Synthesis of Monitoring Studies Conducted Under the Stormwater Assessment Monitoring and Performance Program

SWAMP

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TORONTO AND REGION Conservation

SYNTHESIS OF MONITORING STUDIES CONDUCTED UNDER THE STORMWATER ASSESSMENT MONITORING AND PERFORMANCE PROGRAM

A report prepared by the

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

For

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NOTICE

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- the Ontario Ministry of the Environment
- the Toronto and Region Conservation Authority
- the Municipal Engineers Association of Ontario

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EXECUTIVE SUMMARY

Background

The Stormwater Assessment Monitoring and Performance (SWAMP) Program was initiated in 1995 by 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, along with host municipalities and other owner/operators. The major goals of the program were to evaluate the effectiveness of stormwater technologies and disseminate study results and recommendations within the stormwater management community. Between 1995 and 2002, ten stormwater management facilities were monitored and evaluated. These include:

- Wet ponds and constructed wetlands (4 studies)
- Underground storage tanks (1 study)
- Flow Balancing Systems (1 study)
- Oil and Grit Separators (2 studies)
- Infiltration/ Exfiltration Systems (2 studies)

Another wet pond discussed in this report was monitored in 1993 and 1994 using similar protocols by staff that were later employed by the SWAMP program. Other products of the SWAMP program include an investigation of the storage and transport of chloride (a major constituent of road salt) in stormwater ponds, a discussion paper summarizing data analysis and statistical evaluation methodologies used in SWAMP studies, a stormwater pond sediment maintenance guide, and the proceedings of three major conferences.

Report Objectives

The SWAMP program has contributed to a substantial increase in the body of knowledge regarding the performance of various stormwater management (SWM) technologies in Ontario. The purpose of this report is to synthesize information obtained from individual studies in order to:

- assess the overall effectiveness and limitations of SWM practices evaluated under the program;
- gain insights into patterns or relationships in datasets for like technologies that may not be evident from individual facility assessments;
- document requirements for ongoing maintenance; and
- provide direction for future monitoring programs.

Results are discussed with reference to individual facility design parameters (*e.g.* storage volumes), drainage area characteristics, and monitoring programs. The report also contains a selective literature review that places the SWAMP studies within the larger context of stormwater BMP monitoring in North

America and provides a useful supplement to SWAMP study results, especially for practices not monitored under the program. General recommendations relating to facility design, operation and maintenance, and future research needs are provided in the final chapter of the report.

Findings

With some exceptions, facility evaluations involved comprehensive monitoring of the quantity and quality of flow at facility inlets and outlets to determine overall performance relative to design objectives. Common indicators of performance included the capacity of the facility to control peak flows, reduce runoff volumes, treat runoff and maintain or improve water temperature. Downstream receiving waters were usually not directly monitored because, in most cases, individual facility discharges were only one of many influences on receiving waters. An overview of the main study findings follows.

Water Quantity

The pond and wetland facilities evaluated under the SWAMP program helped to control flooding and downstream channel erosion by significantly reducing peak flows. The average peak flow reduction rate for the five facilities was 77%, with a range between 40 and 95%. Although probably by coincidence rather than design, two of these facilities had exfiltration losses over 15%, which helped to further attenuate flows.

The two exfiltration systems provided on-site water budget control by substantially reducing stormwater flow volumes. Runoff volumes were reduced in the North York and Etobicoke exfiltration systems by approximately 89 and 95%, respectively. In both cases, exfiltration capacities exceeded design criteria. The high exfiltration rates into soils that were identified prior to installation of the systems as having limited permeability was attributed to localized sand lenses or cracks in the clay matrix.

Hydraulic tests at the exfiltration system sites demonstrated that the capacity of the systems to store and infiltrate runoff during high intensity rain invents is primarily limited by throughput capacity, rather than soil permeability. The problem appears to be a result of air entrapment either within the pipe network or the gravel trench, although further investigations are needed to confirm this hypothesis. Installing vent pipes in the upper portion of the gravel bed to facilitate air displacement or increasing the diameter of the perforated exfiltration pipes for at least a few meters downstream of each maintenance hole are suggested as possible solutions to the problem.

Observed runoff coefficients during the May to November period were generally lower than predicted coefficients used in the design of the facilities. The runoff coefficient, which represents the proportion of rainfall that is converted to stormwater runoff, is an important parameter in the sizing of facilities. It is appropriate that average seasonal runoff coefficients would be less than design runoff coefficients because the design coefficients are based on flood flows when runoff coefficients are usually higher than the seasonal average. Designing with higher than average runoff coefficients also helps to ensure adequate levels of treatment during the late winter and early spring when rain on snow and frozen soils can result in unusually large volumes of runoff.

Water Quality

The main findings with respect to water quality apply primarily to the end-of-pipe facilities evaluated. The exfiltration systems achieve water quality benefits primarily through infiltration of runoff, rather than treatment (*i.e.* quantity control rather than quality control). There are important issues relating to the impact of infiltrating stormwater runoff on groundwater quality, but understanding these impacts typically requires long term monitoring of groundwater quality, which was beyond the scope of the SWAMP studies.

The ponds, wetlands and conveyance facilities evaluated under the SWAMP program exceeded their respective design targets. Load-based total suspended solids (TSS) removal rates for ponds and wetlands ranged between 81 and 92%, which is roughly 10 to 21% greater than design predictions. The underground storage tank and OGS units performed less well (approx 60% removal), but water quality treatment was generally within the range of what would be expected based on the design of these facilities. Conveyance facilities exfiltrated over 85% of runoff from rain events, resulting in significant reductions in pollutant loading to surface waters.

TSS removal efficiencies were often considerably greater than the removal efficiencies of other pollutants that readily bind to sediment. For instance, in the four ponds and one wetland, copper, zinc and phosphorus removal efficiencies were on average about 15% less than TSS (Table 1). Other pollutants, such as chloride and nitrate, which are more commonly found in the dissolved (rather than particulate) phase, exhibited much lower and more variable removal rates because they are not subject to sedimentation processes.

The majority of effluent TSS concentrations during individual storm events in ponds and wetlands fell within a relatively narrow range between 10 and 60 mg/L. Less than 10% of observed effluent concentrations exceeded 60 mg/L. Influent TSS concentrations, which varied much more widely, were not correlated with effluent TSS concentrations. Facility design features, such as storage volumes, and the size and intensity of events monitored appeared to be the most important factors contributing to variations in effluent quality.

The size range of particles at the outlet was significantly smaller than at the inlet in all pond and wetland facilities. Roughly 65 to 85% of TSS effluent particles fell within the clay sized range (<4 microns). These particles do not readily settle over the range of detention periods provided by stormwater facilities. Hence, further reductions in observed effluent TSS concentrations may not be practically achievable by simply expanding the volume of storage in the facilities.

Mean effluent concentrations of several stormwater pollutants exceeded receiving water objectives, despite significant reductions in TSS. These pollutants include copper, zinc, iron, *E.coli*, phosphorus, and less frequently, cadmium, lead, and chloride in the winter. Meeting stringent receiving water quality objectives for these pollutants is clearly not an 'achievable' goal for facilities that depend primarily on gravity settling for water quality treatment; even if they are designed to OMOE 'enhanced' level guidelines.

Table 1: Average effluent event mean concentrations (AEMCs) and load based removal efficiencies for selected water quality variables.

Facility	TSS		*E.coli*		Total Phos.		Copper		Zinc	
	Conc. (mg/L)	**% Rem.**	**Conc. (CFU/100mL)**	**% Rem.**	**Conc. (mg/L)**	**% Rem.**	**Conc. (ug/L)**	**% Rem.**	**Conc. (ug/L)**	**% Rem.**
Rouge River Highway Pond	37	90	356	88	0.06	85	10	85	67	84
Harding Park Retrofit Pond	46	80	1429	53	0.11	42	4	48	16	70
Heritage Estates Pond	16	84	1362	79	0.07	71	8	76	10	71
Markham Pond/Wetland	23	95	237	79	0.08	87	8	85	14	87
Aurora Wetland	21	90	477	90	0.13	72	5	68	25	57
Dunkers Flow Balancing System	11	81	279	75	0.06	77	4	85	7	89
Beaches Underground Tank	55	46	44,179	-22	0.31	25	21	44	101	41
3-Chamber OGS	35	57	--	--	--	--	18	56	71	62
Stormceptor® OGS	51	60	--	--	--	--	23	44	129	43
Receiving Water Guideline	25-80 mg/L		100 CFU/100 mL		0.03 mg/L		5 *u*g/L		20 *u*g/L	

Notes: Results are based on monitoring from May to November for all facilities except the underground tank and OGS units, which were monitored continuously during the winter and summer. Average EMCs are geometric means. Receiving water guidelines are PWQOs, except the TSS concentration range, which is from USEPA (1973) and EIFAC (1965).

Oil grit separators exhibited a wider range of performance among individual events than other facilities. Treatment efficiencies for suspended solids varied from zero or negative removal to over 90%. Despite a relatively dry monitoring season, over 25% of effluent TSS event mean concentrations were above 60 mg/L. This is in contrast to the pond and wetland sites where less than 10% of effluent TSS event mean concentrations were above 60 mg/L. Part of this difference in performance relates to the lower capacity of OGS to treat high flows and the greater propensity for re-suspension of previously trapped sediments. Of course, these results only apply to the specific conditions (*i.e.* unit sizing, technology design, catchment characteristics) present at the sites where monitoring occurred; larger or different types of OGS applied under different site conditions may perform quite differently.

Performance of end-of-pipe facilities during the cold season was typically poorer than during warm weather. This result was not definitive as winter performance assessments at several wet pond sites were based on grab samples, and samples sizes were relatively small. Nevertheless, the tendency for lower performance levels (removal efficiencies and effluent concentrations) during the winter was evident for certain water quality variables (*e.g.* TSS, copper, zinc, phosphorus). This general tendency was particularly pronounced at the underground tank, OGS and wetland sites, where heated huts or installations below the frost line allowed for improved characterizations of influent and effluent quality during the winter. The lower winter performance may be attributed to several factors, including reduced permanent pool storage due to ice buildup, and the inhibiting effect of cold temperatures and de-icing salt concentrations on particle settling processes.

Effluent quality during dry weather was generally better than during wet weather, but some variables, such as phosphorus, E.coli and copper, still exceeded receiving water objectives at some facilities. This observation suggests that, for certain pollutants, even very long settling times in detention facilities will not result in effluent concentrations that meet receiving water objectives. If these pollutants are of particular concern in an area, other targeted treatment measures (*e.g.* ultra violet disinfection for bacteria, reactive trenches for phosphorus) must be applied upstream or downstream of the facilities. The quality of dry weather flows is important because, at some facilities, up to 60% of total discharge volumes occurred during dry weather. There were no dry weather flows at the OGS or exfiltration system sites.

A comparison of end-of-pipe facilities showed that, in a very general sense, those with greater storage, longer drawdown times and better length-to-width ratios exhibited improved overall performance as measured by load based removal efficiencies and effluent concentration means and ranges. However, it was not possible to demonstrate this relationship statistically and some facilities with innovative features, such as curtains or exaggerated length-to-width ratios, appeared to compensate for shortcomings in other design elements. Performance results were also influenced by factors related to monitoring programs (*e.g.* average event size monitored). The difference in performance among facilities becomes particularly evident during large, relatively infrequent storm events. Failure to monitor during these events can result in a false impression that the facility is effectively achieving its design targets.

Removal efficiency is a biased indicator of performance that varies with influent concentrations. As a result, end-of-pipe facilities serving clean drainage areas (as reflected by low influent concentrations) exhibit poorer removal efficiencies than those serving dirty catchments (as reflected by high influent concentrations), even though the former may have superior effluent quality. Removal efficiencies are still a useful indicator of facility effectiveness, especially since Ontario stormwater performance guidelines are expressed in these terms. However, they should always be reported with effluent concentrations or loads, as the latter provide a more direct measure of the facility impact on receiving water quality, irrespective of whether the contributing drainage area is clean or dirty.

Accumulation of road salts in storage facilities creates toxic conditions for aquatic organisms living in the facilities and may be contributing to reduced winter performance levels. Monitoring has shown that chloride (a primary constituent of road salt) forms a dense, anoxic layer at the bottom of ponds in the winter with maximum concentrations over 12 times greater than the threshold established for the protection of aquatic life. This stratified layer may reduce cold season performance by slowing the velocity of particle settling, facilitating the release of chemicals from bottom sediments, and inhibiting vertical mixing (*i.e.* reducing hydraulic efficiency). Gradual flushing of the facility during heavy storms in the spring and summer helps to dissipate the layer, but high chloride concentrations in the bottom layers persist into the fall.

Up to 70% of TSS loads captured by ponds and wetlands settle out in the upstream third of the facility. This result is based on data from two ponds where water quality was monitored at intermediate locations in the facilities. The finding highlights the importance of including forebays designed for maximum sediment capture and easy sediment clean-out.

Water temperatures are invariably increased by storage facilities, but bottom draw outlet structures can help to mitigate thermal impacts on downstream aquatic communities. The average increase in water temperature from the inlet to outlet of ponds/wetlands during summer low flow periods ranged from 4 to 11ºC. Maximum water temperatures from outlets that draw water from at least 1 m below the water surface were, on average, 5ºC less than from top draw outlets. Exfiltration facilities had little or no warming effect on water temperature.

Facility Maintenance

The importance of regular facility maintenance can not be over-emphasized. A pond sediment maintenance guide was prepared in 1999 by Greenland International under contract to SWAMP and other agencies to provide direction on stormwater facility maintenance. SWAMP studies provided estimates of clean-out schedules based on influent loading rates and data on the quality of trapped sediments was characterized in order to assess disposal options.

Estimated clean-out intervals varied widely: small ponds may require cleaning after only 10 years, whereas larger 'enhanced' level ponds may only require facility wide clean-out after 50 or more years. In most cases, forebays will need to be cleaned at more regular intervals since these areas accumulate sediment much more quickly. Regular cleaning of forebays will prolong the time required to cleanout the larger main pond. Maintenance programs should include direct measurements of sediment accumulation each year at a minimum to establish clean out schedules.

Sediment chemistry results from SWAMP sites and other studies indicate that stormwater facility sediments are not polluted enough to be classified as hazardous waste, but also do not meet the

requirements for clean fill and therefore usually must be disposed of in a registered landfill. Sediment quality data from SWAMP and other Ontario ponds were compared with the Provincial Sediment Quality Guidelines and the Guidelines for use at Contaminated Sites in Ontario to determine this result. Further guidance on disposal options in Ontario for pond sediments is provided in the *Stormwater Management Facility Sediment Maintenance Guide*.

Monitoring and Reporting Protocols

Much experience was gained through the SWAMP program in monitoring, data analysis and reporting. Chapter 6 provides a brief overview of the steps involved in designing and implementing a monitoring program. Like the practice of stormwater management itself, industry standards for monitoring, analysis and reporting of BMP data have evolved over the past decade. Key elements of recommended practices are provided and reference documents are cited for readers interested in more detailed information.

Concluding Comments

A primary purpose of the SWAMP studies was to evaluate whether or not facilities were meeting their respective design objectives. The individual facility studies show that they are not only meeting these objectives, but in most cases, they are exceeding them. Although effluent quality does not meet receiving water standards for all water quality variables, comparison with stormwater Best Management Practice (BMP) databases in the United States show that the quality of facility effluents monitored under the SWAMP program is as good as, or better than observed in the United States.

Overall, the SWAMP program has contributed to a substantial increase in the body of knowledge regarding the performance of various stormwater management (SWM) technologies in Ontario. Over the years, study results have been used to re-evaluate existing stormwater facility design guidelines, model the watershed wide benefits of stormwater BMPs, define ‘achievable’ levels of effluent quality or load reductions, assess maintenance requirements, and provide insights into the value of different functional components of facilities (*e.g.* outlet structures, forebays).

There is still, however, much to be learned. Studies conducted under SWAMP addressed only a very small subset of the many different types of practices currently used to manage stormwater. More research on source and conveyance controls in particular is needed. In addition, there is little known about the direct impact of stormwater controls on the health of aquatic life or the geomorphic integrity of downstream channels. Studies of end-of-pipe facilities clearly demonstrate that effluent quality is better and catchment flows are more controlled than would have been the case if stormwater facilities had not been constructed. However, the increase in flow volumes and water temperature from pre-development conditions (among other factors) may still be contributing to degradation of downstream aquatic ecosystems. More research linking stormwater BMPs directly to the health of receiving waters is required to determine whether or not stormwater practices currently in use are providing the environmental benefits so often attributed to them.

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1.0 INTRODUCTION

1.1 Overview of the SWAMP Program

Over the past two decades, the Great Lakes Basin has experienced rapid urban growth. Stormwater runoff associated with this growth is a major contributor to the degradation of water quality and the destruction of fish habitat. 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 Stormwater Assessment Monitoring and Performance (SWAMP) Program was designed to address this need.

The SWAMP Program's objectives were to:

- monitor and evaluate the effectiveness of conventional and innovative stormwater management technologies; and
- disseminate study results and recommendations within the stormwater management industry.

The program was 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 also participated in SWAMP studies. Additional information regarding sponsoring agencies, their interests in stormwater management, and the evolution of the SWAMP program is provided in Appendix A.

Between 1995 and 2002, nine stormwater management facilities were evaluated under the SWAMP program. In addition to extensive field-data collection, literature reviews were also conducted as part of many of the studies. The following facility assessments have been published by the SWAMP program:

- *Performance Assessment of Pond-Wetland Stormwater Management Facility – Markham Ontario*
- *Performance Assessment of a Stormwater Retrofit Pond – Harding Park, Richmond Hill Ontario*
- *Performance Assessment of a Highway Stormwater Quality Retention Pond – Rouge River, Markham Ontario*
- *Performance Assessment of an Open and Covered Stormwater Wetland System – Aurora, Ontario*
- *Performance Assessment of the Eastern Beaches Detention Tank - Toronto, Ontario*
- *Performance Assessment of a Flow Balancing and Wetland Treatment System - Toronto Ontario*
- *Performance Assessment of Two Types of Oil and Grit Separator for Stormwater Management in Parking Lot Applications – Markham and Toronto, Ontario*
- *Performance Assessment of a Swale/Perforated Pipe Stormwater Infiltration System – Toronto, Ontario*

- *Performance Assessment of a Perforated Pipe Stormwater Exfiltration System – Toronto, Ontario*

Monitoring of another stormwater pond was conducted in 1993 and 1994 by staff that were later employed by the SWAMP program. The study used similar monitoring and reporting protocols as later SWAMP studies and is discussed in this report for purposes of comparison. The report is entitled: *Performance Assessment of the Heritage Estates Stormwater Management Pond - Richmond Hill Ontario.*

Other products of the SWAMP program include an investigation of the storage and transport of chloride (a major constituent of road salt) in stormwater ponds, a discussion paper on fundamental concepts of pond systems, a stormwater pond sediment maintenance guide, and the proceedings of three major conferences. Individual SWAMP reports are available from the TRCA.

1.2 Future of SWAMP

In 2003, as the SWAMP program was winding down, a workshop hosted by the Canadian Water Resources Association (CWRA) was convened to review the program objectives and explore how the program could be improved or re-organized to better serve the evolving needs of the stormwater management community. The workshop was attended by stormwater industry representatives from government agencies, universities, conservation authorities, consultant firms and other groups. The participants generally expressed strong support for the continued existence of a program like SWAMP. The original program objectives of evaluating stormwater technologies and technology transfer were still thought to be relevant. However, participants thought these should be broadened to included greater focus on stormwater pollution prevention, source controls, construction phase measures, cost factors, maintenance, management and operations practices (e.g. street cleaning) and restoration. There were also several recommendations on how the program could be improved from a functional and organizational standpoint (CWRA, 2004).

Building upon workshop recommendations, a new program led by the TRCA was formed in 2005, called the Sustainable Technologies Evaluation Program (STEP). A discussion paper summarizing the objectives and organizational structure of this new program is available from TRCA (2005). Information about the program and technology evaluations is available on the program web site at www.sustainabletechnologies.ca

1.3 Purpose of this Report

The SWAMP program has resulted in a substantial increase in the body of knowledge regarding the performance of various stormwater management (SWM) technologies in Ontario. Much experience has also been gained in the development of monitoring and data analysis protocols. The purpose of this report is to synthesize information obtained from individual studies as a means of:

- assessing the overall effectiveness and limitations of SWM practices evaluated under the program;
- gaining insights into patterns or relationships in datasets for like technologies that may not be evident from individual facility assessments;
- documenting requirements for ongoing maintenance; and
- providing direction for future monitoring programs.

The report also contains a selective literature review that places the SWAMP studies within the larger context of stormwater BMP monitoring in North America and provides a useful supplement to SWAMP study results, especially for practices not monitored under the program.

Important insights have been gained from monitoring conducted under the SWAMP program but still many questions regarding stormwater management practices remain unanswered. It is hoped that this synthesis of study results will foster support for addressing further study needs through partnerships, and help to refine existing municipal and provincial stormwater management policies and guidelines.

2.0 STORMWATER MANAGEMENT PRACTICES AND GUIDELINES IN ONTARIO

The following brief introduction to stormwater management practices (SWMP) provides a framework for the later description and discussion of the performance evaluation of specific technologies. The evolution of stormwater management from the mid 1970’s to the present is briefly described. Some of the key documents which currently govern the planning and design of stormwater management practices are noted.

2.1 Evolution of Stormwater Management in Ontario

Before the mid-1970’s, stormwater management, *i.e.* control of stormwater to minimize its detrimental effects, was not a feature of engineering practice. Since the formation of the Ontario Water Resources Commission in the 1950s, storm drainage systems required approval as "sewage works". However, designs were approved on the basis of meeting municipal performance standards with little or no consideration given to water quality and other environmental concerns. Conventional design practices were based on providing a predetermined level of property protection, using the Rational Method. In many cases, the resulting increased rates and volumes of flow produced designs that caused significant downstream flooding and erosion. Preventative and remedial measures generally consisted of channelization that left a legacy of engineered watercourses of limited natural value.

2.1.1 Water Quantity Control

Concerns about downstream flooding and channel erosion, as well as a desire to retain natural features of watercourses led to the first attempts to control the rate of flow from urban developments in the mid-1970’s. Generally speaking the design criteria adopted was to control post-development peak flows to pre-development levels on a site by site basis. Temporary storage of flows to attenuate runoff hydrographs was necessary. The use of models (such as HYMO and SWMM) which could calculate hydrographs and could perform hydrologic and hydraulic routing became common. These were used to estimate storage requirements. Various means of implementing the storage were developed which included on-site methods such as roof top and parking lot storage and “regional” methods such as the construction of dry detention facilities to control downstream flows. Both on-line and off-line facilities were commonly used in this period. Overall design practice was also modernized to include consideration of major and minor drainage systems which provide higher levels of property protection. Water quality concerns also began to receive some attention in design practice. Master Drainage Plans (MDPs) began to be developed at this time to address concerns that stormwater management plans implemented for each individual development might result in less than optimum results on a subwatershed level.

2.1.2 Water Quality Control

In the mid to late-1980's, a significant new development in stormwater management took place when control of storm water quality began to be practiced. This was largely a result of increased concern by the federal Department of Fisheries and Oceans (DFO) that release of untreated stormwater constituted a "discharge of a deleterious substance" under the terms of the federal Fisheries Act. Municipalities, Conservation Authorities and federal/provincial agencies began to incorporate requirements for treatment of stormwater in their conditions of approval for development proposals. Initially, there was much uncertainty regarding the appropriate methods needed to address these requirements. Methods such as extended wet detention ponds and artificial wetlands were introduced based upon experience in a few jurisdictions (such as the State of Maryland) outside Ontario.

Recognizing a need for guidelines on the planning and design of such facilities, the Ontario Ministry of Environment commissioned the preparation of the "Ontario Stormwater Management Practices Planning and Design Manual" (1994). This provided a synopsis of the state-of-the-art in the design of such facilities and presented design guidelines for a wide range of facility types from extended detention wet ponds to infiltration trenches to oil/grit separators. It also recognized the evolution of a broader planning context for stormwater management based upon watershed/subwatershed planning. This evolution of approach had begun earlier with ground breaking studies such as the Rouge River Urban Drainage Study (TRCA, 1988) and the Laurel Creek Watershed Plan (GRCA, 1992). Another factor, which received recognition in the SWMP Manual, was the limited understanding of design criteria and performance of SWM measures and the need for future research in those areas.

2.1.3 Erosion Control

Concern over channel erosion downstream of urban areas was one of the initial driving forces which led to stormwater management in Ontario. Control of 2 to 100 year peak flows was initially practiced as a means of achieving the goal of reducing downstream erosion. However, with improved understanding of fluvial geomorphologic processes came the recognition that standard practices were not always managing the flow regime in a sufficiently comprehensive way. Increases in the frequency and duration of relatively small flows (less than bankfull) were found to be contributing significantly to increased channel erosion. Hence, extended detention of frequent flows was incorporated into stormwater management facilities. The standard criteria became detention of runoff from a 25 mm storm with release over a minimum period of 24 hours. Site specific criteria based upon subwatershed planning have become more common in recent years. This evolution was recognized in the updated SWMP Manual (MOE, 2003) by the addition of erosion control/geomorphology considerations to the environmental design criteria.

2.1.4 Treatment Train Approach

As an understanding of the effects of urbanization on watersheds and their associated ecosystems has improved, the objectives of stormwater management were broadened to include maintenance of the natural hydrologic cycle as closely as possible. Ideally, volumes and rates of flow in each component of the cycle (evaporation, transpiration, surface flow and subsurface flow) should be unchanged after urbanization. In practice, this is very difficult to achieve. However, by employing a combination of practices that store, infiltrate and evaporate water, it is feasible to come closer to the ideal than if only a single SWM method is employed.

Another factor favouring the use of multiple stormwater management techniques for a specific development is the ability to improve the level of water quality control achieved. Use of a series of measures has the potential not only to increase the removal efficiency for a particular water quality variable but also to address a wider range of variables more effectively.

The use of a number of practices in series or in parallel is commonly referred to as a "treatment train" approach. In general, it involves the consideration of stormwater controls from source through to discharge into a receiving water. In broad terms these are referred to as "source controls," "conveyance controls" and "end-of-pipe controls." Although many of the controls are physical devices, other non-structural best management practices are also included. This is particularly true in regard to source controls which encompass measures such as encouraging reduced use of pesticides and fertilizers, enforcing sewer use by-laws, encouraging use of water tolerant vegetation, minimizing the impervious footprint of a development, etc.

The use of a treatment train to implement a stormwater management plan developed within a subwatershed plan context can be considered the state-of-the-art approach at the time of writing of this report. Perhaps the most comprehensive application of this philosophy to date in Ontario is embodied by the City of Toronto's Wet Weather Flow Management Master Plan. However, numerous other municipalities such as the City of Ottawa have embraced this concept and have undertaken studies to determine how it can be implemented.

2.2 Stormwater Management Guidelines in Ontario

Stormwater management practices in Ontario have evolved over the past thirty years to address the need to protect natural systems from the potential negative impacts of runoff from urban development. They are required, in part, to meet the legal requirements of various pieces of legislation such as the federal Fisheries Act, the Ontario Water Resources Act or the Conservation Authorities Act. From a broader perspective they are needed as a means of advancing towards sustainable urban development. As practices have evolved, various guidelines have been prepared by municipalities, Conservation Authorities, provincial and federal agencies. These identify both the requirements which must be met to address the policies of the many agencies involved in their approval and the design criteria which should be used to ensure a level of performance that meets safety, environmental and operational standards. These guidelines are subject to relatively frequent updates as research and experience provide new information on SWM facility performance and receiving water impacts. The SWAMP program has played a significant role in this process by providing a basis for improving guidelines through various technology monitoring and evaluation studies.

Some of the current documents which provide guidance on the use of SWM practices in Ontario include:

- Stormwater Management Planning and Design Manual (OMOE, 2003)
- Stormwater Pollution Prevention Handbook (OMOE, 2001)
- Drainage Management Manual (MTO, 1997)
- Stormwater Management Requirements for Land Development Proposals (MTO, 1999)
- Various Conservation Authority documents, such as the Credit Valley Conservation Stormwater Management Guidelines (CVC, 1996)
- Various municipal documents, such as the "City of Toronto Stormwater Management Policy" (2002b)
- National Guide to Sustainable Municipal Infrastructure – Source and On-site Controls for Municipal Drainage Systems Best Practice (NRC and FCM, 2003).

2.3 Current Stormwater Management Methods/Practices

There is a wide range of stormwater management methods and practices in use at this time. In the City of Toronto Wet Weather Flow Management Master Plan, a catalogue of almost 100 techniques was prepared (City of Toronto, 2002b). In this document, techniques were categorized into source control, conveyance control and end-of-pipe techniques. Table 2.1 provides a general description of these broad categories and some examples.

Table 2.1: Stormwater Management Practices

Control Measure	Description	Examples
Source Controls	Controls storm water or pollutants at their source, generally applied on a lot level basis. Includes preventative measures.	Water Conservation, Fertilizer/Pesticide Control, Downspout disconnection, Street Cleaning, Soakaway Pits, Permeable Pavement, Vegetative Filter Strips, Rooftop gardens
Conveyance Controls	Controls located within a drainage system where flows are conveyed along a corridor	Grassed Swales, Roadside Ditches, Pervious Pipe Systems, Sewer Rehabilitation, Stream Corridor Measures
End-of-Pipe Controls	Controls located at the end of a flow conveyance route	Wet Ponds, Dry Ponds, Constructed Wetlands, Tank/Tunnel, Filters, Oil/Grit Separators, Chemical Treatment

In general, stormwater technologies function based on a number of fundamental processes, which may include attenuation of flows using temporary storage, reduction of runoff volume using infiltration, passive treatment using settling, active treatment using physical/chemical treatment, load reductions at source and techniques such as education that help to influence human behaviour. This allows the user of these techniques some freedom in selecting appropriate methods for a given situation in that a group of methods based on the same principle (*e.g.* soak away pits, rear yard infiltration trenches) will perform in a relatively similar manner. Hence similar techniques can be substituted for each other depending upon the physical constraints of a given situation. Studies on the effectiveness of selected practices are reviewed in the next chapter.

3.0 LIMITED LITERATURE REVIEW – STORMWATER MANAGEMENT PRACTICES

3.1 Description of Selected Literature Resources

A limited review of available literature on the topic of stormwater management (SWM) facility performance was conducted. The goal of the literature review was to provide a frame of reference with which to compare the results obtained through the SWAMP program and to gain insight into future needs for stormwater monitoring and assessment. The literature review was also intended to provide additional information on: 1) SWM facility types not monitored by the SWAMP program, and 2) SWM facility issues not addressed through the SWAMP studies.

The literature review was conducted in two phases: 1) review of literature sources in Ontario; 2) review of available databases on stormwater management projects. In phase one of the review, in-house reports and periodicals were reviewed, and a limited internet search was performed. By virtue of the scope of this undertaking, the literature review can not be considered a thorough investigation of all available sources. The literature review was limited primarily to studies from Ontario. Information was categorized under the headings source, conveyance and end-of-pipe controls.

Phase two of the review involved an investigation of two stormwater management databases: (i) the *National Stormwater Best Management Practices (BMP) Database*, developed by the American Society of Civil Engineers (ASCE) the US Environmental Protection Agency (EPA); and (ii) the *National Pollutant Removal Performance Database*, developed by the Centre for Watershed Protection (CWP). A brief description of the databases is followed by a general summary of results. Individual facilities or practices are not compared because the databases do not consistently provide details on facility design and monitoring programs.

3.2 Reports and Periodicals

3.2.1 Source Controls

The term source control is often broadly applied to all measures that can be taken to manage stormwater at, or as close to the 'source' as possible. These management measures may include prevention (referred to in this report as 'non-structural' controls), municipal infrastructure maintenance (*e.g.* catchbasin cleaning, street cleaning), or structural controls on individual development sites (also referred to as 'lot level' or 'on-site' controls).

A good compendium of stormwater source controls is provided in the *Stormwater Pollution Prevention Handbook* (OMOE, 2001). This handbook provides fact sheets on a range of practices from education and awareness to structural control of runoff from individual lots. Another good Canadian review of source controls is provided by the National Guide to Sustainable Municipal Infrastructure, entitled *Source and On-site Controls for Municipal Drainage Systems* (NRC and FEM, 2003).

3.2.1.1 Non-structural Source Controls

The primary objective of non-structural stormwater best management practices is to prevent pollution or damage to receiving water systems before they happen. Typical practices include education and outreach, better planning and management, controls on illegal dumping and other good housekeeping practices by households and industry. Intuitively, practices that prevent pollution should translate into improved receiving water quality, but their benefits to local water bodies are rarely quantified. The environmental value to communities and societies of softer approaches, such as awareness building and education are particularly difficult to measure.

Easier to track are the water quality benefits of regulatory controls on human activities. Legislation that restricts or bans the use of chemicals has been linked to reduced incidence of these chemicals in streams and lakes. For instance, the phase out of phosphates from detergents in the 1970s led to a significant decline in phosphorus loading (OMOE, 1999). Similarly, bans on PCBs and other synthetic chemicals have resulted in reduced concentrations in Great Lakes fish tissues (Hesselberg and Gannon, 2005). Other regulatory measures, such as sewer use bylaws, have measurable impacts on industrial discharges of hazardous waste both to storm and sanitary sewers, but not on general stormwater runoff quality, in part because of the diffuse nature of stormwater inputs to receiving waters. Effective enforcement is a key element of any regulatory control measure.

Clark et al (2001) reviewed literature on the pollutant release potential to stormwater of traditional building and construction materials such as asphalt, galvanized metal, treated wood and concrete. The review identified roofs as a significant contributor of copper, zinc, lead, cadmium, polycyclic aromatic hydrocarbons and organic halogens. Three studies cited concluded that building materials (especially flashing and gutters) are the largest emitter of copper to the environment. Zinc levels are extremely high in sheet roofing, resulting in stormwater runoff concentrations two orders of magnitude above local toxicity thresholds. Asphalt contains PAHs and other chemical modifiers added to improve performance, but there are few data on the effect weathering and road use have on the release of these chemicals into the environment. Treated woods have been shown to leach metals, such as copper and arsenic, and various organic preservatives. The authors conclude that, although further research is required, substitution of traditional infrastructure construction materials with other products that have lower pollutant release potentials could result in a significant reduction of toxicants in stormwater runoff.

In new developments, site plans can incorporate innovative design features that reduce the extent of impervious cover, conserve natural areas and promote infiltration wherever possible. A long list of techniques are available, many of which are more effective when they are built into the original stormwater management plan for the site. These include using back yard soakaway pits, rain barrels, permeable pavements and infiltration trenches to capture roof and driveway runoff, maintaining open spaces by reducing lot sizes, and employing grass swales and filter strips instead of traditional curb and gutter drainage systems (Kwon, 2000). Even simple changes in the way sites are laid out can reduce the area devoted to streets and help conserve natural areas. Research conducted by the Canadian Mortgage and Housing Corporation (2002) showed that, relative to conventional square grid layouts, innovative street pattern designs result in 11.3% percent less area occupied by streets, 8.0% more buildable area and 3.3% more open space. A good summary of alternative site design concepts and tools, is provided in the January 2000 edition of Watershed Protection Techniques, published by the Centre for Watershed Protection.

3.2.1.2 Structural Source Controls

Up to 20% of residential areas are covered by roofs. Drainage from roofs through eaves troughs can be managed relatively easily on-site before it mixes with runoff from roads and parking lots. For this reason, new developments in many GTA municipalities are required to have residential roof runoff drain to the surface where it can infiltrate. Older areas must rely on voluntary programs to disconnect roof leaders from storm sewers. In Toronto, as of May 2001, a total of 22,102 downspouts had been disconnected representing a disconnection rate of between 8 and 10% of the total number of eligible households. At this disconnection rate, approximately 3 to 5% of event runoff would be diverted from storm sewers (Hatziantoniou, 2002). Toronto hopes to increase the disconnection rate to 40% of eligible households in future years (City of Toronto, 2003).

