet water temperature was only 3° C warmer than the pond influent. In summer, the temperature increase across the facility was approximately 6 to 7° C resulting in effluent temperatures generally ranging from 20 to 22 degrees (peak temperature observation = 27° C). The temperature of water in the Rouge River tended to be greater than that of the pond effluent.

- Chemo-stratification was found to occur in the pond, with significant increases in conductivity observed within approximately 1 m of the bottom of the pond. Salt applied to the highway in winter was found to be exported from the pond during the summer/fall monitoring period, resulting in negative removals of chloride and conductivity. Although most of the stratified salt water was apparently below the inlet of the reversed-slope discharge pipe, the design of the outlet may have contributed to the release of the salt.

- The runoff was found to be predominantly non-lethal. However, acute toxicity was occasionally detected. Chloride was considered to be the probably cause of occasional toxicity detected for *Daphnia magna*.

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

Recommendations

Regarding facility design and operation:

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

Regarding monitoring programs:

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

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

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1 INTRODUCTION

1.1 Background

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

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Highway runoff contains a variety of contaminants including heavy metals and hydrocarbons. Specific materials include rubber residue from tire wear, auto body rust and eroded plating, spilled or leaked oil and fuel, hydrocarbons from exhaust, metal and other materials worn from bearings, bushings and brake linings, and hydrocarbons leached from asphaltic pavement. Other contaminants include chloride, sodium, and calcium from de-icing materials, nitrogen and phosphorus from roadside fertilizer applications, and pathogenic bacteria from animal waste. Recent studies (e.g.: Marsalek et al., 1997) have also shown that highway runoff can be toxic to aquatic organisms.

The stormwater pond was designed in response to legislation under the Federal Fisheries Act that requires that water quality be addressed for all new developments that could affect fisheries habitat. In addition, interim guidelines had recently been disseminated by the Ontario Ministry of Natural Resources and the Ontario Ministry of the Environment regarding water quality controls for new development. The expansion of Highway 401 was considered to constitute new development, and the Rouge Valley was considered to be an area of specific interest. The facility was designed to accommodate future monitoring, and recommendations for the monitoring program were included in the preliminary design report (Marshall Macklin Monaghan Ltd., 1993).

1.2 Study Objectives

The primary objectives of this study were:

- to evaluate the effectiveness of the detention facility in controlling stormwater flow rates;
- to evaluate the effectiveness of the facility in enhancing the stormwater quality;
- to assess the status, health and suitability of the wetland vegetation communities at the facility with a view to recommending preferred vegetation planting strategies; and
- to make recommendations for facility improvement and the design of similar facilities in Ontario.

2 STUDY SITE

2.1 The Pond

2.1.1 Introduction

The Rouge River Stormwater Facility at Highway 401 and Highway 2 (Figure 2.1) was constructed in 1995 by the Ontario Ministry of Transportation (MTO) to address water quality and fishery concerns originating from highway runoff. The work was based on the Highway 401 – Rouge River Best Management Practices Preliminary Design Report by Marshall Macklin Monaghan Limited (1993). The report examined stormwater management requirements associated with the expansion of Highway 401 from Morningside Avenue to Rougemont Drive.

2.1.2 Drainage area and watershed

Figure 2.2 illustrates the watershed in the vicinity of Highway 401 and the Rouge River. Three catchment areas are shown in the figure:

- Centennial Creek drainage area (Morningside to west of Meadowvale Road);
- Rouge River drainage area West (west of Meadowvale Road to the Rouge River);
- Rouge River drainage area East (Rouge River to Rougemount Drive).

The central portion, consisting of 129 ha draining to the Rouge River from the west, is the principal catchment for the stormwater management pond. Approximately 75% of the drainage area is used for transportation, and the remaining 25% is primarily residential. Design data for the Rouge Pond catchment include a range of imperviousness from 25% to 95% for individual subcatchments (Yaeger, 1997). The average imperviousness of the catchment is approximately 45%.

Some of the details of the catchment are not clearly defined. According to the Preliminary Design Report (Marshall Macklin Monaghan Limited, 1993), part of the catchment - consisting of 18 ha of highway lands - drains to Centennial Creek but a flow splitter diverts some of the flow to the Rouge River. Also, approximately 18 ha of residential area outside of the catchment drains north to the Rouge River during small storms, but excess flow from larger storms enters the 129 ha catchment and drains westward to the river. A watershed inventory conducted by municipal authorities in 1997 was not able to confirm these variations in the tributary area.

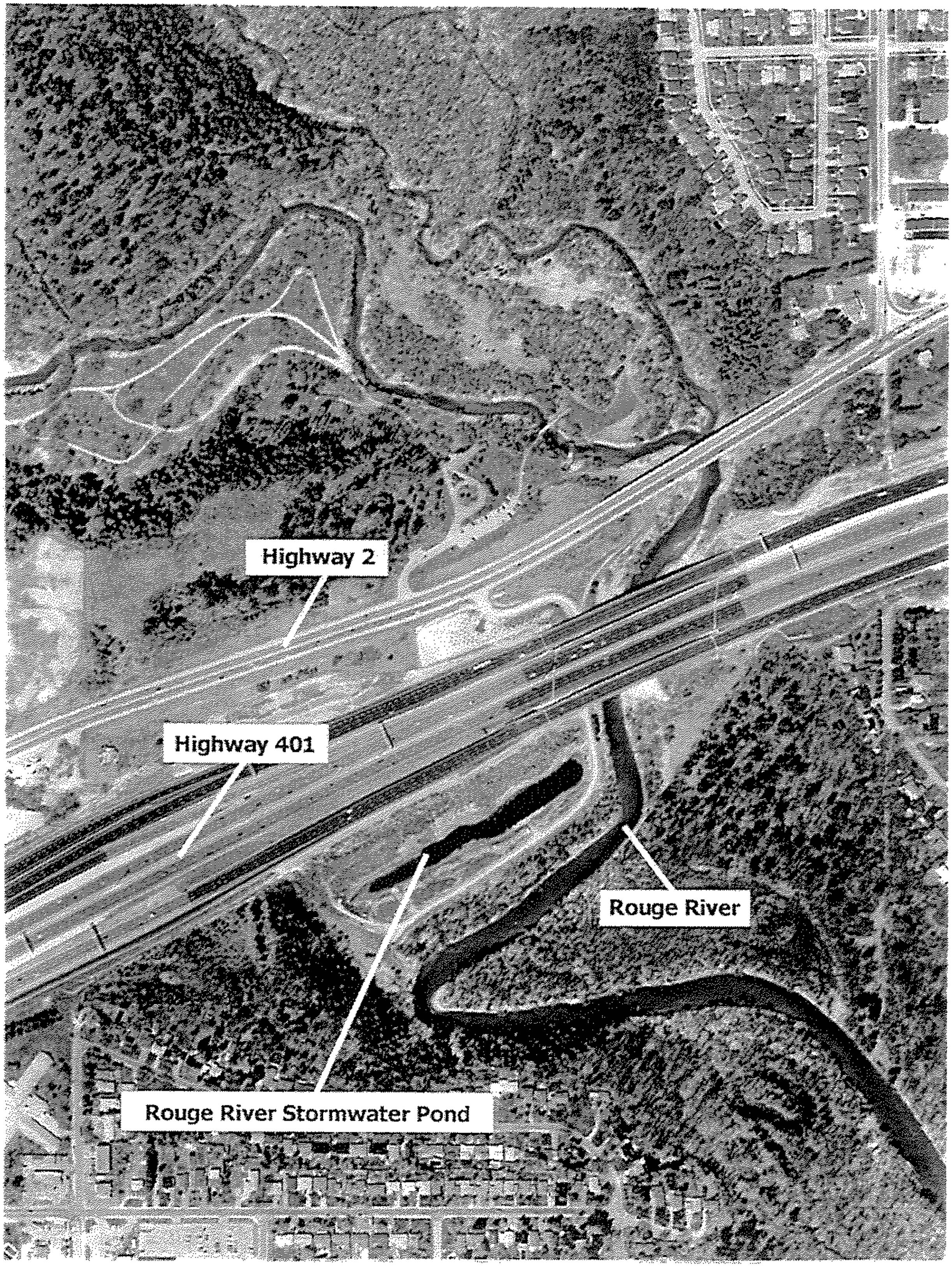

Figure 2.1: Rouge River stormwater facility – aerial photo

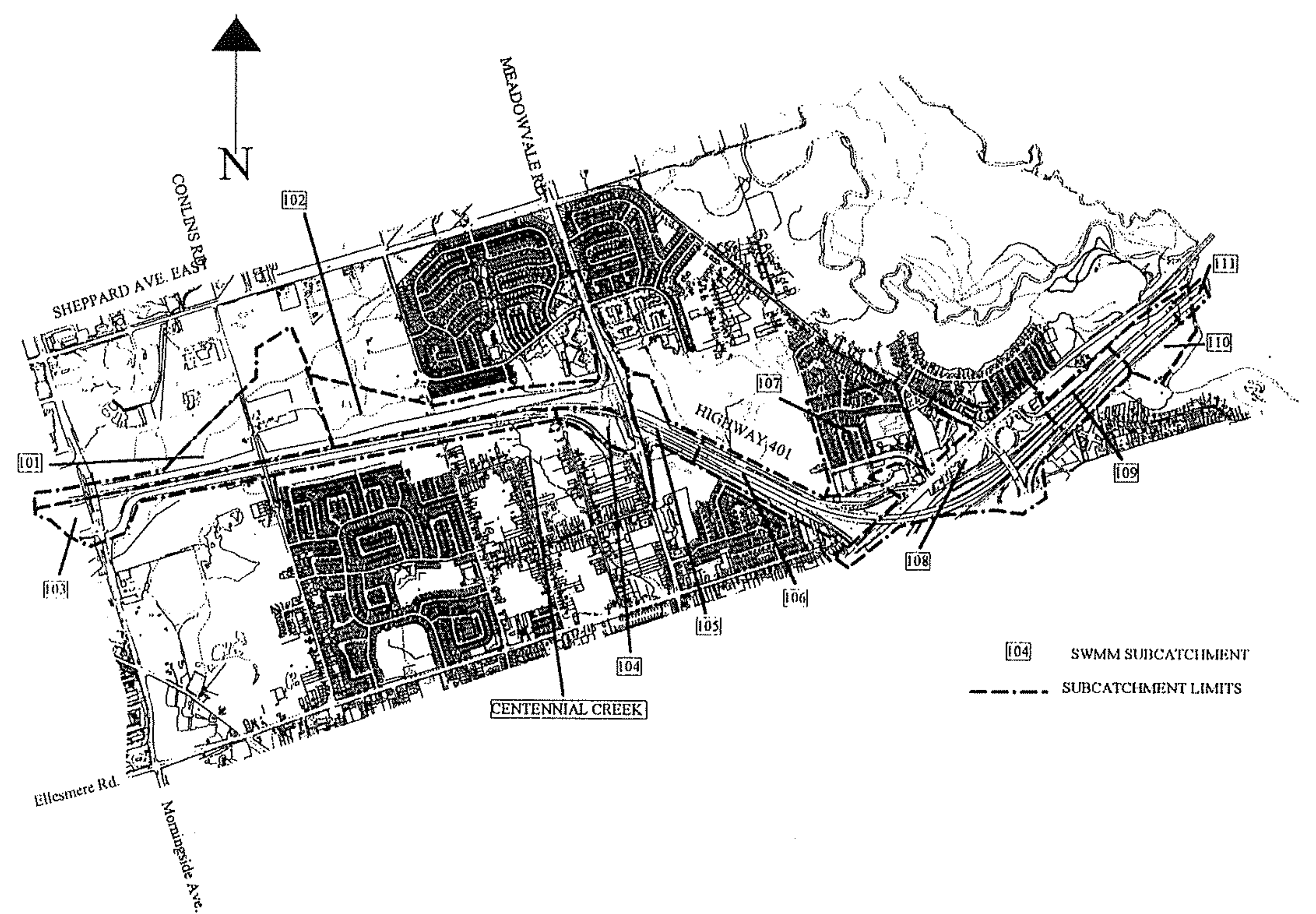

Figure 2.2: Rouge River stormwater facility -- watershed map

2.1.3 *Design of the facility*

Figure 2.3 is a site plan for the stormwater pond facility. Figure 2.4 illustrates the facility as a schematic plan and profile. Runoff from drainage areas is conveyed through two storm sewers of 2000 mm and 1200 mm diameter. These two pipes meet at a drop chamber which, in turn, is connected to a flow splitter chamber via an 1800 mm sewer. The flow splitter chamber was constructed just upstream of the pond to prevent large flows (storms greater than 2 year frequency) from entering the facility. Flow entering the splitter structure is conveyed to the pond through a sluice gate. As the pond fills, the backwater condition increases the water level in the splitter. When the water level reaches the height of the overflow weir, any additional flow will bypass the pond and enter the Rouge River directly through the 1800 mm diameter diversion pipe.

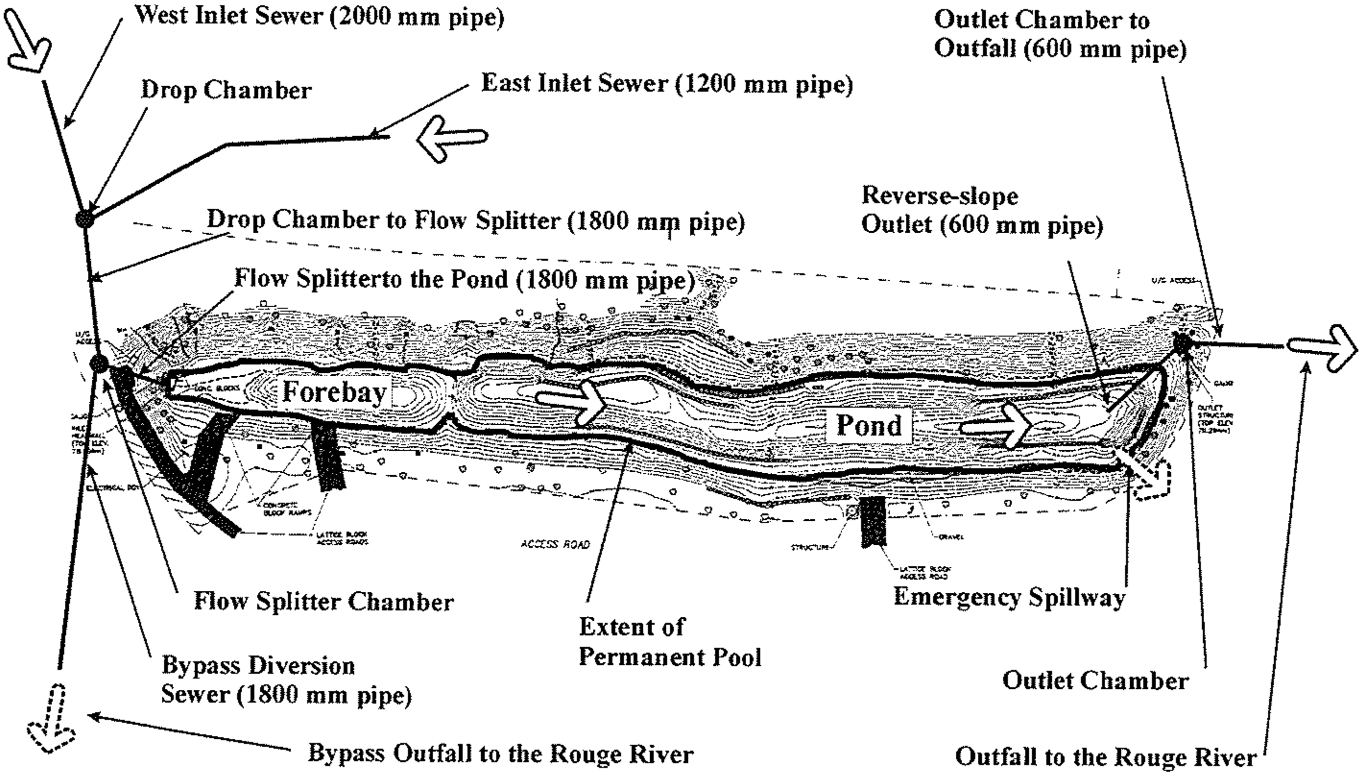

Figure 2.3: Site plan

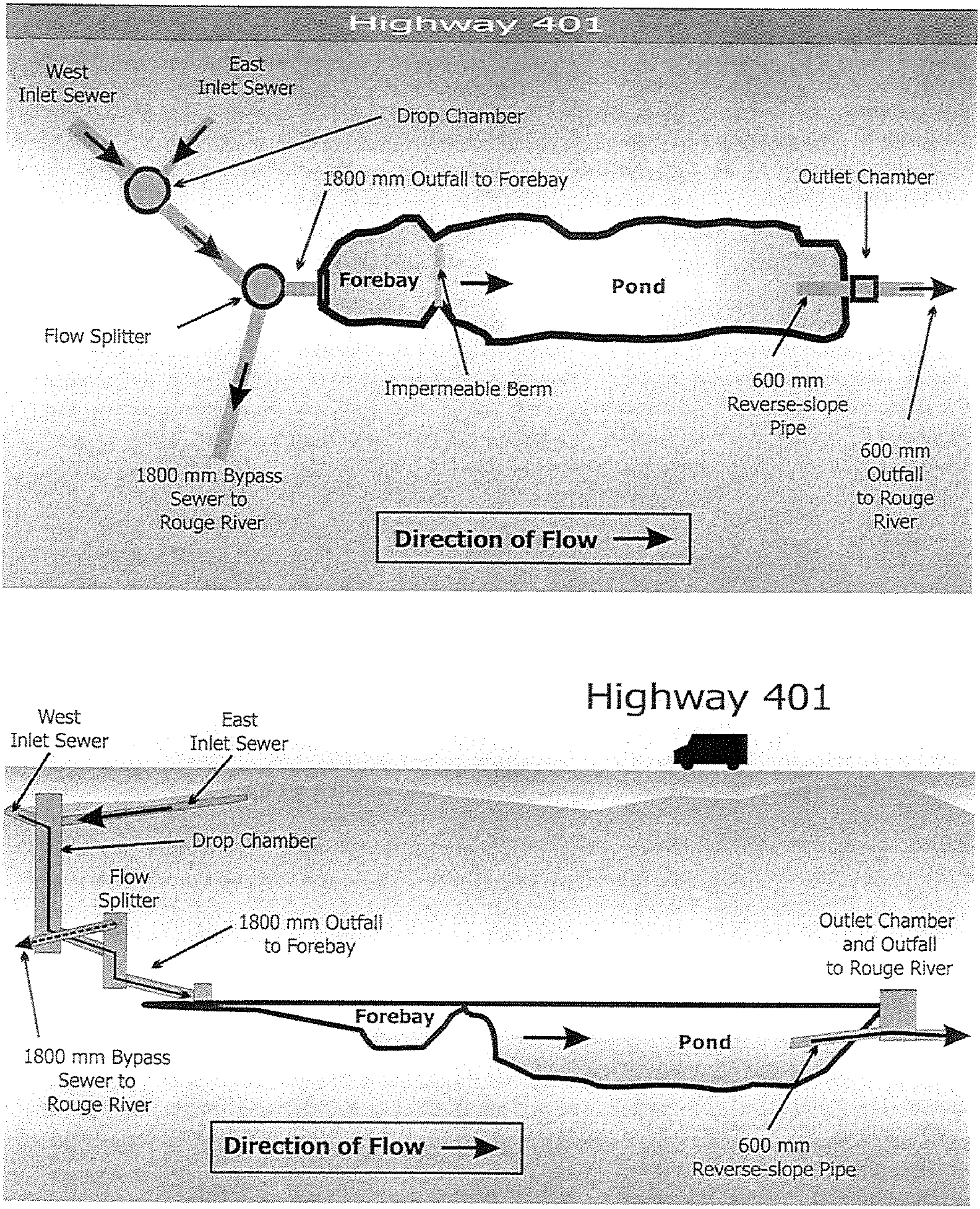

Figure 2.4: Rouge pond -- schematic plan & profile

The pond outlet incorporates of a 600 mm diameter reversed-slope pipe that draws water from below the surface of the pond, minimizing the potential for blockage due to floating debris. At the intake end, the invert of the pipe is 1 metre below the permanent pool water level. The pipe rises 1 metre to where it enters the outlet chamber, thus establishing the permanent pool level. The location of the inlet also prevents the warmer surface water in the pond from being discharged to the river. The outlet chamber contains a sluice gate for the control of the outflow rate. The gate was fully open during the entire monitoring period. A 660 mm pipe conveys the outflow from the outlet chamber to the Rouge River. A separate pipe was installed in parallel one metre below the outlet pipe to allow draw down of the permanent pool for maintenance purposes. Approximately four hours are required to draw down the permanent pool using this drain.

In addition to the bypass system upstream of the pond, there are two safety features incorporated in the pond. The outlet chamber has an open grating at the top. If the water in the pond rises 1.3 m above the level of the permanent pool, flow begins to enter the outlet chamber through the grating. If the water level increases another 0.4 m, flow begins to occur over an emergency spillway, 30 m wide, constructed along the south-east perimeter of the pond, crossing the access road and discharging into the Rouge River.

Concerns regarding the stability of the highway embankment posed a limit to the location of the pond. As a result, in order to accommodate the required storage volume, the pond was constructed approximately 300 m long with a top width varying from 25 m to 40 m. This configuration has a large length to width ratio (10:1), which has the effect of promoting plug-flow conditions. The average depth of the permanent pool is about 2.5 m, with a maximum depth of approximately 4.5 m.

The facility was constructed with a submerged impermeable berm that partitions the pond into a forebay and a treatment/retention zone. The forebay was developed as a sedimentation basin intended to capture the majority of the larger sized suspended solids. The dimension of the sediment forebay is 80 m in length and 20 m to 40 m in width, and it makes up approximately 14% of the total permanent pool volume.

Table 2.1 compares the pond design parameters to the design guidelines included in the Ontario Ministry of the Environment's Stormwater Management Planning and Design Manual (OMOE, 2003). The pond was designed using a rainfall-runoff simulation program (SWMM 4.04) and a pond simulation program (POND). The optimum size was selected based on the shape of predicted performance curves. Total suspended solids (TSS) removal efficiency increased rapidly with increased pond size up to approximately 70%, but improved only slightly with further increases in pond size. That level of performance is classified as "normal" in the OMOE design manual. Enhanced protection is associated with a long-term average TSS removal efficiency of 80%.

As seen in Table 2.1, the Rouge Pond is narrower and deeper than the provincial guidelines recommend. In terms of total volume per hectare served, the pond is larger (160 m^3/ha) than the provincial guidelines recommend for the normal level of protection (100 m^3/ha). The pond is only slightly smaller than the 165 m^3/ha recommendation for the enhanced level of protection. In addition, the total pond volume is divided equally between the permanent pool and the extended detention portions, rather than concentrating most of the volume in the permanent pool.

Table 2.1: Rouge pond design features compared to OMOE guidelines

Design Feature	**Design Objective**	**OMOE (2003) Guidelines**	**Rouge Pond Facility**[ς]
Permanent pool depth (m)	minimize resuspension; avoid anoxic conditions	maximum 3 *(2.5 preferred)*	2.5 average 4.5 maximum
Permanent pool volume (m^3/ha)	provision of level 2 fisheries protection	60* *(normal)* 125* *(enhanced)*	80
Extended detention depth (m)	storage & flow control	1 to 1.5 maximum total = 2	1.7
Extended detention volume (m^3/ha)	provision of level II fisheries protection	40	80
Drawdown time[+] (hours)	suspended solids settling	24	6 *(gate fully open)*
Length-to-width ratio	minimize short circuiting	at least 3:1 *(4:1 to 5:1 preferred)*	10:1 *(incl. forebay)*

[ς] from Marshall Macklin Monaghan Limited (1993)

* based on 45% surface imperviousness (OMOE, 2003)

[+] The SWMP manual (OMOE, 2003) suggests using 'drawdown time' as an approximate measure of 'detention time'.

2.2 The Site

2.2.1 Geology and Soils

The area considered in this study lies within the physiographic region known as the Iroquois Plain. The Rouge River Valley was formed during the most recent glacial period as a result of the Wisconsin Glacier retreat and subsequent erosion of the glacial deposits. Rising lake levels flooded the lower reaches of the Rouge Valley resulting in estuarine deposition above the glacial till. The Rouge River in the vicinity of Highway 401 is relatively wide and shallow for the most part, with its channel morphometry dominated by depositional sands and clay, with gravel bars sometimes covered with a fine layer of silt. The river course has changed considerably since the early 1900s, at least partially as a result of human activities. The soils in this area are predominantly silty sand to sandy silt and are stiff to dense. There is considerable fill throughout the area due to the construction of Highway 401. A perched water table was discovered in some boreholes, further confirming poor subsurface drainage conditions.

2.2.2 Vegetation

The site is located where the northern edge of the Carolinian vegetation zone meets the adjacent mixed deciduous and evergreen forest of the Great Lakes - St. Lawrence Forest Region. This wide variety of plants includes rare or unusual species at the northern or southern limits of their range. One hundred and ten (110) native vegetation communities have been described within the Rouge Valley area, with over 762 individual plant species. This high bio-diversity is unusual for any region within Canada, which by itself justifies the level of importance assigned to the Rouge River Valley. Its importance is enhanced, however, by its function as one of the last major wildlife movement and plant dispersal corridors linking the western shores of Lake Ontario to interior regions of the province.

The study area is bounded by the top of the valley on the east and west, Highway 2 to the north and the switchback bend in the Rouge River to the south of Highway 401. The vegetation in the study area is very diverse and is composed of 31 different vegetation communities. Six uncommon plant species are found in the vicinity, one considered to be locally rare, and five considered to be regionally rare (angelica, a sedge species, robin's plantain, black snakeroot, and slender gerardia). No provincially or nationally rare species have been reported in the study area. Vegetation communities in this area can be characterized as dry-mesic valley slope hemlock and red oak forest, and tableland mesic hemlock and sugar maple forest. The trees are relatively young in this section of the forest, and are not "living museum" specimens. Other vegetation communities include some roadside embankment vegetation and some small patches of coniferous and deciduous plantation.

2.2.3 Terrestrial Habitat

The diversity of vegetation communities found in the Rouge Valley, along with a relatively continuous corridor of naturally vegetated riparian and river valley habitat, results in heavy wildlife use of the area. At least 225 species of birds have been observed in the Rouge Valley; 123 of these are considered to breed in the area. Of these species, six are considered to be nationally and provincially rare (or of concern nationally), and four are considered to be of provincial concern. Another 38 are considered to be locally rare. The rufous-sided towhee, considered to be an uncommon or rare breeder in the area, has been identified in the valley slope forest just to the south of Highway 401 on the east side of the river. It has also been identified on the east bank of Little Rouge Creek just north of Highway 2. A nesting site for the northern rough-winged swallow has been confirmed on the west valley slope just south of the switchback bend in the river, south of Highway 401. This bird is a colonial species. Winter wrens, considered to be uncommon or rare breeders within the Rouge Valley study area, have been confirmed to breed just south of the northern rough-winged swallow location. The Rouge Valley supports approximately 27 mammal species and 19 reptile and amphibian species. While all of the reptile and amphibian species, and some of the mammal species, are considered to be rare or unusual in the Toronto area, none are considered to be nationally or provincially rare. Small pockets of wetland have been identified as being important for the maintenance of reptile and amphibian species in the Rouge Valley.

2.2.4 *Aquatic Habitat*

The Rouge River and its tributaries are home to a highly diverse fish community; over sixty species have been found in the Rouge system, including the Rouge Marsh at the outlet to Lake Ontario. Brook trout are resident and self-sustaining in the upper reaches of the Rouge River, while brown trout and rainbow trout migrate into the Rouge system from Lake Ontario to spawn. Additionally, two pacific salmon species migrate into the lower Rouge River in an unsuccessful attempt to spawn. Two fish species resident in the Rouge system, the redside dace and the stoneroller, are considered to be nationally and provincially vulnerable. The reaches of the Rouge, from the confluence of Little Rouge Creek to Lake Ontario, are considered by Ontario Ministry of Natural Resources (MNR) and the Toronto and Region Conservation Authority (TRCA) to be part of the delta marsh management zone. The management strategy for this section of the river is directed toward protecting or rehabilitating the habitat for a warm-water fishery, while at the same time protecting the reach for salmonid migration (i.e. rainbow and brown trout). White sucker, rock bass, smallmouth bass, and logperch are the most abundant species. Both adult and juvenile stages of the sucker and bass species were captured, confirming the use of this reach of river for rearing of warm-water fish. The water of the Rouge River is alkaline, characteristic of streams flowing across the deep glacial deposits of southern Ontario. Because the Rouge River is wide and shallow in this area, with only a small proportion shaded by canopy cover, solar warming is expected to be considerable in the summer. Oxygen concentrations are not expected to be a problem. Conductivity in stormwater drainage to the Rouge is high on occasions, possibly related to de-icing salt used on Highway 401.

3. METHODOLOGY

3.1. Introduction

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

Table 3.1 summarizes the sampling locations, instruments and methods. Details of the monitoring program and the statistical methods employed in analyzing the data are provided in the following sections of this chapter.

3.2. Water Quantity Monitoring

3.2.1. Flow monitoring operations in 1995

In 1995, for the purpose of gathering the hydrologic information, three flow monitoring stations were set up as illustrated in Figure 3.1. The first flow meter was installed at the 1800 mm diameter pipe downstream of the drop chamber to monitor the total flow entering the facility. Another flow meter was set up at the 1800 mm bypass sewer downstream of the flow splitter to determine the flow volume that bypassed the pond without getting any treatment. A fibreglass hut was used to protect the data loggers and an automatic wastewater sampler. A third flow meter was installed at the 600 mm diameter outlet pipe, just downstream of the outlet chamber, to measure the flow leaving the facility. The outlet equipment was also sheltered in a fibreglass hut. Flow rates were monitored continuously at all three stations during the period from July to November 1995. Rainfall data were obtained using a standard tipping bucket rain gauge, in conjunction with a data logger, which were located at the Rouge Stables approximately 1 km north of the facility.

The water balance between the inlet and outlet stations was found to be poor during the 1995 monitoring season. The poor balance could be attributed to work being done by a landscape contractor, who was planting the permanent pool as well as pond banks and the surrounding area. The water level in the pond was drawn down occasionally in order to facilitate the landscaping activities. In addition, intensive construction activities along Highway 401 caused erosion. At times, runoff from the construction site flowed overland to the pond. Also during the 1995 monitoring period, the flow monitoring station at the inlet was found to be affected by backwater from the facility. The backwater effect complicated the task of computing the water balance.

Table 3.1: An overview of monitoring locations -- Rouge Pond, 1995-1997

Location	Instrument used	Instrument type	Recording interval	Instrument used in 1995	Instrument used in 1996	Instrument used in 1997
Flow splitter upstream 1800 mm	Flow meter	Q-logger	5 min.	×		
	Pressure transducer	Level Tracker	5 min.		×	×
	Temperature probe	RTM	10 min.	×	×	
Flow splitter chamber	Automatic sampler	ISCO 3700	Level triggered	×	×	×
	Multisonde	DataSonde 3	30 min.		×	
Inlet sewer 2000 mm	Flow meter	ISCO 4250	5 min.		×	
	Flow meter	ISCO 4150	5 min.			×
Inlet sewer 1200 mm	Flow meter	ISCO 4250	5 min.		×	
	Flow meter	ISCO 4150	5 min.			×
Bypass sewer 1800 mm	Flow meter	Q-logger	5 min.	×		
Outlet chamber	Automatic sampler	ISCO 2700	Flow proportional	×	×	×
Reverse slope pipe 600 mm	Temperature probe	RTM	10 min.	×	×	
	Multisonde	DataSonde 3	30 min.		×	
Outlet sewer 600 mm	Flow meter	Q-logger	5 min.	×	×	
	Flow meter	ISCO 4150	5 min.		×	×
Rouge River upstream	Temperature probe	RTM, Hobo	30 min.		×	
Rouge River Stables	Rain gauge	TBRG	5 min.	×	×	
	Weather station	CR-10	30 min.		×	
MTO shelter	Rain gauge	TBRG	5 min.		×	×

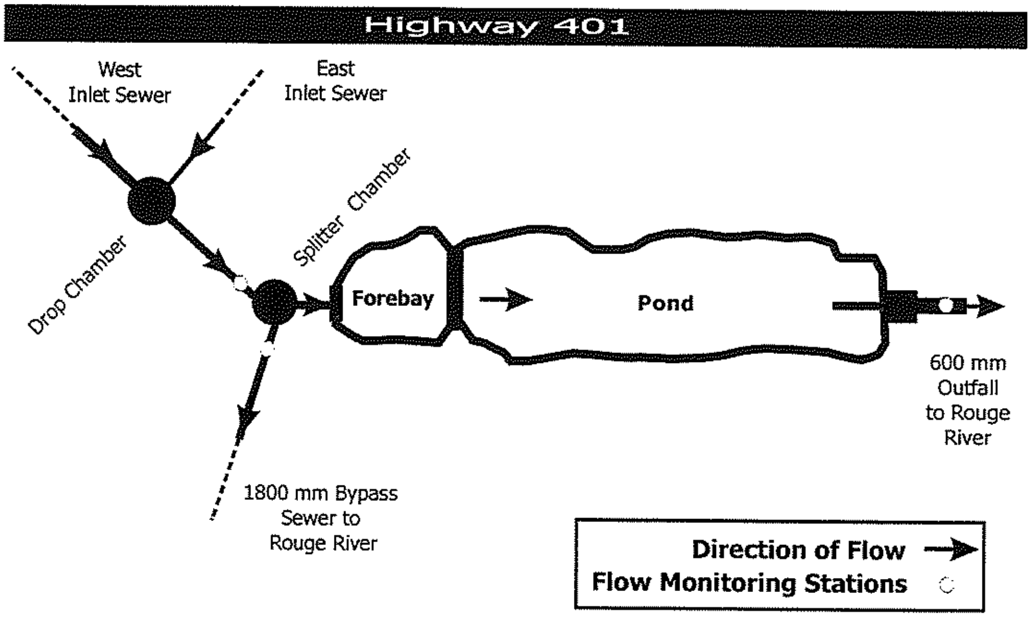

Figure 3.1: Location of flow monitoring stations -- 1995

3.2.2. Flow monitoring operations in 1996 and 1997

Four flow monitoring stations were established in 1996 and 1997. The most suitable location to monitor the flow entering the facility was found to be upstream of the drop chamber, which is a confluence point for two inlet storm sewers (Figure 3.2). The two inlet sewers were straight in the area where the probes were installed, and they were found to be free of sediment at the time of installation. Flow rates were continuously monitored in both sewers over the two monitoring seasons.

The 600 mm outlet pipe was equipped with a flow meter, just downstream of the outlet chamber, during the periods from June to November 1996, and from April to September 1997. An additional pressure transducer was installed upstream of the flow splitter chamber, where the influent flow meter had been in 1995. The depth readings obtained at the flow splitter indicated when overflows had occurred and could be used in data correlation work to assist in the interpretation of the flow data.

Frequent inspections showed that a thick layer of sediment (as thick as 25 to 30 cm) accumulated at the downstream portion of the 1800 mm bypass sewer, next to the Rouge River. This sediment was likely being deposited directly from the river, and not from the sewer. Consequently, maintenance was needed more frequently than expected and reliable flow measurement in the bypass sewer was not possible in 1996 and 1997. The lack of data from this location was not much of a concern, because data collected in 1995 indicated that overflow occurred during very few events, and overflow could be estimated using depth readings from the flow splitter.

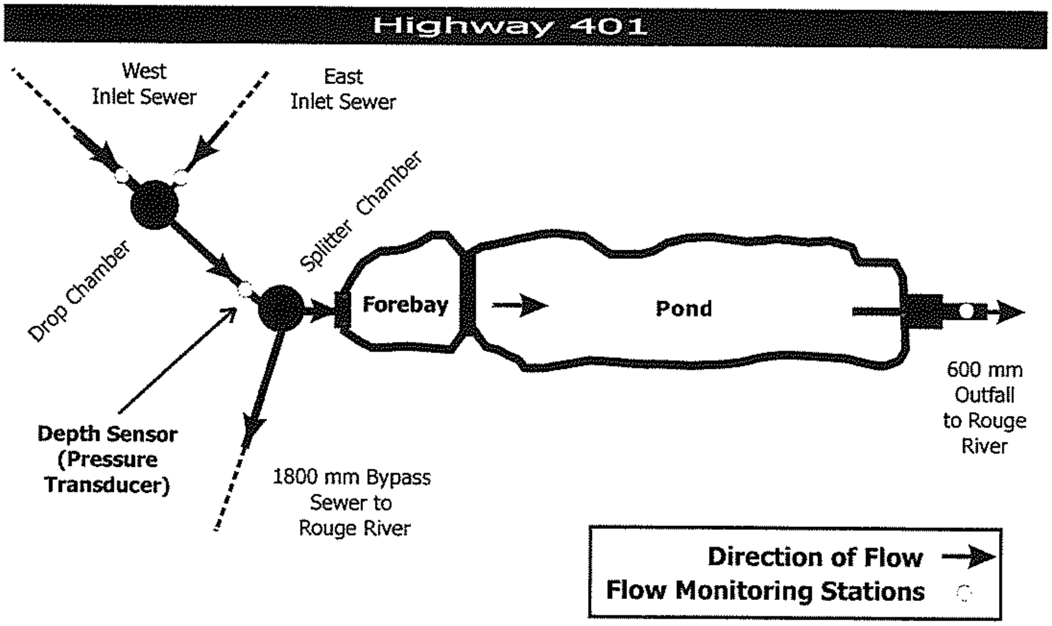

Figure 3.2: Location of flow monitoring stations -- 1996 & 1997

Continuous recording of rainfall accumulation and atmospheric temperature was conducted in the vicinity of the study site in 1996 at the Rouge Stables. Rainfall data were obtained using a standard tipping bucket rain gauge. A supplementary weather station, used to monitor various weather conditions in the pond vicinity, was also located at the Rouge Stables. In April 1997 the rain gauge was transferred from the Rouge Stables location to within the pond facility perimeter. The weather station was operational only in 1996.

3.3. Water Quality Monitoring

3.3.1. Water quality sampling

Two sampling stations were maintained throughout the duration of the study. The inlet station was set up at the 1800 mm diameter inlet pipe, which conveys the runoff from the flow splitter to the facility. The automatic composite sampler was triggered by a liquid level sampler actuator. Once the water level reached the actuator, the sampler initiated the program and collected samples at five-minute intervals. This particular technique was applied in response to rapid changes in flow rate at the inlet[1]. In 1995 the equipment was set

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[1] Flow proportioned sampling is feasible only if the frequency or duration of sampling can be proportioned to the flow in the stream being sampled. Highly variable inlet flows do not provide a suitable hydrograph shape.

up in the same fibreglass shelter used to accommodate the flow monitoring equipment. During the 1996 and 1997 monitoring seasons the sampler was located inside the flow splitter.

The outlet station was set up at the end of the 600 mm reverse slope pipe and the sampler was positioned in the outlet fibreglass shelter. In this case, the automatic sampler was triggered directly by the flow meter. Sampling frequency was one sample per 100 m^3 of runoff volume. From July 1995 to June 1996, for every successful sampling event, approximately 120 litres of sample were collected at the inlet and outlet: 100 litres for toxicity testing and the balance for chemical analysis. After June 1996, the large-volume toxicity samples were no longer required and the total sampling volume was reduced to 20 litres. When appropriate, grab samples were collected at the same locations in corresponding quantities.

3.3.2. Temperature measurement

Water temperature was measured during the 1995 and 1996 monitoring seasons. The inlet station was set up just upstream of the flow splitter where a temperature data logger was installed in the incoming 1800 mm pipe. The outlet station was established near the outlet chamber where a logger was placed at the end of the reverse-slope 600 mm pipe. For these two stations, a ten-minute recording interval was applied.

An additional temperature data logger was installed in 1996 in the Rouge River itself, approximately in the middle of the stream, just upstream from the facility outfall pipe. The purpose of monitoring the river temperature was to investigate the potential impacts the facility might have had on the receiving stream. The recording interval at this station was 30 minutes.

3.4. Vegetation and Algae Monitoring

The aquatic vegetation monitoring component was conducted by the Toronto and Region Conservation Authority during 1996 and 1997. The goal of the study was "to develop a list of recommended vascular wetland plant species and recommended planting strategies for stormwater management pond projects in the Greater Toronto Area". The study surveyed the growth and development of planted and naturally colonized plant species within the facility. A complete description of the methodology and study results is given in Appendix E. Chapter 6 includes a summary of the findings.

The algal community assessment component was conducted by Daniel D. Olding, Consulting Biologist, under contract to the Toronto and Region Conservation Authority during 1996 and 1997. This study documented the baseline conditions of the summer phytoplankton and periphyton communities, compared in-facility community structure and reports on the relevant physical and chemical monitoring conducted in conjunction with the algal monitoring. Algae were used as an indicator of ecological and water quality conditions of the forebay and wet pond. A complete description of the methodology and study results is given in Appendix F. Chapter 6 includes a summary of the findings.

3.5. Summary of Available Data

Water samples from approximately sixty separate rainfall events were collected for this study between June, 1995 and September of 1997. The samples were analyzed for most of the major groups of pollutants commonly found in stormwater runoff, including:

- total suspended solids;
- nutrients (total phosphorus, phosphate, TKN, nitrate, nitrite);
- bacteria (Fecal Coliforms, *Pseudomonas aeruginosa*, *E.Coli*);
- heavy metals (lead, iron, copper, zinc, cadmium, nickel, chromium, etc.); and
- oil and grease.

Analyses were also conducted for polyaromatic hydrocarbons(PAH's), chlorophenols, phenoxy acid herbicides, dissolved carbon, conductivity, chloride, pH, alkalinity, arsenic and selenium. However, data obtained for many of these variables were not included in the statistical analysis procedure due to their low frequency of detection. Data were divided into two distinct seasons for analysis: summer/fall (May to November) and winter/spring (December to April). The data were further subdivided into two time periods that reflect the construction period (June 1995 to August 1996) and post-construction (September 1996 to September 1997). All of the winter/spring data were analyzed together as one group because only two samples were collected during the winter/spring season of 1996-1997.

For most of the water quality variables, approximately 20 samples were included in the summer/fall season data set and approximately 10 were available from the winter/spring season. The number of samples obtained for bacteria tests was limited in both seasons because, in many cases, the samples could not be analyzed within the required 24-hour limit. The number of calcium and magnesium samples was limited because reporting of these two variables began in September 1996, for the purpose of determining the source of dissolved solids.

Detailed lists of the events monitored for rainfall, level and flow, and those sampled for water quality are included in Appendix H.

3.6. Analytical Procedures

3.6.1. Hydraulic analysis

Fundamental concepts of volumetric balances for pond systems are discussed in Appendix C. For this study, the continuous baseflow through the pond became a significant consideration in the analysis. Other factors included data loss due to battery failure or other causes. The data analysis procedure and the hydraulic data obtained from the study are reported in Appendix G. Chapter 4 summarizes the hydraulic monitoring results.

3.6.2. Chemical analysis

Chemical analysis of samples obtained from the field were undertaken by the Ontario Ministry of the Environment laboratory. All analyses were performed according to OMOE procedures. Appendix D summarizes the methods used. Chapter 5 summarizes the laboratory analysis results.

3.6.3. Statistical techniques

Statistical analysis of water quality parameters was performed using a software package developed by the Ministry of the Environment for use in stormwater quality constituent analysis (Maunder *et al.*, 1995). The package was configured to derive several important statistical parameters, including mean concentrations, upper and lower 95% confidence intervals, standard deviations and estimates of left-censored data. Left-censored data are data below the lower detection limit of the analytical lab equipment. The statistical package accounted for left-censored data by assigning values using Probability Distribution Estimation (PDE) techniques and other statistical methods. This feature was very useful in the analysis of some metals and organic constituents, which were often found at trace concentrations. All statistical calculations were based on log-normal probability distributions.

Load-based removal efficiency (*LE*), which requires both the flow volume (V) and event mean concentration (EMC) of constituents, could only be calculated for events during the summer/fall period when the required data were available. Removal efficiency during the summer/fall monitoring period was derived for each sampled event according to the following equation:

$$LE_{emc} = \left[\frac{\left[\left(V_i \times EMC_i \right) - \left(V_O \times EMC_O \right) \right]}{\left(V_i \times EMC_i \right)} \right] \times 100\% \qquad (3\text{-}1)$$

where: o = outlet
i = inlet

Equation 3-1 is equivalent to Equation C-8 in Appendix C.

The event mean concentration must be considered in the context of the monitoring procedure. The inlet sample was time-based, consisting of a composite of several aliquots, each collected at 5-minute intervals. The outlet sample was flow-proportioned, consisting of a composite of several aliquots, each collected every 100 m^3 of flow. One sample was taken from each location for each event, so the samples did not necessarily represent the entire event duration.

The seasonal load based removal efficiency (*SLE)* for the entire summer/fall season is based on cumulative loads, as follows:

$$SLE_{emc} = \left[\frac{\sum_{j=1}^{m} [(V_{i_j} \times EMC_{i_j}) - (V_{O_j} \times EMC_{O_j})]}{\sum_{j=1}^{m} [V_{i_j} \times EMC_{i_j}]} \right] \times 100\% \qquad (3\text{-}2)$$

where: m = total number of storm events monitored

Equation 3-2 is equivalent to Equation C-10 in Appendix C.

In the winter/spring season, when flow was not monitored and grab samples were collected, concentration-based removal efficiency (*CE*) was determined by assuming that there was a good hydrologic water balance (*i.e.* the volume entering the pond within an individual event was equal to the volume leaving the pond), such that,

$$CE = \left[\frac{(C_i - C_O)}{C_i} \right] \times 100\% \qquad (3\text{-}3)$$

where: C_i = influent constituent concentration (grab sample)
C_o = effluent constituent concentration (grab sample)

4 WATER QUANTITY ANALYSIS

4.1 Program Overview

4.1.1 Field data availability and reliability

Flow monitoring was performed at the facility over three seasons: from June to November 1995, from July to November 1996, and from April to September 1997. Small events were not sampled or included in the data analysis procedure. The events of interest were considered to be those with at least 10 mm of total rainfall, and events having less total rainfall but with average intensities greater than 1 mm/h.

Flow data for some events were not available or were considered to be unreliable. For example, in 1995, velocity readings from the flow meter located just upstream of the flow splitter were affected by backwater from the pond for all the depth readings greater than about 250 to 300 mm. In October 1995, equipment at the inlet and outlet stations was washed away during a large storm event. In 1996 and 1997, some data were lost due to equipment breakdown. Otherwise, the hydraulic data that were collected were considered to be generally reliable. Spot measurements were made in the field for quality control using a portable flow meter during some storm events. However, as discussed in Appendix G, detailed analysis of the hydraulic data has revealed some additional problems.

4.1.2 Site conditions -- construction period

When the monitoring equipment was first installed in 1995, the landscape contractor was still at work. At times, the contractor drained the pond through the maintenance pipe, thus affecting the water balance. The landscape work was completed approximately at the end of August 1995, but construction of Highway 401 continued until the end of August 1996. Flow diversion, major construction works and gradual introduction of the total drainage area into the sewer system significantly affected the characteristics of the runoff.

During the construction period, field inspections revealed deep erosion marks on the north bank of the pond. Those erosion channels, draining to the pond forebay directly from the highway, were active until the end of August 1996. Sediment was found accumulating in the facility at a very fast rate, resulting in reduced storage volume. Although the sediment forebay was dredged out in August 1995, it was almost completely filled again by the end of the year. Over-land flow into the facility affected not only the inlet water quality and system performance, but also caused problems with the computation of the water balance through the facility.

The total drainage area was apparently introduced into the sewer system only after all the construction activities had been completed, approximately at the end of August 1996. Because construction activity affected the performance of the pond, only data collected during the period from September 1996 to September 1997 were considered to be representative for the purpose of assessing the normal performance of the facility.

4.1.3 Data generation

A complete set of field data was not available for some storm events. Various strategies were applied to compensate for data loss. The pressure transducer installed in the pipe leading to the flow splitter in 1996 and 1997 provided some backup data. Although several data correlation methods were investigated, only simple, intra-event and intra-station correlations of sensor depth to flow data were employed in the final data analysis process. Data analysis methods are discussed in this chapter and in Appendix G.

4.2 Results of Data Analysis

4.2.1 Rainfall -- post-construction period

Table 4.1 summarizes twenty-eight significant rainfall events during the post-construction monitoring period from September 1996 to September 1997. Several factors should be considered while interpreting the contents of this table:

- Rainfall was tabulated on an hourly basis. Although the rain data were recorded at 5-minute intervals, the detailed data were not available at the time that this report was written.
- *Duration* was determined by summing the number of hours with measured rainfall, over the range of the rainfall-runoff event. This parameter is *not* the elapsed time of rainfall from the start of rainfall to the last hour of measured rainfall inclusive of hours with no measured precipitation.
- Similarly, the *average intensity* is the average of all hourly observations with measured precipitation, excluding hours of no measured precipitation found between the non-zero observations.
- The rainfall intensity and the *peak factor* are based on hourly data. Peak factor is the ratio of the outlet peak to the inlet peak, expressed as a percentage.

4.2.2 Hydraulic data -- post-construction period

Table 4.2 summarizes the availability and quality of hydraulic data for the post-construction period, together with some of the results of the hydraulic analysis work. The data were analyzed using a procedure that separated baseflow from runoff, estimated the exfiltration flow, and calculated the volumetric balance for the pond. The procedure is explained in detail in Appendix G, and Table G.1 contains a more comprehensive summary of the hydraulic data.

Thirteen events were found to have volumetric errors of ±15% or less (i.e., the same order of magnitude as would be expected for the instruments used in the study). The remaining 15 events lacked either inlet or outlet data, or some of the data were suspect and a poor volumetric balance resulted. At the end of the data analysis process, hydraulic data were reported for all 28 events, using substitution methods to replace missing or poor quality observations. The remainder of this chapter discusses the observations and the analysis procedures.

Table 4.1: Significant rainfall events in the post-construction monitoring period

Event Date	Duration (hr.)	Total Rainfall (mm)	Average Intensity (mm/h)	Maximum Intensity (mm/h)	Peak Factor	Rainfall East Inlet (m^3)	Rainfall West Inlet (m^3)	Total Rain Volume (m^3)
Sep. 07, 1996	30	72.4	2.4	9.0	3.69	9,948	83,839	93,787
Sep. 11, 1996	9	14.6	1.6	3.6	2.22	2,006	16,907	18,913
Sep. 13, 1996	31	49.2	1.6	9.4	5.92	6,760	56,974	63,734
Sep. 24, 1996	12	14.2	1.2	2.8	2.37	1,951	16,444	18,395
Sep. 27, 1996	24	27.6	1.2	3.0	2.61	3,792	31,961	35,753
Oct. 09, 1996	17	14.2	0.8	2.0	2.39	1,951	16,444	18,395
Oct. 18, 1996	41	35.2	0.9	5.0	5.82	4,836	40,762	45,598
Nov. 07, 1996	12	12.4	0.8	1.0	1.36	1,704	14,359	16,063
Apr. 27, 1997	11	9.8	0.9	2.2	2.47	1,347	11,348	12,695
May 03, 1997	15	26.2	1.7	6.8	3.89	3,600	30,340	33,939
May 05, 1997	7	9.4	1.3	2.4	1.79	1,292	10,885	12,177
May 11, 1997	25	11.0	0.7	2.2	3.00	1,511	12,738	14,249
May 15, 1997	13	11.2	0.8	2.4	2.84	1,539	12,970	14,508
Jun. 13, 1997	2	11.4	5.7	9.4	1.65	1,566	13,201	14,768
Jun. 16, 1997	9	14.8	1.6	5.0	3.04	2,034	17,138	19,172
Jun. 18, 1997	4	4.6	1.2	4.8	4.00	632	5,327	5,959
Jun. 21, 1997	2	5.6	2.8	5.4	1.93	769	6,485	7,254
Jun. 24, 1997	7	13.8	2.0	5.2	2.64	1,896	15,980	17,877
Jul. 07, 1997	3	7.6	2.5	4.6	1.82	1,044	8,801	9,845
Jul. 08, 1997	9	10.6	1.8	4.6	2.59	1,456	12,275	13,731
Jul. 27, 1997	2	6.8	3.4	6.2	1.82	934	7,874	8,809
Aug. 13, 1997	6	28.2	4.7	11.0	2.34	3,875	32,656	36,530
Aug. 15, 1997	5	29.0	5.8	9.8	1.69	3,985	33,582	37,567
Aug. 20, 1997	17	25.0	1.5	5.6	3.81	3,435	28,950	32,385
Sep. 06, 1997	8	19.0	2.4	11.0	4.63	2,611	22,002	24,613
Sep. 10, 1997	18	24.6	1.4	5.8	4.24	3,380	28,487	31,867
Sep. 25, 1997	7	7.0	1.0	3.4	3.40	962	8,106	9,068
Sep. 28, 1997	17	20.0	1.2	5.2	4.42	2,748	23,160	25,908

Table 4.2: Results of hydraulic analysis -- post-construction monitoring period

Event Date	Total Rainfall (mm)	Rain Volume (m^3)	Inlet Volume (m^3)	Outlet Volume (m^3)	Ex-filtration (m^3)	Vol. Error* (%)	Runoff Coefficient				Data Availability**		
							East Inlet	West Inlet	Total Inlet	Outlet	East Inlet	West Inlet	Outlet
Sep. 07, '96	72.4	93,787	n/a	40,200	n/a	n/a	0.59	n/a	n/a	0.39	●	**n/a**	●
Sep. 11, '96	14.6	18,913	n/a	8,504	n/a	n/a	0.28	n/a	n/a	0.35	●	**n/a**	●
Sep. 13, '96	49.2	63,734	n/a	36,449	n/a	n/a	0.49	n/a	n/a	0.47	●	**n/a**	●
Sep. 24, '96	14.2	18,395	10,428	7,079	3,355	0%	0.39	0.31	0.32	0.32	●	●	●
Sep. 27, '96	27.6	35,753	22,061	16,692	5,915	-2%	0.39	0.38	0.38	0.40	●	●	●
Oct. 09, '96	14.2	18,395	13,220	n/a	n/a	n/a	0.27	0.25	0.25	n/a	●	●	**n/a**
Oct. 18, '96	35.2	45,598	29,534	n/a	n/a	n/a	0.25	0.41	0.39	n/a	●	●	**n/a**
Nov. 07, '96	12.4	16,063	16,112	10,109	9,029	-19%	0.42	0.26	0.28	0.47	●	●	◎
Apr. 27, '97	9.8	12,695	10,026	4,557	6,517	-10%	0.14	0.23	0.22	0.30	●	●	◎
May 03, '97	26.2	33,939	18,666	16,899	5,300	-19%	0.29	0.29	0.29	0.41	●	**?**	●
May 05, '97	9.4	12,177	9,524	6,043	3,646	-2%	0.22	0.33	0.32	0.33	●	●	◎
May 11, '97	11.0	14,249	10,666	4,900	4,560	11%	0.08	0.27	0.25	0.17	●	●	◎
May 15, '97	11.2	14,508	10,697	4,294	5,977	4%	0.16	0.28	0.27	0.24	●	●	◎
Jun. 13, '97	11.4	14,768	n/a	8,361	n/a	n/a	0.40	n/a	n/a	0.48	●	**X**	◎
Jun. 16, '97	14.8	19,172	7,517	5,306	3,398	-16%	0.38	0.13	0.16	0.22	●	**?**	◎
Jun. 18, '97	4.6	5,959	7,485	1,799	5,237	6%	0.18	0.20	0.19	0.12	●	●	◎
Jun. 21, '97	5.6	7,254	7,814	2,730	5,049	0%	0.28	0.23	0.23	0.23	●	**?**	◎
Jun. 24, '97	13.8	17,877	7,644	5,842	3,098	-17%	0.28	0.19	0.20	0.26	●	**?**	◎
Jul. 07, '97	7.6	9,845	3,831	1,841	2,449	-12%	0.22	0.08	0.09	0.12	●	**?**	◎
Jul. 08, '97	10.6	13,731	5,484	2,532	2,520	8%	0.31	0.15	0.17	0.14	●	**?**	◎
Jul. 27, '97	6.8	8,809	2,790	1,791	1,779	-28%	0.19	0.05	0.06	0.15	●	**X**	◎
Aug. 13, '97	28.2	36,530	10,017	9,331	4,197	-35%	0.28	0.10	0.12	0.21	●	**X**	◎
Aug. 15, '97	29.0	37,567	12,539	12,212	4,409	-33%	0.35	0.16	0.18	0.29	●	**X**	◎
Aug. 20, '97	25.0	32,385	12,172	9,166	3,878	-7%	0.27	0.22	0.22	0.25	●	**?**	◎
Sep. 06, '97	19.0	24,613	n/a	7,118	n/a	n/a	0.27	n/a	n/a	0.19	●	**n/a**	◎
Sep. 10, '97	24.6	31,867	n/a	8,545	n/a	n/a	0.27	n/a	n/a	0.19	●	**n/a**	◎
Sep. 25, '97	7.0	9,068	4,369	1,996	2,201	4%	0.21	0.15	0.16	0.14	●	●	◎
Sep. 28, '97	20.0	25,908	8,742	6,086	1,593	12%	0.30	0.20	0.21	0.17	●	●	◎

* Volumetric error is calculated as *inlet volume - outlet volume - exfiltration volume*, and is reported as a percentage of the inlet volume.

** ● Data are available and appear to be in good condition.

◎ Data are available but are incomplete. Typically, the observations lack low values.

? Data are available but the data quality is suspect.

X Data are available but are visibly corrupted. The data may be erratic or apparently out of calibration.

n/a Data are not available, presumably because of complete instrument failure.

