Performance Assessment of Two Types of Oil & Grit Separator for Stormwater Management in Parking Lot Applications - Markham & Toronto, Ontario

2004

Ministry of the Environment

Ontario

TORONTO AND REGION Conservation

TORONTO

PERFORMANCE ASSESSMENT OF TWO TYPES OF OIL & GRIT SEPARATOR FOR STORMWATER MANAGEMENT IN PARKING LOT APPLICATIONS

-

MARKHAM & TORONTO, ONTARIO

a report prepared by the

STORMWATER ASSESSMENT MONITORING
AND PERFORMANCE (SWAMP) PROGRAM

for

Ontario Ministry of Environment
Toronto and Region Conservation Authority
Municipal Engineers Association of Ontario
The City of Toronto

July, 2004

NOTICE

The contents of this report are the product of the SWAMP program and do not necessarily represent the policies of the supporting agencies. Although every reasonable effort has been made to ensure the integrity of the report, the supporting agencies do not make any warranty or representation, expressed or implied, with respect to the accuracy or completeness of the information contained herein. Mention of trade names or commercial products does not constitute endorsement or recommendation of those products. Reviews of commercial products were conducted based on available information. No financial support was received from developers, manufactures or suppliers of technologies used or evaluated in this project.

PUBLICATION INFORMATION

Documents in this series are available from the Toronto and Region Conservation Authority:

Tim Van Seters
Water Quality and Monitoring Supervisor

Toronto and Region Conservation Authority

5 Shoreham Drive,
Downsview, Ontario
M3N 1S4

Tel: 416-661-6600, Ext. 5337
Fax: (416) 661-6898

E-mail: Tim_Van_Seters@trca.on.ca

THE SWAMP PROGRAM

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

Over the past 15 years, 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 habitats. In response to these environmental concerns, a variety of stormwater management technologies have been developed to mitigate the impacts of urbanization on the natural environment. These technologies have been studied, designed and constructed on the basis of computer models and pilot-scale testing, but have not undergone extensive field-level evaluation in Ontario. The SWAMP Program was developed to address this need.

The SWAMP Program's objectives are:

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

For more information about the SWAMP Program, please contact:

Mr. Weng-Yau Liang
Ontario Ministry of the Environment
Phone: 416-327-6409
Fax: 416-327-9091
Email: weng-yau.liang@ene.gov.on.ca

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

ACKNOWLEDGEMENTS

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

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

Funding support for this project was provided by the Great Lakes 2000 Cleanup Fund (superseded by the Great Lakes Sustainability Fund) and the Ontario Ministry of Environment and Energy (OMOE). The OMOE also provided office facilities and logistic support for the SWAMP program. The Laboratory Services Branch of the OMOE provided laboratory analyses. Administrative support to the SWAMP program was provided by the Toronto and Region Conservation Authority. Aquafor Beech Limited and Dr. James Li conducted the literature review and edited an earlier version of the monitoring study portion of the report. Final revisions and editing of the report were undertaken by TRCA, with input from OMOE.

The following individuals provided technical advice and guidance:

• Dale Henry	Ontario Ministry of the Environment
• Weng-Yau Liang	Ontario Ministry of the Environment
• Sonya Meek	Toronto and Region Conservation Authority
• Tim Van Seters	Toronto and Region Conservation Authority
• Sandra Kok	Great Lakes Sustainability Fund, Environment Canada
• Peter Seto	National Water Research Institute, Environment Canada
• Michael D' Andrea	City of Toronto, Municipal Engineers Association of Ontario
• Pat Chessie	City of Toronto
• Bill Snodgrass	City of Toronto (formerly Ministry of Transportation)

EXECUTIVE SUMMARY

Oil grit separators (OGS) are designed to remove sediment, screen debris and trash, and separate oil from stormwater. Removal processes vary for different types of OGS, but most depend at least partly on gravity based settling for sediment and associated contaminants (e.g. heavy metals), and phase separation for oil. OGS do not effectively remove dissolved or emulsified oils and pollutants.

OGS are typically applied to small, highly impervious areas such as parking lots, loading areas at commercial sites, gas stations or as part of a multi-component approach for water quality control. Runoff quantity control is not provided because OGS are not designed with extended detention storage. However, peak flows can be attenuated if temporary storage is provided upstream of the OGS on roof tops, paved surfaces and/or within the storm sewers as part of the site drainage plan.

Although oil grit separators (OGS) are widely employed in Ontario, there are few third party studies demonstrating their effectiveness in improving water quality. To help fill this knowledge gap, the Ontario Ministry of the Environment (OMOE), the Toronto and Region Conservation Authority and the Government of Canada (through the Great Lakes Sustainability Fund), jointly agreed to monitor two types of OGS (Three-Chamber and Stormceptor®) under the Stormwater Assessment Monitoring and Performance (SWAMP) program. The objectives of this study were to:

(i) conduct a literature review of OGS performance and maintenance requirements;
(ii) evaluate the field performance of two types of OGS in terms of runoff quality;[1]
(iii) identify benefits and limitations of the technology, and
(i) provide recommendations for technology improvements and further research needs.

Literature Review

The literature review provides a general overview of the theory and application of Oil Grit Separators (OGS). Various commercially available OGS designs are grouped and discussed for the purposes of the review with regards to their respective functional attributes: high flow bypass, swirl action, screening action, coalescence action and combined system types. Detailed review of design and sizing criteria, performance literature and maintenance requirements is limited to OGS devices for which sufficient literature and monitoring data were available at the time of writing. These devices include the traditional 3 chamber OGS, Stormceptor®, Bay Saver, Vortechs, Downstream Defender and Continuous Deflective Separation Unit. Coalescing Plate

[1] This evaluation should be interpreted within the context of the particular OGS designs and site conditions monitored, not as a general evaluation of all Three-Chamber and Stormceptor® OGS technologies.

separators and combined system type OGS (Multi-chambered Treatment Train and Storm Treat™) are discussed in more general terms.

Most laboratory and field monitoring performance assessments cited in this literature review were conducted by the manufacturer or by manufacturer sponsored organizations. There were considerably fewer independent third party studies available. A review of available studies revealed a wide variation in site conditions (e.g. climate, soil texture, land use) and field monitoring and data analysis protocols, making it difficult to compare performance results among studies, even for the same device. In some studies, essential information (e.g. effluent concentrations, design specifications) required to interpret results was not provided.

Like other stormwater technologies, the water quality performance of OGS declines significantly if they are not regularly maintained. The literature review provides an overview of government agency and manufacturer recommendations for maintenance procedures and schedules. Most guidelines from both sources suggest that the maintenance frequency for OGS be at least once or twice per year, or when the accumulated sediment reaches 15% of the sediment capacity.

Monitoring Study

Study Area and OGS Design

Two types of OGS were monitored in this study: a standard 3-chamber OGS and a Stormceptor® model STC 4000. Both technologies were installed as two parallel units in the parking lots of large Home Depot stores. The 3-chamber OGS study, located in Markham, and the Stormceptor® site, located in Etobicoke, had design drainage areas of 2.2 and 2.6 hectares, respectively. Influent flows were distributed to each unit via a Y-splitter. The asymmetric configuration of these splitters favours greater flow into one of the two parallel units. Recognizing the tendency for uneven flows, the 3-chamber OGS design consists of one larger (35 m^3 capacity) and one smaller unit (17 m^3 capacity). The Stormceptor® OGS parallel units were the same size (17.8 m^3 each), but unlike the 3-chamber site, temporary storage was provided within the sewer network and on the paved surface upstream of the two OGS units. This temporary storage was intended to help control flow rates entering the system and decrease the number of potential by-passes. The upstream storage and differential sizing of units are important features of the overall site design that can influence influent particle size distributions, pollutant removal rates and the variability of system performance among events.