Disconnecting roof drains from sewers is particularly beneficial in combined sewer areas, as they can contribute significantly to reducing the frequency of overflows (CSOs) into area receiving waters. A simulation study of a residential area in Toronto showed that CSOs could be reduced to about 50% if one quarter of the downspouts were disconnected, and to almost zero if two thirds of the downspouts were disconnected (J.F. Sabourin, 1999). Municipalities would also experience considerable savings from not having to treat as much sewage effluent and by reducing the capacity of new infrastructure. Success of the downspout disconnection program in Toronto was responsible for a reduction in the design diameter of the new Western Beaches combined sewer overflow (CSO) tunnel from 6.0 to 5.5 meters (Hatziantoniou, 2002).

Green roofs provide an effective complement to disconnecting downspouts by storing and evaporating rainfall from the roof itself. Excess runoff could be routed to roof leaders where they would drain to green areas surrounding the building. Monitoring of a 241 m^2 roof garden on a building at York University in Toronto showed between 54 and 76% annual reduction in runoff relative to a conventional roof adjacent to the site (TRCA, 2005b). These values are generally in the same range as reported for other green roofs (*e.g.* Liesecke, 1999; Rowe *et al.*, 2003). Effluent water quality from the York University green roof was also cleaner than conventional roof runoff, with the exception of some nutrients, such as phosphorus, that form an important component of green roof growing mediums.

Monitoring data from the York University site were subsequently used in a hydrologic model to simulate the benefits of green roofs at a watershed scale. Assuming green roofs were installed on all commercial buildings in the watershed, or approximately 9% of the watershed area, model simulations showed runoff and peak flow reduction at the watershed mouth of 4 and 13%, respectively. If only 50% of commercial buildings had greenroofs, runoff volumes and peak flow reductions would drop to 2 and 6% at the watershed mouth.

Permeable pavement systems help mimic the pre-development hydrologic cycle by reducing stormwater volumes, promoting groundwater recharge and maintaining or augmenting baseflows. Concrete block pavers have been demonstrated to be among the most effective types of permeable pavement available commercially. Booth and Leavitt (1999) reported virtually no surface runoff during the autumn and winter from planted (*i.e.* turfstone) and unplanted concrete block pavement at a Public Works parking lot in Renton, Washington. A repeat study conducted at the same site four years later revealed similar results (Brattebo and Booth, 2003). At the University of Guelph in Ontario, extensive research on block pavers showed 90% reduction in surface runoff volume compared to traditional impervious pavements (James, 2002). Soluble constituents, such as chloride and nitrate, can percolate through soils into the groundwater but most other stormwater contaminants are adsorbed within the upper 10 cm of native soil (Brattebo and Booth, 2003; Nightingale, 1978).

Street sweeping can be an effective means of removing coarse sediment and debris from streets, but does it help improve the quality of urban runoff? The evidence from early studies conducted by the OMOE and the U.S. Environmental Protection Agency suggests not. These studies showed that street sweeping once or twice a month removes less than 5% of pollutant loadings (as cited in NRC and FEM, 2003). Hopes were renewed, however, when high powered vacuum assisted sweepers were developed, with the ability to capture fine and coarse material from roads. Initial estimates of the underlying potential of new sweeping technologies indicate that monthly sweeping results in sediment and associated contaminant load reductions of between 42 and 50% (Sutherland and Jelen, 1997). Removal of fine particles may also improve air quality.

Roadside catchbasins have the capacity to capture and temporarily store sediment and debris. Many of these also have 'goss traps' that prevent oil and floatables from being discharged into the sewer system. Regular cleaning of catchbasins, usually with vactor trucks, is advocated as a stormwater source control. The effectiveness of this measure, however, strongly depends on the frequency of clean-out because as sediment accumulates it has greater propensity to be flushed from the system during rain events. A study in Alameda County, California showed that monthly clean-outs of catchbasins and storm drain inlets would remove roughly double the sediment mass removed by quarterly, semi-annual or annual cleanouts. Monthly cleanouts at industrial sites removed closed to six times more sediment than annual cleanouts (Mineart and Singh, 1994). Catchbasin filters that improve capture of fine particles in stormwater runoff are undergoing evaluation in Sweden. These have the potential to improve sediment capture but frequent maintenance is required to avoid clogging or freezing of the filter (Mikkelsen et al, 2001).

3.2.2 Conveyance Controls

Research on stormwater infiltration technologies over the past two decades has contributed substantially to our understanding of the benefits and technical constraints associated with these practices. Most stormwater conveyance controls are wholly or partly infiltration systems (*e.g.* roadside ditches, bio-swales, underground perforated pipes). However, unlike ponds or wetlands, infiltration practices can also be applied at the lot level (*e.g.* permeable pavement, backyard soak-away pits) and end-of-pipe (*e.g.* infiltration basins) stages of the treatment train. The aim of these practices is to mitigate the water quality and quantity impacts of urban development by mimicking the pre-development hydrologic cycle. Since the primary water balance impact of increased impervious cover is a reduction in infiltration, they are ideally suited to this task.

There are several good reviews of infiltration systems conducted in the United States (*e.g.* Ferguson, 1994; Pitt et al., 1996). Studies typically report runoff reduction rates from infiltration systems of at least 50%, even for simple roadside ditches (Mattson, 1998). Water quality concentrations of system effluents are not always less than conventional runoff, but due to significant recharge to groundwater, loadings are usually 60-100% lower for most constituents. Failures were common in the early years because of construction related clogging, compaction of the filtration media, high groundwater tables and tight soils (Lindsey *et al.*, 1992). Designs that incorporate pretreatment of runoff (by swales and sediment traps for example) and careful testing of soil and groundwater conditions at proposed sites have substantially improved success rates.

Most studies of infiltration systems have not demonstrated adverse groundwater quality impacts (*e.g.* Nightingale, 1978; Dierkes and Geiger, 1999; Appleyard, 1993), even in systems that have been in place for several decades (Ku and Simmons, 1986). Nevertheless, the concern remains, and is particularly acute regarding systems applied in commercial and industrial areas where concentrations of a diverse range of contaminants may be elevated beyond what is typical in residential areas. As mentioned earlier, soluble and conservative contaminants such as nitrate, a few pesticides, enteroviruses, and road salts have particularly high potential for traveling through soils and contaminating groundwater (Pitt *et al*., 1996).

To avoid groundwater contamination, some infiltration systems are designed only to infiltrate roof and lot runoff, where contaminant loading is less than for roads or parking lots. Examples of systems receiving roof runoff only are starting to become more common in Ontario. A pilot study of such a system in Vaughan demonstrated 100% infiltration of roof drainage over the 15 month study period (Clarifica, 2005). When roads are part of the exfiltration system drainage area, use of certain chemicals (such as road salts) may be restricted to prevent groundwater impacts, or the systems may be installed in urbanized areas where groundwater is not used for drinking water or irrigation (*e.g.* near the Toronto waterfront). Permeable pavements may not be as risky to groundwater as they infiltrate stormwater runoff over a large area, allowing contaminant loads to be more effectively attenuated by soil particles and microbes.

In Ontario, there have been few comprehensive (non-SWAMP) studies of exfiltration systems designed to control stormwater on residential catchments. One study of note was conducted in 1991-1992 by Paul Wisner and Associates at two neighborhood subdivisions with perforated pipe and conventional pipe systems in Ottawa (formerly the City of Nepean) (Paul Wisner and Associates, 1994). J.F. Sabourin and Associates undertook a follow-up study at the same locations in 1998 to evaluate the longevity and long-term performance of these systems (J.F. Sabourin and Associates, 1999).

Drainage areas at the two exfiltration sites (McFarlane and Heart's Desire) and the conventional sewer system (Amberwood, for comparison) were less than 15 ha of predominantly residential land use. Soils were silty loam till and sandy silt till at the Heart's Desire and McFarlane sites, respectively. The McFarlane site had a higher groundwater table and greater baseflow than the Heart's Desire site.

The exfiltration systems consisted of roadside grassed swales below which perforated pipes were embedded in a geotextile lined exfiltration trench of clear stone. Since there was no curb, the catchbasins were located within the grass swale and connected directly to the perforated pipes. Road runoff that did not infiltrate into the swale was conveyed to the catchbasin where it was directed to the perforated pipe and exfiltrated first into the gravel trench and then into the surrounding native soils. When the inflow rate exceeded the exfiltration rate, water was conveyed through the perforated pipe as it would be in a conventional sewer.

In the 1991/92 study, monitoring was conducted for water quantity and the quality of surface runoff and groundwater. Flow monitoring indicated that runoff volumes were 2.7 and 12.0 times smaller at the two exfiltration sites than for the conventional sewer system. The lower runoff reduction at the McFarlane site was attributed to the high groundwater table in the deeper reaches of the system. Monitoring of water quality during 7 to 9 events indicated higher average concentrations of chloride and E.coli in the exfiltration systems, but because of much lower runoff volumes, perforated pipes were shown to release significantly less pollutants than the conventional system. Although only limited groundwater sampling was undertaken, there was no evidence that the perforated pipe system was a source of groundwater contamination (Paul Wisner and Associates, 1994).

Table 3.1: Comparative loadings (kg/ha/6 months) and percent difference between the exfiltration system and conventional storm sewer system (adapted from J.F. Sabourin and Associates, 1999).

Parameter	**Amberwood Conventional System**	**McFarlane Swale-Perforated Pipe System**		**Hearts Desire Swale-Perforated Pipe System**	
	Observed	**Observed**	**% difference**	**Observed**	**% difference**
Runoff coeff.	0.31	0.043	86	0.0024	99
Area (ha)	12.08	10.02	--	13.64	--
Volume (m^3/ha)	1519	211	86	12	99
TP	0.258	0.036	86	0.0026	99
TKN	1.246	0.314	74	0.0400	97
Chloride	34.938	49.720	-45	2.0202	94
TSS	28.862	3.371	88	0.1441	99
Copper	0.0106	0.0013	89	0.0000	100
Lead	0.0030	0.0004	86	0.0000	99
Zinc	0.0319	0.0072	78	0.0001	100

Note: Loadings are based on normal precipitation of 490 mm from May 1 to October 31 (AES).

The follow-up study conducted in 1998 showed that even after seven years the systems continued to exfiltrate similar volumes of water. Peak flows continued to be reduced by over 90% and runoff volumes were only 6 to 30%of the conventional system. Grass swale infiltration rates also had not declined since 1992. Concentrations of most constituents in system effluents were similar to the earlier study. Chloride was the only constituent with concentrations higher than the conventional system. As in the earlier study, however, loads were substantially reduced for all other monitored variables (Table 3.1) (J.F. Sabourin and Associates, 1999).

3.2.3 End-of-Pipe Controls

Ponds and wetlands are the most common management practice employed in Ontario for the control of stormwater runoff. Standard designs in Ontario follow OMOE guidelines and typically include permanent pool and extended detention storage (sized according to catchment impervious levels), length-to-width ratios of at least 3:1, and drawdown times no less than 24 hours for the 25 mm – 4 hour storm. Provincial guidelines recommend controlling for water quantity (*i.e.* peak flow), water quality and downstream erosion.

Although several ponds and wetlands have been monitored in Ontario, most of these studies have employed relatively crude methods (*e.g.* grab sampling) over a narrow range of storm events. One notable exception is a stormwater pond in Kingston Ontario, evaluated extensively in the 1990s by a research team from Queen's University and the National Water Research Institute. Unfortunately, the Kingston pond is a poor representation of current design practice. Constructed in 1982, the pond was designed primarily to control peak flows. The pond receives runoff from a 12.6 ha parking lot and an upstream drainage area of about 4,400 ha. When the pond was first constructed, the upstream drainage area was largely rural in nature, but approximately 77 ha were subsequently paved as suburban development expanded across the watershed. The pond consists of a permanent wet pond (5200 m^3) and a dry pond area (5000 m^2) surrounding the inlet channel that floods when the permanent pool water level increases by 0.2 m (Anderson et al., 1996).

The outdated design of the pond is reflected in performance monitoring results over two field seasons: only 42% of suspended solids were removed by the pond during storm events and the average TSS event mean concentration at the outlet was 70 mg/L. With baseflows factored in, the overall TSS removal rate fell to a mere 17% (Van Buren et al., 1997).

Subsequent studies on the Kingston pond investigated methods of improving pond performance through various retrofit solutions. Installing baffles in the pond, for instance, were shown to increase the length-to-width ratio from 1.5:1 to 4.5:1, reduce short circuiting and ensure that a larger proportion of available storage in the pond was used for treatment (Mathews *et al*., 1997). A 28% increase in removal of a range of particle sizes was predicted from two dye tests conducted on the facility. In another study, two subsurface flow constructed wetlands were added to the outlet of the pond and tested for pollutant removal performance. Monitoring results showed that the wetlands were able to maintain removal rates of 46% for TSS, 39% for orthophosphate and 50% for copper (Rochefort *et al*., 1997). Effluent polishing through use of a submerged aerobic biological filter also showed promise in improving pond performance, although bacterial assimilation and treatment was inhibited by excessive accumulation of solids in the filter (Anderson *et al*., 1997; Mothersill *et al*, 2000).

Four centralized wet ponds serving catchment areas ranging from 210 to 991 hectares were constructed in the City of Ottawa between 1997 and 2002. The ponds were designed to OMOE standards with multiple cells to improve retention times. Four years of monitoring on one of these facilities showed impressive performance, even though construction was ongoing in the watershed. Average seasonal effluent concentrations for suspended solids were consistently below 10 mg/L and removal rates ranged between 80 and 95%. Event mean *E.coli* densities in effluents were below the 100 CFU/100 mL receiving water limit for recreational areas, which is rare for ponds (Graham et al., 2003).

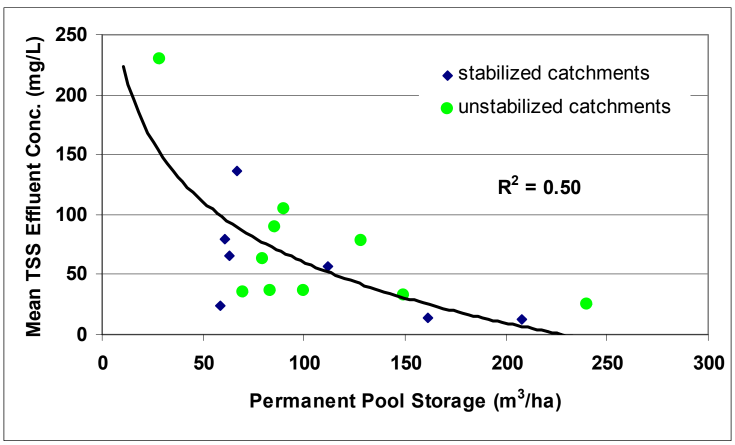


Figure 3.1: Relationship between permanent pool storage and TSS concentrations for stormwater ponds and wetlands in Richmond Hill, Ontario

Detailed evaluations of ponds and wetlands can provide valuable information on the efficacy of particular designs for specific drainage conditions, but they do not reveal whether or not these designs accurately represent the full range of practices employed in any given area. A survey by Olding *et al* (2004) of effluent concentrations from several stormwater ponds and wetlands after rain events provides a general understanding of how well these end-of-pipe controls are operating in the Town of Richmond Hill's jurisdiction, just north of Toronto. In this study, effluent concentrations of suspended solids were determined from grab samples collected within 24 hours of rain events. Figure 3.1 plots permanent pool storage against mean effluent suspended solids concentrations for facilities constructed after 1995. Only those facilities monitored for the same 5 rain events in 2001 were included in this plot to ensure comparability of results. Regression analysis indicated that permanent pool storage explains roughly half of the variation in mean effluent concentrations of suspended solids. Other factors influencing effluent concentrations may include extended detention storage, drawdown time, outlet structure type, facility age, and catchment characteristics. Although not obvious from the abbreviated data set used in Figure 3.1, the status of drainage areas proved to be a particularly important variable. Based on operational monitoring of stormwater facilities over three years, the study authors reported substantially higher mean effluent concentrations from facilities serving drainage areas under construction compared to those from stabilized drainage areas (Olding *et al*, 2004).

Hydrodynamic separators are classified in the OMOE stormwater manual as end-of-pipe controls, but they are not generally recommended by stormwater practitioners as the final element in a treatment train because as stand-alones they do not provide for erosion or water quantity control. In Ontario, they have often been used in re-developments for small drainage areas (< 2 hectares) or as retrofits when space constraints preclude the use of ponds or wetlands.

A review of literature on several different types of hydrodynamic separators was conducted under the SWAMP program (2004). A wide range of performance results were reported. Meaningful performance comparisons were not possible because of inconsistent methods and standards used to assess system effectiveness. Under typical climatic conditions, the literature suggests sediment removal rates of between 30 and 70% and effluent concentrations generally higher than other types of BMPs (Strecker *et al*., 2003). Many systems are designed with high flow bypasses to prevent re-suspension of trapped solids, resulting in significant performance reductions during large storms. Regular clean-out of the units every 6 months to a year is key to ensuring design performance levels are sustained.

3.3 Stormwater BMP Databases

Two stormwater management databases were investigated as part of this literature review. The first source was the National Stormwater Best Management Practices (BMP) Database, developed by the American Society of Civil Engineers (ASCE) and the US Environmental Protection Agency (EPA). The second source was the National Pollutant Removal Performance Database, developed by the Centre for Watershed Protection (CWP).

The National Stormwater BMP Database provides a compilation of over 200 BMP monitoring and evaluation studies from locations across the United States, representing a variety of BMP types. Protocols have been established for data collection, storage, reporting and analysis and only studies that conform to the protocols are included in the database. New studies are added to the database on an ongoing basis. There are a large number of water quality variables included in the database; the more commonly reported variable groups include general chemistry, solids, nutrients, metals, organics and bacteria.

The online search engine can be used to retrieve data on BMP performance using specified search criteria (facility type, state, water quality parameters, etc.). Study summary tables are available which provide information on each project, including: watershed characteristics, facility design, monitoring program information and study results. For a portion of the studies, a text summary is available which provides a synopsis of the above information along with a BMP diagram. Detailed reports are also available which provide statistical performance summaries for each water quality parameter evaluated in the study. A spreadsheet of water quality results is provided which includes a record of average influent and effluent concentrations for each water quality parameter reported for each facility. The database website also houses a number of documents detailing the established study requirements and giving guidance on preferred practices for BMP monitoring. The statistical summary spreadsheet was used to collect performance data for various categories of facilities that were located in the designated search area and reported on the water quality variables that were of interest. The standardization of study methods and reporting practices allowed for direct comparisons of the study results to be carried out.

The Second Edition of the CWP National Pollutant Removal Database for Stormwater Treatment Practices was prepared in 2000. The database includes 153 BMP monitoring studies from the United States and Ontario representing various BMP types. Only a hard copy of the database, consisting of a collection of study data sheets, was available for review. Limited study information is provided in the document, including the number of storm events monitored, watershed area, land use and treatment volume. Study results are reported primarily in the form of percent mean removal efficiency of various pollutants such as solids, nutrients, metals and bacteria. The percent mean removal efficiency values are reported in a variety of ways, on a mass basis, on a concentration basis or under the category of "other" which includes both mass balance and flux analysis methods. Influent and/or effluent concentrations are reported for some of the studies. The database includes a summary table that reports the median removal efficiencies for each BMP type based on all of the study results for each category on a nationwide basis.

Table 3.2 compares median removal efficiencies for selected stormwater practices from the two North American databases to estimates determined from various literature sources for the Toronto Wet Weather Flow Management Master Plan. The majority of studies in the databases are for ponds, wetlands, media filters or filtering pracitices and swales. There were few studies on infiltration trenches, porous pavement and source controls. The ASCE database had 16 hydrodynamic separator studies, but the CWP database had only two. Based on the studies included in the database, wet ponds, wetlands and infiltration/filtration practices were the most effective practices. Dry ponds registered higher removal rates in the ASCE database primarily because of volume (and mass) reductions in the facilities. On average, outflow from dry ponds in the ASCE/EPA database was only 70% of inflow (Strecker, 2003). In some jurisdictions it would appear that dry ponds act partly as infiltration basins.

Table 3.2: Median TSS removal efficiencies (%) for selected stormwater practices

	CWP database (2000)	ASCE database (2003)	Toronto WWFMMP (2003)
Wet Ponds	80	90	80
Dry Ponds	47	75	60
Wetlands	76	75	70
Infiltration Trenches	n/a	n/a	n/a
Filtering Practices	86	85	n/a
Porous Pavement	95	n/a	n/a
Grassed Swales	81	68	80
Ditches	31	n/a	40
Hydrodynamic devices	nsd	48	60

Sources: Centre for Watershed Protection (CWP) database (2000); ASCE/EPA database (Strecker et al, 2004). Toronto WWFMMP (2003).
Note: ASCE values are approximations determined from box plots provided in Strecker et al, 2004. Filtering practices are labeled as 'media filters' in the ASCE database.
nsd = not sufficient data

Table 3.3: Median TSS effluent concentrations for stormwater BMP types.

	TSS (mg/L)		TP (mg/L)		PO_4 (mg/L)		NOx (mg/L)		Cu (µg/L)		Zn (µg/L)	
	CWP	ASCE	CWP	ASCE	CWP	ASCE	CWP	ASCE	CWP	ASCE	CWP	ASCE
Wet ponds	17	10	0.11	0.11	0.03	0.07	0.26	n/a	5.0	5.0	30	30
Dry ponds	28	29	0.18	0.13	n/a	n/a	n/a	n/a	9.0	19.0	98	83
Wetlands	22	7	0.20	0.11	0.07	0.07	0.36	n/a	7.0	3.0	31	50
Infiltration Practices	17	n/a	0.05	n/a	0.003	n/a	0.09	n/a	4.8	n/a	39	n/a
Filtering Practices	11	n/a	0.10	0.10	0.07	n/a	0.60	n/a	9.7	8.0	21	62
Bioswales	14	10	0.19	0.13	0.09	n/a	0.35	n/a	10	6.5	53	40
Ditches	29	n.a	0.31	n/a	n/a	n/a	0.72	n/a	18	n/a	32	n/a
Hydro-dynamic devices	nsd	78	nsd	0.11	nsd	n/a	nsd	n/a	nsd	10.5	nsd	90
Ontario PWQOs	n/a		0.03		n/a		n/a		5		20	

Sources: Centre for Watershed Protection (CWP) database (2000); ASCE/EPA database (Strecker et al., 2004).
Note: ASCE values are approximations determined from box plots provided in Strecker et al, 2004.
nsd = not sufficient data ; PWQO = Provincial Water Quality Objectives for receiving waters.

The heavy influence of influent concentrations on removal efficiencies has led several researchers to caution against using percent removals to characterize BMP performance. Several BMPs have been mischaracterized as ineffective simply because cleaner influent has resulted in low percent removal. Effluent concentrations provide a more meaningful (*i.e.* less biased and more direct) characterization of BMP effectiveness. Median effluent concentrations for a range of stormwater practices are provided in Table 3.3 for the CWP and AASCE databases. Note that median phosphorus, copper and zinc concentrations for most practices exceed Ontario receiving water standards.

Overall, the two databases appear to be in rough agreement for most practices. Wet ponds, wetlands and the various infiltration technologies once again come out as the most effective practices from a water quality perspective. Wetlands evaluated as part of the ASCE database appear to be more effective than those included in the CWP database.

3.4 Receiving Water Impacts of Stormwater BMPs

Until recently, it was generally assumed that water quality treatment and effective attenuation of peak flows by stormwater facilities would automatically translate into improved protection of receiving waters. This assumption, however, remains largely unproven. Maxted and Shaver (1997) attempted to shed some light on the problem by comparing physical habitat and biological measurements taken downstream of urban sites in Delaware with (n=8) and without (n=33) stormwater ponds. None of the eight controlled sites monitored showed any improvement in biological conditions over uncontrolled sites, but three sites appeared to have moderately better physical habitat quality.

Jones *et al*. (1997) performed a similar study in Virginia except that the monitoring program included benthic invertebrates, fish and habitat analysis downstream of BMPs (3 wet ponds, 1 dry pond, 1 retrofitted culvert, 1 riparian park land), and at reference sites with comparable drainage areas. In a few cases, upstream measurements were also conducted. Fish community results varied substantially but benthic indicies and habitat quality downstream of BMPs showed clear signs of degradation relative to reference sites and upstream stations. The authors nevertheless concluded that well designed BMPs can help reduce stormwater impacts on stream communities, but the biotic community structure, diversity and function will be fundamentally different than found in undisturbed streams.

Stribling *et al* (2001) reported on two receiving water impact studies conducted in Maryland. The first involved monitoring the effect of an assemblage of BMPs clustered within a single subwatershed. The BMPs were implemented to help restore what had previously been shown to have degraded benthic and fish communities as a result of urban stormwater runoff and unnatural debris. Comparison of monitoring results one year before and two years after the retrofit/restoration works showed no change in overall benthic index scores, although individual metrics such as ‘taxa richness’ and ‘percent dominant taxon’ did appear to improve for single locations. Fish surveys showed greater indications of improvement, but it was not clear how the stocking of more sensitive species of fish after restoration may have influenced the results. Further monitoring is required to determine whether or not benthic communities will improve over a longer time frame, and newly introduced fish will continue to establish reproducing populations.

The second study conducted by Stribling *et al* (2001) compared instream biological conditions at stream locations with and without stormwater retention ponds and locations with minimum stormwater stressors (*i.e.* less than 5% imperviousness). Results showed that the stream sites with minimum stormwater stressors did generally have better ecological conditions than both groups of sites exposed to stormwater runoff. However, there was no difference between the two groups of stream locations with stormwater stessors, suggesting that single ponds in isolation do little to enhance instream biologic conditions, although they may help to improve the chemical quality of receiving waters. It remains to be determined whether controlling all stormwater stressors within an entire subwatershed or headwater stream reach through multiple BMP types would result in biologic conditions similar to reference sites.

Possible explanations for the absence of any proven benefit of ponds and wetlands to instream ecological conditions include inadequate facility design, changes in water temperature, increased surface runoff volumes, construction period impacts, or the infrequent but potentially significant damage to receiving waters caused by runoff events that exceed the design capacity of the facilities. MacRae (1996) demonstrated that increased runoff volumes following urbanization can cause substantial channel enlargement due to increased frequency of geomorphically significant mid-bank flows. Many receiving water impact studies fail to adequately control for other stressors upstream of the facility being evaluated. Progress on understanding the benefit of BMPs to receiving waters will require more detailed studies that better link causes to effects, and use a consistent set of protocols that facilitate inter study comparisons (Strecker and Urbonas, 2001).

4.0 SYNTHESIS OF MONITORING STUDIES

This chapter provides an overview and synthesis of the studies conducted under the SWAMP program. For the purpose of discussion, studies are categorized as end-of-pipe (9 studies) and conveyance facilities (2 studies). Source controls were not investigated under the program. In addition to extensive field-data collection, literature reviews were also conducted as part of some studies.

All of the studies were conducted within the Greater Toronto Area. The climate in this area is classified as humid continental, with cold winters and warm, humid summers. Lake Ontario has a moderating effect on the climate. Average daily temperature for the region is approximately 13°C, ranging from -5°C in January to 22°C in July. The mean annual precipitation for the Toronto area is roughly 800 mm, 17% of which falls as snow. Mean monthly precipitation values for the cold (December to April) and warm (May to November) seasons are 66 and 68 mm, respectively.

4.1 End-of-Pipe Facility Evaluations (9 Studies)

As indicated previously, nine of the eleven monitoring and evaluation studies completed under the SWAMP program involved end-of-pipe facilities. These include four wet ponds, one stormwater wetland, one underground storage tank, two oil grit separators and one flow balancing system. The reader is referred to the individual SWAMP reports for detailed descriptions of the facility design and study methodologies. The following sections provide a brief description of the facilities, monitoring programs and data analysis methodologies, followed by a comparative analysis of the main study findings.

4.1.1 Site Descriptions and Context

4.1.1.1 Pond-Wetland - Markham

The Markham pond-wetland system replaced a much smaller water quantity dry pond. The facility consists of a sediment forebay, wet pond and wetland and is a unique example of a centralized (or regional) facility treating stormwater runoff from a drainage area several times larger than the typical single-subdivision stormwater pond found in Ontario (Figure 4.1). Stormwater enters the facility through two inlets at the west end of the sediment forebay. Flow from the south inlet passes through a 250 m vegetated channel before discharging into the forebay. A submerged weir separates the forebay and wet pond. Flow exits the wet pond through a 'distributed runoff control' structure consisting of a reverse slope feed pipe, inlet chamber and proportional weir. The structure is designed to release three quarters of the total extended detention volume for the 25 mm event over the first 24 hours, with the remainder draining over a period of 3 to 6 days. Baseflow is augmented through a small orifice plate connected to a perforated inlet control riser pipe. Runoff from events larger than 25 mm over 4 hours bypass the wetland and spill from the wet pond directly over a wide overflow weir to the wetland outlet.

4.1.1.2 Retrofit Pond – Harding Park, Town of Richmond Hill

In 1995, the Harding Park pond, located in the Town of Richmond Hill, was converted from a water quantity dry pond to a multi-celled wetpond/wetland designed to improve stormwater quality and meet erosion control

Figure 4.1: From top left to right - Markham pond/wetland, Harding Park Retrofit Pond, Rouge River Highway Pond, Aurora wetland, Dunkers Flow Balancing System and Eastern Beaches Underground tank.

objectives. The pond retrofit was part of a detailed regeneration plan for German Mills Creek, which includes pollution prevention efforts, establishment of buffer zones, initiation of native planting programs, improvements to community access of natural areas and enhancement of aquatic and terrestrial habitats. The small wetland and forebay are separated from the pond by aggregate berms inlaid with impermeable geotextile. Hickenbottom risers wrapped with geotextile provide hydraulic control from the forebay to the pond and again from the wet pond to the wetland. The wetland does not have a permanent pool and is primarily vegetated with emergent macrophytes.

4.1.1.3 Stormwater Pond – Heritage Estates, Richmond Hill

Constructed in 1987, the Heritage Estates pond in the Town of Richmond Hill is older than other ponds monitored under the SWAMP program. Unlike most older ponds, however, the pond had a permanent pool storage volume comparable to more current pond designs and was designed to provide both water quality and quantity control. The outlet control structure consists of a 1.8 meter wide rectangular weir, which provides the necessary control to maintain pre-development flow rates for the 5 and 100 year storms under full development.

4.1.1.4 Highway Stormwater Quality Retention Pond – Toronto

This stormwater pond was constructed in 1995 by the Ontario Ministry of Transportation to address water quality and aquatic habitat concerns related to runoff from a portion of the 401 Highway. The pond discharges to the Rouge River in Toronto. Approximately 75% of the drainage area is used for transportation, while the remaining 25% is primarily residential.

The facility is long and narrow with a length-to-width ratio of 10:1 (Figure 4.1). A submerged berm partitions the pond into a forebay and a treatment/retention zone. Flow exits the facility via a reversed-slope pipe that draws water from below the surface of the pond such that floatables are trapped in the pond and effluent temperatures are cooler than they otherwise would be. The outlet chamber contains a sluice gate for control of the outflow rate, which was fully open during the entire monitoring period.

4.1.1.5 Stormwater Wetland – Aurora

This wetland was designed and constructed as a dry pond in 1988, but it evolved naturally into a wetland as moist conditions attracted aquatic plants. It has no permanent pool, other than in the forebay, and becomes dry during periods of infrequent rainfall. Modification to the outlet structure prior to the study created an extended detention capacity that increased the time that stormwater resides in the facility and created an event drawdown period of 3 to 5 days. A greenhouse was constructed within the wetland in 1996 to help determine the role temperature plays in wetland treatment and to evaluate its potential for enhancing performance during the cold season (Figure 4.1). The drainage area consists primarily of medium density residential land use with roughly 30% agricultural land use.

4.1.1.6 Dunkers Flow Balancing System - Toronto

Based on a stormwater/CSO treatment system originally developed and patented in 1978 by Karl Dunkers in Sweden, the Toronto flow balancing system consists of five cells separated by berms and pontoon-supported solid and perforated curtains anchored to the bottom with weights (Figure 4.1). The perforated curtains have variable width openings designed to promote plug flow by minimizing short circuiting of flow. The Toronto Dunkers facility incorporates both storage and treatment components. The first three cells function in the conventional storage mode. Stormwater enters cell 1 displacing the contents of the storage cells into Lake Ontario through a swing gate overflow structure in cell 3. The collected runoff in cell 1 is pumped into the 'treatment system' consisting of cells 4 and 5.

Cell 4 was designed as a long rectangular vessel, intended to serve as a sedimentation basin for the removal of suspended solids. Cell 5 is a wetland, intended to remove the lighter suspended pollutants and some dissolved pollutants. Cell 5 discharges to Lake Ontario through a separate outlet weir that is 1 cm lower than the cell 3 outlet. Cells 1 to 3 provide hydraulic buffering such that the flow through cells 4 and 5 can be controlled to provide optimum treatment.

The division of the facility into storage and treatment components is conceptual. In practice, the settling of suspended material and other pollutant removal mechanisms will affect the water quality wherever conditions are suitable. For example, much of the larger and heavier suspended particles are expected to settle out of the stormwater in the forebay and in the first storage cell.

The City of Toronto Dunkers facility does not rely on lake water flowing back into cell 3 via the outlet structure to replace the pumped-out volume. In fact, the swing gate outlet structure in cell 3 inhibits the flow of lake water into the facility, protecting the facility from turbulence caused by lake waves or storm surges. Instead, lake water is pumped continuously into cell 3 and another pump continuously transfers water from cell 1 to cell 4. Thus, under dry-weather conditions, water is circulated continuously through the five cells. This circulation inhibits anaerobic conditions and helps maintain the health of the wetland.

A second pump was installed to transfer water from cell 1 to cell 4 during and after wet-weather events. The second pump is triggered if the peak inflow rate exceeds 4 m^3/s. The normal hydraulic load on cells 4 and 5 is thus doubled, and the chance of discharging untreated stormwater from cell 3 is reduced. Once triggered, the second pump remains on for 60 hours.

4.1.1.7 Underground Detention Tank – Eastern Beaches, Toronto

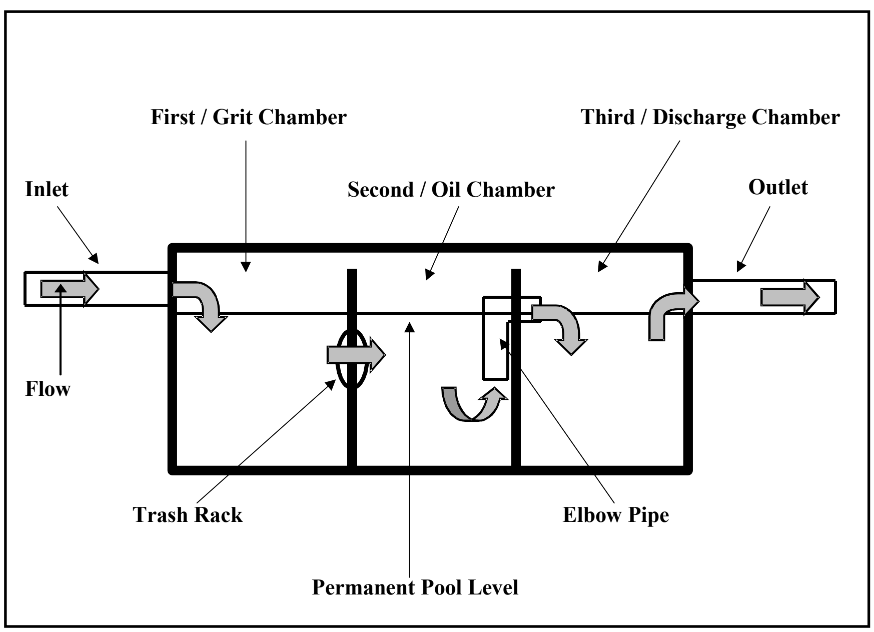
The underground detention tank was put into operation in 1995 by the City of Toronto to reduce adverse impacts of both stormwater and combined sewer overflows (CSO) on Lake Ontario in the Eastern Beaches area. The tank is divided into two compartments: a combined sewer overflow compartment and a stormwater control compartment. The CSOs collected and detained in the CSO compartment are pumped to the Lakefront Interceptor when capacity in the interceptor is available to convey them to the treatment plan. An overflow from the CSO compartment to the storm compartment may occur if the CSO volume is greater than the available storage volume.