Examination of the information in Table 4.2 reveals the following chronology:

- When the post-construction monitoring program began, the west inlet sensor was not functioning; it affected three events.
- Two events were subsequently monitored successfully.
- The outlet sensor ceased functioning, affecting two events.
- When the outlet sensor was returned to service it was no longer capable of measuring the baseline or dry-weather flows that it had measured in the first five events. This limitation persisted to the end of the study.
- The west inlet sensor performed erratically through much of the 1997 season. After being out of service for two events in September, the sensor measured the final two events.

Because a reasonable volumetric balance was not obtained for the majority of the events, alternative criteria were sought as a means of determining the reliability of the inlet or outlet data in specific cases. Runoff coefficients were considered for this purpose. Table 4.2 includes the runoff coefficients calculated for the two inlet sewers and the pond outlet. The runoff coefficients should be of a general magnitude representative of the type of catchment. Variations in value between events are considered to be representative of both the nature of the system and the quality of the hydraulic data. The storage/retention capacity of the catchment would be expected to vary directly with the extent of vegetation and inversely with the degree of soil saturation. The degree of soil saturation would be influenced by both current and antecedent rainfall. The rate of percolation into the soil is also a limiting factor; for example, an intense storm would generate more runoff than a prolonged storm of equal volume. Also, as identified in Chapter 2, the catchment for this pond has extraneous inputs that vary with the size or intensity of the rainfall event. Hence, the calculated runoff coefficients would vary in the absence of any monitoring error, and the relative contributions of the natural system and monitoring error would be difficult to ascertain.

The average runoff coefficient for the smaller, eastern drainage area (14 ha) was 0.29, with a range of 0.08 to 0.59. The smallest value corresponds to a prolonged rainfall event with the smallest average intensity of the 28 events. The largest coefficient value was obtained from the event with the largest rainfall volume.

For the larger, western drainage area (116 ha), the average runoff coefficient was 0.22, with a range of 0.05 to 0.41. The smallest value resulted from a suspect data set. The largest came from the largest event for which the sensor was operational, but with a relatively small average intensity.

The runoff coefficient at the outlet is the ratio between runoff volume at the outlet and total rain volume. Since the baseflow volume has been subtracted from the total outlet volume to produce the runoff volume, and the exfiltration volume is the difference between the two baseflows, the outlet runoff coefficient should be equal to the inlet coefficient if there is a volumetric balance across the system. The average outlet coefficient was 0.27, compared to the overall average inlet coefficient value of 0.23.

The inherent variability of the runoff coefficient, particularly for this catchment, makes it a poor criterion for judging the acceptability of the hydraulic data set. Conversely, if volumetric error is used as a criterion for selecting valid runoff coefficients, the 13 events with volumetric errors of 15% or less yield the following results:

- average total influent runoff coefficient = 0.24 (range = 0.09 to 0.38)
- average outlet runoff coefficient = 0.23 (range = 0.12 to 0.40)

4.3 Examples of Rainfall-Runoff Events

4.3.1 Event of September 24, 1996

The best hydraulic balance was found in a relatively small event in September of 1996. This event and the data analysis procedure are described in detail in Appendix G. Figure 4.1 illustrates the rainfall and the flows in the two inlet sewers and the pond outlet. The difference between the baseflows before and after the event is interpreted as the amount of exfiltration from the pond to the adjacent Rouge River. Figure 4.2 compares the combined inlet hydrograph to the outlet hydrograph and contains the storage volume curve. The storage volume was estimated by subtracting the outflow volume and the exfiltration volume from the influent volume on an incremental basis. The incremental exfiltration volumes during the event were estimated by linear interpolation based on the pre-event and post-event conditions.

Table 4.3 contains the summary statistics for this event. The parameters that quantify the hydraulic performance of the system should be considered with respect to influences of the raw data quality and the analysis procedure. The following points refer to time measurement:

- The rainfall duration was reported as the sum of non-zero hourly observations. The elapsed time was measured from the start of the first non-zero reporting period to the end of the last non-zero period.
- The average rainfall was calculated by ignoring the non-zero observations. That may not be a standard procedure but, for intermittent rainfall, it permits all event precipitation to be included without allowing large gaps in the rainfall to distort the average value.
- The runoff and effluent durations were determined by inspection of the curve shapes.
- The storage duration was determined as the time between start of runoff and the attainment of zero storage. The latter time was later than the end of runoff determined from inspection of the curve shape.
- Lag times were determined based on the centroids of the curves. The "lag time" of the effluent is the hydraulic detention time of the pond.
- The drawdown time is the time interval between maximum storage and the end of the event (based on zero storage). In this case, it is far larger than the detention time.

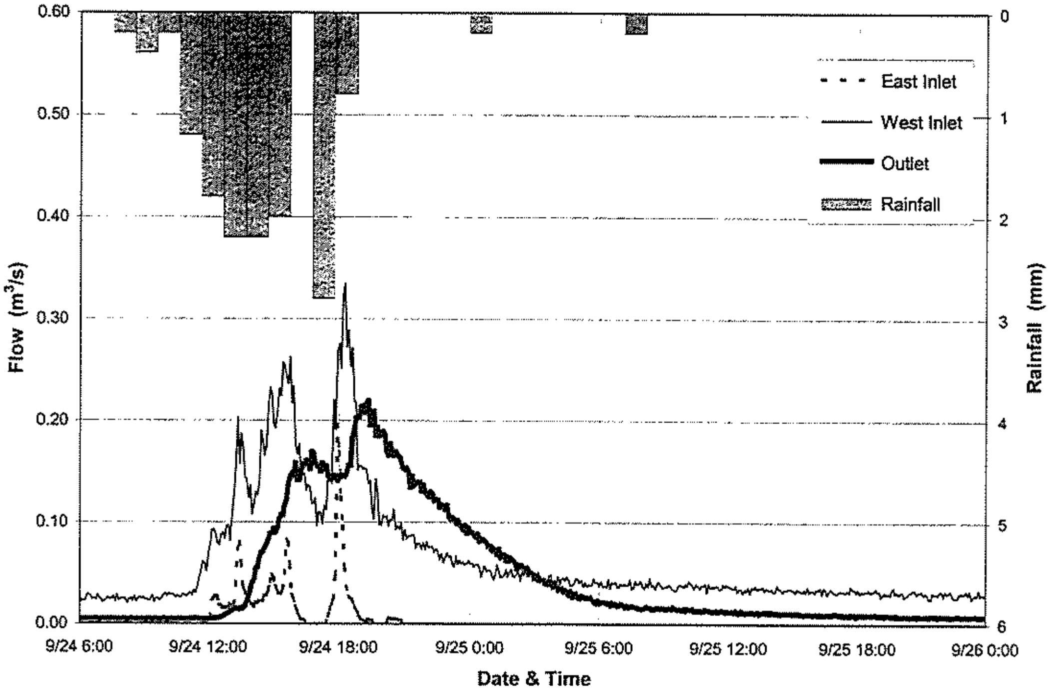

Figure 4.1: Hyetograph and hydrographs -- September 24, 1996

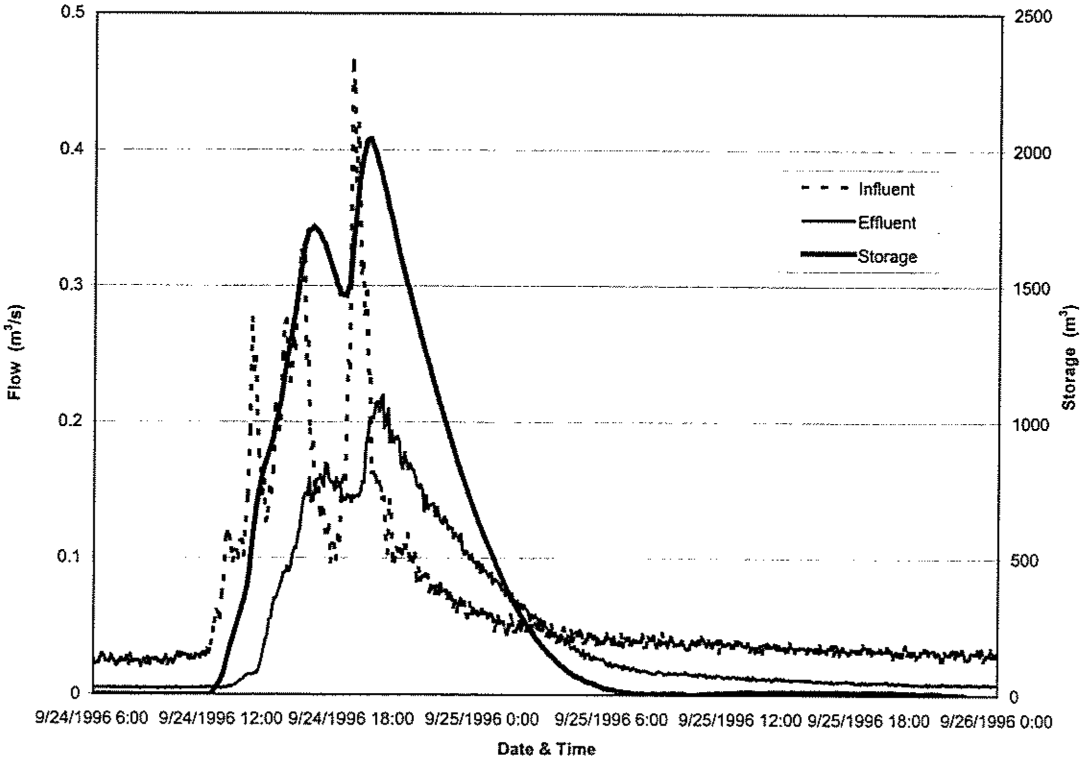

Figure 4.2: Hydrographs and storage curve -- September 24, 1996

Table 4.3: Event statistics -- September 24, 1996

Sept. 24, 1996		**Rainfall**	**Runoff**	**Outflow**	**Exfiltration**	**Storage**
Start	dd/mm/yy	9/24/1996	9/24/1996	9/24/1996	-	9/24/1996
	hh:mm	7:00	11:30	12:20		11:30
End	dd/mm/yy	9/25/1996	9/25/1996	9/25/1996	-	9/25/1996
	hh:mm	7:00	8:50	9:35		22:25
Duration	hh:mm	12:00			-	
Elapsed time	hh:mm	24:00	21:20	21:15		34:55
Centroid	dd/mm/yy	9/24/1996	9/24/1996	9/24/1996	-	-
	hh:mm	14:54	17:32	20:18		
Peak Time	dd/mm/yy	9/24/1996	9/24/1996	9/24/1996	-	9/24/1996
	hh:mm	17:00	17:55	19:20		18:45
Lag (based on centroids)	hh:mm	-	2:38	2:46	-	-
Peak Rain OR Peak Flow	mm/h OR m^3/s	2.8	0.465	0.220	-	-
Mean Rain OR Mean Flow	mm/h OR m^3/s	1.2	0.077	0.055	-	-
Peak Factor		2.37	6.04	4.00	-	-
Peak Ratio	%	-	-	47%	-	-
Rainfall OR Volume - total	mm OR m^3	14.2	10,428	7,079	3,355	-
Volume - baseflow	m^3	-	4,610	1,221	-	-
Volume - net	m^3	18,395	5,818	5,858	-	-
Drawdown Time	hh:mm	-	-	-	-	27:40
Runoff Coefficient		-	0.32	0.32	-	-
Volumetric Error	m^3	-	-	-	-	-6
	%	-	-	-	-	0.00%

The hydraulic residence time was not determined in this study.

Conceptually, peak factors should be reduced as the water moves through the system. In this case, the use of hourly rainfall data has distorted the rainfall peak factor. The peak reduction provided by the pond is an important parameter related to erosion control; unlike many other parameters, it is independent of subjective assessment although it is a function of sampling/reporting frequency. The peak reduction is reported here as the peak ratio, or the outlet peak flow divided by the inlet peak flow, expressed as a percentage.

The baseflow and exfiltration volumes are shown to be very significant quantities, relative to the total flows and the rainfall volume. Any simplistic assessment of the pond system that ignored these components would have generated a very inappropriate impression of system performance.

4.3.2 Event of August 20, 1997

The rainfall-runoff event of August 20th, 1997 is presented here as an illustration of conditions in which the hydraulic data were not of best quality. As seen in Figure 4.3, the sensor in the west inlet sewer was behaving erratically over a small portion of the event, and the outlet sensor was not measuring low flows. Occasional erratic signals are generally the result of debris blocking the flow meter sensor. Failure of the sensor to measure low flows may result from the clarity of the water; the Doppler metering system requires suspended particles to provide a reading. Consequently, data sets of this type are common in stormwater monitoring programs.

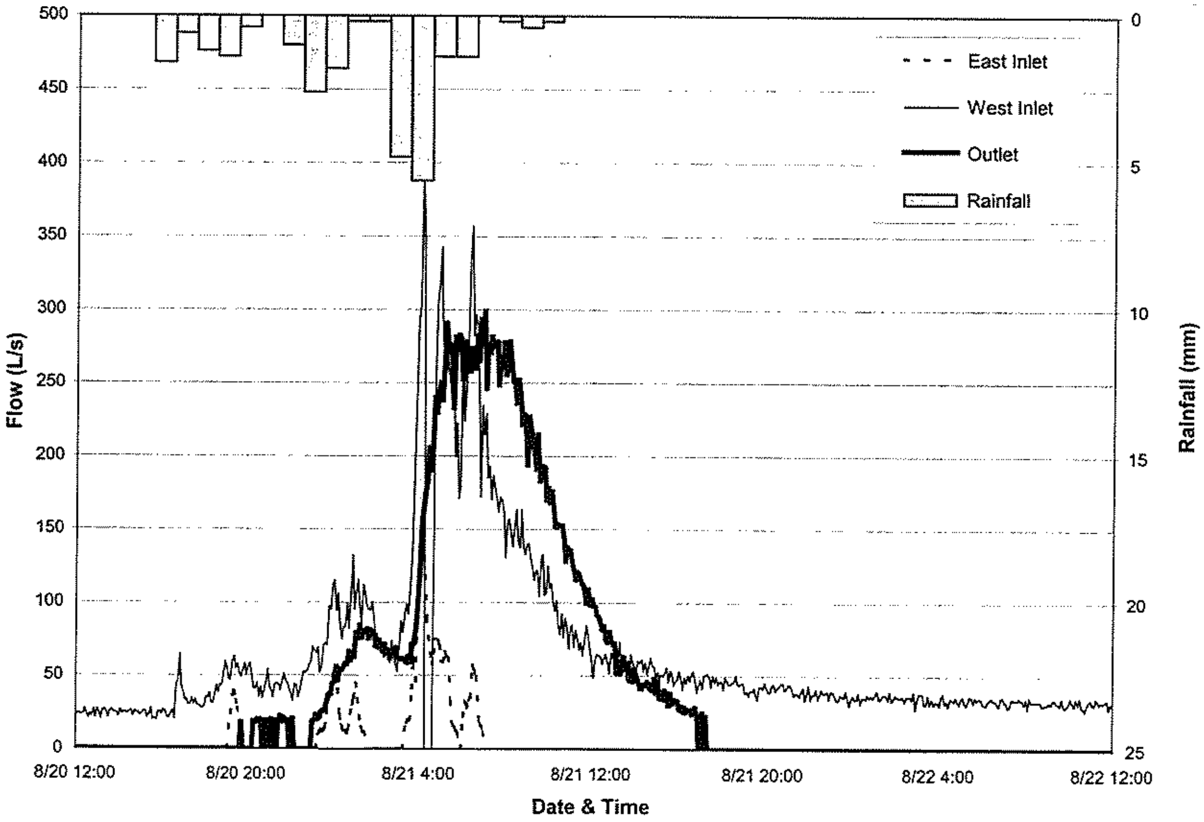

Figure 4.3: Hyetograph and hydrographs -- August 20, 1997

The area-velocity meters provide both flow and depth data. When sewer pipes are not flowing full, they may be analyzed as "open channels" in which there is a correlation between depth and flow rate[2]. In this analysis, the non-zero outlet flow data were correlated to the corresponding depth data (Figure 4.4) and the resulting second-order polynomial equation was used to generate a new hydrograph that extends into the baseflow periods. In addition, linear interpolation was used to replace four erroneous zero-flow readings in the west inlet hydrograph.

Figure 4.5 contains the new outlet hydrograph, the corrected total inlet hydrograph and the storage curve for the August 20th event. The volumetric error in this analysis is -872 m^3, or -7% of the inlet volume. Although the storage curve itself demonstrates a very large error, the peak storage volume of 1087 m^3 was only 9% of the total inlet volume. Hence, a small error in flow measurement can cause a large error in the estimated storage volume. Direct measurement of the volume stored, based on level measurement and detailed site surveys (i.e., an accurate stage-storage curve) would be a better method of estimating the storage volume.

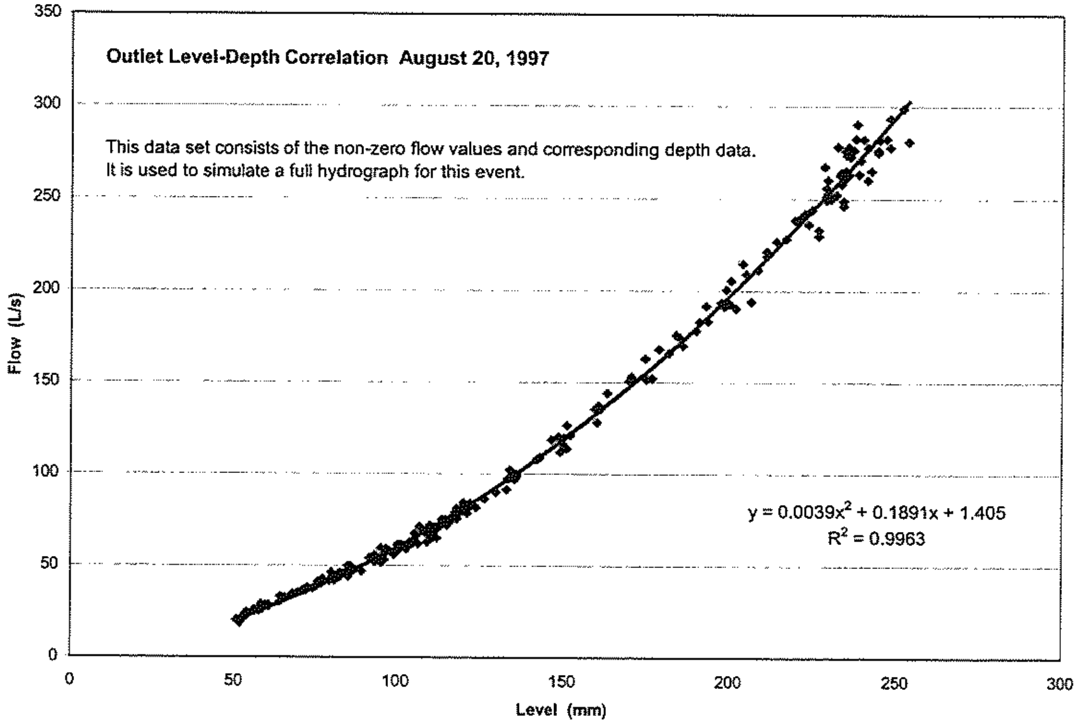

Figure 4.4: Second-order polynomial correlation of outlet data -- August 20, 1997

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[2] The critical parameter is actually the hydraulic radius (ratio of the cross-sectional area of the flowing fluid to the wetted perimeter). For details, refer to any hydraulic engineering text book

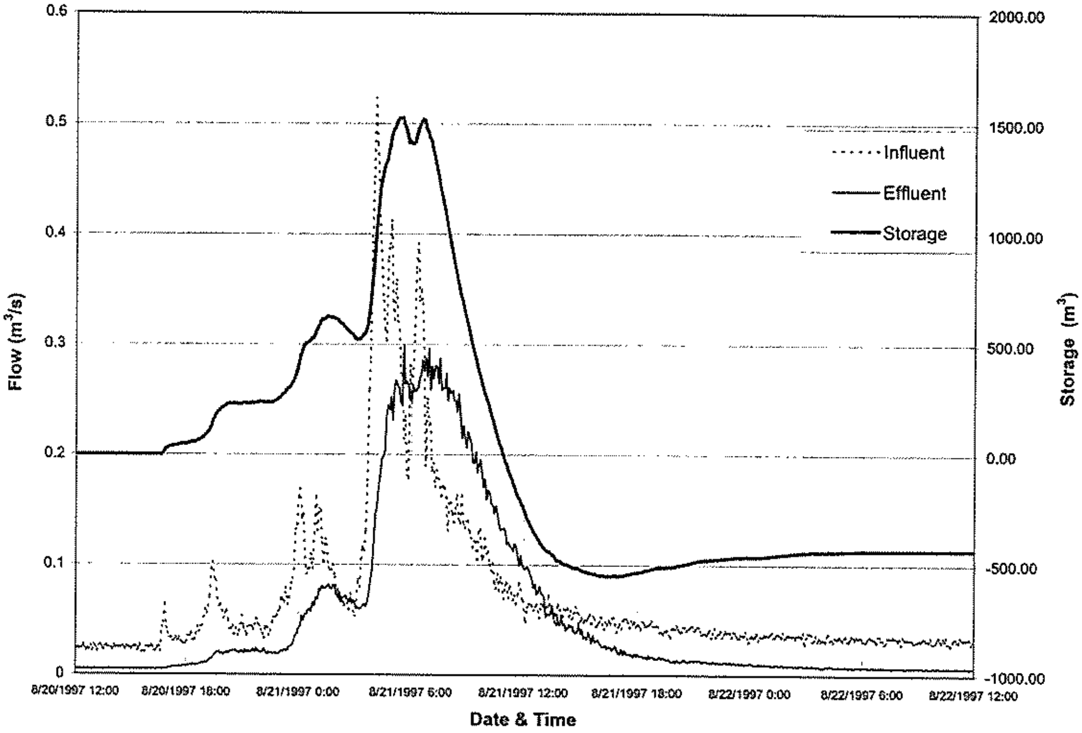

Figure 4.5: Hydrographs and storage curve -- August 20, 1997

4.4 Summary of Hydraulic Performance

The principal function of a stormwater pond is - from the perspective of hydraulic performance - to reduce the impact of elevated storm flows on downstream areas. This task is accomplished by detaining, or holding back, some of the flow for relatively short periods of time to even out the flow rates.

As summarized in Table 4.4, peak factors have been calculated for the influent and effluent flows. A peak factor is the ratio of the maximum flow to the average flow for a given monitoring station and event. The amount by which the runoff peak has been reduced by the pond is quantified as the ratio outlet to inlet peak flows, expressed as a percentage. For those events reporting both influent and effluent flows, the average peak ratio was 47%, with a range of 20% to 81%.

Table 4.4: Summary of hydraulic performance -- post-construction period

Date	Inlet			Outlet				Times		Exfiltration**	
	Total Inflow (m^3)	Total Runoff* (m^3)	Peak Factor	Total Outflow (m^3)	Total Runoff* (m^3)	Peak Factor	Peak Ratio	Drawdown Time (hours)	Detention Time (hours)	Total Volume (m^3)	Average Rate (m^3/s)
Sep. 07, 1996	n/a	n/a	n/a	40,200	36,913	5.72	n/a	n/a	n/a	n/a	n/a
Sep. 11, 1996	n/a	n/a	n/a	8,504	6,638	2.58	n/a	n/a	n/a	n/a	n/a
Sep. 13, 1996	n/a	n/a	n/a	36,449	29,881	4.45	n/a	n/a	n/a	n/a	n/a
Sep. 24, 1996	10,428	5,818	6.04	7,079	5,858	4.00	47%	27.7	2.8	3,355	0.022
Sep. 27, 1996	22,061	13,543	5.84	16,692	14,136	3.54	47%	24.8	2.9	5,915	0.023
Oct. 09, 1996	13,220	4,561	5.19	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Oct. 18, 1996	29,534	17,828	6.28	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nov. 07, 1996	16,112	4,469	11.54	10,109	7,495	6.61	36%	95.6	4.5	9,029	0.014
Apr. 27, 1997	10,026	2,821	2.76	4,557	3,869	0.28	55%	32.1	0.7	6,517	-0.274
May 03, 1997	18,666	9,861	5.75	16,899	13,813	4.66	81%	35.5	3.8	5,300	0.000
May 05, 1997	9,524	3,868	4.03	6,043	4,033	3.17	50%	25.0	0.1	3,646	0.028
May 11, 1997	10,666	3,620	4.86	4,900	2,414	2.67	25%	n/a	0.5	4,560	0.033
May 15, 1997	10,697	3,942	4.90	4,294	3,516	3.21	26%	36.2	1.5	5,977	0.037
Jun. 13, 1997	n/a	n/a	n/a	8,361	7,139	3.03	n/a	n/a	n/a	n/a	n/a
Jun. 16, 1997	7,517	2,980	3.68	5,306	4,167	4.17	80%	19.6	2.2	3,398	0.021
Jun. 18, 1997	7,485	1,161	3.79	1,799	712	3.87	25%	31.8	3.7	5,237	0.033
Jun. 21, 1997	7,814	1,697	5.78	2,730	1,662	5.39	33%	29.6	5.3	5,049	0.029
Jun. 24, 1997	7,644	3,542	6.40	5,842	4,676	4.92	59%	11.5	4.4	3,098	0.017
Jul. 07, 1997	3,831	904	14.84	1,841	1,163	6.22	20%	22.3	3.1	2,449	0.015
Jul. 08, 1997	5,484	2,334	6.20	2,532	1,902	3.56	26%	16.5	2.4	2,520	0.032
Jul. 27, 1997	2,790	560	7.69	1,791	1,341	5.04	42%	17.6	1.1	1,779	0.012
Aug. 13, 1997	10,017	4,259	11.51	9,331	7,770	8.88	72%	46.7	-2.1	4,197	0.003
Aug. 15, 1997	12,539	6,748	9.40	12,212	10,829	7.21	75%	41.0	1.3	4,409	0.002
Aug. 20, 1997	12,172	7,269	7.44	9,166	8,141	5.65	57%	24.5	1.4	3,878	0.017
Sep. 06, 1997	n/a	n/a	n/a	7,118	4,572	10.37	n/a	n/a	n/a	n/a	n/a
Sep. 10, 1997	n/a	n/a	n/a	8,545	6,214	6.78	n/a	n/a	n/a	n/a	n/a
Sep. 25, 1997	4,369	1,445	7.55	1,996	1,273	7.13	43%	46.2	1.5	2,201	0.009
Sep. 28, 1997	8,742	5,148	6.90	6,086	4,313	6.88	n/a	60.6	-2.5	1,593	0.009
Average (all)	10,990	4,926	6.73	9,245	7,479	5.00	47%	33.9	1.9	4,205	0.004
Average (best)***	9,518	4,121	6.20	5,363	4,076	4.27	38%	31.4	1.8	4,069	0.001

* Runoff is inflow or outflow minus the respective baseflow.

** Exfiltration was estimated by subtracting the outlet baseflow from the inlet baseflow. Exfiltration during the event was estimated by linear interpolation of the pre-event and post-event baseflows. Hence, the event was assumed to make no significant change in the exfiltration rate.

*** The "best" events are those for which the volumetric error was ±15% or less.

Another parameter commonly used to quantify pond performance is the drawdown time, the time between the attainment of the maximum storage volume and the end of flow or re-establishment of baseflow[3]. This parameter, which is also included in Table 4.4, is more difficult to quantify because baseflow is never really stable and the selection of the end of the event becomes subjective. A lengthy drawdown time promotes more uniform flow and healthy downstream environmental conditions.

The hydraulic detention time is reported here as the amount of time between the centroids of the influent and effluent hydrographs. It is the average time by which the flow is detained by the facility.

The Rouge Pond has a significant exfiltration flow. In this case, much of the exfiltrated water may be expected to enter the Rouge River after a short passage through the local soil. In other sites, exfiltration would possibly divert significant quantities of runoff to the local aquifer, transferring the rainwater to groundwater rather than to surface runoff. In either case, exfiltration would have a water quality improvement effect through filtration and adsorption in the soil.

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[3] As a design parameter, drawdown time is calculated from the maximum storage elevation and volume, and from the hydraulic characteristics of the outlet structure, exclusive of any simultaneous inlet flow. See Appendix C for a discussion of hydraulic parameters.

5 WATER QUALITY ANALYSIS

5.1 Chemical Characterization Results

Table 5.1 summarizes the chemical and biological characteristics of the pond influent and effluent over the three monitoring periods. The data shown in the table are the averages of the EMC values for the three monitoring periods. This table also includes the reporting method detection limits (RMDL) for each of the constituents analyzed. The analytical methods are described in Appendix D. Appendix H contains the detailed analytical results tables.

The water quality data are discussed with respect to each monitoring period in the following sections of this chapter.

5.1.1 Summer / fall -- construction period

During construction, the runoff entering the pond through the storm sewers contained an appreciable suspended solids concentration, approximately 600 mg/L of TSS on average. As discussed in the previous chapter, significant overland flow was assumed to have carried additional, non-quantified amounts of suspended matter into the pond.

Figure 5.1 compares the pond influent and effluent characteristics for the spring/fall portion of the construction period. As illustrated, most of the contaminant concentrations in the pond effluent were less than those in the influent. Removal efficiency will be discussed in Chapter 6.

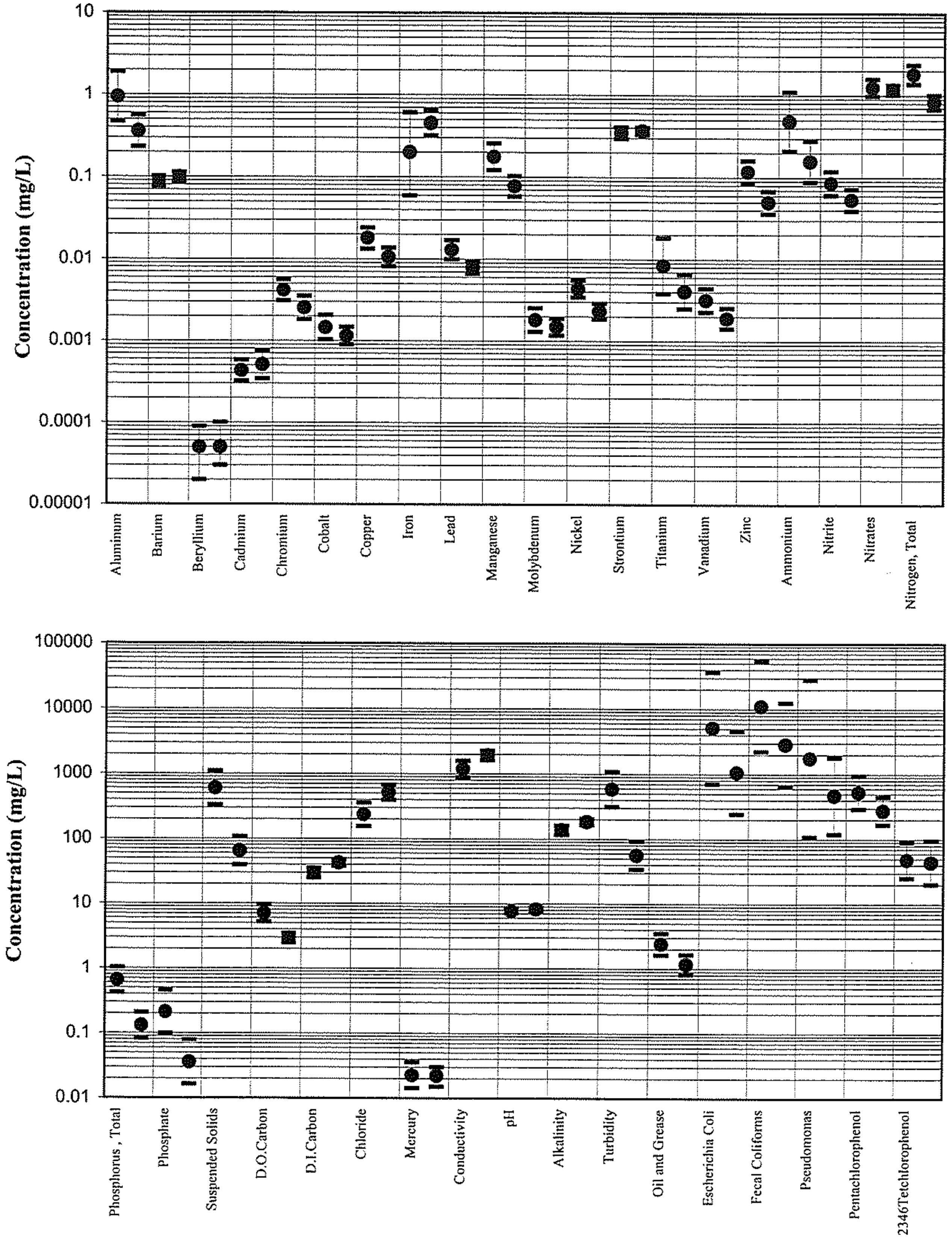
The analytical method used for metals at the beginning of the study provided results that were assumed to represent essentially the soluble fraction of the metals. Hence, the metal concentrations included in Table 5.1 and Figure 5.1 should not be interpreted as total concentrations.

5.1.2 Summer / fall -- post-construction period

Data collected during the summer and fall months in the post-construction period (September 1996 to September 1997) provide an indication of water quality that may be expected under normal operating conditions. In the post-construction period, the average inlet EMC for suspended solids was approximately 330 mg/L, or 45% less than the corresponding value obtained during the construction period. Figure 5.2 compares the pond influent and effluent characteristics for the summer/fall portion of the post-construction period. A revised analytical laboratory method for metals was used in this period. This change resulted in noticeable increases in the inlet concentrations for zinc, copper, and lead between the construction and post-construction periods.

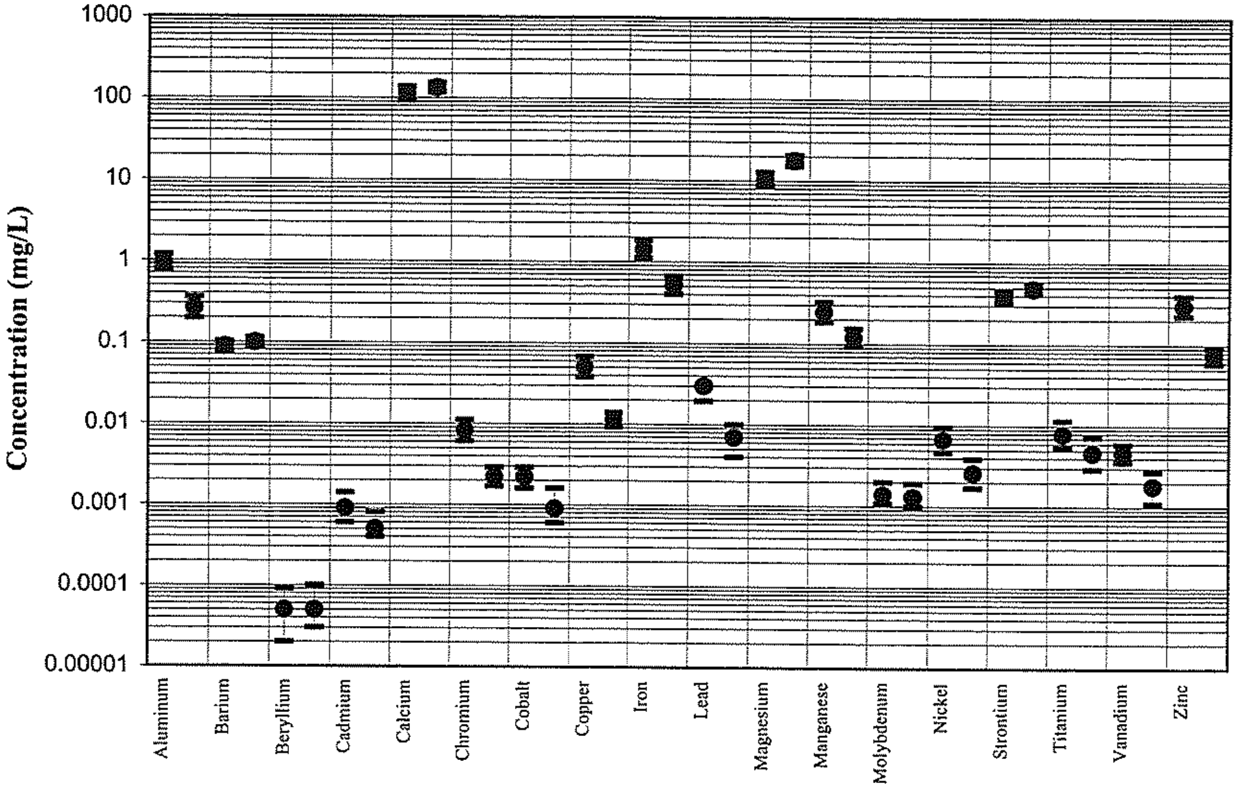
Table 5.1: Summary of influent and effluent characteristics

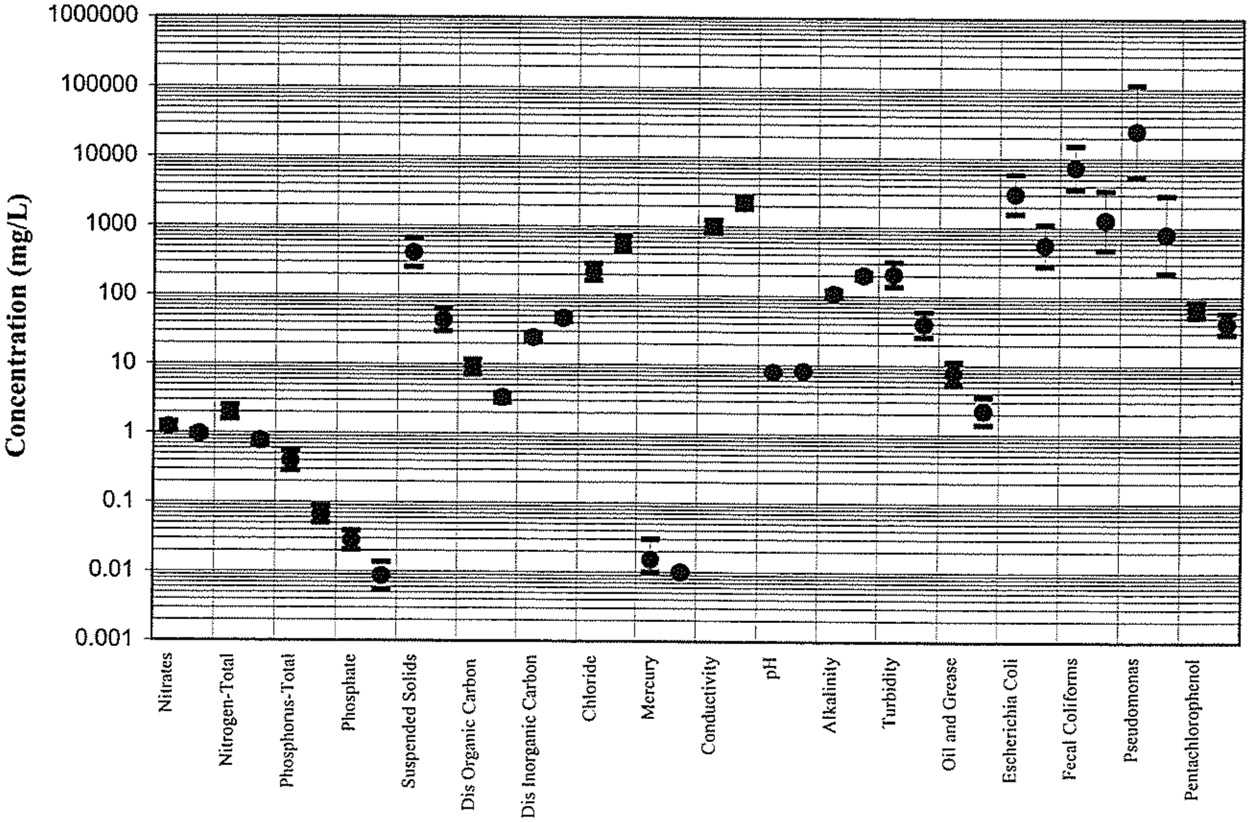
Parameter	Units	RMDL	Summer / Fall Construction Period		Summer / Fall Post-construction		Winter / Spring	
			In	Out	In	Out	In	Out
Aluminum	mg/L	0.011	0.937	0.359	0.945	0.263	0.544	0.212
Barium	mg/L	0.0002	0.0881	0.0989	0.0856	0.1206	0.1017	0.1161
Beryllium	mg/L	0.00002	0.00005	0.00005	0.00009	0.00003	0.00022	0.00004
Cadmium	mg/L	0.0006	0.0004	0.0005	0.0009	0.0005	0.0005	0.0017
Calcium	mg/L	0.005	ND	ND	103.840	143.540	146.000	171.000
Chromium	mg/L	0.0014	0.0042	0.0025	0.0085	0.0020	0.0057	0.0086
Cobalt	mg/L	0.0013	0.0015	0.0012	0.0022	0.0008	0.0024	0.0027
Copper	mg/L	0.0016	0.0181	0.0105	0.0521	0.0102	0.0357	0.0162
Iron	mg/L	0.0008	0.2003	0.4527	1.4666	0.4707	0.3928	0.4014
Lead	mg/L	0.01	0.01	0.01	0.03	0.01	0.02	0.01
Magnesium	mg/L	0.008	ND	ND	10.181	18.048	12.600	18.100
Manganese	mg/L	0.0002	0.1761	0.0773	0.2469	0.1199	0.2231	0.1103
Molybdenum	mg/L	0.0016	0.0018	0.0015	0.0014	0.0014	0.0029	0.0022
Nickel	mg/L	0.0013	0.0044	0.0023	0.0068	0.0024	0.0038	0.0015
Strontium	mg/L	0.0001	0.3478	0.3663	0.3785	0.4888	0.5507	0.5072
Titanium	mg/L	0.0005	0.0084	0.0041	0.0081	0.0044	0.0150	0.0123
anadium	mg/L	0.0015	0.0032	0.0019	0.0048	0.0015	0.0033	0.0015
Zinc	mg/L	0.0006	0.1176	0.0499	0.3021	0.0672	0.1974	0.1089
Ammonium	mg/L	0.002	0.483	0.157	0.604	0.100	1.286	0.523
Nitrite	mg/L	0.001	0.085	0.054	0.096	0.039	0.162	0.073
Nitrates	mg/L	0.005	1.249	1.173	1.207	0.967	1.433	1.583
Nitrogen, Total Kjeldahl	mg/L	0.02	1.81	0.83	2.00	0.75	1.67	1.07
Phosphorus, Total	mg/L	0.002	0.654	0.131	0.393	0.060	0.368	0.092
Phosphate	mg/L	0.0005	0.2114	0.0358	0.0309	0.0067	0.0918	0.0149
Suspended Solids	mg/L	2.5	601	65	331	37	395	46
Dissolved Carbon, Organic	mg/L	0.1	7.0	2.9	9.3	3.1	4.7	4.5
Dissolved Carbon, Inorganic	mg/L	0.2	29.6	42.5	23.6	47.7	34.3	49.1
Chloride	mg/L	0.2	235.1	515.0	205.7	579.5	1689.1	1613.0
Mercury	µg/L	0.02	0.02	0.01	0.02	0.01	0.02	0.01
Conductivity	µS/cm	1	1186	1916	949	2269	3123	3578
pH	nil	0.1	8.0	8.1	7.9	8.2	8.0	8.1
Alkalinity	mg/L	0.2	136.9	184.1	103.4	205.0	176.2	216.0
Turbidity	FTU	0.01	586.02	56.17	209.92	33.82	404.94	33.77
Oil and Grease	mg/L	1	2	1	9	1	3	2
E. Coli	#/100 mL	4	5123	1054	3071	356	20	10
Fecal Coliforms	#/100 mL	4	11026	2859	6517	783	380	20
Pseudomonas	#/100 mL	4	1750	466	29913	206	10	4
Pentachlorophenol	ng/L	10	526	275	69	41	184	111
2,3,4,6 Tetrachlorophenol	ng/L	20	48	44	10	10	27	17



Note: For each parameter, the symbol on the left is the influent and the symbol on the right is the effluent.

Figure 5.1: Summer / fall mean concentrations -- construction period





Note: For each parameter, the symbol on the left is the influent and the symbol on the right is the effluent.

Figure 5.2: Summer / fall mean concentrations -- post-construction period

5.1.3 Winter / spring

The winter/spring samples, collected from December to April, were exclusively grab samples. The influent samples may have been taken after the first flush of contaminants. However, the first flush would not likely be a significant factor under snowmelt conditions because of the associated hydrograph shape and dispersion of the contaminants in the snow. Samples collected from the effluent may have been biased by exclusion of the cleaner, displaced volume at the start of the event. The influent and effluent water quality data from all winter/spring sampling are summarized in Figure 5.3.

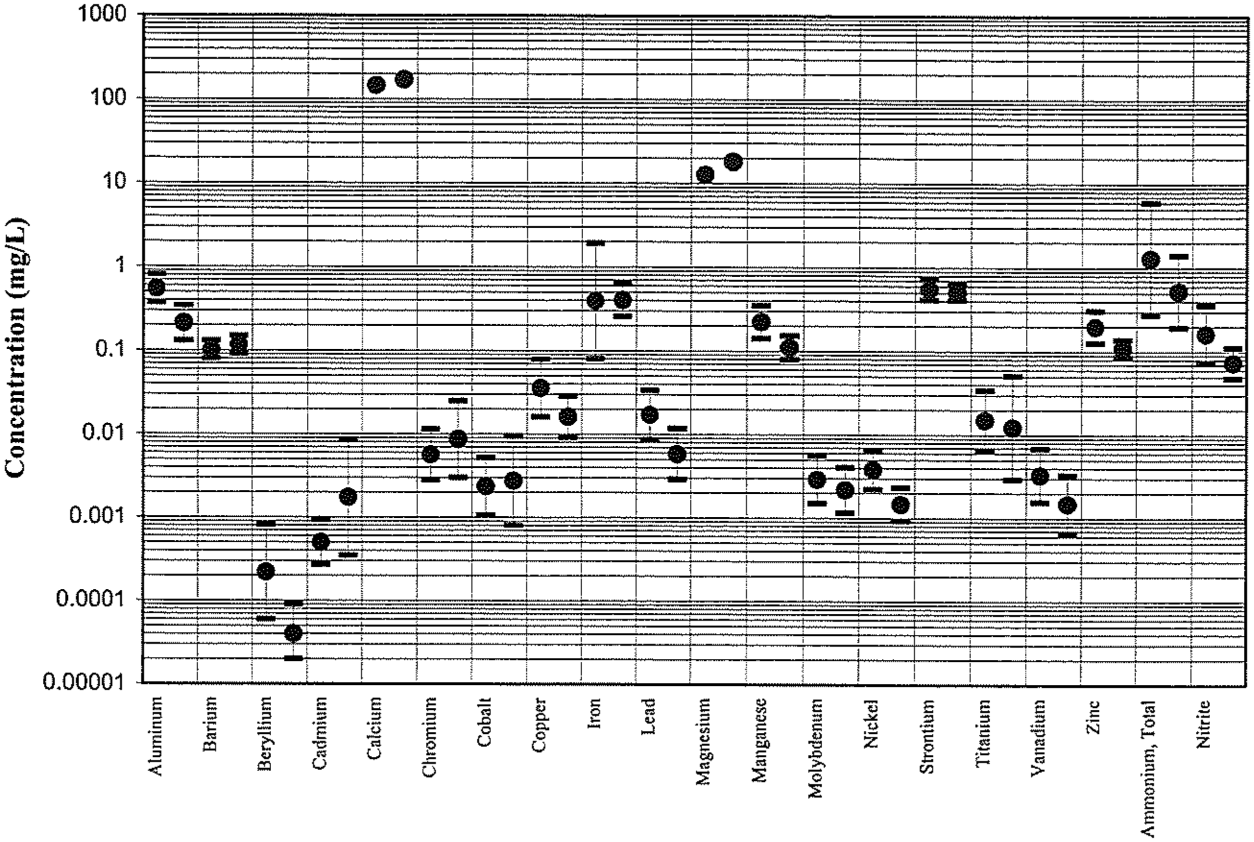
5.1.4 Discussion of water quality data

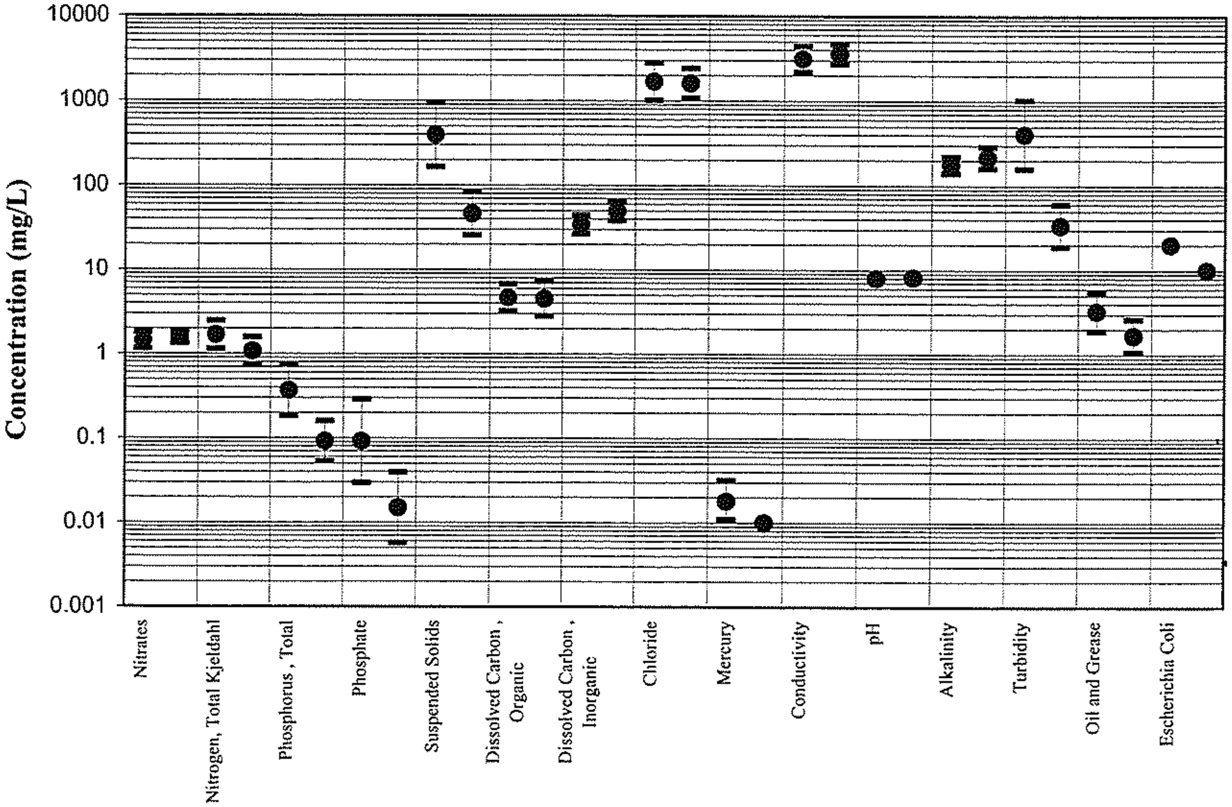
Comparison of Figures 5.1 to 5.3 demonstrates that the variability of the observations was less during the summer/fall post-construction period than during the summer/fall construction period and the combined winter/spring period. Changes in the tributary area due to construction and the reduced confidence associated with the winter grab sampling program make the latter two data sets (construction period and winter/spring grab samples) less reliable as an indicator of pond performance.

5.1.5 Comparison to provincial water quality objectives

One objective of a stormwater treatment facility is to ensure satisfactory surface water quality for aquatic life and recreation. In Table 5.2 the effluent of the stormwater facility is compared to the Provincial Water Quality Objectives (PWQO) developed by the Ontario Ministry of the Environment. The PWQO values apply to receiving waters, and not to stormwater discharges. However, the comparison helps to highlight those chemicals or other characteristics of greatest concern.

There are 18 water quality parameters specified in the PWQO. The pond outlet average event mean concentrations (AEMC) equaled or exceeded the objectives for 9 of the 18 parameters, in both summer/fall and winter/spring seasons. The E. Coli and fecal coliform counts exceeded the respective objectives only in the summer/fall period.





Note: For each parameter, the symbol on the left is the influent and the symbol on the right is the effluent.

Figure 5.3: Winter / spring mean concentrations

Table 5.2: Comparison of 1996/1997 outlet AEMC with PWQO

Parameter	Units	RMDL	PWQO	OUTLET AEMC 96/97	
				Summer/Fall	Winter/Spring
Aluminum	mg/L	0.011	0.0750	**0.263**	**0.212**
Barium	mg/L	0.0002		0.1206	0.1161
Beryllium	mg/L	0.00002	1.1000	0.00003	0.00004
Cadmium	mg/L	0.0006	0.0005	0.0005	**0.0017**
Calcium	mg/L	0.005		143.54	171.00
Chromium	mg/L	0.0014	0.0010	**0.0020**	**0.0086**
Cobalt	mg/L	0.0013	0.0006	**0.0008**	**0.0027**
Copper	mg/L	0.0016	0.0050	**0.0102**	**0.0162**
Iron	mg/L	0.0008	0.3000	**0.4707**	**0.4014**
Lead	mg/L	0.01	0.0050	**0.006**	**0.006**
Magnesium	mg/L	0.008		18.048	18.100
Manganese	mg/L	0.0002		0.1199	0.1103
Molybdenum	mg/L	0.0016	0.0400	0.0014	0.0022
Nickel	mg/L	0.0013	0.0250	0.0024	0.0015
Strontium	mg/L	0.0001		0.4888	0.5072
Titanium	mg/L	0.0005		0.0044	0.0123
Vanadium	mg/L	0.0015	0.0060	0.0015	0.0015
Zinc	mg/L	0.0006	0.0200	**0.0672**	**0.1089**
Ammonium	mg/L	0.002		0.100	0.523
Nitrite	mg/L	0.001		0.039	0.073
Nitrates	mg/L	0.005		0.967	1.583
Nitrogen, Kjeldahl	mg/L	0.02		0.75	1.073
Phosphorus, total	mg/L	0.002	0.0300	**0.060**	**0.092**
Phosphate	mg/L	0.0005		0.0067	0.0149
Suspended solids	mg/L	2.5		37.2	46.3
Dissolved carbon, org.	mg/L	0.1		3.1	4.5
Dissolved carbon, inorg.	mg/L	0.2		47.7	49.1
Chloride	mg/L	0.2		579.5	1613.0
Mercury	µg/L	0.02	0.2000	0.01	0.01
Conductivity	µS/cm	1.0		2269.0	3577.8
pH	nil	0.1		8.2	8.1
Alkalinity	mg/L	0.2		205.0	216.0
Turbidity	FTU	0.01		33.82	33.77
Oil and grease	mg/L	1.0		1.5	1.7
E.Coli	#/100 mL	4.0	100	**356.5**	10.0
Fecal Coliforms	#/100 mL	4.0	100	**782.7**	20.0
Pseudomonas	#/100 mL	4.0		206.1	4.0
Pentachlorophenol	ng/L	10.0	500.0	41.2	110.6
2,3,4,6 Tetrachlorophenol	ng/L	20.0	1000.0	10.0	17.3

Note: Outlet concentrations exceeding the respective PWQO values are shown in bold type.

5.2 Particle Size Analysis

Particle size analysis was conducted using a Coulter LS130 Particle Size Analyzer. Cumulative particle size distribution curves for all the samples analyzed for particle size are presented in Figures 5.4, 5.5 and 5.6 for the three monitoring periods.

During the summer/fall construction period (Figure 5.4), there was no significant difference between the particle size distributions from the inlet and outlet samples, and no consistent distribution pattern could be identified. In many cases the outlet distribution contained coarser material than the inlet. Furthermore, the maximum particle size detected in this period was larger than the corresponding value from the post-construction period. These findings are in agreement with the general remark that the flow was diverted and erosion occurred in the pond area as a result of construction activities. Consequently, the coarser material was introduced directly into the pond. Therefore, the situation illustrated in Figure 5.4 is not representative of the normal operation of the pond.

Because all the construction activities were completed by September 1996, the particle size distribution given in Figure 5.5 is believed to be representative of normal pond performance. The difference between inlet samples and outlet samples can be easily distinguished. The median particle size was reduced from about 6 μm in the inlet to less than 2 μm in the outlet. The largest particle size in the inlet was in the 88 to 125 μm range; that in the outlet was between 62 and 88 μm.

Figure 5.6 demonstrates that both the influent and effluent suspended particle sizes were relatively fine during the winter and spring sampling period. The median particle size in both the inlet and outlet was approximately 3 μm, with the average outlet curve showing slightly smaller sizes than the inlet curve. The runoff sampled in this season was mostly the result of snowmelt during warm intervals in the winter. These events have very low flow rates and wash-off potential, resulting in smaller particle sizes in suspension. Rainfall may have been responsible for the event of March 25, 1996 in which the largest particles were observed in the 88 to 125 μm size range in the inlet sample. The largest particles detected in the outlet were in the 30 to 42 μm range on April 25, 1996.