The design of the 3-chamber OGS is presented in Figure 1. Each separator is a concrete precast tank with three chambers. The first chamber is the sediment chamber, which is designed to trap the 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 (375 mm and 300 mm diameter for the large and small units, respectively) into the third chamber. The intake of the elbow pipe is submerged and located one meter from the bottom of the second chamber. This configuration is effective in capturing free oil because oil has a specific gravity less than water and therefore floats to the top. The third chamber is primarily used to discharge treated runoff from OGS, although the chamber also provides an opportunity for further settling of suspended particles. 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 water levels in the large and small units were approximately 1.8 and 1.5 m deep, respectively. 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 capacities for the large and small units are 31.5 m^3 and 15.5 m^3.

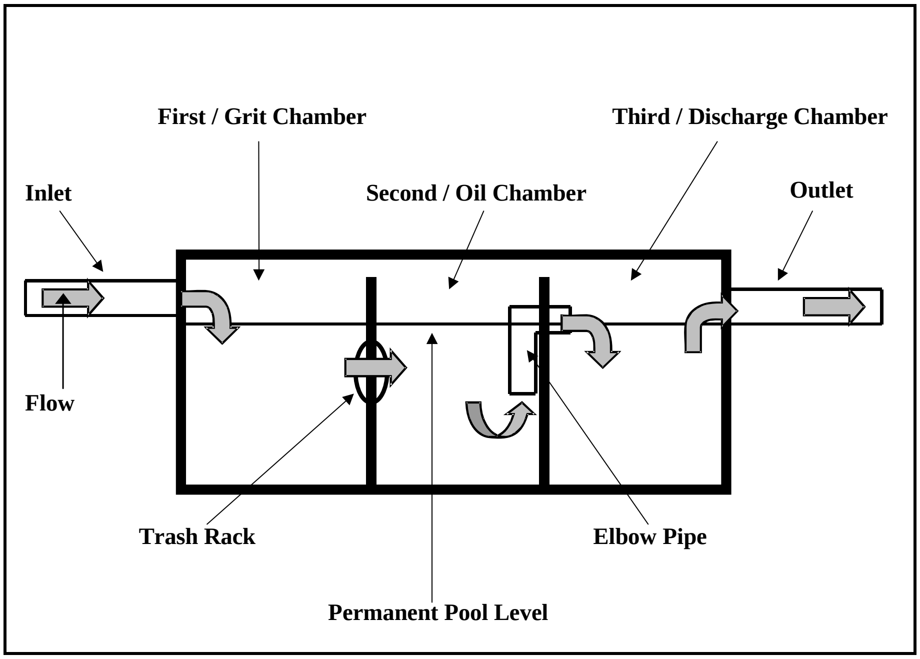


Figure 1 : Design of a three-chamber OGS

Figure 2 shows the design of the Stormceptor® OGS and operation during high flow conditions. Each of the two concrete precast units installed in parallel 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. According to the manufacturer (Stormceptor®, 1998), this design ensures that excessive flows will not be forced into the treatment chamber and re-suspend settled material. The oil and sediment holding capacity of the model monitored in this study is 3,490 and 14,060 L, respectively.

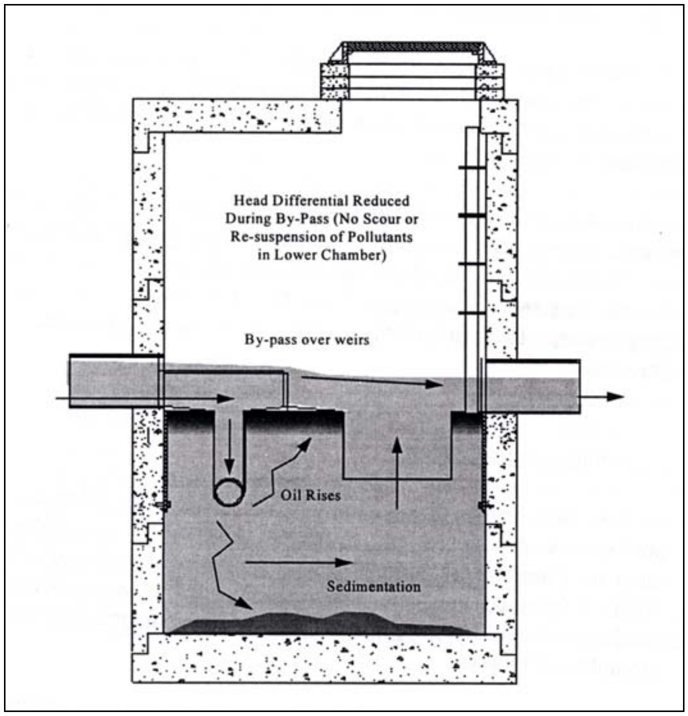


Figure 2: Stormceptor® operation during high flow conditions (Stormceptor®, 1996)

The 1994 version of the Province of Ontario's *Stormwater Management Practices Planning and Design Manual*, which was current at the time the units were installed, recommends a minimum permanent pool storage of 30 m^3 per impervious hectare for 3-chamber OGS, and 15 m^3 per impervious hectare for manhole type OGS (such as Stormceptor®). The total design permanent pool storage provided was 21.3 and 14.0 m^3/impervious ha for the 3-chamber and Stormceptor® sites, which is below the minimum recommended in the 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.* lower 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 water quality performance than would have been the case if the flow were equally distributed.

Study Approach

The performance assessment of the two types of OGS was based on continuous monitoring of precipitation and flows, and water quality sampling during wet weather periods. Precipitation data were obtained at nearby rainfall gauging stations. Flow was monitored at the outlet, downstream of where effluents from the two parallel units merged into a single storm sewer pipe. Inflow measurements were not undertaken because OGS technologies are generally not designed to provide significant peak flow attenuation and detention times are relatively short. Water quality samples were collected during rain events at the inlet of the unit receiving greater flows and at the combined outlet location. Ideally, influent samples would have been collected upstream of the flow splitter, but at both sites, this location was deemed unsuitable for water quality monitoring (see below for results of an error analysis associated with monitoring influent in only one of the two parallel units). Samples were submitted for analysis of solids, oil and grease, and metals to a certified laboratory operated and run by the Ontario Ministry of the Environment. Depth profiles of conductivity at 0.5 m intervals were taken in the treatment chambers of both technologies using a portable meter to determine the degree of mixing occurring within the units and assess potential problems associated with chloride stratification.

The OGS units at both sites were cleaned out prior to the beginning of monitoring. At the end of the study period, the sludge and liquid contents of the OGS were transferred to two off-line sediment holding tanks for further settling. Samples from the tanks were analysed for chemical properties by the OMOE laboratory to determine disposal options and for physical (volume, mass, density) characteristics to determine the total dry mass of the trapped sediment.

The monitored 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 the study period for which measured flow and/or quality data were not available.

Study Findings

Water quantity

<u>Three-chamber OGS</u>

A total of 60 runoff events were monitored at the site from May 1997 to December 1998. Rainfall measurements were available for 30 events occurring during the spring, summer and fall. Average rainfall was 11.4 mm, with a range between 1.8 and 28.6 mm. Mean rainfall intensities averaged 2.1 mm and ranged from 0.5 to 6.8 mm/hour. Twenty out of thirty rainfall events resulted in significant runoff volumes.