The storm compartment receives and detains stormwater for an 8-hour period after the runoff event ceases. After detention, the supernatant is pumped 400 m off-shore to Lake Ontario and the subnatant is drained to the CSO compartment and eventually conveyed to the treatment plant. When the water level in the storm compartment rises to a certain height during the runoff event, the storm pump is initiated to pump the excess runoff 400 m off-shore to the Lake. If the water level rises to the weir height then a near-shore overflow is triggered through the weir to the Lake. In the future, when the Kingswood Trunk Relief Sewer (KTRS) along Queen Street East is constructed, the proposed KTRS will be oversized to provide in-line storage for the CSOs currently discharged to the tank. As a result, the Eastern Beaches detention tank would ultimately receive stormwater only. The two compartments would be interconnected, and the settled sludge after the detention would be pumped to the LFI for further treatment at the Ashbridges Bay treatment plant.

4.1.1.8 Oil Grit Separators - Toronto

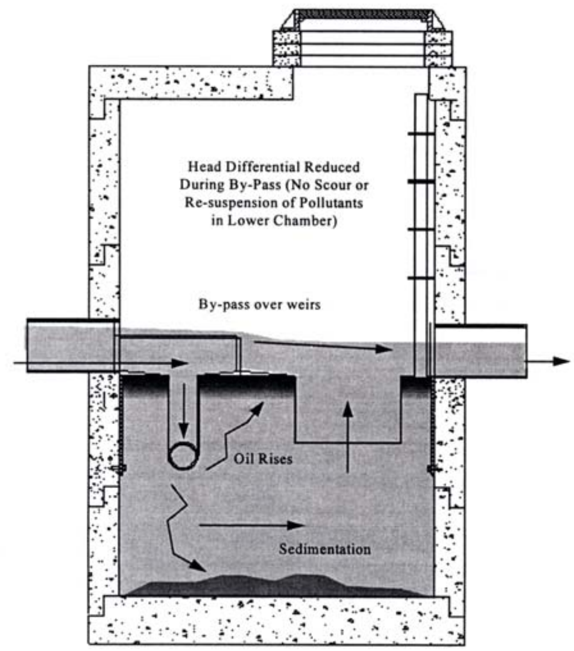
Oil Grit Separators (OGS) are functionally distinct from the other end-of-pipe technologies described above. While all the technologies rely to some extent on settling for suspended solids removal, ponds and wetlands do so by storing and detaining water over extended time periods, whereas OGS provide treatment in real-time through hydrodynamic control of flow in specially designed chambers. Unlike detention facilities, OGS do not provide extended detention and therefore are unable to control peak flows. In most current OGS designs, high flows are bypassed to prevent re-suspension of trapped sediments. Free oils and greases are removed through phase separation of liquids.

There are many types of OGS available commercially. Several products are reviewed based on available literature in the SWAMP report on OGS technologies. The report also includes a detailed assessment of two types of OGS commonly used in Ontario at the time of monitoring (1996-97): a standard 3-chamber OGS and a Stomceptor® model STC 4000.



The 3-chamber OGS, shown to the right, consists of a concrete pre-cast tank with three chambers. The first chamber is the sediment chamber, which traps heavy grit and large floating trash washed off from the streets. The second chamber is the oil chamber. As the water level of the second chamber rises, water is forced through two elbow pipes into the third chamber. The submerged intake of the elbow pipe facilitates capture of free oil, which is lighter than water and therefore floats to the top. The third chamber serves primarily as the discharge point for treated runoff, although it also provides further opportunities for suspended solids settling. The opening that discharges the treated runoff to the sewer also determines the permanent pool level. Once the hydraulic capacity of the trash rack or elbow pipes in the first chamber is exceeded, overflow into the second chamber will occur through the openings located at the top of the interior walls. The permanent pool is an important feature for pollutant removal as it helps to slow down incoming flows, thus improving the settling of suspended particles.

The figure to the right shows the design of the Stormceptor® OGS and operation during high flow conditions. The concrete precast unit consists of a treatment chamber and a by-pass chamber. Stormwater runoff flows into the by-pass chamber from the inlet sewer pipe. Low flows are diverted into the treatment chamber by a weir and drop pipe arrangement. The drop pipe is configured to discharge water tangentially along the treatment chamber wall. Water flows through the treatment chamber to the outlet riser pipe, which is also submerged. The flow rate through the outlet pipe is based on the head at the inlet weir. Stormwater is discharged back into the downstream section of the by-pass chamber, which is connected to the outlet sewer pipe. Oil and other liquids with specific gravity less than water will rise in the treatment chamber and become trapped above the submerged outlet riser pipe. Sediment will settle to the bottom of the chamber by gravity forces. According to the manufacturer, the circular design of the treatment chamber is critical in preventing turbulent eddy currents and promoting settling (Stormceptor®, 1998). During high flow conditions, stormwater in the by-pass chamber will overtop the weir and be conveyed to the outlet sewer directly. The overflow creates a backwater effect on the outlet riser pipe due to head stabilization between the inlet drop pipe and outlet riser pipe which helps to ensure that excessive flows will not be forced into the treatment chamber and re-suspend settled material.



Source: Stormceptor®, 1996

4.1.2 General Study Methodology for End-of-Pipe Facility Studies

Consistent study and reporting methods were employed to facilitate comparisons among various studies. In general, the wet pond and wetland studies consisted of six main components:

- Water Quantity
- Temperature

- Water Quality
- Sediment Analysis
- Particle size distributions
- Vegetation communities

A summary table of the equipment used and data collection methods for each study is provided in Appendix B.

4.1.2.1. Monitoring Program

Water Quantity

Hydrologic monitoring typically included coordinated measurements of rainfall, runoff (influent and effluent) and water levels. Rainfall data were collected from tipping bucket gauges at the site or within a reasonable distance from the site. Flow was monitored continuously using loggers and area-velocity probes in storm sewers, or with flow control structures and calibrated stage-discharge curves. Flow monitoring devices were usually only installed during the summer/fall season (May to Nov.) due to the potential for damage caused by freezing in the winter/spring season (Dec. to April). Only 2 of the 9 sites were serviced with electricity.

Water Quality

Composite water samples were usually collected at the inlet and outlet of the treatment facility using automated wastewater samplers. Several pond studies also included monitoring stations at intermediate locations in the facility (*e.g:* sediment forebay outlet). If possible, composite sample aliquots were proportioned according to flow, but at several sites, technical constraints necessitated collection of time-integrated samples at one or more monitoring stations.

Grab samples were typically collected during the winter/spring season. Grab samples are collected at a single point in time and therefore do not provide a reliable estimate of the event mean concentration. However, they are considered to provide a reasonable estimate of concentrations during interevent periods and long duration snow melt events because under these conditions influent and effluent concentrations do not vary significantly.

Water quality samples were preserved (metals and nutrients) and submitted to the Ministry of the Environment Laboratory in Toronto immediately following collection. Use of the same lab for all of the studies helped to ensure comparability of results. Table 4.1 lists variables for which analysis was undertaken in most SWAMP studies. The variables are organized into six major groups. Samples collected at the OGS sites were analyzed for metals, TSS and solvent extractable (oil and grease) only. All laboratory analytical procedures were conducted by Ontario Ministry of the Environment laboratories following principles outlined in Standard Methods (Eaton *et al*., 1995). OMOE laboratory analytical procedures are summarized in individual SWAMP reports.

Table 4.1: **Water Quality Variables Analysed in SWAMP Studies**

General Chemistry	Metals	Nutrients	Bacteria	Herbicides and Pesticides*	Polycyclic Aromatic Hydrocarbons*
Alkalinity	Aluminum	Ammonia-N	*Escherichia coli*	2,4-dichlorophenol	Napthalene
Carbon (DIC)	Arsenic	Nitrate-N		2,4,6-trichlorophenol	2-methylnapthalene
Carbon (DOC)	Barium	Nitrite-N	*Fecal streptococcus**	2,4,5-trichlorophenol	1-methylnapthalene
Chloride	Beryllium	Phosphate		2,3,4-trichlorophenol	2-chloronapthalene
Conductivity	Cadmium	Total Phosphorus	*Pseudomonas aeruginosa**	2,3,4,5-tetrachlorophenol	Acenapthalene
Dissolved Solids	Calcium			2,3,4,6-tetrachlorophenol	Fluorene
	Chromium	Total Kjeldahl Nitrogen-N		Pentachlorophenol	Phenanthrene
pH	Cobalt			Silvex	Anthracene
Silicon	Copper			Bromoxynil	Fluoranthene
Solvent Extractable	Iron			Picloram	Pyrene
	Lead			Dicamba	Benzo(a)anthracene
Suspended Solids	Magnesium			2,4-D-propionic acid	Chrysene
	Manganese			2,4-D	Benzo(b)fluoranthene
Total Solids	Mercury			2,4,5-T	Benzo(k)fluoranthene
Turbidity	Molybdenum			2,4-DB	Benzo(a)pyrene
	Nickel			Dinoseb	Dibenzo(a,h)anthracene
	Selenium			Diclofop-methyl	Benzo(g,h,i)perylene
	Strontium				1-chloronapthalene
	Titanium				Perylene
	Vanadium				Indole
	Zinc				5-nitroacenapthene
					Biphenyl

*Not analyzed in all SWAMP studies
Note: OGS studies only included analysis of solids, solvent extractable (oil and grease) and metals

<u>Particle Size Analysis</u>

Particle size analysis of suspended solids was undertaken on samples collected at all monitoring stations using an optical laser light diffraction method (Coulter Particle Size Analyzer) and results were reported by size class in percent by volume.

<u>Temperature</u>

Temperature was monitored in ponds and wetlands using automated equipment set to record at regular time intervals (usually 15 minutes). Units were installed at key points within the facility (inlet, outlet). Probes were typically submerged 50 cm below the dry weather water surface. Temperature was not monitored in the OGS studies because the facilities are not expected to have an impact on temperature.

Sediment Analysis

In most studies, samples of sediments deposited in the facilities were analyzed for various chemical constituents to determine disposal options and, in some cases, to assess the suitability of the substrates for aquatic habitat. In the OGS systems, the physical characteristics (*i.e.* volume, dry weight, density) of trapped sediment were also determined to assess the quantity of sediment removed over the entire monitoring period.

Aquatic and Vegetation Communities

Vegetation communities were examined in a few studies. The effectiveness of manual planting versus natural regeneration was assessed in terms of biodiversity and time required to establish the vegetation communities. Studies included measurements of root mass and plant growth over the monitoring period and assessments of plant diversity. A separate study investigated the use of algae as an indicator of biological response to differences in physical and chemical conditions in the forebay and ponds of the Harding Park retrofit and Highway stormwater quality detention facilities. Bio-assays using mayfly, midge and minnow lethal and sublethal endpoints, and bulk sediment chemistry were undertaken in the Aurora wetland to determine the quality of sediments. The reader is directed to individual reports for results of these studies.

4.1.2.2 Data Analysis

Data analysis for water quantity included calculations of volumetric flow balances, peak flow attenuation, hydraulic detention and residence times, outlet flow duration, peak to peak lag times and runoff coefficients. Methods used to calculate these components of flow are widely available in literature and are therefore not discussed in this report.

Statistical analysis of water quality results for most of the SWAMP studies was performed using a software package developed by the Ministry of Environment and Energy for use in stormwater constituent analysis. The package uses probability distribution estimation (PDE) techniques to generate the mean, standard deviation and 95% confidence intervals for data sets containing left censored data (*i.e.* data at or below the limit detectable by lab analytical equipment). These techniques (*e.g.* maximum likelihood estimation) generate values for data below the detection limit based on the log-normal probability distribution of the non-censored data. In instances where PDE techniques could not be used, left censored data were assigned a value equal to half the detection limit. These methods were particularly useful in generating statistics for organic compounds, heavy metals and other constituents typically found at very low concentrations in stormwater.

A load based percent removal efficiency equation was used in all studies to assess the effectiveness of the facilities in removing contaminants from stormwater. This equation requires values both for the event mean concentration (EMC) and the volume of runoff (V) to determine total mass loading into and out of the facility for all events monitored during the study period, as follows:

$$Total\ Load\ Removal\ Efficiency = \left[\frac{\sum_{j=1}^{m} [(V_{i_j} \times EMC_{i_j}) - (V_{O_j} \times EMC_{O_j})]}{\sum_{i=1}^{n} [V_{i_j} \times EMC_{i_j}]} \right] \times 100\%$$

where m = number of storm events monitored
i = inlet
o = outlet

During the winter/spring period (December 1 to April 31), when flow was not monitored at several sites, concentration-based removal efficiencies for individual events were typically determined from inlet and outlet grab sample concentrations (C), as follows:

$$Concentration\ based\ Removal\ Efficiency = \left[\frac{(C_i - C_O)}{C_i} \right] \times 100\%$$

This method assumes a good hydrologic water balance (*i.e.* the volume entering the pond during an individual event was equal to the volume leaving the pond). In the Aurora wetland, Eastern Beaches and OGS studies, flow was monitored during the winter, and therefore winter removal efficiencies were calculated using the load based method.

4.1.2.3 Modelling

At the OGS sites, the field data were used to calibrate and apply a water quantity/quality model (PC-SWMM 98), run in continuous mode for the entire study period. The purpose of the modelling exercise was to (i) verify measured performance and sediment accumulation results, and (ii) estimate water quality loads and removal efficiencies for rainfall events during which measured flow and/or quality data were not available.

A model was also applied to the Harding Park and Heritage Estates sites to predict total flows and TSS loads. Results were run for the historical rainfall period to estimate long term performance of the ponds and provide information on required sediment removal intervals for the facility.

4.1.3 Study Area Comparison

Table 4.2 summarizes characteristics of the catchments serviced by the seven main EOP facilities. As indicated, the drainage areas served by these SWMPs vary from 16.8 hectares to 600 hectares. The majority of them service more than 50 hectares and would therefore be considered as “regional” facilities which would serve a significant subdivision or even an entire Secondary Plan area. Most of these installations serve predominantly residential areas (from 60% to 100% of their catchment area) with the exception of the highway stormwater pond, which was constructed to treat runoff from a multi-lane 400 series highway in Toronto. Some of them have a significant proportion of their area (15% to 40%) in commercial, industrial or institutional land use. Two of the facilities (the

Dunkers facility and the Eastern Beaches storage tank) serve older established areas within the City of Toronto, whereas the remainder serve more recently developed urban areas in the Greater Toronto Area (commonly known as the "905 area"). For the most part, the latter areas have their roof leaders (or downspouts) disconnected from the storm sewer system whereas the former have a relatively high proportion of properties with connected roof leaders. Soils in the drainage areas vary in texture from sand to clay till. The former have much greater potential to infiltrate rainfall and snowmelt.

***Table 4.2*: Catchment Characteristics for EOP Facilities**

Facility	Drainage Area	Predominant Soil Texture	Downspout Disconnection	Receiving Water
Heritage Estates Pond	52.4 ha. 90-100% residential	Clay loam	Yes	Upper East Don River
Markham Pond-Wetland	600 ha. 60% residential 7% commercial 33% open space	Silty-sand	Yes	Upper Morningside (Rouge River tributary)
Harding Park Retrofit Pond	16.8 ha. 90-100% residential	Clay till and some sand till	Yes	German Mills Creek (Don River tributary)
Dunkers Flow Balancing System, Toronto	174 ha. 60% residential 40% combination industrial, institutional, commercial and open space	Sandy silt to sand	Partially	Lake Ontario
Aurora Wetland	82.4 ha 30% rural agricultural 61% residential 4% commercial/ institutional 5% parks and open space	Sandy silt and clayey silt	Yes	Tannery Creek (East Holland River subwatershed)
Highway Stormwater Pond, Toronto	129 ha. 75% transport 25% residential	Silty sand to sandy silt. There is considerable fill throughout the area due to the construction of Highway 401.	No. A major portion of the catchment is transportation land use.	Lower Rouge River
Underground Storage Tank, Toronto	114 ha (storm sewers) 93 ha (combined sewers) 85% residential 15 % commercial and industrial	Sandy silt to sand	Partially	Lake Ontario and Ashbridges Bay Sewage Treatment Plant
OGS studies, Markham and Toronto	3-Chamber: 4.0 ha Stormceptor®: 2.9 ha Home Depot parking lots	n/a	Drainage area does not include roof runoff	3- Chamber: Rouge River Stormceptor®: Lake Ontario

4.1.4 Facility Design Comparison

Table 4.3 compares facility design characteristics with guidelines provided in the OMOE Stormwater Management Planning and Design (SWMP) Manual (1994/2003).[1] Several of the facilities monitored were constructed prior to publication of the guidelines, but were retrofitted or reconstructed after 1994, when the guidelines were released. The Heritage Estates pond is the oldest facility and did not undergo any design changes prior to monitoring in the mid 1990s.

Not all of the facilities meet the criteria in the SWMP manual. For example, two of the facilities (Harding Park and Heritage Estates) do not meet the minimum recommended length to width ratio of 3:1. All of the pond type facilities studied have a permanent wet pool (except the Aurora wetland). However, their sizes vary widely (from 60 to 225 m^3/ha) in relation to the 'Enhanced Protection' (Level 1) requirement of 110 to 150 m^3/ha for the level of imperviousness in the catchment serviced. In most cases the depths of the permanent pools are in the general range recommended (from 1 m to 3 m). The Aurora wetland and Harding Park pond were retrofits of older dry ponds and space constraints prevented strict adherence to the guidelines. These two facilities were designed to provide a 'Normal' level (level 2) of protection to downstream receiving waters.

The extended detention storage in the monitored facilities varies considerably from around 16 m^3/ha to 130 m^3/ha. The OMOE recommends a value of 40 m^3/ha. The large extended detention storage in some facilities is often intended to provide for additional quantity and/or erosion control, which is frequently combined with the "active storage" requirement for water quality control.

The drawdown time for each of the facilities was estimated from monitoring data for events between 20 and 30 mm in size. Drawdown times in the wet ponds varied widely from a low of roughly 16 hours to a high of about 144 hours. Based on these estimates, four of the five wet pond/wetland facilities met the SWMP guideline of 24 hours for the 25mm 4-hour design event. The Dunkers FBS discharges to the lake, and therefore drawdown time is not an important consideration for the protection of the receiving water system.

Table 4.4 compares the OGS systems monitored to guidelines in the 1994 OMOE SWMP manual, which was the version of the manual current at the time of monitoring.[2] The unit area storage provided by the 3-Chamber and Stormceptor® OGS were below the minimum recommended in the 1994 manual. Note, however, that the Stormceptor® site has temporary storage upstream of the separator both within the drainage network and on the paved surface, and flow is distributed unequally to two parallel units of the same size. The first of these factors – additional upstream storage - helps to control flow rates and limit bypasses, thereby contributing to better treatment (i.e. improved effluent concentrations/loads). The second factor – unequal flow distribution to parallel units of the same size – reduces the effective storage of the combined units and may contribute to poorer overall

[1] It should be noted that two of the facilities (the Eastern Beaches tank and the Dunkers flow balancing system) are not specifically addressed in the OMOE guideline document.

[2] The minimum drainage area and unit area storage guidelines were omitted in the 2003 version of the manual. The manual now recommends, among other things, that OGS be implemented as part of a 'multi-component' approach to improving water quality, unless it can be determined that the technology achieves the desired water quality as a stand alone device.

Table 4.3: Facility design features compared to OMOE guidelines.

Design feature	Design Objective	OMOE (2003) guidelines for ponds	Markham Pond-wetland (reconstructed in 1997)	Harding Park Pond (retrofitted in 1995)	Heritage Estates Pond (1987)	Highway Stormwater Pond (1995)	Aurora Wetland (retrofitted in 1996)[1]	Dunkers flow balancing system (1997)[2]	Eastern Beaches Detention Tank (1994) [2]
Permanent Pool Depth (m)	minimize resuspension; avoid anoxic conditions	1-2 average; 3 max.	2.2 to 4.2	1.8 max	1.5	2.5 average 4.5 max.	less than 1 *(to permit aquatic plant growth)*	2.7	5.9
Permanent Pool Volume (m^3/ha)	protection of aquatic habitat	60 *(normal)* 125 *(enhanced)*[3]	129, 122[4]	60	131	80	negligible	225 *(cell 1 to 5)* 164 *(cell 1 to 3)*	Not applicable
Extended Detention Depth (m)	storage and flow control	1 to 1.5	1.6	approx. 2.8	not specified	1.7	approx. 0.5	not specified	Not applicable
Extended Detention Volume (m^3/ha)	protection of aquatic habitat	40	130 *(forebay and pond)*	116	not specified	80	16	not specified	Storm: 35 CSO: 43
Drawdown Time (hr)[5] *(25 mm storm)*	Suspended solids settling	24	approx. 144	approx. 26	approx. 18	approx. 30	approx. 96	approx. 15	Stormwater detained for 8 hours, then pumped offshore.
Length-to-Width Ratio	minimize short circuiting	at least 3:1 *(4:1 or 5:1 preferred)*	5:1	1:1	1:1	10:1 *(incl. forebay)*	2:1 *(wetland)* 4:1 *(+forebay)*	3:1 (*cell 1 to 3*)	Not applicable
Design Protection Level			Level 1 + erosion control *(enhanced)*	Level 2 *(normal)*	Pre-dates guidelines	Level 2 *(normal)*	Level 2 *(normal)*	Not applicable	Not applicable
Outlet Structure Design			Distributed Runoff Control; Bottom draw	Hickenbottom Top draw	1.8x1.7m rectangular weir; Top draw	600 mm reverse slope pipe to outlet chamber with sluice gate; Bottom draw	Combination Hickenbottom and rectangular weir; Bottom & top draw	Swing gate (cell 3) and rectangular weir (cell 5); Top draw	Stormwater supernatant pumped 400m offshore. CSO pumped to Sewage Treatment Plant.

1. The OMOE storage guidelines for wetlands (assuming 45% imperviousness) is 52 and 15 m^3/ha. for enhanced and normal protection levels, respectively. The extended detention storage is the same as for ponds (40 m^3/ha.)
2. There are no guidelines for Flow Balancing Systems or Underground Storage Tanks; The Flow Balancing System includes cells separated be permeable and impermeable curtains, and a pump-back feature to distribute flows and aid in treatment (see text).
3. Based on 45% surface imperviousness.
4. The Markham pond-wetland unit area storage volumes represent the whole system (forebay, pond, and wetland) and the forebay/pond, respectively.
5. The SWMP manual version used for the design of these facilities (OMOE, 1994) suggests using a drawdown time equation to measure 'detention time' (a confusion of terminology that was corrected in the later version of the manual). Drawdown values for individual facilities are approximations based on monitored data for events between 20 and 30 mm.

performance than would have been the case if the flow were equally distributed. These factors are not explicitly addressed in the OMOE sizing guidelines. It may also be noted that both systems, as they have been applied in the site drainage plan, are not ideal representations of how the technologies should be applied (although they may be typical of current practice) – a fact that should be borne in mind when interpreting results.

Table 4.4: Overview of drainage area characteristics, design parameters and provincial guidelines

Site and OGS design attributes and OMOE guidelines	Three-chamber OGS, Markham	Stormceptor® OGS, Etobicoke
Area draining to the monitored units	2.2 ha*	2.6 ha*
Type of drainage area	Paved parking lot servicing Home Depot store, >95% impervious	Paved parking lot servicing Home Depot store, >95% impervious
Number and size of units monitored	2 units, 31.5 m^3 and 15.5 m^3, permanent pool of 47.0 m^3	2 units, 17.8 m^3 each, permanent pool of 35.6 m^3 **
Storage-to-impervious drainage area ratio	Approx. 21.4 m^3/imp. ha	Approx. 14.0 m^3/imp. ha
Number of cells per unit	3 (grit, oil and discharge chambers)	2 (by-pass and oil/grit treatment chamber)
By-pass included in design	No	Yes
Flow restrictor provided	No	Yes
Upstream storage provided	No	Yes (paved surface and storm sewer)
Design criteria per OMOE SWMP (1994)$^+$	**-Drainage area less than 2 ha** **-30 m^3 storage per 1 ha imperviousness**	**-Drainage area less than 1 ha** **-15 m^3 storage per 1 ha imperviousness**

*the actual drainage area of both OGS, as estimated from monitoring data, is larger than the 'design' drainage area and therefore the storage-impervious drainage area ratio in the table is probably overstated. Actual drainage area for the 3 chamber and Stormceptor sites is estimated to be roughly 3.95 and 2.87 hectares, respectively.
** the 'effective' storage is likely less than stated because flows were not equally distributed to the two parallel units of equal size.
$^+$ OGS sizing criteria vary with OGS type and are not provided in the 2003 version of the SWMP manual.

4.1.5 Monitoring/Evaluation Results for End-of-Pipe Facilities

4.1.5.1 Water Quantity

Table 4.5 presents water quantity statistics for end-of-pipe (EOP) facilities based on measured inflow and outflow rates and volumes. In general, the rainfall events monitored fell mostly within the design storm size for the facilities, and did not cause significant overflow or bypass. The average event size ranged from 10 mm in the Eastern Beaches Detention Tank study to 25 mm in the Markham pond/wetland study. These event sizes are entirely appropriate for the evaluation of a facility's performance in controlling runoff peaks and improving water quality since the facilities are typically designed to capture and treat many small events per year. During events that exceed the extended detention storage capacity of the facilities, effluent quality would be expected to decline considerably, as would the capacity of the detention facilities to reduce peak flows. However, this is not particularly significant since the facilities were not designed to provide flood or water quality control for events larger than the design storm, which in most cases is the 2 year event.

Table 4.5: Average values over the monitoring period for selected hydrologic parameters at EOP facilities

Average Hydrologic Parameters	Markham Pond-wetland n=11	Harding Park Pond n=14	Heritage Estates Pond n=14	Aurora Wetland N=29	Rouge Highway Pond n=13	Dunkers FBS n=30	Beaches Detention Tank[1] n=43	3-Chamber/ Stormceptor OGS n=19/16
Rainfall (min/max) (mm)	24.8 (8 – 46)	22.5 (9- 64)	11.4 (4 – 51)	21.8 (2 – 38)	12.6 (5 – 28)	14.5 (4 – 31)	15.9 (1 – 58)	14/12[5] (4-24 / 4-20)
Inflow Vm. per Unit Drainage Area (m^3/ha)	45	100	51	57	74	50	52	155/89
Ratio of Perm. Pool Vm–to–Mean Runoff Vm	2.9	0.6	2.6	No perm. pool.	1.1	3.3	Not applicable	0.1/0.1
Runoff Coeff.: Observed (Design)[2]	0.16 (0.29)[2]	0.38 (0.39)	0.30 (0.39)	0.23 (0.27)	0.24 (0.45)	0.35 (0.39)	0.33 (0.39)	0.85/0.98 (1.0)
Peak Flow Reduction (%)	95	80	~78	~90	~40	~72	Not applicable	Not calculated
Detention Time (hrs)	30.7	5.3	8.6	Not calculated	1.8	~1[6]	8	Negligible
Outflow Duration (hrs)	130.2	Not available	60.2	~96	31.4[3]	~15	Not applicable	Similar to rainfall duration
Volumetric Flow Balance (%)[4]	0.5	11.1	1.9	16	1.1	No losses assumed	No losses assumed	No losses assumed

1. Statistics are for the stormwater compartment; summary only includes events equal to or greater than 5 mm.
2. Design runoff coefficients are theoretical values based on land use. The design value was greater than indicated above for the Markham pond because the facility was monitored before the catchment was fully developed.
3. Represents average 'drawdown time' defined as the time between attainment of maximum storage volume and the end of flow or re-establishment of pre-event baseflow.
4. Volumetric flow balances are calculated for events as the inflow minus outflow divided by the inflow, discounting baseflow. Positive values are primarily a result of exfiltration within the pond. If baseflow is added into the Rouge pond flow balance, the exfiltration component would be significant.
5. Does not include winter precipitation events (n=11/10)
6. Approximate value based on time delay between inlet and cell 3 hydrograph centroids for two large events. Cell 3 flow was crudely estimated by applying a weir equation at cell 3. The estimate does not consider water pumped to cell 4 during the course of the runoff event, which represents a relatively small proportion of total runoff.

The size of rainfall events monitored during the study and percent impervious cover has an important influence on unit area runoff volumes. For example, Heritage Estates and Harding Park ponds are both served by predominantly residential catchments with similar levels of drainage area imperviousness, but the Heritage Estates pond had half the unit area inflow volumes of the former, primarily due to differences in the size of rainfall events monitored in the two studies (Table 4.5). Conversely, the low average unit area inflow volumes and runoff coefficients for the Markham pond-wetland and the Aurora wetland reflect the relatively low levels of imperviousness in these catchments; both drainage areas were not fully developed at the time of monitoring.

With the exception of the OGS study, the average observed runoff coefficients are in all cases below the "theoretical" or design value based upon catchment imperviousness (Table 4.5). This observation suggests that, over the full range of events monitored, more rainwater is infiltrating than assumed, resulting in a lower "effective" imperviousness. This finding is not unexpected because design runoff coefficients are based on large rain events when the proportion of rainfall converted to runoff (i.e. the runoff coefficient) is larger than for more frequent events. Since facilities are sized based on these large events, the designs should provide better runoff and water quality control than expected on a seasonal average basis.

Average peak flow reduction by the ponds and wetlands monitored was significant, averaging 76%, with a range between 40 and 95%. The Rouge Highway Pond provided the lowest level of flow attenuation. In this case, the extended detention storage was double that recommended in the SWMP manual, but the outlet flow control structure was operated with the gate fully open, resulting in less than 20% of the available storage being used during a typical 25 mm event. Operating the facility with the gate partially closed would provide for improved flow control and better overall performance.

The average duration of outflows was highly variable ranging from less than 15 hours in the Dunkers facility to 130 hours in the Markham pond-wetland (Table 4.5). The outlet structure in the Markham facility is designed to release 75% of the extended detention for the two year event over the first 24 hours, and the remainder over a period of several days, in part to ensure baseflow is maintained in the downstream channel. Average detention times, calculated as the time delay between the inlet and outlet hydrograph centroids, were considerably less than the outflow durations, ranging widely from 1.9 hours in the Rouge River Pond to over 30 hours in the Markham pond-wetland.

In all cases, the volumetric flow balance (inflow volume minus outflow volume divided by inflow volume) is positive, indicating that, on average, more flow entered the facility than left it. Losses within the facility are primarily a result of recharge of water into the ground (or exfiltration) through the pond bottom and sides. Instrument errors in the measurement of flow are also an important source of inlet and outlet flow volume discrepancies.

The OGS systems were not evaluated for water quantity because they are not designed with extended detention storage, and therefore provide little or no benefit in controlling peak flows or augmenting baseflows. In the case of the Stormceptor unit, peak flows were probably somewhat attenuated by temporary storage provided upstream of the OGS on the parking lot surfaces and within the storm sewers as part of the site drainage plan, but only for larger storms.

4.1.5.2 Water Quality

Influent concentrations

As noted in section 4.1.2.1, water quality samples collected in each of the studies were analyzed for a wide range of water quality variables. Table 4.6 shows the average influent concentrations observed during the warm (May to November) and cold season (December to April) at each of the EOP studies for selected variables including Total Suspended Solids (TSS), nutrients (phosphorus and nitrogen compounds), metals, and bacteria. Organic compounds were frequently detected below detection limits and are therefore not presented in the Table.

Seasonal comparisons show that consistent differences in concentrations across all of the studies occur for only two water quality variables: chloride and *E.coli* . The higher winter/spring chloride concentrations are, of course, related to the application of road salts as de-icing agents during the cold season. *E. coli* and other bacteria are temperature dependent and experience significant die off as the temperature falls during the winter.

Comparisons among facilities show that the stormwater facility which drains a major transportation corridor (Rouge pond) has elevated concentrations of some metals relative to other sites; notably copper, zinc, cobalt and lead, although lead concentrations were higher in the predominantly residential Eastern Beaches catchment. Chloride, oil and grease, and TSS concentrations were also elevated in the Rouge pond above those of most other catchments.

Influent concentrations in Table 4.6 are compared to guidelines set by the Ontario Ministry of the Environment or aquatic threshold values derived from other literature sources (e.g. TSS, chloride) in order to identify contaminants that pose a potential threat to the health or recreational use of receiving water systems. Contaminants with mean influent concentrations that consistently exceeded receiving water standards include the following:

- TSS
- Chloride
- Cadmium
- Chromium
- Cobalt
- Copper
- Iron
- Lead
- Zinc
- *E.coli*
- Nitrite/nitrate
- Total phosphorus

Un-ionized ammonia also regularly exceeded the guideline at the Eastern Beaches Underground tank study. Other variables not on this list but which may be of concern include oil and grease (solvent extractables), poly aromatic hydrocarbons (PAHs) or selected herbicides/pesticides. These variables either do not have a receiving water objective or the objective was above the laboratory analytical detection limit and therefore could not be assessed.

***Table 4.6* :** Influent Average Event Mean Concentrations (AEMCs). Shaded values indicate AEMCs that exceed receiving water guidelines.