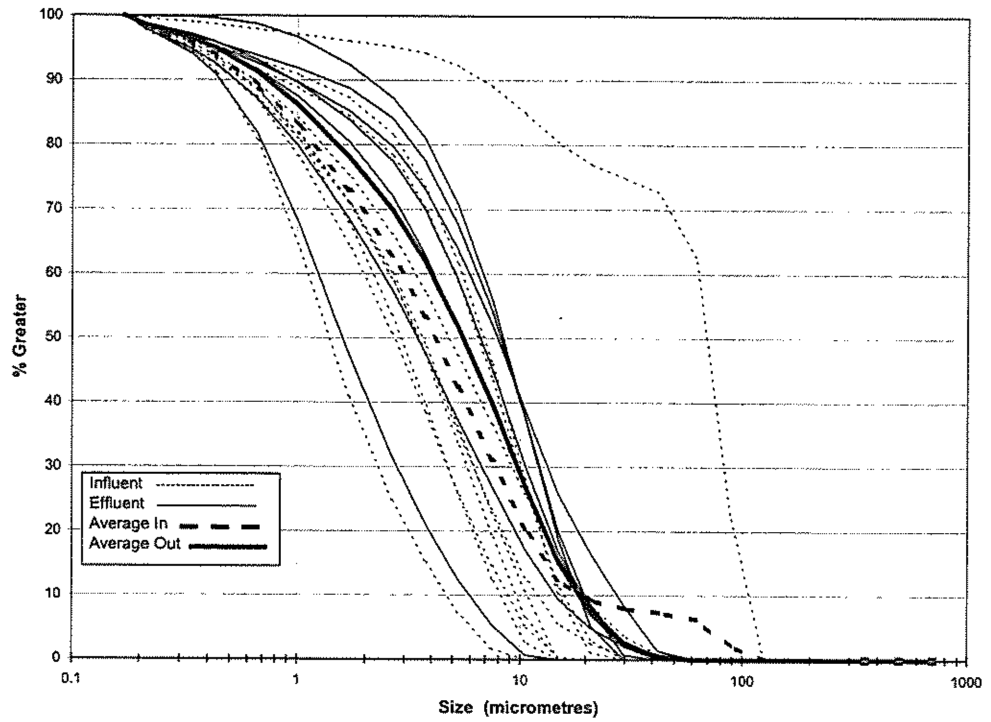


Figure 5.4: Inlet and outlet particle size distributions -- summer / fall construction period

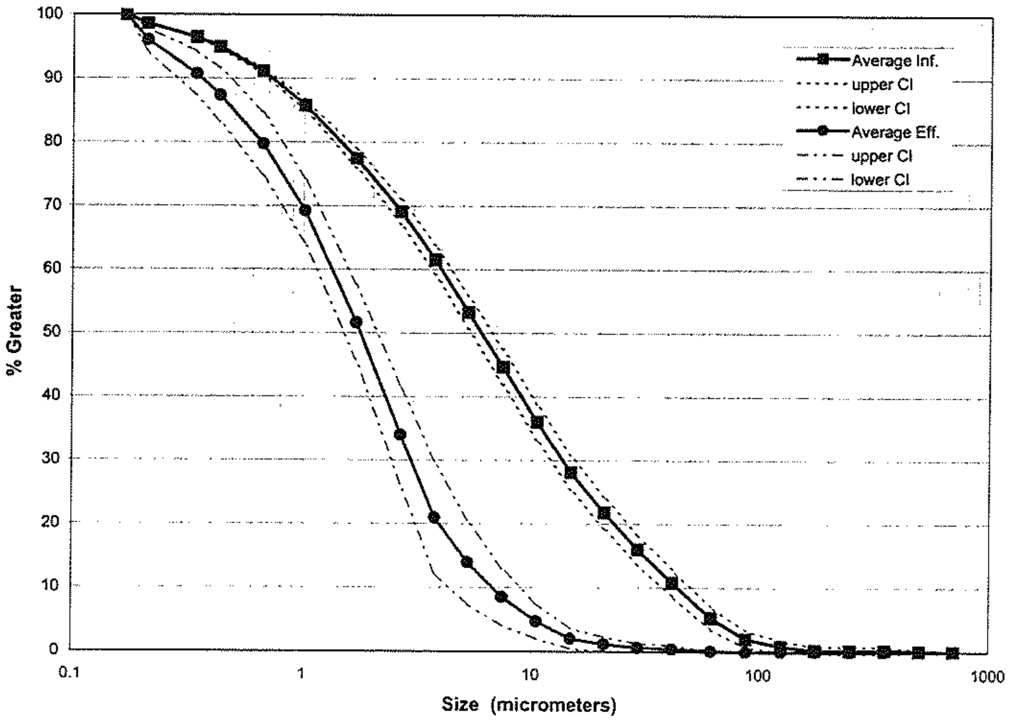


Figure 5.5: Inlet and outlet particle size distributions -- summer / fall post-construction period

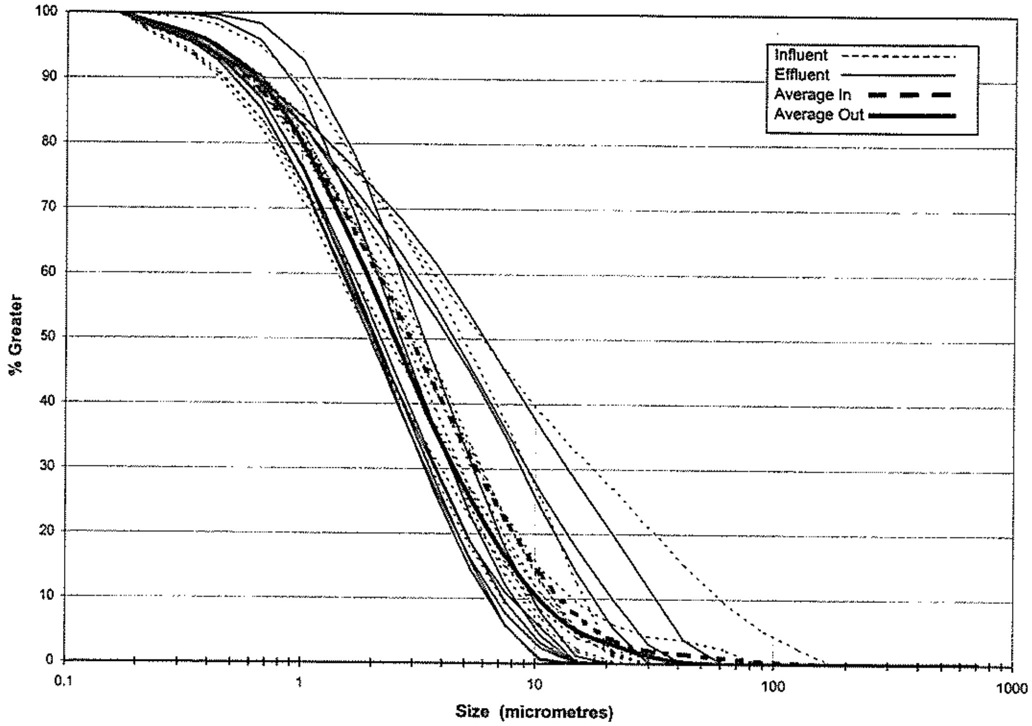


Figure 5.6: Inlet and outlet particle size distributions -- winter / spring period

5.3 Temperature Data Analysis

5.3.1 Introduction

Urbanization alters the temperature regime of receiving streams. Reduction of baseflow, loss of riparian vegetation and rapid delivery of large volumes of warm or cold stormwater runoff are among the principal modifying factors of the thermal regime. Water temperature has considerable influence on a number of water quality variables, particularly with regard to dissolved oxygen. The minimum concentrations of dissolved oxygen needed to maintain healthy warm-water and cold-water fish populations are considered to be 5.0 and 6.0 mg/l, respectively. Water temperature greater than 21° Celsius has been shown to severely stress most cold-water organisms.

5.3.2 Data Summary

Water temperature data are tabulated in Appendix H. Table 5.3 and Figure 5.7 summarize the average temperatures and the temperature ranges. Some data were lost due to malfunctioning of the equipment or vandalism.

Table 5.3: Summary of inlet and outlet water temperatures

Month & Year	In (Deg. C)			Out (Deg. C)			Average Change (Deg. C)
	Min.	Mean	Max	Min.	Mean	Max.	
July 1995	12.6	13.6	18.3	18.6	20.8	22.9	7.2
August 1995	13.4	15.0	22.3	19.2	21.9	24.3	6.9
September 1995	11.9	14.2	17.2	14.0	17.3	21.3	3.1
October 1995	4.9	12.6	16.9	9.2	12.6	17.7	0.0
November 1995	1.6	7.5	12.4	4.6	7.4	10.5	-0.1
June 1996	8.4	11.0	20.0	12.9	16.1	20.2	5.1
July 1996	10.9	13.4	20.5	15.5	18.2	19.6	4.8
August 1996	11.8	14.4	23.6	18.6	20.4	23.1	6.0
September 1996	12.9	15.0	20.0	13.7	17.3	26.9	2.3
October 1996	7.1	12.1	15.3	6.0	12.2	15.6	0.1
November 1996	1.8	7.4	12.1	4.2	7.4	10.5	0.0
Summary	1.6	12.4	23.6	4.2	15.6	26.9	3.2

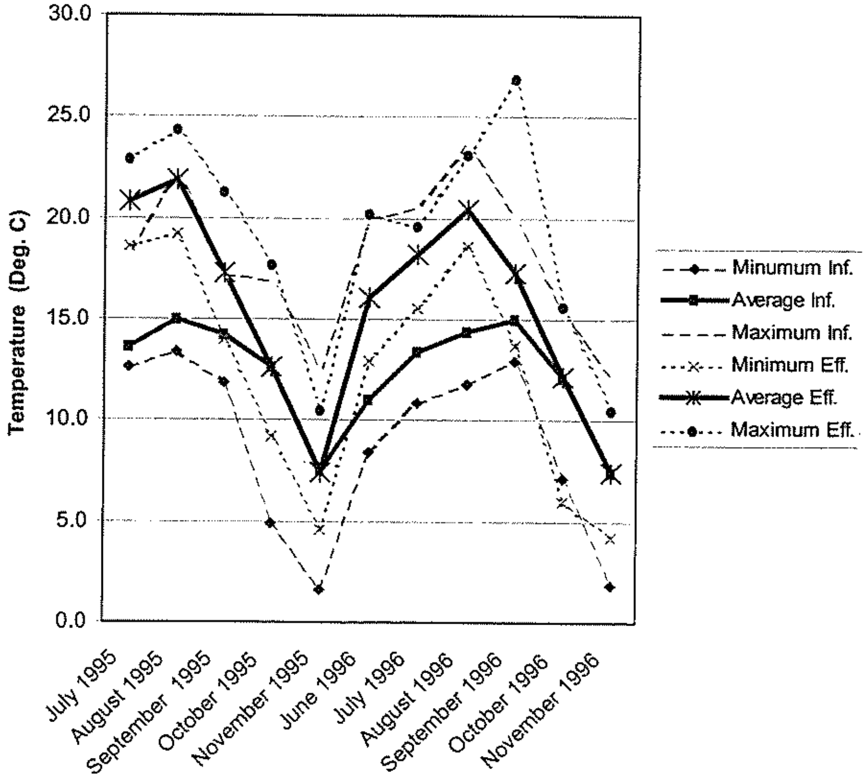


Figure 5.7: Monthly average, minimum and maximum water temperatures

Overall, the pond was responsible for a modest increase in runoff temperature. The effect was more pronounced in July and August, with increases of about 6 to 7 degrees Celsius. In October and November there was essentially no change in the water temperature across the pond.

Average outlet temperatures of 20 to 22 degrees Celsius in the summer months would be expected to stress cold-water organisms. Short-term maximum temperatures are also of concern. The maximum outlet temperature of 26.9 °C was observed in September of 1996.

5.3.3 Time Series Data

Figures 5.8 and 5.9 include all available temperature records for the influent, effluent, receiving water and atmosphere for the typically warmest period of the year (August, 1995; July and August, 1996). For Figure 5.8, air temperature data were obtained from the Buttonville airport weather station maintained by Environment Canada, and for Figure 5.9 data were recorded using the weather station set up in the vicinity of the pond. These charts also include rainfall data, which are presented to illustrate the impact of storm events on the pond influent and effluent temperature. Figure 5.10 shows what kind of temperature impact could be expected in cooler weather conditions.

For the summer months of July and August, the average influent temperature under dry-weather conditions was around 13 to 14 °C, while the average effluent temperature remained around 20 to 22 °C, resulting in a 6 to 7 °C temperature increase attributable to the pond. The temperature gain across the pond decreased toward the beginning of the fall, dropping to some 3 °C in September. For the months of October and November, the temperatures of the influent and effluent were essentially the same (Figure 5.10).

During dry weather the influent temperature remained essentially constant. The effluent temperature demonstrated a diurnal pattern that would presumably be in response to changes in air temperature and solar radiation. Air temperature data for 1995 did not demonstrate any obvious diurnal patterns but the local air temperature data from 1996 did.

For brief periods in both summers, and much more noticeably in the fall (Fig. 5.10), there was an apparent influence of the air temperature on the inlet water temperature. To an appreciable extent, the baseline flow consisted of groundwater infiltration that would have been influenced by soil temperature, which typically varies very slowly. However, heat exchange in the sewer pipes, particularly at drops, may have been responsible for this effect.

In summer, the influent temperature typically increased by 7° to 10° Celsius at the beginning of a storm event, and returned to the dry-weather temperature within 24 hours (Figures 5.8 and 5.9). During the autumn, precipitation appears to have cooled the influent, particularly at times when the air temperature was less than the groundwater temperature.

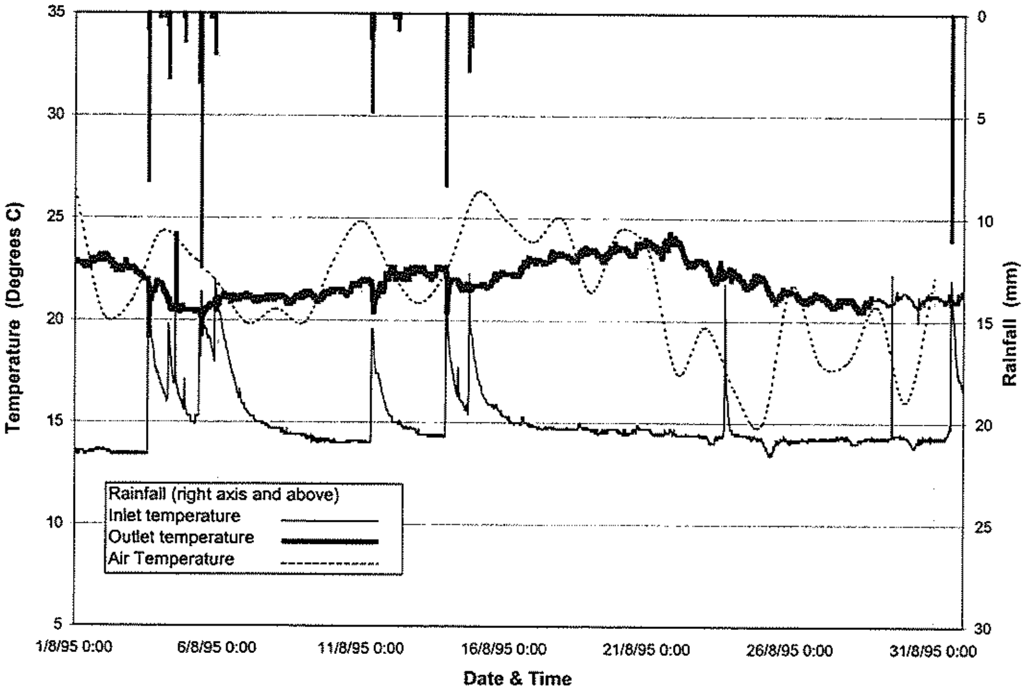


Figure 5.8: Temperature and rainfall -- August 1995

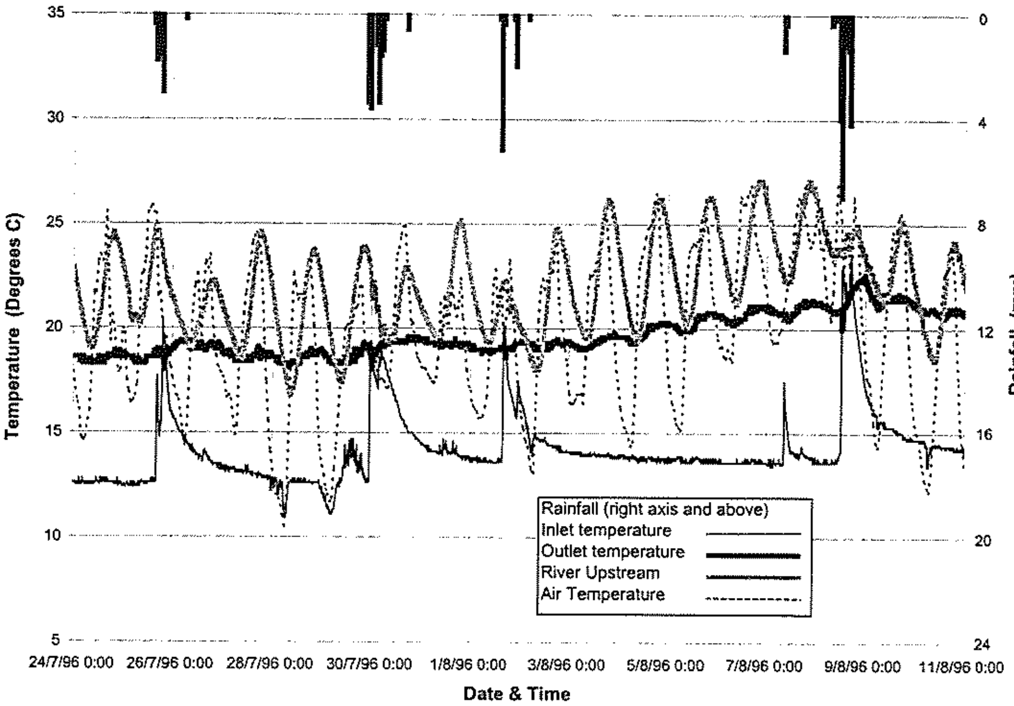


Figure 5.9: Temperature and rainfall -- July - August 1996

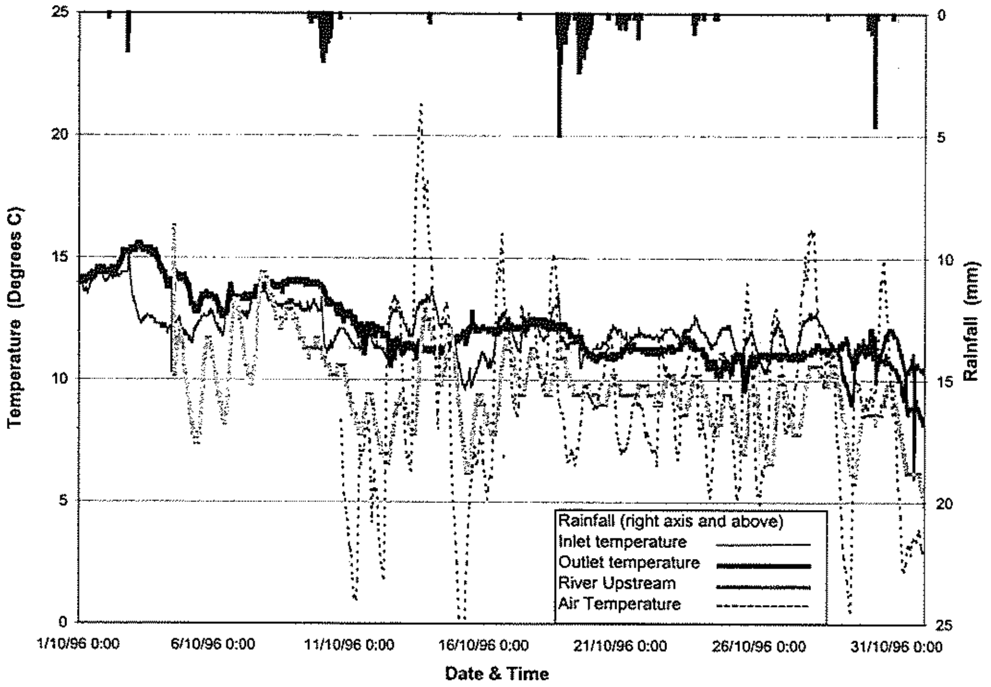


Figure 5.10: Temperature and rainfall -- October 1996

The temperature of the pond effluent responded little to storm events. In general, the effluent temperature decreased by 1 or 2 °C during a storm event. In the summer months, the pond temperature was relatively high and the runoff was cooler than the pond contents. Some of the cooler water would appear in the effluent. A reduction in radiant heating of the pond surface caused by cloud cover may also have contributed to the overall reduction in effluent temperature.

Frequency distribution analysis was performed on the occurrence of the first maximum temperature within a day (i.e., 12:00 am to 11:59 PM) in July and August 1996 (Figure 5.11). Maximum temperature at the outlet location usually occurred between 5 PM and 8 PM. Warming of the pond contents by solar radiation and convection from the air would be expected to cause this effect. Maximum temperatures at the inlet location, on the contrary, were found to occur in the first hours of the day, between 12:00 am and 2:00 am, exclusive of rainfall events. Thermal conductivity of the soil and groundwater would be expected to retard the diurnal temperature patterns. As discussed previously, the pond influent temperature was significantly influenced by the summer stormwater runoff; usually increasing influent temperature by 6 to 8 °C. Therefore, maximum temperatures at the inlet location always coincided with the beginning of the inlet runoff hydrographs. In the summer season, rainstorms usually occur in the first hours of the day (12:00 midnight to 2:00 am) when condensation begins and, as a result, about 70% of the maximum temperature for the inlet station was found to occur at these hours.

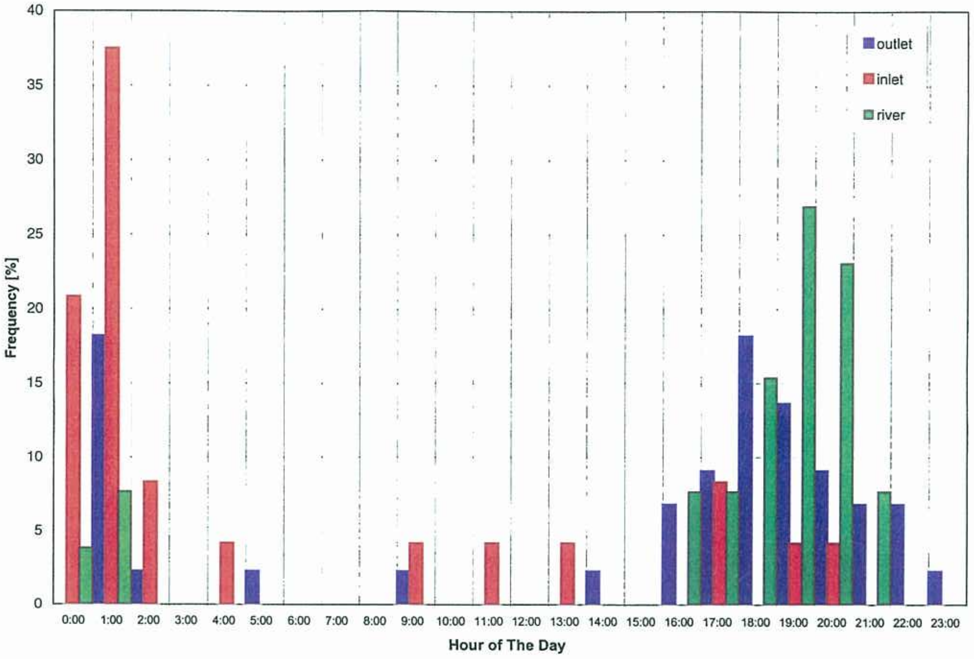


***Figure 5.11**:* Maximum temperature occurrence -- July - August 1996

5.3.4 Thermal Impact on the Receiving Stream

Average temperatures recorded at the outlet in August 1995 and August 1996 were very close to the suggested limit for cold-water fishery (21 °C), and the maximum recorded temperature exceeded that limit. However, the thermal impact of the pond on the receiving stream can be properly assessed only by comparing pond effluent temperature with the Rouge River temperature. Although some temperature data for the Rouge River at the location just upstream from the facility outfall were not available, river temperature generally followed the same pattern as the air temperature (Figure 5.9). As the air temperature changed over the monitoring period, the temperature of the river followed closely. More importantly, the maximum river temperature was greater than the pond effluent temperature. The maximum temperature of 23.1° Celsius recorded in August 1996 at the pond effluent coincided with 30.0 °C measured at the Rouge River, and the maximum temperature recorded for the Rouge River ranged from 20.5 to 30.0 °C in August 1996. Consequently, the temperature impact of the pond on the Rouge River was not a cause for concern during the monitoring period.

5.4 Conductivity and Chloride

Conductivity depth profiles were measured to examine the location of salt in the pond, beginning in September of 1997. Figure 5.12 presents the results of a survey conducted on September 12, 1997. Figure 5.13 contains the results of conductivity profile measurements made on February 26, 1998[4]. Conductivity observations were made at the surface and at depth increments of 0.5 metres. Additional measurements were made at the bottom. One profile was measured in the forebay, and four were located in the main body of the pond. The reverse-slope outlet pipe is located such that its intake is one metre below the surface of the permanent pool, and the invert of its downstream end establishes the permanent pool level.

Near the end of the summer, the forebay was well mixed as evidenced by relatively uniform conductivity values. The upper portion of the permanent pool had conductivity readings generally less than 1 mS/cm, the middle had readings of 1 to 2 mS/cm, but the majority of the salt was apparently confined to the deepest parts of the pond and well below the opening of the outlet pipe. From a depth of 2.5 to 3.0 m, conductivity increased from approximately 1.75 to greater than 10 mS/cm, and a conductivity of greater than 13 mS/cm was measured at the 3.5 m depth.

In winter, the forebay was also well mixed but the average conductivity had increased from 2.44 mS/cm in September to 3.75 mS/cm in February. Conductivity in the main pond had also increased in winter, and it demonstrated less stratification than observed in summer. Conductivity readings of about 7 to 8 mS/cm obtained at the bottom of both the forebay and the upstream location in the main pond suggest that salt particulates may have been carried into the facility in winter.

Figures 5.12 and 5.13 suggest that the conductivity of the outlet was about 0.9 mS/cm in summer and about 3.5 mS/cm in winter. The average outlet value during the post-construction summer/fall monitoring period was 2.3 mS/cm; during the winter period it was 3.6 mS/cm.

Figure 5.14 illustrates the chloride concentrations in the inlet and outlet over the duration of this study. A net release of chloride from the pond in summer is evident. The winter data tend to show similarity between the inlet and outlet chloride concentrations. Average data for both chloride and conductivity (Appendix H) show large increases across the pond in the summer/fall period and smaller increases during the winter/spring period. This failure to show a material balance probably resulted from the use of grab samples during the winter/spring period.

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[4] The results of the chloride and conductivity survey will be presented in greater detail in a subsequent SWAMP report.

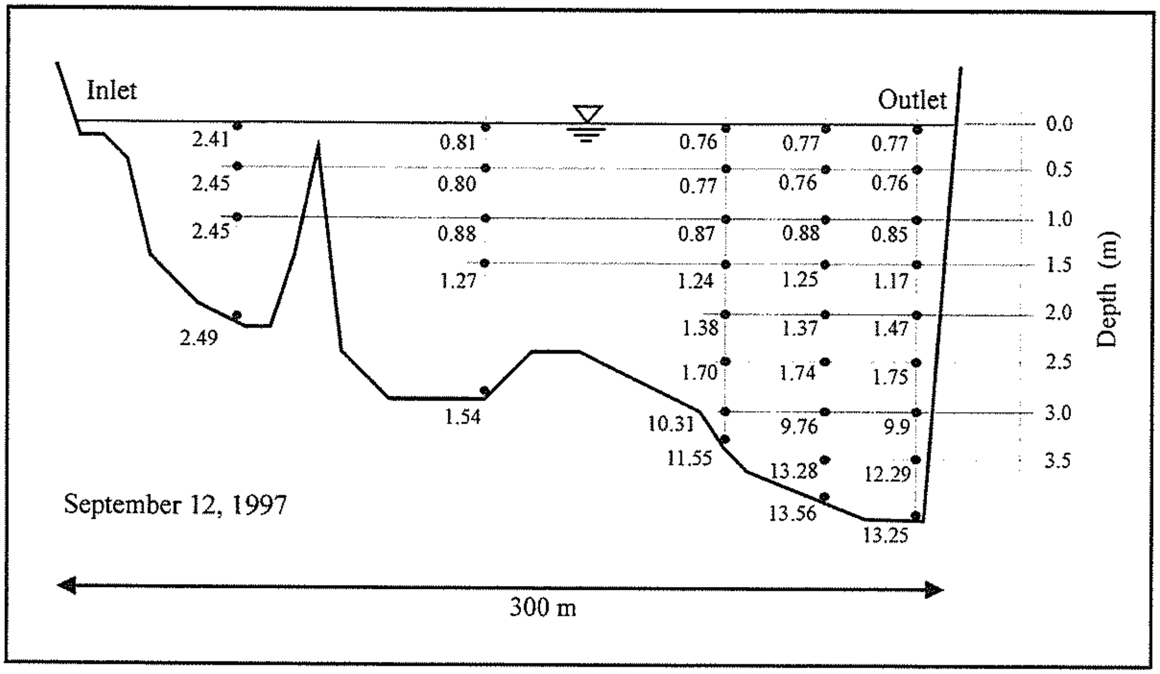

Figure 5.12: Conductivity profiles -- September 12, 1997

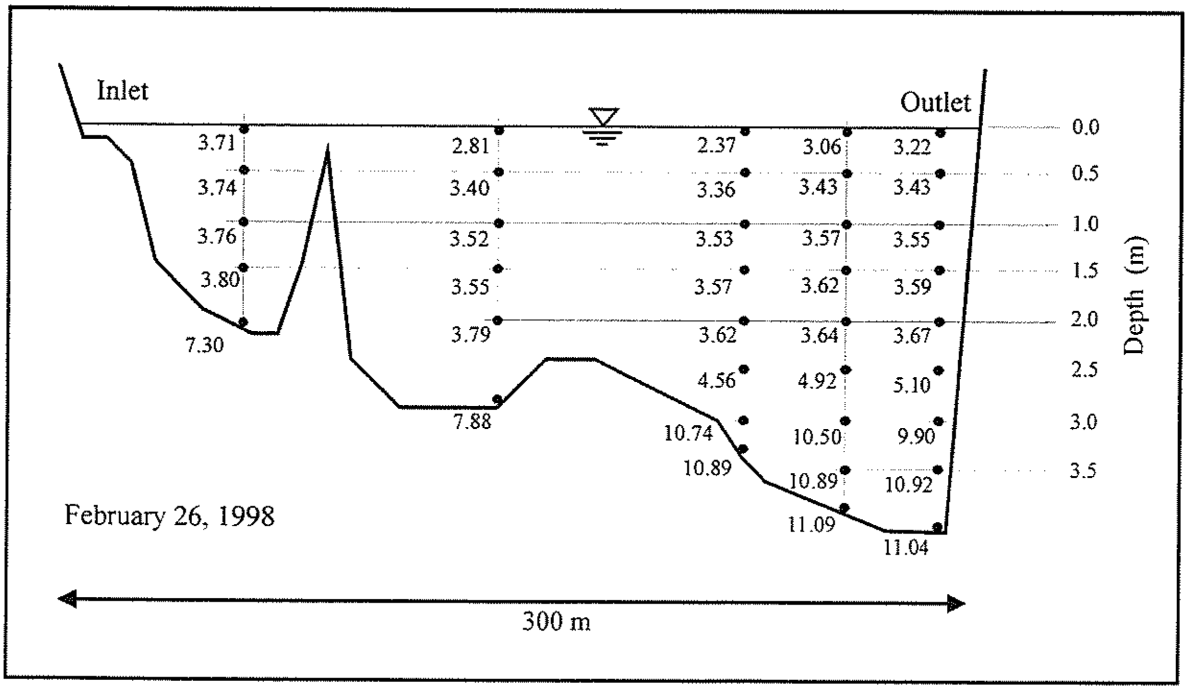

Figure 5.13: Conductivity profiles -- February 26, 1998

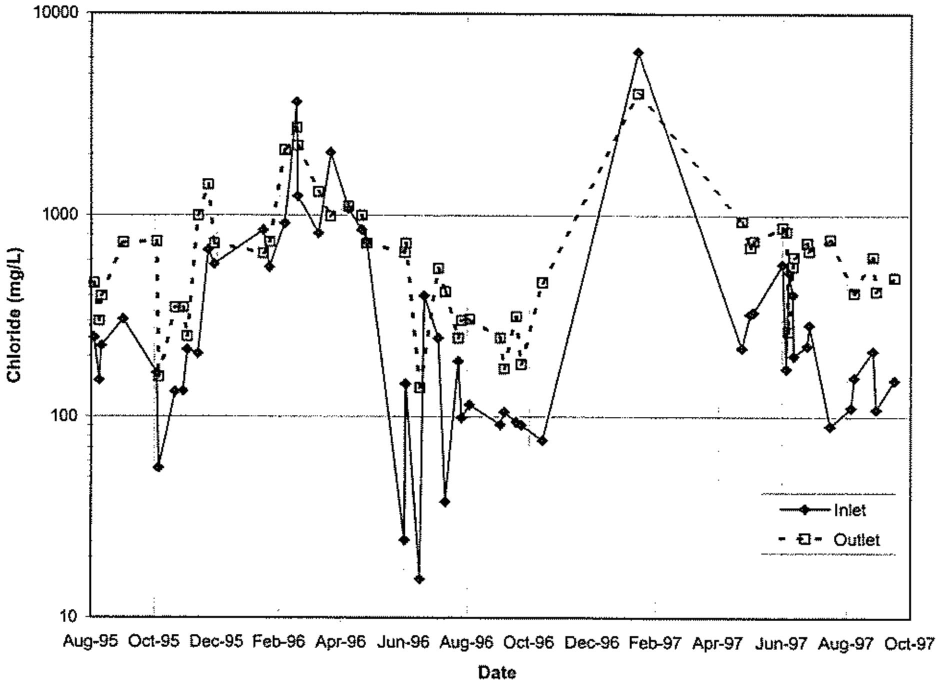

Figure 5.14: Inlet and outlet chloride concentrations

5.5 Water Toxicity Testing

A cooperative study, conducted by the SWAMP Program and the Standards Development Branch of the MOE, measured the acute lethality of runoff samples obtained at the inlet and outlet of the pond. Samples were tested for acute lethality using the rainbow trout 96-hour acute lethality test and the *Daphnia magna* 48-hour acute lethality bioassay. Sub-samples were tested for conventional water quality variables and heavy metals.

A total of nine influent and nine effluent samples were submitted for toxicity testing using the two single-species bioassays, *Daphnia magna* 48-hour acute lethality test and rainbow trout (*Oncoryhnchus mykiss*) 96-hour acute lethality test. Based on these samples, highway runoff from Highway 401 was found to be occasionally toxic for *Daphnia magna*, and non-lethal for the rainbow trout. One of the nine samples from the inlet, and three samples from the outlet, were toxic to *Daphnia magna*. It is suspected that chloride compounds might have caused the toxicity to *Daphnia magna*, for the samples found to be toxic were all collected during the winter, when the chloride concentrations were at their highest. Chloride concentrations above 3,000 mg/l are known to be toxic to *Daphnia magna*. The results of the toxicity tests are summarized in Table 5.4.

Table 5.4: Toxicity testing results, 1996

Sampling Date	*Daphnia magna*		Rainbow Trout (*Oncoryhnchus mykiss)*	
	Inlet	Outlet	Inlet	Outlet
January 17, 1996	NL	NL	NL	NL
January 18, 1996	NL	>100	NL	NL
January 19, 1996	NL	>100	NL	NL
February 8, 1996	NL	Invalid	NL	NL
February 20, 1996	NL	NL	NL	NL
February 21, 1996	>100	>100	NL	NL
April 25, 1996	NL	NL	NL	NL
April 30, 1996	NL	NL	NL	NL
June 7, 1996	NL	NL	NL	NL

Reported as Non-lethal (NL) or LC_{50}

5.6 Vegetation and Aquatic Community Monitoring

5.6.1 Vegetation community assessment

After three growing seasons, all the introduced plant species were still present in the facility. Based on the planting plan, all the areas planted, except one, had thrived and expanded. A grouping of 44 soft stem bulrush was planted adjacent to submerged weir in the main pond. These plants had survived along the pond edges but did not expand out into the pond. The higher flow currents that were experienced in this area could have impeded the growth of the plant into this zone.

Within two growing seasons of construction and planting, 76 aquatic and meadow marsh plant species had naturally colonized the main pond area. During the same period, 50 aquatic and meadow marsh plant species had naturally colonized the sediment forebay. The natural colonization was probably brought about through wind, water and animal transportation. Vegetation communities at this site showed a tendency to evolve toward a common group of dominant species.

The full report is included as Appendix E.

5.6.2 Assessment of Phytoplankton and Periphyton Communities

The algae found in the Rouge Pond, while having some ubiquitous taxa and some representatives indicative of nutrient rich conditions, showed an exceptional number of salt tolerant marine or brackish water diatoms.

The quality of incoming stormwater had a strong impact on the algal composition present in the forebay. The degraded algal communities at this location suggested that poor runoff quality had been experienced. The periphyton in the forebay was characterized as being extremely species poor, with only four taxa recorded. The impact was likely caused by the quality of the sediments since the phytoplankton (which uptake their nutrient from the water column) community did not seem to be affected in the same manner. The bio-volume of the phytoplankton community was sparse, and the periphyton communities were impaired. In the main pond, the number of species in both the phytoplankton and periphyton community increased, and the impairment of the periphyton diminished.

The full report is included as Appendix F.

6 ASSESSMENT OF POND PERFORMANCE

6.1 Introduction

Water quantity and quality data presented in the previous two chapters were used to assess pond performance to the extent made possible by the monitoring program and external factors. The assessment of pond performance focuses on the post-construction summer/fall period which is considered to be representative of normal operation. Performance was computed on a mass loading basis. The lack of volumetric balance in several of the events was circumvented by accepting either the measured influent volume or effluent volume, and estimating the missing or suspect volume based on an average exfiltration rate.

6.2 Performance Assessment -- Summer/Fall Post-Construction Period

Figure 6.1 summarizes the results of the performance assessment for the summer/fall post-construction period. The bar chart compares the seasonal average removal efficiencies for the wastewater constituents monitored in the study. Performance data for individual events are tabulated in Appendix H.

6.2.1 Suspended solids and related parameters

The average removal efficiency for total suspended solids (TSS) was 90%. The load-based efficiencies for individual events ranged from 47% to 99%. The mean inlet concentration was 331 mg/L and the mean outlet concentration was 37 mg/L[5].

The turbidity results support the suspended solids observations. The mean influent and effluent turbidity values were 210 and 34 FTU respectively. The average removal efficiency was 82%. As seen in Chapter 5, a significant change in the suspended particle sizes occurred across the pond. The particle size distribution (PSD) of stormwater is important for several reasons. The relationship between suspended solids removal and the removal of other constituents is greatly influenced by particle size. Clay particles, in particular, have a large capacity to carry nutrients and contaminants due to their high cation exchange capacity (CEC), and large surface area to mass ratio. The change in size distribution observed between the inlet and outlet is an important indicator of size-selective particle removal by settling. The outlet particle size distribution has important implications for effluent impacts to receiving waters both in terms of aquatic habitat and erosion potential.

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[5] Mean concentrations were produced by the statistical analysis program (Table H.4). Removal efficiencies are load-based as described in Chapter 3.

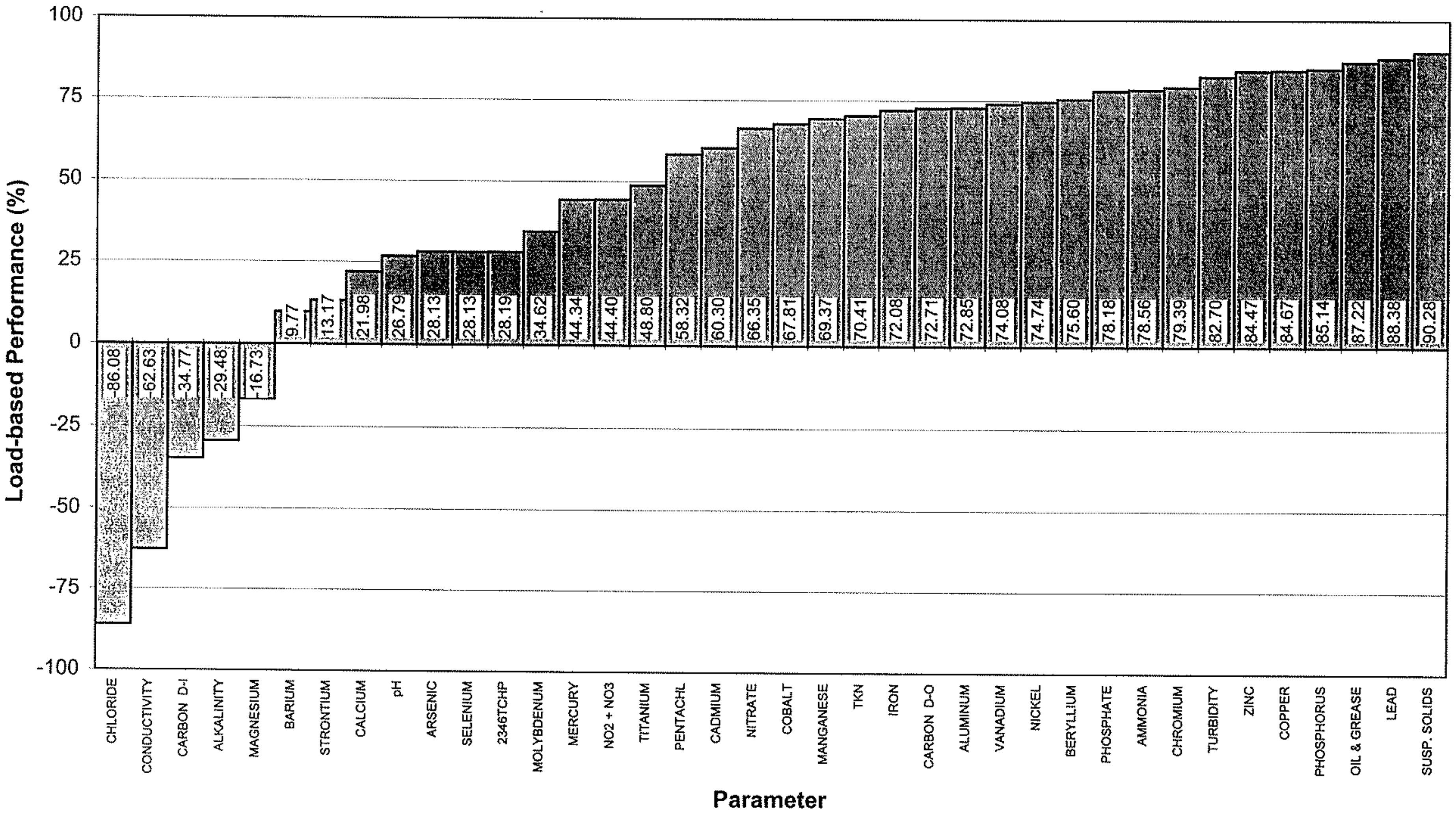

Figure 6.1: Performance summary -- summer / fall post-construction period

The generally accepted particle size division between bed load (the larger particles transported along the bottom of the flow channel) and suspended load (the smaller particles in hydraulic suspension) is about 62 µm. Clay particles are often classified as less than 4 µm in diameter (Waters, 1995).

Table 6.1 summarizes the particle sizes in terms of conventional soil classification categories. The particle size analysis procedure results in 24 size classifications, eight of which fall into each of the three size classifications in Table 6.1. The data in this table were generated from the average inlet and outlet particle size distributions. Inlet solids consisted mostly of silt-sized particles with a significant component of clay-sized particles. The outlet was dominated by clay-sized particles.

Total suspended solids is measured using glass fibre filters that have a nominal pore size of approximately 1 to 2 µm. The particle size data may be used to generate a distribution for particles within the TSS range and, if uniform particle density is assumed[6], the mass in each size range may be estimated. Hence, the removal efficiencies for each soil type may be estimated, as shown in Table 6.1.

Table 6.1: Particle size distributions expressed in terms of soil classifications

Particle Class	Size Range (µm)	Inlet Volume* (%)	Outlet Volume$^{\beta}$ (%)	Estimated TSS In (mg/L)	Estimated TSS Out (mg/L)	Estimated Removal$^{\delta}$ (%)
FINE TO COARSE SAND	62 - 999	5.3	0.1	23	≈ 0	100
Silt	3.7 – 62	56.2	20.9	240	15	95
Clay	0.17 - 3.7	38.5	79.0	-	-	-
Clay (in TSS range)	1.69 - 3.7			68	22	73

* n = 19
$^{\beta}$ n = 18
$^{\delta}$ on a mass basis, adjusted for relative inlet and outlet volumes

Suspended solids removal is achieved by gravity settling. Hence, removal efficiency would be expected to vary directly with particle size and density and inversely with residence time. Some of these relationships can be tested with the available data.

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[6] The particle size analysis method used by the OMOE laboratory did not count particles. Hence particle volumes could not be derived and average density within size categories could not be determined.

Greater suspended solids removal efficiencies are typically associated with the greater influent concentrations. Figure 6.2 illustrates the relationship between influent TSS and removal efficiency for the post-construction summer/fall monitoring period.

The variability of the influent suspended solids concentration was appreciable, ranging from 25 to 2070 mg/L in the post-construction summer/fall monitoring period. The effluent TSS concentration ranged from 4 to 150 mg/L.

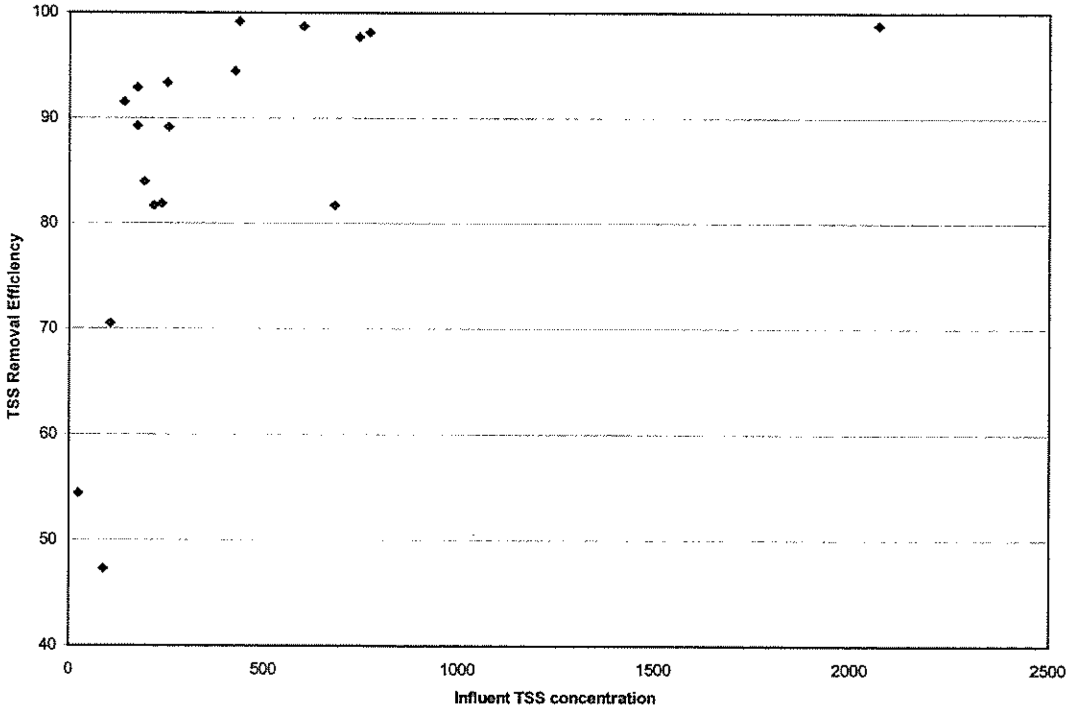

Figure 6.2: TSS removal efficiency versus influent TSS concentration

Examination of the data from this study demonstrated that the influent TSS concentrations, the effluent TSS concentrations and the related removal efficiencies were not correlated with the size of the event (i.e., the influent volume) except that the greatest effluent concentration coincided with the largest event. The response parameters also failed to correlate with the peak inlet flow. Correlation of performance with the mean particle size would not be informative as the mean size varied over a relatively narrow range.

In any sedimentation system having adequate residence time, the effluent TSS concentration is determined predominantly by the concentration of non-settleable or poorly-settleable suspended solids in the influent.

Typically, that concentration varies over a relatively narrow range, as seen in the effluent TSS data. Increased influent TSS concentrations result from the addition of faster-settling particles, generally from events with more intense rainfall and faster runoff. Hence, increased influent TSS concentrations result in increased removal efficiency but may have little effect on the effluent TSS concentration[1].

6.2.2 Metals

The concentrations and removal efficiencies for metals in the summer/fall post-construction monitoring period are summarized in Table 6.2. In most cases the measured concentrations were above the reporting method detection limits (RMDL). Mercury was an exception, with 33% above the RMDL for the inlet samples and only 5% above for the outlet samples. For the outlet samples, molybdenum observations were 95% above the MDL.

Several metals are toxic to fish and wildlife even at low concentrations. The most common toxic metals in stormwater are zinc, lead and copper. Metals in ponds and wetlands can be taken up by plants and bacteria, precipitate as insoluble salts and bind to soluble organics, particulates and sediment (Kadlec and Knight, 1996). As seen in Table 6.1, positive removal efficiencies were achieved for all metals and substantial removals were achieved for most. The exceptions were barium and strontium, both of which - like calcium and magnesium - are Group IIA elements. Because alkalinity and the magnesium concentration increased across the facility, significant removals of barium and strontium should not be expected.

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[1] The implication of this finding is that removal efficiency is a biased indicator of performance. Effluent concentration is the important criterion with regard to environmental protection.

Table 6.2: Summary of performance for metals -- summer / fall post-construction

Metal	RMDL µg/L	PWQO µg/L	Influent Conc.* µg/L	Effluent Conc.* µg/L	Removal Efficiency** %
Aluminum	10		945	263	73
Arsenic	1.0	100	-	-	-
Barium	1		85.6	120.6	10
Beryllium	0.1	1100	0.09	0.03	76
Cadmium	0.1	0.5	0.9	0.5	60
Chromium	0.2	100§	8.5	2.0	79
Cobalt	0.2	0.9	2.2	0.8	68
Copper	0.2	5	2.1	10.2	85
Iron	20	300	1,467	471	72
Lead	5	5	27	6	88
Manganese	0.5		246.9	119.9	69
Mercury	0.02	0.2	0.02	0.01	44
Nickel	0.5	25	6.8	2.4	75
Strontium	2		378.5	448.8	13
Titanium	1		8.1	4.4	49
Vanadium	0.2	6.0	4.8	1.5	74
Zinc	0.5	20	302.1	67.2	84

* Concentration data were determined by the ASAP statistical program. See Table H.4. Arsenic was not included.

** Efficiency data are load-based (i.e., calculated from volume-weighted concentration data). See Table H.12.

§ 1.0 µg/L for chromium VI and 100 µg/L for chromium III

6.2.3 Nutrients

Table 6.3 summarizes the performance of the Rouge Pond with respect to nitrogen and phosphorous compounds.

Table 6.3: Summary of performance for nutrients -- summer / fall post-construction

Compound	RMDL mg/L	PWQO mg/L	Influent Conc.* mg/L	Effluent Conc.* mg/L	Removal Efficiency** %
TKN	0.02		2.00	0.75	70
$NH_3 + NH_4$	0.002		0.604	0.100	79
NH_3		0.02			
$NO_2 + NO_3$	0.005		1.207	0.967	43
NO_2	0.001		0.096	0.039	65
TP	0.02	0.03	0.393	0.060	85
PO_4	0.0005		0.0309	0.0067	77

* Concentration data were determined by the ASAP statistical program. See Table H.4.

** Efficiency data are load-based (i.e., calculated from volume-weighted concentration data). See Table H.12.

High nutrient (phosphorus and nitrogen) loading can lead to eutrophic conditions in receiving waters. Algal shading limits photosynthetic oxygen production beneath the water surface, resulting in depleted oxygen supply to aquatic organisms. The nutrient mass ratio between nitrogen and phosphorus in healthy aquatic ecosystems has been estimated to be about 5:1 (Metcalf and Eddy, 1991). Phosphorus uptake is often the limiting factor in nutrient uptake in wastewaters. The mean TKN:TP ratios of the influent and effluent during the summer/fall were approximately 5:1 and 12:1, respectively. Hence, although the influent N:P ratio was favourable, there was excess nitrogen in the effluent. Physical removal of phosphorus was probably the cause of this change in the N:P ratio.

Phosphate (PO_4) represents the dissolved fraction of total phosphorus and hence removal predominantly occurs through mechanisms other than settling, such as plant uptake or fixation by calcium, magnesium or aluminum. The load-based removal efficiency for phosphate during the summer/fall was 77%. For total phosphorus the removal efficiency was 85%.

The nitrogen cycle describes the conversion of nitrogen in its original organic form to ammonia (NH_3) or its ionized form, ammonium (NH_4), then to nitrite (NO_2) and nitrate (NO_3), and finally to nitrogen gas (N_2), nitrous oxide (N_2O), or nitric oxide (NO) (Kadlec and Knight, 1996). Nitrification to nitrite and nitrate and denitrification to the gaseous phase are both biologically mediated processes that typically occur within aerobic and anaerobic environments, respectively.

6.2.4 Other parameters

Table 6.4 lists the inlet and outlet EMC values and the seasonal load-based removal efficiencies for general water characteristics, organic substances and bacteria during the summer/fall post-construction monitoring period.

Alkalinity and related parameters increased in concentration from the pond inlet to the outlet. Alkaline soil and rock may have been solubilizing to cause some of this effect. Other factors affecting the chemical balance are the acid rain components in the runoff, photosynthesis occurring in the pond and equilibria between atmospheric and dissolved oxygen and carbon dioxide. This condition is natural and consistent with the generally hard, alkaline surface water in the Lake Ontario basin. Alkalinity levels are an important consideration when discussing the concentrations of some metals since they can significantly influence their mobility and bioavailability (OMOEE, 1994).

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

The data indicate that substantial quantities of organic material were being removed by the pond. The removal efficiency for oil and grease (solvent extractables) was 86%. Solvent extractables are organic carbon compounds that are less dense than water and therefore tend to float on the surface; the design of the outlet structure would have helped to contain these materials. Two chlorinated hydrocarbon compounds, pentachlorophenol and 2,3,4,6 tetrachlorophenol, were shown to be removed although, in the latter case, the mean concentrations were less than the laboratory detection level.

The *Escherichia coli.* and fecal coliform concentrations in the pond effluent were one order of magnitude less than in the influent. Those of Pseudomonas were two orders of magnitude less. Fecal coliforms and *E. coli* are used to indicate fecal contaminant levels, and hence, the possible presence of other harmful bacteria in receiving waters. Fecal coliforms often exceed established threshold levels (OMOEE, 1994) for body-contact recreational activities at downstream beaches in the Toronto area. Die off of fecal coliforms in stormwater

stormwater treatment facilities occurs naturally and has been shown to be dependent on water temperature and the residence time of stormwater runoff in the facility (Kadlec and Knight, 1996; Reed *et. al.*, 1995).

Table 6.4: Summary of performance for other constituents – summer / fall post-construction

Constituent	RMDL	PWQO	Influent Conc.*	Effluent Conc.*	Removal Efficiency[§] %
pH	0.1	6.5 - 8.5	7.9	8.2	**
Alkalinity as HCO_3 mg/L	0.2		103	205	-34
Calcium mg/L	0.005		104	144	21
Magnesium mg/L	0.008		10.2	18.0	-20
Diss. Inorg. Carbon mg/L	0.2		23.6	47.7	-40
Chloride mg/L	0.2	*(250)******	206	580	-97
Conductivity µS/cm	1		949	2,269	**
Carbon, dissolved organic mg/L	0.1		9.3	3.1	72
Pentachlorophenol ng/L	100	500	69.4	41.2	58
2,3,4,6,Tetrachlorophenol ng/L	20	1000	<MDL	<MDL	26
Solvent extractables mg/L	1		9.0	1.5	86
E. Coli. #/100 mL		100	2,867	348	82
Fecal Coliform #/100 mL		100	6,245	798	72
Pseudomonas #/100 mL			10,154	190	94

* Concentration data were determined by the ASAP statistical program. See Table H.4.
Exception: Concentration data for bacteria are simple averages.

[§] Efficiency data are load-based (i.e., calculated from volume-weighted concentration data). See Table H.12.

** A "mass" of pH or conductivity is not a relevant number.

*** Suggested by Environment Canada and Health Canada as an approximate limit for the protection of aquatic life.

6.3 Discussion -- Performance, Guidelines and Other Factors

6.3.1 Guidelines and design procedures

In Chapter 2 the design of the Rouge Pond was compared to the guidelines included in the Stormwater Management Planning and Design (SMPD) Manual issued by the Ontario Ministry of the Environment (OMOE, 2003). The highest level, "enhanced", is equated to 80% long-term TSS removal. The Rouge Pond had a seasonal average TSS removal efficiency of 90%.

Figure 6.3 summarizes the SMPD Manual's suggested pond sizes in cubic metres per hectare of drainage basin. The Rouge Pond has a total volume (permanent pool plus extended detention) of 21,000 m^3 and a tributary area of 129 ha, resulting in a design size of 163 m^3/ha. At an estimated catchment imperviousness of 45%, the Rouge Pond is seen to conform to the enhanced performance design as suggested by the SWPD Manual. However, the design of the pond (Marshall Macklin Monagnan Ltd., 1993) was based on modelling that predicted an average 70% TSS removal, or normal performance as defined in the SWPD Manual.