The average volumetric runoff coefficient was 0.85, indicating that, on average, 85% of the precipitation that fell within the drainage area during monitored rain events passed through the OGS as stormwater runoff. As expected, rainfall depths were well correlated with runoff volumes (R^2=0.81).

The capacity of the system to control water quantity (i.e. attenuate peak flows and extend release times) was not evaluated because the storage-to-drainage area ratio is relatively small and the technology is not designed with extended detention storage. This assumption is further corroborated by hydrologic data showing that the duration of effluent runoff and rainfall were similar during individual storm events.

<u>Stormceptor®</u>

A total of 44 events were monitored at the Etobicoke site during the period from August 1997 to December 1998. The absence of winter rainfall measurements meant that only 24 of the 44 runoff events were monitored for rainfall. Rainfall depths averaged 11.8 mm, ranging in depth between 2.3 and 36.8 mm. Mean rainfall intensities averaged 2.3 mm/hour, with a range between 0.4 and 8.6 mm/hour.

The volumetric runoff coefficient averaged 0.98. There were substantial variations in the runoff coefficient among individual events, suggesting possible discrepancies between the rainfall gauging stations, located 3 to 5 km away, and actual rainfall at the site. The relatively weak correlation between runoff volumes and rainfall depths (R^2 = 0.54) lends additional support to this hypothesis.

As at the Markham site, the duration of rainfall and outflow were similar during rain events, indicating that stormwater runoff was not detained for significant time periods within the OGS units. Although not monitored in this study, additional storage provided upstream of the OGS units (via a flow restrictor) may have helped to reduce peak flow during large events.

There were few overflows and those that did occur were of relatively short duration. Hence, effluent concentration and removal efficiency estimates provided in this study are based largely on flows that passed through the treatment chamber of both units.

Water Quality

<u>Three-chamber OGS</u>

A total of 26 influent and 54 effluent water samples were collected from May 1997 to December 1998. Fewer influent samples were available because of challenges associated with sample collection at this location in the early part of the study. Samples were analyzed for particle size, total dissolved and suspended solids, heavy metals and oil and grease.

The median influent and effluent TSS concentrations were 109 and 40 mg/L, respectively (Table 1). Concentrations during individual events ranged widely from 34 to 378 mg/L at the inlet and 4 to 268 mg/L at the outlet. Median concentrations of oil and grease (solvent extractable) were 22 and 8 mg/L at the inlet and outlet, respectively. The highest concentrations of TSS and O&G were measured in winter and early spring, approximately from January to April 1998.

Total suspended solids were well correlated with most heavy metals, indicating that these contaminants are removed with suspended solids through sedimentation processes.

Load based removal efficiencies for metals ranged from 42 to 60%. Median effluent concentrations of copper (17 μg/L), lead (11 μg/L), zinc (77 μg/L), and iron (383 μg/L) exceeded provincial receiving water standards (Table 1). Although effluent concentrations are not expected to meet receiving water criteria, comparisons made against the provincial standards are helpful in identifying water quality variables of potential concern.

The size of particles entering the OGS units was significantly lower than those exiting the units. Average influent and effluent particle size distributions (n=18) had median particle sizes of 8.7 and 3.8 microns, respectively. These were significantly different at the 95% level of confidence. Particle size distributions in the warm and cold seasons were similar.

On-site depth profiles of electrical conductivity in all three chambers did not show any signs of stratification, suggesting well mixed conditions and periodic re-suspension of previously settled solids. The tendency for re-suspension may partly explain the wide range of removal efficiencies observed among storm events.

The total load based TSS removal efficiency for 19 events was 57%, with individual event removal efficiencies ranging widely from –81 to 96%. In comparison, the total load-based removal of oil and grease was 51%, with a range between -200 and 84%. Total runoff volumes were not well correlated with removal efficiencies either for TSS or oil and grease. There was also no discernible seasonal variation in removal.

Continuous model simulation results for all storms occurring over the study period indicated a total load TSS removal efficiency of 62%, which matches results from the monitoring study within 5%.

<u>Stormceptor®</u>

A total of 20 influent samples and 37 effluent samples were collected from the Stormceptor® OGS between August 1997 and December 1998. As at the Markham site, collection of reliable samples was more challenging at the inlet than at the outlet, hence fewer influent samples were collected.

Median influent and effluent TSS concentrations were 112 and 48 mg/L, respectively (Table 1). Influent TSS concentrations ranged from 28 to 634 mg/L, compared to an effluent concentration range of 10 to 451 mg/L.

These ranges are considerably wider than at the 3-chamber site in Markham. Median concentrations of oil and grease (solvent extractable) were 17 and 7 mg/L at the inlet and outlet, respectively.

Load based removal efficiencies for heavy metals commonly found in urban runoff ranged from 42 to 52%. Median effluent concentrations of the following metals exceeded provincial receiving water standards: copper (22 μg/L), lead (19 μg/L), zinc (120 μg/L), and iron (515 μg/L) (Table 1). As at the3 chamber site in Markham, total suspended solids were strongly correlated with most heavy metals.

Influent and effluent concentrations were well correlated for the two main parameters of interest, TSS and O&G. The relationship (R^2 = 0.7 for TSS), which is also observed at the 3 chamber site, suggests that unit sizing should be based not only on the size of the drainage area and level of imperviousness, but also on pollutant loading potentials associated with specific land use types.

Average influent and effluent particle size distributions were similar. The median particle size at the inlet was 6.5 um, compared to a median size of 5.8 um at the outlet. The low influent particle size relative to the 3-chamber OGS site may be partly explained by the presence of upstream storage and catchbasin sumps, where coarser particles may have settled out of suspension before reaching the OGS units. The cause of the unexpectedly coarse effluent particle size distributions requires further investigation.

Table 1: Median influent/effluent concentrations and overall load based removal efficiencies for selected parameters

		Three-Chamber OGS			***Stormceptor® OGS***		
Parameter	*PWQO*	*Median influent conc.⁺ (n=26)***	*Median. effluent conc (n=54)**.*	*Rem. Eff. (%)⁺ (n=19)***	*Median influent conc.⁺ (n=18)***	*Median. effluent conc (n=36)***	*Rem. Eff. (%)⁺ (n=16)***
TSS (mg/L)	--	109.0	40.0	57.2	112.5	47.5	60.1
O &G (mg/L)	--	22.0	7.8	51.2	17.0	6.8	44.1
Cu (μg/L)	5	46.2	17.0	55.6	46.7	22.0	43.7
Zn (μg/L)	20	217.0	77.2	61.7	247.5	120.5	43.1
Pb (μg/L)	5	28.7	11.1	50.0	35.4	18.8	42.4
Cd (μg/L)	0.5	0.7	0.4	49.0	0.6	0.5	42.7
Fe (μg/L)	300	762	383	40.4	922	516	45.3
Co (μg/L)	0.9	1.4	0.6	28.7	1.3	0.8	51.9
Cr (μg/L)	8.9*	9.5	4.7	44.1	10.8	6.1	49.4
Ni (μg/L)	25	6.2	2.9	56.5	6.8	2.9	45.0

+ Based on samples collected at the inlet of only one of the two parallel units (see text for discussion)
* CrIII = 8.9 μg/L; CrVI = 1 μg/L
**The heavy metal concentration and removal efficiency data sets contained two to three fewer observations than indicated.