Variable	Influent AEMC Units	Inlet Average Event Mean Concentrations (AEMC) [1]																		Receiving Water Guidelines[4]
		Rouge River Highway pond		Harding Park Retrofit pond		Heritage Estates pond		Markham pond/wetland		Aurora Wetland		DFBS	Toronto Eastern Beaches Detention Tank			3-Chamber OGS		Stormceptor® OGS		
													CSO	Stormwater						
		winter/ spring	summer/ fall	winter/ spring	summer/ fall	winter/ spring	summer/ fall	winter/ spring	summer/ fall	winter/ spring	summer/ fall	summer/ fall		summer/ fall	winter/ spring	summer/ fall	winter/ spring	summer/ fall	winter/ spring	
General Chemistry		n=11	n=21	n=15	n=22	n=14	n=17	n-8-9	n=15	n=11	n=18	n=20[2]	n=3	n=12-13	n=9-11	n=15	n=11	n=14	n=7	
Suspended Solids	mg/l	394.7	331.4	270.0	345.0	194.7	175.7	291.2	313.7	79.7	135.1	117.1	57.0	163.4	68.0	98.2	132.8	103.1	133.2	25-80
Oil and Grease	mg/l	3.2	9.0	-	-	-	-	6.5	4.8	2.4	2.3	4.8	5.0	8.3	7.0	16.8	19.8	12.1	16.1	-
Chloride	mg/l	1689.1	205.7	497.0	22.0	880.6	25.3	612.1	95.6	181.7	4.2	53.9	39.0	87.1	1609.1	-	-	-	-	250
Carbon; DO	mg/l	4.7	9.3	3.9	3.4	-	-	5.2	7.0	-	-	7.1	6.2	6.4	6.9	-	-	-	-	-
Carbon; DI	mg/l	34.3	23.6	27.0	14.7	-	-	29.0	29.9	-	-	18.5	14.3	25.4	23.4	-	-	-	-	-
Metals		n=11	n=21	n=12-15	n = 20-22	n=14	n=17	n=9[3]	n=15	n=11	n=18	n=20	n=3	n=13	n=11	n=15	n=11	n=11	n=7	
Aluminum	ug/l	544.0	945.0	596.0	1422.0	-	-	1030.8	942.6	398.4	554.8	450.3	880.0	1011.8	470.0	418.1	565.9	408.9	762.4	-
Barium	ug/l	101.7	85.6	44.7	45.8	-	-	64.2	60.0	22.0	20.8	34.7	41.0	50.8	35.0	37.5	51.2	38.3	42.6	-
Cadmium	ug/l	0.2	0.9	1.5	0.6	2.4	2.1	1.0	0.6	0.7	1.2	0.3	0.8	1.2	1.0	0.5	1.2	0.2	1.6	0.5
Cobalt	ug/l	2.4	2.2	1.1	2.2	-	-	1.5	1.7	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.1	0.6	1.5	0.9
Chromium	ug/l	5.7	8.5	4.7	3.3	14.0	17.0	6.2	3.6	2.6	1.7	2.9	3.0	4.4	14.0	7.1	12.1	9.2	11.3	8.9
Copper	ug/l	35.7	52.1	23.2	22.2	39.0	42.0	19.5	17.1	7.9	10.6	19.3	31.0	46.7	46.0	33.9	54.6	31.3	66.0	5.0
Iron	ug/l	392.8	1466.6	861.0	1069.0	5920.0	3150.0	1216.7	951.1	638.9	567.3	747.2	700.0	1806.9	1000.0	609.8	777.0	676.1	1195.7	300.0
Lead	ug/l	17.0	30.00	11.8	10.5	8.0	8.0	23.5	10.9	5.4	5.5	9.4	25.0	58.1	57.0	18.5	40.1	21.0	64.4	5.0
Manganese	ug/l	223.1	246.9	96.7	162.4	-	-	184.1	118.9	72.9	77.5	108.2	65.0	224.4	103.0	106.3	177.8	150.1	201.7	-
Nickel	ug/l	3.8	6.8	3.0	3.4	7.0	6.0	3.7	3.6	1.3	1.9	2.7	3.0	4.6	3.0	5.2	6.2	5.1	8.2	25.0
Strontium	ug/l	550.7	378.5	361.0	195.0	-	-	349.0	293.2	198.2	123.5	119.2	70.0	129.8	280.0	148.7	332.3	136.1	228.9	-
Titanium	ug/l	15.0	8.1	6.5	5.5	-	-	12.0	5.4	4.4	3.9	6.8	2.0	4.5	10.0	6.4	6.5	5.4	6.7	-
Vanadium	ug/l	0.3	4.8	2.0	3.4	-	-	5.2	4.5	1.5	2.5	2.6	2.0	3.9	5.0	6.9	5.2	4.9	5.6	6.0
Zinc	ug/l	197.4	302.1	79.0	66.7	130.0	80.0	110.5	87.2	35.4	33.6	66.5	128.3	212.5	158.9	208.1	267.5	196.2	259.7	20.0
Bacteria		n=1	n=13	n=3	n = 12	n=12	n=12	n=3	n=10	n=11	n=13	n=7	n=2	n=7	-	-	-	-	-	
Escherichia Coli	c./100ml	20	3071	2272	8075	1072	25911	1750	7048	478	2574	19692	318362	35052	-	-	-	-	-	100.0
Nutrients		n= 9-11	n=21	n=12-15	n=21	n=13-14	n=17	n=9	n=15	n=11	n=18	n=20	n=3	n=13	n=9-11	-	-	-	-	
Ammonia - N	mg/l	1.29	0.60	0.01	0.01	0.77	0.16	0.25	0.35	0.11	0.15	0.14	1.49	1.17	4.88	-	-	-	-	-
Un-ionized amm.- N	mg/l	0.02	0.02	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.03	0.04	0.06	-	-	-	-	0.02
Nitrite-N	mg/l	0.16	0.10	0.10	0.08	0.08	0.06	0.10	0.14	0.04	0.04	0.12	0.90	0.16	0.10	-	-	-	-	0.06
Nitrate-N	mg/l	1.43	1.21	1.80	1.00	1.29	1.41	1.84	1.80	0.66	0.67	0.88	1.47	1.23	1.47	-	-	-	-	1.0
Phosphate	mg/l	0.09	0.03	0.21	0.26	0.08	0.06	0.05	0.08	0.10	0.13	0.05	0.37	0.18	0.21	-	-	-	-	-
Phosphorus; total	mg/l	0.37	0.39	0.40	0.39	0.40	0.28	0.37	0.55	0.27	0.35	0.28	1.15	0.59	0.42	-	-	-	-	0.03
TKN	mg/l	1.7	2.0	2.2	1.3	6.0	1.4	1.7	1.8	1.1	1.6	1.6	4.6	3.1	4.1	-	-	-	-	-

Notes: 1. The terms 'winter/spring' and 'summer/fall' refer to the periods December to April and May to November, respectively. Grab samples were collected during the winter/spring at all but the OGS and Underground Detention Tank sites. 2. n=30 for TSS. 3. n=5 for lead during the winter/spring period 4. Guideline Sources are PWQOs except as follows: TSS (EIFAC, 1965; USEPA, 1973); Chloride (Environment Canada and Health Canada, 2001); Nitrate (CAST, 1992); The PWQO for aluminium is 75 μg/L but applies only to clay free samples.

Effluent Concentrations and Removal Efficiencies

Table 4.7 compares mean effluent concentrations and removal efficiencies for EOP facilities. As discussed in section 4.2, mean concentration values are based on log-transformed data sets. Additional statistics are available in individual facility reports. The following sections discuss the results with respect to each of the main groups of parameters: suspended solids, chloride, nutrients, metals, organic compounds, chloride and bacteria.

Total Suspended Solids

The level of total suspended solids (TSS) are a particularly important indicator of water quality because many other stormwater contaminants of concern bind readily to solid particles and, at elevated TSS concentrations, can affect the behaviour and survival of various forms of aquatic life. A healthy fishery typically requires that TSS concentrations in the receiving water body remain below 80 mg/L, even during wet weather (EIFAC, 1965; USEPA, 1973; Ward, 1992). In the City of Toronto's Wet Weather Flow Management Master Plan, the target for 'moderate' improvement in water quality (over the next 25 years) is a TSS concentration of 100 mg/L for 80% of the events. For 'significant' enhancement (over a 100 year period), the target is to achieve a TSS concentration of 40 mg/L for 80% of the events.

The mean effluent TSS concentrations and 95% confidence intervals illustrated in Figure 4.2 suggest that the first target can be readily achieved by implementing retention basin type EOP facilities and that the second target could be achieved by some of the better performers. All facilities had average effluent TSS concentrations of less than 60 mg/L during runoff events. Six of the nine facilities had mean effluent TSS concentrations below 30 mg/L. The underground storage tank was the worst performer with an average effluent concentration of 56 mg/L.

Figure 4.3 plots influent versus effluent TSS concentration data from all of the EOP facilities for individual rain events. The graph shows that effluent EMCs above about 60 mg/L were relatively infrequent, regardless of the influent concentration. Most facilities had an upper effluent concentration limit of between 50 and 60 mg/L. This upper limit varies depending on the length of detention provided, but appears to represent a 'non-settlable' fraction consisting of relatively small clay sized particles that are not readily deposited over the treatment periods provided.

Influent concentrations were generally not correlated with effluent concentrations. A weak correlation (R^2=0.44) between the two was evident in the Aurora data set, possibly because this was the only facility without a permanent pool. The size of rain events appeared to affect effluent concentrations during large events, but relationships could not be demonstrated statistically. The relationship may have been stronger if more sampling data were available for large storm events. Based on data from 17 wet ponds, Strecker et al (2004) showed significantly poorer effluent quality in ponds where mean monitored runoff volumes were greater than the facility permanent pool.

Table 4.7 **:** Effluent average event mean concentrations (AEMCs) and removal efficiencies. Shaded values represent AEMCs above receiving water objectives.

Parameter	units	Outlet Average Event Mean Concentrations (AEMC) and Performance (%)																							Receiving Water Guidelines
		Rouge River Highway pond				Harding Park Retrofit pond				Heritage Estates pond				Markham pond/wetland				Aurora Wetland				Dunkers FBS			
		summer/fall		winter/spring		summer/fall		winter/spring		summer/fall		winter/spring		summer/fall		winter/spring		summer/fall		winter/spring		summer/fall			
		Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	cell 5	cell 3	%	
General Chem.		n=21	n=21	n=11	n=8-11	n=12	n=10	n=4	n=4	n=19	n=9	n=14	n=11	n=12-13	n=9	n=6	n=5	n=18	n=18	n=11	n=11	n=38	n=52	n=11[2]	
Suspended Solids	mg/l	37.2	90	46.3	75	46.0	80	39.2	78	15.7	85	14.9	86	23.0	95	7.1	98	20.9	90	29.3	79	13.8	11.2	81	25 - 80
Oil and Grease	mg/l	1.5	87	1.7	51	0.8	48	1.1	6	-	-	-	-	1.0	80	0.9	77	1.0	71	1.6	52	0.8	0.8	70	-
Chloride	mg/l	579.5	-86	1613.0	-17	71.0	-548	274.0	-3	81.4	-487	251.4	-73	107.9	-60	325.5	-76	15.7	45	254.1	-5	47.6	46.8	10	250.0
Carbon; DO	mg/l	3.1	73	4.5	1	4.6	-70	2.6	-24	-	-	-	-	4.3	46	3.0	54	-	-	-	-	3.1	3.3	49	-
Carbon; DI	mg/l	47.7	-35	49.1	-64	30.7	-155	32.3	-95	-	-	-	-	22.9	26	24.4	21	-	-	-	-	22.5	23.0	-37	-
Metals		n=21	n=21	n=11	n = 4-11	n=9-12	n=7-10	n=3-4	n=1-4	n=19	n=8-9	n=14	n=5-11	n=13	n=8-9	n=5-6	n=5	n=18	n=18	n=11	n=11	n=38	n=52	n=11	
Aluminum	µg/l	263.0	73	212.0	65	290.0	74	226.0	48	-	-	-	-	187.1	86	115.4	80	291.3	53	419.1	20	95.0	80.9	78	-
Barium	µg/l	120.6	10	116.1	-21	36.5	-11	39.0	-14	-	-	-	-	35.0	40	37.2	35	16.0	46	22.0	6	28.2	27.9	20	-
Cadmium	µg/l	0.5	60	1.7	64	0.5	11	0.1	83	0.3	21	0.9	49	0.4	29	0.4	49	0.3	85	0.4	55	0.3	0.3	-25	0.5
Cobalt	µg/l	0.8	68	2.7	57	0.8	82	0.4	60	-	-	-	-	0.9	53	0.8	36	0.7	69	<dl	39	0.6	0.6	43	0.9
Chromium	µg/l	2.0	79	8.6	-108	2.4	53	2.2	-13	1.0	59	5.0	59	0.6	84	0.7	74	1.2	48	2.0	27	0.7	0.6	81	8.9
Copper	µg/l	10.2	85	16.2	41	4.5	48	10.2	22	8.0	76	9.0	65	8.2	85	3.7	76	5.0	68	5.8	42	3.4	4.1	85	5.0
Iron	µg/l	470.7	72	401.4	59	386.0	66	431.0	48	320.0	74	350.0	79	199.5	81	107.7	80	363.4	49	515.5	29	233.6	188.8	75	300.0
Lead	µg/l	6.0	88	6.0	73	2.5	83	6.0	10	4.0	18	5.0	27	<dl	n/a	<dl	n/a	<dl	n/a	<dl	n/a	5.2	4.7	73	5.0
Manganese	µg/l	119.9	69	110.3	45	115.8	9	159.4	-23	-	-	-	-	42.8	86	14.1	88	51.6	66	57.7	41	33.8	33.8	63	-
Nickel	µg/l	2.4	75	1.5	61	3.2	62	1.8	38	20.0	16	7.0	44	1.3	62	1.0	79	1.0	56	1.0	32	0.9	0.9	77	25.0
Strontium	µg/l	488.8	13	507.2	2	270.5	-63	264.0	43	-	-	-	-	275.2	7	332.3	-12	129.7	27	218.1	4	160.7	161.7	-41	-
Titanium	µg/l	4.4	49	12.3	59	-	-	2.7	-19	-	-	-	-	3.8	34	2.1	68	-4.0	24	6.1	44	4.0	2.8	55	-
Vanadium	µg/l	1.5	74	1.5	69	1.1	66	1.6	-3	-	-	-	-	1.1	75	1.1	72	1.7	24	1.3	28	0.8	0.7	79	6.0
Zinc	µg/l	67.2	84	108.9	25	16.4	70	40.0	38	10.0	71	20.0	72	14.1	87	7.0	88	25.3	59	46.1	-40	4.9	6.7	89	20.0
Bacteria		n=13	-	n=1	-	n=4	n=5	n=3	n=3	n=15	n=7	n=12	n=8	n=7	n=4	n=3	n=2	n=18	n=18	n=11	n=11	n=7	n=11	n=4	
Escherichia Coli	c./100ml	356.5	-	10.0	-	1429.0	53	185.0	-44	1362.0	79	395.0	75	236.9	79	10.1	99	477.0	90	444.4	31	73.5	279	75	100.0
Nutrients		n=21	n=21	n=9-11	n=8-11	n=12	n=10	n=4	n=4	n=19	n=7-9	n=9-14	n=10-11	n=12-13	n=8-9	n=6	n=4-5	n=18	n=18	n=11	n=11	n=37	n=52	n=11	
Ammonia	mg/l	0.1	79	0.5	14	0.1	54	0.4	18	0.1	-123	0.4	-68	0.1	22	0.1	37	0.06	75	0.07	46	0.10	0.09	-24	-
Un-ionized amm.	mg/l	0.00	-	0.01	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	-	0.00	0.00	-	0.02
Nitrite	mg/l	0.04	44	0.07	-18	0.02	28	0.04	-12	0.04	-15	0.03	45	0.04	64	0.03	46	0.03	28	0.04	0	0.03	0.04	56	0.06
Nitrate	mg/l	0.97	66	1.58	-18	0.70	42	1.10	52	0.65	62	1.17	-1	0.56	69	0.92	51	0.16	61	0.66	19	0.30	0.41	64	1.0
Phosphate	mg/l	0.01	78	0.01	74	0.01	87	0.03	66	0.03	71	0.07	30	0.01	89	0.01	82	0.04	59	0.07	22	0.01	0.01	75	-
Phosphorus; total	mg/l	0.06	85	0.09	67	0.11	42	0.10	56	0.07	80	0.10	65	0.08	87	0.04	80	0.13	72	0.17	33	0.07	0.06	77	0.03
Nitrogen; TK	mg/l	0.8	70	1.1	31	1.0	-24	1.1	31	0.9	-19	1.3	34	0.8	55	0.7	45	0.9	59	0.9	37	0.7	0.68	59	-

Notes: 1. The terms 'winter/spring' and 'summer/fall' refer to the months from December to April and from May to November, respectively. Water quality samples in the winter/spring were collected as grabs at the Rouge, Harding Park, Heritage Estates, and Markham sites. 2. n=30 for TSS at the Dunkers FBS. 3. n=5 for lead during the winter/spring period 4. Guideline Sources are Provincial Water Quality Objectives (OMOE, 1999) except as follows: TSS (EIFAC, 1965; USEPA, 1973); Chloride (Environment Canada and Health Canada, 2001); Nitrate (CAST, 1992); The PWQO for aluminium is 75 ug/L but applies only to clay free samples.

Table 4.7 (continued) **:** Effluent average event mean concentrations (AEMCs) and removal efficiencies. Shaded values represent AEMCs above receiving water objectives.

Parameter	units	Effluent Average Event Mean Concentrations (AEMCs)[1] and Load Based Removal Efficiencies (%)												Receiving Water Guidelines[2]
		Beaches Detention Tank				3-Chamber OGS				Stormceptor® OGS				
		summer/fall		winter/spring		summer/fall		winter/spring		summer/fall		winter/spring		
		Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	Effl.	%	
General Chemistry		**n=9-10**	**n=6-7**	**n=7-9**	**n=4-5**	**n=40**	**n=14**	**n=14**	**n=5**	**n=23-24**	**n=7-10**	**n=13**	**n=6**	
Suspended Solids	mg/l	55.8	59	56.0	24	30.4	58	59.0	53	42.1	65	72.5	47	25 - 80
Oil and Grease	mg/l	3.4	29	5.0	24	5.3	60	11.8	39	5.9	51	10.3	34	-
Chloride	mg/l	138.5	-27	1052.5	8	-	-	-	-	-	-	-	-	250.0
Carbon; DO	mg/l	4.9	12	5.8	11	-	-	-	-	-	-	-	-	-
Carbon; DI	mg/l	25.9	-15	36.8	-43	-	-	-	-	-	-	-	-	-
Metals		**n=10**	**n=5-7**	**n=9-11**	**n=3-5**	**n=40**	**n=12**	**n=14**	**n=5**	**n=23**	**n=8**	**n=13**	**n=6**	
Aluminum	µg/l	342.8	52	450.0	5	186.4	60	396.4	47	238.5	55	448.9	41	-
Barium	µg/l	32.6	22	39.0	8	24.5	41	30.3	44	34.7	4	42.5	1	-
Cadmium	µg/l	0.6	56	0.5	68	0.3	58	0.6	42	0.1	46	1.1	41	0.5
Cobalt	µg/l	0.9	59	n/a	76	0.5	42	0.9	10	0.6	43	0.4	64	0.9
Chromium	µg/l	2.9	92	5.0	96	3.4	53	9.1	40	4.6	52	8.7	45	8.9
Copper	µg/l	19.0	45	26.0	43	15.4	63	31.1	47	17.7	51	36.5	37	5.0
Iron	µg/l	849.2	47	900.0	8	345.7	40	596.7	41	404.0	52	759.9	37	300.0
Lead	µg/l	25.2	47	26.0	62	8.2	57	28.6	48	9.7	59	41.9	28	5.0
Manganese	µg/l	101.5	36	105.0	6	59.9	35	103.7	53	109.8	51	134.6	36	-
Nickel	µg/l	4.1	39	4.0	53	2.4	60	3.8	52	2.9	45	4.9	45	25.0
Strontium	µg/l	121.7	-4	280.0	15	133.7	10	216.1	41	177.0	-75	245.6	-76	-
Titanium	µg/l	8.6	15	11.0	24	3.4	58	7.3	-29	1.3	33	5.4	32	-
Vanadium	µg/l	2.3	-	4.0	-	3.2	57	3.7	37	3.0	46	3.7	24	6.0
Zinc	µg/l	87.7	52	135.5	29	62.2	62	116.8	62	110.4	47	169.4	36	20.0
Bacteria		**n=6**	**n=3**	-	-	-	-	-	-	-	-	-	-	
Escherichia Coli	c./100ml	44179.0	**-22**	-	-	-	-	-	-	-	-	-	-	100.0
Nutrients		**n=10**	**n=6-7**	**n=6-9**	**n=3-5**	-	-	-	-	-	-	-	-	
Ammonia	mg/l	0.35	-25	0.29	33	-	-	-	-	-	-	-	-	-
Un-ionized amm.	mg/l	0.01	-	0.00	-	-	-	-	-	-	-	-	-	0.02
Nitrite	mg/l	0.10	-37	0.21	35	-	-	-	-	-	-	-	-	0.06
Nitrates	mg/l	2.07	-33	2.85	-41	-	-	-	-	-	-	-	-	1.0
Phosphate	mg/l	0.17	-39	0.15	24	-	-	-	-	-	-	-	-	-
Phosphorus; total	mg/l	0.31	29	0.34	22	-	-	-	-	-	-	-	-	0.03
Nitrogen; TK	mg/l	1.4	22	1.2	78	-	-	-	-	-	-	-	-	-

Notes: 1. The terms 'winter/spring' and 'summer/fall' refer to the months from December to April and from May to November, respectively. 2. Guideline Sources are Provincial Water Quality Objectives (OMOE, 1999) except as follows: TSS (EIFAC, 1965; USEPA, 1973); Chloride (Environment Canada and Health Canada, 2001); Nitrate (CAST, 1992); The PWQO for aluminium is 75 ug/L but applies only to clay free samples.

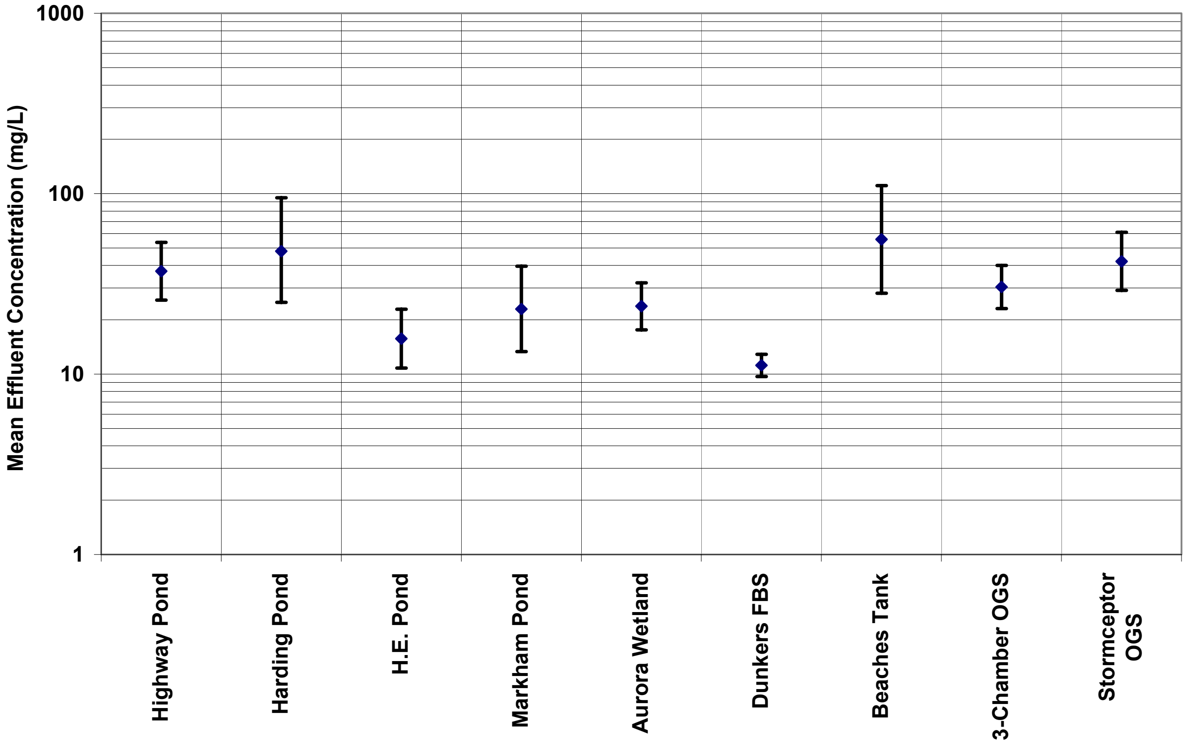


***Figure 4.2*: Mean TSS concentrations and 95% confidence intervals**

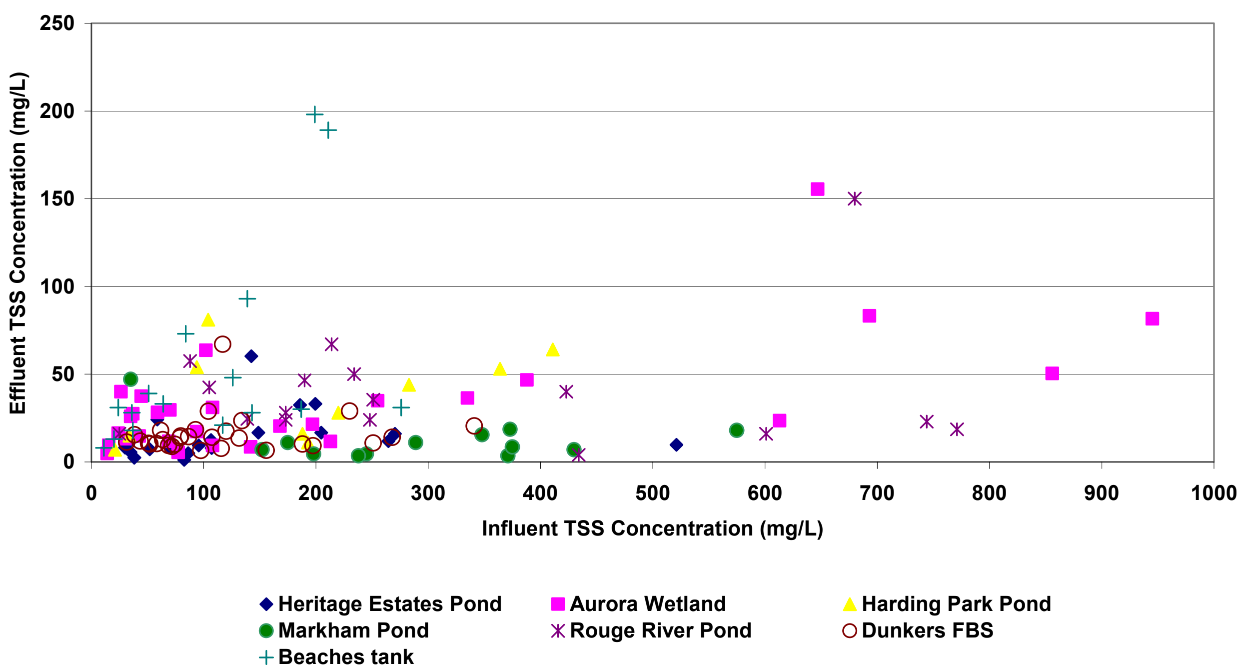


Figure 4.3 : Influent vs effluent concentrations during individual storm events at retention/detention facilities

Oil grit separators exhibited poorer effluent quality and stronger relationships between influent and effluent TSS concentrations than other EOP facilities (Figure 4.4). The 3-chamber and Stormceptor® studies indicated that 26% (n=54) and 38% (n=38) of effluent samples collected had TSS concentrations above 60 mg/L, respectively. This compares to only 8% above 60 mg/L at the pond and wetland sites. This result was not un-expected given the relatively small amount of storage provided by the OGS technologies. The relationship between influent and effluent concentrations implies that the quality of OGS effluent may improve if every effort is made to ensure that the contributing drainage area is kept relatively clean.

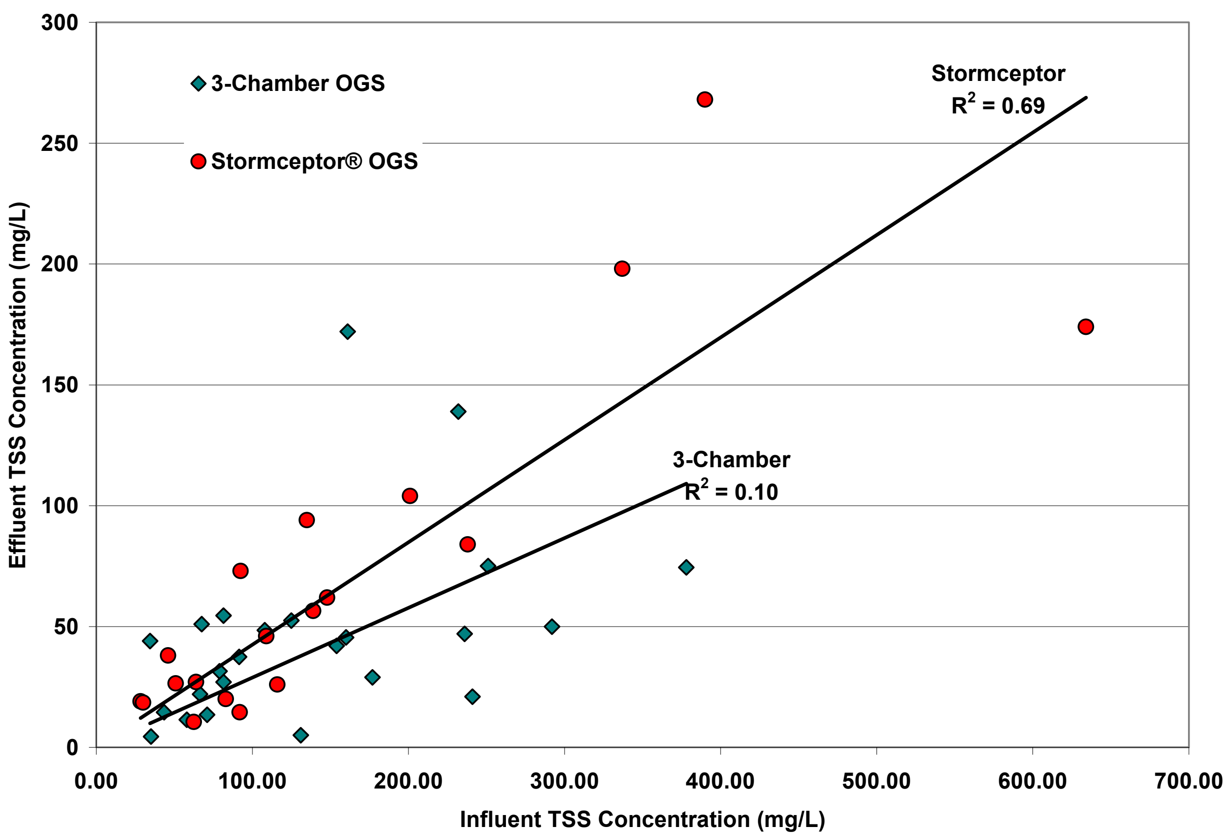


Figure 4.4: Influent vs effluent TSS concentration at OGS sites.[3]

Design criteria are established in the OMOE SWMP manual based on long term suspended solids removal. The manual defines three levels of aquatic habitat protection for receiving water systems: enhanced, normal and basic based on removal of 80, 70 and 60% of total suspended solids, respectively. Hence removal efficiency is an important variable to consider in evaluating facility performance. As shown in Figure 4.5, all of the monitored facilities except the Underground Storage Tank and OGS units achieved TSS load-based removal efficiencies in

[3] Data are provided only for events where both influent and effluent samples were collected. Effluent data are available for a larger number of events. Note that at both OGS sites, influent samples were collected at the inlet of only one of two parallel units, whereas effluent data were collected downstream of where discharge from the two units joins together (*i.e.* effluent quality represents total facility discharge).

the 80 to 95% range, corresponding to an 'Enhanced Level' of treatment. The remaining facilities had removal efficiencies consistent with a 'basic' level of protection.

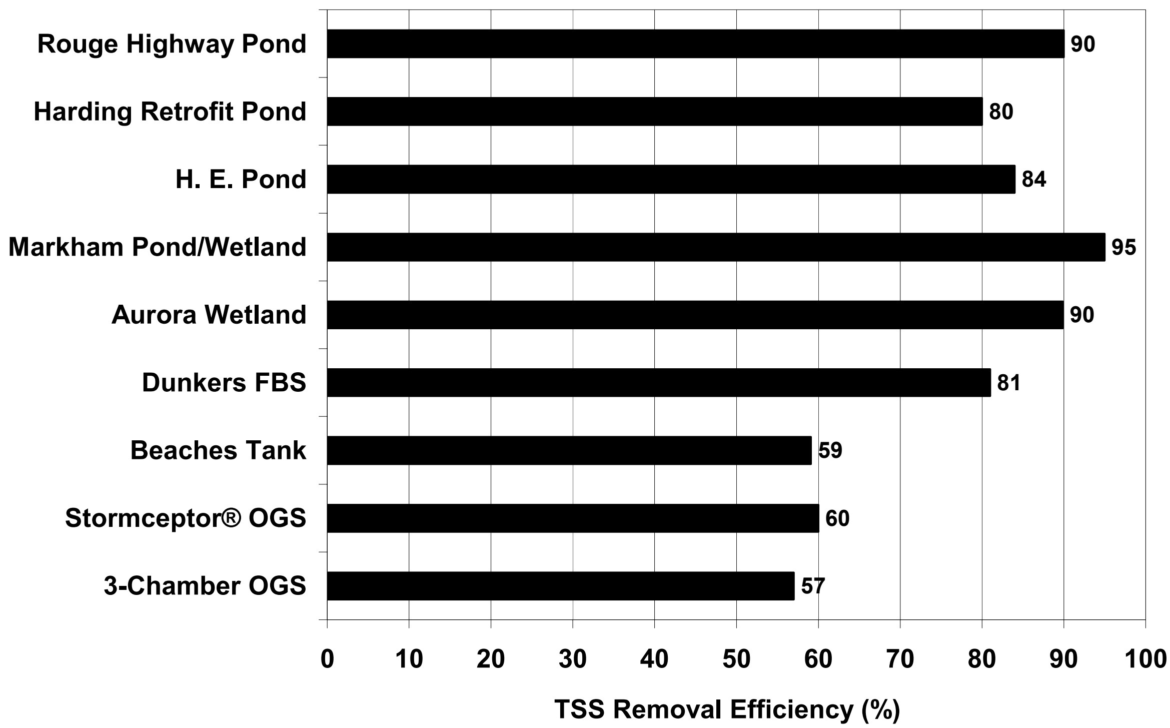


Figure 4.5: Load-based TSS removal efficiencies

Before discussing other water quality variables, it should be noted that removal efficiency is a biased indicator of facility performance. This point has been made be several other researchers and is also evident from SWAMP data sets. The problem lies with the correlation between removal efficiencies and influent concentrations. As illustrated in Figure 4.6, better removal rates are achieved when the influent is dirty than when it is clean, especially when influent concentrations fall below about 150 mg/L. The relationship is not primarily a function of any physical or chemical process associated with the concentration of influents, but rather, of the equation used to calculate removal - as influent concentrations approach background levels of TSS (approximately 10 to 20 mg/L in stormwater ponds), there is simply less material available for removal, causing efficiencies to decline precipitously.[4] Use of effluent concentrations and loads as measures of system performance avoids this problem because they indicate actual facility outputs of pollutants to receiving waters, regardless of how clean or dirty the contributing drainage area may be.

[4] The curve shown in Figure 4.6 can and has been reproduced using randomly generated data sets. This does not preclude the possibility that other processes, such as the tendency for greater flocculation in dirty influents, may contribute to the relationship. It only demonstrates that these other processes are not the primary cause of the observed relationship. Another hypothesis often put forward as an explanation for the relationship – *i.e.* that dirtier effluents are associated with coarser particle size distributions – was not borne out by the data.

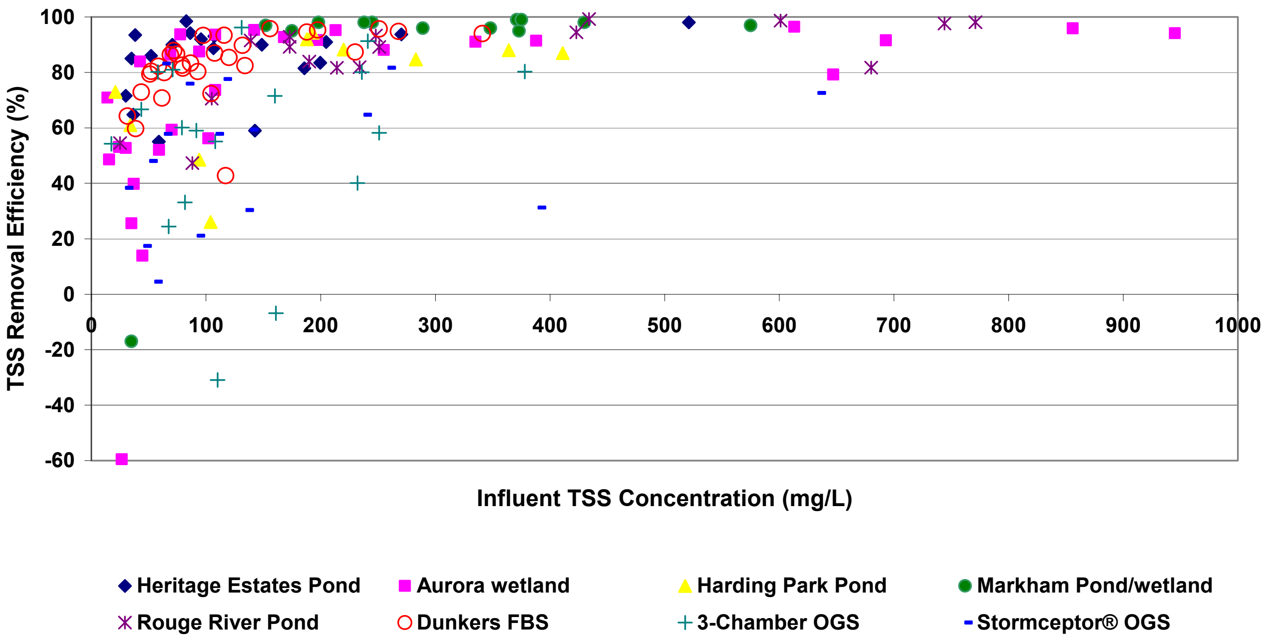


Figure 4.6: Removal efficiency vs. influent TSS concentration

Particle Size Distributions

The change in the size distribution of suspended particles from the inlet to the outlet is an important indicator of size selective particle removal either by settling, flocculation or filtration, and is therefore an important variable to consider in evaluating the effectiveness of stormwater facilities.