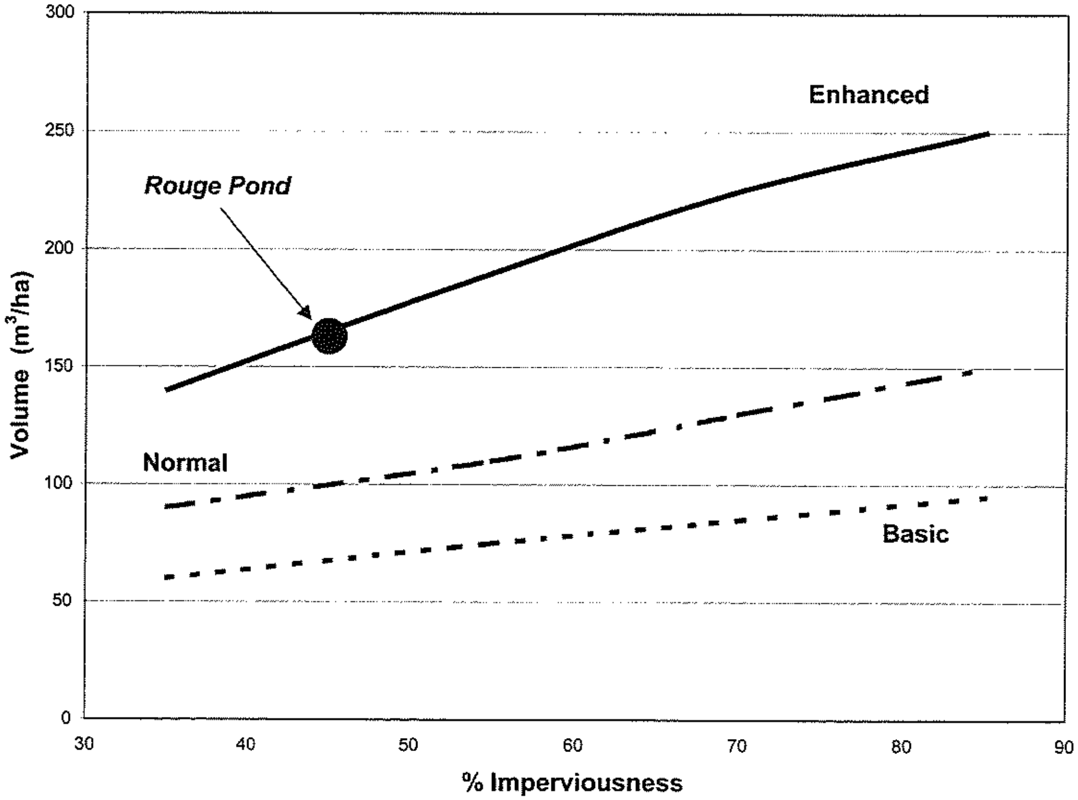

Figure 6.3: Comparison of pond size to MOE guidelines

6.3.2 Effluent quality criteria

As seen in this chapter, removal efficiencies for several other stormwater constituents were also very good. There are currently no criteria for judging the effluent quality of stormwater management facilities in Ontario. In lieu of effluent concentration criteria, the Provincial Water Quality Objectives have been used to provide a basis for comparison. Where the effluent concentrations exceed the PWQO values, the reader should be aware that dilution of the runoff in the receiving stream would probably result in acceptable concentrations in receiving streams having flows appreciably in excess of the pond outlet flows.

6.3.3 Sampling methods and concentrations

The use of time-based composite sampling for the pond influent stream generally tends to underestimate the average pollutant concentration. The cause of this error is the variability of the inlet hydrographs and pollutographs and the tendency for the two curves to peak simultaneously; faster flows generally carry more suspended material. Consequently, the mass of pollutant conveyed during such time intervals is far greater than would be estimated by applying a long-term average (i.e., a composite) concentration value to the same volume of runoff.

There is less variability and less error associated with effluent flows. In this study, the effluent samples were flow-proportioned, further reducing the error. The consequence of these considerations is that the performance of the stormwater pond was probably greater than was measured by this monitoring program.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

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

chloride and conductivity. Although most of the stratified salt water was apparently below the inlet of the reversed-slope discharge pipe, the design of the outlet may have contributed to the release of the salt.

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

7.2 Recommendations

7.2.1 Regarding facility design and operation

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

7.2.2 Regarding monitoring programs

- Monitoring programs intended to provide data on normal operating conditions should be started after all construction activity has ceased and after environmental factors such as vegetation have stabilized to at least some extent. Those programs designed to monitor sediment removal during construction should select sites where the inlet sewers and the pond contents will not be changed while the study is under way.
- Future pond monitoring programs should make use of back-up flow sensors, and combine flow measurement with pond surface level measurement, to ensure that throughput and storage volumes are adequately quantified.
- Further consideration should be given to road salt management programs, to studies of the presence of salt in stormwater management facilities and to potential desalting operations.

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APPENDIX A

Historical Context of the SWAMP Program

HISTORICAL CONTEXT OF THE SWAMP PROGRAM

In the latter part of the 20th century, the Great Lakes Basin experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management programs have been developed in the Great Lakes basin.

A number of complementary programs have been established at the international, national, provincial and municipal levels to protect the Great Lakes ecosystem. The SWAMP program and the study that is the subject of this report are parts of the overall effort.

International Joint Commission

The International Joint Commission (IJC) prevents and resolves disputes between the United States of America and Canada under the Boundary Waters Treaty of 1909. The IJC pursues the common good of both countries as an independent and objective advisor of the two governments.

In particular, the IJC rules upon applications for approval of projects affecting boundary or transboundary waters and may regulate the operation of these projects; it assists the two countries in the protection of the transboundary environment. Among the responsibilities of the IJC is the implementation of the Great Lakes Water Quality Agreement.

Great Lakes Water Quality Agreement

The first Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States was signed in 1972 in recognition of the urgent need to improve environmental conditions in the Great Lakes. The focus of the agreement was to improve water quality through pollution control programs. Objectives included the reduction of nuisance conditions and control of toxic substances. Specific numerical targets were included for the reduction of phosphorus loadings.

The Great Lakes Water Quality Agreement was amended in 1978 to include the objective of controlling persistent toxic substances. The new agreement also incorporated the ecosystem approach to environmental management.

In 1987, the Canadian and U.S. governments signed a protocol that identified local Areas of Concern (AOC's) where beneficial uses of the ecosystem had been significantly degraded. Remedial Action Plans (RAP's) were to be prepared by various levels of government for the AOC's. The plans would contain strategies to clean up problem areas in the Great Lakes region. In addition, the 1987 protocol included annexes addressing specific subjects such as non-point contaminant sources and contaminated sediments.

In total, 43 Areas of Concern were identified throughout the Great Lakes basin. Of the total, 17 AOC's were in Canada.

Great Lakes Sustainability Fund

The Canadian federal government's commitment to the Great Lakes ecosystem was initially managed through the Great Lakes Action Plan (GLAP). In 1990, the Great Lakes Cleanup Fund (GLCuF) was created to provide support for environmental projects designed to benefit the Great Lakes basin ecosystem.

In 1994, GLAP was replaced by the Great Lakes 2000 Program. GLCuF was extended and renamed the Great Lakes 2000 Cleanup Fund. In 2000, the Great Lakes Basin 2020 Action Plan was introduced in addition to the successor to the GLCuF, the Great Lakes Sustainability Fund (GLSF). The new plan and fund place priority on the restoration of environmental quality in Canada's remaining 16 Areas of Concern.

The GLSF supports the implementation of remedial actions falling within federal responsibilities that will lead to the restoration of beneficial uses in the Canadian Great Lakes Areas of Concern. The five-year, $30 million GLSF builds on past successes and is administered by Environment Canada on behalf of eight Government of Canada departments.

To restore these beneficial uses in the Great Lakes Areas of Concern, joint Canada-Ontario teams work in consultation with local Public Advisory Committees to develop Remedial Action Plans (RAPs) aimed at eliminating or reducing the major sources of contamination in these areas. When all beneficial uses in an AOC have been restored, the area is delisted. The RAPs have had some important successes. Collingwood Harbour was delisted in 1994, and Spanish Harbour was designated an Area of Recovery in 1999.

Canada – Ontario Agreement

Canada and Ontario have had Great Lakes environmental agreements in effect since 1971. The latest version of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) was signed in June, 2002. The agreement provides the framework for systematic and strategic coordination of shared federal and provincial responsibilities for environmental management in the Great Lakes basin. The main objectives are to restore degraded areas, to prevent and control pollution, and to conserve and protect human and ecosystem health.

Ontario Ministry of the Environment

The Ontario Ministry of the Environment (OMOE) manages a number of programs that contribute to the protection and clean-up of the Great Lakes basin. The Provincial Water Protection Fund assists municipalities to address water and sewage treatment problems and to undertake related studies. The Ontario Great Lakes Renewal Foundation, established in 1998, provides seed money to support local projects that include habitat restoration and stormwater management. The OMOE works in partnership with federal and state agencies and municipal governments to achieve numerous environmental goals; the Great Lakes Remedial Action Plans have been a prominent example of such work.

Toronto and Region Conservation Authority

The Toronto and Region Conservation Authority (TRCA) is one of 38 conservation authorities in Ontario that develop and implement programs for the management of water and natural resources on a watershed basis. Conservation authorities are created and given their mandate under the Conservation Authorities Act and involve a partnership of the municipalilties within a watershed and the Province of Ontario. The TRCA jurisdiction includes nine watersheds in the Toronto Region.

The TRCA and the Waterfront Regeneration Trust are the local coordinating agencies for the Toronto and Region Remedial Action Plan. The two agencies help the provincial and federal governments fulfill their obligations under the Great Lakes Water Quality Agreement and Canada-Ontario Agreement. The TRCA's general RAP role is to focus implementation activities on an individual watershed basis and provide technical expertise to its implementation partners. Stormwater management and the remediation of combined sewer overflows are integral to the restoration of the Toronto and Region Area of Concern.

SWAMP

In 1995, the Storm Water Assessment Monitoring and Performance Program (SWAMP) was created as a cooperative initiative of agencies interested in monitoring and evaluating the performance of various stormwater management technologies. The SWAMP program acts as a vehicle whereby federal, provincial, municipal and other interested agencies can pool their resources in support of shared research interests.

The objective of SWAMP is to collect data and report on the performance of stormwater treatment facilities. SWAMP is supported by the Great Lakes Sustainability Fund, the Ontario Ministry of the Environment, the Toronto and Region Conservation Authority, the Municipal Engineers Association, a number of individual municipalities in Great Lakes Areas of Concern, and other owner/operator agencies.

A variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. Prior to the creation of SWAMP, these technologies had been studied using computer models and pilot-scale testing, but had not undergone extensive field-level evaluation in southern Ontario.

The objectives of the SWAMP Program are:

- to monitor and evaluate the effectiveness of new or innovative stormwater management technologies,
- to disseminate study results and recommendations within the stormwater management community.

Technologies that have been addressed by the SWAMP program include:

- wet ponds and constructed wetlands,
- underground storage tanks,
- flow balancing systems,
- oil and grit separators,
- conveyance exfiltration systems.

A number of people have been part of the SWAMP team since the inception of the program. In alphabetical order, the staff members have been:

David Averill	Program Co-ordinator [July 2001 to May 2003]
David Fellowes	
Rene Gagnon	
Dajana Grgic	
Weng Liang	Program Co-ordinator [1995 to 2000]
Serge Ristic	
Derek Smith	
Sheldon Smith	
William Snodgrass	Program Co-ordinator [December 2000 to June 2001]
Michael Thompson	
Tim Van Seters	

In addition, several student employees contributed to the success of the projects. Staff of the Ontario Ministry of the Environment, Standards Development Branch, provided administrative and facility support. In addition, Standards Development Branch staff have contributed their technical expertise through informal advice and review of draft reports.

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APPENDIX B

Glossary

GLOSSARY

active storage: see 'extended detention storage'

adsorption: the adhesion of a liquid, gaseous or dissolved substance to a solid, resulting in a higher concentration of the substance (Raven *et al*., 1992)

alga; *pl.* algae: traditional term for a series of unrelated groups of photosynthetic eukaryotic organisms lacking multicellular sex organs (except for the charophytes); the 'blue-green algae,' or cyanobacteria, are one of the groups of photosynthetic bacteria (Raven *et al*., 1992)

autochtonous: pertaining to organisms or organic sediments that are indigenous to a given ecosystem (Parker, 1989)

autotroph: an organism that is able to synthesize the nutritive substances it requires from inorganic substances in its environment (Raven *et al*., 1992)

average event mean concentration (AEMC): the arithmetic mean of two or more individual storm runoff Event Mean Concentrations

bankfull stage: typically defined as the elevation of the active floodplain surface. The bankfull stage corresponds go the bankfull discharge, often considered to be the dominant channel forming discharge and has been shown to occur with a frequency of about 1.5 years. (Badelt, 1999)

benthic: pertaining to occurrence on or in the bottom sediments of wetland and aquatic ecosystems (IWA, 2000)

best management practice (BMP): a device, practice, or method for removing, reducing, retarding, or preventing targeted stormwater runoff constituents, pollutants, and contaminants from reaching receiving waters (ASCE, 1999)

catchment: that area determined by topographic features within which falling rain will contribute to runoff to a particular point under consideration; the area tributary to a lake, stream, sewer or drain. See also drainage area, drainage basin, river basin, catchment area, watershed. (James and James, 2000)

climax community: the final stage in a successional series; its nature is determined largely by the climate and soil of the region (Raven et al., 1992)

diatom: the common name for algae composing the class *Bacillariophyceae*; noted for the symmetry and sculpturing of the silicieous cell walls (Parker, 1989)

drawdown time: during a storm runoff event, the time required for water levels in a pond, retention basin or tank to return to the water level existing prior to the storm event, beginning at the peak level.

emergent macrophytes: a rooted, vascular aquatic plant that grows in periodically or permanently flooded areas and has portions of the plant (stems and leaves) extending through and above the water column (adapted from IWA, 2000)

eutrophic: pertaining to a water body containing a high concentration of dissolved nutrients; often shallow, with periods of oxygen deficiency (Parker, 1989)

evapotranspiration: the combined processes of evaporation from the water or soil surface and transpiration of water by plants (IWA, 2000)

event mean concentration (EMC): the arithmetic mean concentration of an urban pollutant measured during a storm runoff event. The EMC is calculated by flow-weighting either grab samples or consecutive composite concentrations collected over the course of an entire storm event. (James and James, 2000)

extended detention storage: the storage provided by temporarily retaining water within a basin, tank or reservoir; also called active storage

flora: Plants (Parker, 1989)

geotextile: a woven or nonwoven fabric manufactured from synthetic fibres or yarns that is designed to serve as a continuous membrane between soil and aggregate in a variety of earth structures

glacial till: unsorted and unstratified drift consisting of a heterogeneous mixture of clay, sand, gravel and boulders which is deposited by and underneath a glacier (Parker, 1989)

groundwater recharge: replenishment of groundwater naturally by precipitation or runoff or artificially by spreading or injection (James and James, 2000)

groundwater table: the upper surface of groundwater, or the surface below which the pores of rock or soil are saturated (James and James, 2000)

heterotroph: an organism that cannon manufacture organic compounds and so must feed on organic materials that have originated in other plants and animals (Raven *et al.*, 1992)

hydraulic detention time: the time delay in a pond or reservoir between the inlet and outlet hydrograph centroids

hydraulic residence time (or hydraulic retention time): a measure of the average duration over which an element of fluid occupies a given volume or vessel, as estimated from tracer studies with conservative tracers such as lithium or dyes (adapted from IWA, 2000)

hydraulic conductivity: the rate of water flow through a cross section under a unit hydraulic gradient (Parker, 1989)

hydrograph: a graph showing, for a given point on a stream or conduit, the discharge, stage, velocity, available power, or other property of water with respect to time (James and James, 2000)

hyetograph: a graphical representation of the variation in rate of rainfall over time (James and James, 2000)

hyper- : prefix meaning 'above' or 'over'

infiltration rate: the rate at which water enters the soil or other porous material under a given condition (James and James, 2000) (also see hydraulic conductivity and permeability)

lag time: in this study, the time delay between the centroids of a hyetograph and hydrograph, or between the centroids of two hydrographs. The lag time between the influent and effluent hydrographs of a pond is the hydraulic detention time of the pond. Lag time may alternatively be the time interval between event start times or event peaks.

left-censored data: data sets including pollutant concentrations at or below the laboratory analytical detection limit

mass balance: an accounting for all identified materials entering, leaving, or accumulating within a defined region

matric forces: forces acting on soil water that are independent of gravity but exist due to the attraction of solid surfaces for water, the attraction of water molecules for each other, and a force in the air-water interface due to the polar nature of water (Parker, 1989)

olfactory: of or relating to the sense of smell (Oxford Dictionary, 1995)

peak discharge: the maximum instantaneous flow at a specific location resulting from a given storm condition (James and James, 2000)

peak factor: the maximum rate of rainfall or flow for an event divided by the corresponding average rate

peak ratio: the outlet peak flow divided by the inlet peak flow

peak reduction: percent reduction in peak flow, equal to [(peak inflow - peak outflow) ÷ peak inflow] * 100

peak-shaving: reduction of peak discharge rates by providing temporary detention in a BMP: also called peak flow attenuation (adapted from James and James, 2000)

perched water table: the water table or upper surface of groundwater that is unconfined and separated from an underlying main body of groundwater by an unsaturated zone (Parker, 1989)

performance: a measure of how well a BMP meets its goals for stormwater that the BMP is designed to treat. (ASCE, 1999)

periphyton: the community of microscopic plants and animals that grows on the surface of submergent subjects in water bodies (IWA, 2000)

permanent pool volume: a volume of water that is stored permanently in a pond, reservoir or tank, as compared to extended detention volume, which exists only temporarily during storm runoff events

permeability (of soil): property of soil which governs the rate at which water moves through it (James and James, 2000) (also see infiltration rate and hydraulic conductivity)

phytoplankton: microscopic algae that are suspended in the water column and are not attached to surfaces (IWA, 2000).

plug flow: flow in which fluid particles are discharged from a tank or pipe in the same order in which they entered it. The particles retain their discrete identities and remain in the tank for a time equal to the theoretical detention time. A flow value used to describe a constant hydrologic condition. Also a sequence of parcels of water. (James and James, 2000)

porosity: the fraction of a solid, as a percent of its total volume, occupied by minute channels or open spaces (Parker, 1989)

recharge basin: a basin excavated in the earth to receive the discharge from streams or storm drains for the purpose of replenishing groundwater supply (James and James, 2000)

regolith: the layer of rock or blanket of unconsolidated rocky debris of any thickness that overlies bedrock and forms the surface of the land (Parker, 1989)

removal efficiency: a percentage reduction in a specific contaminant or constituent of the wastewater or runoff, as measured across a treatment system or an individual treatment unit

runoff: that part of the precipitation which runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer (James and James, 2000)

runoff coefficient: the ratio of the depth of runoff from the drainage basin to the depth of rainfall (James and James, 2000)

taxon; ***pl.*** **taxa:** general term for any one of the taxonomic categories, such as species, class, order or division (Parker, 1989)

transpiration: the transport of water vapour from the soil to the atmosphere through actively growing plants (IWA, 2000)

unsaturated zone: a subsurface zone containing water below atmospheric pressure and air or gases at atmospheric pressure (Parker, 1989)

vascular: pertains to any plant tissue or region consisting of or giving rise to conducting tissue *e.g.* xylem, phloem, vascular cambium (Raven et al, 1992)

watercourse: a natural or artificial channel for passage of water (James and James, 2000)

watershed: a topographically defined area drained by a river or a stream or a system of connecting rivers and streams such that all outflow is discharged through a single outlet (James and James, 2000)

zooplankton: microscopic animals that move passively in aquatic ecosystems (Parker, 1989)

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APPENDIX C

Fundamental Concepts of Pond Systems

C. FUNDAMENTAL CONCEPTS OF POND SYSTEMS

The purpose of this appendix is to explain the basic principles of stormwater storage pond systems. Material balance principles will be used to derive important relationships and to explain relevant definitions.

C.1 System Definition

Figure C.1 illustrates the basic system diagram for a stormwater pond. A fundamental feature of this system is that its operation is not steady-state; the hydraulic and pollutant loadings vary appreciably with time. Storage within the vessel makes the effluent hydrograph differ from that of the influent. Separation of the pollutants, in both suspended and dissolved forms, within the pond can result in both positive and negative removal efficiencies as a function of time and the many mechanisms that control the process. If there is a continuous dry-weather flow through the pond, the effect of storm events is modified by that flow, and vice-versa. In cases without a continuous dry-weather flow (baseflow), operation of the system is completely intermittent and both the storm event and the inter-event quiescent period must be considered.

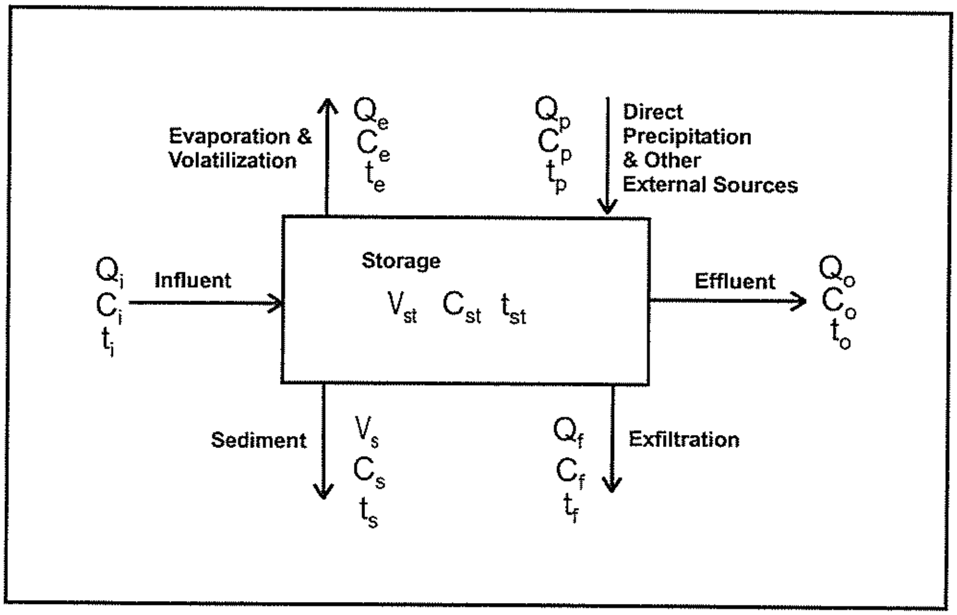

Figure C.1: Stormwater pond material balance diagram

In Figure C.1, "Q" represents a flow rate, "C" represents a pollutant concentration and "V" represents a volume. The symbol "t" represents a time period over which the respective flows, concentrations or volumes are being considered, or are of significance. As will be discussed, this time frame is of importance in the determination of system performance, particularly in situations that include long inter-event periods (quiescent or low-flow conditions) or emptying of the vessel between events.

Inlet flow (Q_i) and outlet flow (Q_o) are typically represented by time-series graphs called *hydrographs*. Inlet concentration (C_i) and outlet concentration (C_o) may be represented by time-series graphs called *pollutographs*. However, monitoring of the inlet and outlet concentrations may be based on composite samples and may not always continue for the full duration of the respective flows. Hence, hydrographs and pollutographs may not always be available.

The volume of water in the pond is typically variable, resulting from the flow-throttling effect of the effluent structure. Concentrations in the pond may be measured only in the more intensive studies. Storage time in the pond has various meanings, as will be discussed.

Exfiltration, through the pond bottom and sides or through a semi-pervious dam, may be a significant factor in some installations. Conversely, a high water table in the vicinity of the pond may result in infiltration of groundwater into the treatment facility. The quantity of infiltration/exfiltration is generally estimated by summing the other flows.

In most stormwater pond studies, losses and gains to and from the atmosphere are seldom considered. These factors are more relevant to lake studies and lake modelling. However, other non-point contributions to the pond can result from waterfowl and other wildlife, including overland drainage from the surrounding area.

The volume and quality of the sediment are important considerations in stormwater ponds. The residence time is governed by decomposition rates and clean-out frequency.

The material balance diagram provides the basis for computing material (mass and volume) balances for the system. An understanding of the dynamics of the system is also necessary to design monitoring programs, and to define parameters representing system performance.

C.2 Quantity Considerations

Stormwater ponds are often designed in accordance with runoff quantity, quality and erosion control objectives. The characteristics relevant to runoff quantity and erosion control will be discussed with reference to actual data from a stormwater storage pond (Figure C.2). This example will help to illustrate not only the basic principles but also some of the constraints associated with the analysis of real-world data.

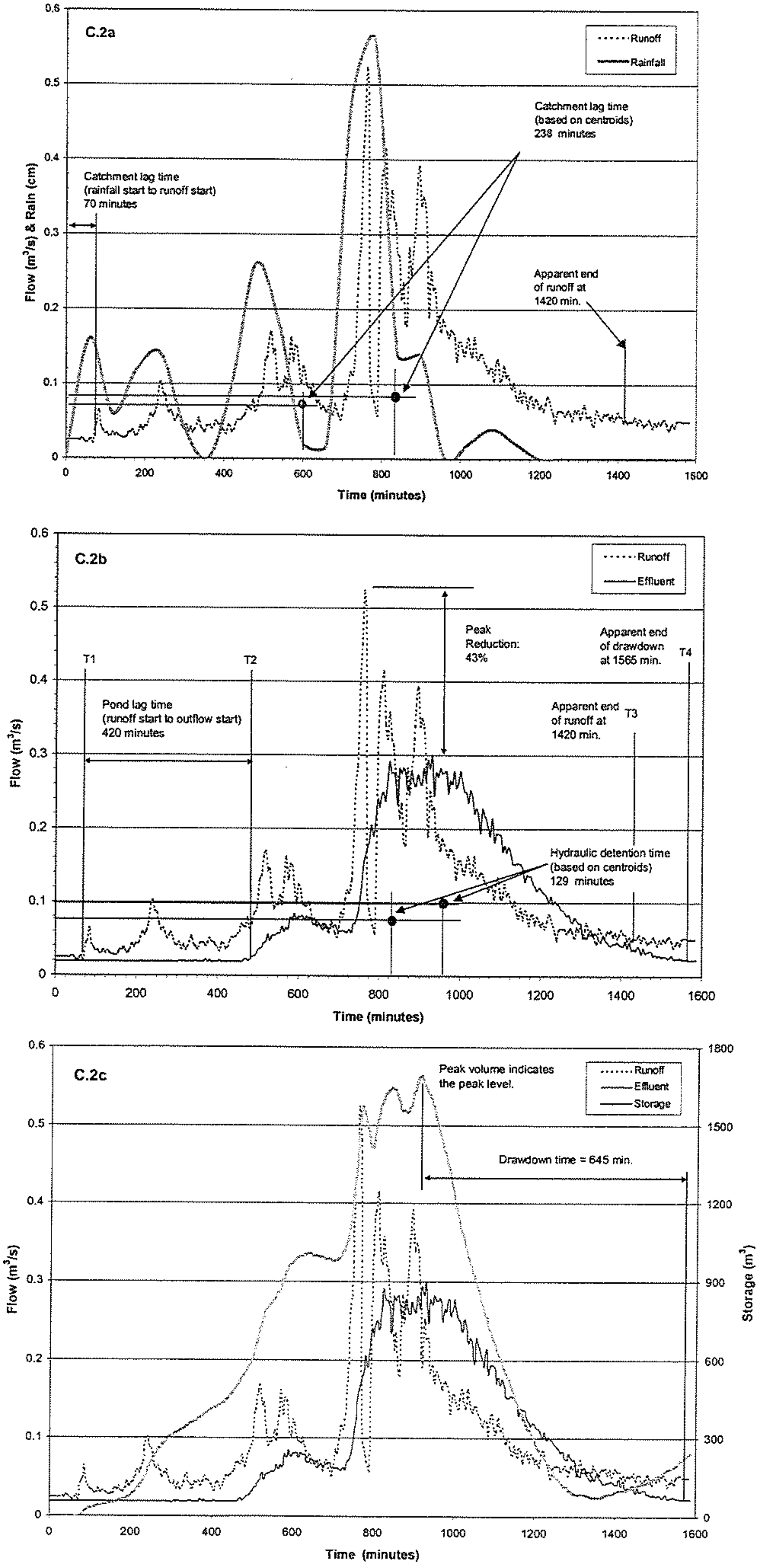

Figure C.2: Hydrologic time series graphs for a single event

Figure C.2a contains the rainfall *hyetograph* and the runoff *hydrograph*. The hyetograph is a plot of rainfall depth versus time. Unlike the example in Figure C.2a, the rainfall data are often plotted as a bar graph using an inverted y-scale. The hydrograph is a plot of runoff flow rate versus time; in this case, the hydrograph contains the inflow to the stormwater pond. Given the surface area of the catchment, both data sets can be converted to volumes of water, or to a uniform depth of water over the catchment area.

The runoff coefficient for the catchment is the ratio of the runoff volume (or depth) to the rainfall volume (or depth). In this case, the value of the runoff coefficient was 0.28. The runoff coefficient is a measure of the ability of the catchment to retain rainfall, such that it percolates into the ground or returns to the atmosphere through evaporation and transpiration, rather than generating runoff. A high value of the runoff coefficient is indicative of a large percentage of impervious surfaces in the catchment. In this example, a little more than one-quarter of the rainfall was measured as runoff.

Various event characteristics related to time and intensity can be extracted from Figure C.2a:

- The lag time of the catchment may be expressed as the time delay between the start of the rainfall and the start of runoff at the point of measurement. This quantity may be influenced by the frequency of observation; in the example data set, the rainfall was reported hourly and the runoff was reported every 5 minutes. Lag times reflect the geometry of the catchment and conveyance infrastructure, but can also be affected by the intensity of the storm, since a light rainfall may be largely contained in depression storage and infiltrated into the soil.
- The centroids of the hyetograph and hydrograph may be computed (from the first moment) and used to represent the variables as existing in points of time. The time difference between the centroids provides an alternative means of characterizing the catchment lag time, one that takes the total volume into consideration and is not biased by the initial rainfall intensity. Baseflow is not included in the calculation of the runoff hydrograph centroid, such that the centroid represents the average runoff conditions independent of the dry-weather flow.
- The durations of both the rainfall event and the runoff are also of interest. Because of the distance over which the runoff must flow, and the resistance to flow created by different surfaces and different paths of flow, the duration of runoff must exceed the duration of rainfall. The duration of the runoff event is measured from the appearance of a flow greater than the baseflow (or dry-weather flow) and ending with the return to baseflow. However, the end of the runoff event may be defined somewhat subjectively because surface and subsurface storage can cause the tails of the runoff curves to persist for long time periods. Also, the duration of intermittent rainfall may be difficult to quantify.
- Each curve may be represented by its peak factor: the ratio of the maximum value to the mean. Because of flow attenuation in the catchment, the peak factor for the runoff is expected to be less than that of the rainfall. In some cases, the temporal relationships of the rainfall and runoff peaks may be documented (e.g., a peak-to-peak lag time); however, in events with multiple peaks, the significance of such relationships is not clear. In this case, the peak rainfall and the peak runoff flow were essentially simultaneous, a situation which would not be expected under most (simpler) conditions.

- The baseflow, or dry-weather flow, may be different before and after the event. A prolonged dry period before the event would cause a small baseflow. The rainfall event would be expected to increase the elevation of the groundwater table, promoting infiltration into the sewer system, and residual surface and subsurface water would enter subgrade drains and other parts of the system slowly. Consequently, the baseflow after the event would be elevated for a considerable time, making estimation of the duration of runoff difficult. The baseflow may not return to the initial conditions before the next rainfall event. In the example, the initial and final baseflows were smoothed and extended for illustrative purposes; the initial value was 0.025 m^3/s and the final value was 0.050 m^3/s.

Figure C.2b contains the runoff hydrograph and the pond effluent hydrograph. Several system characteristics can be determined:

- The lag time of the pond may be expressed as the time delay between the start of the runoff flow (pond influent) and the start of the pond effluent flow. Several factors can influence this variable. In the example, the base effluent flow was often too small to be measured with the installed equipment and some manual extrapolation was employed to adjust the curve. In some cases, a combination of evaporation and exfiltration from the pond can lower the surface of the water below the effluent control structure, producing a storage volume that would otherwise be unavailable and delaying the start of the effluent flow.
- The centroids of the hydrographs may be computed (from the first moment) and used to represent the variables as existing in points of time. The time difference between the centroids is defined as the *hydraulic detention time*, or the average time by which the bulk of fluid is held back or detained by the pond. The hydraulic detention time is determined primarily by the throttling effect of the effluent control structure. It is a measure of the ability of the facility to smooth and extend the runoff hydrograph to reduce its impact on the receiving stream.
- Differences in the durations of the influent and effluent hydrographs are another measure of the flow throttling effect of the facility. Normally, the effluent duration would be expected to exceed the influent duration. However, in this case, the effluent duration was less than that of the influent because of the shapes of the curves and the possible (extra) storage volume. Also in this case, the average effluent flow was observed to be greater than the average influent flow, as a consequence of uncertainty in the initial conditions.
- Because of flow attenuation in the pond, the peak factor for the effluent is expected to be less than that of the runoff (influent). Peak reduction is calculated as the ratio of the outlet peak flow to the inlet peak flow and may be expressed as a percentage. In some cases, the temporal relationships of the influent and effluent peaks may be documented (e.g., a peak-to-peak lag time); however, in events with multiple peaks, the significance of such relationships is not clear.
- The effluent baseflow may be less than the influent baseflow because of evaporation and exfiltration losses from the pond. At other sites, groundwater may flow into the pond causing the effluent

baseflow to exceed that of the influent. Also, the initial and final effluent baseflows may be different because of changes in these gain or loss rates and in the influent baseflow. In this example, the initial effluent baseflow was 0.019 m^3/s and the final value was 0.022 m^3/s. The initial and final evaporation/exfiltration losses were therefore approximately 0.006 m^3/s and 0.028 m^3/s respectively. These estimates were affected by the poor quality of the initial data; if the initial effluent baseflow had actually been closer to zero, the losses would have been similar.

Figure C.2c contains the active (or dynamic) storage volume of the pond together with the influent and effluent hydrographs. The storage volume is calculated from the two sets of flow data. This graph is particularly useful as a means of testing the volumetric balance of the data set. Any deviation from zero storage at the end of the event indicates inaccuracy in the flow measurements and/or the estimation of other gains or losses. In this case, the evaporation/exfiltration losses were estimated from the initial data alone. Failure to include the final baseflow conditions in the calculation procedure is evident in the upward slope of the storage curve after the event. The overall volumetric error was 9%; if measurement of the small initial outflow had been feasible, the computed error may have been smaller.

The water level in the pond is another variable of interest. Water level measurements provide an independent check on volumetric data, providing that a reasonable stage-storage relationship can be derived for the pond based on its geometry. In the example, the pond level was not measured but survey data resulted in a linear stage-storage relationship over the range of active storage volumes. Hence, the pond level is proportional to the stored volume. Knowledge of the water level also permits the computation of another typical pond parameter:

- The *drawdown time* is defined as the period between the maximum water level and the minimum level (dry-weather or antecedent level) in the pond. For design purposes, the drawdown time is computed from the stage-discharge relationship of a specific effluent control structure. This theoretical value would be approached in practice only if there was no influent flow at the time that the pond was draining. Because there is typically some inflow during this time, the observed drawdown time is expected to exceed the design value.

C.2.1 Summary – stormwater quantity

Table C.1 summarizes the hydraulic characteristics of the pond for the stormwater event used as an example in Figure C.2. The underlying principle for runoff quantity analysis is that the displacement of water is acknowledged. In other words, the emphasis is on bulk water quantities. The actual molecules of water entering the system are not necessarily those exiting the system within the timeframe considered. Hence, these quantity relationships should not be confused with the water quality relationships discussed in the next section.

Table C.1: Hydraulic characteristics – example pond event

Parameter	Rainfall	Runoff (Influent)	Pond Effluent
Volume (cubic metres)	32,380	8,950	8,130
Duration (minutes)	1,200	1,350	1,075[1]
Runoff Coefficient		0.28	
Pond Volumetric Error[2] (%)			9
Peak Factor	7.6	5.2	3.3
Peak Reduction			43%
Lag Time (minutes)			
- start-to-start		70	420[1]
- centroid-to-centroid		238	129
- peak-to-peak[3]		n/a	n/a
Pond Drawdown Time (minutes)			645

Notes: [1] Difficulty measuring initial effluent flow reduced the duration and increased the lag time.
[2] Volumes and volumetric error are determined after accounting for baseflow.
[3] Peak-to-peak time intervals can not be adequately defined in a multi-peak event.

C.3 Quality Considerations

Stormwater quality refers to the pollutants in the water. Runoff pollutant concentrations typically vary with time as a result of erosive forces (flow rate) and the duration of runoff events. Consequently, water quality data are often represented by *pollutographs*. Pollutographs are measured by collecting discrete samples at uniform time intervals, and are graphed as time-series data sets.

The fate of pollutants in a pond or other treatment system is determined by the physical, chemical and biological forces or mechanisms to which the pollutants are exposed, and the duration of exposure. Each element of fluid that enters the treatment system has a specific residence time (or retention time) within that system. The *hydraulic residence time* is determined by the pond volume, the flow rate and the flow patterns within the pond. The flow rate and the volume of water within the pond vary as described under the heading of "quantity considerations". The flow patterns are determined by several factors including the geometry of the pond, hydraulic conditions at the inlet and outlet, thermal stratification, density stratification and wind effects.

Because different elements of fluid can take different paths through the pond, a range of residence times exists for each facility. This range is quantified as a residence time distribution, which is measured through the use of an inert tracer material. The tracer is added to the inlet flow at a point in time and concentrations in the outflow are measured as a function of time. The average residence time is measured as the centroid of the residence time distribution curve.

The fate of pollutants in a treatment system may be predicted knowing the hydraulic residence time and a "decay rate" specific to each pollutant. The decay rate is the rate of reaction for substances that are destroyed or transformed within the treatment system, or the settling rate for suspended material that is retained within the system. Reaction rates for specific pollutants depend on many physical, chemical and biological factors. Some pollutants may be both settled and reacted. Some substances may be produced within the pond, for example by photosynthesis. Hence, the residence time of a pollutant is specific to each situation. For inert suspended materials, residence time is determined in part by the frequency of clean-out operations. Inert soluble materials such as chloride may follow the flow paths and leave the ponds in the effluent or the exfiltration flow, but may also be stored for extended periods of time in density layers within the ponds.

No tracer tests were undertaken for the pond used as an example above. Hence, the hydraulic residence times were not determined. A general impression of the hydraulic residence time may be obtained by assuming steady-state flow, an average pond volume and plug-flow conditions (no mixing of influent and pond contents and no short-circuiting of flow). If the average flow were 0.1 m^3/s and the average volume were 7,000 m^3 (both consistent with the above example), the hydraulic residence time would be 1,170 minutes (19.4 hr.) under plug-flow conditions. Short-circuiting of flow, internal mixing and other factors would tend to reduce that value, on average. However, since many rainfall/runoff events are shorter than 19 hours, some of the runoff may be expected to reside in the pond for several days (inter-event periods). Also, eddy currents and dead spaces within the ponds can hold elements of water and associated pollutants for extended periods of time and produce long tails on the residence time distribution curves.

C.4 Detention, Retention and Geometry

Hydraulic detention time and hydraulic residence time (a.k.a. hydraulic retention time) are two distinctly different concepts and are used for different purposes. Detaining, delaying or holding back runoff is an important aspect of hydraulic control – the flattening of runoff hydrographs. Retaining, storing or holding volumes of stormwater is an important aspect of pollution control – the destruction or separation of pollutants. Detention times and residence times can be vastly different within any given system. Figure C.3 illustrates extreme conditions that emphasize the choice of appropriate system characteristics.

A long, narrow pond with inlet and outlet structures at either end (Figure C.3a) forces the flow to proceed under essentially "plug-flow" conditions, such that each element of flow entering the pond has essentially the same residence time as well as the maximum time permitted by the pond volume and flow rate. The average residence time under such conditions could be measured in days. The water level in the pond, however, responds quickly to inflow. If there is minimal effluent flow throttling, the effluent hydrograph could follow very quickly after the influent hydrograph, resulting in a hydraulic detention time of minutes.

The other extreme case is a long, thin pond with the inlet and outlet structures located very close together (Figure C.3b). The pond may be large with good effluent flow throttling, resulting in a long hydraulic detention time. However, elements of the influent flow can proceed quickly from the inlet structure to the outlet structure or, if stored for longer periods of time, would not migrate far from the two structures such that they are discharged before significant treatment can occur. The hydraulic residence time in this case is very short, and much of the volume of the pond is essentially inactive from the perspective of quality control.

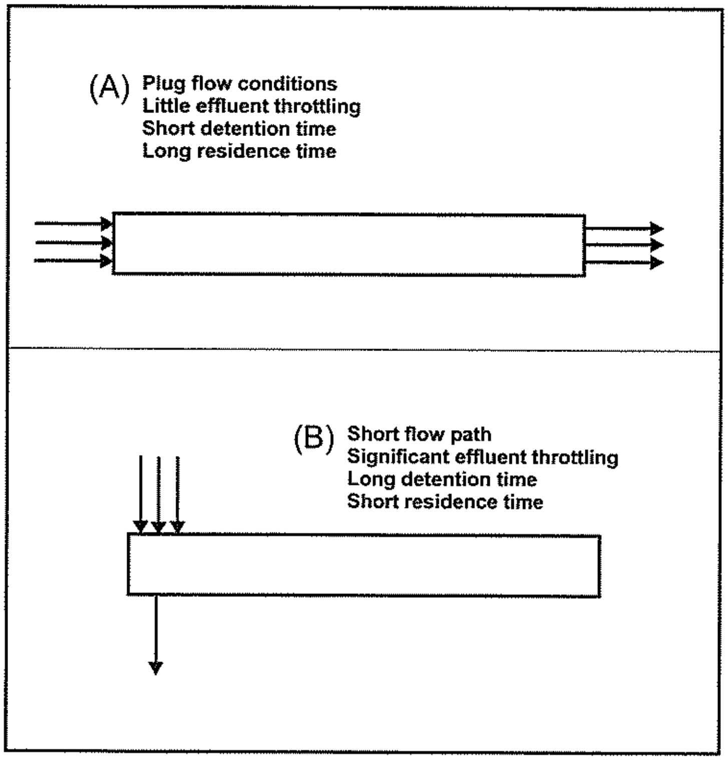

Figure C.3: Detention and residence time scenarios

The two cases illustrated in Figure C.3 are intended to demonstrate the independence of detention time and residence time. One could also envisage a best case scenario that includes both plug flow conditions and good effluent throttling, and a worst case scenario that includes neither plug flow nor effluent throttling.

There is a tendency in the stormwater literature to interchange – or at least confuse - hydraulic detention time and hydraulic residence time. Hydraulic detention time may be discussed (incorrectly) in the context of settling rates or treatment efficiency. Assuming that pond geometry guidelines are followed, a reasonable correlation between detention and retention times may exist for some installations and, by extension, a correlation between detention time and treatment efficiency. However, in a general sense, such correlations do not imply a cause-and-effect relationship, nor can they be used to examine removal mechanisms. Only an extensive review of performance data would indicate whether any such correlations may be reliable, and within what range of system geometry.

C.5 Performance

C.5.1 *Volume, mass and concentration*

The total volume and total pollutant mass found in any water or wastewater stream may be determined by summation over the appropriate time intervals. For example, with reference to Figures C.1 and C.2, the influent volume (V_i) and influent pollutant mass (M_i) are calculated as:

$$V_i = \sum_{k=T1}^{T3} Q_{i_k} \Delta t_k \tag{C-1}$$

$$M_i = \sum_{k=T1}^{T3} C_{i_k} Q_{i_k} \Delta t_k \tag{C-2}$$

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

The flow-weighted average influent pollutant concentration ($\overline{C}_i$) may be determined from the total influent mass and the total influent volume:

$$\overline{C}_i = \frac{M_i}{V_i} \tag{C-3}$$

Similarly, the volume, mass and a flow-proportioned mean concentration may be calculated for the effluent or any other significant flow.

Ideally, the average pollutant concentration measured at a specific location for one event is determined by integration of continuous data or the summation of multiple flow-weighted discrete observations. However, sampling programs seldom generate sufficient data for a rigorous analysis. The average concentration is often determined from composite samples. Important considerations include whether or not the composite sample was flow-proportioned (flow-weighted) and whether the sampling period included the entire runoff event.

Given appreciable temporal variation in most storm events (i.e., in hydrograph and pollutograph shapes), the lack of flow-proportioned samples can result in appreciable error. The worst case scenario consists of simultaneous peaking of the hydrograph and pollutograph, such that high concentrations occur at high flow and a large mass of pollutant is transported during that part of the event. Hence, the type of sampling should be indicated when an average concentration is reported.

Figure C.4 contains a hypothetical example of the effect of using simple average concentrations, or non-flow-proportioned composite samples, to determine pollutant loads. In this example, the pollutographs for two events are identical. The hydrographs have different shapes but represent the same total runoff volume. In the first scenario, with similar hydrograph and pollutograph shapes, the mass loading error resulting from the use of a simple average concentration is 30%. As the curve shapes become dissimilar, the error is reduced (9% in the second scenario). Much larger errors can be caused by simultaneous peaking of the hydrograph and pollutograph.

An average concentration, measured at a specified location over the duration of one event, is typically called the *event mean concentration* (EMC). Ideally, the type of sampling used to determine the EMC should be indicated:

EMC^{p} = flow-proportioned event mean concentration

EMC^{t} = time-averaged or non-flow-proportioned event mean concentration

C.5.2 Event efficiency -- load-based

Load-based efficiency (LE) is defined as the ratio of the mass of a specific pollutant removed to the corresponding influent concentration[1]. This parameter may also be referred to as *mass efficiency*. The *LE* is determined by considering the entire event cycle: the time from the start of the stormwater flow to the end of the effluent drawdown curve. Equation C-4 is written using the summation of incremental mass quantities (the product of flow and pollutant concentration over finite observation intervals). Ideally, all sources and destinations of flow and pollutants would be considered; practically, only the influent and effluent are included in the definition of efficiency.

$$LE = \frac{\sum_{k=T1}^{T3} Q_{i_k} C_{i_k} \Delta t_k - \sum_{k=T2}^{T4} Q_{o_k} C_{o_k} \Delta t_k}{\sum_{k=T1}^{T3} Q_{i_k} C_{i_k} \Delta t_k} \qquad \text{(C-4)}$$

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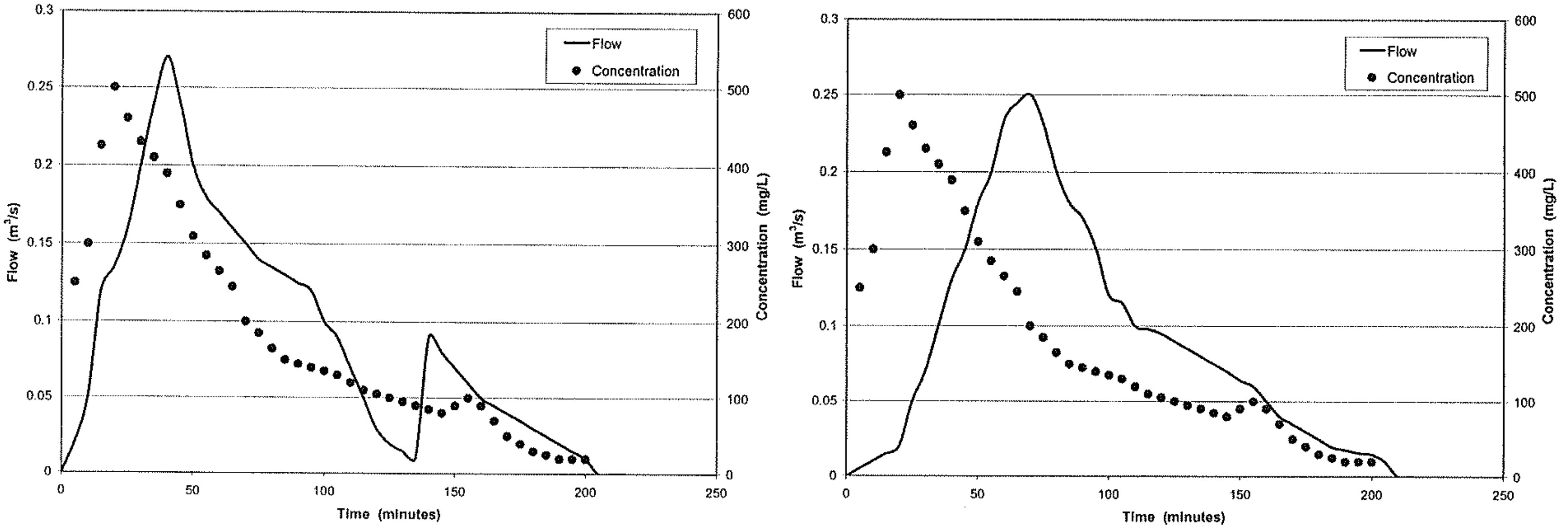
[1] In this appendix, removal efficiency is expressed as a fraction rather than a percentage, primarily to simplify the equations.



Scenario 1: Similar Hydrograph & Pollutograph Shapes

Total runoff volume =	1,170 m^3
Total pollutant mass =	301 kg
Average pollutant concentration =	180 mg/L
Pollutant mass estimated from avg. concentration =	211 kg
Mass loading estimate error =	30 %

Scenario 2: Hydrograph & Pollutograph Displaced in Time

Total runoff volume =	1,170 m^3
Total pollutant mass =	233 kg
Average pollutant concentration =	180 mg/L
Pollutant mass estimated from avg. concentration =	211 kg
Mass loading estimate error =	9 %

Figure C.4: Effect of using average concentration data -- hypothetical data set

Equation C-4 may also be written using the sums of all mass loads entering (SOL_{in}) and leaving (SOL_{out}) the facility.

$$LE = \frac{SOL_{in} - SOL_{out}}{SOL_{in}} \tag{C-5}$$

In Equation C-5, the summations are assumed to be over the time periods relevant to the influent and effluent.

C.5.3 Event efficiency - concentration-based

In stormwater studies, flow and volume data may not always be available. In such cases, the Event Mean Concentration *(EMC)* is an average concentration that has been obtained without flow-proportioned sampling. Using the *EMC* values, a concentration-based pollutant removal efficiency for a single event may be defined as follows:

$$CE = \frac{EMC_i - EMC_o}{EMC_i} \tag{C-6}$$

$$CE = 1 - \frac{EMC_o}{EMC_i} \tag{C-7}$$

This expression for concentration-based efficiency is the definition of efficiency commonly used for continuous-flow clarifiers with negligible underflow.

C.5.4 Residence time and intermittent operation

There are further complications to be considered when examining effluent samples and calculating removal efficiencies. These considerations are consequences of the long residence times and intermittent operation common to stormwater treatment systems.

Ideally, removal efficiency should be associated with each element (or incremental volume) of suspension that enters the treatment system. Each element of fluid entering the system contains a specific matrix of pollutants that will be removed in accordance with their characteristics, the hydraulic and other conditions in the system, and the time during which the element of fluid resides in the system. Comparison of the characteristics of that element of fluid, as it leaves the system, with its initial characteristics would provide a true measure of treatment efficiency.

Consider a large wet pond treatment system:

- Effluent flow at the start of an event consists primarily of displaced fluid that had been in the pond since the previous event or had accumulated during the intervening dry-weather period. The long residence times for these elements of fluid would probably result in pollutant concentrations equivalent to the non-settleable (non-treatable) residual concentrations.
- As the event progresses, the component of the effluent flow generated by the current event begins to increase. Some influent flow will mix with the pond contents and some elements of the influent may short-circuit to reach the effluent structure before the majority of the flow. The result is measurement in the effluent stream of partly diluted and partly settled current-event influent.
- In moderate-size events, the remainder of the influent fluid elements would reside in the pond until the next event or until they are gradually displaced by dry-weather flow. These elements would be expected to receive the maximum treatment efficiency possible for the specific installation.
- In large events, the total contents of the pond may eventually be exchanged. The effluent would then reflect only the current influent conditions and the treatment efficiency of the pond in continuous (flow-through) operation mode.

Effluent samples are typically collected during each runoff event and only for the duration of the event hydrographs. Effluent quality from that sampling period may be compared directly to the influent quality from the same event to estimate treatment efficiency. The result is a measure of the change in water quality across the pond, and the reduction in pollutant loading during that specific event. However, that procedure ignores the residence time in the system and would not provide removal efficiency values that could be related to specific removal mechanisms.

Ideally, the least error would result from continuous measurement of influent and effluent during both wet-weather and dry-weather. Short-term efficiency would be best represented by comparison of influent samples to effluent samples with the latter offset by the residence time in the system. However, the residence time could not be measured on a continuous basis because it is a distribution that is influenced by many physical factors, and it is measured by a pulse addition of a tracer. The concept of following elements of fluid through the treatment system may be appropriate to numerical simulation techniques.

Inter-event (or dry-weather) flow and pollutant loading are often not considered. Low flows and small concentrations may be difficult to measure, and differential concentrations (removals) may not be significant numbers. However, the long dry-weather time periods can conceptually result in large volumes and pollutant masses.

Practically, composite samples are collected for each event and few - if any - samples are collected between events. Hence, the data analysis options are: (1) compare the effluent data to the influent data of the same event, (2) compare the effluent data to the influent data of the previous event, or (3) calculate efficiency based only on long time periods considering the total influent and effluent masses (long-term mass efficiency). The latter option will provide the best estimate of system efficiency.

C.5.5 Long-term efficiency - load-based

Load-based efficiency calculations provide the most accurate method of determining long-term efficiency. In this procedure, the summations are made over the full time frame of interest (several events, a season, a year or several years).

The sum-of-loads concept may be expressed in terms of *EMC* values and event volumes *(V)*. Hence, the efficiency ratio based on mass load for a single event is:

$$LE_{emc} = 1 - \frac{EMC_o \times V_o}{EMC_i \times V_i} \tag{C-8}$$

An average efficiency ratio could be calculated for several events:

$$ALE_{emc} = \frac{\sum_{j=1}^{m} LE_j}{m} \tag{C-9}$$

where: m represents the number of events.

However, a simple average of efficiencies gives equal importance (weight) to each event, regardless of event size. A better estimate of long-term efficiency is obtained by totalling the mass quantities over the time period of interest:

$$SLE_{emc} = 1 - \frac{\sum_{j=1}^{m} EMC_{o_j} \times V_{o_j}}{\sum_{j=1}^{m} EMC_{i_j} \times V_{i_j}} \tag{C-10}$$

Table C.2 contains an example of the extent to which averaging of event performance can distort the estimate of long-term efficiency. In this hypothetical example, one large event, one small event and two moderate-sized events each have reasonable TSS removal efficiencies. A simple average of the four efficiencies, however, does not adequately represent actual system performance.

These definitions of efficiency are not as rigorous as those derived from material balance principles. The difference is that the composite samples that are used to determine the *EMC* values were not necessarily flow-proportioned. However, from a practical perspective (given current sampling practice), mass loading based on *EMC* values and computed over as large a variety of events as possible is the best feasible method of representing stormwater pond performance.

Table C.2: Effect of averaging performance data -- hypothetical data set

Event No.	Volume	*EMC* in	*EMC* out	% Rem.	Mass in	Mass out
1	2,000	125	50	60	250,000	100,000
2	500	110	15	86	55,000	7,500
3	10,000	165	120	27	1,650,000	1,200,000
4	1,500	115	30	74	172,500	45,000
ALE				62		
Total					2,127,500	1,352,500
SLE				36		

C.5.6 Long-term efficiency – concentration-based

Flow and volume data are not always available; consequently, pollutant mass can not be determined. In such cases, an average event mean concentration *(AEMC)* may be calculated for several events, for example over one year or a runoff season.

$$AEMC = \frac{\sum_{j=1}^{m} EMC_j}{m} \qquad \text{(C-11)}$$

where: m represents the number of events.

Similarly, long-term *average efficiency (ACE)* can be calculated from *AEMC* values:

$$ACE^* = \frac{AEMC_i - AEMC_o}{AEMC_i} \qquad \text{(C-12)}$$

$$ACE^* = 1 - \frac{AEMC_o}{AEMC_i} \qquad \text{(C-13)}$$

Alternatively, individual efficiencies can be averaged. Numerically, averaging the concentrations over a season and calculating a seasonal efficiency based on averages is not the same as calculating individual *EMC*-based efficiencies and averaging them $(ACE^{*} \neq ACE^{\#})$.

$$ACE^{\#} = \frac{\sum_{j=1}^{m} CE_j}{m} \qquad \text{(C-14)}$$

C.6 Correlating Efficiency to Hydraulic Load and System Parameters

For design purposes, anticipated pollutant removal efficiency must be correlated to the hydraulic load and to parameters that describe the treatment facility. Such correlations are not easily determined and may not be reliable predictors of performance.

The traditional method of reporting clarifier performance is to correlate removal efficiency to the surface loading rate, or surface overflow rate (SOR). The SOR is the hydraulic load per unit surface area of the separation vessel, generally in units of metres per hour ($m^3/hr \div m^2$). The SOR may be shown to be the numerical equivalent of the critical settling rate, or the settling rate of a particle that travels the full depth of the vessel in the hydraulic residence time[2]. However, the correlation applies to vessels with vertical sides and fixed surface areas, as well as to cases in which the hydraulic load is constant or varies little in the time frame relevant to the hydraulic residence time. These conditions do not apply to stormwater ponds.

From a mechanistic perspective, performance could be related to the settling rate of the suspended particles, the depth of the pond and the hydraulic residence time. Or, more simply, the performance data could be correlated with the hydraulic residence time. Unfortunately, the hydraulic residence time is a generally unknown quantity, and it is influenced by both flow-through conditions and inter-event times.