Depth profiles of electrical conductivity showed a distinct stratified layer in the winter and summer, starting at 0.5 to 1 m depth below the permanent pool surface in the treatment chamber. The stratified layer had completely dissipated by the fall, when a third measurement was taken. Winter conductivity levels reached a maximum of 72,700 µS/cm at 1.5 m below the water surface, which is roughly equivalent to a chloride concentration of 36,500 mg/L. The existence of a stratified layer of chloride suggests that turbulent flows causing re-suspension of accumulated solids were minimized. However, the stratification also raised concerns as reduced vertical mixing may decrease the effective storage available for treatment, resulting in poorer pollutant removal during the winter and spring.

The total load based TSS removal efficiency for events with co-ordinated inlet and outlet sampling (n=16) was 60%, with individual event removal efficiencies ranging from 4.5 to 83%. Total load-based removal for oil and grease was 44%, with a range between -6 and 84%. Both of these ranges are less than observed at the 3-chamber site, although the total load results are similar (Table 1). Runoff volumes were not well correlated with removal efficiencies either for TSS or oil and grease, but unlike the 3-chamber site, TSS removal was generally better during the summer.

Continuous simulation results for all storms occurring over the 16-month study period indicated a total load TSS removal efficiency of 60%, which closely matches results from the monitoring study.

Analysis of Potential Errors

There was some concern that the performance results may be biased because influent concentrations were measured at only one of the two inlets, whereas effluent concentrations were measured from the combined discharge of both units. To estimate the potential error associated with unequal influent TSS concentrations, total TSS load calculations were repeated assuming that: (i) inflow was equally distributed between the two units; and (ii) influent TSS concentrations in the unmonitored unit differed consistently (*i.e.* during all events) by ±20% from that measured in the monitored unit. Results of this scenario indicated a total load TSS removal efficiency range of between 52 and 61% for the 3-chamber OGS and between 56 and 64% for the Stormceptor® OGS. These ranges narrow slightly if the error calculations account for larger flow volumes entering the monitored unit, which is known to occur at both sites.

The potential error associated with flow measurement inaccuracies were estimated by randomly varying the measured flow rate among events by ±20%. This exercise was repeated for several randomly generated combinations resulting in an error range in TSS removal efficiencies at both sites of approximately ±3%. A consistent increase or decrease in flow volumes by exactly the same magnitude for all events would, of course, have no impact on removal efficiencies because a perfect flow balance through the OGS is assumed (i.e. the volume of stormwater entering the OGS units is the same as the volume of stormwater leaving them).

Another source of error relates to the use of removal efficiencies as an indicator of performance. The removal efficiency equation is a biased indicator of performance because the fraction of pollutants removed by hydrodynamic separators (and stormwater BMPs generally) is partly a function of the influent concentration. Thus a performance evaluation based solely on removal efficiencies can lead to misleading conclusions, especially when additional water quality storage or treatment provided upstream of the OGS facility contributes to cleaner influents. Effluent concentrations or loads are a more reliable indicator (*i.e*. not subject to the errors noted above) and in any assessment of OGS performance, should be evaluated in combination with removal efficiencies, and in relation to effluent concentration ranges of other similar technologies.

Sediment Analysis

The total dry mass of sediment measured in the two parallel three chamber OGS units from July 1997 to August 1998 was 957 kg. This compares reasonably well to the 922 kg of sediment accumulation generated over the same period by the calibrated water quantity/quality model.

The measured and simulated dry mass of accumulated sediment in the Stormceptor® units from July 1997 to August 1998 was also in reasonably good agreement. Measured sediment accumulation from the offline holding tanks was 1067 kg, compared to a dry mass of 1142 kg of sediment generated by the model.

The good correspondence between accumulated sediment measured from the holding tanks and model simulations based on influent and effluent measurements lends confidence to the monitored results.

The concentrations of several metals in the trapped sediment of both OGS types were above the lowest effect level guidelines defined by the Province for the protection of aquatic life. High concentrations of oil and grease in the sediment suggest that special considerations may be required in the disposal of trapped sediment.

Conclusions and Recommendations

This report reviews the literature on various OGS technologies and provides a detailed field study evaluation of two types of OGS commonly used in Ontario. In general, results indicate that effluent concentrations of TSS, oil and grease and some heavy metals are greater in OGS than have been reported for other end of pipe facilities in Ontario (see other SWAMP reports in this series). However, these concentrations still represent a significant improvement over the quality of untreated stormwater runoff. Removal efficiency calculations indicate that both types of OGS provide moderate removal of oil and grease, suspended solids and heavy metals.

As reports of OGS water quality performance vary widely among studies, the monitoring results should be reviewed carefully in relation to other studies of similar technologies and with full consideration of the technology/site design (*e.g.* unit sizing, provision of upstream storage, distribution of influent to the two parallel units), the drainage area characteristics of the sites selected for the study (*e.g.* runoff quality, influent particle sizes), and the potential errors associated with the monitoring and data analysis protocols used to generate results.

The following recommendations are provided based on study findings and field observations:

Maintenance issues

- To avoid re-suspension of trapped oil and sediment, an aggressive maintenance schedule/plan for inspections and clean-out should be established upon the installation of any and all OGS. High oil and grease concentrations may limit disposal options.

- To help prevent adverse effects on performance due to chloride stratification, annual or bi-annual maintenance of OGS units should be timed to correspond with the end of the snow melt season, when elevated concentrations of chloride are commonly observed in the treatment chamber.

Site/technology design improvements

- The Three chamber OGS should include a high flow bypass design feature to avoid re-suspension of accumulated pollutants.

- The asymmetrical "Y" splitter at both sites consisted of one straight and one angled pipe section that distributed flows unequally to the two parallel units. The two 3-chamber units were sized differently to accommodate variable flows, but the Stormceptor® units were the same size. The storage treatment capacity of the two Stormceptor® units could be better utilized if either the splitter was redesigned to distribute equal or similar flow volumes to both units (i.e. it was shaped like a true "Y"), or the units were sized to compensate for unequal flow distribution.

- The correlation between influent and effluent concentrations for TSS and O&G suggests that unit sizing should be based not only on the size of the drainage area and level of imperviousness, but also on estimates of how much O&G and sediment are likely to be generated by land use activities within the drainage area.

Further Research

- Removal efficiencies and effluent concentrations varied widely among events for both types of OGS monitored in this study. Factors contributing to this variability may include resuspension of settled solids (especially in the 3- chamber OGS), varying inter-event periods, storm sizes and intensities, chloride stratification (Stormceptor), presence of upstream storage (Stormceptor), and bypass events (Stormceptor). Detailed research into the inter-relationships between these and other potential contributing factors is required in order to quantify their effects on performance and better understand how application of the technology or maintenance procedures may be modified to minimize adverse effects.

- Oil Grit Separators require regular maintenance if they are to function according to design. However, discharge regulations are not currently enforced to the degree necessary to ensure that the required maintenance is indeed being undertaken. A detailed field assessment of accumulated sediment in previously installed units would help to show whether or not owners and operators are actually 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.

- OGS are often recommended in provincial and state stormwater guidance documents as best applied in conjunction with other treatment technologies (i.e. as part of a treatment train) or as part of a 'multi-component' approach to stormwater management. The effectiveness of separators when installed together with other control measures, both from a quantity and quality perspective, needs further study.

- This study showed strong stratification of chloride in the Stormceptor units. It has been suggested that this stratified layer may inhibit mixing and reduce the effective permanent pool storage available for treatment. Further research is required to quantify the effect (if any) of chloride buildup and stratification in the treatment chamber on water quality performance.

TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

1.1 Background

Oil grit separators (OGS) are designed to remove sediment, screen debris and trash, and separate oil from stormwater. Removal processes are based on gravity based settling for sediment and associated contaminants (e.g. heavy metals), and phase separation for oil. Suspended solids that are denser than water will settle out at a rate determined by their relative density and size. The portion of sediment that is removed is determined by the velocity of water flowing through the separator, relative to the settling velocity of the sediment and the depth of the separator. Particles lighter than water, such as small oil droplets and hydrocarbons, will rise at a velocity that depends on the droplet size and density. OGS do not effectively remove dissolved or emulsified oils and pollutants. Runoff quantity control is not provided because they have small permanent pool-to-drainage area ratios and are not designed with extended detention storage.

OGS technologies are typically applied to small, highly impervious areas such as parking lots, loading areas at commercial and industrial sites, gas stations, transit yards or other areas that have a high risk of spills and are significant sources of sediment. They are also applied as pre-treatment for other stormwater facilities lacking the capacity for pre-treatment or as one of a series of water quality control measures at a particular site. In new developments where space is not constrained, OGS usually must be used in combination with other stormwater management measures in order to meet multiple objectives for erosion, flood and water quality control (MOE, 2003).

1.2 Study Objectives

Although oil grit separators (OGS) are widely employed in Ontario, there are few third party studies demonstrating their effectiveness in removing pollutants from stormwater. To help fill this knowledge gap, the Ontario Ministry of Environment and Energy (OMOEE), the Toronto and Region Conservation Authority and the Government of Canada (through the Great Lakes Sustainability Fund), jointly agreed to monitor the facility under the Stormwater Assessment Monitoring and Performance (SWAMP) program. The objectives of this study were to:

(i) conduct a literature review of OGS performance and maintenance requirements;
(ii) evaluate the field performance of two types of OGS in terms of runoff quality;
(iii) investigate operational and maintenance requirements
(iv) identify benefits and limitations of the technology, and
(v) provide recommendations for technology improvements and further research needs.

The two types of OGS evaluated in this study are: (a) the three-chamber OGS, and (b) manhole type OGS, patented under the name Stormceptor®. In order to ensure a truly independent and non-biased evaluation, no financial or other kind of support was received from either the manufacturers or developers of the selected technologies.

2.0 LITERATURE REVIEW

The use of best management practices (BMP's) is required to control the quantity and quality of stormwater runoff. However, in areas that are characterized by a high percentage of imperviousness (e.g. greater than 50%) and limited space (e.g., less than 5 hectares) conventional BMP's such as detention basins and constructed wetlands are not appropriate (Shaw, 2001). As a result, several "space-limited" BMP's have been developed, such as oil and grit separators (OGS), bioretention areas and sand filters. OGS technologies, such as the 3-chamber oil/grit separator and other proprietary devices (*e.g.* Stormceptor®, Vortechs™, Downstream Defender™) are designed for underground installation and as part of a storm drainage system. Bioretention areas, such as StormTreat™, utilize soil filtration and vegetative uptake to remove pollutants. Sand filters make use of sand as a media to filtrate stormwater pollutants. The following literature review focuses on OGS types of BMP's and reviews their performance, maintenance requirements, design and sizing criteria.

2.1 General Review of Oil and Grit Separators

2.1.1 Classification of Oil Separators

Oil and grit separators (OGS) are one component of a large technology class labeled oil separators. Oil separators include catchbasins with goss traps, oil/grease separators, oil interceptors and oil/grit separators (Tran 1996). They come in different shapes, sizes, designs and materials, some are commercially available while others are custom built and designed. These different types of oil separators have two things in common: i) the primary design function is to separate free oil from water or wastewater, and ii) they all rely on gravity to achieve their function.

- Catchbasins with Goss Trap

Catchbasins are standard appurtenances for any urban stormwater collection system. In Ontario, catchbsins are constructed with a sump to trap dirt and debris. As an appurtenance to capture oil, catchbasins have little value since the outflow is drawn from the upper layer of the sump. If a Goss Trap is used in a standard catchbasin, it has the potential of capturing 48 L of floatable spill material (Tran 1996). This capacity is sufficient for a low spill risk area and can be considered an asset when combined with a municipal spill response program.

- Oil/Grease separators

Oil/Grease separators are also known as grease traps or grease interceptors. These devices are commonly found in restaurants and food services centers. The design of these closely follows the requirements of the standard American Petroleum Institute (API) method of calculating oil and grease separation. Flow rates for these devices are generally in the range of 0.51 L/s to 4 L/s.

The inlet pipe diameter ranges from 50 mm to 75 mm. Grease interceptors are connected to sanitary sewers.

- Oil Interceptors

Oil interceptors generally have a higher flow rate than grease interceptors, however both grease traps and oil interceptors are not designed for stormwater runoff. Typically, oil interceptors are used indoors in service station repair bays, landfill leachate systems, and food processing plants. The oil capacity in the first chamber should be the greatest, followed by the second chamber. Oil found in the third chamber indicates the need for removal of oil in the first two chambers. Typical flow rates range from 10 to 20 L/s. This class of oil interceptor usually has the highest oil storage capacity and allows for less frequent pump out.

- Oil/Grit separator (OGS)

Oil/Grit separators (OGS) are also known as water quality inlets or oil sediment interceptors. They are usually found in stormwater best management practice manuals, and are the main focus of this review. OGS have the potential to remove significant TSS at the design flow rate, but efficiency declines at higher flow rates, both for sediment and oil. Ideally, OGS should:

  - separate and trap free oil from stormwater, with the use of by-pass;
  - capture and trap trash and floatable solids without clogging the inlet pipe or overflowing;
  - be maintained at regular intervals;
  - used as a stand-alone technology only where quantity or erosion control is not required, and it is shown to achieve desired water quality targets (MOE, 2003).

Oil separators have been installed indoors and outdoors at various locations for different applications:

  - landfill sties as part of leachate collection systems;
  - sewage treatment plants for removal of oil and grease;
  - inside food service sites for oil and grease removal;
  - inside and outside gas stations for collecting oil and gasoline spills and drippings; and
  - in parking lots, service depots and more recently under roadways to treat stormwater.

2.1.2 Theory of Oil separators

The design of oil grit separators (OGS) was first formalized by the American Petroleum Institute. These early separators were initially designed for wastewater treatment with a constant inflow rate. The following provides a brief review of the basic principles of oil/water separators.

The design of gravity-type oil separators is based on Stokes' Law. The larger the oil droplet, the faster it rises through water. Thus, the degree of separation of an oil/water mixture is a function of the distribution of oil droplets. API separators are designed to remove free oil globules and sediment larger than 150 microns (API 1990). Oil/water mixtures can be classified into four classes as indicated in Table 2.1.

Table 2.1: Classification of oil/water mixtures (American Petroleum Institute 1990)

OIL CLASSIFICATION	SIZE OF OIL DROPLETS
Free Hydrocarbon	150 microns or greater
Dispersed Oil	20 to 150 microns
Emulsified	<20 microns
Dissolved-Phase Hydrocarbons	Not typically removable by physical treatment

Figure 2.1 shows a conventional API oil-water separator (3 chamber OGS). There are three chambers separated by 2 baffles. The baffles are placed within the chamber to block oil from flowing out of the separator and to reduce turbulence. Oil-water separation occurs in the first and center chambers. Oil floats to the top of the chamber while sediment sinks to the bottom. Another baffle is fastened to the bottom to trap the sediment at the bottom of the separator. An oil-skimming device is typically installed to remove the trapped oil. The API guidelines recommend that the maximum allowable mean horizontal velocity for API separators (3 chamber OGS) be limited to approximately 1m/min (3 ft/min). In order to satisfy the maximum allowable velocity specified by API in the storm system, the size of an API separator (3 chamber OGS) may be in the order of tens of metres. The lengthy treatment process and the enormous size of the separator limits the application of API separators (3 chamber OGS) in an urban stormwater system.