At all the wet pond and wetland sites, average effluent particle size distributions were significantly less than average influent particle size distributions (Figure 4.7 – confidence intervals are not shown).[5] The median particle size of untreated stormwater entering the facilities ranged between 3.4 and 8.0 µm. Effluent particle sizes were both smaller and less variable in size, with median sizes ranging between 1.6 and 3.1 µm. Roughly 65 to 85% of effluent particles were in the clay size range (less than 4 µm in diameter), compared to approximately 35 to 55% of particles in the same range at the inlet.

Dry weather particle size distributions were available at only two sites (Figure 4.8). Influent particle sizes during dry weather were much coarser at the Markham facility compared to the Dunkers FBS. Effluent median particle sizes averaged between 2 and 2.5 µm, which is within the range observed during wet weather. Since the dry weather particle size distribution likely represents the minimum settleable size fraction, it seems reasonable to suggest that, during wet weather, the facilities are removing most of the suspended solids that are physically settleable.

[5] Particle size distributions were determined using optical laser light diffraction (Coulter LS130 Particle Size Analyzer).

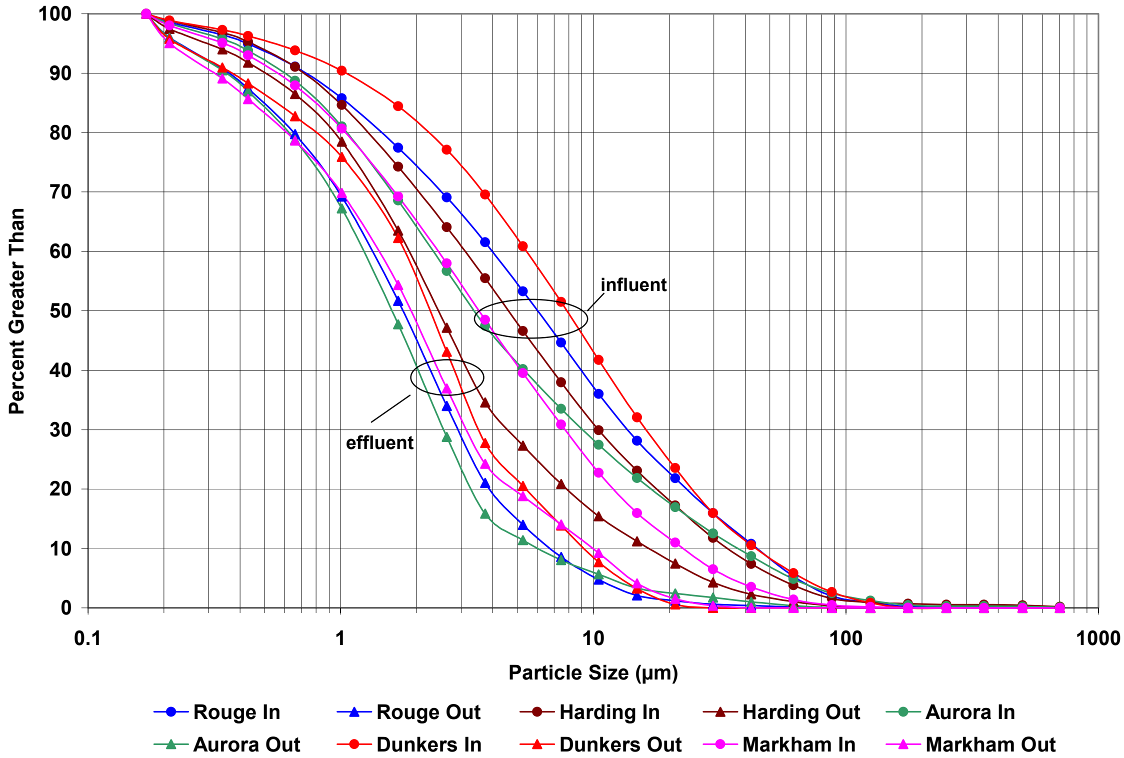


Figure 4.7: Average cumulative particle size distributions at pond and wetland sites during wet weather

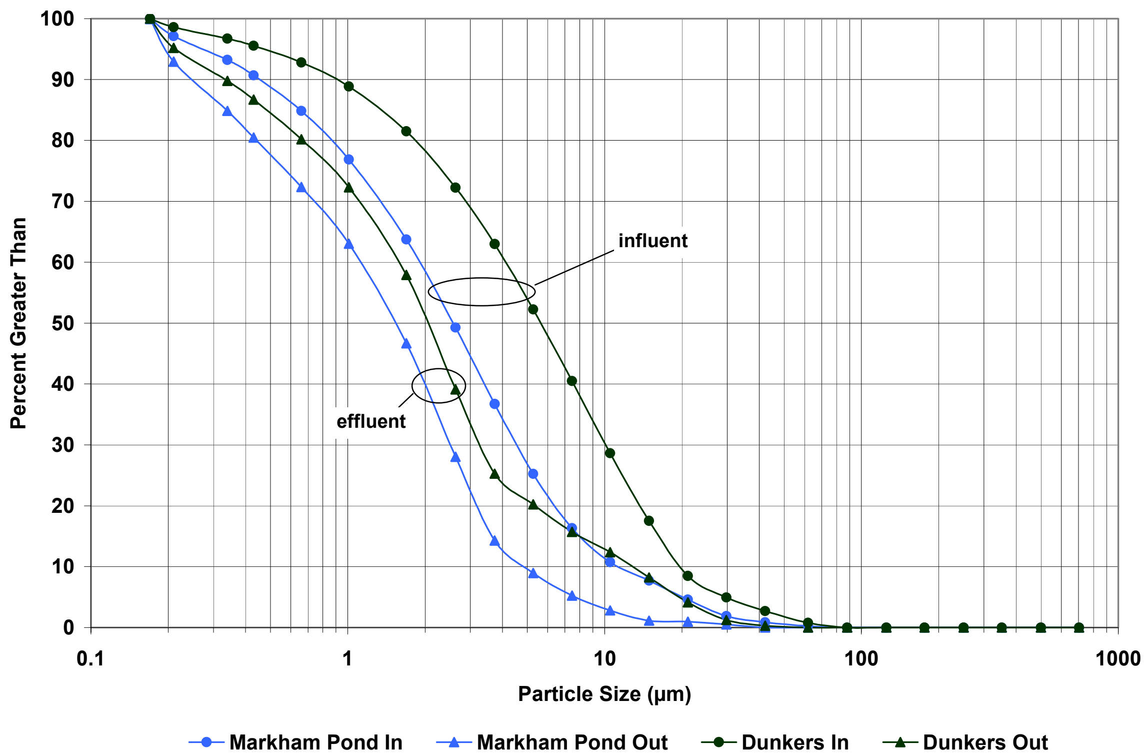


Figure 4.8: Average cumulative particle size distributions at pond and wetland sites during dry weather

The influent particle size distributions from parking lot runoff at the two OGS sites were similar to those observed at the other EOP sites (Figure 4.9). Effluent particle size distributions from the OGS, however, were generally coarser than from the other EOP facilities. The median size of average effluent particle size distributions at the OGS sites was between 4 and 5.9 µm. Approximately 40 to 50% of effluent suspended sediment particles were in the clay sized range (*i.e.* < 4 µm).

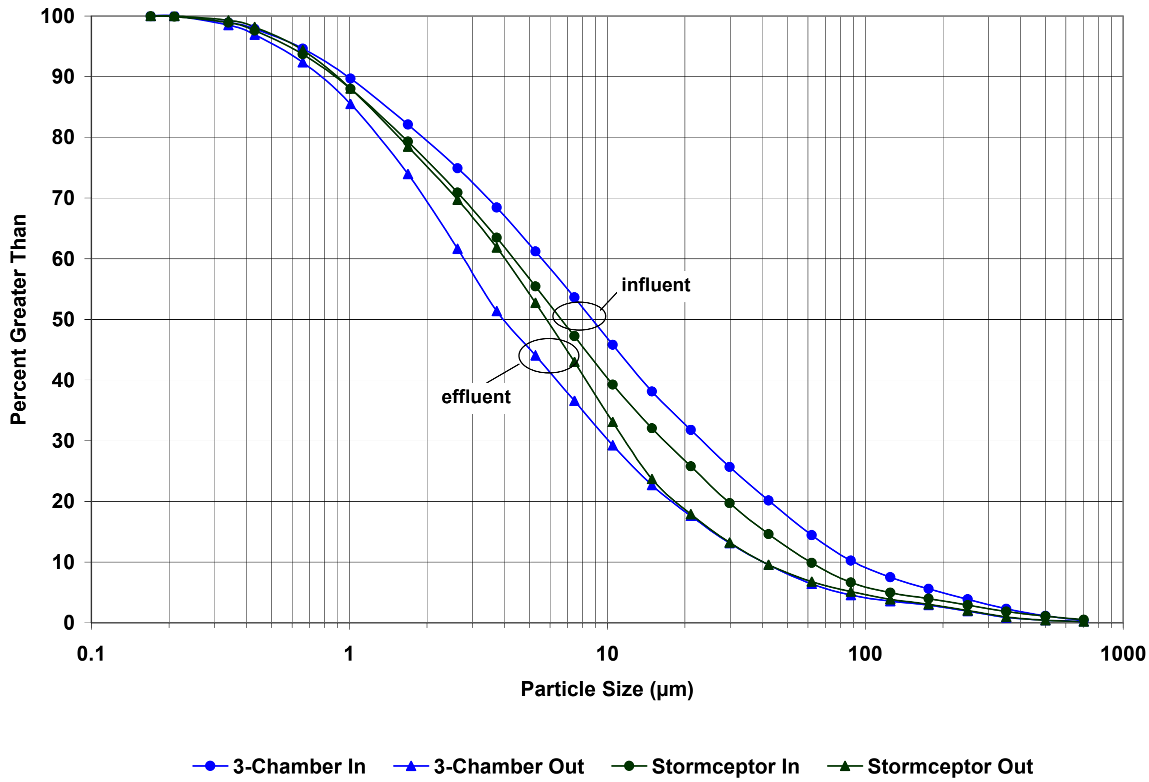


Figure 4.9: Average cumulative particle size distributions at OGS sites during wet weather

Nutrients

Nutrient variables analyzed in water samples include total phosphorus, ortho-phosphorus, nitrate, nitrite, total kheldjal nitrogen (TKN), and ammonia. Synthetic fertilizers applied to lawns and agricultural fields are a primary source of these nutrients. Average effluent concentrations and load based removal efficiencies for these variables for each EOP facility are provided in Table 4.7.

Three nutrient variables were selected for graphical presentation in Figures 4.10 and 4.11: total phosphorus, TKN and nitrate. Total phosphorus concentrations include the particulate and dissolved phases of phosphorus. The provincial interim guideline for total phosphorus to prevent excessive plant growth in rivers and streams is 0.03 mg/L. TKN includes ammonia and nitrogen oxides. There is no guideline for TKN, but mean concentrations in rivers draining forest or open space are usually less than 1 mg/L (*e.g.*: Rouge River National Wet Weather

Demonstration Project, 1994). Nitrite is an intermediate stage in the nitrification process whereby ammonium is converted to nitrite and then to nitrate, and is usually observed at much lower concentrations than nitrate. There is no established guideline for nitrate, but studies have shown that nitrogen concentrations above approximately 1 mg/L can contribute to the eutrophication of water bodies (e.g. CAST, 1999, CCME, 1999), and concentrations in excess of 2.5 mg/L have been shown to cause adverse effects in certain amphibian species (Rouse et al, 1999). The City of Toronto WWFMMP 'significant enhancement' target for nitrate + nitrite is 0.5 mg/L during wet weather and 0.06 mg/L during dry weather.

Figure 4.10 shows mean effluent concentrations of total phosphorus in EOP facilities generally within the same range, with the exception of the Eastern Beaches stormwater tank, which had significantly greater concentrations than most other facilities. Phosphorus levels in all facilities were substantially higher than the Ontario Provincial Water Quality Objective of 0.03 mg/L. This is consistent with design practice in that if phosphorus is of specific concern, additional components must be added to a typical EOP design to address that concern. Removal efficiencies for total phosphorus ranged from 22% at the Eastern Beaches tank to 87% in the Markham pond (Figure 4.11). Among the pond/wetland facilities, the Harding Park retrofit pond fared the worst, with removal of only 42% for total phosphorus. Other facilities of this type had removal rates above 70%.

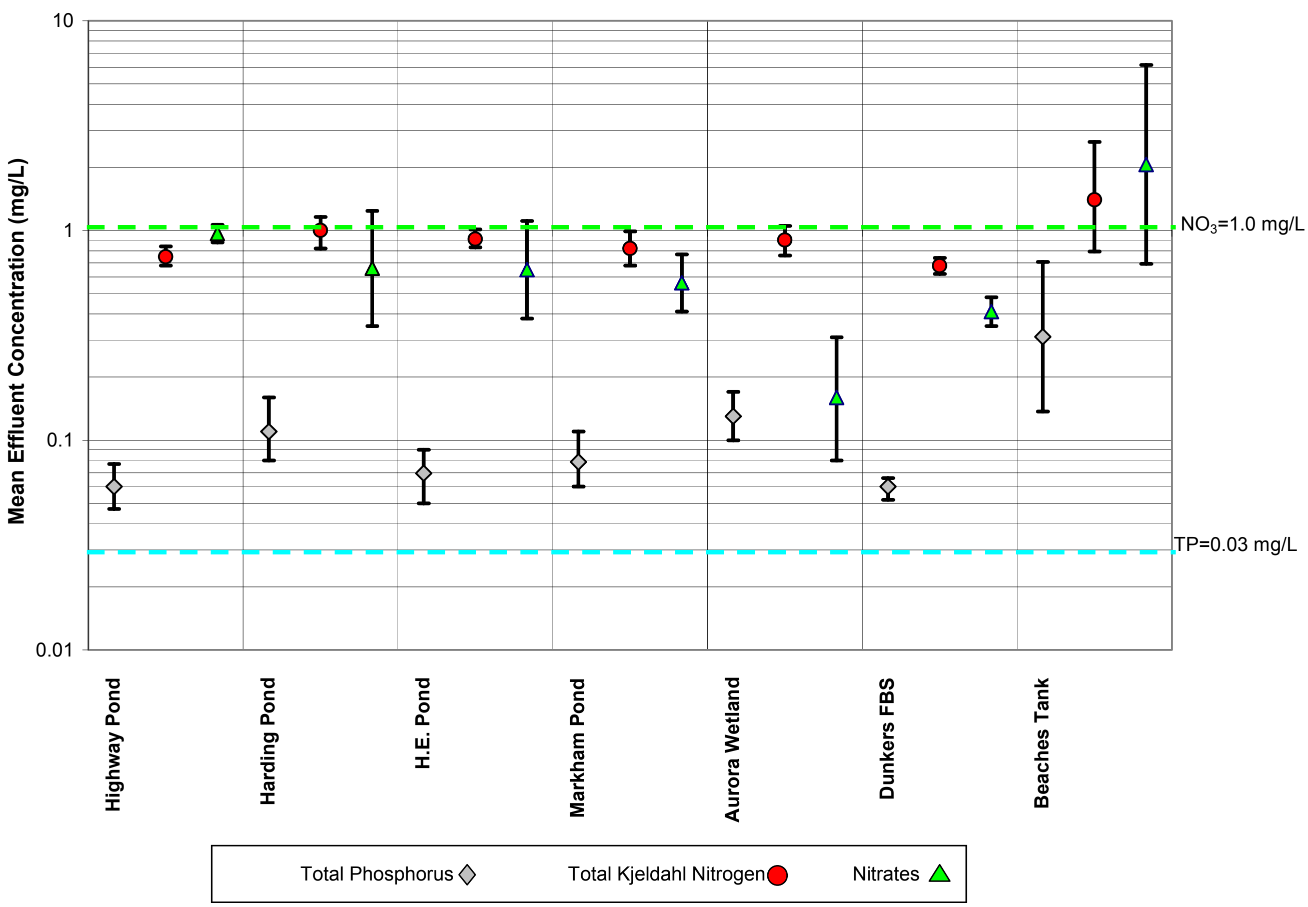


Figure 4.10: Mean effluent concentrations and 95% confidence intervals for total phosphorus, TKN and nitrate.

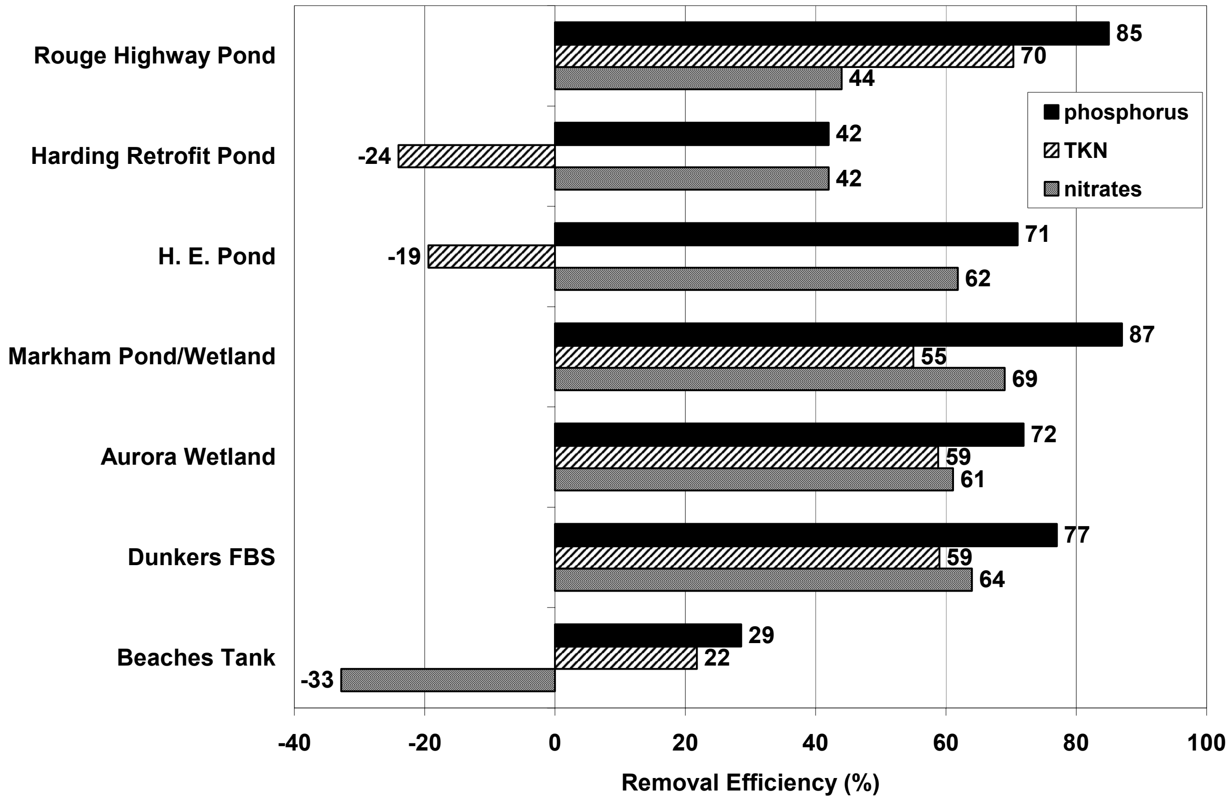


Figure 4.11: Load based removal efficiencies for phosphorus, TKN and nitrate.

Mean sample concentrations of TKN and nitrate were generally within acceptable levels. Removal efficiencies among the facilities were generally not as good for nitrogen as for phosphorus, in part because nitrogen is found mostly in soluble form, and is therefore not subject to sedimentation processes. However, this is not a serious concern because effluent concentrations were not usually observed at levels that would pose a threat to receiving waters.

Metals

Samples were analyzed for a wide range of metals (Table 4.7). Figures 4.12 and 4.13 show summer/fall season effluent concentration means and 95% confidence intervals for three of the most common metal contaminants in stormwater: chromium, copper and zinc. Lead and cadmium are also common stormwater contaminants. However, cadmium is found mostly in soluble form, and is therefore not effectively removed by sedimentation processes. Lead was not included because, in most samples, lead concentrations were below the laboratory reporting method detection limit of 10 ug/L, and therefore mean concentrations and confidence intervals could not be accurately determined. Concentrations of lead in stormwater runoff have dropped considerably in the past 25 years due to the phase out of lead from gasoline, paints, some solders and other products.

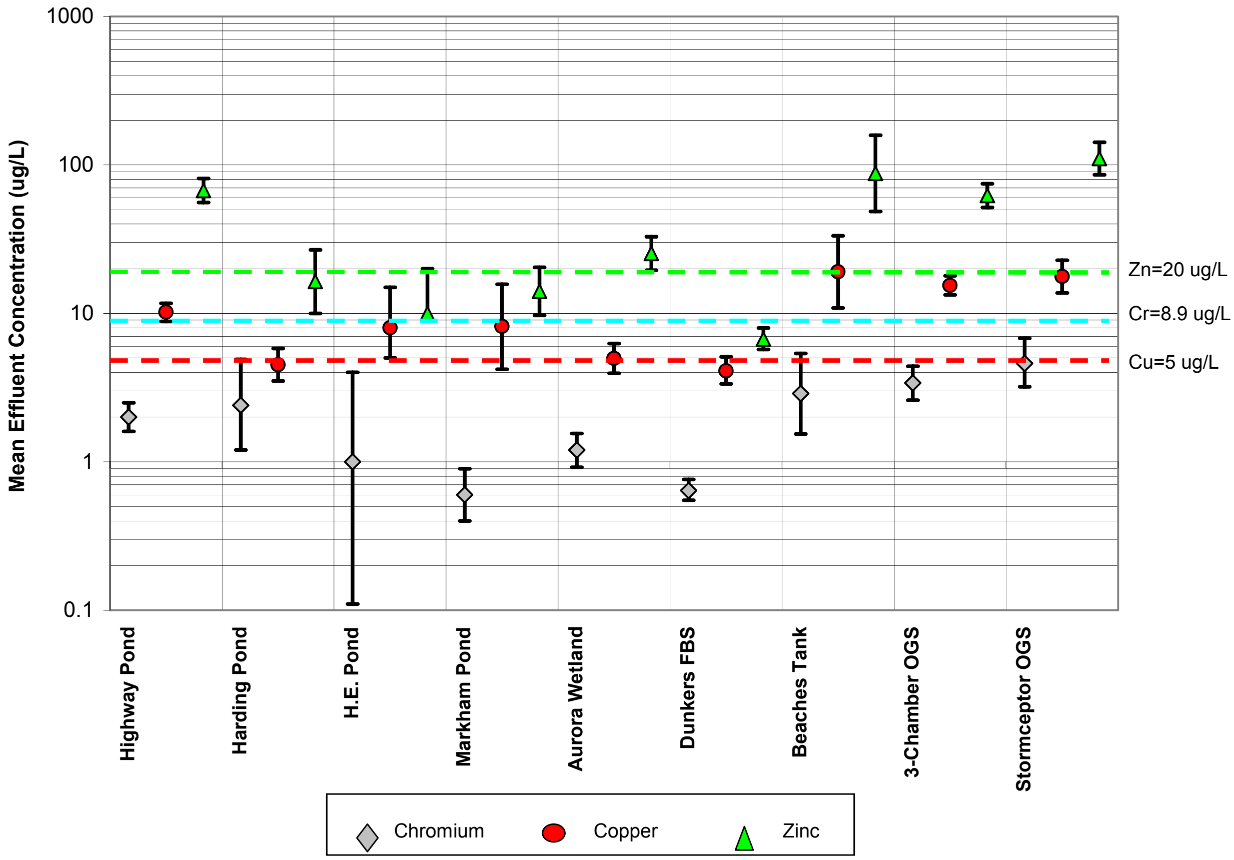


Figure 4.12: Mean effluent concentrations and 95% confidence intervals for selected metals. Dashed lines represent provincial receiving water objectives for the protection of aquatic life.

Most metals in urban stormwater are associated with automobile use, wind-blown dusts, roof runoff and road surface materials (Campbell, 1994). Heavy metals have a strong affinity to sediments and can accumulate in benthic organisms, phytoplankton, and fish (Wanielista and Yousef, 1993; Campbell, 1994). Wilbur and Hunter (1980) found that easily extracted metals in urban sediment comprised about 21% of the total concentration. Soluble portions of copper and zinc concentrations in highway runoff have been estimated to range from 20-40% and 30-50%, respectively (Ellis et al., 1987). Cadmium is found mostly in soluble form, but usually at very low concentrations. Chromium is relatively insoluble in its more common form as CrIII, but highly soluble and toxic as CrVI. Hard water and high pH (as found in the Markham wet pond) significantly reduces the solubility of most heavy metals (Ellis et. al., 1987).

Effluent concentrations of copper and zinc often exceeded receiving water standards for these constituents. Levels were particularly elevated in the Beaches tank, Oil Grit Separators and Rouge Highway stormwater retention pond. In general, removal rates for metals were good, ranging from 45 to 92% for the three metals shown in Figure 4.13. Results for other metal contaminants during the summer/fall and winter/spring periods are provided in Table 4.7.

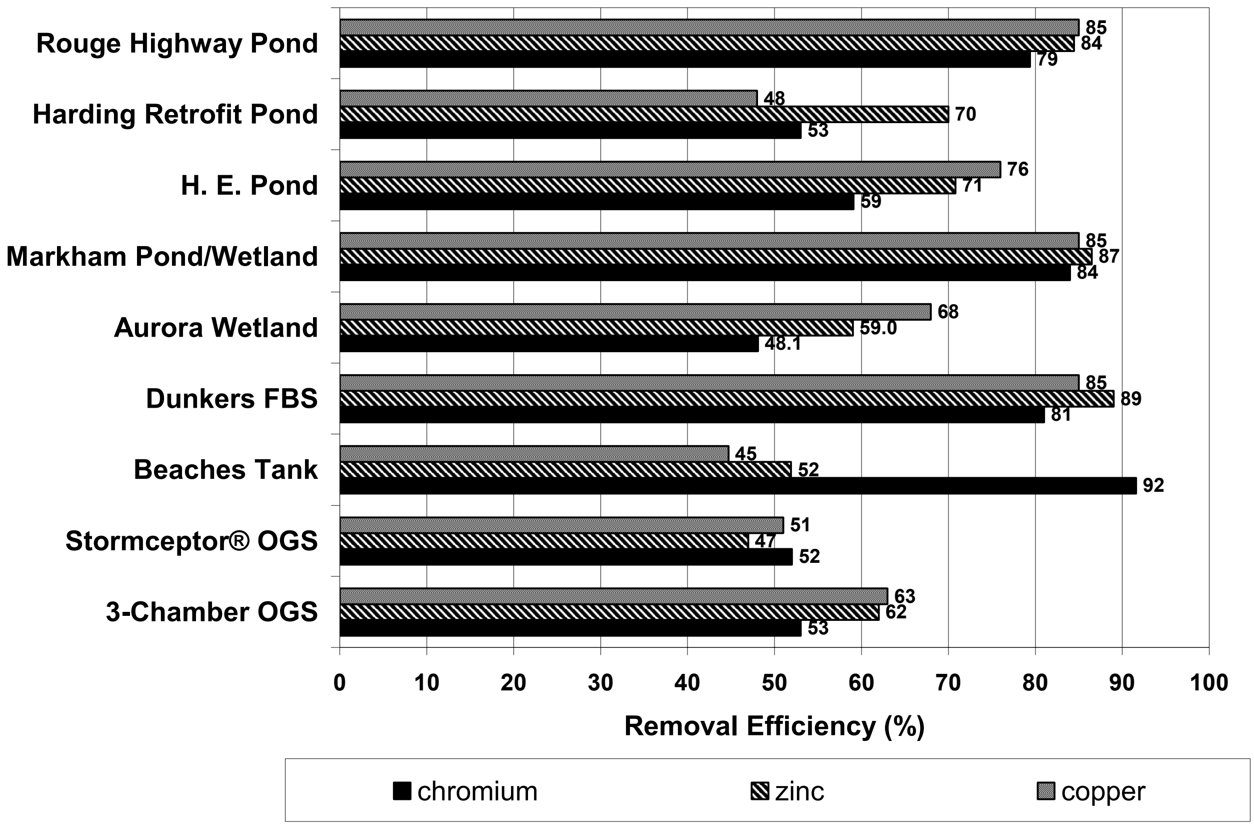


Figure 4.13: Load based removal efficiencies for selected metals.

Bacteria

Bacteria in storm runoff are a significant concern because of their potential impact on public health in swimming areas. Sources of bacteria typically include pets, raccoons, wildfowl and illegal sanitary connections to storm sewers. The *E.coli* group of bacteria is used to indicate the presence of fecal wastes and other harmful bacteria. The provincial *E.coli* guideline for recreation areas is 100 cfu/100 mL.

As indicated in Figure 4.14, mean effluent concentrations in the wet pond and wetland systems vary from 237 to 1429 cfu/100 mL. The lowest bacteria densities and highest removal efficiencies were observed at the Markham BMP (Figure 4.15). This facility had a very long drawdown time allowing for significant natural die-off of bacteria due to sunlight and other physical, chemical and biological factors. Under more typical conditions with drawdown times of 24 hours, effluent concentrations in the order of 1,000 counts/100 mL can be expected.

The Eastern Beaches Tank had very high bacteria densities in the effluent and was the only EOP facility with a negative removal rate for this variable (although sample sizes were very small). In this facility, the closed tank does not allow for die-off of bacteria from sunlight, and residues on the concrete surfaces provide a ready habitat for bacteria colonies to grow (despite the tank being hosed down occasionally). Influent loading of *E.coli* was also considerably higher than other facilities (Table 4.6).

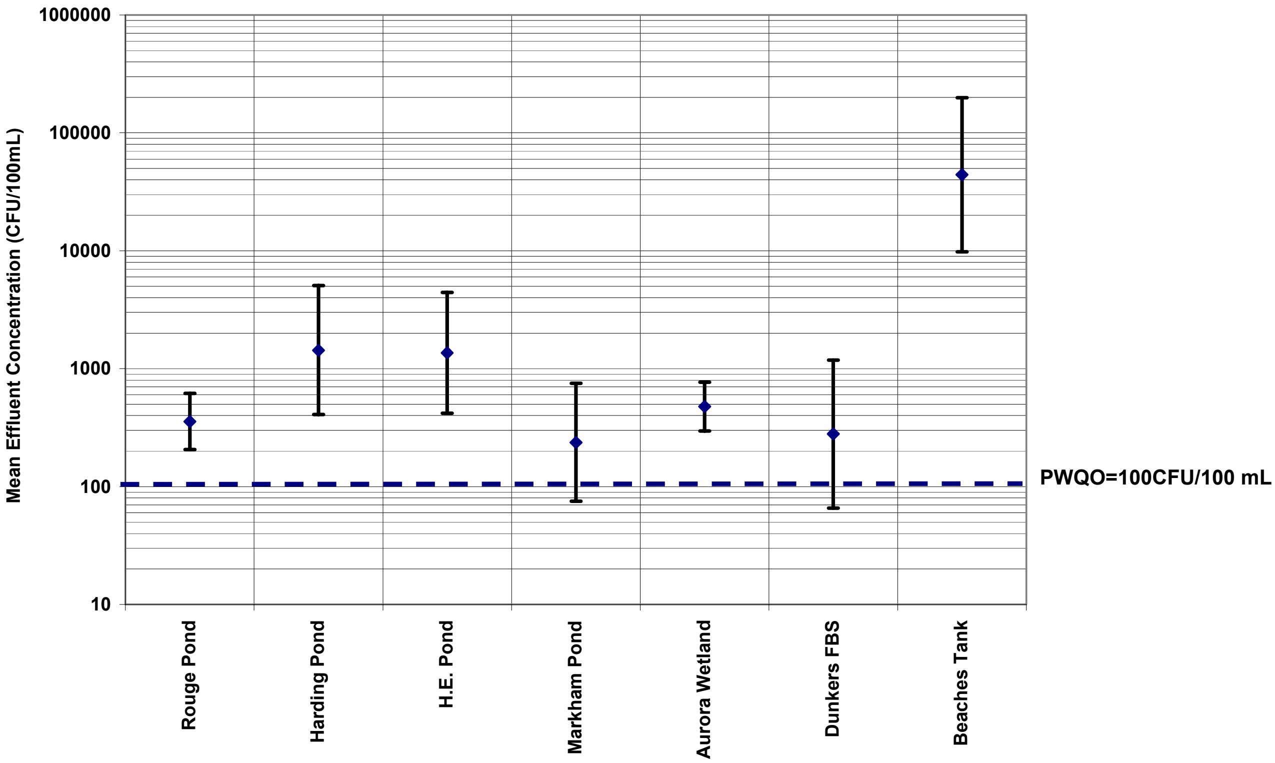


Figure 4.14: Mean *E.coli* concentrations and 95% confidence intervals.

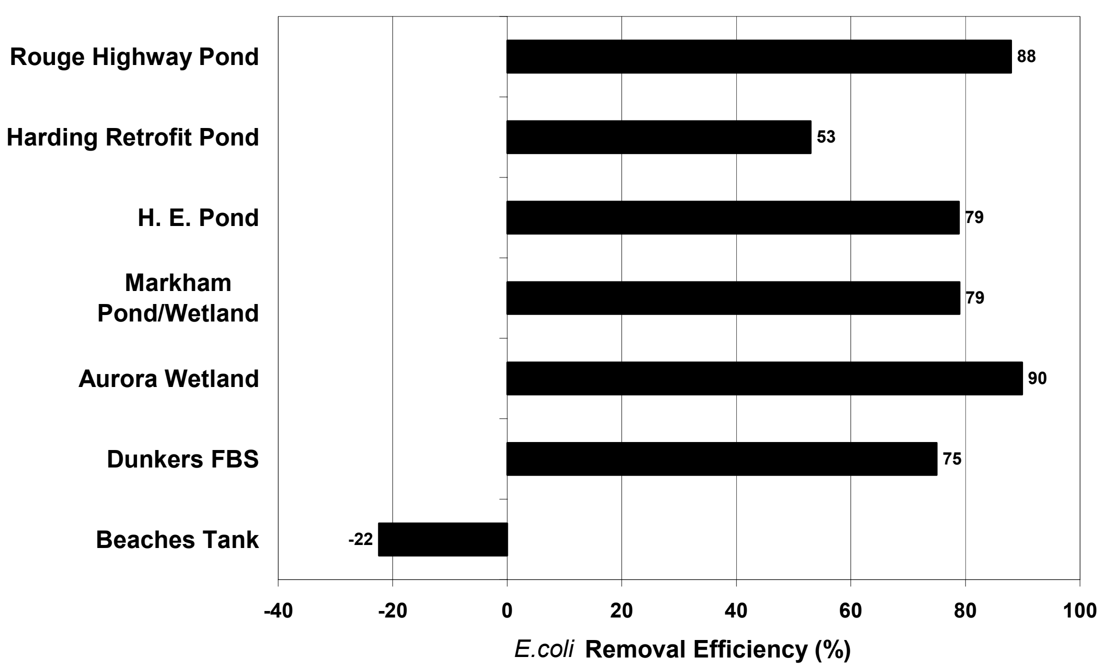


Figure 4.15: Load based removal efficiencies for *E.coli*.

Organic Compounds

Several organic compounds were sampled at the monitoring sites. However, only pentachlorophenol, 2,3,4,6-tetrachlorophenol, 2-4-D and Dicamba were actually detected in a significant number of samples, and concentrations were always at levels below PWQOs. The laboratory procedure used to analyze poly-aromatic hydrocarbons (PAHs) in SWAMP studies had detection limits above the PWQO for these constituents. Thus, the studies were only able to prove that effluents were below established detection limits, not that PAH levels in effluents were suitable for discharge to receiving waters. In future studies, a special high sample volume, low detection limit methodology is recommended to accurately determine the concentration of organic compounds in runoff samples.