From a practical perspective, there may be two reasonable approaches to the problem. A set of simplifying assumptions may lead to a suitable correlation. For example, given conformity to geometric guidelines, the volume of the pond – perhaps as a function of the surface area and other properties of the catchment – may be an adequate parameter for correlation to performance. A more complex, but potentially more reliable method, would be to develop a generic simulator that could take both pond geometry and seasonal loading dynamics into consideration in predicting pond performance.

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[2] The derivation may be found in most sanitary engineering textbooks.

APPENDIX D

Analytical Procedures

Table D.1: **OMOE analytical procedures employed in the Rouge Pond stormwater study**

Method Number	Product Number	Constituent	Procedure	Comments
E3016A	CL3016	Chloride	Colourimetry following two-stage reaction with mercuric thiocyanate and ferric iron	interferences from bromide, iodide, sulphide, cyanide, thiosulphate
E3060B	HG3060	Mercury	Cold vapour flameless atomic adsorption spectrophotometry (CV-FAAS) at 253.7 nm following acid digestion and reduction with stannus chloride solution	method is suitable for "clean" waters
E3080A*	MET3080	Metals	Inductively coupled plasma-optical emission spectroscopy (ICP-OES) analysis following preconcentration and digestion with nitric acid and aqua regia -- only the supernatant is analyzed	A preconcentration step (evaporation) used in a previous method was found to result in lower levels for some elements.
E3089A	ASSE3089	Arsenic, Selenium & Antimony	Flameless atomic adsorption spectroscopy (FAAS) following acid digestion and hydride generation	
E3119A	CPA3119	Chlorophenols and phenoxyacid herbicides	Solid phase extraction (SPE) using pre-conditioned C_{18} cartridges followed by elutriation with solvent, treatment with diazomethane and analysis gas chromatography with electron capture detectors (GC-ECD)	16 compounds
E3120B	OCS3120	Organochlorine pesticides (OC's), polychlorinated biphenols (PCB's) and other chlorinated organic compounds	GC-ECD following solvent extraction and clean-up with Florisil™	38 compounds
E3265A	PAH3265	Acid/base and neutral compounds	In-situ acetylation and liquid/liquid extraction with dichloromethane, followed by drying with sodium sulphate, concentration and analysis by gas chromatography with a mass selective detector (GC-MSD) with single ion monitoring (SIM) data capture	a wide range of organic compounds including phenolics and PAH's
E3289A	PHALCO 3289	Conductivity, pH, Alkalinity	Automated system using electrodes in a constant temperature bath for conductivity, a calibrated potentiometric system for pH and titration for TFE alkalinity (to an end-point of pH 4.5)	Supernatant or filtrate is analyzed. Gran alkalinity by special request only
E3311A	TURB3311	Turbidity	Measurement of light scattering at 90° ±30° by nephelometry calibrated to Formazin turbidity standards	

E3328A	PART3328	Particle size	Optical – laser light diffraction (Coulter LS130 Particle Size Analyzer)	0.1to 900 µm in 27 size channels. Reported as % by volume (no count data)
E3334A	ID3334 SXT3334	Organic Solvent Extractable Matter (liquid-liquid or liquid-solid extraction)	Diffuse reflectance infrared Fourier transform spectroscopy (DR-IR) after extraction with dichloromethane	3 major groups: non-volatile petroleum hydrocarbons, cooking oils, soaps and detergents (Presence of humic acid detected in several samples).
E3364A	DISNUT 3364	Dissolved nutrients: ammonia + ammonium nitrite nitrate + nitrite phosphate	Simultaneous, automated analysis of one aliquot of sample: - ammonia by conversion to indophenol blue with sodium nitroprusside as a catalyst - nitrite by colourimetric method after reaction with sulphanilamide and N (1-napthyl) ethylenediamine dihydrochloride - nitrate + nitrite by colourimetric method following conversion of nitrate to nitrite - phosphorus, as orthophosphate, by colourimetric method folowing reaction with ascorbic acid	
E3365A	SS3365	Suspended Solids	Suspended solids are determined as the material removed from suspension by a 1.5 to 2.0 µm glass fibre filter, after drying at 103° ±2°C	
E3367A	TOTNUT 3367	Total nutrients: total P TKN	Total P: digestion in sulphuric acid, mercuric oxice, potassium sulphate media followed by reduction with ascorbic acid – measured a orthophosphate Total Kjeldahl Nitrogen: digestion with Kjeldahl's reagent, neutralization and analysis for ammonia species by colourimetry	
E3370A	DCSI3370	Silicon: reactive silicate Dissolved organic carbon Dissolved inorganic carbon	Molybdate reactive silicates: dissolved reactive silicate ions are measured through the formation of molybdenum heteropoly blue complex Dissolved inorganic carbon (+ carbon dioxide) are measured by acidifying the sample supernatant, extracting the CO_2 through a dialysis membrane and reacting it with phenolphthalein and colourimetric measurement Organic carbon is measured in the sample supernatant by acidification followed by nitrogen flushing to remove inorganic carbon and UV digestion in an acid-persulphate medium. The resulting CO_2 is analyzed as above.	

E3371A	ECFSPS 3371	Escherichia coli Fecal streptococcus	Membrane filtration procedures are used to recover and enumerate several bacteria or bacterial groups. The culture media, incubation temperatures and incubation periods are specific to each bacterial analyte.	
E3386A*	MET3386	Metals	Inductively coupled plasma (ICP) following ultrasonic nebulizer	Digestion is not used.

* Note: The analytical method for metals changed from MET3080 up to and including Aug. 9, 1996 to MET3386 after this time.

Table D.2: Analytical detection limits and provincial water quality objectives (PWQOs) for herbicides, phenols and PAHs analyzed in this study

Polynuclear Aromatic Hydrocarbons	**Reporting Method Detection Limit (µg/L)**	**PWQO Limit (µg/L)**
Napthalene	1.6	7
2-methylnaphthalene	2.2	2
1-methylnaphthalene	3.2	2
2-chloronaphthalene	1.8	0.2
Acenaphthene	1.3	
Acenaphthylene	1.4	
Fluorene	1.7	0.2
Phenanthrene	0.4	0.03
Anthracene	1.2	0.0008
Fluoranthene	0.4	0.0008
Pyrene	0.4	
Benzo(a)anthracene	0.5	0.0004
Chrysene	0.3	0.0001
Benzo(b)fluoranthene	0.7	
Benzo(k)fluoranthene	0.7	0.00002
Benzo(a)pyrene	0.6	
Indeno (1,2,3-c,d) pyrene	1.3	
Dibenz(a,h)anthracene	1.3	0.002
Benzo(g,h,i)perylene	0.7	0.00002
1-chloronaphthalene	2.5	0.1
Perylene	1.5	0.00007
Indole	1.9	
5-nitroacenaphthene	4.3	
Biphenyl	0.6	0.2
Herbicides and Pesticides		
2,4-dichlorophenol	2.0	0.2
2,4,6-trichlorophenol	0.02	18
2,4,5-trichlorophenol	0.1	18
2,3,4-trichlorophenol	0.1	18
2,3,4,5-tetrachlorophenol	0.02	1
2,3,4,6-tetrachlorophenol	0.02	1
Pentachlorophenol	0.1	0.5
Dicamba	0.05	200
Bromoxynil	0.05	
2,4 - D-propionic acid	0.1	
2,4 -D	0.1	4
Silvex	0.02	
2,4,5 -T	0.05	
2,4 -DB	0.2	
Dinoseb	0.02	
Picloram	0.1	
Diclofop-methyl	0.1	

Note: Only pentachlorophenol and 2-3-4-6 Tetrachlorophenol were observed at concentrations consistently above laboratory analytical detection limits.

APPENDIX E

Vegetation Monitoring

The following report was produced by the Toronto and Region Conservation Authority (TRCA). It includes studies of the highway stormwater pond adjacent to the Rouge River in Toronto in addition to a stormwater retrofit pond in Richmond Hill. This document has been reformatted but is substantially as submitted by TRCA.

STORM WATER ASSESSMENT MONITORING & PERFORMANCE (SWAMP) PROGRAM

VEGETATION MONITORING COMPONENT

FINAL REPORT for YEARS 1 & 2

June, 1998

Prepared by: Jennifer Vincent (TRCA) and Gavin Miller (TRCA)

STORM WATER ASSESSMENT MONITORING
& PERFORMANCE (SWAMP) PROGRAM

AQUATIC VEGETATION MONITORING COMPONENT

Final Report for Years 1 & 2 – June, 1998

1.0 BACKGROUND

The Storm Water Assessment Monitoring and Performance (SWAMP) Program is an initiative of the Government of Canada's Great Lakes Sustainability Fund, the Ontario Ministry of Environment (OMOE), the Toronto and Region Conservation Authority (TRCA), and the Municipal Engineer's Association. A number of individual municipalities and other owner/operator agencies have also participated in SWAMP studies.

As urban areas within the Great Lakes Basin expanded during the mid to late 1980s, stormwater runoff associated with urban growth increased. The increase has had a pronounced environmental effect on water quality and fish habitat raising concerns over stormwater management. In response to these concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied using computer models and pilot-scale testing, but have not undergone extensive field level evaluation in southern Ontario. The SWAMP Program evaluates these technologies at the field level. The purpose of the SWAMP Program is to monitor and evaluate new and conventional stormwater management technologies; to disseminate study results; and to make recommendations to the stormwater management (SWM) industry. Monitoring components include: rainfall, flow, water quality and temperature, sediment particle size distribution, sediment quality, toxicity, and vegetation.

The research addresses questions raised by SWM practitioners concerning the performance of SWM facilities in improving stormwater quality. Studies will also respond to questions regarding appropriate plant species and effective planting strategies in facilities with a constructed wetland component. Based on the Toronto area experience, the aquatic plant component of a SWM pond facility can represent up to 7% of the total facility construction cost to the developer. Aquatic plants can represent up to 30% of the total planting plan cost. Therefore, the developer and the municipality (which often becomes the owner of the facility) both have an interest in ensuring that the plant species selected and the planting strategy employed will be the most suitable for conditions found in the stormwater management facility. Conservation agencies and municipalities are interested in ensuring that the plants fulfil short-term objectives of soil stabilization and provide optimal pollutant removal over the life of the facility. Vegetation community monitoring and assessment have, therefore, been included as part of the monitoring program applied to these facilities.

It is important for project managers to design and implement planting plans that are compatible with site conditions, will provide a basis for other plants to colonize, meet sediment and erosion control objectives while plants are establishing, and are cost effective. In order to provide insight into which plant species would best accomplish these objectives, this study examined the establishment of a plant community, documenting which plants were present in, or dominated, the aquatic vegetation community and at what times of the year. Dominance is a function of the plant's ability to compete within the community structure and a function of season, as plants mature at different times of the year.

In 1996 and 1997, the TRCA undertook aquatic vegetation community monitoring on behalf of the SWAMP Program. This monitoring program looks at the ***aquatic*** vegetation community only. Monitoring of the algal community was undertaken by Dan Olding, and results are documented in a separate report. Monitoring of the terrestrial component of planting plans was deemed to be beyond the scope of this program.

This report summarizes the results of the first two years of aquatic vegetation community monitoring at two newly constructed SWM ponds within the Greater Toronto Area: the Ontario Ministry of Transportation's (MTO) Rouge/401 SWM pond and the Town of Richmond Hill's Harding Park SWM retrofit pond.

1.1 Literature Review

Loiederman Associates, Inc. (1996) note findings from a literature review on the subject of vegetation in stormwater wetlands:

- Vegetation contributes to the water quality function of stormwater ponds. Nutrients are assimilated into plant biomass, providing temporary storage. Dead and decaying biomass can fuel reduction/oxidation processes such as nitrification/denitrification, providing both substrate and carbon sources. Plants transport oxygen deeper into the soil than it would travel by diffusion alone.
- Many of the biogeochemical processes involved with water quality treatment, including nitrification/denitrification, phosphorus retention, and pollutant immobilization, can be linked with oxygen availability.
- The average root depth penetration of wetland plants varies with species. (E.g., cattails root down to 30 cm, reeds root down to 60 cm, and bulrushes root down to 75 cm.) Wetlands with a *variety* of plant species can therefore expand the aerobic zone of the soil, enhancing removal of biological oxygen demand (BOD).
- The nutrient assimilative capacity of wetland plants varies with species, even in the same habitat.

- Constructed wetlands were found to exhibit a high percent cover of non-native species, which peaked one to four years after construction and declined to natural levels in seven years.
- The diversity in new wetlands may diminish after a few years, due to competitive exclusion and species dominance.
- Planted wetlands tend to maintain or have increased species richness and diversity when compared to wetlands that are not planted but instead rely on natural colonization. Unplanted wetlands may be dominated by a few species. Planted wetlands resist domination by invading colonizers.
- Stormwater ponds planted with a greater diversity of plant species may perform water quality functions, such as nutrient removal, better than those having few species.

Data from Loiderman Associates (1997) indicate little difference in species richness and diversity in stormwater wetlands that were five to seven years old compared to stormwater wetlands that were ten to twelve years old, in Maryland and Virginia. This may indicate that the wetland plant dynamics have stabilized in five years.

1.2 Goal

The goal of the Aquatic Vegetation Monitoring Program is to develop a list of recommended vascular wetland plant species and recommended planting strategies for stormwater management pond projects in the Greater Toronto Area.

1.3 Objectives

This goal will be achieved through the following objectives:

- To monitor the effectiveness of planting plans in developing a balanced desirable aquatic vegetation community.

- To identify the presence of plant species below the "top of active storage" line for each cell of the stormwater management pond.

2.0 STUDY SITES

2.1 Harding Park Regeneration Project, Richmond Hill, Ontario

This constructed wet pond/wetland facility is a retrofit of an existing dry flood control pond. The retrofit project was constructed in 1995 by the Town of Richmond Hill, in response to recommendations in *Forty Steps to a New Don*, a regeneration strategy for the Don River watershed. The facility consists of a sedimentation forebay, a wet pond, and a wet meadow area. The total storage volume meets current guidelines for stormwater quality and erosion control and maintains the original flood storage capacity.

The planting plan for this facility concentrated on terrestrial and meadow marsh type plants. No true aquatic plants were introduced. As such this site presented the opportunity to monitor which aquatic plants would colonize naturally.

2.2 Highway 401/Rouge River Stormwater Management Facility, Scarborough, Ontario

This extended wet pond was constructed in 1994 by the Ministry of Transportation as part of a Highway 401 widening project. It was constructed to address water quality and fisheries concerns originating from highway water runoff. The facility is designed with a submerged impermeable weir that partitions the pond into a forebay and a quiescent treatment zone. The outflow structure consists of a reversed slope pipe to draw water from below the permanent pool level. This minimizes the impact of the elevated runoff water temperature on the cooler waters of the Rouge River.

The planting plan for this facility comprised both a terrestrial and aquatic component. This study is looking at the aquatic component only. There were 5 aquatic/meadow marsh species planted at the Rouge/401 SWM pond: 156 common arrowhead, 350 softstem bulrush, 60 fragrant waterlily, 88 curled pondweed, and 496 reed canary grass. Of these five species, curled pondweed is a non-native submergent, fragrant waterlily is a floating leaf, and arrowhead, bulrush, and reed canary grass are emergent to meadow marsh. While reed canary grass is native, it is considered an invasive.

3.0 METHODS

Many aquatic plants (e.g., sedges) are difficult to identify without having the fruiting bodies. By visiting the sites multiple times throughout the growing season we were able to confirm the identification of some of these more difficult plants. All plants were identified at minimum to the genus level. The vast majority of the plants found were identified on-site to the species level. For those species that were not identified in the field, a sample was taken and identification of the plant was verified by a botanist using the appropriate keys referenced at the end of this report. The dominant plant species within each area was determined visually.

The TRCA began vegetation monitoring at the Town of Richmond Hill's Harding Park Stormwater Management Pond in 1996 after completion of the reconstructed pond facility. The newly developing vegetation community was inventoried twice in 1996 (June 22 and September 17) and three times in 1997 (June 26, August 5, and September 24).

On August 21, September 15 and October 12, 1995 the MTO visited the Rouge/401 pond to inventory the newly establishing vegetation community. It is believed that the MTO followed a similar methodology and therefore the results from 1995 are comparable to 1996 and 1997. In 1996 and 1997 the TRCA continued with this role at the Rouge/401 pond, inventorying the vegetation community on three occasions each year (June 22, August 1, and September 17, 1996; June 26, August 5, and September 24, 1997).

The intent of this monitoring program is to identify aquatic plant community establishment. To do this it was decided that all plants found below the "top of active storage" line would be identified. This recognized that due to the frequent water fluctuations of a stormwater management pond, the transition zone between aquatic and terrestrial is blurred.

"Top of active storage" is the maximum height to which stormwater will rise within the facility. The difference between the top of active storage and the permanent storage can be as high as one metre. This water fluctuation zone develops into a diverse vegetation community consisting of both terrestrial and aquatic vegetation species. The "top of active storage" was determined using the design drawings, an "as-built" bathymetric (contour) map, and confirmed visually in the field. At the Rouge SWM pond this was verified as the absence of wood chips used in the planting beds (i.e., wood chips float to shore at the highest water level). At the Harding Park SWM pond this was verified using the locations of the concrete pillars, incorporated into the pond design for the purposes of future monitoring.

Vegetation establishment is not an instantaneous event. It takes five years or more for a wetland community to mature. A couple of years of very dry or very wet weather can dramatically affect this process in a wetland. For these reasons, aquatic vegetation monitoring should be continued over several years until the vegetation community stabilizes.

4.0 RESULTS AND DISCUSSION

Tables in Annex E1 list all plant species found at the Rouge/401 MTO SWM Pond and the Harding Park SWM Pond. The tables also provide information about each plant's native status and habitat requirement. The status of plants observed at the two study sites was determined using *Distribution and Status of the Vascular Plants of Central Region, Ontario Ministry of Natural Resources* (Riley, 1989). Symbols used in these and other tables in this report are defined by Riley as follows:

n	the species is considered native to Ontario's Central Region.
+	the species is introduced or escaped from cultivation in Central Region
(+)	the species may be considered native in some regions but is introduced to Central Region.
?	the status of the species was unknown.

The following symbols and definitions are used in this report for the habitat in which these plants may be found.

d	*disturbed*	a recently altered natural state (e.g.: due to construction)
m	*meadow*	closed graminoid and herb vegetation behind areas of shoreline emergent vegetation and on wet floodplains adjacent to open water systems. Usually seasonally flooded or subject to storm floods.
mm	*meadow marsh*	having a canopy of 75% to 100% with standing water and/or muck/mud flats beneath canopy or between clumps; characterized by more or less continuous stands of dominant graminoids of medium to low stature with surface water; water depth up to 1 m (flooded), but usually shallower, or exposed mud, during much of the summer.
upland	*upland*	well-drained hilltops, steep to moderate slopes, sand flats, etc. Stands normally dominated by dryland species of trees, shrubs, and/or herbaceous ground vegetation.
sm	*shallow marsh*	having a canopy of 75% to 100% with standing water and/or muck/mud flats beneath canopy or between clumps. Characterized by more or less continuous stands of tall emergent aquatics with surface water up to 1 m (flooded), but usually less during much of the summer months.
e	*emergent*	emergent aquatic vegetation in or adjacent to open shallow water, pools or channels; commonly interspersed or dominated by clumps of vegetation (rooted, unconsolidated, or floating) with open water channels between or with open water beneath the canopy of sedges, grasses, reeds, cattails; cover by emergents or shrubs greater than 25%.

(The definitions above are from *Ontario Wetland Evaluation System for Southern Ontario* - Ontario Ministry of Natural Resources, 1993)

a	*aquatic*	adapted to living partially or wholly submerged in water or in waterlogged soils.
r	*riparian*	growing adjacent to a river or stream including shores and floodplains.

(The definitions above are from *Wetland Plants of Ontario* - Newmaster *et al*, 1997)

m	*mesic*	characterized by moderately moist conditions; neither too moist nor too dry (*Dictionary of Biology* - Steen, 1971)
sub	*submergent*	growing below the water surface
f	*floating*	the majority of the plant grows on the water's surface

4.1 Harding Park Stormwater Management Pond

Two years of monitoring the aquatic vegetation community at the Harding Park facility has resulted in some interesting observations. Due to the fact that wetland vegetation takes, on average, five years or more to become well established, it is too early, after two years, to make any clear conclusions. Nevertheless, several trends are beginning to emerge.

Table E.1 illustrates which meadow marsh plants were introduced and which ones are still found on-site after two years of monitoring. It is interesting to note that of the 11 species originally planted, seven can still be found within the pond. Four plant species did not survive. The reasons for this could be improper placement for their habitat requirements or the possibility that the stock received was not in good health. One species of concern that was planted is Common Reed. It is considered an invasive plant that, while native to Central Region, is not normally suggested in plantings, as it will almost always colonize on its own and has a strong tendency to "take over" an area. This reduces the vegetation community's plant diversity that reduces its ability to provide good quality habitat for fauna.

Table E.2 summarizes the total number of plant species that were found in the Harding Park SWM pond. Table E.3 summarizes the number of meadow marsh (mm) and aquatic (a) plants that were identified. Of these plants identified, Table E.4 summarizes the total number of native and non-native plant species found.

There were significant changes in the plant community from 1996 to 1997. In 1996 there was often no dominant plant species and the shoreline still had large patches of bare, unvegetated ground. By the end of the 1997 growing season, these barren areas were well-vegetated and the diversity of plants had increased significantly. The total number of plants found below the "top of active storage" line since the 1996 meadow marsh planting has increased from 11 plants species to 43 species in the sediment forebay. In the main pond, 47 plant species became established, and in the wet meadow 52 plant species became established. A significant increase in diversity has been observed. To the best of our knowledge, all of these new plant species have naturally colonized the site.

Table E.1: The fate of marsh meadow plants planted at the Harding Park SWM pond

Common Name	Scientific Name	Status	Originally Planted	Present in 1996	Present in 1997
New England Aster	*Aster novae-anglia*	n	x	x	x
Turtlehead	*Chelone glabra*	n	x	x	x
Spotted Joe-pye-weed	*Eupatorium maculatum*	n	x	x	x
Boneset	*Eupatorium perfoliatum*	n	x		x
Sweet Joe-pye-weed	*Eupatorium purpure*	n	x		
Helen's flower	*Helenium autumnale*	+	x	x	x
Stella d'or daylily	*Hemerocallis "stall d'oro"*	+	x		
Bergamot	*Monarda didyma*	n	x		
Common Reed	*Phragmites australis*	n	x		x
False Dragonhead	*Physostegia virginiana*	?	x	x	x
Black eyed susan	*Rudbeckia hirta*	n	x		

Status: n = native species + = introduced species ? = unknown status

Table E.2: Harding Park pond - total number of plant species found

Location	1996			1997			
	June 22	Sept. 17	Total # of species found	June 26	Aug. 5	Sept. 24	Total # of species found
Sediment Forebay	11	12	19	28	28	24	43
Main Pond	7	19	23	25	28	23	47
Wet Meadow	15	18	25	24	29	31	52

Table E.3: Harding Park pond - total number of aquatic (a) and meadow marsh (mm) plant species found at the end of two growing seasons (* if the plant is considered both "mm" and "a" it will be counted as "a" for this table)

Location	Total # of mm & a Wetland Habitat Species		Total # of Planted mm & a Wetland Habitat Species		Total # of Colonized mm & a Wetland Habitat Species	
	mm	a	mm	a	mm	a
Sediment Forebay	30	6	7	0	23	6
Main Pond	32	9	5	0	27	9
Wet Meadow	36	9	6	0	30	9

mm = meadow marsh species a = aquatic species

Table E.4: Harding Park pond - native vs. non-native plant species found

Location	1996			1997			Original Planting	
	native	non-native	unknown	native	non-native	unknown	native	non-native
Sediment Forebay	14	5	0	30	12	1	4	2
Main Pond	19	4	0	27	16	4	4	0
Wet Meadow	14	9	2	33	19	0	4	2

Dominance is a function of season and competition. For example in the Harding Park SWM pond, the rush species (*Juncus spp.*) tended to dominate in the early part of the season (June) and were succeeded by water plantain (*Allisma plantago-aquatica*) in August. This change in dominance as the season progresses is something that needs to be considered in SWM pond designs. If good vegetative cover is required throughout the growing season, plants that mature at different times of the season may be required to meet this objective.

It is also important to examine the dominant plant species within the community composition. Often the plant species introduced are not the dominant species found after one or two growing seasons. By examining systems, such as the Harding Park SWM pond, that are naturally colonizing, we can get a better idea of which plants will dominate the community structure. In September 1996, the first growing season, the dominant species in the sediment forebay was pale smartweed (*Polygonum lapathifolium*) a plant often found in disturbed meadow marsh type habitats. This is consistent with the disturbance the area received due to construction. As the area began to recover from this disturbance, the community structure changed toward a more stable aquatic/meadow marsh habitat. By August 1997, the dominant species found were purple loosestrife *(Lythrum salicaria)*, broad-leaf cattail (*Typha latifolia*), water plantain (*Allisma plantago-aquatica*), and softstem bulrush (*Scirpus validus*). These plants are all aquatic to meadow marsh in habitat. This trend toward an aquatic to meadow marsh dominated system was prevalent in all three areas of the Harding Park SWM pond.

There are plant species present that are not recommended for planting, as they are considered invasive, difficult to remove once established, and provide poor habitat. Within the Harding Park facility these species include common reed, reed canary grass, and purple loosestrife. These plants will likely colonize a site naturally and have a strong tendency to result in a monoculture of one or two species.

The number of both native and non-native plants increased between 1996 and 1997. However, there was no significant change in the proportion of native to non-native plants in each area. The ideal would be to have a facility that has only native plant species. The reality is that non-native plants are common in urban areas and without intensive management are impossible to remove entirely from the facility. Permitting and wildlife agencies recommend that planting plans include only native plant material, in an effort to reduce the number of non-natives introduced to the facility. The problem with non-natives is that they can out-compete and displace native species. Their seeds may be transported to other, more natural areas of the watershed.

4.2 Rouge/401 MTO Stormwater Management Pond

After three growing seasons, all the plant species introduced are still present in the facility (see Table E.5). Based on the planting plan, all the areas planted, except one, have thrived and expanded. A grouping of 44 softstem bulrush was planted adjacent to the submerged weir in the main pond. These plants have survived along the pond edges but not out into the pond. This is probably due to the currents that flow through this area during a storm event.

In the two growing seasons since the facility was planted, 76 aquatic and meadow marsh plant species have naturally colonized the main pond of the facility (Table E.6). In the same time period, 50 aquatic and meadow marsh plant species have naturally colonized the sediment forebay. This is not unexpected for this pond as it is located within the Rouge River Valley, adjacent to high quality habitat. The high quality of this adjacent habitat is also evident in the high number of native plant species that have colonized in comparison to non-native species (Table E.7). These natural colonizations are probably a result of wind, water and animal transportation. When we visited this site, we often observed deer tracks, and saw leopard frogs, dragonflies, and several species of birds using the site.

Table E.5: Fate of aquatic and meadow marsh plants planted at the Rouge/401 SWM pond

Common Name	Scientific Name	Status	Originally Planted	Present in 1995	Present in 1996	Present in 1997
Common arrowhead	Sagittaria latifolia	n	x	x	x	x
Softstem bulrush	Scirpus validus	n	x	x	x	x
Fragrant waterlily *(horticultural variety)*	Nymphaea odorata	+	x	x	x	x
Curled pondweed	Potamogeton crispus	+	x	x	x	x
Ribbon reed canary grass	Phalaris arundinacea var. picta	+	x		x	x

Status: n = native species + = introduced species

Table E.6: Rouge/401 MTO SWM pond - total number of plant species found

Date:	Sediment Forebay	Main Pond
Original Planting	1	5
Aug. 21/95	0	8
Sept. 15/95	0	13
Oct. 12/95	0	11
TOTAL 1995	*0*	*13*
June 22/96	9	9
Aug. 1/96	8	25
Sept. 17/96	12	37
TOTAL 1996	*16*	*45*
June 26/97	28	45
Aug. 5/97	33	48
Sept. 24/97	34	60
TOTAL 1997	*51*	*81*

Table E.7: Rouge/401 MTO SWM pond - native vs. non-native plant species found

Location	Originally Planted		1995		1996			1997		
	native	non-native	native	non-native	native	non-native	unknown	native	non-native	unknown
Sediment Forebay	0	1	0	0	12	3	1	32	17	2
Main Pond	2	2	10	3	35	8	2	53	28	0

The long term results of this initial planting will not be known for several years. Within the emergent aquatic and meadow marsh area the dominant plants in the sediment forebay were spikerush (*Eleocharis)* throughout the growing season with water plantain (*Allisma plantago-aquatica*) becoming dominant in late summer to early fall. In the main pond the dominant emergent/meadow marsh plants were cattail (*Typha*), water plantain (*Allisma plantago-aquatica*), spikerush (*Eleocharis*), and jointed rush (*Juncus articulatus*). Of these dominant plants, none of them were introduced through the planting plan. Within the submergent plant community, the dominant species in both the sediment forebay and the main pond was Canada waterweed (*Elodea*). This native submergent is a well-known food source for ducks. Curled pondweed (*Potomogeton crispus*) is still significant within the submergent community, however, it is no longer the dominant plant species.

It was observed that a non-native horticultural variety of the Fragrant Water Lily (*Nymphaea odorata [hort.])* was substituted for the native Fragrant Water Lily (*Nymphaea odorata*) specified in the planting plan. Similarly, a non-native horticultural variety of Ribbon Reed Canary Grass (*Phalaris arundinacea var. picta*) was substituted for the native Reed Canary Grass (*Phalaris arundinacea*) specified in the planting plan. This was probably because the supplying plant nursery did not have the correct plants available in stock. In order to prevent these problems, project managers should specify in their Planting Specifications and their Plant Order that "NO SUBSTITUTIONS" are to be allowed. A botanist or horticulturist should be on-site to receive and confirm the plant material.

The evolution of the non-native plant species introduced through the planting plan is interesting. While they are all still present within the system, only the waterlily has remained a dominant species, with some spreading. This observation is not unexpected, as there are no other competing species. The water lily situation requires careful monitoring, as there is some risk that it may escape into the Rouge Valley system. Ribbon Reed Canary Grass *(Phalaris arundinacea variety picta)*, the native variety of which is known for its aggressiveness, has remained with only limited spreading along the north shore of the SWM pond. Its relative dominance has decreased significantly as natives naturally colonized the site. Curly pondweed (*Potomogeton crispus*) is a common non-native submergent aquatic plant. Its dominance within the submerged community appears to be lessening with the natural establishment of other pondweeds.

The community developing at the Rouge/401 SWM pond ranges from meadow marsh to aquatic. As the development of the vegetation community at this site proceeds it is expected that the diversity of plant species will be reduced as the early successional colonizing plant species are out-competed and the meadow marsh to aquatic species continue to spread and dominate.

The main pond consistently shows more plant diversity and more plant colonization than the sediment forebay.

5.0 OBSERVATIONS AND RECOMMENDATIONS

In summary, several trends have been observed in the evolution of vegetation communities at the two SWM facilities. These trends may have implications for the design of planting plans in future facilities.

1. Substantial natural colonization appears to occur at the sites, even after only one growing season. If this trend is common to other SWM facilities, there may be justification for a reduction in the number of plant species identified in the initial planting plan.

2. Vegetation communities at these sites have tended to evolve toward a common group of dominant species. While considerably more work will need to be completed to confirm this, the results from these two ponds would suggest that cattail (*Typha*), spikerush (*Eleocharis*), rush (*Juncus*), bulrush (*Scirpus*), water plantain *(Allisma*) and waterweed (*Elodea*) may be effective species for inclusion in planting plans.

3. At both sites there was evidence that alternative, often non-native species were substituted by the plant supplier for the species prescribed in the planting plan. This finding underscores the need for instructions stating that no substitutions will be accepted and closer inspection of plant material delivered should be made by the landscape supervisor.

As it is premature to draw any conclusions after monitoring only two ponds for two growing seasons, the following are recommendations made by the authors for further work:

1. The monitoring of both the Rouge/401 SWM pond and the Harding Park SWM pond can be discontinued in years 3 and 4, except for a single inspection of the status of invasive (e.g., purple loosestrife) and potentially invasive (e.g., horticultural variety of water lilies) plants. If these species appear to be expanding, recommendations should be made to the pond operators for implementing

control measures. In year 5, a complete assessment of the vegetation community should be undertaken, following the methodology described in this report.

2. The results of this study should be compared to the results of inventories at other SWM ponds within the GTA that have an established vegetation community before any general conclusions can be made about the appropriateness of planting species in SWM pond systems. Each SWM pond is unique (i.e., differing catchments, differing chemical issues, etc.). Recommendations about the types of wetland plants and planting techniques suitable in general for all SWM pond facilities should not be based on the results of two SWM ponds.

3. Dominance will change as the growing season progresses. Dominance is often a function of "time of year" rather than "number of plants present". To determine the dominant species of a system, the site should be allowed to evolve for at least five growing seasons, and the plants should be identified at least three times over a growing season.

4. A similar study should be undertaken to address the terrestrial planting portion of these facilities. This type of study would probably best be undertaken by a municipality in partnership with SWAMP.

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ANNEX E-1

The following tables contain the complete lists of plant species for the two sites.

Table E-1-1: Plant species identified at Harding Park Stormwater Management Pond

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	June 22, 1996	Sept. 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
Wet Meadow	n	a - e	Soft stem bulrush	Scirpus validus		x	x	x	x*	x
	n	a - e	Barberpole sedge	S. rubrotinctus (macrocarpus)				x	x	x
	n	mm	Black bulrush	S. atrovirens			x		x	x
	n	a - e- mm	Broad leaf cattail	Typha latiflia			x	x*	x*	x*
	n	a - e- mm	Narrow-leaved cattail	Typha angustifolia						x
	+	mm	Purple loosestrife	Lythrum salicaria		x	x	x	x*	x
	n	mm	Turtlehead	Chelone glabra	x	x	x			x
	n	mm	Spotted Joe pye-weed	Eupatorium maculatum	x	x	x	x	x	x
	n	mm - mesic	Reed canary grass	Phylaris arundinacea		x		x		
	+	mm - mesic	Barnyard grass	Echinochloa crusgalli			x			
	n	mm	Spotted jewelweed	Impatiens campensis			x		x	x
	n	d - mm	Pale smartweed	Polygonum lapathiifoium		x	x			
	+	mm	Charlock mustard	Brassica kabor		x		x		
	(+)	upland	Canada bluegrass	Poa compressa		x				
	n	mm	Fowl meadow grass	Poa palustris				x		
	+	mesic	Timothy grass	Phleum pratense				x		
	+	mesic	Perennial rye-grass	Lolium parenne				x		
	n	mm	Field horsetail	Equisetum arvense				x		x
	n		Red baneberry	Actaea rubra		x				
	+	mesic	White clover	Trifolium repens			x			
	?	mesic	Fescue	Festuca sp.		x				
	?	mm	False dragonhead	Physostegia virginiana	x		x		x	x
	+	mm	Helen's flower	Helenium autumnale	x		x			x
	n	mm - mesic	Tall white aster	Aster simplex			x	x		x
	n	m	New England aster	Aster novae-angliae	x		x			x
	+	m	Ox-eye daisy	Chrysanthemum leucanthemum				x		
	n	m - mm	Tall goldenrod	Solidago altissima						x
	n	m - mm	Narrow-leaf goldenrod	Solidago graminifolia		x	x			
	n	m	Canada goldenrod	Solidago canadensis		x			x	
	+	m	White campion	Lychnis alba				x		
	+	m	Indian mustard	Brssica juncea		x				
	+	d m	Canada thistle	Circium arvense		x				x
	+	d m	Bull thistle	Circium vulgare						x
	n	mm	Cursed crowfoot	Ranunculus scelera tus				x	x	
	+	upland	Queen Anne's lace	Daucus carota					x	
	+	upland	Bird's foot trefoil	Hosackia americana				x	x	
	+	m - mm	Sweet coltsfoot	Tussilago farfara					x	
	n	mm	Boneset	Eupatorium perfoliatum	x				x	
	n	mm	Sedge	Carex sp.						x
	n	mm	Fox sedge	Carex vulpinoidea					x	x
	n	mm	Bebb's sedge	Carex bebbeyi/crystatella				x		
	?	mm	Rush	Juncus sp.		x	x			
	n	a - e- mm	Rush	Juncus tenuis			x			
	n	a - e- mm	Rush	Juncus bufonius			x			
	n	a - e- mm	Didley's sedge	Juncus dudlyii					x	
	n	mm	Jointed sedge	Juncus articulatus				x	x	
	n	mm	Torrey's sedge	Juncus torreyi					x	x
	+	mm	Rush	Juncus compressus				x		
	n	a - e- mm	Common rush	Juncus effusis				x		x
	n	sm - mm	Tall manna grass	Glyceria grandis				x*	x*	x
	+	mm	Redtop	Agrostis gigantia					x	x
	(+)	mm	Creeping bent grass	Agrostis stolonifera					x	
	n	mm	Spikerush	Eleocharis erythropoda					x	x
	n	mm	Spikerush	Eleocharis sp.				x		
	+	mm	Rice cut grass	Homalocenchus oryzoides					x	
	n	a - e- mm	Water-plantain	Alisma plantago-aquatica				x	x	
	n	mm	Nodding bur-marigold	Bidens cernua					x	x
	n	mm	Devil's beggartricks	Bidens frondosa					x	x
	+	mm	Great hairy willowherb	Epilobum hirsutum					x	x
	n	mm - r	Red osier dogwood	Cornus stolonifera						x
	n	r - mm	Peach-leaved willow	Salix amygdaloides				x	x	x
	+	r - mm	Crack willow	Salix fragilis					x	x
	n	not a	Manitoba maple	Acer negundo						x
Main and wet Pond	n	mm	Spotted Joe pye-weed	Eupatorium maculatum	x	x				
	n	mm	Jewelweed	Impatiens campensis		x	x			
	+	a - e- mm	Purple loosestrife	Lythrum salicaria			x	x	x	x
	n	mm - mesic	Common reed	Pragmites autralis	x				x	x
	n	mm - mesic	Reed canary grass	Phylaris arundinacea		x	x			x
	+	r - mm	European water horehound	Lycopus europaeus		x	x			
	n	mm	Common mint	Mentha arvensis						x
	n	mm	Common horsetail	Equisetum arvense		x				
	n	mm	Boneset	Eupatorium perfoliatum	x	x				
	+	m	Chickory	Chicorium intybus					x	
	n	mm	Cursed crowfoot	Ranunculus sceleratus			x	x		
	+	upland	Bird's foot trefoil	Hosackia americana				x	x	
	n	m	New England aster	Aster novae-angliae	x			x		

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	June 22, 1996	Sept. 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
	n	mm - m	Tall white aster	Aster lanceolatus (simplex)						x
	+	m	Prickly lettuce	Lactuca virosa						x
	(+)	mm	False dragonhead	Physostegia virginiana			x			
	+	mm	Broad-leaved plantain	Plantago major				x	x	x
	n	mm	Nodding bur-marigold	Bidens cernua			x		x	x
	n	mm	Devil's beggarticks	Bidens frondosa					x	
	n	mm	Bur-marigold	Bidens sp.				x		
	n	mm	Pale smartweed	Polygonum lapathifolium			x		x	x
	?	mm	Smartweed	Polygonum sp.				x		
	n	m	Tall goldenrod	Solidago altissima						x
	n	m	Grass-leaved goldenrod	Solidago graminifolia		x				
	n	m	Canada goldenrod	Solidago canadensis				x		
	+	m	Creeping thistle	Circium arvense				x	x	
	+	m	Oakleafed goosefoot	Chenopodium glaucum				x		
	+	m - mm	Sweet coltsfoot	Tussilago farfara				x		x
	+	m - mm	Common charlock	Simapis sp.				x		
	n	d - m	Common ragweed	Ambrosia elatior					x	x
	?	d - m	Cross-straight knotweed	Polygonum aviculare				x		
	+	mesic	Perennial rye-grass	Lolium perenne				x	x	
	+	m	Common flax	Linum usitatissimum			x			
	+	d - m	Curly dock	Rumex crispus					x	x
	n	d - m	American water horehound	Lycopus americanus			x			
	?	mm - mesic	Barnyard grass	Echinochloa sp.					x	x
	n	mm - mesic	Barnyard grass	Echinochloa crusgalli			x			
	n	d -mm	Witch grass	Panicum capillare						x
	+	m	Red clover	Trifolium pratense						x
	n	mm	Blue vervain	Verbena hastata					x	x
	+	d - m	Sunflower	Helianthus annuus					x	
	+	upland	Queen Anne's lace	Daucus carota					x	
	n	mm	Spikerush	Eleocharis sp.			x			
	n	a - e- mm	Broad leaf cattail	Typha latifolia			x*	x		x
	n	a - e- mm	Narrow leaf cattail	Typha angustifolia				x	x	
	n	a - e- mm	Water plantain	Allisma plantago-aquatica			x	x	x*	x*
	n	mm	Fox sedge	Carex volupinoides				x	x	x
	n	mm	Crested sedge	Carex cristatella					x	
	n	a - e	Soft stem bulrush	Scripus validus				x	x	x
	n	mm	Black bulrush	Scripus atrovirens				x	x	
	n	a - e- mm	Rush	Juncus tenuous			x			
	n	mm	Toad rush	Juncus bufonius			x			
	n	a - e- mm	Dudley's rush	Juncus dudleyi				x*	x	
	n	a - sub	Sago pondweed	Potamogeton pectinatus			x	x		
	n	a - sub	Stonewort	Chara sp.			x	x*	x	
	(+)	r	Cottonwood seedling	Populus deltoides				x	x	
	n	r - mm	Peached-leaved willow	Salix amygdaloides			x		x	
	n	r -mm	Heart-leaved willow	Salix eriosephella					x	x
	+	r - mm	Crack willow	Salix fragilis					x	x
	?	r - mm	Willow seedling	Salix sp.				x		
Sediment Forebay	n	mm	Turtlehead	Chelone glabra	x				x	
	n	mm	Cursed crowfoot	Ranunculus sceleratus		x				
	n	mm	Water hemlock	Circuta maculata				x		x
	n	r - mm	Water horehound	Lycopus unifloris				x	x	
	n	mm	Spotted Joe pye-weed	Eupatorium maculatum	x	x	x		x	x
	n	mm	Blue vervain	Verbena Hastata				x	x	
	n	mm - mesic	Common reed	Phragmites autralis	x	x	x	x	x	x
	n	mm - mesic	Reed canary grass	Phylaris arundinacea				x	x	
	+	mm	Purple loosestrife	Lythrum Salicaria					x*	x
	n	m	Tall goldenrod	Solidago altissima			x			x
	n	m	Canada goldenrod	Solidago graminifolia		x				
	n	m - mm	Narrow-leaf goldenrod	Euthiamia graminifolia				x	x	x
	n	mm	Spotted jewelweed	Impatiens campensis		x	x		x	x
	n	d - m	Common ragweed	Ambrosia artemisiifolia		x		x		x
	n	d - m	Daisy fleabane	Erigeron annus				x		
	+		Common wintercress	Barbarea vulgaris						
	+	m	Prickly lettus	Lactuca virsa				x	x	
	n	mm	Common mint	Mentha rotundifolia				x	x	
	+	upland	Bird's foot trefoil	Hosackia americana				x	x	
	?	m	Forget-me-not	Myosotis sp.				x		
	n	mm - mesic	Tall white aster	Aster lanceolatus			x	x		x
	+	mm	Harry willow herb	Epilobium hirsutum			x		x	
	+	mm	Indian mustard	Brassica Juncea		x				
	+	m	Pennycress	thlapsi arvense		x				
	+	m	Chickory	Chicorium intybus			x*		x	
	+	mm	Sneezeweed	Helinium autumnale	x				x	x
	(+)	mm	False dragonhead	Physostegia virginiana	x				x	x
	n	mm	Pale smartweed	Polygonum lapathifolium			x*		x	x
	+	d - m	Canada thistle	Circium arvense						x
	n	mm	Boneset	Eupatorium perfoliatum	x	x	x			
	+	m - mm	Barnyard grass	Echinochloa crusgalli					x	x
	n	m - mm	Barnyard grass	Echinochloa microstachya						x

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	June 22, 1996	Sept. 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
	+	mm	Rice cut grass	Homalocenchus oryzoides				x		
	n	sm - mm	Tall manna grass	Glyceris grandis				x	x	x
	+	d - m	Curly dock	Rumex crispus			x		x	x
	n	mm	Spikerush	Eleocharis erythropoda				x	x	
	n	a - e	Broad leaved cattail	Typha latifolia					x*	x
	n	a - e	Cattail	Typha x glauca				x		
	n	a - e	Soft stem bulrush	Scripus validus		x		x	x*	x
	n	mm	Black bulrush	Scripus atrovirens				x (?)	x	x
	n	mm	Woolgrass	Scripus cyperinus			x	x		
	n	mm	Barberpole sedge	S. microcarpus (rubrotinctus)						
	n	a - e- mm	Rush	Juncus tenuous				x*		
	n	a - e- mm	Dudley's rush	Juncus dudleyi						
	n	mm	Fox sedge	Carex vulpinoidea				x	x	x
	n	mm	Sedge	Carex stipata				x		
	n	mm	Sedge	Carex granularis				x		
	n	a - e - mm	Water plantain	Allisma plantago-aquatica			x	x	x*	x*
	+	d - m	Common plantain	Plantago major				x		x
	n	not a	Manitoba maple seedling	Acer negundo		x				
	n	r -mm	Peach leaf willow	Salix amygdaloides				x	x	

Symbols Used:

n	native to Ontario Central Region
+	introduced or escaped from cultivation in Central Region
(+)	considered native in other regions but is non-native to Central Region
?	not enough of an identification was made to determine status
r	riparian
m	mesic
sub	submergent
fl	floating leaf
d	disturbed habitat
m	meadow
mm	meadow marsh
upland	well drained habitat
sm	shallow marsh
e	emergent
a	aquatic
*	species that were dominant in 1997

Table E-1-2: Plant species found at the Rouge/401 Stormwater Management Pond

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	Aug. 21, 1995	Sept. 15, 1995	Oct. 12, 1995	June 22, 1996	Aug. 1, 1996	Sept 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
Sediment Forebay	n	a - e- mm	Narrow leaf cattail	Typha angustifolia							x	x	x	x
	n	a - e- mm	Broad leaf cattail	Typha latifolia										x
	n	a - e- mm	Cattail	Typha x Glauca								x	x	x
	n	a - e -mm	Black bulrush	Scirpus atrovirens					x	x	x	x	x	x
	n	mm	Soft stem bulrush	Scirpus validus					x	x	x	x	x	x
	?	mm	Barberpole sedge	Scirpus marcocarpa (rubrotinctus)									x	
	r	a - fl	Floating arrowhead	Sagittaria cuneata									x	
	+	a - e- mm	Purple loosestrife	Lythrum salicaria								x	x	x
	n	mm - mesic	Common reed	Phragmites australis										x
	+	mm - mesic	Reed canary grass	Phalaris arundinacea var. picta	x				x	x	x	x	x	x
	n	a - e- mm	Water plantain	Allisma plantago-aquatica							x*	x	x*	x (eaten)
	n	mm	Bebb's sedge	Carex bebbii/cristatella								x	x	x
	n	mm	Fox sedge	Carex vulpinoidea								x	x	x
	n	mm	Sedge	Carex hystricina								x		
	n	mm	Rush	Juncus sp.					x		x			
	n	mm	Jointed rush	Juncus articulatus								x	x	x
	n	mm	Rush	Juncus compressus									x	
	n	a - mm	Dudley's rush	Juncus dudeyi								x		x
	n	mm	Tory's rush	Juncus toreyi										x
	n	a - mm	Rush	Juncus bufonius					x	x	x			
	n	mm	Spikerush	Eleocharis sp.						x	x*	x*	x*	x
	n	mm	Spikerush	Eleocharis erythropoda										x
	n	a - sub	Canada waterweed	Elodea canandensis						x	x	x	x*	x
	+	a - sub	Curly leaved pondweed	Potomogeton crispus						x	x		x	x
	n	a - sub	Sago pondweed	Potomogeton pectinatus						x	x	x	x	x
	n	a-sub	Chara	Chara sp.							x		x*	x
	+	d - m	Curled dock	Rumex crispus								x	x	
	+	mm	Harry willowherb	Epilobium hirsutum										x
	n	mm	Devli's beggarticks	Bidens frondosa					x					x
	n	m	Canada goldenrod	Solidago canadensis									x	
	n	mm	Rough bed-straw	Galium asprellum					x					
	+	mm - m	Rayless aster	Aster brachyactis										x
	n	mm - m	Tall white aster	Aster lanceolatis								x		
	n	upland	Bird's foot trefoil	Hosackia americana								x	x	x
	n	mm	Pale smartweed	Polygonum lapathifolium										x
	+	m	Chickory	Cichorium intybus										x
	n	mm	Cursed crowfoot	Ranunculus sceleratus								x	x	
	n	mm	Blue vervain	Verbena hastata									x	
	+ salty	m - mm	Alkali grass	Puccinellia distens								x	x	
	+	r - mm	Crack willow	Salix fragilis					x					
	n	r mm	Heart-leaved willow	Salix eriocephala								x		
	n	r - mm	Peach-leaved willow	Salix amygdaloides									x	x
	n	not a	Manitoba maple	Acer negundo										x
	n	mm	Canada bluejoint	Calamagrostis canadensis									x	x
	?	mm		Agrostis sp.					x			x		
	+	mm	Redtop	Agrostis gigantea									x	x
	(+)	mm	Creeping bentgrass	Agrostis stolonifera									x	x
	n	m	Fescue	Fescue sp.								x		
	+	mesic	Perennial rye-grass	Lolium perenne								x	x	x
	+ salty	m	Foxtail barley	Hordeum jubatum								x	x	
	+	mm - mesic	Barnyard grass	Echinochloa crusgalli									x	x
	+	m	Meadow fescue	Festuca pratensis								x		
	?	m	Tall fescue	Festuca gigantea									x	
	(+)	upland	Canada blue grass	Poa compressa								x	x	
	+	mesic	Timothy grass	Phleum pratense								x		
	+		Quack grass	Elymus (Agropogon) repens										x

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	Aug. 21, 1995	Sept. 15, 1995	Oct. 12, 1995	June 22, 1996	Aug. 1, 1996	Sept 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
Main	n	a-e	Broad leaf cattail	Typha latifolia		x	x	x	x	x	x	x	x*	x*
Pond	n	a-e	Narrow leaf cattail	Typha angustifolia						x	x	x		x
	n	a-e	Cattail	Typha x Glauca					x			x	x	x*
	n	mm	Black bulrush	Scirpus atrovirens						x	x	x	x	
	n	a-e-mm	Soft stem bulrush	Scirpus validus	x	x	x	x		x	x	x	x	x
	n	a-e-sm	Pickerelweed	Pontederia cordata		x	x			x			x	
	n	a-e-sm	Arrowhead	Sagittaria latifolia	x	x	x	x		x	x	x	x	x
	+	sm -mm	Purple loosestrife	Lythrum salicaria		x	x	x	x	x	x	x	x	x
	n	mm- mesic	Common reed	Phragmites australis										x
	+	mm - mesic	Reed canary grass	Phalaris arundinacea var. picta	x					x	x	x	x	x
	n	a-e-mm	Water plantain	Allisma plantago-aquatica								x*	x*	x*
	n	mm	Bebb's sedge	Carex bebbii/cristatella								x	x	x
	+	m - mm	Sedge	Carex spicata								x		
	n	mm	Fox sedge	Carex vulpinoidea								x	x	x
	n	mm	Sedge	Carex hystricina							x		x	
	?	mm	Rush	Juncus sp.										
	n	mm	Jointed rush	Juncus articulatus						x		x*	x	x
	+	mm	Rush	Juncus compressus						x				
	n	a-e-mm	Dudley's rush	Juncus dudleyi						x		x	x	x
	n	mm	Rush	Juncus nodosus						x				
	n	mm	Rush	Juncus toreyi									x	x
	n	a-e-mm	Rush	Juncus tenuis						x				
	n	a-e-mm	Rush	Juncus bufonius						x	x		x	
	n	a-e-mm	Rush	Juncus effusus								x		
	n	mm	Spikerush	Eleocharis sp.			x			x	x	x*		
	n	mm	Spikerush	Eleocharis erythropoda									x	x
	+	a - fl	Fragrant water lily	Nymphaea odorata (hort.)	x	x	x	x	x	x	x	x	x	x
	n	r - mm	American water-horehound	Lycopus americanus										x
	+	r - mm	European water horehound	Lycopus europaeus						x	x	x	x	x
	n	a - sub	Canada waterweed	Elodea canandensis		x	x	x		x	x	x	x*	x
	n	a - sub	Eel grass	Valisneria americana		x	x	x			x			
	R	a - sub	Horned pondweed	Zannichellia palustris						x	x			
	+	a - sub	Curly leaved pondweed	Potomogeton crispus	x		x	x		x	x	x		
	R	a - sub	Pondweed	Potomogeton nodosus			x	x						
	n	a - sub	Sago pondweed	Potomogeton pectinatus			x	x			x	x	x	
	n	a - sub	Chara	Chara sp.			x	x		x	x	x	x	x
	+	d - m	Curled dock	Rumex crispus								x	x	x
	n	mm	Field horsetail	Equisetum arvense								x		
	n	sm - mm	Blue flag	Iris versicolor										x
	n	mm	Boneset	Eupatorium perfoliatum									x	x
	n	mm	Swamp milkweed	Asclepias incarnata									x	x
	n	mm - mesic	Lady's thumb	Persicaria persicaria								x	x	x
	+	mm	Harry willowherb	Epilobium hirsutum						x	x			x
	n	mm	Sticky willowherb	Epilobium ciliatum							x		x	x
	n	mm	Mad-dog skullcap	Scuterllaria lateriflora										x
	+	m	Chickory	Cichorium intybus										x
	n	mm	Devil's beggarticks	Bidens frondosa							x	x	x	x
	n	m - mm	Tall goldenrod	Solidago altissima									x	
	n	m	Canada goldenrod	Solidago canadensis							x			
	n	m	Late goldenrod	Solidago gigantea										x
	n	m - mm	Narrow-leaved goldenrod	Solidago graminifolia					x	x		x		
	?	mm	Bedstraw	Galium sp.									x	
	n	mm	Bedstraw	Galium palustre										x
	n	mm	Rough bed-straw	Galium asprellum							x	x	x	
	+	m - mm	Sweet coltsfoot	Tussilago farfara										x
	n	upland	Bird's foot trefoil	Hosackia americana							x	x	x	x
	n	m	Rugel's plantain	Plantago rugelii										
	+	m	English plantain	Plantago lanceolata								x	x	
	n	d - m	Common ragweed	Ambrosia artemisifolia									x	x

LOCATION	STATUS	WETLAND HABITAT	COMMON NAME	SCIENTIFIC NAME	Original Planting	Aug. 21, 1995	Sept. 15, 1995	Oct. 12, 1995	June 22, 1996	Aug. 1, 1996	Sept 17, 1996	June 26, 1997	Aug. 5, 1997	Sept. 24, 1997
	n	m	New England aster	Aster novae-angliae							x		x	x
	n salty	mm salty	Rayless aster	Aster sp.							x			x
	n	m - mesic	Tall white aster	Aster lanceolatis							x	x	x	x
	n	mm	Nodding bur-marigold	Bidens cernua										
	n	m	Lily of the valley	Convallaria magalis					x		x			
	n	m	Oxeye daisy	Helopsis helianthoides					x	x	x	x		
	+	mesic	White clover	Trifolium repens					x		x	x	x	
	+	m	Red clover	Trifolium pratense									x	
	n	mm	Cursed crowfoot	Ranunculus sceleratus							x	x	x	x
	+	m	Common sunflower	Helianthus annus							x			
	n	mm	Blue vervain	Verbena hastata							x		x	x
	n	d- mm	Pale smartweed	Polygonum lapathifolim										x
	n	d - m	Witch grass	Panicum capullare										x
	n	mm	Rice cut-grass	Homalocenchrus oryzoides							x			x
	+ salty	m - mm	Alkali grass	Puccinellia distens								x		x
	n	d - m	Bull thistle	Circium vulgare							x			
	n	d - m	Canada thistle	Circium arvense										
	+	r mm	White willow	Salix alba										x
	+	r - mm	Crack willow	Salix fragilis							x			
	n	mm	Narrow heart-leaved willow	Salix eriocephala							x	x		x
	n	r - mm	Peach-leaved willow	Salix amygdaloides										x
	+	m	European pussy willow	Salix caprea								x		x
	n	r - mm	Sandbar willow	Salix exigua										x
	+	m	Bay leaved willow	Salix pentandra								x		x
	+	m	Quack grass	Agropyron repens									x	x
	?	mm		Agrostis sp.					x	x				
	+	mm	Redtop	Agrostis gigantea									x	x
	+	mm	Creeping bentgrass	Agrostis stolonifera								x	x	x
	(+)	mesic	Perennial rye-grass	Lolium perenne								x	x	
	+ salty	m	Foxtail barley	Hordeum jubatum									x	x
	+	mm - mesic	Barnyard grass	Echinochloa crusgalli							x		x	x
	+	mm - mesic	Barnyard grass	Echinochloa microstachya										x
	+	mesic	Meadow fescue	Festuca pratensis								x		x
	+	mesic	Fescue	Festuca trachyphylla									x	
	(+)	upland	Canada blue grass	Poa compressa								x		
	+	mesic	Timothy grass	Phleum pratense										
	n	m	Red Ash	Fraxinus pennsylvanica var. pennsylvanica	x									
	n	m	Green ash (seedling)	Fraxinus pennsylvanica var. subintegerrima	x							x		x
	n	not a	Manitoba maple (seedling)	Acer negundo								x	x	x
	(+)	m	Eastern cottonwood	Populus deltoides								x		x

Symbols Used:

n	native to Ontario Central Region
+	introduced or escaped from cultivation in Central Region
(+)	considered native in other regions but is non-native to Central Region
?	not enough of an identification was made to determine status
r	riparian
m	mesic
sub	submergent
fl	floating leaf

d	disturbed habitat
m	meadow
mm	meadow marsh
upland	well drained habitat
sm	shallow marsh
e	emergent
a	aquatic
*	species that were dominant in 1997

APPENDIX F

Assessment of Phytoplankton and Periphyton Communities

The following report was produced by Daniel D. Olding, Consulting Biologist, for the Toronto and Region Conservation Authority (TRCA). It includes studies undertaken at the Rouge Pond and a retrofit stormwater pond in Richmond Hill. This document has been reformatted but is otherwise substantially as submitted to the TRCA.