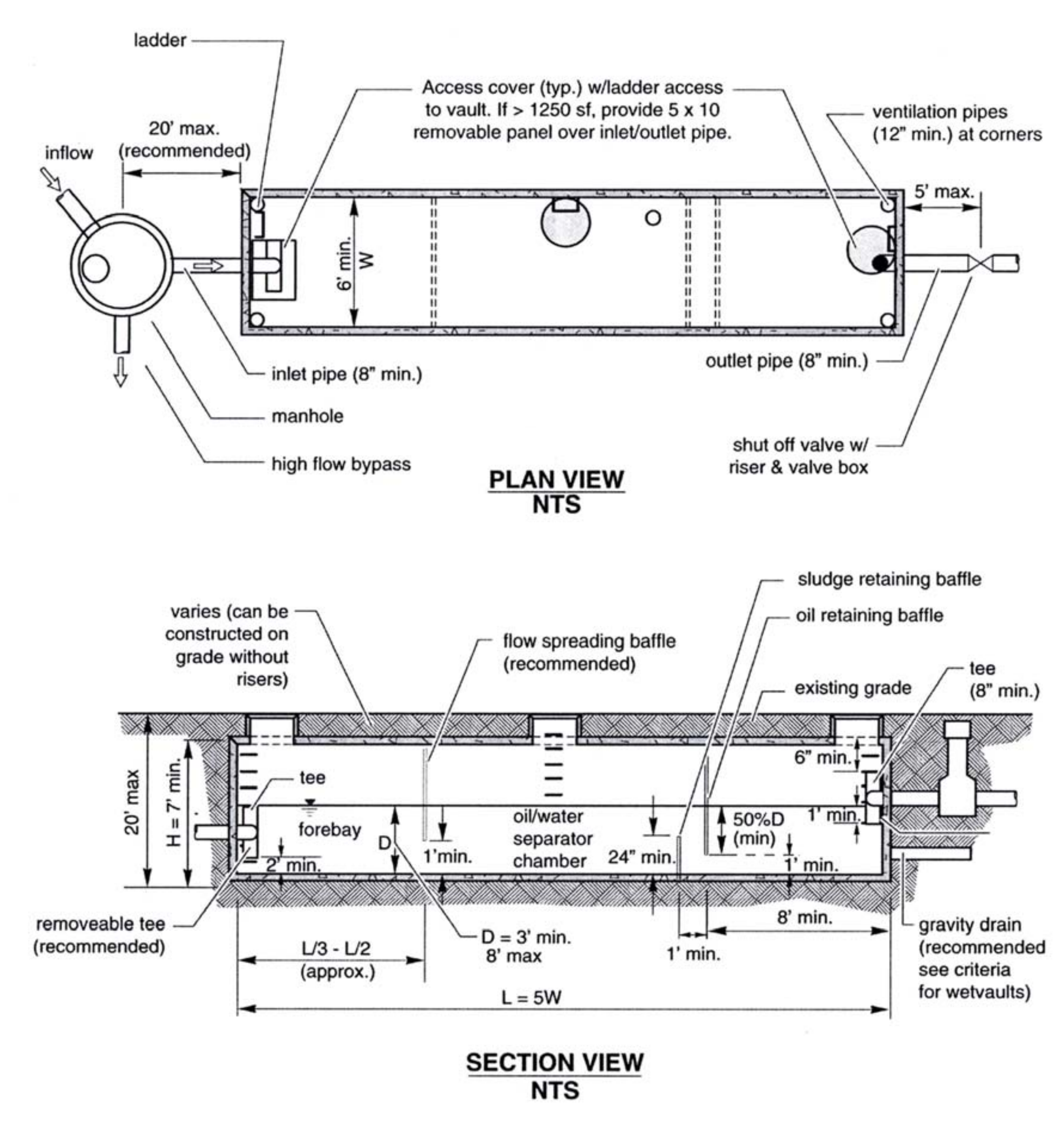


Figure 2.1: A typical API Oil Water Separator (Washington Department, 1990)

2.2 Overview of Different Types of Modified OGS

Since the API separator (3 chamber OGS) is relatively cheap and can be easily installed at many small sites without sacrificing land, they became popular in stormwater treatment practices (Schueler, 1997). The 3 chamber OGS for stormwater particles were initially designed to trap and settle large sediment, debris and hydrocarbons from highly impervious development areas such as gas stations, fast food joints, parking lots and even roadside rest areas. However, the accumulated sediment in the separator could be re-suspended during high intensity rainstorms. Consequently, various modified OGS designs were developed to reduce the potential for resuspension of accumulated sediment and enhance separation (e.g. Stormceptor®, Vortechs™, BaySaver®, Downstream Defender™, V2B1™ Stormwater Treatment System, Continuous Deflective Separation Unit, Multi-Chamber Treatment Train, Baffle Box). The different designs are classified for the purpose of this review as by-pass types, swirl action types, screening action types, coalescence action types and combined system types. These classifications are not strict delineations, since some separators may include more than one design feature (e.g. by-pass and swirl action), but are employed here to facilitate discussion. The reader is directed to individual manufacturers for more detailed design information on each of the technologies reviewed.

2.2.1 By-pass types of OGS

One way to by-pass high flows is to install a weir inside the separator to separate low and high flows. Stormceptor® (Figure 2.2) and BaySaver® (Figure 2.3) both use this approach.

The Stormceptor® system is divided into a lower treatment chamber and an upper bypass chamber. Low flows enter the unit and are directed by a diversion weir into an inlet down-pipe, which discharges into the lower treatment chamber. Water exits the treatment chamber through an outlet riser pipe at the same elevation as the inlet pipe. Inside the lower treatment chamber, oil and grease float to the inlet/outlet elevation while solids settle down to the bottom. Higher flows in excess of the capacity of the inlet pipe overtop the weir and bypass the treatment chamber.

The BaySaver® system is comprised of two precast concrete manholes and a high-density polyethylene separator unit. The two manholes allow the removal and storage of pollutants, while the separator unit directs the flow of water to provide the most efficient treatment possible. During low flow, coarse sediment settles in the first manhole and fine sediment and floatables settle at the second manhole. During more intense storms, the elbow pipes begin to draw water just below the surface in the first manhole. This water is free of oil and sediment. The elbow pipes draw water from the first manhole and discharges it directly downstream. At the same time, influent water is diverted into the second manhole by a surface-skimming weir. In this manner, the BaySaver® system continues to remove oil and sediment in the second manhole while it maintains a higher flow rate through the system. The separator unit includes an internal bypass which by-passes extreme flow rates downstream without treatment.