Chloride

Chloride has come under increased scrutiny after a federal government decision in 2001 to include road salts on the Priority Substances List under the Canadian Environmental Protection Act (Environment Canada and Health Canada, 2001). A synthesis of scientific studies conducted as part of the designation process suggested a value of approximately 250 mg/L as a reasonable target for the protection of aquatic life.

Most stormwater management facilities function on the basis of suspended solids settling and are therefore not designed to remove dissolved constituents such as chloride. However, monitoring of wet pond facilities for chloride has shown that while there is no net removal of chloride on an annual basis, the facilities do prolong its release over a longer period than would be the case if the stormwater were discharged directly into the river. This phenomenon is a result of densimetric stratification in ponds and formed the basis for a separate SWAMP study on the fate of chloride in stormwater facilities.

The Rouge River Highway Retention Pond facility was selected for this study because it receives runoff from a large transportation corridor with elevated chloride levels. The objectives of the study were to: (i) determine whether and to what extent densimetric stratification occurred in the Rouge River Pond; (ii) determine the annual cycle of chloride entering/exiting the facility; and (iii) investigate the concentration levels within the facility. Based on the results, recommendations could be developed on improved facility design and operations and maintenance procedures for SWM facilities that experience densimetric stratification.

The dynamics of chloride movement through the pond was characterized by vertical depth profiles of conductivity conducted at 15 locations 7 times over the cycle of one year (September 1997 to October 1998) and by continuous measurements of flow and conductivity into and out of the Rouge River pond over the same period. Since sodium chloride is a strong conductor of an electric current, a good relationship was achieved between chloride collected in water samples and conductivity measured at the same locations with an on-line meter. This relationship was used to convert conductivity measurements to chloride concentrations.

Figure 4.16 shows cumulative loading of chloride into and out of the Rouge SWM facility from February 20, 1998 to September 23, 1998. The curves indicate that during the winter, when chloride loading is high, the pond stores chloride. That is, chloride loads entering the facility are greater than chloride loads leaving the facility during winter months. In mid April, when the snow has melted and spring rains begin, this pattern is reversed resulting in negative removal rates well into the summer and fall.

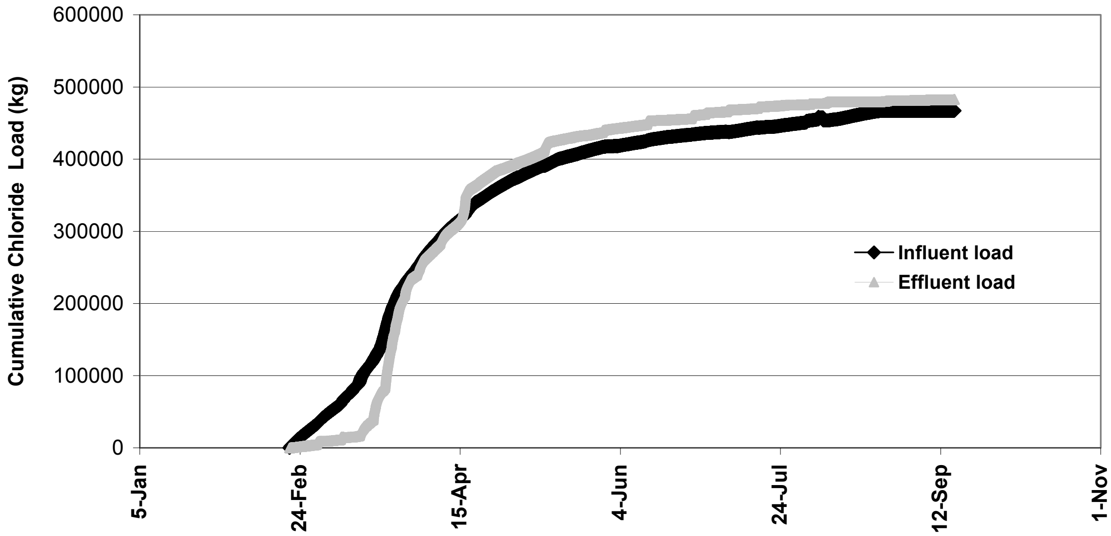


Figure 4.16: Cumulative loading into and out of the Rouge River Pond

The conductivity depth profile survey provides an indication of the seasonal distribution of conductivity within the forebay and pond. Figure 4.17 show results for February 26, 1998 and October 23, 1998. Values above 1 m in the forebay and above 2 m in the pond represent an average of 3 measurements across the pond. Below these depths, single measurements were taken at the middle point, where water depths are greatest. Since the pond was drained in October 1997, the conductivity values represent accumulation of dissolved solids over a relatively short period of time.

The two profiles show results that are consistent with the cumulative loading data. Conductivity readings were highest during the winter, with values in the water column between 2.4 and 10.9 mS/cm, roughly equivalent to chloride concentrations of 550 and 3700 mg/L. By contrast, fall values ranged between 2.0 and 8.8 mS/cm, corresponding to chloride concentrations of 500 and 2,900 mg/L. In general, the permanent pool is better mixed in the fall than the winter, except for a deep point near the outlet where mixing appeared to be relatively limited.

Elevated chloride levels in ponds were accompanied by very low dissolved oxygen levels. Together these conditions create highly toxic conditions for aquatic life inhabiting these areas, and may stimulate the release of heavy metals from bottom sediments (Mayer et al., 1999). The density differences within the water column slows particle settling and may inhibit vertical mixing which, in turn, reduces treatment effectiveness by facilitating short circuiting of flows across the top of the pond.

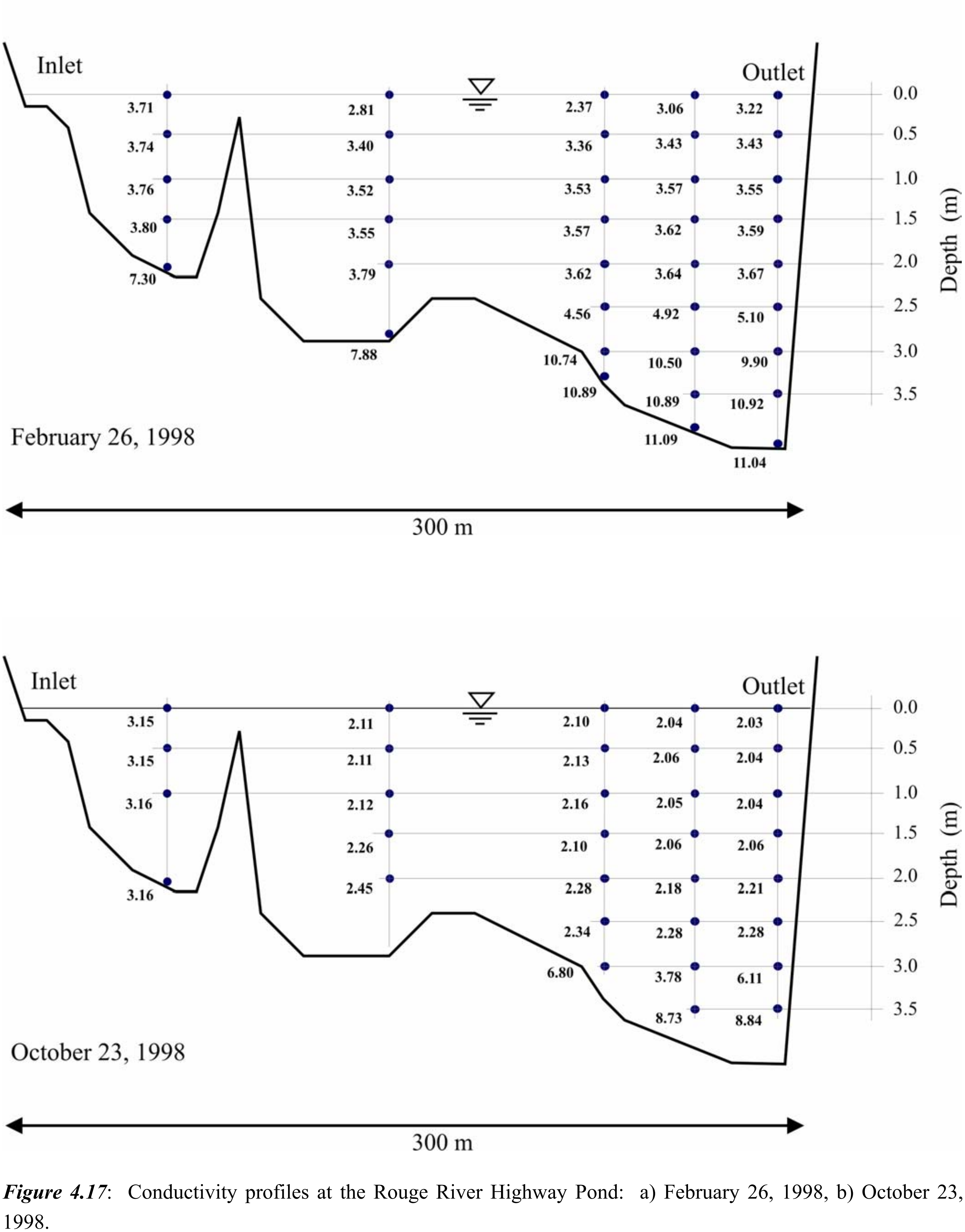


Figure 4.17: Conductivity profiles at the Rouge River Highway Pond: a) February 26, 1998, b) October 23, 1998.

Mitigation of these impacts could be accomplished by cutting down on the use of road salts or designing ponds that naturally flush more efficiently (Marsalek and Schaefer, 2003). From a maintenance perspective, the pond would best be drained in the fall when chloride concentrations in the pond and river are at a minimum. Impacts on rivers would be least if the pond water was released during high flow conditions, when the river has greater dilution capacity. In areas where the nearest sewage treatment plant discharges to the ocean or a large water body, a more effective, but expensive option would be to drain the pond contents to the sanitary sewer. This option would remove the chloride entirely from the river system. The best time for draining in this case would be in the spring, when chloride concentrations in the pond are at a maximum.

Water Toxicity

The acute lethality of runoff samples was measured at the inlet and outlet of three facilities using two single species bioassays: *Daphnia magna* 48-hour test and rainbow trout (*Oncoryhnchus mykiss*) 96-hour test. None of the samples collected at the Dunkers flow balancing system were acutely toxic to either species (Table 4.8). The Rouge pond influent and effluent was occasionally toxic to *Daphnia magna*, probably because of high chloride concentrations, as all the samples found to be toxic were collected during the winter. Three of the 23 Eastern Beaches tank influent samples were toxic to *Daphnia Magna* and 1 of the 10 outlet samples was toxic to rainbow trout.

Table 4.8: Toxicity test results

Species	Number (percent) of samples collected found to be lethal					
	Rouge River Pond		Dunkers FBS		Eastern Beaches Tank	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Daphnia magna	1 of 9 (11%)	3 of 9 (33%)	0 of 4 (0%)	0 of 3 (0%)	3 of 23 (13%)	0 of 10 (0%)
Rainbow Trout	0 of 9 (0%)	0 of 9 (0%)	0 of 4 (0%)	0 of 3 (0%)	0 of 23 (0%)	1 of 10 (10%)

Seasonal Variations in Performance

Efficiencies typically fell during the winter/spring period, but most pond and wetland TSS removal rates continued to exceed the ‘Normal Level’ criteria of 70% removal (Figure 4.18). Effluent concentrations of several water quality variables during cold weather also exceeded warm season values at most facilities (Table 4.9). As noted previously, cold season sampling programs at most sites consisted of a relatively small number of inlet and outlet grab samples, many of which were collected during ice-free conditions. Since grab samples may not accurately represent the mean concentration for the event, and removal efficiencies are based on concentrations rather than loads, winter data should be interpreted with caution. The Beaches underground tank, Aurora wetland and OGS sampling programs are exceptions. Underground installation of monitoring equipment or heated huts allowed for automated measurements of water quality through the winter. All three sites showed lower removal rates and dirtier effluent quality during the winter.

Table 4.9: Average effluent concentrations for selected water quality variables during the summer/fall (May – Nov) and winter/spring (Dec – Apr) periods.

	Summer/fall				Winter/spring			
	TSS (mg/L)	**TP (mg/L)**	**Cu (ug/L)**	**Zn (ug/L)**	**TSS (mg/L)**	**TP (mg/L)**	**Cu (ug/L)**	**Zn (ug/L)**
Ponds	23	0.07	8	14	27	0.10	10	30
Aurora Wetland	21	0.13	5	25	29	0.17	6	46
Underground Tank	56	0.31	19	88	56	0.34	26	136
3 Chamber/ Stormceptor® OGS	30 / 42	n/a	15 / 18	62 / 110	59 / 72	n/a	31 / 36	117 / 169

Notes: Pond concentrations represent the median of all pond-type facilities. The summer/fall pond concentrations include the Dunkers facility. See Table 4.7 for sample sizes.

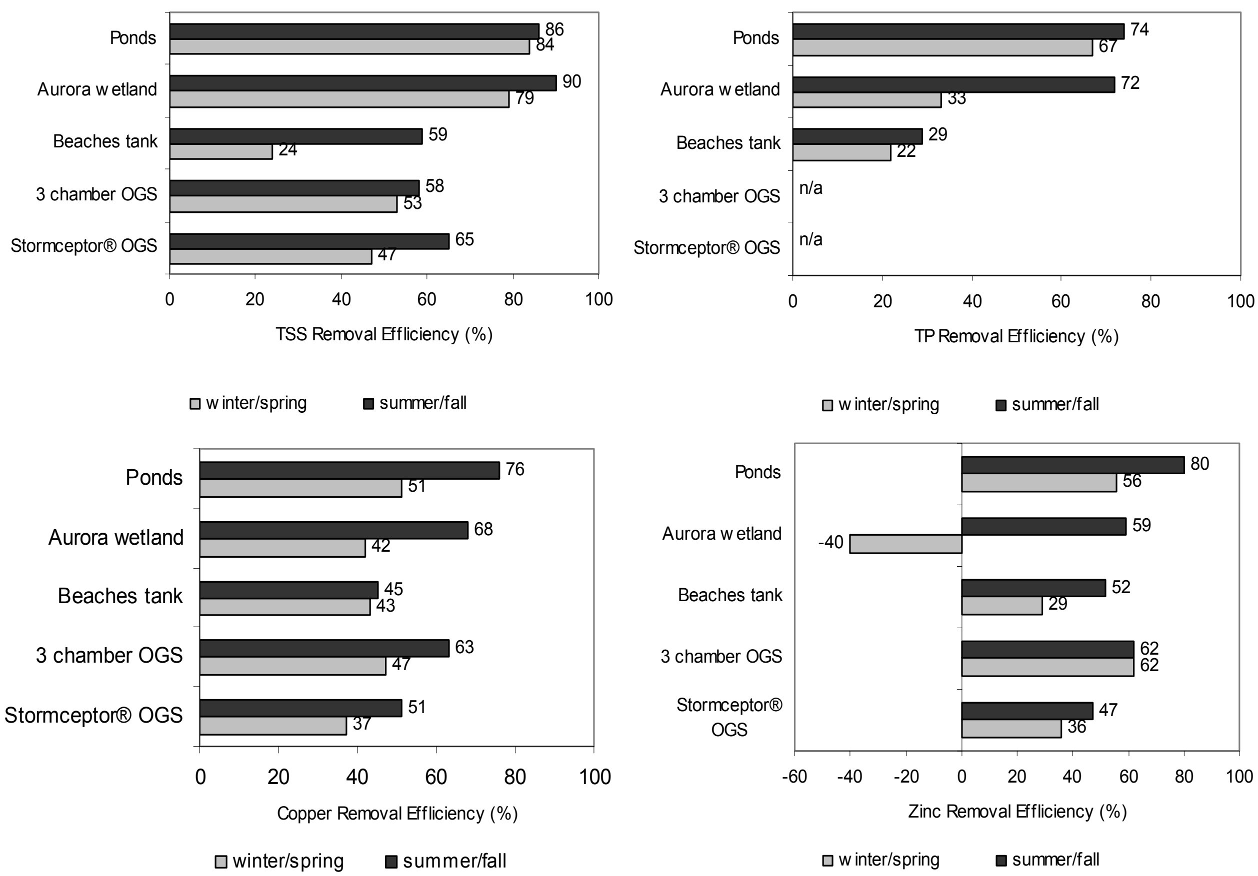


Figure 4.18: Removal efficiencies for selected water quality variables during the summer/fall (May to Nov.) and winter/spring (Dec. to Apr.).

Oberts (1994) reported a similar result from monitoring of four ponds and a wetland during rain and snowmelt conditions in Minnesota. Removal rates of TSS, nutrients and lead were all considerably lower during snowmelt events. The result is attributed to the reduction in permanent pool volume caused by the formation of a surface ice layer. When inflows enter the pond, they are forced below the ice layer, where pressurized conditions create turbulence and re-suspension of bottom sediments. Runoff that flows over the ice surface receives little treatment.

Other factors contributing to reduced cold season performance may include lower winter biological activity and the inhibiting effect that cold temperatures and elevated road salt concentrations have on particle settling processes. As discussed above, chloride accumulation in facilities creates a dense bottom layer that reduces settling depths for finer particles. This was particularly evident in the Stormceptor® OGS, where extreme densimetric stratification of road salts in the treatment chamber was identified as a possible cause of reduced winter performance of the facility in the winter.

Dry Weather Water Quality

Flows into stormwater ponds and wetlands during dry weather typically consist of relatively clean groundwater seepage through cracks or joints in sewer pipes. Other sources in urban areas include leakage from adjacent sanitary sewers, illegal sanitary connections to storm sewers, runoff from lawn watering, vehicle washing, industrial cooling water, swimming pool cleaning and accidental or deliberate spills to roadside catchbasins. The conveyance system itself may also be a source of faecal matter and other contaminants in dry weather flow. At SWAMP study sites, dry weather flows comprised up to 60% of total annual discharge to and from the facilities.

Table 4.10 presents influent and effluent dry weather sampling results at three of the facilities monitored under SWAMP. Effluent concentrations at these facilities were similar for suspended solids, phosphorus and *E.coli*. The Heritage Estates pond had considerably higher effluent concentrations of copper, lead and zinc, cadmium and nickel than the other facilities, although the sample size at this site was very small. Phosphorus was the only variable that consistently exceeded provincial receiving water standards at all facilities.

Discrepancies in influent dry weather concentrations among facilities reflect the large diversity of possible sources of dry weather flow mentioned earlier. The Markham facility had surprisingly high concentrations of suspended solids, possibly because construction was on-going in the catchment at the time of monitoring. Metal concentrations in dry weather discharges to the Heritage Estates pond were also unusually high, considering the low suspended solid levels.

Table 4.10: Dry weather concentrations. Shaded values represent concentrations above receiving water guidelines

	units	Heritage Estates pond		Markham pond/wetland		Dunkers FBS		Receiving Water Guidelines
		Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	
General Chemistry		**n=3**	**n=3**	**n=4**	**n=4**	**n=28**	**n=23**	
Suspended Solids	mg/l	3.6	12.0	108.9	10.1	3.2	13.1	25 - 80
Oil and Grease	mg/l	--	--	1.3	1	--	--	--
Chloride	mg/l	136	133	268	122	388	108	250
Carbon; DO	mg/l	--	--	2.0	3	3.7	3.3	--
Carbon; DI	mg/l	--	--	35.0	24	49.2	25.4	--
Metals		**n=3**	**n=3**	**n=4**	**n=4**	**n=28**	**n=23**	
Aluminum	µg/l	--	--	402	209	76	105	--
Barium	µg/l	--	--	59.3	32.0	57.9	33.7	--
Cadmium	µg/l	6.7	6.7	0.6	0.4	0.4	0.3	0.5
Cobalt	µg/l	--	--	<dl	<dl	0.7	0.7	0.9
Chromium	µg/l	4.3	5.7	1.5	1.4	1.0	0.9	8.9
Copper	µg/l	6.1	6.7	6.1	3.6	8.5	3.0	5.0
Iron	µg/l	265	226	352	173	132	228	300
Lead	µg/l	20.0	11.0	<dl	<dl	5.5	<dl	5.0
Manganese	µg/l	--	--	54.3	15.0	24.2	55.9	--
Nickel	µg/l	8.0	10.3	<dl	<dl	1.0	1.0	25.0
Vanadium	µg/l	--	--	1.5	0.8	0.8	0.8	6.0
Zinc	µg/l	7.3	17.0	22.2	9.0	19.7	7.5	20.0
Bacteria		**n=3**	**n=3**	**n=2**	**n=2**	**n=22**	**n=18**	
Escherichia Coli	cfu/100ml	100	25	486	27	1492	74	100
Nutrients		**n=3**	**n=3**	**n=4**	**n=4**	**n=28**	**n=23**	
Ammonia	mg/l	0.1	0.07	0.01	0.05	0.07	0.10	--
Un-ionized amm.	mg/l	0.002	0.003	0.001	0.002	0.003	0.004	0.02
Nitrite	mg/l	0.07	0.02	0.03	0.04	0.07	0.04	0.06
Nitrate	mg/l	2.83	0.33	2.27	1.13	2.35	0.46	1 - 2.5
Phosphate	mg/l	0.02	0.02	0.02	0.01	0.07	0.01	--
Phosphorus; total	mg/l	0.03	0.04	0.11	0.07	0.13	0.08	0.03
Nitrogen; TK	mg/l	0.5	0.83	0.6	0.70	0.80	0.84	--

Note: Influent concentrations at the Heritage Estates and Markham ponds represent samples collected from the larger of two inlet sewers. Dunkers effluent concentrations represent samples collected from the larger of two outlets (cell 3).

Irreducible Concentrations

As effluents become increasingly dilute, the capacity of a BMP to achieve incremental improvements in water quality diminishes rapidly to the point where further treatment is no longer practical. Once this practical limit has been reached, effluent concentrations become, for all intents and purposes, 'irreducible' (Schueler, 2000). In sedimentation basins, this limit is typically associated with very fine particle sizes, which can remain in suspension for extremely long time periods.

Based on a review of published pond and wetland studies, the Center for Watershed Protection (CWP) reported 'irreducible' effluent concentrations for several water quality variables (CWP, 2000; Schueler, 1996) (Table 4.11). A similar exercise was performed for SWAMP studies using wet weather effluent concentrations from ponds and wetlands (n = 6) monitored under the program. The values may be regarded as conservative, as some of the facilities evaluated under SWAMP were not designed to current standards, and one facility received runoff from a multi-lane highway with unusually high concentrations of metals.

Table 4.11: Group median effluent concentrations ± one standard deviation

	TSS (mg/L)	**TP (mg/L)**	**PO_4 (mg/L)**	**NO_3 (mg/L)**	**Cu (μg/L)**	**Zn (μg/L)**
Ponds (CWP)*	17 ± 17	0.11 ± 0.08	0.03 ± 0.03	0.26 ± 0.6	5.0 ± 5.7	30 ± 16
Wetlands (CWP)*	22 ± 14	0.20 ± 0.81	0.07 ± 0.03	0.36	7.0 ± 5.0	31 ± 14
Ponds/Wetlands (SWAMP)	22 ± 13	0.07 ± 0.03	0.01 ± 0.01	0.61 ± 0.27	6.5 ± 2.5	15 ± 22
Ontario Guidelines	25	0.03	n/a	n/a	5.0	20

**National Pollutant Removal Performance Database for Stormwater Treatment Practices* (CWP, 2000)

The values from the CWP database and from SWAMP studies are generally within the same range. SWAMP studies show notably lower effluent concentrations than the US database studies for dissolved and particulate phosphorus and zinc. The SWAMP study wet weather phosphorus ranges were similar to those observed during dry weather (see Table 4.10), which supports the notion that reductions below these concentrations may not be practical through sedimentation processes alone. Unlike phosphorus, zinc effluent concentrations were typically lower during dry weather. The soluble fraction of zinc is estimated to fall between 30 and 50% (Ellis et al., 1987), which may partly explain the wet-dry discrepancy.

Water Temperature

The temperature of stormwater effluents is an important issue because even minor changes in water temperature can adversely affect fish species and benthic invertebrates adapted to cool and cold water conditions living downstream of stormwater facilities. Many aquatic organisms experience severe stress if water temperatures rise above their tolerance levels, which for many cold water species is approximately 19 to 21°C. Unfortunately, increases in water temperature are inevitable when ponds are used to treat stormwater because permanent pools are exposed to solar radiation for long periods between rain events.

Influent and effluent water temperatures were monitored continuously at most SWAMP EOP sites. Table 4.12 shows the maximum temperatures measured at the pond outlets and the range of changes in baseflow temperature between the influent and effluent during July and August. Effluent temperatures as high as 31°C were experienced in two facilities where the outflow is from the surface via an overflow weir or hickenbottom structure. Such temperatures would be lethal to most cool and cold water species. In contrast, the facilities which use bottom draw outlets have discharge temperatures in the range of 23 to 24 °C. This is at the upper end of the tolerance range for cool water species but well within the range for warm water species.

Table 4.12: Maximum temperatures and baseflow temperature increases from the inlet to the outlet in July and August

Facility name	Maximum Temperature at Outlet (°C)	Increase in baseflow Temperature (°C)	Outlet structure type
Heritage Estates pond	31	6 to 11	Top draw
Markham pond/wetland*	24	4 to 10	Bottom draw
Harding Park pond	31	6 to 9	Top draw
Dunkers FBS	29	5 to 11	Top draw
Aurora Wetland**	24	n/a	Top and bottom draw
Rouge River Pond	24	5 to 7	Bottom draw

*not including August
** The permanent pool in the Aurora wetland is very small.

Depth profiles of temperature illustrated in Figure 4.19 at the Dunkers FBS further illustrate the potential benefits of top versus bottom draw outlet structures on effluent temperatures. In the example shown, temperature was measured at depths of 0.5, 1.5 and 2.5 m below the permanent pool water surface during a particularly warm period in July 2002. At a depth of 2.5 m, the temperature is as much as 9 °C lower than the surface temperature. At 1.5 m, the difference is roughly 6 °C. Most bottom draw outlets have upstream inverts approximately one meter below the water surface. These data suggest that even further reductions in maximum summer temperatures could be achieved if the outlet invert is located further below the permanent pool surface.

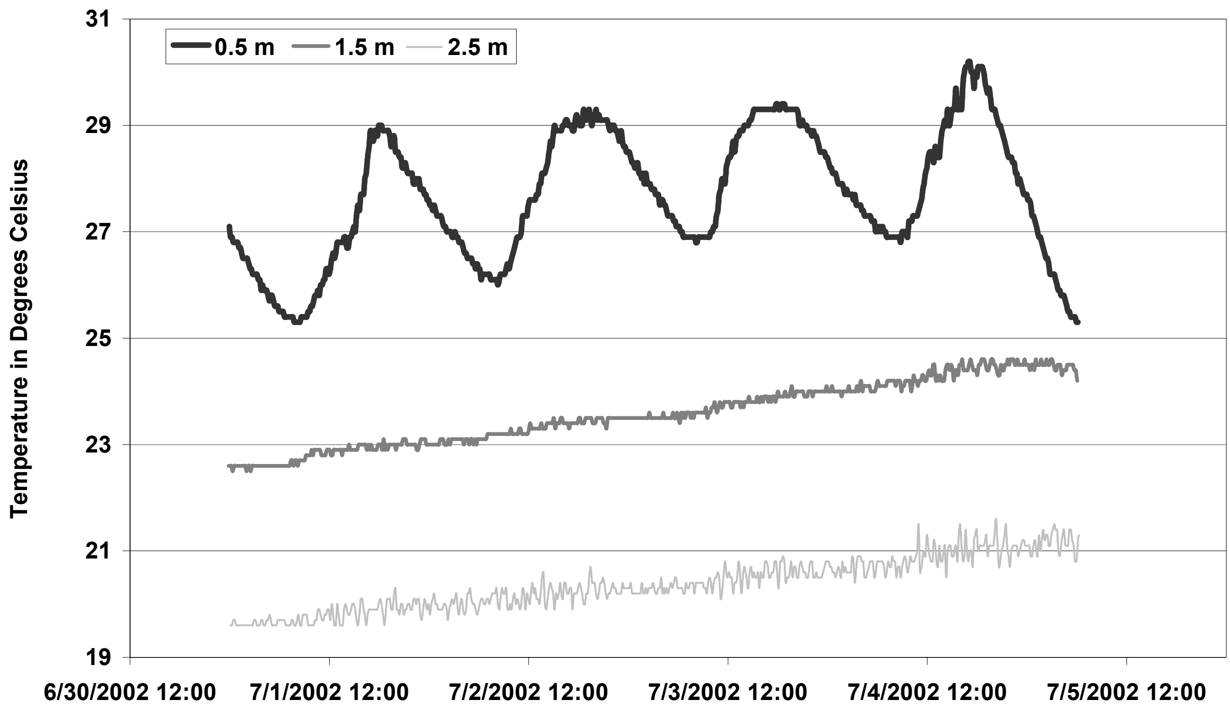


Figure 4.19: Water temperatures at 0.5, 1.5 and 2.5 m below the permanent pool surface on a warm day in July, 2002.

4.1.5.3 Relationships between facility design and performance

Each facility was quantitatively evaluated as a means of assessing, in general terms, whether or not there is a discernable relationship between facility design and overall facility performance. Three design parameters were selected for evaluation: permanent pool storage, drawdown time, and length-to-width ratio. Extended detention storage was not included because in some cases significant extended storage was provided but the outlet control structure did not allow for full utilization of this storage (*i.e.* stormwater was released faster than it needed to be). Design parameters are rated for each facility as poor (1 star), fair (2 stars) or good (3 stars). Each facility is subsequently assessed an overall score out of 9 and these scores are compared to their respective TSS load based removal efficiencies and TSS effluent concentrations.

Table 4.13: Facility design and performance comparison (summer/fall). Ratings from 1 to 3 stars represent poor, fair and good, respectively.

Facility Design Parameter	Markham Pond-wetland	Harding Park Pond	Heritage Estates Pond	Highway Pond	Aurora Wetland	Dunkers FBS	Eastern Beaches Detention Tank	Oil Grit Separators
Ratio of perm. pool storage-to-drainage area	***	**	***	**	*	***	No permanent pool. +	Small relative to ponds
Drawdown time	***	**	**	**	***	*	* (8 hour settling time)	Similar to rainfall duration
Length-to-width ratio	***	*	*	***	***	**	Not applicable	Not applicable
Rating	9 (Good)	5 (Fair)	6 (Fair)	7 (Fair)	7 (Fair)	6 (Fair)	Not applicable	Not applicable
Mean (min/max) TSS Rem. Efficiency (%)	92~ (76 - 97)	80 (26 – 94) (modeled: 75%)	84 (55 – 98) (modeled: 80%)	90 (47 – 99)	90 (40 – 96)	81 (43 – 96)	46 (-11 – 86)	57 & 60 (-81 – 96/ 4 – 83) (modeled: 62 & 60%)*
Design TSS Removal Efficiency (%)	80	70	n/a	70	70	60	n/a	At least 60%
Mean (min/max) TSS effl. conc. (mg/L)	21** (5 – 88)	48 (5 – 145)	16 (2 – 60)	37 (4 – 150)	24 (5 – 155)	Cell 3/5: 11/14 (3 – 67)	55 (8 – 198)	35 & 51* (4 – 268 & 10 – 451)
Comments	Catchment was only approx. 70% developed at the time of monitoring, resulting in lower runoff coefficients than most other sites.	Highest unit area inflow volumes and the only pond facility with mean inflow volume greater than permanent. pool volume.	Storm events monitored were small relative to those monitored at most other sites.	Catchment contains 75% transportation land use. Significant exfiltration and relatively small average event size improved measured performance.	Catchment contains 30% agricultural land use. Significant exfiltration improves removal rate.	Includes additional innovative design features intended to enhance system performance (see section 4.1.1.6)	8 hour detention prior to discharge of stormwater supernatant to lake. Subnatant is pumped with CSO runoff to a water pollution control plant for treatment after the rain event.	Provides real-time treatment based on principles of hydrodynamic settling. Storm events monitored were small relative to most other sites

+Unit area storage ($35 m^3/ha$) is less than other pond facilities.
*3-Chamber and Stormceptor, respectively
**wetpond outlet

Results of the evaluation are provided in Table 4.13 (See table 4.3 in section 4.1.4 for actual values associated with design parameters). Since the purpose of this simple evaluation is to compare facilities, the ratings were assigned in relation to other facilities, rather than in relation to the OMOE guidelines. Other site specific design or monitoring program issues that may have influenced performance results are provided at the bottom of the Table in the 'comments' field.

Relationships between the three design parameters evaluated and overall performance could not be demonstrated statistically. However, the Markham pond-wetland, which has the largest unit area storage volume and longest drawdown time, exhibits the highest (and most consistent) load-based TSS removal efficiency and comparably low mean effluent TSS concentrations. By contrast, the Harding Park retrofit pond rates the lowest on the three design elements and, among the ponds and wetlands, the facility has the lowest removal efficiency and highest mean effluent TSS concentration. The Rouge River pond and the Aurora wetland are ranked second, followed by the Dunkers flow balancing system and Heritage Estates pond. These four facilities were all designed to a 'normal' protection level (*i.e*. 70% TSS removal) and are comparable in terms of performance. The Dunkers flow balancing system had the lowest mean effluent TSS concentration and good overall removal despite a relatively short detention and drawdown time. The enhanced performance in this case may be attributed to the perforated curtains separating the cells, which are designed to improve settling by increasing residence time (i.e. reducing short circuiting). Impressive removal rates in the Aurora wetland and Rouge River pond are in part attributable to volume reductions due to exfiltration within the pond; effluent concentrations show these facilities to be on par with the other facilities.

The Eastern Beaches detention tank and oil grit separators operate based on different principles than the other facilities and therefore direct comparisons in terms of design and performance could not be made. Acknowledging these differences, however, it is worth noting that in a settling basin such as the Eastern Beaches tank, 8 hours of detention does not provide a similar level of treatment to that of the other pond and wetland facilities monitored. The oil grit separators, on the other hand, have only a fraction of the storage of all the other systems, and negligible detention times, yet through special hydrodynamic designs they are able (if regularly maintained) to remove up to ¾ of the suspended solids load that the other facilities remove (*i.e.* OGS remove 60% of the suspended solids load versus an average of 80% for ponds and wetlands).

4.1.6 Process Study Components

Although the primary purpose of SWAMP studies was to evaluate the effectiveness of stormwater practices in relation to design standards, there were some additional components added to the conventional monitoring set-up that also helped address questions related to treatment processes. For instance, at two of the sites (Markham pond-wetland and Toronto Dunker FBS) intermediate stations were set-up within the facility at the forebay and wetpond outlets. Monitoring results showed that between 50 and 70% of the total influent suspended solids load was deposited in the upstream third of the facility (in these cases, a forebay and cell partitioned by permeable curtains). The size distribution of particles in the water (suspended) and bottom sediments (deposited) were reduced by similar proportions. The larger quantities of sediment deposited in the upstream portions of the facilities also corresponded to poorer sediment quality relative to downstream locations (see section 5.2.2). These findings highlight the importance of forebays in retention facilities. These enhanced settling areas should include features such as designated drying areas and machinery access from the banks to facilitate sediment clean-out. Designing for future maintenance can result in significant savings on clean out costs over the life of the facility.

Wetlands constructed at the end of ponds or detention basins were limited to providing a stormwater polishing function. The concentration of TSS in stormwater entering and exiting the wetland was not significantly different. The quality of bottom sediments in the wetland was also cleaner than other cells (see section 5.2.2). In the future, the wetland may start to fill up more quickly as sediment accumulation in the forebay and main pond areas reduces the treatment effectiveness of these areas.

Stormwater facilities are typically designed based the assumption that new stormwater entering the facility displaces all of the facility contents before discharging to receiving waters. This condition is referred to as 'plug flow.' Dye tests at the Dunkers facility, however, showed that this 'ideal' condition is rarely realized in practice. Influent water (represented by the dye) traveled over twice as far than would be predicted under plug flow conditions. Vertical profiles of dye revealed that, instead of displacing the permanent pool, influent water moved first across the surface and only later mixed with cell contents. Depth profiles of temperature and chloride (see discussion above) further corroborated these findings.