Stormwater Management Ponds:

Assessment of Phytoplankton and Periphyton Communities (1997)

Final Report

Harding Pond
Rouge Pond

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1.0 INTRODUCTION

This report describes the investigation into algal dynamics in two stormwater management ponds as part of the Stormwater Assessment Monitoring & Performance (SWAMP) Program.[1] The report describes baseline conditions of the summer phytoplankton and periphyton, compares within and between pond differences, and reports on chemical and physical field monitoring relevant to the algal dynamics. The two ponds included the following:

a) Harding Pond - Harding Park Pond in Richmond Hill, Ontario.
b) Rouge Pond - MTO Pond at Highway 401 and the Rouge River, Scarborough, Ontario.

2.0 METHODS

2.1 Phytoplankton and Chemical Analysis

Sites were sampled every two and one half weeks from late June to early September. Water samples for phytoplankton analysis were taken from the deepest point of each basin in the study locations. Samples were taken by Kemmerer bottle at one metre intervals to twice the secchi depth, and were field composited and preserved with Lugol's Iodine Solution. Field parameters were measured including temperature-depth profiles, conductivity, pH, and water transparency (secchi depth). In mid August, dissolved oxygen profiles were taken and samples were collected in the same manner as for phytoplankton and field preserved for total nitrogen and total phosphorus.

Phytoplankton samples for each site were composited from the five samples over the summer period. Samples were prepared by Utermohl sedimentation and identified to species level, where possible, at 625X magnification under phase contrast on an inverted microscope. Diatom species identifications were confirmed from peroxide cleaned mounts using DIC microscopy at 1250X magnification. Identifications were based on Prescott (1962), Taft and Taft (1990), Kramer and Lange-Bertalot (1986, 1988, 1991a, 1991b), Anton and Duthie (1981), Komarkova-Legnerova (1969) and Starmach (1985). Algal biovolumes were determined through measurements of individual algal species and calculations based upon geometric shapes (MOEE 1992). Estimated chlorophyll a was calculated by the following conversions:

1. Wet weight (mg/l) = Biovolume (mm^3/l)* 1.1
2. Dry weight (mg/l) = Wet weight * 0.2
3. Chlorophyll a (mg/l) = Dry weight (mg/l) * 0.01

Final Calculation:Chlorophyll a (mg/l) = Biovolume (mm^3/l)*0.0022

The phytoplankton counting procedure was developed to ensure consistent enumeration of rare species. Each sample was appropriately diluted or concentrated so that complete transects were viewed until a minimum of

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[1] See Appendix B for a glossary of terms used in this report.

500 individuals of all taxa were counted. The number of fields of view was recorded. A second count on the same sample was performed covering the same number of fields of view, but only recording those taxa which occurred at less than four in 500 (0.8%) individuals. The results of the two counts were combined, and only those phytoplankton taxa which were recorded at a percentage greater than 0.4% (four in 1000) in the combined count were identified and recorded in the taxa lists.

2.2 Periphyton

Periphyton were sampled through the use of artificial substrate tiles (10 x 10 cm unglazed ceramic), acid washed in dilute HCl prior to installation. Tiles were placed at the time of first sampling in late June. Two tiles were placed in the littoral zone of each sampling site at depths varying from 20 to 50 cm, and fixed in a vertical position with aluminum pegs so as to prevent accumulation of sedimented particles. Tile locations (i.e. rock or sand) were chosen to reflect the different types of bottom substrate available in each sampling site.

Harvesting of the tiles was performed in early September at the time of the final sampling. Attached algae were harvested by removing the tiles from the sampling location, with care not to disturb any loosely attached algae, and placing them in a sampling bin. The macroalgae was first removed into the bin with a wide blade scraper, and the scraper was rinsed into the bin after use with distilled water. The tile was then scrubbed vigorously with a fine plastic brush and rinsed into the bin a minimum of three times, or until no additional algae could be seen to be removed. The samples were made up to 250 ml with distilled water, transferred to sampling bottles and field preserved with Lugol's Iodine Solution.

Periphyton samples were prepared and enumerated in the same manner as phytoplankton samples, except that diatoms were identified to species level (where possible) and other groups were identified to genus level. Higher taxonomic resolution for the diatoms was required to take advantage of extensive monitoring data based on species level identifications (i.e. Hofmann 1996, Lowe 1974).

3.0 RESULTS

3.1 Harding Pond

3.1.1 Site description

Harding Pond consisted of four distinct areas:

- Sediment Forebay
- Wet Pond
- Wetland Pool
- Wet Meadow

Only two of these areas, Sediment Forebay and Wet Pond, contained sufficient water for a phytoplankton survey. The other two sites were shallow and heavily vegetated. Phytoplankton and chemical sampling locations were established at the deepest points of the Sediment Forebay (HP1), and the Wet Pond (HP2), and a third location was added in the southern bay of the Wet Pond (HP3). Periphyton sampling tiles were established in the littoral zone of each of the three locations. In HP1, Tile 1 was placed at 25 cm depth in a sandy substrate, and Tile 2 was placed at 50 cm depth in proximity to rocks. In HP2, Tile 1 was placed at 40 cm depth among rocks, and Tile 2 was placed at 50cm depth in a sandy substrate. In HP3, Tile 1 was placed at 25 cm depth in proximity to rocks, and Tile 2 was placed at 25 cm depth in a sandy substrate. The purpose of the third location (HP3) was to evaluate whether consistent differences in phytoplankton/ periphyton and chemical composition were observed between the deepest part of the main basin and its associated bays.

3.1.2 Phytoplankton survey

HP1 contained 13 taxa (Table F.1) and was dominated (i.e. groups comprising 10% or more of the total) in numerical abundance by green algae and euglenoids (Table F.2). Key taxa (>10% by numerical abundance) were *Spermatozoopsis* sp. and *Euglena* sp. When biovolume corrections were added to compensate for the relative size of different phytoplankton, the only dominant group (greater than 10% by biovolume) was the euglenoids, made up entirely of *Euglena* sp., with an abundance of 88.8% (Table F.3). The total biovolume was 41.1 mm^3/l approximately equivalent to 90.4 µg/l chlorophyll a. 87.5% of the phytoplankton biovolume had a GALD (greatest axial linear dimension) of less than 35 microns. This class of phytoplankton is generally considered to represent those phytoplankton easily susceptible to grazing (Watson and McCauley 1988).

HP2 contained 19 taxa (Table F.1). Four groups were numerically dominant; green algae, followed by cryptophytes, diatoms and euglenoids (Table F.2). *Pyramimonas* sp. and *Euglena* sp., were the primary taxa. The majority of the biovolume was split between the euglenoids (59.3%) and the cryptophytes (19.3%), represented primarily by *Euglena* sp. and *Cryptomonas erosa* (Table F.3). The total biovolume was 9.5

mm^3/l (20.9 ug/l chlorophyll a). The biovolume was approximately equal between the size classes with 55% being grazable (GALD < 35 μm), and 45% ungrazable (GALD >35 μm).

Nineteen phytoplankton taxa were recorded in HP3 (Table F.1), with the same dominant groups as HP2 (Table F.2). The dominant taxa numerically were *Euglena* sp., *Fragilaria nanana*, and *Stephanodiscus* sp. Biovolume dominants were the same as HP2 with *Euglena* sp. being the dominant taxa, comprising 71.7% of the biovolume (Table F.3). The total phytoplankton biovolume was 8.0 mm^3/l (17.6 μg/l chlorophyll a) with 59.5% of the biovolume having a GALD of less than 35 μm.

The three Harding Pond sites showed a similarity in being dominated by one taxa of phytoplankton, *Euglena* sp. However, there were distinct differences in phytoplankton assemblages between the Sediment Forebay (HP1) and the Wet Pond (HP2 and HP3). HP1 while having a much higher total phytoplankton biovolume, was comprised of fewer taxa than HP2 and HP3. The rank-abundance distribution of HP1 (Figure F.1) showed a phytoplankton community which was unbalanced in favour of one taxa, whereas HP2 and HP3 showed a more even distribution. Seven of thirteen taxa present in HP1 were not found in either HP2 or HP3. In contrast, the two locations in the Wet Pond were similar with respect to total biovolume, number of taxa recorded, and size distribution. However, there were some differences in phytoplankton assemblages between HP2 and HP3, with only thirteen of 26 taxa being common between the two sites, and slight differences in the evenness of rank-abundance distributions.

3.1.3 Periphyton

Both artificial substrate tiles were recovered from HP1, and microscopic analysis recorded nine taxa (Table F.4). The diatoms dominated numerically (Table F.5), with two small pennate diatoms, *Achnanthes minutissima /Cymbella microencephala,* comprising over 80% of the individuals counted. Despite the presence of relatively few green algae numerically (<5%), the one taxa recorded (*Oedegonium* sp.) was a large filamentous green macroalgae which dominated the biovolume, accounting for 58.5% of the total (Table F.6). Most of the rest of the biovolume was made up of diatoms (32.7%). The total biovolume expressed by surface area was 179 mm^3/100 cm^2.

HP2 and HP3 were similar in composition, with eight and ten taxa recorded respectively (Table F.4). Only one substrate tile was recovered from each location (Tile 2 from HP2, Tile 1 from HP1). Both sites were dominated numerically by diatoms, blue-green algae and green algae (Table F.5). Taxa comprising greater than 10% numerically included *Achnanthes minutissima /Cymbella microencephala* (HP2, HP3), *Leptolyngbya* sp. (HP2, HP3), *Protococcus viride* (HP2) and *Cocconeis placentula* (HP3). The total biovolume was primarily made up of green algae and diatoms in each of the sites (Table F.6), with green algae being more abundant in HP2 and diatoms more abundant in HP3. Dominant species included *Achnanthes minutissima /Cymbella microencephala* in both sites, *Protococcus viride* in HP2, and *Cocconeis placentula* and *Oedegonium* sp. in HP3. Total areal biovolumes were similar at 1.8 mm^3/100 cm^2 (HP2) and 0.8 mm^3/100 cm^2 (HP3).

The Sediment Forebay of Harding Pond (HP1) showed a distinct floristic assemblage compared to the Wet Pond (HP2 and HP3) with only two taxa from the Sediment Forebay being found in the Wet Pond. Additionally, the areal periphyton biovolume of HP1 was approximately two magnitudes higher than HP2 or HP3. Rank-abundance distributions of all three sites were similar in length and evenness (Figure F.2).

3.1.4 Chemical and physical characteristics

The three Harding Pond locations differed in key chemical and physical characteristics over the summer sampling period (Tables F.7, F.12, F.13 and F.14). HP1 was characterized by higher total phosphorus, total nitrogen and conductivity, lower pH, and cooler surface water temperatures. Mean summer transparencies were similar between the three sites, although HP1 showed greater variation throughout the summer. Nitrogen:phosphorus levels were similar between HP1 and HP2 at 11.9:1 and lower at HP3 with a ratio of 7.8:1. Littoral zone macrophyte vegetation was sparse in HP1.

HP2 was the deepest site and appeared to be chemically stratified (meromictic) with a dense layer of cooler saline water underlying lighter warmer water. The chemical stratification weakened gradually throughout the summer, but was still present on September 5. At midsummer, the bottom waters (2 metres) were anoxic. Littoral zone macrophyte vegetation was dense throughout HP2 except near the rocky flow-through structure from HP1.

HP3, being a shallower site in the same basin as HP2, was outside the area of meromixis. Heavy growths of macrophytes were present at the phytoplankton sampling site and in the littoral zone.

Based on trophic state indicators such as secchi depth, total phosphorus, total nitrogen, and estimated chlorophyll a, HP1 can be classed as hypereutrophic, and HP2 and HP3 as eutrophic bordering on hypereutrophic.

3.1.5 Comparison with previous studies

Two previous studies were performed on the algal communities of Harding Pond. The first survey by Melkic (1996), undertaken in mid-September, identified only the dominant macroalgae, i.e. those large filamentous algae which were visually seen to colonize substrates around the ponds perimeter. Comparison of results from the sediment forebay and the wet pond with the current study reveal one similarity. In both cases, *Oscillatoria* (= *Phormidium*) was recorded in the sediment forebay. Additional similarities to the present study might have been realized, had the tile placed near the flowthrough from the sediment forebay to the wet pond been able to be recovered, as this was a site specifically sampled in Melkic's study. However, the tile could not be located due to extensive growths of vegetation/algae. A more formal comparison between the two studies, identifying possible trends, would be difficult since sampling techniques were very different between the two studies.

The second study (Olding 1997) covered the early summer phytoplankton using an identical sampling methodology as the current study. The phytoplankton analysis was less stringent, with only 200 individuals per sample being counted. The phytoplankton species composition and richness of the early summer phytoplankton was not seen to differ much from the summer composite conditions (i.e. not many new taxa were found, and not many lost). Both studies recorded 32 taxa in all three locations of the pond. However, the relative proportion of phytoplankton groups did change, with green algae and euglenoids increasing in the summer composite, and diatoms decreasing, a typical summer transition. Additionally, total biovolume showed some location specific changes, with HP1 increasing greatly (1.7 to 41.1 mm^3/l), HP2 decreasing (18.2 to 9.5 mm^3/l) and HP3 staying constant.

Errata: The species identified in Olding (1997) as *Spondylomorum quaternium* (HP1) has since been confirmed at *Spermatozoopsis* sp., and the species *Achnanthes minutissima* also includes individuals of *Cymbella microencephala.*

3.2 Rouge Pond

3.2.1 Site description

Rouge Pond consisted of two distinct areas:

- Sediment Forebay
- Quiescent Treatment Zone

Both of these areas were suitable for phytoplankton study, and sampling sites were established in the deepest points of each of the basins. The sampling sites were identified as RP1 (Sediment Forebay) and RP2 (Quiescent Treatment Zone). Periphyton sampling tiles were established in the littoral zone of each of the two locations. In RP1, both tiles were placed in sandy substrates with Tile 1 at 25 cm depth and Tile 2 at 50 cm depth. In RP2, Tile 1 was placed at 20cm depth in a sandy substrate and Tile 2 was placed at 25 cm depth among rocks.

3.2.2 Phytoplankton

RP1 contained 21 taxa (Table F.8) which were numerically dominated by diatoms, green algae and cryptophytes (Table F.2). Key taxa were *Achnanthes minutissima/Cymbella microencephala, Cryptomonas phaseolus,* and *Carteria* sp. Four groups were dominant by biovolume, euglenoids, green algae, diatoms and cryptophytes, with key taxa *Euglena* sp., *Carteria* sp. and *Cryptomonas erosa* (Table F.3). The total phytoplankton biovolume was 0.7 mm^3/l (1.5 ug/l chlorophyll a), and 57.2% of the biovolume had a GALD less than 35 μm.

Twenty-four taxa were recorded at RP2 (Table F.8), numerically dominated by green algae, chrysophytes and cryptophytes (Table F.2). Key taxa were *Dinobryon divergens* and chlorophyte cells. The dominant groups by biovolume were euglenoids, dinoflagellates, cryptophytes and green algae, with *Euglena* sp:., *Peridinium* sp. and *Cryptomonas erosa* being the dominant taxa (Table E3). The total phytoplankton biovolume was 3.4 mm^3/l (7.5 ug/l chlorophyll a) with 54.3% having a GALD less than 35 μm.

RP1 and RP2 showed similarities in species richness, size distribution, and rank-abundance distribution. However, RP2 had a higher total phytoplankton biovolume and only seventeen of thirty-two taxa were common between the two sites. Additionally, diatoms were much more prevalent both numerically and by biovolume in RP1, whereas chrysophytes numerically and dinoflagellate biovolume were more abundant in RP2.

3.2.3 Attached algae

Two tiles were recovered from RP1, and only four taxa were identified at levels greater than 0.4% (Table F.9). The diatoms dominated numerically (Table F.5) with *Achnanthes minutissima /Cymbella microencephala* comprising over 90% of the individuals found. The biovolume (Table F.6) was dominated primarily by the diatoms *Achnanthes minutissima /Cymbella microencephala,* and *Gomphonema parvulum/angustatum,* and secondarily by a large green filamentous macroalgae (*Spirogyra* sp.), which despite being found at numerical abundance less than 0.4%, accounted for 23.8% of the biovolume. The total areal biovolume was 54.0 $mm^3/100\ cm^2$.

Two tiles were recovered from RP2, but only Tile 1 was analyzed. Tile 2 was located in rock and had extensive periphyton growth so far in excess of the other tiles that comparison would have be difficult. This tile may be analyzed separately for comparison of periphyton growths between rock and sand substrates. Eighteen taxa were recorded from Tile 1 of RP2 (Table F.9), dominated numerically by the diatoms *Achnanthes minutissima /Cymbella microencephala* (Table F.5). Total biovolume (Table F.6) was dominated by large filamentous green (*Mougeotia* sp.) and blue-green (*Oscillatoria* sp.) algae. The total areal biovolume was 470 $mm^3/100\ cm^2$.

The sediment forebay (RP1) and quiescent treatment zone (RP2) showed dramatic differences in periphyton assemblages, especially with regards to species richness (4 vs. 18) and areal biovolume (54.0 vs. 470 $mm^3/100\ cm^2$). Rank-abundance distributions reflect the differences in community structure, with low length and evenness in RP1 compared to RP2 (Figure F.2).

3.2.4 Chemical and physical characteristics

The two Rouge Pond sites differed in many chemical and physical properties (Tables F.7, F.10 and F.11). RP1 had a higher surface conductivity and nitrogen:phosphorus ratio, slightly lower pH and lower total nitrogen and total phosphorus levels. In addition, the surface waters were several degrees cooler than RP2, averaging 16.5°C throughout the summer. The transparency in RP1 extended right to the bottom sediments (1.7 m) all summer, in contrast with the mean transparency of RP2 (1.3 m). RP2 had a maximum depth of 4.0 m and was strongly chemically stratified with the chemocline between two and three metres. The chemical stratification persisted strongly throughout the summer, although some erosion of the saline layer was evident, especially at 3 meters (Table F.11). At mid summer the bottom waters of RP2 below 3 meters were anoxic. Littoral zone macrophyte vegetation was sparse in RP1 and moderate to dense in RP2.

Based on trophic state indicators such as secchi depth, total phosphorus, total nitrogen, and estimated chlorophyll a, RP1 can be classed as oligotrophic, and RP2 as eutrophic.

3.2.5 Comparison with previous studies

Two previous studies were performed on the algal communities of Rouge Pond. The first survey by Melkic (1996), undertaken in mid-September, identified only the dominant macroalgae, i.e. those large filamentous algae which were visually seen to colonize substrates around the ponds perimeter. Comparison of results from the sediment forebay and the wet pond with the current study show two similarities, i.e. in both studies, *Spirogyra* was recorded as the only filamentous macroalgae in the sediment forebay, and *Oedegonium* was present in the quiescent treatment zone. The analysis of Tile 2 from the quiescent treatment zone might reveal additional similarities as this was an area extensively sampled in Melkic's study. A more formal comparison between the two studies, identifying possible trends, would be difficult since sampling techniques were very different between the two studies.

The second study (Olding 1997) covered the early summer phytoplankton using an identical sampling methodology as the current study. The phytoplankton analysis was less stringent, with only 200 individuals per sample being counted. The phytoplankton species composition and richness of the summer composite phytoplankton community was seen to differ considerably from that in the early summer. The same taxa were recorded in both studies, but the summer composite contained many new species (i.e. 30 compared to 16 in the early summer). In general, from early summer to summer composite conditions, the proportion of green algae and dinoflagellates decreased in both locations, and proportion of diatoms (RP1), chrysophytes (RP2) and cryptophytes (RP1 and RP2) increased. The biovolume of RP1 remained constant between the two studies, and the summer composite biovolume of RP2 was approximately double that of the early summer.

Errata. The species identified in Olding (1997) as *Achnanthes minutissima* also includes individuals of *Cymbella microencephala.*

4.0 DISCUSSION

Harding Pond and Rouge Pond are both shallow stratifying stormwater management ponds with high overall productivity. However, considerable differences in physical and chemical parameters between the two ponds are observed. The majority of these differences can be explained with reference to the water quality of the incoming stormwater quality, i.e. Rouge Pond treats stormwater received primarily from a major highway, with high levels of heavy metals, petroleum hydrocarbons and road salt (Marsalek et. al. 1997), while Harding Pond treats stormwater received from an urban subdivision, with elevated levels of nutrients. The algae of the two sites, both phytoplankton and periphyton, reflect the quality of the incoming water. The algae of Rouge Pond, while having some ubiquitous "tolerant" taxa , i.e. *Cryptomonas erosa*, *Achnanthes minutissima* (Lowe 1974), *Cymbella microencephala* (Lowe 1974) and some representatives indicative of nutrient rich conditions, i.e. *Gonium sociale* (Prescott 1962), *Nitzschia acicularis* (Lowe 1974), and *Euglena* sp., showed an exceptional number of salt tolerant marine or brackish water diatoms, i.e. *Caloneis amphibaena, Entomoneis alata, Navicula pygmae, Fragilaria fasciculata, Diatoma tenuis* (Germain 1981, Lowe 1974). Harding Pond was similar to the Rouge Pond in having "tolerant" taxa, but had relatively more nutrient rich taxa, and no marine or brackish water diatoms. The presence of taxa such as *Cocconeis placentula* (Germain 1981), and *Protococcus viride* (Prescott 1962) in the Wet Pond (HP2 and HP3) reflected the extensive littoral zone macrophyte vegetation which characterized these locations.

The algal communities also provide insight into the performance of the ponds from a biological perspective. It appears as though the incoming stormwater has a strong impact on the algal composition of the Sediment Forebay of both Harding and Rouge Ponds, resulting in disturbed algal communities. The effects of the disturbance is not identical between the two ponds, but instead reflects the qualities of the incoming stormwater. For example, in the Sediment Forebay of Rouge Pond (RP1), the periphyton is characterized by being extremely species poor, with only four taxa recorded, and this is strong evidence that some environmental factor(s) related to the incoming stormwater is/are having a strong negative impact on the periphyton community. The impact is likely related to the sediments since the phytoplankton community does not seem to be affected in the same way. While further investigation would be necessary to conclusively isolate the causative agents, evidence from another study links exclusive domination of the two main periphyton taxa in RP1, (*Achnanthes minutissima /Cymbella microencephala* and *Gomphonema parvulum/angustatum*) with high levels of heavy metals (Whitton 1984). As heavy metals are often present in roadway runoff, a similar explanation could be hypothesized in this case. The effects of disturbance are also seen in the Sediment Forebay of Harding Pond. In this case, the phytoplankton community is impacted, being relatively species poor, and dominated by a large bloom of *Euglena* sp. (greater than 88% by biovolume). The cause of the disturbance is almost certainly related to the input of excessive nutrient concentrations (i.e. total nitrogen and total phosphorus in hypereutrophic range) which is typical in urban stormwater runoff.

As the inputs of stormwater move through the various compartments of the stormwater treatment ponds, evidence is seen of change towards a healthier and more diverse algal community. In the Rouge Pond, this effect is quite dramatic, with the species richness of the periphyton increasing from four in the sediment forebay (RP1) to eighteen in the quiescent treatment zone (HP2). Similarly, in Harding Pond, the species richness of the phytoplankton increased from thirteen in the sediment forebay (HP1) to nineteen in the Wet Pond (HP2 and HP3), and the bloom of *Euglena* sp. was significantly reduced in magnitude. These biological changes appear to be well correlated with pollutant reductions documented in the main body of this report. Further, the role of the ponds in protecting the biological communities of the receiving waters of Rouge River (Rouge Pond), and German Mills Creek (Harding Pond) can begin to be clearly seen. The use of biological community monitoring such as phytoplankton and periphyton, provides an essential link between designated substance reductions (i.e. heavy metals, nutrients) and the objectives for which these guidelines were established, the protection of biological habitat and communities.

Several other factors relevant to the biological functioning of the two ponds should be mentioned. First, the pathway through the Rouge Pond and Harding Pond systems can be seen to be fundamentally different. In the Sediment Forebay of the Rouge Pond, nutrients are low, the phytoplankton community biovolume is sparse, and periphyton communities are impaired. As we move into the Quiescent Treatment Zone, nutrients increase, the phytoplankton and periphyton community biovolume increases, and the disturbing effects on the periphyton are reversed. In contrast, in the Sediment Forebay of Harding Pond, nutrients are extremely high, and phytoplankton and periphyton community biovolume is high. As we move through the system into the Wet Pond, nutrients decrease, as do phytoplankton and periphyton biovolumes.

Second, the effects of aquatic vegetation can have a modifying effect on the periphyton communities. This can be seen most strongly in the Wet Pond sites of Harding Pond (HP2 and HP3), where the periphyton biovolumes were much lower than expected. At both sites the littoral macrophyte community was able to almost completely outcompete the periphyton community throughout the summer. The comparison of periphyton communities across the sites in Harding and Rouge Ponds needs to take into consideration the extent of macrophyte vegetation at the sampling sites. The present study fairly accurately reflects the actual differences in littoral zone periphyton, related to both biotic and abiotic factors. In order to separate the biotic differences from the abiotic, the sampling tiles would need to be placed out of the zone of vegetation influence, perhaps by suspending them just below the surface in the middle of the pond. In this way, the periphyton community would more accurately represent the water quality of the system, free from the confounding effects of vegetation. However, this change in sampling location also has drawbacks in that the sampling tiles would be removed from the influence of the sediments, an important factor affecting some periphyton communities. Ultimately, periphyton sampling locations need to be chosen to reflect the design objectives of the study, thereby providing information appropriate to the questions being posed.

Thirdly, there is a conspicuous absence of blue-green algae in all locations of the two stormwater ponds. This absence is somewhat unexpected, given the usual association of blue-green algae with nutrient rich conditions. Studies have suggested that the dominance of blue-green algae may be related to additional factors such as low nitrogen:phosphorus ratios, low (or moderate) turbulence levels, high water temperatures, low light levels, high pH and/or low carbon dioxide levels, or high zooplankton grazing levels (Shapiro 1990). Interestingly, most of these factors are consistent with conditions in Harding Pond, and to a lesser extent, Rouge Pond. The absence of blue-green algal dominance represents a beneficial state for the two stormwater ponds, and further study may reveal what critical factor(s) are behind this state.

Finally, while there are many attributes of the algal community composition which are documented in this study (i.e. absence of blue-green dominance), most will only be able to be interpreted in comparison with other sites. The comparison of the two ponds in this study could only be performed with reference to established ecological interpretations of a few indicator taxa. Similarly, environmental variables could only be related to algal composition in an ad hoc manner due to the small sample size. Future studies will incorporate Harding Pond and Rouge Pond into a larger set of sites and allow for a more formal establishment of relationships between environmental parameters and the entire algal community species composition. Additionally, the utility and effectiveness of other phytoplankton community measures (GALD, algal taxonomic or functional groups, etc.) will be able to be evaluated, perhaps leading to a greater understanding of the dynamics within these ponds.

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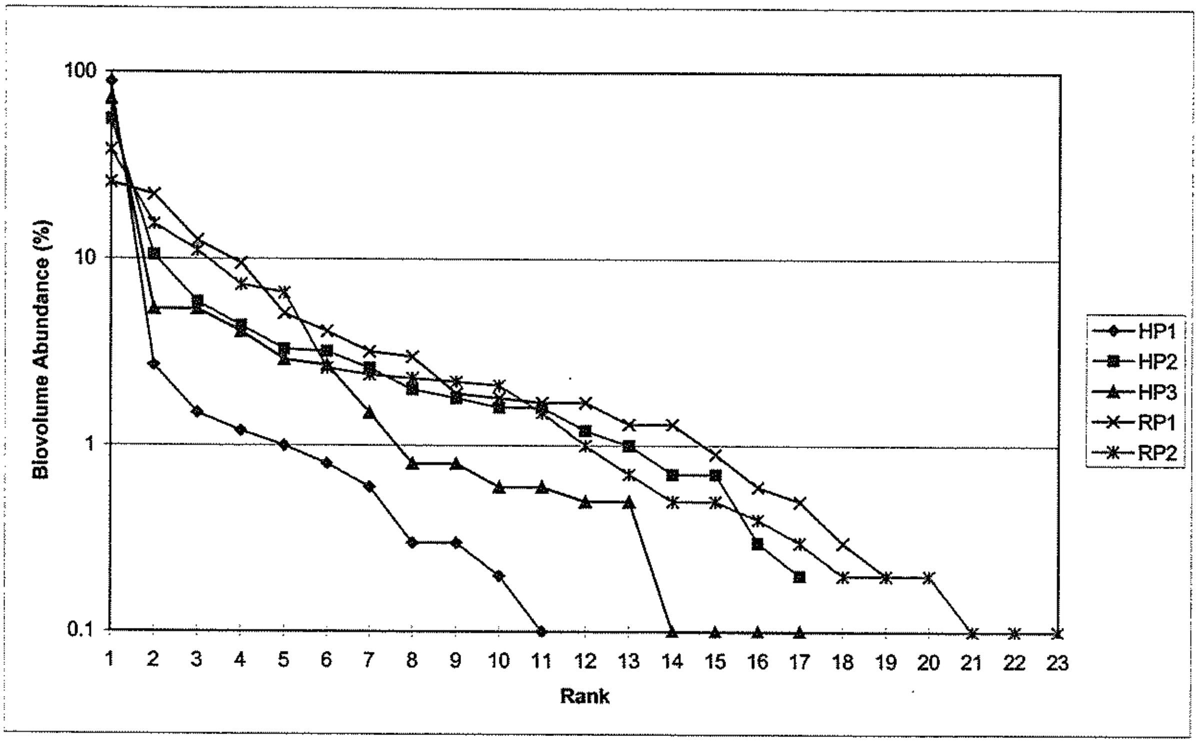

Figure F.1: Rank-abundance for phytoplankton of Harding Pond and Rouge Pond.

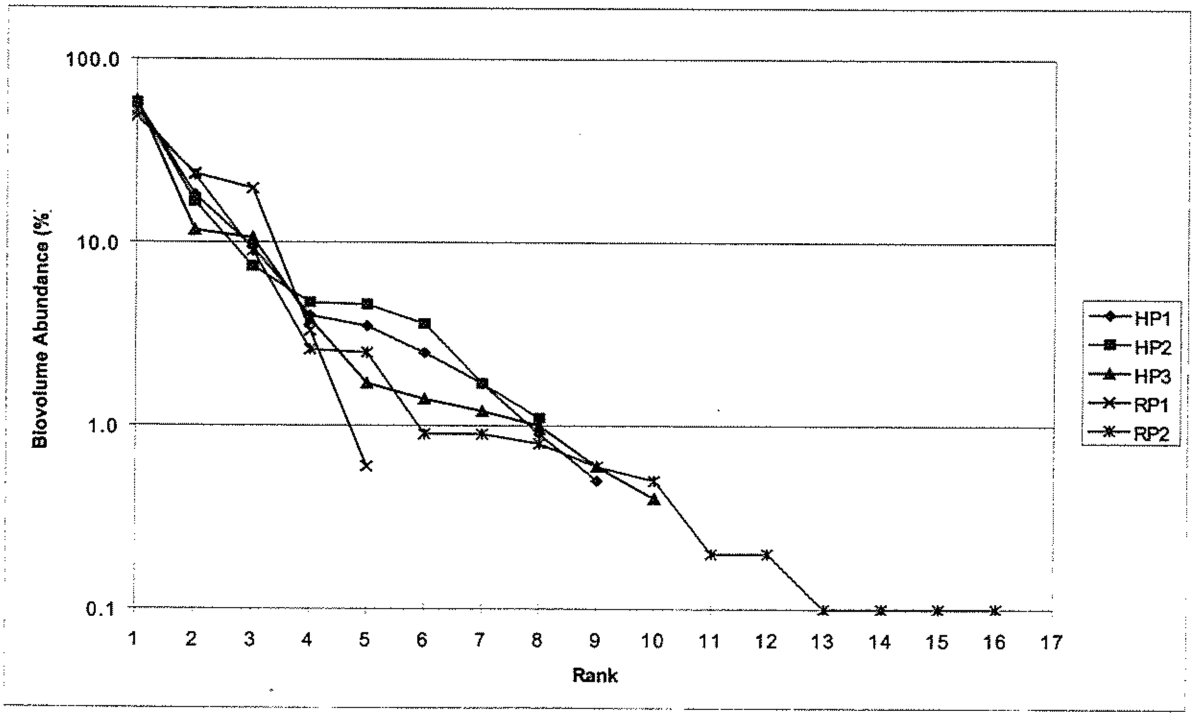

Figure F.2: Rank-abundance for periphyton of Harding Pond and Rouge Pond.

Table F.1: Phytoplankton taxa recorded from Harding Pond in numerical abundance and biovolume
Group symbols are: bg = blue-green algae, ch = chrysophyte, cr = cryptophyte, d = diatom, df = dinoflagellate, e = euglenoids, g = green algae, x = xanthophyceae.

			% by Number			**% by Biovolume**		
	Taxa	**Group**	**HP1**	**HP2**	**HP3**	**HP1**	**HP2**	**HP3**
1.	Achnanthes minutissima	d		0.9	3.0		0.2	0.5
	Cymbella microencephala							
2.	Carteria sp.	g		0.9	0.4		1.0	0.6
3.	Chlamydomonas sp.	cr		1.9	3.8		0.7	2.7
4.	Chlorophyte cells	g	0.5	1.8	6.8	0.3	0.3	1.5
5.	Chroococcus dispersus	bg			1.1			<0.1
6.	Cryptomonas erosa	cr	0.9	5.3	2.3	2.7	10.5	2.9
7.	Cryptomonas erosa v. reflexa	cr	0.8	2.5	7.9	1.2	2.6	5.4
	Cryptomonas pyrenoidifera							
8.	Cryptomonas ovata	cr		1.9	2.8		4.4	4.1
9.	Cryptomonas phaseolus	cr		4.9			1.8	
10.	Dinobryon divergens	ch	0.7			0.3		
11.	Euglena sp.	e	13.3	10.5	21.8	88.8	55.7	71.7
12.	Fragilaria nanana	d		7.7	19.8		3.2	5.4
13.	Golenkinia radiata	g	5.4			0.8		
14.	Mallomonas tonsurata	ch		0.6			0.7	
15.	Monoraphidium braunii	g	0.4			<0.1		
16.	Monoraphidium contortum	g		0.9			<0.1	
17.	Monoraphidium setiforme	g	1.2			0.1		
18.	Nitzschia acicularis	d			0.6			0.1
19.	Nitzschia sp.	d	1.7			1.0		
20.	Peridinium sp.	df		0.7			3.3	
21.	Phormidium sp.	bg	0.9			0.6		
22.	Pyramimonas sp.	g		35.5	4.9		5.9	0.5
23.	Rhodomonas minuta	cr	1.0	9.1	8.9	0.2	1.2	0.8
24.	Scenedesmus longus	g			0.7			0.1
25.	Selenastrum minutum	g	0.5			<0.1		
26.	Spermatozoopsis sp	g	70.3	0.4		1.5	<0.1	
27.	Sphaerellopsis sp.	g			0.5			0.1
28.	Stephanodiscus sp.	d		9.5	10.7		1.6	0.8
29.	Trachelomonas sp.	e		0.4			1.6	
30.	Trachelomonas volvocina	e		0.9	0.5		2.0	0.6
31.	Unidentified volvocale sp.1	g			0.5			<0.1
32.	Unidentified volvocale sp.2	g			0.4			0.1

Table F.2: Numerical abundance (%) of phytoplankton groups and species richness across stormwater pond locations

Algal Group	**HP1**	**HP2**	**HP3**	**RP1**	**RP2**
Green Algae	78.3	41.4	18.0	26.9	39.4
Euglenoids	13.3	11.8	22.3	4.6	3.2
Dinoflagellates		0.7		0.6	5.4
Diatoms	1.7	18.1	34.1	33.9	6.2
Cryptophytes	2.7	23.7	21.9	26.3	16.2
Chrysophytes	0.7	0.6		4.4	24.3
Blue-green Algae	0.9		1.1	0.6	
Xanthophyceae				0.5	3.3
Species Richness	13	19	19	21	24

Table F.3: Biovolume abundance (%) of phytoplankton groups and total biovolume (mm^3/l), chlorophyll a (ug/l) and % edible algae across stormwater pond locations

Algal Group	**HP1**	**HP2**	**HP3**	**RP1**	**RP2**
Green Algae	2.7	7.9	5.6	25.7	13.6
Euglenoids	88.8	59.3	72.3	27.0	38.4
Dinoflagellates		3.3		1.9	17.6
Diatoms	1.0	5.0	6.7	23.0	3.7
Cryptophytes	4.1	19.3	13.2	18.7	16.0
Chrysophytes	0.3	0.7		0.9	6.6
Blue-green Algae	0.6		<0.1	0.3	
Xanthophyceae				<0.1	0.3
Total Biovolume	41.1	9.5	8.0	0.7	3.4
Chlorophyll a*	90.4	20.9	17.6	1.5	7.5
Edible Algae**	87.4	54.8	59.3	57.2	54.2

* calculated from biovolumes

** proportion of phytoplankton biovolume with GALD (greatest axial linear dimension) less than 35 microns.

Table F.4: Periphyton taxa recorded from Harding Pond in numerical abundance and biovolume
Group symbols are: bg = blue-green algae, cr = cryptophyte, d = diatom,
e = euglenoids, g = green algae.

			% by Number			% by Biovolume		
	Taxa	Group	HP1	HP2	HP3	HP1	HP2	HP3
1.	Achnanthes minutissima Cymbella microencephala	d	83.3	27.4	17.3	18.2	16.7	10.6
2.	Characium sp.	g		1.2			3.6	
3.	Chlamydomonas sp.	g			1.7			0.6
4.	Chlorophyte cells	g		2.1	3.7		1.7	1.4
5.	Chlorophyte colony	g		1.0	0.8		1.1	0.4
6.	Cocconeis placentula	d		3.9	31.2		7.4	59.5
7.	Cryptomonas sp.	cr	0.6			0.5		
8.	Euglena sp.	e	0.8			4.0		
9.	Filamentous blue-green sp.	bg			2.7			1.0
10.	Gomphonema parvulum Gomphonema angustatum	d	1.1	1.2		2.5	4.6	
11.	Gomphonema truncatum	d	2.9			9.4		
12.	Leptolyngbya sp.	bg		44.1	35.5		4.7	3.8
13.	Navicula sp.	d	1.1			1.7		
14.	Nitzschia sp.	d	1.4			0.9		
15.	Oedegonium sp.	g	4.5		0.5	58.5		11.7
16.	Phormidium sp.	bg	3.3			3.5		
17.	Protococcus viride	g		17.9	2.3		57.9	1.7
18.	Scenedesmus sp.	g			1.9			1.2

Table F.5: Numerical abundance (%) of periphyton groups and species richness across stormwater pond locations

Algal Group	**HP1**	**HP2**	**HP3**	**RP1**	**RP2**
Green Algae	4.5	22.2	10.9		7.5
Diatoms	89.8	32.5	48.5	98.3	83.1
Blue-green Algae	3.3	44.1	38.2		7.9
Euglenoids	0.8				
Cryptophytes	0.6				
Species Richness	9	8	10	4	18

Table F.6: Biovolume abundance (%) of periphyton groups and total biovolume ($mm^3/100cm^2$) across stormwater pond locations

Algal Group	**HP1**	**HP2**	**HP3**	**RP1**	**RP2**
Green Algae	58.5	64.3	17.0	23.8*	61.2
Diatoms	32.7	28.7	70.1	72.4	9.2
Blue-green Algae	3.5	4.7	4.8		23.5
Euglenoids	4.0				
Cryptophytes	0.5				
Total Biovolume	179	1.8	0.8	54.0	470

* found at less than 0.4% numerical abundance

Table F.7: Summer average chemical and physical characteristics across stormwater pond locations

Parameter	**HP1**	**HP2**	**HP3**	**RP1**	**RP2**
Transparency (m)	0.8	1.0	0.8b	1.7b	1.3
pH*	7.8	8.5	8.8	7.8	7.9
Conductivity* (us/cm)	1150	520	530	2950	1900
Temperature* (°C)	20.5	24.5	24.0	16.5	23.5
Maximum Depth (m)	1.2	2.0	0.8	1.7	4.0
Total Nitrogen (mg/l)	3.7	0.75	0.69	0.33	0.61
Total Phosphorus (mg/l)	0.31	0.063	0.089	0.012	0.035
Nitrogen:Phosphorus	11.9	11.9	7.8	27.5	17.4
Dissolved Oxygen	oxic	anox	oxic	oxic	anox

b: transparent to bottom *: at surface
oxic: oxygenated at bottom anox: anoxic at bottom

Table F.8: Phytoplankton taxa recorded from Rouge Pond in numerical abundance and biovolume
Group symbols are: bg = blue-green algae, ch = chrysophyte, cr = cryptophyte,
d = diatom, df = dinoflagellate, e = euglenoids, g = green algae, x = xanthophyceae.

			% by Number		**% by Biovolume**	
	Taxa	**Group**	**RP1**	**RP2**	**RP1**	**RP2**
1.	Achnanthes minutissima Cymbella microencephala	d	20.9	2.4	3.0	0.4
2.	Caloneis amphisbaena	d	1.0		9.5	
3.	Carteria sp.	g	12.9	3.3	22.1	7.3
4.	Chlamydomonas sp.	g	3.8	1.7	0.6	0.1
5.	Chlorophyte cells	g	7.0	15.4	1.7	2.4
6.	Chrysophyte flagellate	ch	4.4		0.9	
7.	Cryptomonas erosa	cr	8.2	6.5	12.6	11.1
8.	Cryptomonas erosa v. reflexa Cryptomonas pyrenoidifera	cr	2.2	1.4	1.8	1.5
9.	Cryptomonas marsonii	cr		1.1		1.0
10.	Cryptomonas phaseolus	cr	14.3	6.4	4.1	2.3
11.	Dinobryon divergens	ch		24.3		6.6
12.	Entomoneis alata	d	0.8		5.1	
13.	Euglena sp.	e	4.2	3.2	25.7	38.4
14.	Fragilaria nanana	d		1.3		0.5
15.	Fragilaria sp.	d		0.6		2.1
16.	Gonium sociale	g	1.6	2.2	1.3	2.6
17.	Gymnodinium sp.	df		1.9		2.2
18.	Microactinium pusillum	g		5.8		0.7
19.	Monoraphidium braunii	g	1.6	8.5	<0.1	0.2
20.	Navicula pygmaea	d	1.8		1.7	
21.	Nitzschia acicularis	d	1.4	1.5	0.5	0.5
22.	Nitzschia sp.	d	8.0	0.4	3.2	0.2
23.	Oocystis sp.	g		0.4		0.2
24.	Ophiocytium capitatum	x	0.5	3.3	<0.1	0.3
25.	Peridinium sp.	df	0.6	3.5	1.9	15.4
26.	Phormidium sp.	bg	0.6		0.3	
27.	Rhodomonas minuta	cr	1.6	0.9	0.2	0.1
28.	Scenedesmus longus	g		0.4		0.1
29.	Selenastrum minutum	g		1.7		<0.1
30.	Trachelomonas sp.	e	0.4		1.3	

Table F.9: Periphyton taxa recorded from Rouge Pond in numerical abundance and biovolume
Group symbols are: bg = blue-green algae, d = diatom, g = green algae.

	Taxa	Group	% by Number RP1	% by Number RP2	% by Biovolume RP1	% by Biovolume RP2
1.	Achnanthes minutissima Cymbella microencephala	d	92.1	67.9	48.7	2.6
2.	Chlorophyte cells	g		1.7		0.1
3.	Chroococcus sp.	bg		0.4		0.1
4.	Cyclotella sp.	d		0.9		0.6
5.	Denticula elegans	d	0.6	2.8	3.3	0.9
6.	Diatoma tenuis	d		2.5		0.8
7.	Fragilaria fasciculata	d		1.7		0.9
8.	Fragilaria ulna	d		2.2		2.5
9.	Gomphonema parvulum Gomphonema angustatum	d	4.8	2.0	19.8	0.5
10.	Gomphonema truncatum	d		0.4		0.2
11.	Merismopedia sp.	bg		5.6		<0.1
12.	Mougeotia sp.	g		1.2		51.8
13.	Navicula sp.	d		1.2		0.1
14.	Nitzschia sp.	d	0.8	1.5	0.6	0.1
15.	Oedegonium sp.	g		2.6		9.0
16.	Oscillatoria sp.	bg		1.9		23.4
17.	Protococcus viride	g		0.9		0.3
18.	Scenedesmus sp.	g		1.1		<0.1
19.	Spirogyra sp.	g	**		23.8	

** less than 0.4%

Table F.10: Physical and chemical characteristics at Rouge Pond sampling site 1 (RP1) through the summer of 1997

Parameter	Sampling Date June 27	July 16	Aug 1	Aug 20	Sept 5
Secchi Depth (m)	1.7b	1.7b	1.7b	1.7b	1.7b
pH	7.9	7.8	7.8	7.8	8.0
Temperature (°C)					
0 m	17	18	17	17	13
1 m	13.5	14.5	15	14.5	12
Conductivity (uS/cm)					
0 m	3100	2900	3000	2500	3200
1 m	3200				
Dissolved Oxygen (mg/l)					
0 m				13.0	
1 m				13.0	
Total Phosphorus (mg/l)				0.012	
Total Nitrogen (mg/l)				0.33	

b: to bottom

Table F.11: Physical and chemical characteristics at Rouge Pond sampling site 2 (RP2) through the summer of 1997

			Sampling Date		
Parameter	**June 27**	**July 16**	**Aug 1**	**Aug 20**	**Sept 5**
Secchi Depth (m)	0.8	1.7	1.9	1.0	1.1
pH	8.2	7.8	7.9	7.6	7.9
Temperature (°C)					
0 m	28	27	23	21	18
1 m	21	21.5	22	19.5	18
2 m	18.5	19	19	18	17
3 m	14.5	15.5	16	16	16
3.8 m	14	14	13	13	12
Conductivity (uS/cm)					
0 m	1200	2500	2200	1300	2400
1 m	1900	3050	2450	1600	2400
2 m	2250	3150	2650	1700	2500
3 m	12500	13000	10000	10000	9500
3.8 m	14500	15500	15000	14000	14000
Dissolved Oxygen (mg/l)					
0 m				8.0	
1 m				7.8	
2 m				6.7	
3 m				0	
3.8 m				0	
Total Phosphorus (mg/l)				0.035	
Total Nitrogen (mg/l)				0.61	

Table F.12: Physical and chemical characteristics at Harding Pond sampling site 1 (HP1) through the summer of 1997

			Sampling Date		
Parameter	**June 27**	**July 16**	**Aug 1**	**Aug 20**	**Sept 5**
Secchi Depth (m)	0.8	0.7	1.0	0.3	1.1b
pH	7.7	7.4	7.7	8.2	7.8
Temperature (°C)					
0 m	24	24	20	17	16.5
1 m	18	16.5	18	15	14.5
Conductivity (uS/cm)					
0 m	1200	1200	1200	900	1200
Dissolved Oxygen (mg/l)					
0 m				>20	
1 m				18.2	
Total Phosphorus (mg/l)				0.31	
Total Nitrogen (mg/l)				3.7	

b: to bottom

Table F.13: Physical and chemical characteristics at Harding Pond sampling site 2 (HP2) through the summer of 1997

			Sampling Date		
Parameter	**June 27**	**July 16**	**Aug 1**	**Aug 20**	**Sept 5**
Secchi Depth (m)	1.0	0.9	1.0	0.8	1.1
pH	8.7	8.8	8.4	9.0	7.8
Temperature (°C)					
0 m	29	28.5	23	20	21
1 m	22.5	24	23	19	18
2 m	15	16	18	17.5	17
Conductivity (uS/cm)					
0 m	480	600	600	450	520
1 m	650	750	700	490	550
2 m	4850	4450	4400	3000	1150
Dissolved Oxygen (mg/l)					
0 m				17.4	
1 m				8.4	
2 m				0	
Total Phosphorus (mg/l)				0.063	
Total Nitrogen (mg/l)				0.75	

Table F.14: Physical and chemical characteristics at Harding Pond sampling site 3 (HP3) through the summer of 1997

			Sampling Date		
Parameter	**June 27**	**July 16**	**Aug 1**	**Aug 20**	**Sept 5**
Secchi Depth (m)	0.8b	0.8b	0.8b	0.6v	0.6v
pH	8.7	8.9	8.6	9.2	8.7
Temperature (°C)					
0 m	27	29	23	20	21
Conductivity (uS/cm)					
0 m	480	600	600	450	520
Dissolved Oxygen (mg/l)					
0 m				18.6	
Total Phosphorus (mg/l)				0.089	
Total Nitrogen (mg/l)				0.69	

b: to bottom
v: to vegetation

APPENDIX G

Analysis of Hydraulic Data

G.1 DATA ANALYSIS PROCEDURE

G.1.1 Introduction

The general principles of material balance calculations are described in Appendix C. The specific procedures applied for interpretation and analysis of the data from this study are described in the following sections of Appendix G.

The event that took place on September 24 and 25, 1996 produced a good data set. The data analysis procedure was developed using data from that event. Data anomalies and the methods used to overcome data problems are discussed subsequently.

G.1.2 Inspection of Rainfall and Flow Data

Figure G.1 contains the hyetograph and the inlet and outlet hydrographs for the September 24th, 1996 rainfall-runoff event. Several characteristics of the facility and of the specific event should be noted.

Both the west inlet sewer and the pond outlet have baseflows. The inlet baseflow is consistently greater than the outlet baseflow. Hence, water is exiting the pond by other routes. Evaporation would be expected to account for some loss, but the rate would be dependent upon atmospheric conditions, and evaporation alone would not create the rate of loss observed. Exfiltration from the pond to the local groundwater and to the adjacent Rouge River was considered to account for most of the observed water loss.

The data sets for all monitoring locations and all events must be examined carefully for possible erroneous zero readings caused by a flow meter failure. The east inlet sewer has no baseflow. The flow meter signal can legitimately go to zero during an event. Comparison of the shapes of the two inlet hydrographs and assessment of the runoff coefficient values are options for assessing the reliability of the east inlet flow data.

The flow data were recorded, and are plotted, using 5-minute intervals. The rainfall data shown in Figure G.1 were tabulated on an hourly basis. The rain gauge recorder originally saved data in 5-minute increments for compatibility with the flow data. At the time this report was revised, the original rain data could not be recovered. The 1-hour frequency of the available rain data has affected some parameters (such as the rain peak factor) that were calculated in the report revision process.

The flow data are time series vectors that contain both noise and trend components. Such data sets could be analyzed mathematically to quantify specific characteristics and to identify points of change. However, for this study, the determination of start times, end times and durations has been accomplished by inspection of the data.

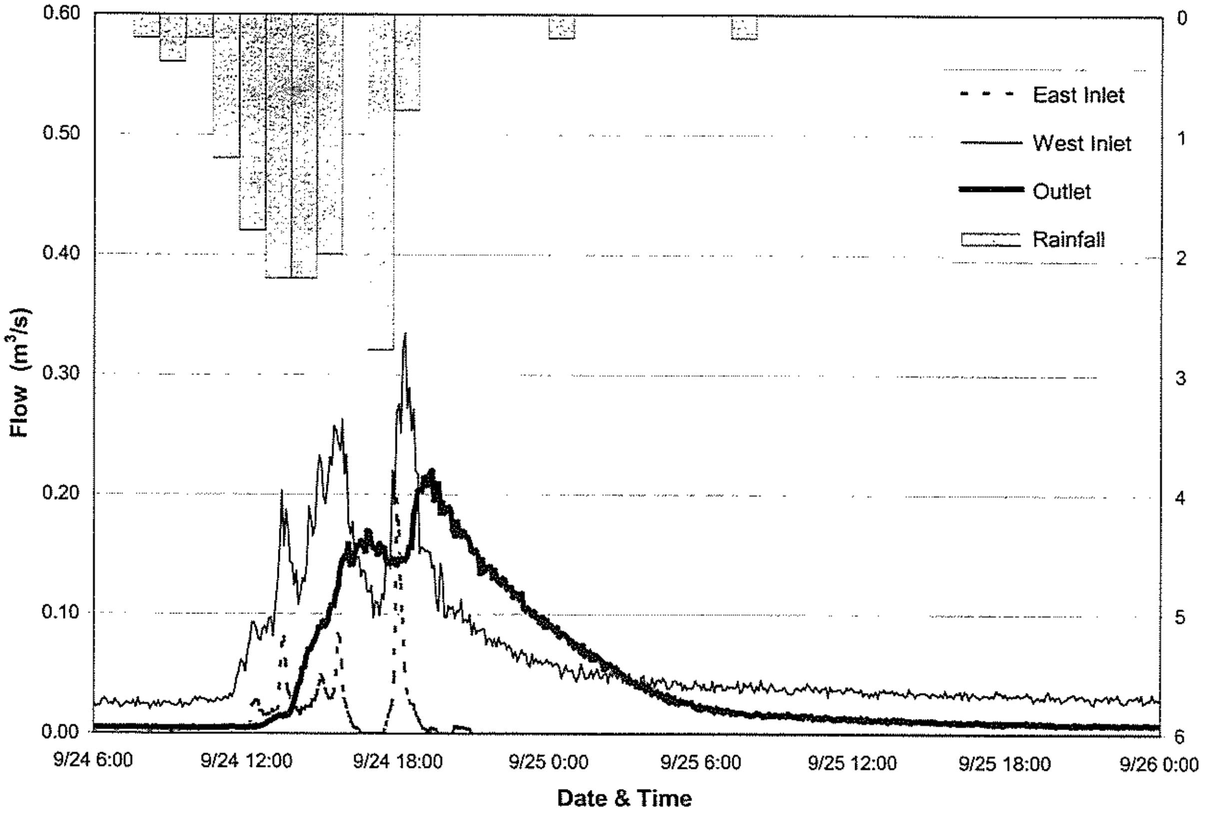

Figure G.1: Hyetograph and hydrographs -- event of Sept. 24, 1996

A subjective definition of the influent and effluent start times, based on curve shapes, is probably sufficient for the overall analysis. However, the selection of end points is more difficult because the dry-weather baseflows are greater at the end of the event than at the beginning. Rain recharges the groundwater within the catchment, resulting in increased infiltration to the sewers and an increased baseflow. The inlet and outlet baseflows may take several days to return to pre-event conditions or may not reach the initial values before the next rainfall event. Hence, for the purpose of reporting, both the inflow and outflow are considered to end when their respective flow rates attain a near steady-state condition. The outflow end time was subsequently adjusted to the end of the event as determined by the calculation of a volumetric balance when feasible.

The temporal distribution of the rainfall can be irregular. Selection of the component of the rainfall that contributed to a specific event may be partly subjective. Where intervals of no precipitation occur between intervals of rainfall, the method of quantifying the event - particularly with respect to duration and average intensity - also require some thought.

G.1.3 Volumetric Balance

G.1.3.1 Introduction

As discussed in Appendix C, a material balance may be determined for any system by defining a system boundary and measuring all inputs and outputs crossing that boundary. In addition, if any changes occur within the system boundaries, the internal variables must also be measured. The monitoring protocol for the Rouge Pond study did not include all of the measurements necessary to complete a material balance and to calculate the measurement error.

With respect to a volumetric balance for the system:

- evaporation from the pond will be ignored,
- direct precipitation and local runoff will be ignored,
- storage volume was not measured.

The quantity of runoff stored in the pond could conceivably be determined from topographic data and measurement of the pond surface level. Level data were available from the sensors in the splitter chamber and at the outlet flow monitoring station. However, headloss between the monitoring locations and the pond, and the base elevation of the sensor in the splitter chamber, make the observations unsuitable for estimating the water level in the pond. Also, the topographic contours used to generate the depth-volume curve provide only limited information over the active storage depth.

As discussed in the preceding section, exfiltration from the pond was considered to be a significant factor in the system. The exfiltration rate can not be measured directly. It could be estimated using conventional hydrogeological methods, but such methods were not included in this study. An "exfiltration volume" could be calculated as the difference between the measured inlet and outlet volumes; it would incorporate all unmeasured (or un-estimated) inputs and outputs, plus any measurement error. However, in this study, the exfiltration flow during the event was estimated from the pre-event and post-event dry-weather flows by linear interpolation of the baseflow conditions.

G.1.3.2 Calculation Method

An average influent baseflow is calculated for the period prior to each event. The period of time is arbitrary but would normally include at least 10 to 12 data points (50 to 60 minutes). An average influent baseflow is calculated for the period after the end of the runoff; a time period is selected near the end of the data set at which the flow has reached near steady-state conditions. To estimate the influent baseflow rate during the event, the initial and post-event averages are assigned to the start and end times, respectively, and intervening values are obtained by linear interpolation (Figure G.2.a).

The above procedure is repeated for the effluent hydrograph (Figure G.2.b).