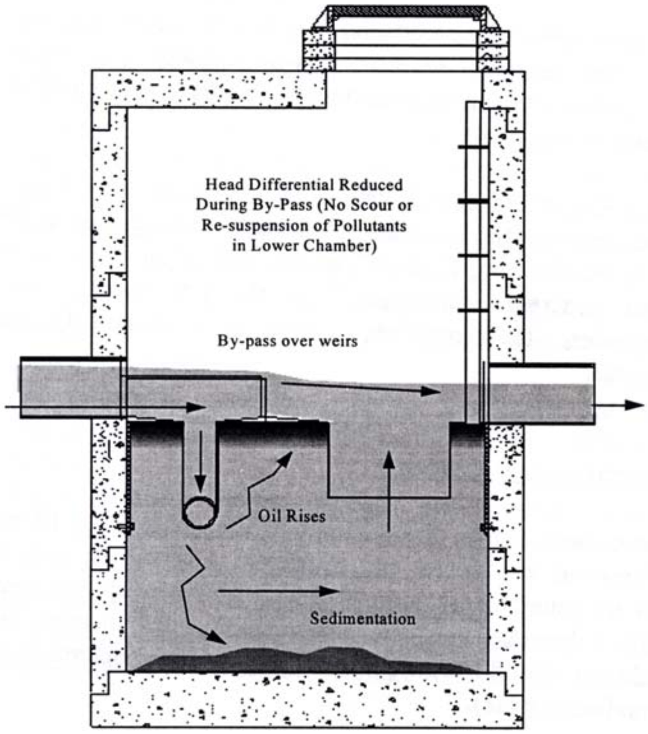


Figure 2.2: Stormceptor® Operation During High Flow Conditions (Stormceptor®, 1996)

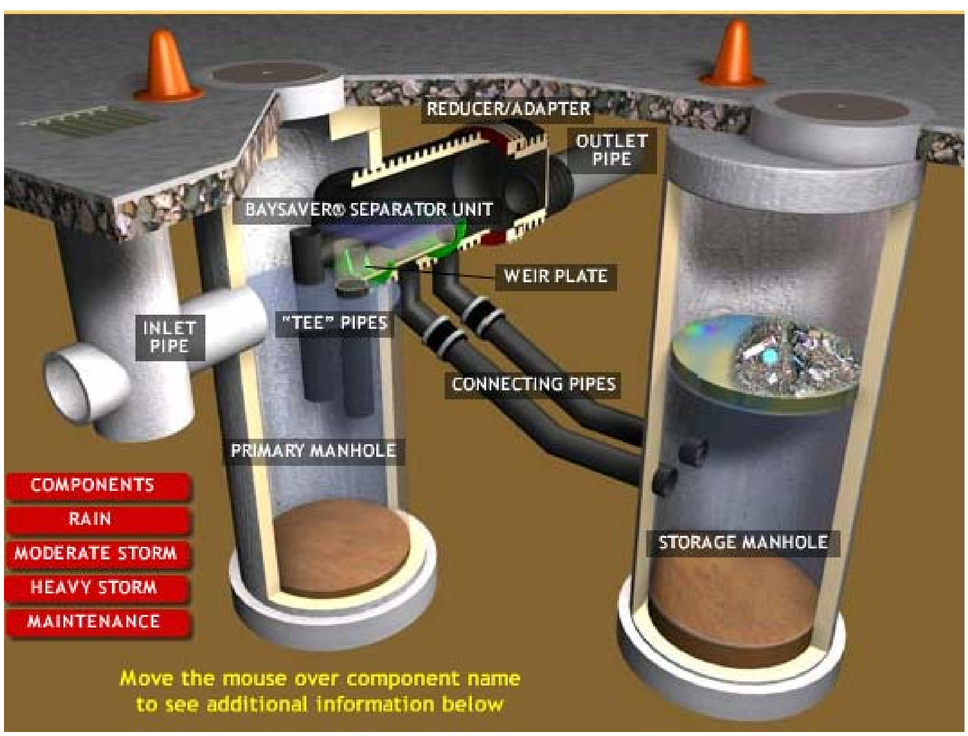


Figure 2.3: Typical Details of BaySaver® (www.BaySaver.com)

2.2.2 Swirl action types of OGS

Another feature designed to enhance oil separation augments gravity separation with a swirling flow field. The Vortechs™ System, the Downstream Defender™ and the V2B1™ Stormwater Treatment System are all based on this approach. These types of OGS can also incorporate by-pass mechanisms, such as a by-pass weir upstream of the separator in an off-line configuration.

The Vortechs™ System consists of three chambers to treat stormwater runoff: a grit chamber, an oil chamber with a baffle wall, and a flow control chamber to regulate the rate of outflow from the system (Figure 2.4). The tangential inlet directs the inflow into a swirling flow field, which induces solids to settle in a pile at the center of the grit chamber. The overflow passes under a baffle wall to the next chamber which is designed to trap oils and other floatables. The third chamber is designed with dual level outlets to regulate the flow through the system and to minimize resuspension of the trapped pollutants.

The Downstream Defender™, manufactured by H.I.L. Technology Inc, has only one chamber (Figure 2.5). It consists of a concrete cylindrical vessel with polypropylene internal components and a stainless steel support frame. The concrete vessel is a standard cylindrical manhole with a tangential inlet pipe that is installed below ground. Two ports at ground level provide access for inspection and clean out of stored floatables and sediment. The internal components consist of two concentric hollow cylinders (the dip plate and center shaft), an inverted cone (the center cone), a benching skirt and a floatable lid. Stormwater is introduced through the submerged tangential inlet, which generates a rotational flow, initially spiraling around the perimeter, in the outer annular space (between the dip plate cylinder and manhole wall), where oil and floatables rise to the water surface and are trapped. As the flow continues to rotate about the vertical axis, it travels down towards the bottom of the dip plate. Sediment is directed toward the center and base of the vessel where they are collected in the sediment storage facility, beneath the vortex chamber. The center cone protects the stored sediment and redirects the main flow upwards and inwards. Flow passes under the dip plate and up through the inner annular space, inside the dip plate (between the dip plate and center shaft cylinders), as a narrower spiraling column rotating at a slower velocity than the outer downward flow. The outlet of the Downstream Defender™ is a single central discharge from the top water level in the inner annulus. Discharge from the inner annulus forces each fluid element to pass through a long spiral path from the inlet, downward through the outer annulus, then upward through the inner annulus before it can be released. This increases the time for separation of pollutants. By the time the flow reaches the top of the outlet, it is free of coarse solids and floatables.

In a manner similar to Vortechs™ System and Downstream Defender™, theV2B1™ stormwater Treatment System also uses the swirl technology to provide primary treatment for stormwater. This system has another series of environmental products called Environment 21 and is manufactured by Kistner Concrete Products Inc. The system consists of two chambers. The first chamber is the sediment removal chamber. This chamber has a tangential inlet pipe which provides optimum swirl distribution for sediment removal. A 4-5 foot deep sump provides ample sediment storage. Treated surface water enters the second chamber where floating particles and debris are trapped by a baffle wall. An underflow opening in the bottom of the baffle wall directs flow to the system outlet pipe.