4.2 Conveyance System Evaluations (2 Studies)

Two monitoring and evaluation studies completed under the SWAMP program involved conveyance facilities. The purpose of this section is to consider the results of these studies as a group and synthesize information related to common elements of their research. Findings are presented which may assist in predicting the performance of future facilities designed in a similar manner or may aid in improving future designs. Any significant differences in the facilities are also highlighted.

4.2.1 Study Site and Context

4.2.1.1 Exfiltration/Filtration Systems – Etobicoke, Toronto

This study examined three conveyance control systems constructed between 1992 and 1994 as a demonstration project in Toronto (formerly the City of Etobicoke). These systems consisted of two conveyance pipe-based exfiltration facilities on Princess Margaret Boulevard and Queen Mary's Drive, and a conveyance pipe-based filtration system on Braecrest Avenue. All three systems were installed under municipal streets. Perforated pipes embedded in geotextile lined gavel-filled trenches were installed in parallel with conventional storm sewers designed to convey all of the runoff from a standard design storm.

As illustrated in Figure 4.20, the exfiltration systems consist of two perforated pipes located below the main sewer pipe. Runoff from catchbasins enters the systems by way of catchbasin leads connected to the sewer pipes or maintenance holes in the conventional manner. At each maintenance hole, runoff enters the perforated pipes to be distributed into the gravel bed from where it exfiltrates into the soil. If the volume or rate of runoff exceeds the exfiltration capacity of the system, the water level in each maintenance hole increases to the point at which the excess flow 'overflows' to the conventional sewer pipes.

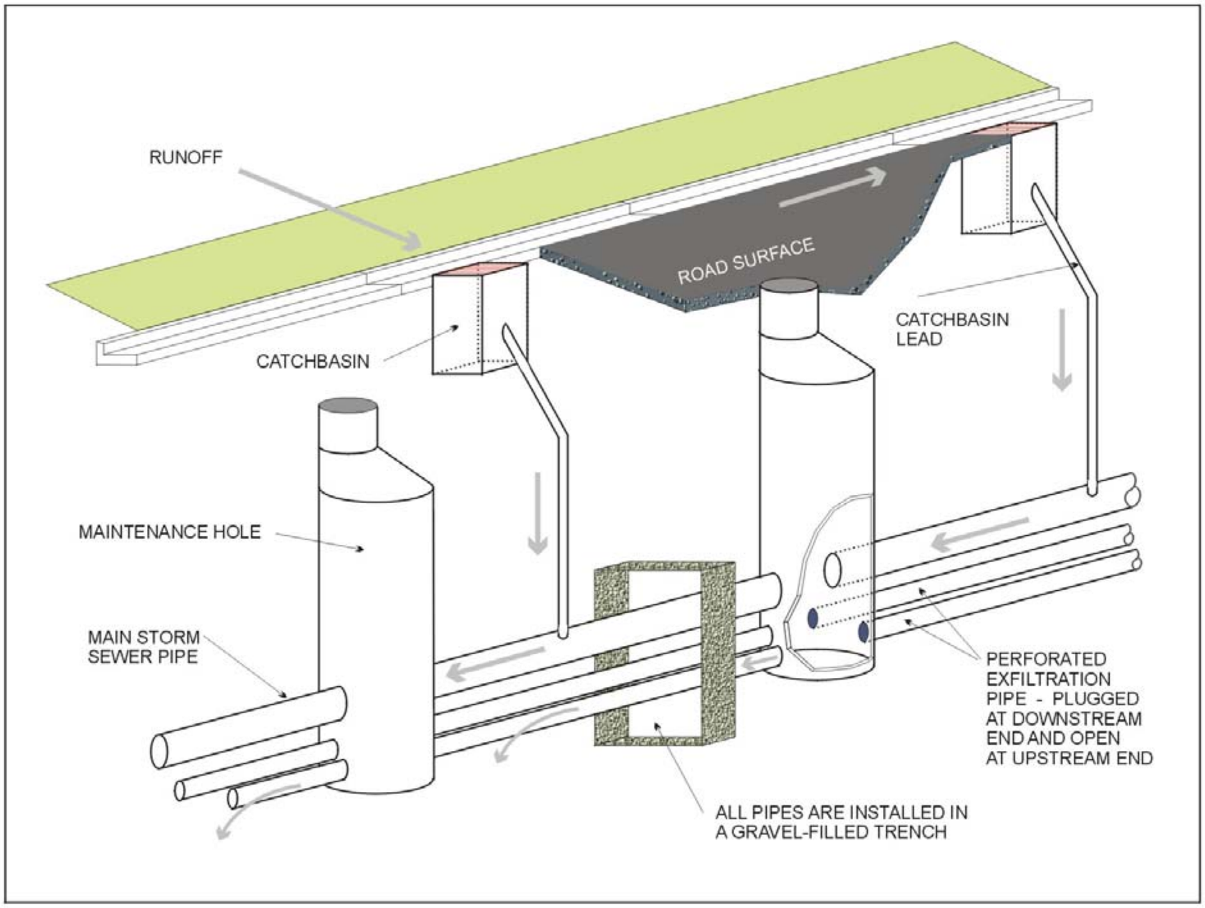


Figure 4.20: Exfiltration system schematic, Etobicoke, Toronto

In the filtration system, a perforated pipe is located above the main sewer pipe (Figure 4.21). Runoff from the catchbasins is directed to this perforated pipe, from where it is distributed into the gravel bed. The runoff is filtered down through the gravel and some of it may exfiltrate to the local soil. Most of the filtered water is collected by two perforated pipe underdrains located below the main sewer pipe and discharged to the downstream maintenance hole from where it is conveyed by the next leg of the main sewer pipe. The principle effects of the filtration system are to dampen variations in flow rate and to filter contaminants from the runoff. If the rate of runoff exceeds the throughput capacity of the filtration system, water in the catchbasins rises to a level at which a second catchbasin outlet pipe conveys the excess flow directly to the main sewer pipe, by-passing the gravel filter bed. The filtration system was designed for use in areas where percolation rates through local soils are too slow to provide effective exfiltration.

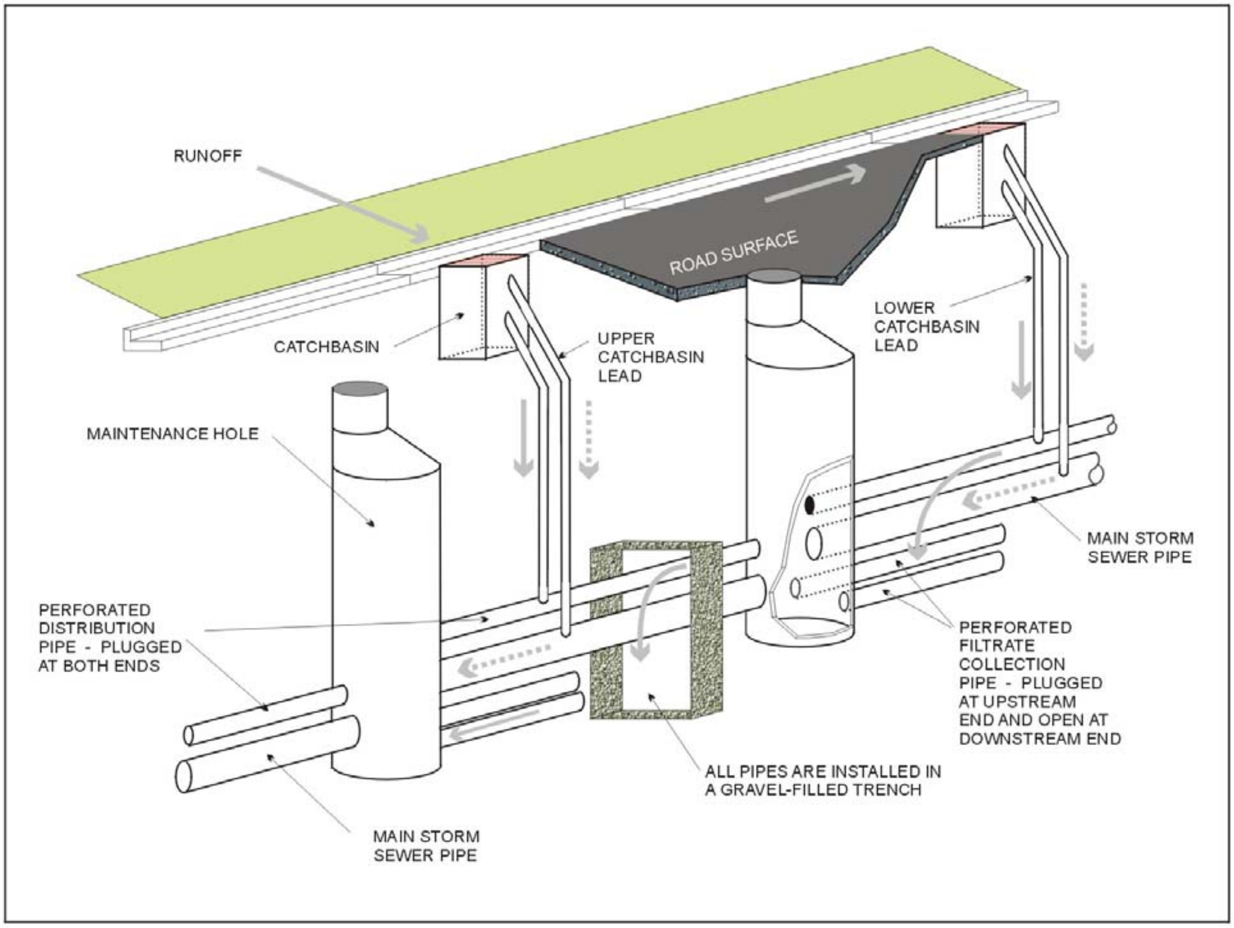


Figure 4.21: Filtration system schematic, Etobicoke, Toronto

4.2.1.2 Infiltration System – North York, Toronto

The swale and perforated pipe infiltration stormwater system was constructed in a low density residential neighbourhood within the Wilket/Milne Creek subwatershed of the Don River. The system was intended to provide runoff quantity and quality control as part of the Wilket/Milne Creek Regeneration Plan and Don Watershed Management initiatives undertaken by the City of Toronto and the Toronto and Region Conservation Authority (TRCA). Use of this stormwater management approach was expected to provide significant improvements over the former ditched road network while avoiding the need to construct new storm sewer outfalls.

Figure 4.22 shows a simplified schematic of the infiltration system. The system consists of two components; a grassed swale (0.3 m deep x 3.0 m wide) and an underground infiltration trench (2 x 2 m in cross-section) located below the swale. The trench is lined with filter cloth and filled with granular 'A' gravel. The swale receives drainage from sidewalks, driveways and adjacent grassed areas. Runoff from the roadway is routed to catchbasins and subsequently directed to the infiltration trench via a 250 mm diameter lateral pipe. This lateral connects with a central 150 mm diameter filter cloth-wrapped perforated pipe laid within the trench aggregate at about 700 mm above the trench base.

At the downstream end of the trench, another 150 mm diameter pipe routes discharge water from the trench to a central storm sewer. A 250 mm diameter overflow relief pipe is connected to each catchbasin at 300 mm above the level of the infiltration lateral and drains into the central storm sewer. By design, the free water level within the trench must rise above 1.0 m from the base of the trench to engage the overflow relief pipe. Goss traps in the catchbasins, located at the lateral into the filtration trench and at the overflow lateral to the central storm sewer, reduce the amount of floating material that enters the pipes.

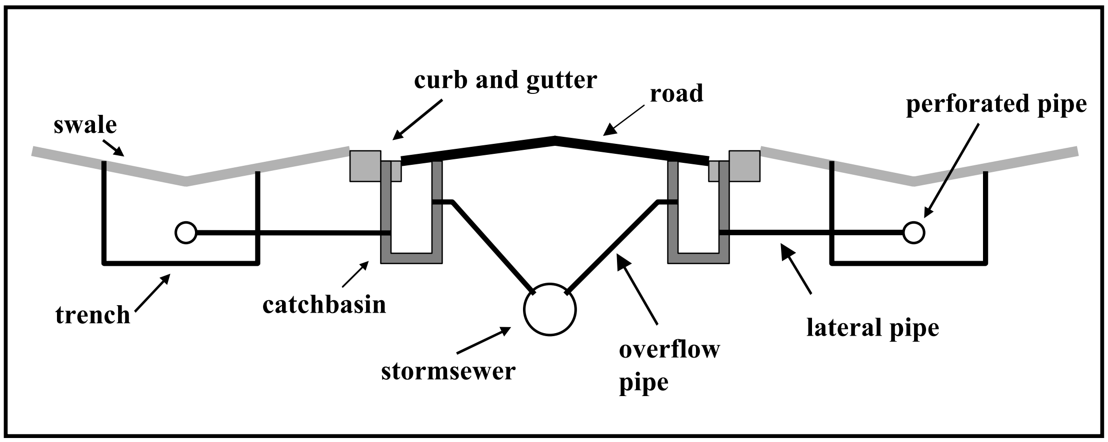


Figure 4.22: Simplified schematic of the infiltration system.

4.2.2 Monitoring Programs

The Etobicoke exfiltration/filtration systems were monitored for quality and quantity (water level and flow) at the downstream ends of each system. Since the gravel trench does not continue past the last maintenance hole in the drainage system, the monitoring stations provided access to all flows exiting the study areas. Water quality samples were collected using a combination of automated samplers, grab samples and buckets placed in the maintenance holes. Rainfall was monitored at a school in the general study area. Additional rainfall data were obtained from L.B. Pearson International Airport, somewhat further away.

Monitoring at the Queen Mary's Drive and filtration system sites (Braecrest Ave) was terminated after only one runoff season because the sites were not considered to be representative of their respective design objectives (see section 4.4.4). The Princess Margaret Boulevard site was monitored for the full three years from 1996 to 1998.

Results were compared to an earlier monitoring study of the same system conducted from April 1994 to October 1995 by A.M. Candaras Associates Inc. for the City of Etobicoke.

Monitoring of the swale/perforated pipe infiltration system in North York was similar to that of the systems in Etobicoke, except that a reference site with similar land use was used to estimate the volume of flow entering the system (this was not monitored in Etobicoke). Inflow volumes in infiltration/exfiltration systems are notoriously difficult to monitor because of the multiplicity of overland flow and catchbasin inputs to the system – the reference site provided a reasonable means of accomplishing this task. Detailed impervious area estimates of roads, roofs and driveways provided the basis for comparing the reference and infiltration system results. Additional insights on the hydraulic capacity of the system were gained by pumping water into the system from fire hydrants and monitoring the effects.

4.2.3 Study Area and Design Comparison

Table 4.14 presents design elements for each of the exfiltration systems monitored by SWAMP. All of the systems were installed in low density residential areas. The North York system trench storage capacity is roughly double that of the Etobicoke systems and was designed for a storm size of approximately 25 mm over 1 hour. This system also contained a screened 150 mm bleeder pipe at the downstream end of the street which would have reduced the capacity of the system to exfiltrate runoff. In hindsight, this additional 'safety' feature may not have been necessary since the system was very effective in exfiltrating runoff and bypass capacity was provided within the catchbasins. The Braecrest Avenue filtration system had less effective storage below the overflow elevation but contained a similar storage capacity because of the relatively small drainage area. Since this system was designed to filtrate rather than exfiltrate runoff, maximizing trench storage was not a major objective of the filtration system design.

Geotechnical investigations conducted prior to installation of the systems revealed that the soils in the area were a combination of sand and silt at the exfiltration sites, and clay loam at the filtration site. Groundwater tables were well below the base of the trenches at all but the Queen Mary's site, which had considerably higher water tables, ultimately reducing the effectiveness of the system (see below). The North York system had groundwater within 2 m of the surface at a few locations, but borehole logs showed these to be a result of perched water tables that were not representative of local or regional groundwater levels.

Table 4.14: Site characteristics and design elements of exfiltration/filtration systems monitored under SWAMP

	Princess Margaret Drive Perforated Pipe Exfiltration System	Queen Mary's Drive Perforated Pipe Exfiltration System	Braecrest Ave. Perforated Pipe Filtration System	North York Swale/Perforated Pipe Exfiltration System
SITE CHARACTERISTICS				
Soil texture	clay to clay-silt till over silty sand	sand to sandy silt	clay loam	silty sand
Hydraulic Conductivity*	10^{-5} to 10^{-9} m/s	10^{-4} to 10^{-6} m/s	10^{-8} to 10^{-10} m/s	2 to 8 x 10^{-5} m/s
Groundwater Elevation Below Surface	>14.0 m	1.2 – 2.5 m	n/a	> 5 m^{+}
Drainage Area	30.5 ha.	13.3 ha.**	2.4 ha.	64.0 ha.
DESIGN ELEMENTS				
Exfiltration Trench (cross sectional area)$^{+}$	3.5 m^2	4.4 m^2	3.5 m^2	2 trenches, 4 m^2 each
Exfiltration Trench below overflow elevation (cross sectional area)$^{+}$	1.7 m^2	1.9 m^2	0.8 m^2	2 trenches, 2 m^2 each
Trench Storage per unit drainage area	25 m^3/ha	13 m^3/ha**	23 m^3/ha	51 m^3/ha
Design Storm	15 mm AES 1-hour storm	15 mm AES 1-hour storm	15 mm AES 1-hour storm	Approx. 25 mm AES 1-hour
Pipe/Channel Specs	Perforated pipes: 2 – 200 mm	Perforated pipes: 2 - 200 mm	Upper perforated pipe: 200 mm Lower perforated pipes: 2 - 100 mm	Grassed swale: 0.3 m deep x 3.0 m wide Perforated pipes: 2 - 150 mm
Bedding	16 mm clear stone	16 mm clear stone	16 mm clear stone	Granular 'A'
Filter Material	Geotextile filter cloth	Geotextile filter cloth	Geotextile filter cloth	Geotextile filter cloth

*Hydraulic conductivities were estimated from soil texture at all but the North York site.
$^{+}$Geotechnical investigations revealed water tables up to 2 m below the surface but these were not deemed to be representative of local or regional groundwater levels.
$^{++}$Cross sectional areas varied over the length of the systems. Values provided are approximate average areas.
**Design drawing indicated that an 9.6 hectares drained by conventional sewers was discharging to the exfiltration system. Without the conventional sewer discharge, the unit area storage of the Queen Mary's Drive system would be approximately 22 m^3/ha.

4.2.4 Monitoring/Evaluation Results for Conveyance Facilities

4.2.4.1 Water Quantity

The four systems were effective in exfiltrating most of the runoff directed into the perforated pipes. Even the Braecrest filtration system, which was designed to filter, not exfiltrate runoff, generated very little flow from storm events up to 66 mm in size. The high exfiltration rates in soils that were identified prior to installation of the system as having very limited permeability was attributed to localized sand lenses or cracks in the clay matrix. The Princess Margaret and North York systems exceeded their design criteria, exfiltrating approximately 95 and 89% of all flows respectively. Peak flows were also significantly reduced. Antecedent moisture conditions and runoff intensities were the major factors contributing to overflows.

The Queen Mary Drive system also reduced runoff, but much less effectively than expected based on the 15 mm 1-hour design storm. The high groundwater table, which intersected the perforated pipe at the downstream end of the system, was thought to be a contributing factor. In addition, design drawings revealed that an appreciable area drained by conventional sewers was discharging to the exfiltration system. Thus, the hydraulic load placed on the system was greater than it would have been for a system consisting exclusively of the exfiltration design. Despite these limitations, an examination of runoff coefficients revealed that up to two-thirds of the runoff was being exfiltrated.

Hydraulic tests at both exfiltration study sites demonstrated that the capacity of exfiltration systems to store and exfiltrate runoff is limited by throughput capacity. Consequently, stormwater entering the system at high flow rates overflowed before storage in the stone trench had been fully utilized. The problem appears to be a result of air entrapment either within the pipe network or the gravel trench. Various design modifications are recommended to reduce this problem, such as installing vent pipes in the upper portion of the gravel bed to facilitate air displacement or increasing the diameter of the perforated exfiltration pipes for at least a few metres downstream of each maintenance hole.

4.2.4.2 Water Quality

The availability of water quality data was restricted by the relatively small number of overflows that occurred. Based on the few samples collected, the Braecrest filtration system was observed to have the greatest benefit from a water quality perspective. Overflow from the Etobicoke exfiltration systems was marginally cleaner than the influent runoff. Since in these systems only a portion of the overflow is filtered through the trench, overflow concentrations are not expected to be clean. The North York system overflows consisted primarily of catchbasin effluent and a small quantity of effluent from the downstream bleeder pipe. Two samples showed the quality of effluent at this site to be dirtier than untreated runoff from a nearby reference site. This is not a serious concern as the primary mechanism for water quality improvement in exfiltration systems is through a reduction in loads, not concentrations. Since runoff during the large majority of rain events is fully exfiltrated (*i.e.* exhibit 100% removal), the seasonal load reduction achieved by these facilities exceeded 80% for most variables.

These results are consistent with those from a study of two swale-perforated pipe exfiltration systems in Ottawa (see study summary in section 3.2.2). The Ottawa study showed that, even after several years of operation, runoff volumes from the exfiltration systems continued to be at least 85% less than a conventional sewer system. Also, peak flows were reduced by over 90% and loads were significantly lower than the conventional system for all water quality variables analyzed except chloride (J.F. Sabourin and Associates, 1999).

5.0 MAINTENANCE CONSIDERATIONS

5.1 General Maintenance

In the past, stormwater management facilities were designed to control peak flows. These facilities required little maintenance, as residence times were short and pollutant removal rates were low. Re-suspension of trapped sediment was not a concern as long as the quantity control function of the facilities was maintained. The later addition of water quality control functionality to stormwater management facilities dramatically increased the requirements for operation and maintenance. Sediments and pollutants trapped by the facilities needed to be regularly removed to ensure water quality performance levels were maintained. Maintenance programs typically include consideration of the following factors:

- site inspection
- sediment removal
- vegetation
- condition of structures
- aesthetics
- cost

The following discussion of maintenance practices is based largely on guidance provided in the *Stormwater Management Practices Planning and Design* (SWMP) *Manual* (OMOE, 2003). Other literature sources on maintenance practices reviewed in preparation of this chapter also made significant references to the "Operation, Maintenance and Monitoring" section of the SWMP manual. The information presented here summarizes the major maintenance issues. The reader is directed to the SWMP manual for more detailed information on stormwater management maintenance. Further information on disposal options and guidelines specifically for ponds and wetlands can be found in a study commissioned by the SWAMP program and others called the *Stormwater Management Facility Maintenance Guide*, prepared by Greenland International in 1999.

5.2 Developing a Maintenance Program

5.2.1 Inspections and Monitoring

Inspection of SWM facilities is necessary to confirm proper operation and identify maintenance needs. The OMOE recommends that new installations be inspected following every significant storm during the first two years of operation. For BMPs that are well established, an annual inspection is considered to be adequate. The inspection should include a visual assessment of the hydraulic operation of the facility, in the case of a wet pond or wetland; this can be accomplished by visiting the site after a period of three days without precipitation. If the water is higher than the normal permanent pool elevation, the outlet structures should be inspected for blockage. The condition of the vegetation associated with a BMP should be inspected to determine if any maintenance is required. Sediment accumulation rates in the facility should be monitored to establish an appropriate schedule for sediment removal. Since sediment removal in some facilities such as ponds is expensive, it is important to plan well in advance for the necessary expenditures.

The reader is directed to the SWMP Manual (OMOE, 2003) for a more comprehensive list of suggested inspection and maintenance activities.

5.2.2 Sediment Removal

Sediment accumulation is widely viewed to be the most critical maintenance consideration. Stormwater management ponds and wetlands are particularly effective in capturing suspended sediment, but as sediment accumulates in the facility, the storage volume decreases along with the treatment efficiency. Thus accumulated sediment must be removed to allow SWM facilities to continue to function properly.

The required frequency of sediment removal depends on the amount of sediment input to a facility, which is a function of upstream land use and impervious cover. Sediment loading is also affected by municipal practices such as street sanding and cleaning, and whether or not construction or landscaping is occurring within the drainage area. The acceptable amount of sediment accumulation in a pond or wetland is dependent on the amount of storage provided (oversized ponds can accommodate greater sediment accumulation).

The frequency of sediment removal is determined based on the available storage volume, the minimum required volume for acceptable pond performance and the rate of sediment accumulation. The preferred method for determining sediment accumulation rates involves a program of direct measurements of sediment depth in a facility over time (Greenland Consulting Inc., 1999). Alternatively, if monitoring data are available, sediment accumulation rates can be roughly estimated from influent total suspended solids loading and an empirical value for the bulk density of wet sediment (approx. 1230 kg/m^3).

Whatever method is used, sediment accumulation depths must be converted to reductions in storage volume and removal efficiency based on empirical relationships between unit area storage volumes and TSS percent removal provided in the first edition of the SWMP manual (OMOE, 1994). Clean-out is generally recommended when the loss in storage volume due to sediment accumulation causes a reduction in removal efficiency by 5% below the original target efficiency for the facility. In the second edition of the SWMP manual (OMOE 2003), this procedure is simplified by a series of graphs showing predicted relationships between sediment removal frequency and unit area storage volumes for a range of BMP types and levels of imperviousness. Sediment accumulation rates and required clean-out frequencies based on SWAMP monitoring results and the new OMOE graphs are provided in Table 5.1.

Sediment can be removed either by mechanical excavation/dredging or hydraulic (suction) dredging. The advantages and disadvantages of sediment removal methods are discussed in the *Storm Water*

Management Facility Sediment Maintenance Guide, along with other information relating to sediment maintenance in SWM facilities (Greenland Consulting Inc., 1999).

Table 5.1: Estimated sediment accumulation rates and clean-out frequencies

Facility	Cell	Unit Area Storage Volume (m^3/ha)	Estimated Accumulation Rate (mm/year)	Pond Clean-out Frequency Estimates (years)	
				SWAMP Studies	**OMOE SWMP Manual (2003)**
Markham	Forebay	75	15.2	21	22
	Pond	122*	5.5*	54*	60*
	Wetland	129*	0.2*	193*	80*
Harding Park	Pond	60	1.5	16	11
Heritage Estates	Pond	131	3.0	52	65

* SWAMP estimates of accumulation rates and clean-out frequencies for the Markham forebay, pond and wetland are based on sediment loads entering and exiting each cell. The OMOE estimates are cumulative and assume sediment settling depths are equal in all 3 cells. The difference in clean-out frequency estimates for the Markham pond and wetland are largely attributable to this difference in method.

Consideration must also be given to the method of disposal for the removed sediment, based on the type and concentration of contaminants present in the soil. The disposal of contaminated soil is governed by Regulation 347 under the Environmental Protection Act. Under this regulation, materials that do not meet inert fill requirements, as defined in Table F of the Guidelines for Contaminated Sites in Ontario (GCSO) (OMOE, 1997), must be disposed of in a designated waste disposal site. For stormwater pond sediments, this site is usually a landfill site, unless the dredged material is designated as hazardous waste, in which case the material would need to be disposed of at a hazardous waste facility. Open water disposal is an inexpensive option for disposal because dewatering of sediment is not required. However, to qualify for open water disposal, pond sediments must meet the ‘Lowest Effect Level’ (LEL) concentrations listed in the Provincial Sediment Quality Guidelines (PSQG), which is rarely the case.

Table 5.2 compares sediment sampling results for various stormwater ponds in Ontario to Provincial Sediment Quality Guidelines (PSQGs) and Background Soil Concentrations (i.e. inert fill) from Table F of the GCSO. Results show that pond sediments generally do not meet PSQG or GCSO criteria, and therefore landfill disposal would be required. The exception is cell 5 of the Dunker’s Flow Balancing System, which provides polishing of stormwater runoff following treatment in other cells. In cell 5, sediment concentrations for variables tested meet both the LEL and GCSO agricultural criteria, suggesting that currently land application or open water disposal may be appropriate options for this sediment. This may no longer be true several decades later when sediment removal is required.

Table 5.2: Comparison of sediment quality at stormwater end-of-pipe facilities to Provincial Sediment Quality Guidelines (PSQG) and Guidelines for Contaminated Soil in Ontario (GCSO).

	SWAMP Studies												Literature			PSQG[3]		GCSO Background Conc.[4]	
	H.E.	Aurora	Harding Park		Rouge River		Dunkers FBS				OGS		Ottawa Study[1]		Kingston Study[2]				
Variable	**Pond**	**Wetland**	**Fore-bay**	**Pond**	**Fore-bay**	**Pond**	**C. 1**	**C. 3**	**C. 4**	**C. 5**	**3 C**	**S-C®**	**Pond 1**	**Pond 2**	**Wet Pond**	**LEL**	**SEL**	**Agr.**	**Non-agr.**
Nutrients																			
``TKN (mg/g)	--	0.80	--	--	--	--	1.7	2.2	1.6	0.5	0.8	0.9	--	--	--	0.55	4.80	--	--
``TP (mg/g)	--	0.70	--	--	--	--	0.8	0.8	0.8	0.5	0.54	0.53	--	--	--	0.60	2.00	--	--
Conventionals																			
``Cl (mg/g)	--	524	--	--		1626	--	--	--	--	210	29250	--	--	--	--	--	58	330
``TOC (%)	--	2.3	3.1	2.1	2.4	2.1	3.0	3.2	2.1	0.5	2.9	2.3	--	--	--	1	10	--	--
Metals																			
``Al (%)	--	1.0	1.5	1.8	0.6	1.3	1.2	1.5	1.6	0.5	0.8	1.1	--	--	--	--	--	--	--
``As (ug/g)	--	1.6	--	--	--	--	3.3	4.2	4.3	1.4	--	--	--	--	2	6.0	33.0	14	17
``Cd (ug/g)	1.60	<1	1.0	1.1	1.0	1.1	1.3	1.1	1.0	0.4	1.5	2.0	<1	<1	1.2	0.60	10.00	1.0	1.0
``Cr (ug/g)	17	23	32	32	31	28	39	35	37	10	58	28	42	31	--	26	110	67	71
``Co (ug/g)	--	6	--	--	--	--	8	9	10	4	12	10	--	--	110	--	--	19	21
``Cu (ug/g)	25	18	57	42	77	55	66	50	47	9.0	91	48	28	22	88	16	110	56	85
``Fe (%)	--	1.5	1.6	2.3	1.2	2.0	1.9	1.4	2.4	0.9	1.6	1.8	2.8	1.8	3.0	2	4	--	--
``Pb (ug/g)	42	11	36	21	48	56	53	36	36	7.7	88	54	20	19	125	31	250	55	120
``Mn (ug/g)	--	433	480	560	357	545	453	460	503	217	445	585	--	--	495	460	1100	--	--
``Hg (ug/g)	--	--	--	--	--	--	0.16	0.04	0.02	0.01	0.04	0.06	--	--	0.05	0.20	2.00	0.16	0.23
``Ni (ug/g)	25	12	14	18	10	17	21	24	26	9	20	18	25	15	32	16	75	43	43
``Zn (ug/g)	93	71	260	130	343	260	233	166	157	29	380	200	127	95	319	120	820	150	160

Note: Samples typically represent a composite set of 3 grab samples. The sample size in the Ottawa study was much larger than in SWAMP studies (n=30-32). LEL: Lowest Effect Level. SEL: Severe Effect Level. Dunkers facility: C1 = cell 1. Oil Grit Separators: 3 C and S-C refer to the 3 chamber and Stormceptor® OGS, respectively.
References: 1. VanLoon et al., 2000; 2. Marsalek et al., 1997. 3. Provincial Sediment Quality Guidelines (Persaud et al., 1993); 4. Guidelines for use at contaminated sites (OMOEE, 1996).

5.2.3 Vegetation

Occasional maintenance of plantings may be required. Upland plants do not require much maintenance once established, however; shoreline fringe and aquatic plantings may need routine replanting or enhancement. Grass cutting should be avoided where possible, as grass growth has been found to enhance water quality and discourage nuisance wildlife. When it is not possible to avoid grass cutting entirely, the grass should not be cut to the edge of the permanent pool and clippings should not be allowed to enter the pond. Weed control activities should be carried out annually to remove invasive species that threaten the viability of the chosen plantings.

5.2.4 Condition of Structures

Inspections of all structures should be carried out annually to ensure proper functioning and identify maintenance needs. Structures include all of the designed elements of a SWM facility such as inlets, outlets, maintenance roads, access chambers and spillways.

5.2.5 Aesthetics

Stormwater management facilities, particularly ponds and wetlands, can be valuable landscape features. Maintenance should be carried out to enhance the public aesthetic value of SWM facilities. Debris that has collected at inlets and outlets should be removed to ensure proper performance and to improve visual appeal. Facilities generally require a “spring cleanup” and one other cleanup over the course of a year.

5.2.6 Costs

Typical unit costs for maintenance activities are provided in the SWMP manual. For reference, “Table 7.5: Unit Costs for Operations” from the OMOE SWMP manual is included in Appendix C. Since the cost of dredging is often very significant, municipalities should set aside funds each year to pay for the eventual clean-out of these facilities.

5.3 Maintenance Issues Specific to Infiltration Facilities

It has been found that the long term performance of infiltration facilities can be preserved only if proper inspection and maintenance is carried out. A field survey carried out in Maryland compared the condition of a range of infiltration facilities in 1986 with their observed condition in 1990 (Lindsey *et a*l. , 1992). The most widespread problem reported was sediment entry, resulting in clogged inlets and outlets as well as erosion problems. Sediment entry can be significantly reduced by providing some form of pre-treatment. In systems where water infiltrates from swales or depressions, screening can be accomplished using vegetation, most commonly grass. In systems where water enters the infiltration system from catch basins or other drop structures, sand filters, aggregate socks, screens or goss traps can be used for pre-treatment (SWAMP, 2002). Filters and aggregate socks also act as an adsorptive surface for oil and grease, which can significantly reduce the effectiveness of infiltration systems due to clogging and fouling effects. Other maintenance needs may include upkeep of vegetation used as a buffer or for bank stabilization, and aeration or tilling of soils on swales or around trenches to sustain adequate infiltration rates. Pooled water on the surface or in a basin or trench over extended periods (e.g. 24 hours) is usually a good indication that soil and vegetation maintenance is required.

Table 5.3: Typical maintenance requirements of infiltration facilities

Infiltration Facility Type	Common Performance Malfunctions	Maintenance Requirements
Infiltration Basins	Inappropriate water ponding Excessive sediment or debris Woody/Excessive vegetation	Bank stabilization Thinning of excess vegetation Sediment/Debris removal
Trenches	Excessive sediment or debris Clogging of facility	Buffer strip maintenance Sediment/Debris removal
Porous Pavement	Excessive sediment or debris Clogging of facility	Sediment/Debris removal Buffer Strip maintenance
Vegetated Swale	Water bypassing facility Inappropriate water ponding	Soil aeration or tilling
Dry Wells	Inappropriate water ponding	Soil tilling

Source: OMOE, 2003.

5.4 Consideration of Maintenance Costs When Selecting SWM Practices

The expected operation and maintenance costs for a given SWM practice should be considered when selecting an appropriate SWM strategy for a site. Many structural source controls require little or no maintenance, and may be a less costly alternative to end-of-pipe facilities when all costs are considered.

6.0 DESIGNING A MONITORING PROGRAM

6.1 Key Components

The development of a monitoring program involves several key components:

- planning
- implementation and management
- reporting and development of recommendations for management

In the planning stage, general goals of the monitoring program should be proposed in order to address a well defined question or set of questions. These will be refined into a more specific set of objectives based on the availability of resources to conduct the monitoring and a review of existing literature on similar monitoring programs conducted elsewhere. It is important to survey what others have done to ensure that the study builds upon existing experience and successfully fills gaps in knowledge about the specific topic or issue being investigated.

The site and methodology for the study are determined once the specific objectives have been defined. The site selected for the study should be representative of a broad range of typical sites where the technology being evaluated can or has been applied. Monitoring and analytical methods should follow standard, internationally recognized procedures to ensure comparability of results with other similar studies. Decisions on the site for the study and methods may force a re-assessment and refinement of the initial objectives.