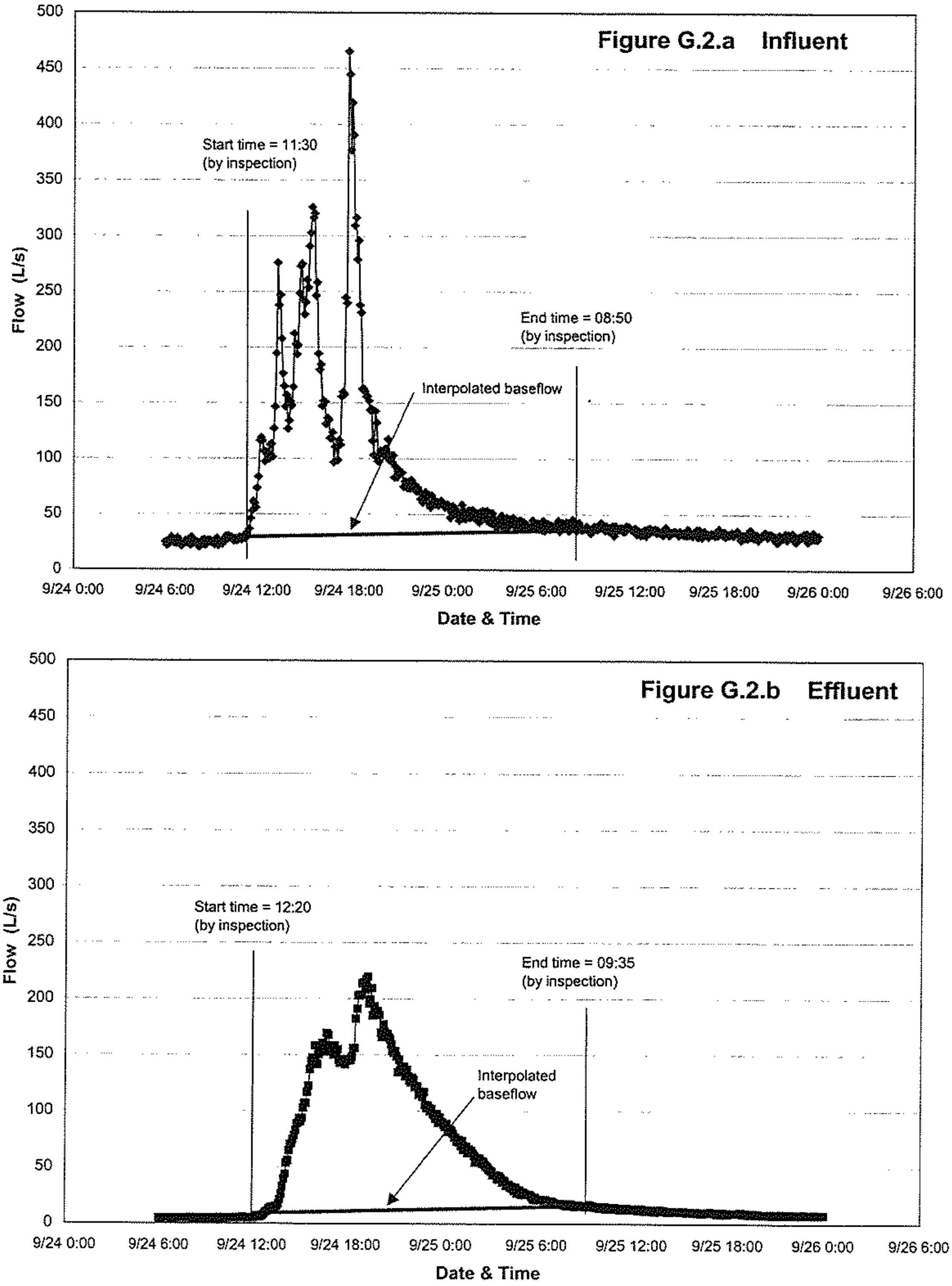

Figure G.2: Interpolation of baseflow data

Determination of the baseflow quantities permits the calculation of the surface runoff volumes attributed to a single event. The pre-event baseflow was the effect of previous rainfall. Although the post-event baseflow was caused in part by the event in question, elevated groundwater flow is not included as runoff.

At the start of an event, and at the end of an event, when the water level in the pond is neither rising nor falling, the difference between the inflow and outflow may be defined as the amount of "exfiltration". This value also includes any direct precipitation or evaporation (any gains or losses not measured) and any instrument error over that period of time.

The exfiltration rate during the event is estimated from the interpolated baseflow rates, as the difference between the influent and effluent baseflows. From a physical perspective, the depth of active storage and the hydrogeological conditions related to the increased hydraulic head and saturation of the soil would influence the exfiltration rate during this period. However, these physical factors would be difficult to quantify except by means of a complex model.

The volume of water stored in the pond in any interval of time is simply the volume of inflow, minus the volume of outflow and minus the volume of exfiltration. These incremental values will be positive as the pond fills and negative as the pond empties.

The inflow and outflow were measured quantities. The exfiltration flow was estimated from the baseflow observations. Hence, the volumetric error associated with the measurement/estimation procedure may be obtained by subtracting the total measured outflow volume and the estimated exfiltration volume from the total measured inflow volume.

The event of September 24th, 1996 was exceptional in that the volumetric error was very small. Figure G.3 includes the estimated storage curve for this event. The amount of exfiltration was over-estimated by assuming that the pond had reached equilibrium at the "event end" times selected by inspection. Consequently, the estimated storage volume became negative at the right-hand side of the curve. In this case, the exfiltration rate was subsequently adjusted by interpolation. A final average value was taken over a few (10 to 12) observations at the extreme end of the data set when the water level and flow conditions were likely to be as stable as possible. Figure G.4 illustrates the revised cumulative storage curve obtained by interpolating the exfiltration from the start of the event to a point near the end of the data set. In this particular case, the volumetric error was very close to zero and the storage curve did "close". The lesson learned from this protocol development exercise was to use a wide time base for the initial interpolation of the baseflows. The wide-base approach was applied to the analysis of data from the other events. In those cases, the greater volumetric errors precluded "closing" of the storage curves and, hence, re-assessment of the event end-time based on storage curve closure.

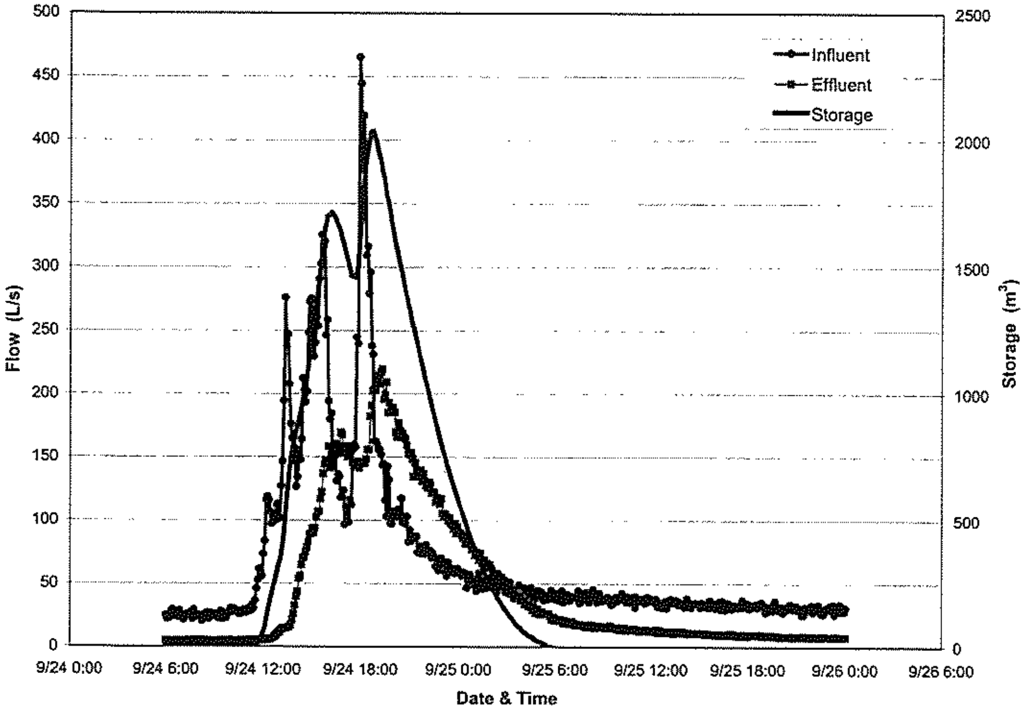

Figure G.3: Effect on volumetric balance of using interpolated baseflows

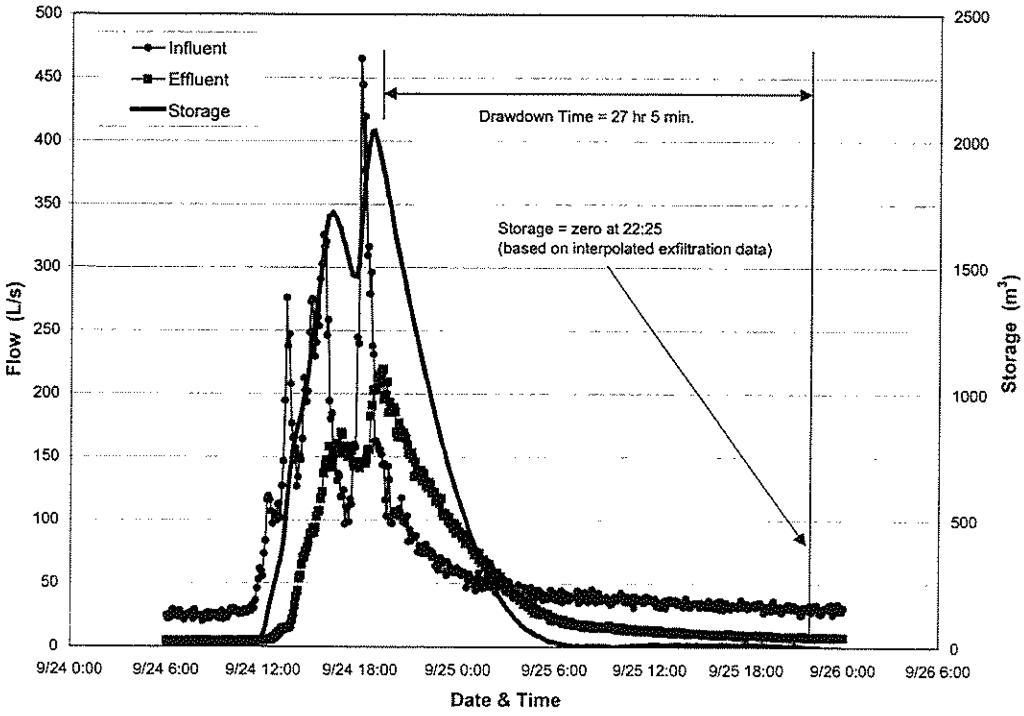

Figure G.4: Hydrographs and storage curve -- September 24-25, 1996

In an ideal case, the end of the event occurs when the storage has gone to zero - or has reached a minimum value - and both the inflow and outflow have attained essentially steady-state conditions. Assuming that the volumetric calculations are reasonably accurate, the minimum or zero storage criterion is assumed to be the correct end point for the event.

G.1.4 Other Calculations

G.1.4.1 Drawdown time

Figure G.4 includes "drawdown time" as a performance parameter characterizing the system and the event. More commonly, drawdown time is a design parameter that is determined by applying the maximum range of water surface elevation to a rating curve for the outlet structure. It is, therefore, the time required for the maximum active storage volume to drain from the pond in the absence of any inflow. This design parameter is used in lieu of detention time to design pond facilities, because detention time depends upon system dynamics and is much more difficult to estimate.

G.1.4.2 Centres of mass and the hydraulic detention time

The centroid of a hydrograph is calculated by multiplying each elemental area under the curve by its moment arm (distance from a common reference point) and dividing the sum of these first moments by the total area under the curve. Since a moment can be taken about any point, the beginning of the data set is used as the origin. The areas considered in this analysis were from the event start to the event end and between the inflow curve or outflow curve and the respective baseflow curve. Hence, the centroids were calculated for only the runoff portions of the hydrographs.

Hydraulic detention time is the average amount of time by which flow is held back by the pond system. Since the average element of fluid entering or leaving the system is represented by the respective hydrograph centroids, the average detention time is the time span between the inlet and outlet centroids.

Other measures of the hydraulic "lag" of the system may include the differences in the inlet and outlet hydrograph start times, or the differences in the hydrograph peak times. Multiple curve peaks and difficulty associated with the measurement of low flows can make these event parameters more ambiguous that the use of the hydrograph centroids.

G.1.4.3 Alternative view of volumetric error

As discussed above, the volumetric error was determined as:

Volumetric Error = (gross volume in - gross volume out - estimated exfiltration volume)

However, the exfiltration volume has been estimated as a function of the baseflows. If the net flows (i.e., the event runoff) are defined as:

$$\text{Net flow}_{\text{in or out}} = \text{gross flow}_{\text{in or out}} - \text{baseflow}_{\text{in or out}}$$

Then, an alternative expression for the volumetric error is:

$$\text{Volumetric Error} = \text{net volume in} - \text{net volume out}$$

G.1.5 Simulation of Data

G.1.5.1 Introduction

The Doppler flow sensors can be blocked by debris transported through the sewers, and they rely on the presence of particulates (or bubbles) in the water to measure flow. Hence, zero readings in field monitoring data are common and unavoidable observations. Interruptions caused by debris are often of a short-term nature and can be corrected by data interpolation. Extended periods of flow with insufficient particulate matter require a more elaborate correction procedure.

In addition to these unavoidable gaps in instrument data, battery or instrument failure and other operational problems affected several data sets. Different strategies were applied to compensate for data loss. An additional pressure transducer was installed in the pipe leading to the flow splitter in 1996 and 1997 (the location where the flow meter had been in 1995) to provide an indication of the water depth in the system.

G.1.5.2 Random signal irregularities

Flow sensors occasionally reported one or two erroneous zero readings within a string of non-zero values. This error occurred randomly, presumably because of sensor fouling. Figure G.5 illustrates an example in which the west inlet signal dropped to zero unexpectedly for a short period of time. Correction of this data problem was accomplished by elimination of the zero data values and replacement by simple trend values, based upon the adjacent non-zero observations.

G.1.5.3 Low-flow measurement

The flow sensors used in this study were mounted on the bottoms of the sewer pipes. Because they had a small but significant height, the sensors could not measure flows less than a few centimeters in depth. Normally, this limitation was not a problem because baseflows, where they existed, were of sufficient magnitude to be measured most of the time. However, because either a sensor lost low-flow sensitivity over time or because the water was particularly clean, the baseflow was often reported as zero when it was presumably non-zero. At the beginning of such time periods, the signal could be seen fluctuating between a significant low-flow value and zero, followed by continuous zero readings. This phenomenon is also illustrated in Figure G.5.

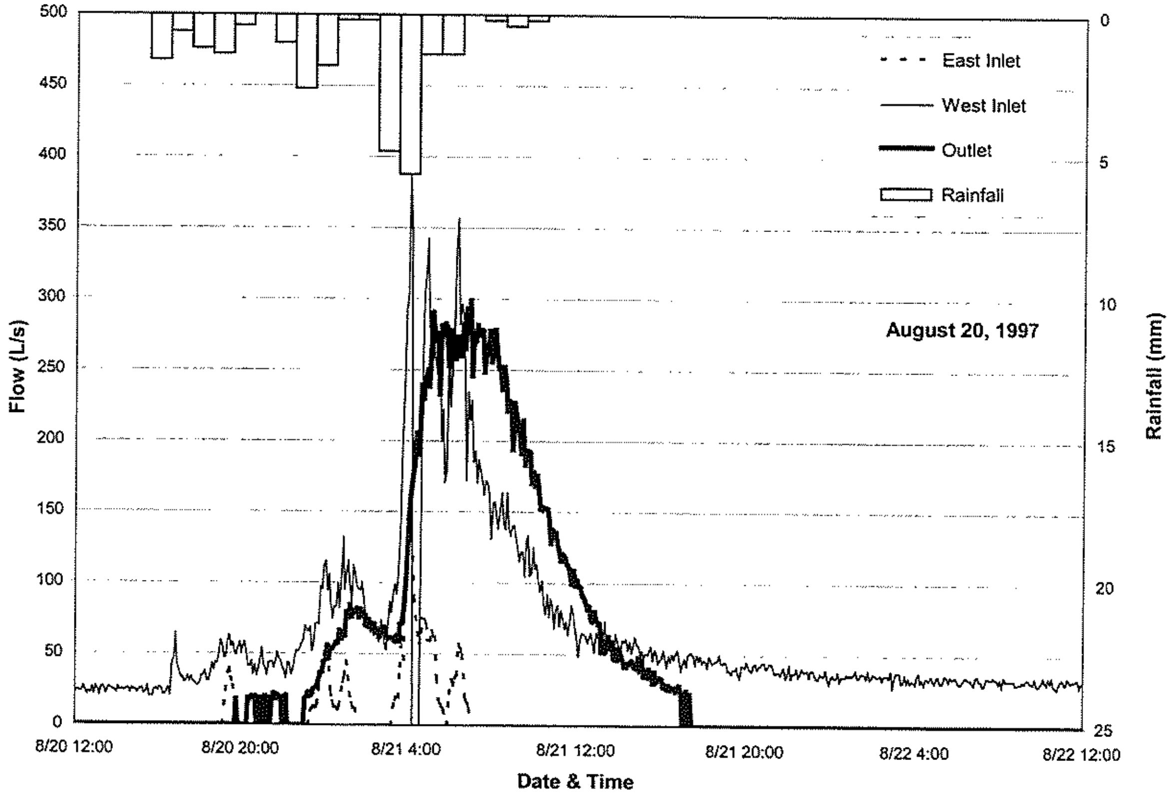

Figure G.5: Illustration of flow measurement problems

G.1.5.4 Missing data

On occasions, a sensor would fail to record data because of a failure of the battery or the instrument itself. At other times, the instrument may have recorded non-zero level values but zero flows.

G.1.5.5 Calibration problems

For some events, an apparently complete set of data was recovered at all monitoring stations. However, when the data were analyzed for a few of these events, a large volumetric error indicated that one or more of the influent and effluent data sets must have been in error. In such cases, only the flow data may have been incorrect, or both the level and flow data may have been in error.

G.1.5.6 Depth-to-flow correlations within and between events

Since the flow sensors provide both depth and flow data, a simple correlation procedure is to use the level data to simulate missing or suspect flow values. Depth-to-flow correlations were developed for numerous events and monitoring locations. The correlations were not consistent from location to location, nor from event to event at one location. Several causes for this lack of consistency were considered to be possible. Early data analysis work focused on using what was thought to be a reliable data set to generate a correlation for use in other events. However, the resulting volumetric balances were not very good. In the final analysis, only single-station and single-event correlations were used to replace a set of flow data that included missing low-flow observations.

G.1.5.7 Station-to-station correlations

As seen in several hydrographs included in this report, there are appreciable differences between the hydraulic behaviours of the two inlet sewers. The east inlet sewer has no baseflow and its runoff flows tended to be flashy and of short duration. The west inlet sewer has a larger tributary area, a continuous baseflow, and runoff flows that tended to be distributed over a broader timeframe. Attempts were made during early data analysis work to achieve correlations between data from these two stations. Subsequent volume balance calculations revealed that the simulation work was not successful.

The level sensor installed in the (combined) inlet sewer, upstream of the splitter chamber, had been thought of as a possible indicator of the level in the pond. However, the depth sensor was measuring the inflow depth plus any back up of water from the pond. Also, between the sensor location and the pond there would be headloss due to pipe friction. An occasional bypass flow would also affect the data.

The water level upstream of the splitter chamber could represent the combined inflow to the facility, but only early in each event before the water level in the pond backed up into the splitter chamber. The deeper water levels would be expected to have no correlation to the inflow. The range over which a correlation between the combined inflow and the splitter level may be expected is not entirely clear. This information was also not used in the final analysis.

At low pond levels, the water level upstream of the splitter chamber would be of no value in estimating the outlet flow because of the base elevation of the sensor. However, at greater levels, ignoring headloss between the splitter chamber and the pond, the splitter data should be correlatable with the outflow. Preliminary analysis indicated that, for the summer of 1996, there was good agreement between the water level upstream of the splitter chamber and the measured outflow. Such a correlation would imply extrapolating the level-outflow relationship below the elevation of the level sensor. This method was not used in the final analysis.

G.2 POST-CONSTRUCTION PERIOD EVENTS AND AVAILABLE DATA

G.2.1 Introduction

The post-construction period began in September of 1996. Monitoring was undertaken until the end of September 1997. This section provides an overview of the rainfall and runoff during the monitoring period.

The procedure described in the following sections consists generally of examination of monthly rainfall and flow sensor data, using the rain depth and level data to detect events. The level data were generally more reliable than the flow data. The more significant events from each month were then subjected to a volumetric balance calculation by spreadsheet using the procedure described previously in this appendix.

G.2.2 Summary by Month

September '96: There were approximately 9 events with a total rainfall of 184.6 mm (Figure G.6). The events of September 7, 11, 13, 24 and 27 were selected for analysis. The event of September 24th proved to have a very good volumetric balance and has been used as a prototype event for methodology development in this study.

October '96: There were approximately 10 events with a total rainfall of 62.4 mm (Figure G.7)[1]. The events of October 9-10 and 18-21 were selected for analysis.

November '96: A minor amount of rainfall early in the month did not produce a significant response by the flow monitoring system (Figure G.8). The event of November 7th was analyzed. Monitoring was ended for the season at mid-month.

April '97: A single event on April 27th was monitored after re-installation of the equipment for the new season.

May '97: Approximately 8 events occurred in the first 19 days, followed by a minor amount of precipitation later in the month, with a total rainfall of 73.0 mm (Figure G.9). Four events, on May 3, 5, 11 and 15 were analyzed.

June '97: Seven events occurred in June, with a total precipitation of 56.4 mm (Figure G.10). The rainfall patterns were typical of summer storms, being shorter and more intense than rainfall patterns seen previously. The events of June 13, 16, 18, 21 and 24 were analyzed.

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[1] The complete flow sensor data sets for October were not found at the time that the data were re-examined. Figure G.7 contains the flow data converted to m^3/s rather than original depth readings.

July '97: Approximately 11 events occurred in July, for a total precipitation of 40.4 mm (Figure G.11). The rainfall patterns were similar to those seen in June but the durations were shorter. Three events, on July 7, 8 and 27 were analyzed.

August '97: Three significant events and some minor precipitation occurred in August, for a total precipitation of 86.2 mm (Figure G.12). The three large events were analyzed.

September '97: Four significant events and some minor precipitation occurred in September, with a total precipitation of 76.4 mm (Figure G.13). The four large events were analyzed.

G.2.3 Summary of Hydraulic Analyses

Table G.1 summarizes the results of the hydraulic analysis work undertaken on the 28 events selected from the September 1996 to September 1997 monitoring program. The following sections explain the calculation procedures.

G.2.3.1 Rainfall

The rainfall duration was calculated as the number of hours containing non-zero rain depths during the rainfall-runoff event. Hours without rainfall were excluded. Hence, the duration does not represent the elapsed time from the initial rainfall to the final hour of rainfall.

The average rainfall intensity was calculated considering only the hours with non-zero rainfall data. Intervening hours with no precipitation were ignored.

Rainfall volumes were calculated using a tributary area of 13.74 ha for the east inlet (1,200 mm diameter stormsewer) and 115.80 ha for the west inlet (2,000 mm diameter stormsewer).

Centroids were calculated based on the first moment of area as discussed previously.

The peak factor is the ratio of the maximum hourly rainfall to the average rainfall intensity. The calculated values are a function of the reporting frequency (hourly) and the method of computing the average intensity as well as the characteristics of the rainfall itself.

G.2.3.2 Flow times

The inlet start time was determined by inspection of the inlet hydrographs. The west inlet flow invariably responds to a rain event before the east inlet. Where west inlet data are not available, the start time was approximated based on the rainfall and east inlet data. The outlet start time was determined by inspection of the outlet hydrograph.

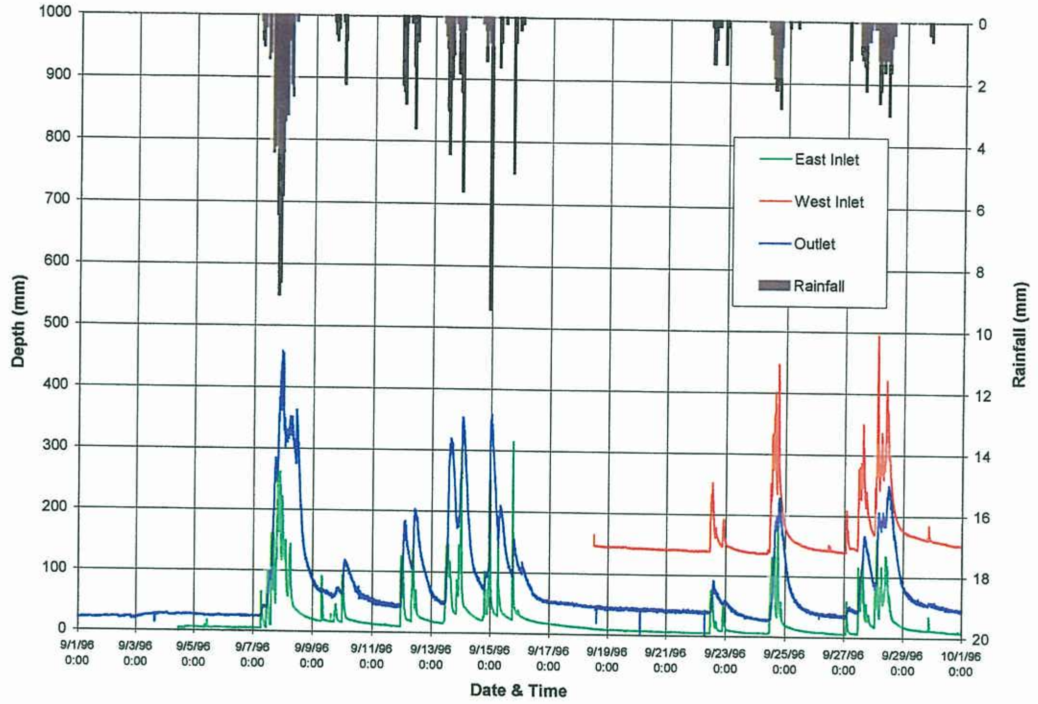


Figure G.6: Depth and rainfall data -- September 1996

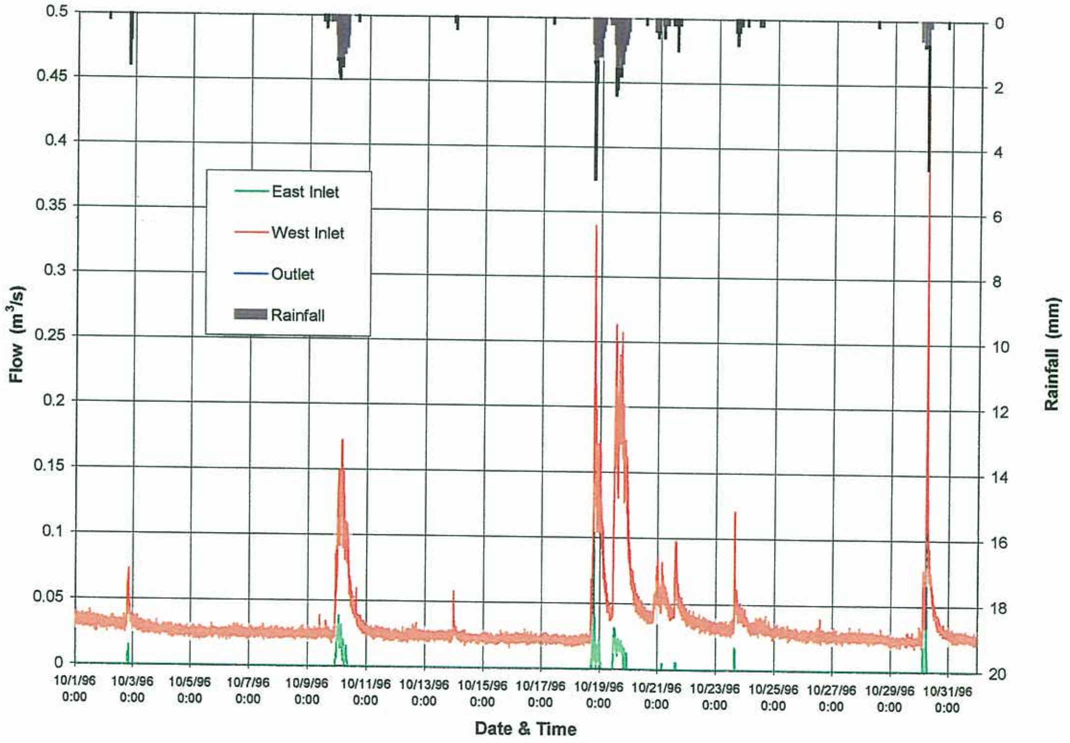


Figure G.7: Flow and rainfall data -- October 1996

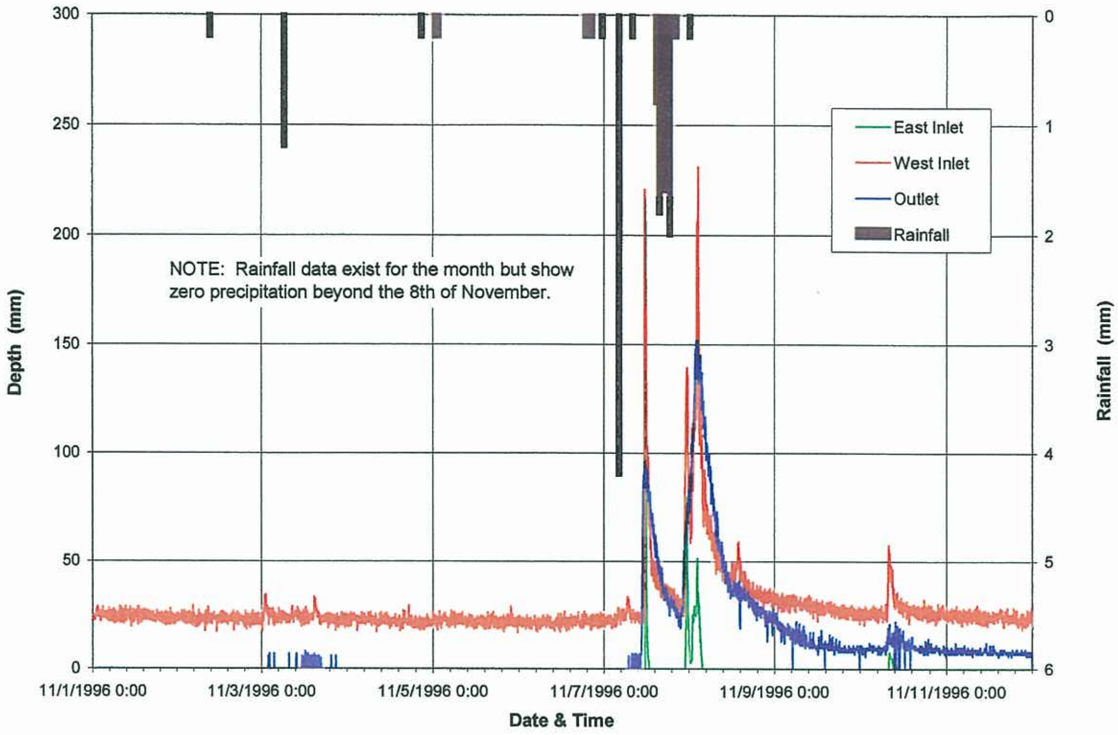


Figure G.8: Depth and rainfall data -- November 1996

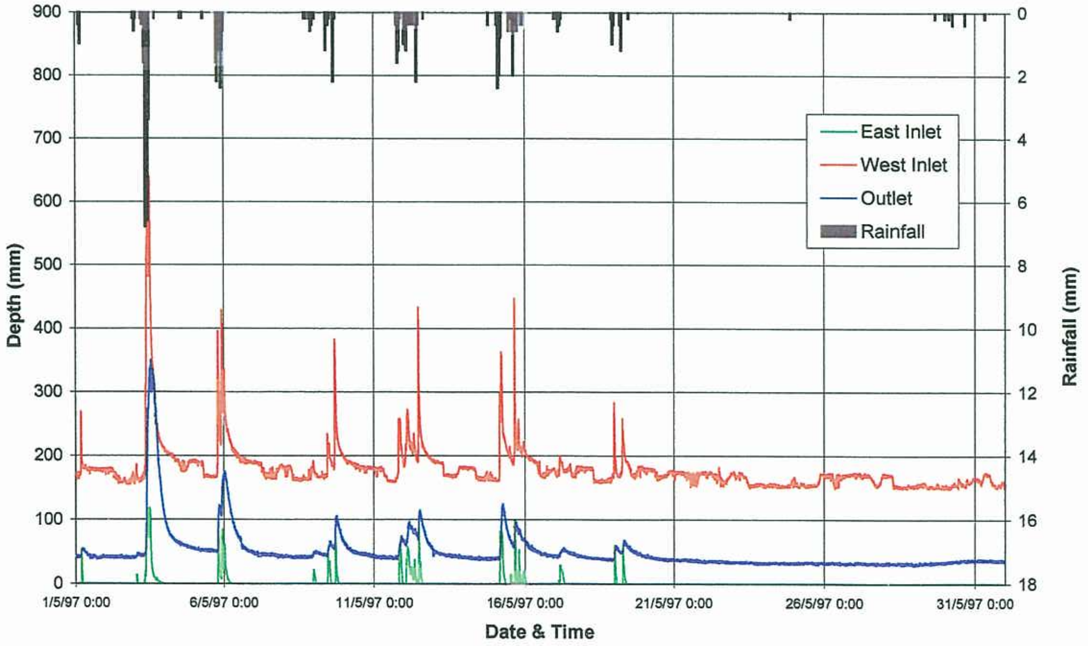
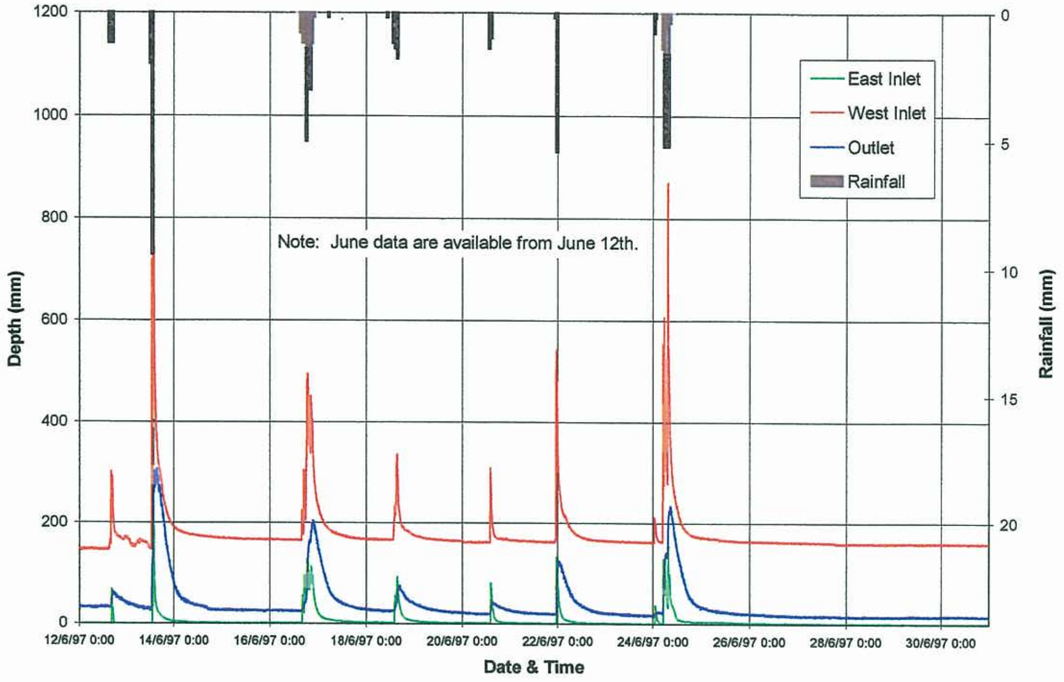


Figure G.9: Depth and rainfall data -- May 1997



F***igure G.10:*** Depth and rainfall data -- June 1997

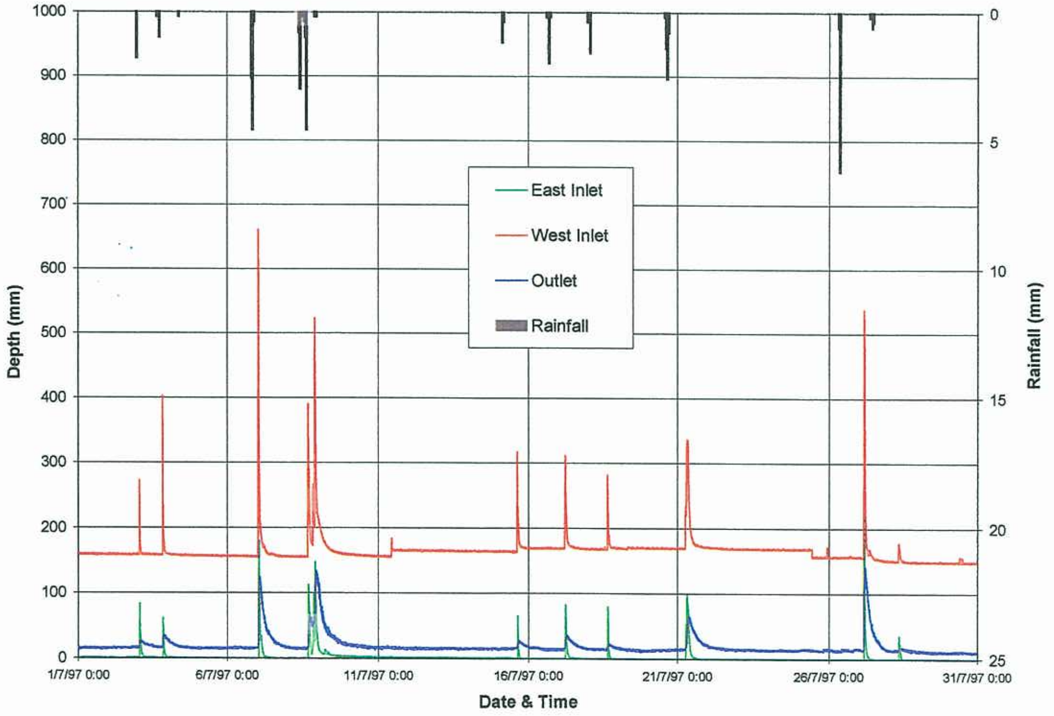


Figure G.11: Depth and rainfall data -- July 1997

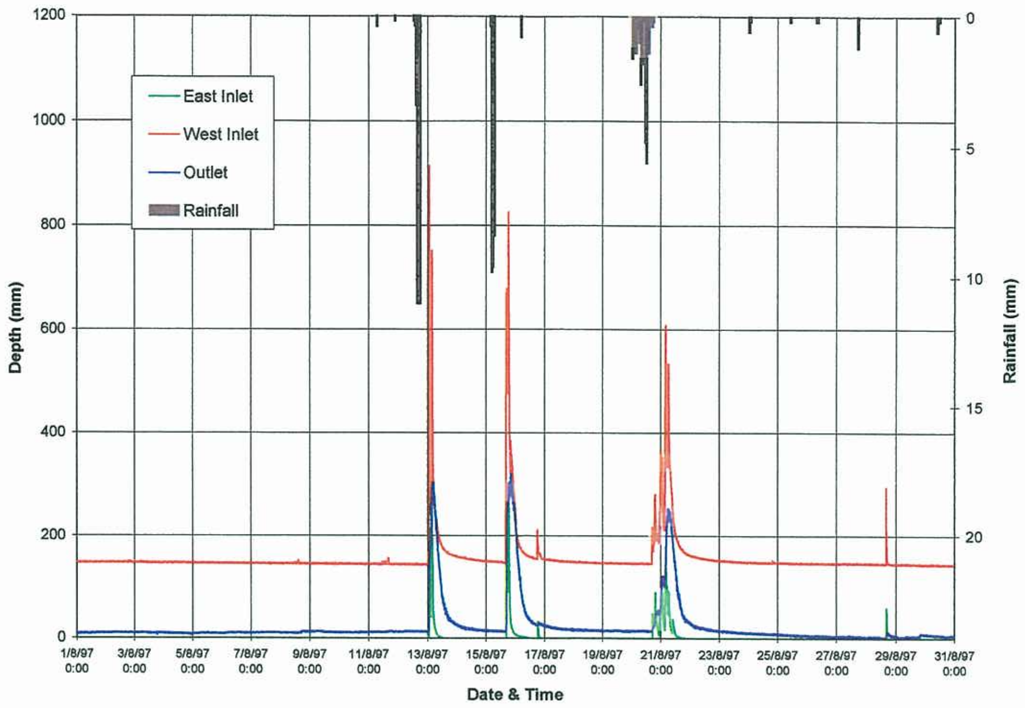


Figure G.12: Depth and rainfall data -- August 1997

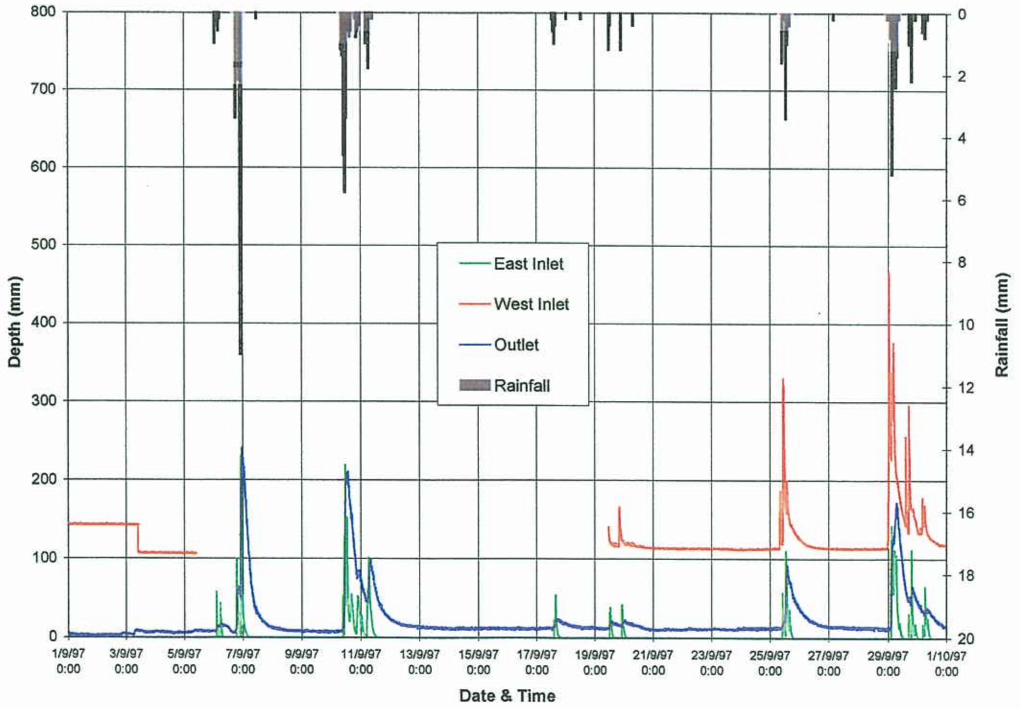


Figure G.13: Depth and rainfall data -- September 1997

Table G.1: Summary of monitored rainfall and runoff events in the post-construction period

Event Date	Rain									Flow Times							Inlet										Outlet										Exfiltration		Error		Runoff Coefficient				Data Availability		
	Duration [hr.]	Total Rainfall [mm]	Average Intensity [mm/h]	Maximum Intensity [mm/h]	Rainfall Volume - East Inlet [m^3]	Rainfall Volume - West Inlet [m^3]	Rainfall Centroid Date & Time	Peak Factor	Total Rain Volume [m^3]	Inlet Start Time *	Inlet Centroid Time	Outlet Start Time	Outlet Centroid Time	Storage Peak Time	Event End Time**	Overall Duration [hr.]	East Inflow = East Runoff [m^3]	West Inflow [m^3]	West Baseflow [m^3]	West Runoff [m^3]	Average Inflow Rate [m^3/s]	Peak Inflow Rate [m^3/s]	Peak Factor	Total Inflow [m^3]	Total Runoff [m^3]	Lag - Centroid to Centroid [min.]	Total Outflow Volume [m^3]	Baseflow Volume [m^3]	Outflow Runoff Volume [m^3]	Average Outlet Flow Rate [m^3/s]	Peak Outlet Flow [m^3/s]	Peak Factor	Peak Ratio	Drawdown Time [hr.]	Lag - Inlet Start to Outlet Start [min.]	Lag - Centroid to Centroid [min.]	Average Rate [m^3/s]	Total Volume [m^3]	Volume [m^3]	% of Influent	East Inlet	West Inlet	Total Inlet	Outlet	East Inlet	West Inlet	Outlet
Sep 07,1996	30	72.4	2.4	9.0	9,948	83,839	9/7/96 23:27	3.69	93,787	9/7/96 6:15	n/a	9/7/96 6:40	9/8/96 7:46	n/a	9/11/96 12:00	102	5,908	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	40,200	3,287	36,913	0.109	0.622	5.72	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.59	n/a	n/a	0.39	●	n/a	●
Sep 11,1996	9	14.6	1.6	3.6	2,006	16,907	9/12/96 3:54	2.22	18,913	9/11/96 22:00	n/a	9/11/96 23:35	9/12/96 10:11	n/a	9/13/96 5:00	33	556	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8,504	1,866	6,638	0.070	0.181	2.58	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.28	n/a	n/a	0.35	●	n/a	●
Sep 13,1996	31	49.2	1.6	9.4	6,760	56,974	9/14/96 8:35	5.92	63,734	9/13/96 11:00	n/a	9/13/96 11:45	9/14/96 16:39	n/a	9/18/96 6:00	115	3,304	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	36,449	6,568	29,881	0.087	0.385	4.45	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.49	n/a	n/a	0.47	●	n/a	●
Sep 24, 1996	12	14.2	1.2	2.8	1,951	16,444	9/24/96 14:54	2.37	18,395	9/24/96 11:30	9/24/96 17:32	9/24/96 12:20	9/24/96 20:18	9/24/96 18:45	9/25/96 22:25	35	768	9,662	4,610	5,052	0.077	0.465	6.04	10,428	5,818	158	7,079	1,221	5,858	0.055	0.220	4.00	47%	27.7	50	168	0.022	3,355	-6	0%	0.39	0.31	0.32	0.32	●	●	●
Sep 27,1996	24	27.6	1.2	3.0	3,792	31,961	9/28/96 0:03	2.61	35,753	9/27/96 1:15	9/28/96 4:31	9/27/96 2:00	9/28/96 7:26	9/28/96 11:10	9/29/96 12:00	59	1,463	20,598	8,518	12,080	0.100	0.583	5.84	22,061	13,543	268	16,692	2,556	14,136	0.077	0.274	3.54	47%	24.8	45	175	0.023	5,915	-546	-2%	0.39	0.38	0.38	0.40	●	●	●
Oct 09,1996	17	14.2	0.6	2.0	1,951	16,444	10/10/96 0:35	2.39	18,395	10/9/96 21:50	10/10/96 5:16	n/a	n/a	n/a	*10/12/96 12:00*	*62*	521	12,699	8,659	4,040	0.038	0.199	5.19	13,220	4,561	281	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.27	0.25	0.25	n/a	●	●	n/a
Oct 18,1996	41	35.2	0.9	5.0	4,836	40,762	10/19/96 21:11	5.82	45,598	10/18/96 16:20	10/19/96 20:52	n/a	n/a	n/a	*10/23/96 6:00*	*110*	1,217	28,317	11,706	16,611	0.088	0.430	6.28	29,534	17,828	-19	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.25	0.41	0.39	n/a	●	●	n/a
Nov 07,1996	12	12.4	0.6	1.0	1,704	14,359	11/7/96 18:57	1.36	16,063	11/7/96 10:40	11/7/96 23:33	11/7/96 10:40	11/8/96 4:05	11/7/96 12:25	11/11/96 12:00	97	722	15,390	11,643	3,747	0.037	0.427	11.54	16,112	4,469	276	10,109	2,614	7,495	0.023	0.152	6.61	36%	95.6	0	272	0.014	9,029	-3,026	-19%	0.42	0.26	0.28	0.47	●	●	◍
Apr 27,1997	11	9.8	0.9	2.2	1,347	11,348	4/28/97 2:10	2.47	12,695	4/27/97 22:20	4/28/97 7:19	4/27/97 23:35	4/28/97 8:04	4/28/97 1:35	4/29/97 9:40	35	188	9,838	7,205	2,633	0.060	0.166	2.76	10,026	2,821	309	4,557	688	3,869	0.334	0.092	0.28	55%	32.1	75	45	-0.274	6,517	-1,048	-10%	0.14	0.23	0.22	0.30	●	●	◍
May 03,1997	15	26.2	1.7	6.8	3,600	30,340	5/3/97 9:21	3.89	33,939	5/3/97 8:00	5/3/97 14:58	5/3/97 8:50	5/3/97 18:49	5/3/97 12:30	5/5/97 0:00	64	1,050	17,616	8,805	8,811	0.110	0.832	5.75	18,666	9,861	337	16,899	3,086	13,813	0.110	0.513	4.66	81%	35.5	50	231	0.000	5,300	-3,533	-19%	0.29	0.29	0.29	0.41	●	?	●
May 05,1997	7	9.4	1.3	2.4	1,292	10,885	5/5/97 20:42	1.79	12,177	5/5/97 18:50	5/6/97 2:14	5/5/97 19:10	5/6/97 2:21	5/5/97 23:00	5/7/97 0:00	29	281	9,243	5,656	3,587	0.076	0.305	4.03	9,524	3,868	332	6,043	2,010	4,033	0.048	0.152	3.17	50%	25.0	20	7	0.028	3,646	-165	-2%	0.22	0.33	0.32	0.33	●	●	◍
May 11,1997	25	11.0	0.7	2.2	1,511	12,738	5/12/97 2:19	3.00	14,249	5/11/97 19:10	5/12/97 8:45	5/11/97 19:15	5/12/97 8:14	n/a	5/13/97 10:00	39	120	10,546	7,046	3,500	0.082	0.300	4.86	10,666	3,620	386	4,900	2,486	2,414	0.028	0.076	2.67	25%	n/a	5	29	0.033	4,560	1,206	11%	0.08	0.27	0.25	0.17	●	●	◍
May 15,1997	13	11.2	0.8	2.4	1,539	12,970	5/15/97 9:35	2.84	14,508	5/15/97 3:10	5/15/97 14:13	5/15/97 3:35	5/15/97 15:45	5/15/97 5:50	5/16/97 18:00	39	253	10,444	6,755	3,689	0.082	0.303	4.90	10,697	3,942	278	4,294	778	3,516	0.025	0.080	3.21	26%	36.2	25	92	0.037	5,977	426	4%	0.16	0.28	0.27	0.24	●	●	◍
Jun 13,1997	2	11.4	5.7	9.4	1,568	13,201	6/13/97 12:49	1.65	14,768	6/13/97 12:50	n/a	6/13/97 12:50	6/13/97 17:11	n/a	6/14/97 5:00	16	625	1,107	3,613	-2,506	n/a	n/a	n/a	n/a	n/a	n/a	8,361	1,222	7,139	0.122	0.370	3.03	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.40	n/a	n/a	0.48	●	x	◍
Jun 16,1997	8	14.8	1.6	5.0	2,034	17,138	6/16/97 18:36	3.04	19,172	6/16/97 15:00	6/16/97 21:29	6/16/97 16:10	6/16/97 23:40	6/16/97 19:25	6/17/97 15:00	23	772	6,745	4,537	2,208	0.070	0.256	3.68	7,517	2,980	173	5,306	1,139	4,167	0.040	0.205	4.17	80%	18.6	10	131	0.021	3,398	-1,187	-18%	0.38	0.13	0.16	0.22	●	?	◍
Jun 18,1997	4	4.6	1.2	4.8	632	5,327	6/18/97 13:57	4.00	5,959	6/18/97 13:35	6/18/97 21:44	6/18/97 13:55	6/19/97 1:26	6/18/97 16:05	6/19/97 23:55	34	113	7,372	6,324	1,048	0.043	0.163	3.79	7,485	1,161	467	1,799	1,087	712	0.010	0.040	3.87	25%	31.8	20	222	0.033	5,237	449	6%	0.18	0.20	0.19	0.12	●	●	◍
Jun 21,1997	2	5.6	2.8	5.4	769	6,485	6/21/97 22:58	1.93	7,254	6/21/97 23:05	6/22/97 3:32	6/21/97 23:15	6/22/97 8:50	6/22/97 0:25	6/23/97 6:00	31	219	7,595	6,117	1,478	0.045	0.281	5.78	7,814	1,697	274	2,730	1,068	1,662	0.016	0.085	5.39	33%	29.6	10	318	0.029	5,049	35	0%	0.28	0.23	0.23	0.23	●	?	◍
Jun 24,1997	7	13.8	2.0	5.2	1,896	15,980	6/24/97 5:26	2.64	17,877	6/24/97 0:50	6/24/97 8:43	6/24/97 1:10	6/24/97 13:05	6/24/97 8:30	6/24/97 20:00	19	522	7,122	4,102	3,020	0.071	0.453	6.40	7,644	3,542	187	5,842	1,166	4,676	0.054	0.268	4.92	59%	11.5	20	262	0.017	3,098	-1,296	-17%	0.26	0.19	0.20	0.26	●	?	◍
Jul 07,1997	3	7.6	2.5	4.6	1,044	8,801	7/7/97 0:43	1.82	9,845	7/7/97 0:45	7/7/97 2:00	7/7/97 1:00	7/7/97 5:04	7/7/97 1:40	7/8/97 0:00	23	231	3,600	2,927	673	0.028	0.416	14.84	3,831	904	77	1,841	678	1,163	0.014	0.084	6.22	20%	22.3	15	184	0.015	2,449	-459	-12%	0.22	0.08	0.09	0.12	●	?	◍
Jul 08,1997	9	10.6	1.8	4.6	1,456	12,275	7/8/97 7:07	2.59	13,731	7/8/97 16:00	7/8/97 21:40	7/8/97 16:15	7/9/97 0:11	7/8/97 22:30	7/9/97 15:00	23	453	5,032	3,150	1,882	0.059	0.363	6.20	5,484	2,334	882	2,532	630	1,902	0.027	0.096	3.56	26%	16.5	15	142	0.032	2,520	432	8%	0.31	0.15	0.17	0.14	●	?	◍
Jul 27,1997	2	8.8	3.4	6.2	934	7,874	7/27/97 3:56	1.82	8,809	7/27/97 4:00	7/27/97 8:25	7/27/97 4:10	7/27/97 7:31	7/27/97 4:25	7/27/97 22:00	18	178	2,812	2,230	382	0.032	0.248	7.69	2,790	560	150	1,791	450	1,341	0.021	0.104	5.04	42%	17.6	10	66	0.012	1,779	-780	-28%	0.19	0.05	0.08	0.15	●	x	◍
Aug 13,1997	6	28.2	4.7	11.0	3,875	32,656	8/13/97 1:41	2.34	36,530	8/13/97 0:15	8/13/97 9:18	8/13/97 0:35	8/13/97 7:14	8/13/97 1:20	8/15/97 0:00	48	1,083	8,934	5,758	3,176	0.044	0.501	11.51	10,017	4,259	457	9,331	1,561	7,770	0.041	0.360	8.89	72%	46.7	20	-124	0.003	4,197	-3,511	-35%	0.26	0.10	0.12	0.21	●	x	◍
Aug 15,1997	5	29.0	5.8	9.8	3,985	33,582	8/15/97 16:55	1.69	37,567	8/15/97 15:55	8/15/97 21:39	8/15/97 16:05	8/15/97 22:56	8/15/97 19:00	8/17/97 12:00	44	1,399	11,140	5,791	5,349	0.058	0.545	9.40	12,539	6,748	284	12,212	1,382	10,829	0.057	0.407	7.21	75%	41.0	10	77	0.002	4,409	-4,082	-33%	0.35	0.16	0.18	0.29	●	x	◍
Aug 20,1997	17	25.0	1.5	5.6	3,435	28,950	8/21/97 0:54	3.81	32,385	8/20/97 16:35	8/21/97 6:07	8/20/97 17:00	8/21/97 7:29	8/21/97 5:30	8/22/97 6:00	37	931	11,681	4,903	6,778	0.073	0.524	7.18	12,612	7,709	313	9,166	1,025	8,141	0.053	0.300	5.65	57%	24.5	25	82	0.020	3,878	-432	-3%	0.27	0.23	0.24	0.25	●	?	◍
Sep 06,1997	8	19.8	2.4	11.0	2,611	22,002	9/6/97 19:02	4.63	24,613	9/6/97 2:00	n/a	9/6/97 2:25	9/7/97 1:18	n/a	*9/8/97 12:00*	*58*	713	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	7,118	2,546	4,572	0.028	0.285	10.37	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.27	n/a	n/a	0.19	●	n/a	◍
Sep 10,1997	16	24.6	1.4	5.6	3,380	28,487	9/10/97 14:55	4.24	31,867	9/10/97 8:56	n/a	9/10/97 9:05	9/10/97 19:29	n/a	*9/12/97 12:00*	*51*	928	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	8,545	2,331	6,214	0.033	0.224	6.78	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.27	n/a	n/a	0.19	●	n/a	◍
Sep 25,1997	7	7.0	1.0	3.4	962	8,106	9/25/97 11:32	3.40	9,068	9/25/97 7:55	9/25/97 16:26	9/25/97 10:05	9/25/97 16:58	9/25/97 13:50	9/27/97 12:00	52	207	4,162	2,924	1,239	0.017	0.128	7.55	4,369	1,445	414	1,996	723	1,273	0.008	0.055	7.13	43%	46.2	130	92	0.009	2,201	172	4%	0.21	0.15	0.16	0.14	●	●	◍
Sep 28,1997	17	20.0	1.2	5.2	2,748	23,160	9/29/97 8:08	4.42	25,908	9/28/97 23:30	9/29/97 14:44	9/29/97 2:20	9/29/97 12:15	9/29/97 5:25	10/1/97 18:00	67	822	7,920	3,365	4,555	0.031	0.215	6.90	8,742	5,377	396	6,086	1,773	4,313	0.022	0.149	6.88	n/a	60.6	170	-149	0.009	1,593	1,063	12%	0.30	0.20	0.21	0.17	●	●	◍
Average	13	19.1	2.0	5.3	2,627	22,143		3.01	24,770							49	912	9,973	5,926	4,045	0.057	0.358	6.73	10,950	4,957	304	9,245	1,767	7,479	0.058	0.222	5.00	47%	33.9	30	116	0.004	4,205	-814	-8%	0.29	0.22	0.23	0.27	all available data		
Maximum	41	72.4	5.8	11.0	9,948	83,839		5.92	93,787							115	5,908	28,317	11,706	16,611	0.110	0.632	14.84	29,534	17,828	882	40,200	6,568	36,913	0.334	0.622	10.37	81%	95.6	170	318	0.037	9,029	1,206	12%	0.59	0.41	0.39	0.48			
Minimum	2	4.6	0.7	1.0	632	5,327		1.36	5,959							16	113	1,107	2,230	-2,506	0.017	0.128	2.76	2,790	560	-19	1,791	450	712	0.008	0.040	0.28	20%	11.5	0	-149	-0.274	1,593	-4,082	-35%	0.08	0.05	0.08	0.12			
Total	303	535.4			73,564	619,993			693,557							1,364	25,543	229,375	138,343	93,031				241,777	109,046		240,381	45,940	194,441									84,107	-16,288								
Average	12	12.6	1.4	3.7	1,729	14,573		2.85	16,302							39	465	9,053	5,346	3,707	0.056	0.322	6.20	9,518	4,172	350	5,383	1,286	4,076	0.065	0.131	4.27	38%	31.4	47	108	0.001	4,069	87	1%	0.24	0.23	0.24	0.23	selected*** data only		
Maximum	25	27.6	2.8	5.6	3,792	31,961		4.42	35,753							67	1,463	20,598	8,518	12,080	0.100	0.583	14.84	22,061	13,543	882	16,692	2,556	14,136	0.334	0.300	7.13	57%	60.6	170	318	0.037	6,517	1,206	12%	0.39	0.38	0.38	0.40			
Minimum	2	4.6	0.7	2.2	632	5,327		1.79	5,959							23	113	3,600	2,924	673	0.017	0.128	2.76	3,831	904	77	1,799	630	712	0.008	0.040	0.28	20%	16.5	5	-149	-0.274	1,593	-1,048	-12%	0.08	0.08	0.09	0.12			
Total	151	163.6			22,479	189,449			211,927							503	6,046	117,693	69,500	48,193				123,739	54,239		69,715	16,722	52,993									52,897	1,127								

Legend:

- ● Data are available and apparently in good condition.
- n/a No data are available.
- ◍ Data are available but lack baseflow values.
- x The data set is visibly corrupt.
- ? The quality of the data set is suspect.