In the implementation and management phase, monitoring is undertaken according to the plan developed and the data are analyzed and interpreted. In some cases it may be appropriate to use the monitoring data to calibrate predictive models in order to simulate various ‘what if’ scenarios. These ‘what if’ scenarios may include an evaluation of the technology over long time periods or help us understand receiving water benefits associated with replication of the technology over an entire subwatershed. Once the monitoring and modeling studies have been completed, recommendations for management are developed. Recommendations may address issues related to technology improvement, replicability, site selection criteria, maintenance and further research needs. These recommendations should be based not only on the monitoring results but also on an assessment of potential barriers (*e.g.* cost, public perception, regulations) to technology implementation. Finally, if a technology has been demonstrated to be effective, a program should be implemented that ensures that the results are disseminated and the technology is applied at a broader scale.

The following sections briefly elaborate on the various steps typically involved in developing a monitoring program. A more detailed and thorough treatment of this topic can be found in two documents published in the United States: (i) *Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements* (Geosyntec and ASCE; 2002); (ii) *Wet Weather Flow Assessment Protocols* (Moffa and Associates, 2001).

6.2 Defining the Goals

The goal of a SWM facility monitoring program should be to provide meaningful, representative and useful data in the most cost effective manner possible. The evaluation of the performance of stormwater management facilities is a complex undertaking, made difficult by temporal and spatial variability of stormwater flows and pollutant concentrations. Variability is an inherent property of the systems. Since it is clearly not possible to measure every component at all times, clear goals should be established at the onset of the monitoring program to facilitate the collection of relevant and useful data with the limited resources available.

The guidance manual developed as part of the ASCE BMP database (GeoSyntec and ASCE, 2002) noted that studies aimed at addressing the efficiency of stormwater management facilities in attaining water quality goals were usually concerned with one or more of the following questions:

- What degree of pollution control or effluent quality does the BMP provide under normal conditions?
- How does this efficiency vary from pollutant to pollutant?
- How does this normal efficiency vary with large or small storm events?
- How does this normal efficiency vary with rainfall intensity?
- How do design variables affect efficiency?
- How does efficiency vary with different operational and/or maintenance approaches?
- Does efficiency improve, decay, or remain stable over time?
- How does this BMPs efficiency compare with the efficiency of other BMPs?

In the planning stage, it is important to identify what questions are to be answered so that the appropriate data can be collected. The goals may also affect the method of sampling and the method of processing data. It is also important to identify constraints. For example, if access to the inlet of a facility is restricted, it may not be possible to obtain the necessary samples for analysis. Limitations relating to laboratory analyses, cost factors and the length of the program are also major constraints to be considered (Moffa and Associates, 2001).

6.3 Development of the Plan

Once the goals are established, the development of a monitoring plan can begin. The following list identifies the main issues to be considered when developing a monitoring plan:

- site selection
- length of program & monitoring frequency
- water quality variables and analytical methods

- monitoring methods and equipment
- data management plan
- budget

6.3.1 Site Selection

One of the most critical components of a monitoring program is the careful selection of a study site. Ideally, the site selected would be representative of typical conditions such that the monitoring results closely reflect average performance for a given facility type and can therefore be used to justify replication of the technology elsewhere. The representativeness of the site is also a critical factor when assessing benefits of technology implementation through predictive models at broader spatial scales.

Quite often unforeseen conditions impose significant constraints on the monitoring program. For instance, entry into outlet structures may be limited, or flow may back-up to the location selected for measurement, making it difficult to gather reliable data. A review of historical information and available mapping is necessary to select an appropriate site. Availability of electrical supply is important if monitoring is to be conducted during the winter.

In most cases a field investigation should be conducted to confirm that conditions at the site are suitable for monitoring. Undertaking a short pilot monitoring program would help to confirm that conditions are suitable before initiating the full scale monitoring program. If it is discovered that the site is not suitable for monitoring, an alternate site should be selected.

6.3.2 Length of Program

The study duration & sampling frequency should be selected with regard to how the water quality variables of interest vary over time. The time scale for contaminant concentration variation may be short, long or both short and long, as is the case with metals and nutrients. The duration of the study will also be dictated in part by the amount of funding available to support the program. To gain the best representation of the performance of a BMP the study duration should be at least one year so that both cold and warm seasons are included. The program duration should be based on the statistical properties of the data collected. The four factors that influence the probability of identifying changes in water quality are: overall variability in data, minimum detectible changes in water quality, number of samples collected and the desired confidence level (ASCE, 2002). Statistical analysis may be carried out to determine the number of samples required to achieve a given level of confidence.

Naturally, any program must operate within a given budget. The budget should include all costs associated with labour, equipment and laboratory services. The cost of a monitoring program will depend on a number of factors:

- number of events to be analyzed
- number of water quality variables to be monitored

- number of inlets and outlets
- size of contributing drainage area
- accessibility of site
- need for confined spaces entry

Monitoring program costs will also depend on whether the program is properly planned, designed and implemented. A short trial-and-error period during which monitoring protocols are fine-tuned should be built into the budget. The estimated cost for monitoring and data analysis at a site with 1 rain gauge, 1 inlet and 1 outlet, with continuous flow monitoring and automated sampling, allowing for 30-40 flow proportioned composite samples is approximately $100,000 per year.

6.3.3 Water quality variables & Analytical Methods

A monitoring program should target storms of varying size and duration to allow for the evaluation of the facility performance for a range of hydrologic events.

A number of water quality variables may be investigated as part of a comprehensive stormwater sampling program. Standard pollutants characterizing urban runoff include the following:

- TSS
- BOD
- *E.coli*
- Cu – Copper
- Pb – Lead
- Zn – Zinc
- TP – Total Phosphorus
- SP – Soluble Phosphorus
- TKN – Total Kjeldahl Nitrogen
- NO_3+NO_2 – Nitrate + nitrite
- Herbicides and pesticides
- Polycyclic Aromatic Hydrocarbons (PAHs)

The majority of SWAMP studies tested for additional metals, nutrients, bacteria and organic constituents. Organic compounds (pesticides and PAHs) are often omitted from sampling programs because they are very expensive to analyze and often require special low level detection limit methods that not all laboratories are capable of conducting.

TSS is the easiest variable to monitor and is usually well correlated with a number of other variables such as metals, phosphorous etc. When detailed discrete sampling data are required to, for instance, characterize storm event pollutographs, it may be advisable (and more affordable) to analyze a large number of samples for a single variable (TSS) than to analyze one or two composite samples for many different water quality variables. The sensitivity of the receiving water body should also guide the choice of water quality variables to be included in the monitoring (*e.g.* Lake Simcoe is sensitive to elevated concentrations of phosphorous). Temperature, conductivity, pH and turbidity should be monitored continuously on site to achieve the most useful results.

Laboratories selected for sample analysis should be certified and use standard methods that are comparable to those used internationally. A program of quality assurance/quality control (QA/QC) should be implemented to validate analytical data. Recommended QA/QC procedures include the use of method blanks, which involve the testing of a blank sample to determine the level of contamination present in laboratory glassware and reagents, and the use of laboratory duplicates, where one sample is divided into two portions and analyzed twice to assess the reproducibility of the results. Matrix spike and spike duplicates, which are prepared by adding a known concentration of a contaminant to a sample, should be used to determine the precision of the results (GeoSyntec and ASCE, 2002).

6.3.4 Monitoring Methods and Equipment

6.3.4.1 Sampling Protocol

As with other study components, the overall goals of the program should guide the development of the sampling protocol.

Samples should be carefully collected and processed within 24 hours of each event. If samples cannot be submitted to a laboratory for analysis within 24 hours of collection they should be stored in a refrigerator at 4 deg. C. The Ontario Ministry of the Environment (MOE) has developed a set of standard protocols for sample preparation. Individual SWAMP reports contain summaries of MOE analytical procedures.

Samples may be discrete (individual samples taken at a point in time) or composites (a combination of several discrete samples taken over a specified length of time). They may be used alone or in combination.

Flow proportioned samples provide the best representation of the event mean concentration and pollutant load as flow rates and water quality can vary significantly over the course of a runoff event. Different methods can be employed to proportion samples. The most common method is through the use of an automatic sampler and flow logger, programmed to collect an equal sample volume for each increment of a predetermined runoff volume. Unfortunately the programmed runoff volume upon which sample collection is based is never ideal for all storm sizes. An alternative method that avoids this problem involves forming a composite from several discrete sample aliquots collected at equal time intervals. Flow proportioning is achieved by removing from each aliquot a volume that is proportional to the flow volume since the previous aliquot was collected. This method requires that flow data be downloaded at the time of sample collection to determine the appropriate volume to remove from each aliquot.

6.3.4.2 Equipment and Field Monitoring Procedures

Calibration procedures are specific to the type of monitoring equipment used. Equipment should be tested and calibrated prior to installation and at regular intervals throughout the study period. During the

SWAMP program, flow meters and area velocity probes were found to be most susceptible to error. Equipment should be installed in appropriate locations and in a manner that minimizes damage caused by vandalism, or extreme weather events. Consideration should be given to the use of back-up instruments that could be used in instances of equipment malfunction, or to verify the accuracy of field measurements.

Maintenance of field instruments is of paramount importance in order to limit data losses due to equipment malfunction. Maintenance and cleaning once every two weeks is recommended as a minimum requirement to ensure quality control for the monitoring program. Desiccants and batteries may require changing on a more frequent basis. Seasonal maintenance activities may also be required to meet more complex maintenance needs.

At the start of the field program it is usually necessary to build into the schedule a two to three-week period during which the location of instruments and methods of data collection are tested and evaluated against pre-determined quality control criteria. A similar but less thorough verification procedure needs to be undertaken at regular intervals during the course of the monitoring program to ensure data collected are fulfilling project goals.

Data from field equipment should be downloaded at one to two week intervals to avoid loss of data. Raw data should be subsequently analyzed so that potential problems with the equipment or set-up of the instruments can be quickly rectified. It is also preferable to use the same type of monitoring equipment upstream and downstream of a facility to prevent the amplification of errors from two different types of equipment. Detailed records must be kept documenting maintenance and sampling activities as well as field observations.

6.3.5 Data Management

A stormwater monitoring program may generate a significant amount of data. Procedures for data management should therefore be established before initiating the monitoring program. A data management program should include protocols for dating and filing hard copy data and the creation of a database to manage digital data. The goal of the data management program is to allow data to be stored, retrieved, transferred and analyzed in such a way that the integrity of the data is preserved.

6.3.6 Reporting Methods

Consistent methods for reporting monitoring results are necessary to ensure that results can be compared within a particular site as well as with SWM facilities in other locations with different design features. The ASCE guidance manual (GeoSyntec and ASCE, 2002) reviewed and evaluated historical and current reporting methods used to assess stormwater management best management practices in the United States. A summary of these methods provided in the guidance manual is reproduced in Table 6.1 with minor modifications and an additional column that describes the methods.

A thorough discussion of these methods is beyond the scope of this chapter. However, some general comments may be made. Most methods used historically to evaluate BMP water quality performance have attempted to express effectiveness in terms of a fraction or percent of contaminants removed by the facility (i.e. removal efficiency). As stand alone measures of performance, these methods suffer from a similar drawback: they ignore statistical relationships between influent and effluent data sets and do not provide a measure of performance that is independent of influent concentrations. In combination with an analysis of effluent data sets, however, they do provide some value. This was the approach adopted in SWAMP studies, which employed the sum of loads method for events and the mean concentration method for dry weather grab samples. Influent and effluent (dry and wet) data sets were statistically analyzed based on event mean concentrations to assess differences. The ‘effluent probability method’, as described in the ASCE manual, would provide a more rigorous refinement of the SWAMP approach and is recommended for future studies. It should be noted, however, that removal efficiencies will still need to be reported as Ontario guidelines for stormwater BMPs are denominated in these terms.

Concentrations of water quality variables are often expressed in probabilistic terms, using the mean value and standard deviation of selected data values. The log-normal probability distribution has generally been assumed to apply to the concentration of stormwater constituents. However, Van Buren et al (1996) have demonstrated the normal distribution may be more appropriate for describing the distribution of soluble contaminants and storm event outflow from ponds. Selection of the most suitable probability distribution or using non-parametric statistical test is key to avoiding significant errors when calculating pollutant loads and extrapolating estimated values.

6.3.7 Error Analysis

Uncertainties in data collected through monitoring programs are rarely assessed or quantified. These uncertainties may relate to the field equipment, the study design, site specific factors, operator errors, statistical methods used to analyze data, or final interpretation of field observations. Errors can also propagate through a data set as some variables are used to estimate the value of others through, for instance, equations or model calibration. Although it is impossible to quantify most areas with a high degree of confidence, the relative importance of errors on final results can usually be assessed. Examples of this type of assessment for specific measurements and for an entire BMP evaluation are provided in Appendix A of the ASCE guidance manual.

6.4 Monitoring Considerations for SWM Facility Design

Stormwater BMPs can be designed to allow performance monitoring to be carried out more easily and with greater accuracy. The provision of AC power supply at the monitoring site, for instance, opens up a number of monitoring options that would otherwise not exist. Other modifications may include the inclusion of primary structures in the inlet or outlet of ponds and wetland to facilitate flow measurements and the improvement of access to key underground monitoring locations. Many newer facilities incorporate special design features to facilitate maintenance, but few consider additions that would make monitoring and evaluation of the facility easier.

Table 6.1: Summary of methods for stormwater BMP water quality monitoring data analysis

Method Name	Description	Recommendation	Evaluation Comments
Efficiency Ratio	$ER = 1 - \frac{\text{avg outlet EMC}}{\text{avg inlet EMC}}$	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Most commonly used method to date. Does not account for differences in loads among storms as all events are weighted equally. Does not account for differences in inlet and outlet runoff volumes.
Summation of Loads	$SOL = 1 - \frac{\text{sum of outlet loads}}{\text{sum of inlet loads}}$	Not recommended as a stand-alone assessment of BMP performance. More meaningful when statistical approach is used.	Utilizes total loads over entire study. May be dominated by a small number of large events which have a larger relative impact on receiving waters. Results are similar to ER method if event concentrations are not correlated with event size.
Regression of Loads	Regression efficiency is slope of least squares linear regression of inlet and outlet loads with intercept constrained to zero	Not recommended.	Assumptions of method are rarely valid. Can not be universally applied to monitoring data.
Mean Concentration	$MC = 1 - \frac{\text{avg effl. C}}{\text{avg infl. C}}$ where C = concentration	Not recommended, may have value for grab samples when flow data are not available	Difficult to "track" slug of water through BMP without extensive tracer data/hydraulic study. Results are only for one portion of the pollutograph.
Average Efficiency of Storm Loads	$AvgE = \frac{\sum_{j=1}^{m} StormEff._j}{m}$ where m = number of events	Not recommended; may be useful in some circumstances.	Storage of pollutants is not taken into account. Gives equal weight to all storm event efficiencies.
Achievable Efficiency based on Irreducible Concentrations	$AE = \frac{C_{influent} - C_{limit}}{C_{influent}}$ where limit = irreducible concentration and C = concentration	Not recommended, may be useful in some circumstances.	Typically only applicable for individual events to show compliance with standards.
Relative Efficiency	$RE = \frac{Eff.Ratio}{AchievableEff.}$	Not recommended; may be useful in some circumstances.	Typically only applicable for individual events to demonstrate actual BMP performance relative to possible performance.
Multi-variate and Non-linear models	Employs multivariate equation that corrects for efficiency bias caused by variations in influent concentration	Possible future use.	Additional development of methodology is required based on more complete data sets than are currently available.
Effluent Probability Method	**Determine if influent and effluent AEMCs are statistically different and plot data as cumulative distribution function**	**Recommended Method.**	**Provides a statistical view of influent and effluent quality. The ASCE guidance manual recommends this method.**

6.5 Limitations of Monitoring Studies for Facility Evaluation

The results from a single monitoring study can not be considered representative of the performance of an entire facility type. Pollutant loads vary considerably with the size of the contributing drainage area, land use, on-site conditions, design guidelines and particle size distribution. As well, monitoring results will depend on climatic conditions observed during the study period, which may not represent the average for a given location. Extending the length of the study and monitoring at more than one site helps to improve our understanding of BMPs, but ultimately model simulations are needed to draw firm conclusions about long term performance and the relative contribution to performance of specific design variables.

6.6 Final Comments on Field Monitoring

Over the past 15 years, much has been learned about designing and implementing monitoring evaluations of stormwater BMPs. Monitoring and reporting methods used by SWAMP and other researchers were industry standards at the time, but have since been refined or revised to provide for greater accuracy and comparability among studies. A key lesson learned over the seven years of intensive monitoring at SWAMP sites is that monitoring is never as simple as it first appears. Equipment breaks down unexpectedly, rain rarely comes when it is most needed, and often sites are not designed for monitoring, making it difficult (but not usually impossible) to collect reliable data. Some keys to success in the field include careful consideration of study design in the planning stage, scheduled time allowances in the initial stages to fine-tune monitoring protocols, regular analysis of monitoring data such that potential problems are quickly detected, built in redundancy to monitoring programs in the form of back-up measurements, , and strict attention to detail. In field work, there is no substitute for experience.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The primary purpose of this report was to summarize and synthesize the findings of stormwater BMP monitoring studies conducted from 1995 to 2002 under the SWAMP program. To this end, key study findings have been compiled from individual technical reports and re-interpreted relative to one another. Care has been taken to provide adequate facility design information and monitoring study overviews as a basis for the cross-facility comparisons. Literature from periodicals and stormwater management BMP databases were reviewed to provide a context for SWAMP study findings and highlight areas in need of further research.

A broad level conclusion of the SWAMP studies was that, with the possible exception of the Beaches tank, the facilities evaluated under the program met or exceeded their respective design targets. Since, in most cases, the targets were based on Ontario stormwater facility design guidelines, it seems reasonable to conclude that the guidelines are sufficient and do not require significant revision. Note, however, that this conclusion only applies to the limited range of measures used to evaluate Ontario design targets – measures such as suspended solids removal rates, peak flow attenuation and, in the case of exfiltration facilities, runoff volume reduction. While it can be said with confidence that ponds and wetlands designed according to Ontario design guidelines will likely achieve rates of TSS removal and peak flow reduction at least as good as suggested in the manual, it can not be then concluded that following the guidelines will ensure receiving waters will be adequately protected. The same is true for exfiltration facilities – volume reduction rates will likely be as good as, or better than the manual indicates if Ontario design guidelines are followed, but the long term effects of infiltrating stormwater runoff on groundwater resources requires further study.

The issue of receiving water protection is an important point because available literature reviewed in chapter 3 suggests that aquatic communities downstream of end-of-pipe facilities show substantial alterations from pre-development or reference site conditions, despite the presence of relatively clean effluents. Increased water temperature, greater runoff volumes and infrequent but erosive overflows are thought to be important causes of these alterations. Downstream channels are also not necessarily more stable because the larger post-development surface runoff volumes have been shown to increase the frequency of geomorphically significant mid-bank flows (MacRae, 1996). The shift in stormwater management over the last 5 years (see chapter 2) from an approach that focuses on controlling for water quantity, water quality and downstream erosion to one emphasizing volume (or water budget) control through implementation of a combination of practices is in part a response to the limitations of the previous approach from a receiving water protection perspective.

The following provides a summary of key findings with regard to the quantity and quality functions of the facilities monitored under the SWAMP program.

7.1 Water Quantity

The proportion of rainfall converted to runoff in a given drainage area is a key factor in the sizing of end-of-pipe facilities. This proportion is typically expressed as a runoff coefficient, calculated as the ratio of runoff volume to rainfall volume. In most cases, theoretical values based on impervious cover estimates under full development are used. Flow monitoring results at SWAMP sites showed that these theoretical values are usually greater than the average observed over an entire season. This result was not unexpected as theoretical values are based on flood flows, which generally have higher than average runoff coefficients (*i.e.* less runoff infiltrates because inputs to the surface are large and rapid). Values in the early spring before the frost layer has dissipated are also unusually high. Sizing facilities for all weather conditions is considered good design practice because adverse environmental consequences associated with under-predicting runoff volumes are much greater than the opposite consequences of over-prediction.

Other important water quantity performance parameters relate to the capacity of the pond or wetland to attenuate peak flows by detaining and gradually releasing water to streams or lakes. These features of the pond are typically measured as the percent reduction of peak flows from the inlet to the outlet, and as the length of time over which water is detained in or drains out of the facility. Average peak flow reduction for pond and wetland facilities was 77% with a range between 40 and 95%. Although more by coincidence than by design, two of the 5 pond/wetland facilities monitored had exfiltration losses of greater than 15%, which helped improve overall performance.

Detention times were highly variable ranging from 1 to 31 hours, with an average value of 9 hours. Outflow duration was used as an approximate substitute for drawdown time, and these values were also highly variable, ranging from 15 to130 hours. All facilities met the Ontario drawdown guideline of 24 hours, except the Dunkers facility, which was not designed with extended detention capabilities because it discharges to Lake Ontario.

Unlike ponds and wetlands, conveyance facilities help to maintain the pre-development water budget by exfiltrating runoff into the ground. During large events when the volume of inflow exceeds the exfiltration capacity of the system, excess runoff overflows to the conventional sewer where it discharges untreated to receiving waters. Thus, the runoff reduction capacity of these systems is a key measure of how well they function both from a water quantity and water quality perspective. The two SWAMP studies of these systems showed impressive runoff reduction capabilities, with average runoff volume reductions above 85%. Hydraulic tests showed that even better runoff reduction may have been possible with system design modifications that prevented air entrapment or pipe throughput limitations.

7.2 Water Quality

Effluent event mean concentrations of total suspended solids (TSS) from ponds and wetlands were generally acceptable from a receiving water protection perspective. Concentrations during individual events mostly fell within a relatively narrow range between 10 and 60 mg/L. These levels would not be expected to adversely impact receiving waters because in-stream concentrations of suspended solids are often above 60 mg/L during storm events. Unlike removal efficiencies, effluent concentrations were not correlated with influent concentrations. Event size and intensity appeared to have an effect on effluent quality only during events with runoff volumes close to or greater than the facility permanent pool volume.

Approximately 65 to 85% of TSS effluent particles were in the clay sized range (<4 microns). These particles do not readily settle over the range of detention periods provided by stormwater facilities. Hence, effluent TSS concentrations likely approach what has been called an "irreducible concentration', defined as a level of quality beyond which further reductions are no longer practically achievable. The concept applies equally to other stormwater contaminants, such as heavy metals and nutrients, since many of these bind readily to solid particles. A comparison of 'irreducible concentrations' derived from a large U.S stormwater BMP database (CWP, 2000) with those determined from SWAMP studies showed similar levels for TSS, copper and nitrates, but lower values for phosphorus and zinc.

In the absence of effluent quality guidelines in Ontario, median effluent concentration ranges from SWAMP study sites may be used as a general guide to 'achievable' targets with respect to BMP effluent quality. While values for some contaminants meet provincial receiving water standards, others such as phosphorus, *E.coli*, and copper do not, even in very large facilities such as the Markham pond/wetland. Clearly, there are limits to the capacity of the facilities to treat stormwater and these limits must be acknowledged in pollution control programs.

Current BMP performance standards in Ontario are based on removal efficiencies, which vary with influent concentrations and are poor predictors of the quality of water discharged into receiving waters. The correlation between influent concentrations and removal efficiencies is primarily a mathematical function of the equation used to calculate removal rates, such that when the value of the numerator (influent concentration) approaches that of a fixed denominator (background effluent concentration), the ratio of the two falls precipitously. Performance standards expressed as effluent concentrations or loads are more meaningful than removal rates because they provide a more direct measure of the facility impact on receiving water quality, irrespective of whether the contributing drainage area is clean or dirty (*i.e.* has low or high influent concentrations).

A comparison of end-of-pipe facilities showed that those with greater storage, longer drawdown times and better length-to-width ratios generally exhibited better overall performance as measured by load based removal efficiencies and effluent concentration means and ranges. However, there were other design and monitoring program features unique to each facility that also influenced measured performance. For instance, the Dunkers facility had pumps and curtains separating cells that likely improved the facility's hydraulic efficiency; a factor which may help explain why effluent TSS concentrations were low relative to other facilities. Other facilities may have performed less well if the average size of events monitored was larger.

Two studies in which monitoring stations were established at intermediate locations within the facility showed that between 50 and 70% of the suspended solids load entering the basins settles out in the upstream third of the facility. This finding highlights the importance of including forebays designed for maximum sediment capture and easy sediment clean-out. Forebay designs should include designated sediment drying areas and long forebay shapes that allow dredging to occur from the forebay banks. A well designed forebay can substantially reduce the frequency that downstream portions of the facility (e.g. main pond and/or wetland) require cleaning.

7.3 Water Temperature

The impact of stormwater facilities on water temperature was investigated because aquatic communities are very sensitive to even relatively small changes in this variable. One downside of ponds and wetlands is that they invariably increase water temperature. These increases during low flow were in the range of 4 to 11ºC from the inlet to the outlet, with smaller changes typically found in facilities with bottom draw outlets or small permanent pools. Maximum summer effluent temperatures in facilities with bottom draw outlets was approximately 24ºC, compared to maximums with top draw outlets of 29 to 31ºC. Depth profiles of temperature at one facility showed that maximum surface water temperatures were 6 and 9ºC higher than water temperatures at 1.5 and 2.5 m below the surface, respectively. These data indicate that bottom draw outlets can be an effective means of mitigating temperature impacts in retention facilities.

7.4 Facility Maintenance

The challenge of stormwater management is as much about maintenance of existing facilities as it is about devising new and innovative means of preventing receiving water impacts. A large proportion of the many hundreds of facilities constructed and installed in the Greater Toronto Area during the 1980s and 1990s are now in need of costly maintenance and repair. Failure to ensure adequate maintenance will dramatically compromise the function and effectiveness of these facilities.

This report outlines basic features of a maintenance program and summarizes SWAMP findings with respect to sediment clean-out intervals and disposal options from a sediment quality point of view. Estimated clean-out intervals varied widely depending on permanent pool volume per unit drainage area. Small ponds may require cleaning after only 10 years, whereas larger ‘enhanced’ level ponds may only require facility wide clean-out after 50 or more years. In most cases, forebays will need to be cleaned at more regular intervals since these areas fill more quickly.

Sediment chemistry results from SWAMP sites and other facilities in Ontario indicate that stormwater facility sediments are not polluted enough to be classified as hazardous waste, but also do not meet the requirements for land spreading and therefore must be disposed of in a registered landfill.

7.5 Recommendations

The following recommendations are based on the general synthesis of study findings presented in this report. Specific recommendations for each facility are provided in the individual performance assessment reports (see reference section for listing).

Stormwater facility design

- Ontario sizing guidelines for ponds, wetlands and infiltration trenches achieve or exceed predicted levels of suspended solids removal (see Table 3.2 in the SWMP manual) and are, therefore, not in need of significant revision.

- Design targets in the OMOE's SWMP manual should include both removal efficiencies and effluent concentrations for selected water quality variables.

- Bottom draw outlets in facilities with permanent pools help to cool effluent temperatures and should be encouraged wherever possible. Reverse slope intakes should be located at least 1 m below the permanent pool surface but not so close to the bottom that clogging will be a problem as sediment accumulates in the facility.

- High runoff reduction rates in the relatively low permeability soils at the North York and Etobicoke exfiltration sites suggests that infiltration trenches may function well even in soils that have lower permeability than the upper limit of 15 mm/hr indicated in the OMOE's SWMP manual.

- Alternative designs to exfiltration systems should be examined to overcome throughput limitations that cause overflow to occur before storage in the stone trench has been fully utilized.

- Use of adsorbent or ion exchange materials in or beneath exfiltration trenches should be considered in areas where groundwater contamination is, or will be, a concern.

Operations and maintenance

- In addition to regular inspections and repair, pond and wetland maintenance programs should include direct measurements of sediment accumulation each year at a minimum to establish clean out schedules. Municipalities should also provide annual contributions to facility maintenance funds which can be drawn upon periodically to pay for the significant costs of dredging or repair when it is needed.

- Long term maintenance procedures and requirements for exfiltration systems needs to be better documented by approval agencies. Whenever possible, the trenches should be located in pervious boulevards or beneath grass swales where they can be more readily excavated for servicing.

- Pond and wetland facilities should include forebays designed for maximum sediment capture, easy access, and designated sediment drying areas to reduce the effort and cost associated with facility maintenance. The use of source and conveyance controls and pretreatment of influent using devices that are easy to clean-out, such as OGS, should also be explored as a means of extending the frequency and expense of facility wide sediment dredging.

- Certificate of Approvals issued by the Ontario Ministry of the Environment for stormwater facilities should be consistent in stipulating long term maintenance requirements and inspection schedules. These requirements should be strictly enforced by Ministry staff and penalties associated with the failure to comply should be clearly articulated.[1]

- An aggressive maintenance schedule/plan for inspections and clean-out should be established and enforced for all OGS in order to avoid re-suspension of trapped oil and sediment.

Reporting and data analysis

- Monitoring, analysis and reporting protocols developed by the American Society of Civil Engineers and U.S. EPA (2002) should be used as a minimum standard in all stormwater BMP assessments to ensure data collected in different jurisdictions are more useful, representative and comparable.

- Special low detection limit sampling and analytical methods should be used for organic compounds to permit comparison of effluent quality to receiving water guidelines for these constituents.

- Removal efficiency is widely recognized as a biased indicator of facility performance and, therefore, should always be reported with data on effluent quality.

Further research needs

- Studies that relate stormwater BMPs directly to the health of receiving waters are needed to determine the benefit stormwater practices are having on downstream aquatic ecosystems and channel morphology. Wherever possible, these studies should consider the cumulative effect of several practices (*i.e.* combinations of source, conveyance and end-of-pipe facilities) on receiving waters at subwatershed and watershed scales.

- While there have been several studies of infiltration practices (*e.g.* soak-away pits, infiltration trenches, roof leader disconnection) on relatively permeable soils, few if any have been conducted on tight (clay and silty clay) soils. Understanding the capacity of these practices to reduce runoff volumes will help to determine the type and size of additional stormwater management measures required downstream.

- Long-term studies are needed on the performance and maintenance requirements of infiltration practices, and the potential water quality impacts these may have on groundwater resources.

- The effect of winter conditions, such as frozen soils and ice build-up, on the performance of BMPs, and the benefit of facility design modifications that help overcome limitations caused by cold weather are in need of further study.

[1] Currently some but not all Certificate of Approvals for stormwater facilities include prescriptions for maintenance.

- A detailed field survey of accumulated sediment in existing OGS should be conducted to determine whether or not owners and operators of these facilities are maintaining their separators according to manufacturers' recommendations. If OGS are not being appropriately maintained, the cause of these failures and the need for enforcement mechanisms required to correct them should be further investigated.

- Research is needed on the relationship between climate change effects (*e.g.* temperature increases, changes in intensity-duration-frequency curves, seasonal changes in precipitation, etc.) and the design of stormwater BMPs.

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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 was to collect data and report on the performance of stormwater treatment facilities. SWAMP was 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 were to:

- monitor and evaluate the effectiveness of new or innovative stormwater management technologies;
- 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, and
- conveyance exfiltration systems.

The following individuals, in alphabetical order, were part of the SWAMP team:

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

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 logistic support.

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APPENDIX B:

Summary of Monitoring Methods

Table B1 : Summary of monitoring methods used in studies conducted under the SWAMP program.

Facility	Hydrology		Water Quality		Distance of raingauge from site (km)	Vegetation Monitoring	Sediment Analysis	Temperature Monitoring
	Inlet(s)	Outlet	Warm season	Cold season				
Heritage Estates Pond	Area-velocity flow logger	Area-velocity flow logger	Time-proportioned composites. Grabs during dry weather	Grabs at the inlet and outlet.	On-site. Back-up at the Buttonville Airport AES (5km east of the site)	no	yes	Continuous, inlet and outlet
Markham Pond-Wetland	Area-velocity flow logger	Area-velocity flow logger at the wet pond outlet. Continuous water level with a stage discharge curve at the wetland outlet	Time-proportioned composites at inlet, forebay, wetpond outlet and wetland outlet. Grabs during dry weather	Grabs at the inlet and outlet.	Located within the drainage basin approximately 1km west of facility at St. Vincent School	yes	no	Continuous, inlet and outlet
Harding Park Retrofit Pond	Area-velocity flow logger	area-velocity flow logger and orifice equation	Flow-proportioned composites. Grabs during dry weather	Grabs at inlet and outlet	1995 to 1996 - Toronto Buttonville Airport (7km southeast) 1997 - Steelworkers Co-op (adjacent to the facility)	yes	no	Continuous, inlet, outlet and upstream in receiving water
Dunkers Flow Balancing System	Area-velocity flow logger and weir equation	Area-velocity flow loggers and weir	Time-proportioned composites. Grabs during dry weather	Grabs at inlet and outlet	St. Augustine Seminary in the drainage basin and at the facility	yes	no	Continuous, inlet and outlet
Aurora Wetland	Area-velocity flow logger	Area-velocity flow loggers used when facility water level was <1m; weir equation was used when levels were >1m	Flow-proportioned composites at the inlet, partially flow-proportioned composites at the outlet and other intermediate locations in the facility	Grabs at inlet and partially flow-proportioned composites at the outlet	2 manual rain gauges and one tipping bucket rain gauge, all at the facility.	yes	yes	Continuous, inlet and outlet
Rouge River Highway Pond	Area-velocity flow logger	Area-velocity flow logger	Flow-proportioned composites. Grabs during dry weather	Grabs at inlet and outlet	Rain gauge at Rouge Stables located 1km north of the facility. In April 1997 rain gauge was moved to within facility perimeter	yes	yes	Continuous, inlet, outlet and upstream in receiving water
Beaches Underground Tank	Level sensor and tank dimensions; area-velocity flow logger	Level sensor and tank dimensions; overflow weir equation; offshore pump-out rate	Flow-proportioned composites. Grabs during dry weather	Time-proportioned composites. Grabs during dry weather	Rain gauge in the tank drainage area and nearby back-up	n/a	yes	Not measured. Effluent is discharged to the lake and sewage treatment plant
Oil Grit Separators	Area-velocity flow loggers and weir	Area-velocity flow logger	Time-proportioned composites at the inlet, flow-proportioned composites at the outlet. Grabs during dry weather	Time-proportioned composites. Grabs during dry weather	Rain gauge 3 km from site	n/a	yes	Facility does not have a significant effect on temperature

APPENDIX C:

Unit Costs for Operation and Maintenance Activities

Typical costs associated with different stormwater BMP operation and maintenance activities (OMOE, 2003).

Table 7.5: Unit Costs for Operations and Maintenance

Type of Maintenance	Maintenance Interval (yrs)	Unit	Price
Litter Removal	1	ha	$ 2,000
Grass Cutting	***	ha	$ 250
Weed Control	1	ha	$ 2,500
Vegetation Maintenance (Aquatic/Shoreline Fringe)	5	ha	$ 3,500
Vegetation Maintenance (Upland/Flood Fringe)	5	ha	$ 1,000
Sediment Removal (front end loader)	*	m^3	$ 15
Sediment Removal (vacuum truck or manual)	*	m^3	$ 120
Sediment Testing (lab tests on quality)	*	each	$ 365
Sediment Disposal (off-site landfill)	*	m^3	$ 300
Sediment Disposal and Landscaping (on-site)	*	m^3	$ 5
Inspection (Inlet/Outlet, etc.)	1		$ 100
Pervious Pipe cleanout (flushing)	5	m	$ 1
Pervious Pipe cleanout (Radial Washing)	5	m	$ 2
Seasonal Operation of Infiltration By-pass	0.5	**	$ 100
Infiltration Basin Floor Tilling and Re-vegetation	2	ha	$ 2,800

* *Frequency of sediment removal depends on SWMP type and volume.*

** *Dependent of infiltration facility (based on centralized facility). Seasonal operation of a system with many inlets (i.e., pervious pipe system) would be more expensive.*

*** *No grass cutting or minimal frequency of grass cutting (once or twice per year).*