Catchment areas:

13.74 ha drains to the east inlet (1,200 mm diameter stormsewer)
115.80 ha drains to the west inlet (2,000 mm diameter stormsewer)

Event Notes:

Sept. 7, 1996	West inlet data are not available. The outlet had not stabilized before small events on the 9th of September that are included in this data set.
Sept. 11, 1996	West inlet data are not available. The outlet flow may not have stabilized before the event on the 13th.
Sept. 13, 1996	West inlet data are not available. The east inlet and outlet data include minor irregularities.
Sept. 24, 1996	All data are available and the volumetric balance is very good. This is the prototype event.
Sept. 27, 1996	All data are available. The hydrographs were truncated to avoid subsequent minor rainfall. Since storage was approximately 10% of inflow, a 3% volumetric error resulted in difficulty closing the storage curve.
Oct. 9, 1996	No outlet data are available.
Oct. 16, 1996	No outlet data are available.
Nov. 7, 1996	The outlet signal became erratic under baseflow conditions. Some timescale problems are apparent; rainfall, inlet flow and outlet flow appear to be offset in time.
April 27, 1997	The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
May 3, 1997	The volumetric balance is not good. Early notes suggested that the west inlet data were unreliable. However, the runoff coefficients suggest that the outlet flow was excessive.
May 6, 1997	The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
May 11, 1997	The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
May 15, 1997	The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
June 13, 1997	The west inlet data are corrupt. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
June 16, 1997	The west inlet sensor recovered part way into the event. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
June 18,1997	The west inlet data appear to be normal. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
June 21, 1997	The west inlet data are slightly irregular. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
June 24, 1997	The west inlet data are irregular. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
July 7, 1997	The west inlet data are irregular. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
July 8, 1997	The west inlet data are irregular in places. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
July 27,1997	The west inlet flows are unusually small. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Aug. 13, 1997	The west inlet flows are unusually small. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Aug. 16, 1997	The west inlet flows are unusually small. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Aug. 20, 1997	The west inlet flows are erratic but the magnitude is more normal. Zero readings were replaced by linear interpolation. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Sept. 6, 1997	The west inlet data are not available. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Sept. 10, 1997	The west inlet data are not available. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Sept. 25,1997	The west inlet data are available but noisy. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data.
Sept. 28,1997	The west inlet data are available but noisy; zero readings were replaced by linear interpolation. The outflow baseflow data are missing and have been substituted with depth-flow correlation model data. Note that the noise may have affected the calculation of the centroid.

Parameter Notes:

* Generally, the west inlet flow began first. Inlet start time was taken from the rainfall and/or the east inlet if west inlet data were not available.
** Event end time was determined by inspection of the outlet hydrograph where available. Otherwise, an approximation was made using the inlet hydrograph.
*** Event parameters were determined for only those events with volumetric errors of 15% or less.

Centroids were calculated based on the first moment of area as discussed previously. Only the runoff portion of the hydrographs were included in these calculations.

The peak storage time was taken from the storage curve for each event.

As discussed previously, the event end time is, ideally, the time at which the storage volume went to zero. However, the end of the event was generally determined by inspection of the hydrographs.

G.2.3.3 ***Inlet, outlet and exfiltration hydraulic parameters***

Inflow, outflow and baseflow volumes were determined using the interpolation method described in Section G.1. A separate spreadsheet was prepared for each event and the hydrographs were plotted as an aid to data interpretation. The "gross" inlet, outlet and baseflow volumes were determined over as wide a time base as possible to minimize the effects of selection of event start and end times. The volumetric error was calculated from these gross values as *inlet volume - outlet volume - exfiltration volume,* and was expressed as a percentage of the inlet volume.

Average flows would be unduly influenced by baseflow over a broad time base and, consequently, were calculated over the perceived event duration. The peak factor was calculated as the ratio of the 5-minute maximum flow to the average flow. The peak ratio was calculated by dividing the outlet peak flow by the inlet peak flow, expressing the result as a percentage[2]. The drawdown time was measured from the maximum storage volume to the perceived end of the event. Centroids were computed over the perceived event duration.

G.2.3.4 ***Runoff coefficients***

The runoff coefficients were calculated as the ratio of the runoff volume to the rainfall volume for the respective catchment. The purpose of including both inlet sewers and the pond outlet in these calculations was to disclose any obvious anomalies and, thus, contribute to the assessment of the quality of the data. As discussed in the main body of this report, inherent coefficient variability was concluded to be a significant factor in this analysis.

G.2.3.5 ***Data availability***

Chronologically, when the post-construction monitoring program began the sensor in the west inlet stormsewer was not functioning; it affected three events. After that problem was corrected and two events were monitored successfully, the outlet sensor ceased functioning, affecting two events. When the outlet sensor was returned to service it was no longer capable of measuring the baseline or dry-weather flows that it

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[2] Alternatively, *peak reduction* may have been calculated as (peak flow in - peak flow out) / peak flow in.

The resulting measured and estimated event volumes will be utilized in Appendix H for the calculation of pollutant loads and removal efficiency.

Table G.2: Summary and estimation of inlet and outlet event volumes

Date	Total Inflow [m^3]	Total Outflow [m^3]	Event Duration [hr.]	Exfiltration Rate [m^3/s]	Volumetric Error [%]	"Measured" Exfiltration [m^3]	Estimated Exfiltration [m^3]	Estimated Volume In [m^3]	Estimated Volume Out [m^3]
Sep 07,1996	**n/a**	39,852	101.75				8,242	48,094	
Sep 11,1996	**n/a**	8,361	33.00				2,673	11,034	
Sep 13,1996	**n/a**	35,466	115.00				9,315	44,781	
Sep 24, 1996	9,756	6,941	34.92	**0.022**	**0%**	2,815	2,829		
Sep 27,1996	21,150	16,396	58.75	**0.023**	**-3%**	4,754	4,759		
Oct 09,1996	10,167	**n/a**	62.17			n/a	5,036		5,131
Oct 18,1996	28,508	**n/a**	109.67			n/a	8,883		19,625
Nov 07,1996	14,154	9,748	97.33	0.014	-19%	4,406	7,884	17,632	
Apr 27,1997	7,681	4,263	35.33	-0.274	-14%	3,418	2,862		
May 03,1997	15,900	15,929	64.00	0.000	-23%	-29	5,184	21,113	
May 05,1997	8,532	5,691	29.17	0.028	-2%	2,841	2,363		
May 11,1997	9,420	4,461	38.83	0.033	11%	4,959	3,145		
May 15,1997	9,381	4,129	38.83	0.037	4%	5,252	3,145		
Jun 13,1997	*x*	8,196	16.17				1,310	9,506	
Jun 16,1997	6,474	5,047	23.00	0.021	-16%	1,427	1,863	6,910	
Jun 18, 1997	5,688	1,489	34.33	0.033	6%	4,199	2,781		
Jun 21, 1997	5,644	2,348	30.92	0.029	0%	3,296	2,505		
Jun 24,1997	6,199	5,448	19.17	0.017	-17%	751	1,553	7,001	
Jul 07,1997	2,703	1,582	23.25	0.015	-12%	1,121	1,883		
Jul 08,1997	5,136	2,468	23.00	0.032	8%	2,668	1,863		
Jul 27,1997	2,244	1,680	18.00	0.012	-28%	564	1,458	3,138	
Aug 13,1997	8,503	8,932	47.75	0.003	-35%	-429	3,868	12,800	
Aug 15,1997	10,987	11,781	44.08	0.002	-33%	-794	3,570	15,351	
Aug 20,1997	11,082	8,938	37.42	0.017	-7%	2,144	3,031		
Sep 06,1997	**n/a**	6,625	58.00				4,698	11,323	
Sep 10,1997	**n/a**	7,866	51.08				4,137	12,003	
Sep 25,1997	3,567	1,796	52.08	0.009	4%	1,771	4,218		
Sep 28,1997	8,252	5,827	66.50	0.009	12%	2,425	5,387		

Legend:		
	n/a	data set not available
	x	data set very distorted

APPENDIX H

Water Quality Data

APPENDIX H

WATER QUALITY DATA

Contents:

H.1 INTRODUCTION

Tables H.1 and H.2 provide a chronological summary of the monitoring program and indicate the availability of field data. In the preparation of the final version of this report, data from the construction period (Table H.1) were not reviewed in detail; rainfall data, runoff data and water quality data were not relocated for all events. Data for all events in the post-construction period (Table H.2) were tabulated and plotted.

Event volume data are included in Table H.2. These volumes consist of both direct observations and estimated values as discussed in Appendix G and summarized in Table G.2.

Tables H.3 to H.5 contain water quality summary. data for the summer/fall construction period, the summer/fall post-construction period, and the combined winter periods. These data were developed using the ASAP statistical program as described in Chapter 3. The results are discussed in Chapter 5.

Tables H.6 to H.9 contain water temperature data. The results are discussed in Chapter 5.

Tables H.10 and H.11 contain the individual water quality observations for the inlet and outlet in the post-construction summer/fall period. The inlet concentrations were analyzed from time-proportioned composite samples. The outlet concentrations were analyzed from flow-proportioned composite samples. Both of these sampling methods have inherent limitations. In particular, the time-proportioned inlet samples are assumed to under-estimate the true average concentration because of the typical hydrograph and pollutograph shapes, as discussed in Appendix C. The results of the 21 monitored events are summarized as simple averages and as volume-weighted averages. Also for comparison, the results of the ASAP statistical analysis from Table H.4 have been added to Tables H.10 and H.11.

Table H.12 contains the performance data for the 21 monitored post-construction events. As discussed in Chapter 3, the performance values were determined on a "load" basis. Actual pollutant loads conveyed into and out of the pond were not determined because the sampling periods did not include all of the event durations and the resulting concentration data do not represent true "event mean concentrations". However, the use of available data to calculate "volume-weighted concentrations" in the determination of performance is considered to be preferable to the use of concentration alone because:

- with respect to individual events, the inlet and outlet volumes were not equal;
- in determining the seasonal performance, a simple average of event performance would weight all events equally but the determination of overall mass removal takes the magnitude of the events into consideration.

Table H.12 summarizes the load-based efficiencies (% removals) determined for the stormwater constituents. The results are discussed in Chapter 6.

Table H.1: Event detection and monitoring summary - construction period

Sampling Period	Event Date	Rainfall	Quality	Quantity	Sample Collection	Sample Submission
Summer / Fall 1995			Y		June 26, '95	June 27
			Y		June 27, '95	June 28
			Y		July 05, '95	July 05
	Jul. 20, '95		N	Y		
	Jul. 23, '95		Y	N	July 24, ‘95	July 24
	Jul. 28, '95		Y	N	July 31, ‘95	July 31
	Aug. 03, '95	Y	Y	Outlet	Aug.03, ‘95	Aug. 04
	Aug. 05, '95	Y	Y	Outlet	Aug. 09, ‘95	Aug. 09
	Aug. 11, '95	Y	Y	Outlet	Aug. 11, ‘95	Aug. 14
	Aug. 13, '95	Y	N	N		
	Aug. 31, '95	Y	Y	Outlet	Aug. 31, ‘95	Sept. 01
					Sept. 01, '95	Sept. 01
	Oct. 03, 95	Y	Y	N	Oct. 04, ‘95	Oct. 05
	Oct. 05, '95	Y	Y	N	Oct. 06, ‘95	Oct. 10
	Oct. 07, '95	Y	N	N		
	Oct. 14, '95	Y	N	N		
	Oct. 20, '95	Y	Y	N	Oct. 23, ‘95	Oct. 24
	Oct. 27, '95	Y	Y	Outlet	Oct. 30, ‘95	Oct. 31
	Nov. 01, '95	Y	Y	Outlet	Nov. 03, ‘95	Nov. 03
	Nov. 07, ‘95		N	Outlet		
	Nov. 10, ‘95	Y	N	Outlet		
			Y	N	Nov. 14, ‘95	Nov. 15
			Y	N	Nov. 24, ‘95	Nov. 27
			Y	N	Nov. 30, ‘95	Dec. 01
Winter / Spring 1995-1996	Jan. 12, '96		Y	N	Jan. 12, '96	Jan. 18
	Jan. 18, '96		Y	N	Jan. 18, '96	Jan. 22
	Jan. 19, '96		Y	N	Jan. 19, '96	Jan.22
	Jan. 24, ‘96		Y	N	Jan. 24, '96	
	Feb. 08, ‘96		Y	N	Feb. 08, '96	Feb. 18
	Feb. 20, ‘96		Y	N	Feb. 20, '96	Feb. 22
	Feb. 21, ‘96		Y	N	Feb 21, '96	Feb.22
	Mar. 13, ‘96		Y	N	Mar. 13, '96	Apr. 02
	Mar. 25, ‘96		Y	N	Mar. 25, '96	Apr. 02
	Apr. 12, ‘96		Y	N	Apr. 12, '96	Apr. 15
	Apr. 25, ‘96		Y	N	Apr. 25, '96	Apr. 26
	Apr. 30, ‘96		Y	N	Apr. 30, '96	May 01
Summer / Fall 1996	May 01, ‘96	Y	N	N		
	May 09, ‘96	Y	N	N		
	May 10, ‘96	N	N	N		
	May 20, ‘96	N	N	N		
	June 06, ‘96	Y	Y	N	Jun. 06, '96	June 10
	June 07, ‘96	N	Y	N	Jun. 07, '96	June 10
	June 21, ‘96	N	Y	N	Jun. 21, '96	
	June 22, ‘96	Y	N	N		
	June 25, ‘96	N	Y	N	Jun. 25, '96	
	June 29, ‘96	Y	Y	N	Jul. 03, '96	July 3
	July 09, ‘96	N	Y	N	Jul. 10, '96	July 10
	July 15, ‘96	Y	Y	Inlet	Jul. 16, '96	July 16
	July 19, ‘97	N	Y		Jul. 22, '96	July 22
	July 25, ‘96	Y	N	Y		
	July 29, ‘96	Y	Y	Y	Jul. 31, '96	Aug. 01
	Aug. 01, ‘96	Y	N	Y	Aug. 01, '96	Aug. 07
	Aug. 08, ‘96	Y	Y	Y	Aug. 09, '96	Aug. 12

Note: This table was assembled from laboratory submission sheets, and from available spreadsheets containing rainfall and flow data. Complete data sets could not be relocated at the time that the final report was produced.

Table H.3: Summer/fall chemical constituents summary - construction period

Variable	Units	RMDL	Inlet							Outlet						
			N	%>DL	MINIMUM	MAXIMUM	MEAN	95% CI-LL	95% CI-UL	N	%>DL	MINIMUM	MAXIMUM	MEAN	95% CI-LL	95% CI-UL
Aluminum	mg/L	0.011	22	95.5	0.010	1.800	0.937	0.466	1.882	22	100.0	0.014	0.880	0.359	0.231	0.558
Barium	mg/L	0.0002	22	100.0	0.0350	0.1800	0.0881	0.0764	0.1016	22	100.0	0.0560	0.1800	0.0989	0.0869	0.1126
Beryllium	mg/L	0.00002	22	9.1	0.00002	0.00300	0.00005	0.00002	0.00009	22	9.1	0.00002	0.00310	0.00005	0.00003	0.00010
Cadmium	mg/L	0.0006	22	72.7	0.0001	0.0020	0.0004	0.0003	0.0006	22	45.5	0.0001	0.0028	0.0005	0.0003	0.0008
Calcium	mg/L	0.005		0	ND	ND	ND	ND	ND		0	ND	ND	ND	ND	ND
Chromium	mg/L	0.0014	22	86.4	0.0002	0.0120	0.0042	0.0031	0.0056	22	100.0	0.0004	0.0056	0.0025	0.0018	0.0035
Cobalt	mg/L	0.0013	22	77.3	0.0002	0.0040	0.0015	0.0010	0.0021	22	68.2	0.0000	0.0048	0.0012	0.0009	0.0015
Copper	mg/L	0.0016	22	95.5	0.0064	0.0420	0.0181	0.0133	0.0246	22	100.0	0.0036	0.0340	0.0105	0.0082	0.0136
Iron	mg/L	0.0008	22	86.4	0.0200	2.2000	0.2003	0.0596	0.6733	22	100.0	0.1000	1.3000	0.4527	0.3200	0.6404
Lead	mg/L	0.01	22	59.1	0.005	0.045	0.013	0.010	0.017	22	22.7	0.000	0.020	0.008	0.007	0.009
Magnesium	mg/L	0.008		0	ND	ND	ND	ND	ND		0	ND	ND	ND	ND	ND
Manganese	mg/L	0.0002	22	100.0	0.0360	0.5600	0.1761	0.1212	0.2557	22	100.0	0.0200	0.2300	0.0773	0.0584	0.1024
Molybdenum	mg/L	0.0016	22	81.8	0.0002	0.0056	0.0018	0.0013	0.0025	22	90.9	0.0002	0.0034	0.0015	0.0012	0.0019
Nickel	mg/L	0.0013	22	100.0	0.0015	0.0180	0.0044	0.0034	0.0055	22	95.5	0.0005	0.0060	0.0023	0.0019	0.0029
Strontium	mg/L	0.0001	22	100.0	0.1400	0.5800	0.3478	0.2955	0.4092	22	100.0	0.2000	0.5000	0.3663	0.3305	0.4059
Titanium	mg/L	0.0005	22	59.1	0.0010	0.0160	0.0084	0.0038	0.0184	22	81.8	0.0010	0.0080	0.0041	0.0025	0.0066
Vanadium	mg/L	0.0015	22	90.9	0.0002	0.0120	0.0032	0.0023	0.0044	22	95.5	0.0002	0.0052	0.0019	0.0014	0.0025
Zinc	mg/L	0.0006	22	100.0	0.0120	0.2600	0.1176	0.0862	0.1605	22	100.0	0.0095	0.2200	0.0499	0.0364	0.0684
Ammonium, Total	mg/L	0.002	22	95.5	0.002	0.890	0.483	0.212	1.099	22	95.5	0.002	0.580	0.157	0.088	0.281
Nitrite	mg/L	0.001	22	100.0	0.018	0.420	0.085	0.061	0.119	22	100.0	0.014	0.164	0.054	0.040	0.073
Nitrates	mg/L	0.005	22	100.0	0.285	2.800	1.249	0.983	1.587	22	100.0	0.450	1.680	1.173	1.025	1.343
Nitrogen, Total Kjeldahl	mg/L	0.02	22	100.0	0.32	3.60	1.81	1.38	2.37	22	100.0	0.40	2.10	0.83	0.68	1.01
Phosphorus , Total	mg/L	0.002	22	100.0	0.032	1.800	0.654	0.418	1.022	22	100.0	0.018	0.560	0.131	0.083	0.208
Phosphate	mg/L	0.0005	22	100.0	0.0020	1.0000	0.2114	0.0986	0.4532	22	100.0	0.0005	0.4800	0.0358	0.0164	0.0784
Suspended Solids	mg/L	2.5	21	100.0	22.0	1990.0	601.3	329.1	1098.8	21	100.0	5.0	203.0	64.8	39.3	106.9
Dissolved Carbon , Organic	mg/L	0.1	22	100.0	1.6	16.9	7.0	5.2	9.5	22	100.0	1.3	4.6	2.9	2.5	3.5
Dissolved Carbon , Inorganic	mg/L	0.2	22	100.0	14.8	62.8	29.6	24.8	35.1	22	100.0	18.8	59.4	42.5	37.8	47.7
Chloride	mg/L	0.2	22	100.0	15.6	675.0	235.1	155.1	356.4	21	100.0	140.0	1420.0	515.0	394.6	672.1
Mercury	µg/L	0.02	22	31.8	0.02	0.06	0.02	0.01	0.04	22	9.1	0.02	0.04	0.01	0.01	0.01
Conductivity	µS/cm	1.0	22	100.0	245.0	2800.0	1186.1	884.2	1591.0	22	100.0	772.0	3380.0	1916.4	1616.4	2272.0
pH	nil	0.1	22	100.0	7.6	8.3	8.0	7.9	8.0	22	100.0	7.7	8.3	8.1	8.1	8.2
Alkalinity	mg/L	0.2	22	100.0	78.4	268.0	136.9	116.3	161.0	22	100.0	86.0	262.0	184.1	164.6	205.9
Turbidity	FTU	0.01	22	100.0	24.80	2000.00	586.02	315.63	1088.06	22	100.0	6.31	197.00	56.17	34.15	92.39
Oil and Grease	mg/L	1.0	22	81.8	0.5	7.0	2.4	1.6	3.5	22	45.5	0.5	5.5	1.2	0.8	1.7
E. Coli	# / 100 mL	4	5	100.0	100	5600	5123	713	36812	7	100.0	30	2680	1054	245	4531
Fecal Coliforms	# / 100 mL	4	5	100.0	700	24000	11026	2239	54303	7	100.0	60	8800	2859	651	12557
Pseudomonas	# / 100 mL	4	5	100.0	20	4200	1750	109	28147	7	100.0	10	800	466	120	1812
Pentachlorophenol	ng/L	10.0	22	100.0	10.0	2200.0	526.5	293.4	944.8	22	90.9	10.0	1600.0	274.6	168.5	447.6
2,3,4,6 Tetrachlorophenol	ng/L	20.0	22	45.5	20.0	240.0	48.1	25.4	91.0	22	31.8	20.0	200.0	44.1	20.3	96.1

Table H.5: Winter/spring chemical constituents summary - all data

Variable	Units	RMDL	Inlet							Outlet						
			N	%>DL	MINIMUM	MAXIMUM	MEAN	95% CI-LL	95% CI-UL	N	%>DL	MINIMUM	MAXIMUM	MEAN	95% CI-LL	95% CI-UL
Aluminum	mg/L	0.011	11	100.0	0.170	1.200	0.544	0.371	0.796	11	100.0	0.065	0.470	0.212	0.130	0.343
Barium	mg/L	0.0002	11	100.0	0.0550	0.1630	0.1017	0.0796	0.1299	11	100.0	0.0610	0.1790	0.1161	0.0907	0.1486
Beryllium	mg/L	0.00002	11	27.3	0.00010	0.00090	0.00022	0.00006	0.00081	11	18.2	0.00002	0.00080	0.00004	0.00002	0.00009
Cadmium	mg/L	0.0006	11	36.4	0.0001	0.0016	0.0005	0.0003	0.0009	11	27.3	0.0001	0.0150	0.0017	0.0004	0.0085
Calcium	mg/L	0.005	1	100.0	146.000	146.000	146.000	0.000	0.000	1	100.0	171.000	171.000	171.000	0.000	0.000
Chromium	mg/L	0.0014	11	72.7	0.0002	0.0170	0.0057	0.0028	0.0114	11	90.9	0.0002	0.0430	0.0086	0.0030	0.0249
Cobalt	mg/L	0.0013	11	72.7	0.0002	0.0180	0.0024	0.0011	0.0052	11	36.4	0.0002	0.0170	0.0027	0.0008	0.0095
Copper	mg/L	0.0016	11	90.9	0.0096	0.1100	0.0357	0.0162	0.0789	11	100.0	0.0036	0.0450	0.0162	0.0091	0.0286
Iron	mg/L	0.0008	11	90.9	0.2800	2.0000	0.3928	0.0804	1.9184	11	100.0	0.1400	0.8800	0.4014	0.2566	0.6280
Lead	mg/L	0.01	11	54.5	0.005	0.060	0.017	0.009	0.034	11	27.3	0.002	0.030	0.006	0.003	0.012
Magnesium	mg/L	0.008	1	100.0	12.600	12.600	12.600	0.000	0.000	1	100.0	18.100	18.100	18.100	0.000	0.000
Manganese	mg/L	0.0002	11	100.0	0.0760	0.4900	0.2231	0.1415	0.3519	11	100.0	0.0340	0.1500	0.1103	0.0796	0.1527
Molybdenum	mg/L	0.0016	11	72.7	0.0002	0.0078	0.0029	0.0015	0.0057	11	63.6	0.0002	0.0062	0.0022	0.0012	0.0041
Nickel	mg/L	0.0013	11	81.8	0.0020	0.0085	0.0038	0.0022	0.0065	11	63.6	0.0005	0.0065	0.0015	0.0009	0.0023
Strontium	mg/L	0.0001	11	100.0	0.2700	1.1100	0.5507	0.4135	0.7334	11	100.0	0.2600	0.8000	0.5072	0.4076	0.6311
Titanium	mg/L	0.0005	11	90.9	0.0035	0.0250	0.0150	0.0065	0.0344	11	63.6	0.0005	0.0190	0.0123	0.0029	0.0513
Vanadium	mg/L	0.0015	11	72.7	0.0002	0.0130	0.0033	0.0016	0.0069	11	63.6	0.0001	0.0066	0.0015	0.0007	0.0033
Zinc	mg/L	0.0006	11	100.0	0.0850	0.7200	0.1974	0.1269	0.3072	11	100.0	0.0420	0.1500	0.1089	0.0856	0.1384
Ammonium, Total	mg/L	0.002	11	90.9	0.002	1.920	1.286	0.276	6.005	11	100.0	0.008	0.962	0.523	0.194	1.409
Nitrite	mg/L	0.001	11	100.0	0.012	0.470	0.162	0.073	0.358	11	100.0	0.024	0.160	0.073	0.048	0.112
Nitrates	mg/L	0.005	11	100.0	0.940	2.800	1.433	1.147	1.789	11	100.0	1.170	2.190	1.583	1.338	1.874
Nitrogen, Total Kjeldahl	mg/L	0.02	9	100.0	0.800	3.100	1.674	1.137	2.465	9	100.0	0.540	2.040	1.073	0.734	1.567
Phosphorus , Total	mg/L	0.002	9	100.0	0.084	0.820	0.368	0.182	0.742	9	100.0	0.026	0.210	0.092	0.053	0.159
Phosphate	mg/L	0.0005	11	100.0	0.0010	0.4030	0.0918	0.0294	0.2863	11	100.0	0.0005	0.0355	0.0149	0.0057	0.0392
Suspended Solids	mg/L	2.5	9	100.0	57.0	848.0	394.7	165.0	943.8	9	100.0	14.0	115.0	46.3	25.7	83.5
Dissolved Carbon , Organic	mg/L	0.1	11	100.0	2.0	11.0	4.7	3.2	6.7	11	100.0	1.6	20.0	4.5	2.8	7.3
Dissolved Carbon , Inorganic	mg/L	0.2	11	100.0	15.8	58.6	34.3	26.6	44.2	11	100.0	22.0	60.8	49.1	38.2	63.2
Chloride	mg/L	0.2	11	100.0	555.0	6480.0	1689.1	1020.1	2796.9	11	100.0	649.0	4040.0	1613.0	1075.4	2419.3
Mercury	µg/L	0.02	11	27.3	0.02	0.04	0.02	0.01	0.03	11	0.0	0.02	0.02	0.01	0.00	0.00
Conductivity	µS/cm	1.0	8	100.0	1550.0	6330.0	3123.4	2191.8	4450.8	8	100.0	2360.0	6370.0	3577.8	2726.8	4694.5
pH	nil	0.1	9	100.0	7.7	8.3	8.0	7.8	8.1	9	100.0	7.9	8.4	8.1	8.0	8.3
Alkalinity	mg/L	0.2	9	100.0	107.0	258.0	176.2	140.5	221.1	9	100.0	99.4	267.0	216.0	160.5	290.7
Turbidity	FTU	0.01	11	100.0	29.80	972.00	404.94	159.50	1028.06	11	100.0	7.55	124.00	33.77	18.93	60.26
Oil and Grease	mg/L	1.0	11	90.9	1.0	9.5	3.2	1.9	5.6	11	90.9	0.5	4.5	1.7	1.1	2.6
E. Coli	# / 100 mL	4.0	1	100.0	20.0	20.0	20.0	0.0	0.0	1	100.0	10.0	10.0	10.0	0.0	0.0
Fecal Coliforms	# / 100 mL	4.0	1	100.0	380.0	380.0	380.0	0.0	0.0	1	100.0	20.0	20.0	20.0	0.0	0.0
Pseudomonas	# / 100 mL	4.0	1	100.0	10.0	10.0	10.0	0.0	0.0	1	100.0	4.0	4.0	4.0	0.0	0.0
Pentachlorophenol	ng/L	10.0	9	100.0	40.0	380.0	183.7	107.3	314.3	10	100.0	17.0	220.0	110.6	65.1	187.9
2,3,4,6 Tetrachlorophenol	ng/L	20.0	9	44.4	20.0	54.0	26.7	14.4	49.7	10	30.0	20.0	32.0	17.3	13.6	22.1

Table H.7: Water temperature data - outlet, 1995

Date	July1995			August 1995			September 1995			October 1995			November 1995		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
1				22.8	23.2	22.6	20.8	21.3	19.8	15.3	15.6	15.1	9.1	9.6	8.5
2				22.7	23.2	22.4	20.2	20.5	19.8	16.4	17.7	15.3	8.9	9.5	8.3
3				21.9	22.6	19.2	19.9	20.1	19.9	16.1	16.6	15.6	10.0	10.5	8.8
4				20.8	24.2	20.4	19.5	19.9	19.1	15.4	15.7	15.2	7.9	8.9	7
5				20.5	21	19.3	19.5	19.6	19.3	15.2	15.5	13.4	6.6	7.1	6
6				21.1	21.3	20.8	19.6	19.8	19.3	13.2	13.6	13	6.8	7.4	5.6
7				21.1	21.2	20.9	19.6	20.4	19.2	13.9	14.1	13.6	7.3	7.7	6.6
8				21.1	21.4	20.8	17.9	19.2	17.2	13.0	13.6	12.2	6.6	7.4	4.9
9				21.2	21.5	20.9	17.0	17.6	16.8	13.4	13.7	13.1	6.6	7.3	4.6
10				21.6	21.9	21.2	16.8	17.1	16.5	13.5	13.9	13.2	6.5	6.8	5
11				21.7	22.5	20.4	16.6	17	16.4	13.8	14.2	13.5	7.1	8.1	6.3
12				22.3	22.6	22	16.7	16.8	16.5	14.1	14.4	13.8	6.6	7.7	5.3
13				22.3	22.6	20.4	17.0	17.5	16.7	14.5	14.8	14.2	6.0	6.4	5.2
14	20.4	21.2	19.3	21.7	22	21.3	17.5	18	17.1	14.6	15.2	13.3			
15	21.5	22	21.1	21.9	22.4	21.6	17.5	17.9	17.2	12.8	13.4	12			
16	21.8	22.2	20.2	22.5	23.1	22.2	17.3	17.7	17	12.2	12.6	11.6			
17	19.9	20.8	18.8	23.0	23.4	22.8	17.6	18	17.1	11.4	13.9	10.4			
18	20.1	20.7	19.6	23.2	23.6	22.9	17.4	18	17.1	11.5	12.1	11.1			
19	20.2	20.4	19.9	23.3	23.8	22.9	16.8	17.3	16.5	11.6	11.9	11			
20	19.9	20.3	19.4	23.6	24	23.2	16.7	16.8	16.5	11.7	12.5	11.4			
21	19.6	20.1	19.3	23.7	24.3	23.1	16.6	16.9	16.4	11.8	12.5	11.3			
22	20.1	20.7	19.8	23.1	23.9	22.7	16.8	17.5	16	10.9	11.4	10.5			
23	20.5	21.3	18.6	22.4	22.9	21.9	15.0	16	14.7	10.8	11.1	10.5			
24	20.9	21.4	20.6	22.0	22.5	21.6	14.5	14.8	14.2	10.8	11.3	10.4			
25	20.7	20.8	20.5	21.4	22.1	20.9	14.4	14.8	14	10.3	10.5	10			
26	20.5	20.8	20.3	21.2	21.4	20.9	14.5	14.7	14.3	10.2	10.6	9.6			
27	20.7	21	20.5	21.0	21.3	20.7	14.6	15.1	14.1	10.4	10.6	10.1			
28	21.1	21.6	19.6	20.9	21.2	20.5	14.9	15.3	14.6	10.7	11.2	10.1			
29	22.4	22.9	21.6	21.1	21.5	20.8				10.0	10.3	9.5			
30	22.4	22.6	22.1	21.1	21.4	20	15.1	15.3	14.8	9.8	10.3	9.2			
31	22.5	22.9	22.1	21.1	21.5	20.1				9.8	10	9.6			
Month	20.8	22.9	18.6	21.9	24.3	19.2	17.3	21.3	14.0	12.6	17.7	9.2	7.4	10.5	4.6

Table H.9: Water temperature data - outlet, 1996

day	Outlet June 1996				Outlet July 1996				Outlet August 1996				Outlet September 1996				Outlet October 1996				Outlet November 1996			
	max [oC]	min [oC]	average [oC]	median [oC]	max [oC]	min [oC]	average [oC]	median [oC]	max [oC]	min [oC]	average [oC]	median [oC]	max [oC]	min [oC]	average [oC]	median [oC]	max [oC]	min [oC]	average [oC]	median [oC]	max [oC]	min [oC]	average [oC]	median [oC]
1	15.4	14.1	14.67	14.6	19.2	18.0	18.64	18.6	19.3	18.6	19.01	19.0	20.5	19.8	20.14	20.2	14.6	14.0	14.30	14.3	8.1	6.7	7.39	7.4
2	15.3	14.6	14.93	14.9	18.9	17.4	18.12	18.2	19.5	19.0	19.24	19.3	20.5	19.9	20.22	20.2	15.4	14.4	14.84	14.8	7.1	6.0	6.48	6.5
3	15.1	14.4	14.69	14.7	18.3	16.9	17.50	17.4	19.8	19.0	19.33	19.3	26.9	19.8	20.26	20.2	15.6	14.7	15.30	15.3	7.1	5.4	6.36	6.4
4	14.6	14.0	14.24	14.2	17.1	16.4	16.74	16.7	20.3	19.3	19.80	19.7	20.3	19.8	20.06	20.1	14.7	10.7	14.13	14.1	7.6	5.3	6.73	7.0
5	15.4	13.7	14.21	14.1	17.6	15.5	16.67	16.8	20.8	19.8	20.30	20.2	20.2	19.7	19.99	20.0	14.0	12.8	13.33	13.4	8.5	6.8	8.04	8.2
6	14.2	13.6	13.85	13.9	17.6	16.7	17.13	17.1	21.1	20.2	20.69	20.6	20.3	19.6	19.91	19.9	13.9	12.6	13.17	13.3	8.9	8.1	8.45	8.5
7	14.1	13.4	13.81	13.9					21.4	20.4	20.95	21.0	20.2	19.4	19.79	19.8	14.0	13.3	13.60	13.5	8.5	8.1	8.23	8.2
8	13.8	13.1	13.44	13.4					22.6	20.0	21.38	21.2	19.8	19.0	19.52	19.6	14.1	13.6	13.91	13.9	10.5	8.3	9.74	10.0
9	13.6	12.9	13.24	13.2					22.3	21.0	21.51	21.5	19.0	18.0	18.60	18.6	14.1	13.8	13.95	13.9	10.3	9.8	10.08	10.0
10	14.5	13.2	13.90	14.0					21.3	20.5	20.87	20.9	19.4	18.2	18.46	18.4	13.8	12.4	13.00	13.0	10.0	9.1	9.52	9.4
11	16.0	13.6	14.99	15.4					20.8	20.0	20.34	20.3	19.7	17.7	18.56	18.4	12.8	11.1	12.14	12.2	9.2	6.7	8.04	7.9
12	16.2	15.3	15.65	15.6					20.4	19.8	20.03	20.0	19.0	18.1	18.56	18.6	12.2	10.6	11.54	11.6	8.5	6.2	8.08	8.1
13	17.0	15.8	16.36	16.4					20.9	19.5	19.88	19.8	18.1	16.6	17.40	17.6	11.6	10.9	11.30	11.3	8.1	4.2	7.50	7.7
14	17.4	16.3	16.75	16.8					20.5	19.6	19.96	19.9	16.6	14.9	15.85	15.9	11.8	11.1	11.34	11.3	7.9	7.5	7.71	7.7
15	18.2	16.6	17.19	17.0					20.6	19.9	20.27	20.2	16.0	15.4	15.71	15.7	12.8	11.5	11.94	12.1	7.7	6.9	7.20	7.1
16	17.8	17.1	17.44	17.4					20.5	20.0	20.21	20.2	16.2	15.2	15.90	16.0	12.3	11.9	12.10	12.1	7.0	6.3	6.67	6.7
17	17.4	17.0	17.14	17.1					20.4	19.6	19.93	19.9	16.6	15.0	16.14	16.2	12.5	12.0	12.19	12.2	6.7	6.2	6.37	6.4
18	17.1	16.4	16.72	16.7					20.6	19.8	20.17	20.2	16.8	15.8	16.33	16.2	12.5	12.1	12.25	12.3	7.1	6.4	6.68	6.6
19	16.6	15.7	16.24	16.2					20.9	20.1	20.44	20.4	17.3	16.2	16.70	16.6	12.2	10.9	11.56	11.6	7.7	6.0	7.21	7.2
20	16.2	15.3	15.84	15.9					21.0	20.3	20.61	20.6	17.4	16.6	16.96	17.0	11.1	10.8	11.00	11.0	7.8	7.1	7.48	7.5
21	16.4	15.7	16.04	16.0					21.2	20.3	20.68	20.6	17.4	16.8	17.11	17.1	11.5	11.1	11.29	11.3	7.1	6.4	6.87	6.9
22	18.6	13.6	17.05	17.2					21.4	20.5	21.00	21.0	17.2	16.5	16.89	16.9	11.4	11.1	11.26	11.3	7.1	5.3	6.82	7.0
23	18.1	17.1	17.70	17.7					21.6	20.7	21.06	21.1	16.7	15.8	16.12	16.0	11.8	11.0	11.44	11.5	7.1	4.5	6.49	6.9
24	17.9	17.4	17.66	17.7	18.9	18.3	18.52	18.6	21.1	20.3	20.72	20.8	15.9	14.8	15.47	15.6	11.1	10.2	10.58	10.6	6.4	5.9	6.12	6.1
25	17.6	16.8	17.09	17.1	19.0	18.0	18.59	18.6	23.1	20.3	21.34	21.0	14.8	13.7	14.27	14.4	11.1	9.6	10.73	10.9	6.4	5.7	6.07	6.1
26	18.0	16.4	17.27	17.1	19.4	18.9	19.16	19.2	21.0	20.1	20.46	20.4	14.4	13.7	14.07	14.1	11.1	10.9	11.03	11.0	6.2	4.8	5.43	5.4
27	18.9	17.5	18.11	17.8	19.1	18.4	18.66	18.6	20.3	19.7	20.11	20.2	15.0	14.0	14.37	14.4	11.3	10.9	11.06	11.0				
28	18.8	17.8	18.33	18.3	19.0	18.1	18.54	18.6	20.5	19.7	20.06	20.1	16.1	15.0	15.73	15.9	11.6	11.1	11.31	11.3				
29	19.4	16.5	18.41	18.4	19.3	18.0	18.61	18.6	20.5	19.8	20.10	20.1	15.6	14.6	14.87	14.8	11.8	10.5	11.24	11.3				
30	20.2	18.6	19.27	19.3	19.6	18.1	19.30	19.4	20.5	19.8	20.15	20.2	14.8	14.1	14.51	14.5	11.3	10.3	10.82	10.8				
31					19.5	19.0	19.27	19.3	20.5	19.8	20.13	20.2					10.3	6.0	9.06	8.9				
month	20.2	12.9	16.07	16.3	19.6	15.5	18.25	18.6	23.1	18.6	20.35	20.2	26.9	13.7	17.28	16.95	15.6	6	12.15	11.6	10.5	4.2	7.38	7.15

Table H.11: Outlet water quality data - summer/fall post-construction period

OUTLET VOLUME (m³)				39,852	9,361	6,941	16,396	19,625	15,929	4,461	4,129	8,196	5,047	1,489	2,348	5,448	1,582	2,468	1,680	11,781	8,938	6,625	7,866	5,627	Average		
EVENT DATE				7/9/1996	11/9/1996	24/9/96	27/9/96	18/10/96	3/5/1997	11/5/1997	15/5/97	13/6/97	16/6/97	18/6/97	21/6/97	24/6/97	7/7/1997	8/7/1997	27/7/97	15/8/97	20/8/97	6/9/1997	10/9/1997	28/9/97			
SAMPLE DATE	UNITS		RMDL	9/9/1996	13/9/96	25/9/96	30/9/96	21/10/96	5/5/1997	13/5/97	16/5/97	13/6/97	17/6/97	19/6/97	23/6/97	24/6/97	7/7/1997	9/7/1997	29/7/97	18/8/97	21/8/97	8/9/1997	11/9/1997	29/9/97	Simple	ASAP Mean	Volume Weighted
2,3,4,6 TCHP	ng/L		20	20	20	20	20	20	20	0	20	20	20	20	20	20	20	20	20	20	20	20	20	20	19	10	20
ALKALINITY	mg/L	as $CaCO_3$	0.2	119.0	138.0	206.0	150.0	165.0	263.0	222.0	247.0	226.0	227.0	204.0	223.0	230.0	237.0	228.0	235.0	160.0	198.0	228.0	178.0	210.0	204.5	205.0	180.4
ALUMINUM	mg/L	as Al	0.011	0.875	0.524	0.188	0.277	0.265	0.127	0.264	0.211	0.035	0.101	0.322	0.177	0.192	0.251	0.210	0.086	0.168	0.308	0.249	0.316	0.243	0.257	0.263	0.371
ARSENIC	mg/L	as As	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	n/a	0.001
BARIUM	mg/L	as Ba	0.0002	0.0790	0.0645	0.0980	0.0674	0.0764	0.1620	0.1240	0.1180	0.1350	0.1330	0.1240	0.1330	0.1440	0.1560	0.1350	0.1530	0.0893	0.1290	0.1500	0.1130	0.1370	0.1200	0.1206	0.1045
BERYLLIUM	mg/L	as Be	0.00002	0.00006	0.00003	0.00001	0.00002	0.00002	0.00003	0.00004	0.00004	0.00001	0.00002	0.00004	0.00003	0.00003	0.00005	0.00003	0.00002	0.00002	0.00003	0.00003	0.00002	0.00003	0.00003	0.00002	0.00003
CADMIUM	mg/L	as Cd	0.0006	0.0006	0.0007	0.0004	0.0011	0.0003	0.0005	0.0003	0.0006	0.0004	0.0002	0.0004	0.0003	0.0000	0.0000	0.0000	n/a	0.0000	0.0000	0.0000	0.0002	0.0012	0.0004	0.0004	0.0004
CALCIUM	mg/L	as Ca	0.005	93.100	75.400	114.000	80.800	92.200	188.000	155.000	136.000	176.000	172.000	0.135	140.000	154.000	174.000	148.000	154.000	95.600	137.000	167.000	121.000	149.000	129.630	143.540	119.599
CARBON	mg/L	dis. org.	0.1	4.3	4.1	3.2	3.8	3.2	2.1	3.0	3.0	1.6	2.5	3.7	3.5	3.3	2.3	3.0	2.3	4.1	3.2	2.0	3.7	3.1	3.1	3.1	3.4
CARBON	mg/L	dis. inorg.	0.2	24.0	30.2	42.4	29.6	39.4	61.8	51.4	54.2	53.2	53.6	49.6	52.6	54.8	58.6	54.0	55.2	38.2	47.0	54.6	44.8	48.2	47.5	47.7	40.9
CHLORIDE	mg/L	as Cl	0.2	248.0	174.0	317.0	183.0	467.0	938.0	696.0	748.0	876.0	834.0	526.0	561.0	626.0	735.0	670.0	765.0	0.0	415.0	625.0	423.0	494.0	539.1	579.5	441.3
CHROMIUM	mg/L	as Cr	0.0014	0.0043	0.0019	0.0013	0.0020	0.0021	0.0023	0.0057	0.0014	0.0000	0.0015	0.0036	0.0016	0.0017	0.0011	0.0010	0.0009	0.0013	0.0023	0.0020	0.0016	0.0013	0.0019	0.0020	0.0024
COBALT	mg/L	as Co	0.0013	0.0019	0.0006	0.0003	0.0001	0.0008	0.0015	0.0011	0.0015	0.0000	0.0004	0.0008	0.0007	0.0014	0.0000	0.0000	n/a	0.0002	0.0000	0.0002	0.0003	0.0002	0.0006	0.0008	0.0008
CONDUCTIVITY	µS/cm		1	1,130	929	1,580	973	1,100	3,540	2,710	3,010	3,390	3,290	2,090	2,300	2,440	2,920	2,660	2,870	1,640	1,810	2,620	1,860	2,210	2,242	2,269	1,859
COPPER	mg/L	as Cu	0.0016	0.0114	0.0163	0.0065	0.0071	0.0071	0.0123	0.0145	0.0092	0.0056	0.0134	0.0144	0.0112	0.0105	0.0084	0.0084	0.0051	0.0089	0.0101	0.0095	0.0112	0.0112	0.0101	0.0102	0.0101
IRON	mg/L	as Fe	0.0008	1.2500	0.6820	0.2960	0.3770	0.3310	0.2310	0.4120	0.2920	0.1750	0.3600	0.4980	0.3620	0.3790	0.4740	0.3670	0.3290	0.2250	0.6850	0.8070	0.6470	0.7060	0.4707	0.4707	0.5919
LEAD	mg/L	as Pb	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	n/a	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
MAGNESIUM	mg/L	as Mg	0.008	12.200	8.290	15.300	10.000	12.500	22.600	18.600	17.600	26.300	24.200	15.800	16.800	16.500	23.500	20.100	22.400	12.400	16.800	24.600	17.000	21.400	17.947	18.048	15.799
MANGANESE	mg/L	as Mn	0.0002	0.1170	0.0720	0.0490	0.0440	0.0380	0.1060	0.0820	0.0660	0.0550	0.1200	0.1590	0.1400	0.1270	0.1680	0.1010	0.1120	0.0690	0.2500	0.2790	0.1450	0.1890	0.1185	0.1199	0.1055
MERCURY	µg/L	as Hg	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02
MOLYBDENUM	mg/L	as Mo	0.0016	0.0016	0.0009	0.0015	0.0012	0.0013	0.0012	0.0018	0.0018	0.0004	0.0002	0.0029	0.0026	0.0026	0.0009	0.0015	0.0017	0.0004	0.0002	0.0008	0.0011	0.0013	0.0013	0.0014	0.0012
NICKEL	mg/L	as Ni	0.0013	0.0036	0.0022	0.0010	0.0017	0.0001	0.0018	0.0024	0.0023	0.0003	0.0022	0.0028	0.0016	0.0012	0.0014	0.0033	0.0014	0.0014	0.0029	0.0045	0.0024	0.0035	0.0021	0.0024	0.0022
NITROGEN	mg/L	NH_3+NH_4	0.002	0.032	0.008	0.078	0.088	0.100	0.066	0.104	0.044	0.008	0.118	0.166	0.110	0.134	0.018	0.088	0.052	0.002	0.128	0.016	0.120	0.048	0.073	0.100	0.063
NITROGEN	mg/L	as NO_2	0.001	0.041	0.034	0.041	0.041	0.030	0.028	0.037	0.026	0.012	0.024	0.062	0.052	0.035	0.021	0.024	0.076	0.074	0.037	0.012	0.084	0.027	0.039	0.039	0.039
NITROGEN	mg/L	NO_2+NO_3	0.005	0.755	0.695	0.755	0.655	0.835	1.460	1.030	1.200	1.050	1.070	1.180	1.100	1.150	1.020	1.140	1.010	0.925	0.745	0.785	0.765	0.965	0.966	0.967	0.897
NITROGEN	mg/L	as TKN	0.02	0.82	0.58	0.60	0.56	0.70	0.64	0.60	0.60	0.44	1.10	0.96	0.80	0.84	0.70	0.72	0.62	0.90	0.90	1.00	0.90	0.80	0.75	0.75	0.74
PENTACHLOROPHENOL	ng/L		100	39	78	30	35	35	17	0	12	10	10	18	13	12	10	10	30	61	21	10	10	10	22	41	30
pH			0.1	8.0	8.3	8.1	8.4	8.1	8.2	8.3	8.3	8.2	8.0	8.2	8.3	8.3	8.2	8.3	8.0	8.2	8.3	8.0	8.1	8.0	8.2	8.2	8.2
PHOSPHATE	mg/L	as PO_4	0.0005	0.0180	0.0030	0.0020	0.0010	0.0035	0.0030	0.0075	0.0040	0.0050	0.0090	0.0095	0.0045	0.0050	0.0050	0.0010	0.0070	0.0350	0.0015	0.0075	0.0050	0.0045	0.0067	0.0067	0.0088
PHOSPHORUS	mg/L	Total P	0.002	0.128	0.064	0.032	0.046	0.046	0.036	0.030	0.040	0.012	0.060	0.018	0.036	0.040	0.066	0.042	0.046	0.070	0.100	0.120	0.096	0.076	0.057	0.060	0.071
SELENIUM	mg/L	as Se	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	n/a	0.001
OIL & GREASE	mg/L		1	1	1	1	1	1	1	2	1	1	9	2	2	2	1	2	2	2	1	1	2	1	2	2	1
STRONTIUM	mg/L	as Sr	0.0001	0.3130	0.2700	0.3910	0.2930	0.3080	0.6660	0.5920	0.5200	0.6260	0.6010	0.4930	0.5190	0.5650	0.5950	0.5320	0.5700	0.3590	0.4650	0.5810	0.4490	0.5120	0.4867	0.4888	0.4254
SUSPENDED SOLIDS	mg/L		2.5	150.0	50.0	16.0	24.0	24.0	23.0	16.0	28.0	4.0	32.5	27.0	14.5	18.5	40.0	24.5	21.0	35.5	57.5	67.0	46.5	42.5	36.3	37.2	56.4
TITANIUM	mg/L	as Ti	0.0005	0.0082	0.0091	0.0034	0.0053	0.0060	0.0009	0.0059	0.0031	0.0005	0.0004	0.0063	0.0038	0.0045	0.0019	0.0057	0.0003	0.0036	0.0026	0.0015	0.0044	0.0014	0.0038	0.0044	0.0047
TURBIDITY	FTU		0.01	133.00	32.90	14.50	21.30	25.30	12.50	17.80	11.50	2.50	12.50	26.50	14.20	17.20	31.80	24.40	15.70	52.00	52.00	70.00	54.00	41.00	32.50	33.82	50.93
VANADIUM	mg/L	as V	0.0015	0.0038	0.0018	0.0010	0.0014	0.0012	0.0001	0.0010	0.0010	0.0000	0.0012	0.0015	0.0005	0.0007	0.0019	0.0017	0.0017	0.0015	0.0020	0.0013	0.0015	0.0002	0.0013	0.0015	0.0017
ZINC	mg/L	as Zn	0.0006	0.0589	0.0548	0.0432	0.0566	0.0487	0.0978	0.0963	0.0811	0.0195	0.1140	0.0749	0.0674	0.0599	0.0637	0.0494	0.0399	0.0432	0.0568	0.1240	0.0639	0.0833	0.0665	0.0672	0.0635
E. COLI	#/100 mL			1,400		500	160	220		300			90	210		190	190	450		320	330			30	338	357	417
F. COLIFORM	#/100 mL			5,200		1,460	460	1,140		140			60	230		270	130	350		20	270			80	755	783	1,367
PSEUDOMONAS	#/100 mL			1,300		290	52	60		5			4	70		28	32	280		36	172			24	181	206	317

NOTE: The average outlet concentration values are given as simple averages, the results of the ASAP statistical program (transcribed from Table H.4) and volume-weighted means.

Table H.13: Performance data - winter/spring periods

Parameter / Date	Units	RMDL	18/1/96	24/1/96	8/2/96	20/2/96	21/2/96	13/3/96	25/3/96	12/4/96	25/4/96	30/4/96	22/1/97	Average
2,3,4,6 TCHP	ng/L	20			55	47			63			35		50
Aluminum, as Al	mg/L	0.011	61		67	83	49	59	80	62	37	80	78	65
Barium, as Ba	mg/L	0.0002	16	-27	-69	-70	-21	-61	31		14	-11	-10	-21
Cadmium, as Cd	mg/L	0.0006				50		92				50	63	64
Carbon, DIS ORG	mg/L	0.1		43	-9	-125	-61	38	68	18	-6	38		1
Carbon, DIS INOR	mg/L	0.2	15	-2	-254	-127	-21	-99	-20		6	-86	-48	-64
Chloride, as Cl	mg/L	0.2	23	-34	-131	25	-78	-61	52	-3	-18	1	38	-17
Chromium, as Cr	mg/L	0.0014	-760	-260	60	82		80	56	-400	-111	88	84	-108
Cobalt, as Co	mg/L	0.0013		6			50	94		80	60	67	44	57
Copper, as Cu	mg/L	0.0016	-29	-24	34	60	5	48	95	67	48	75	72	41
Iron, as Fe	mg/L	0.0008	53		59	77	37	36	84	61	35	77	68	59
Lead, as Pb	mg/L	0.01			88	75			92		50	50	85	73
Manganese, as Mn	mg/L	0.0002	54		67	13		81	69	45	17	55	3	45
Molybdenum, as Mo	mg/L	0.0016				96	92	49	53			67	13	62
Nickel, as Ni	mg/L	0.0013			24	86	67	83	82	75	25	50	56	61
Nitrogen, NH_3+NH_4	mg/L	0.002	-61	-26	36	74	-8	47	-34	39			59	14
Nitrogen, as NO_2	mg/L	0.001	-13	-3	19	83	-10	8	88	23	-208	-258	75	-18
Nitrogen, NO_2+NO_3	mg/L	0.005	-21	-4	-90	22	-1	-51	-20	-11	23	-56	16	-18
Nitrogen, as TKN	mg/L	0.02	8	7	48			48	74	33	13	42	6	31
Pentachlorophenol	ng/L	100	-38	-120	72	53	-33		86	42		63	58	20
Phosphorus, as PO_4	mg/L	0.0005	91	46	84	90	48	92	84	50		83	70	74
Phosphorus, as Total P	mg/L	0.002	66	16	90			90	88	76	40	68		67
Oil & Grease	mg/L	1			45		50	50	95	33	25	33	73	51
Strontium, as Sr	mg/L	0.0001	10	-17	-32	-5	-18	-16	46	10	9	4	28	2
Suspended Solids	mg/L	2.5	77	29	96			97	90	85	54	71	77	75
Titanium, as Ti	mg/L	0.0005				79	24	80	56	56	20	75	86	59
Turbidity	FTU	0.01	89	16	96	82	65	97	97	73	65	78	78	76
Vanadium, as V	mg/L	0.0015			49	74	78	96			38	67	80	69
Zinc, as Zn	mg/L	0.0006	-50	-15	52	40	-18	6	87	29	34	54	52	25