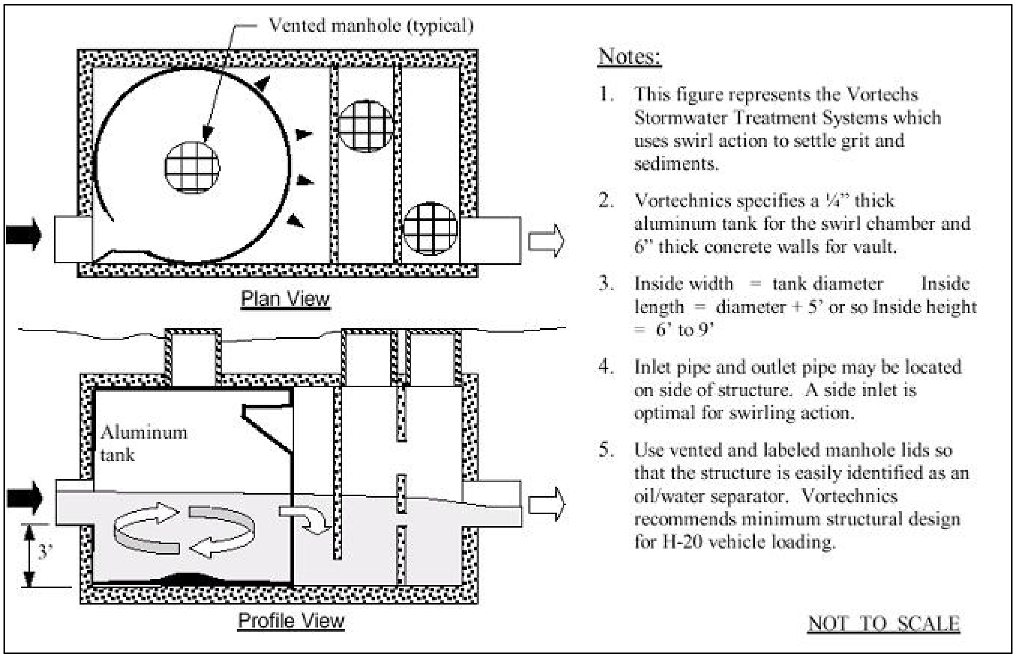


Figure 2.4: Typical Details for the Vortechs™ System

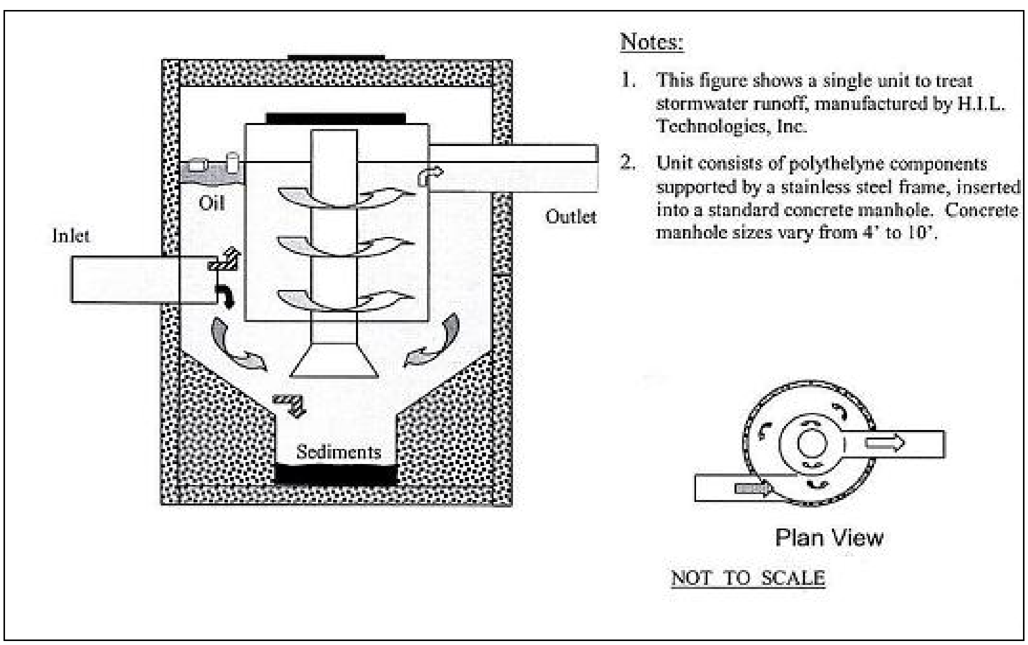


Figure 2.5: Typical Details for the Downstream Defender™

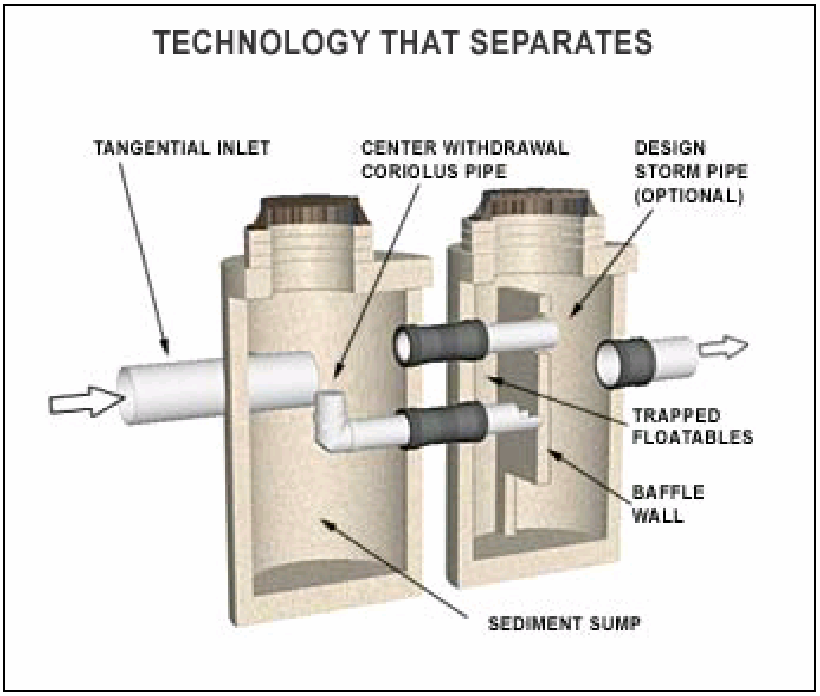


Figure 2.6: Typical Detail of V2B1™ Stormwater Treatment System

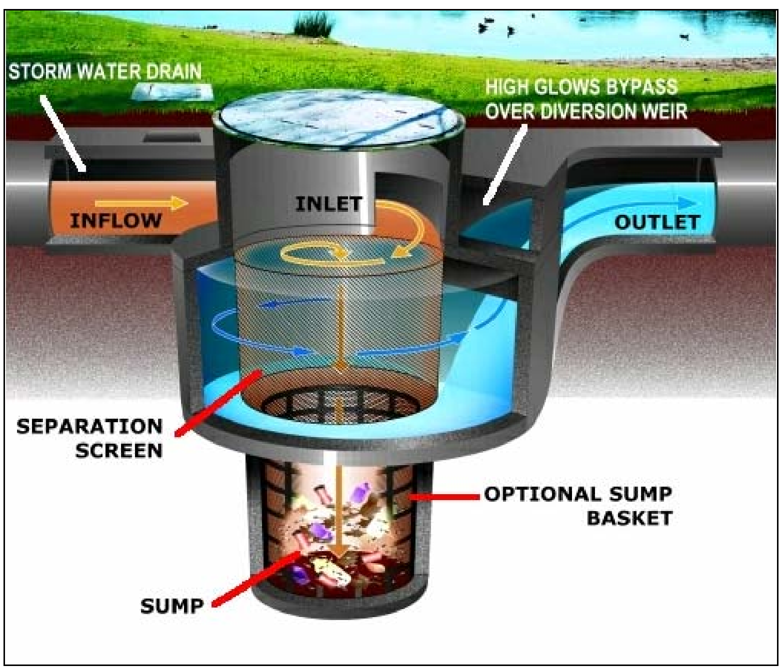


Figure 2.7: Typical Detail for Continuous Deflection Separators (http://www.CDStech.com)

2.2.3 Screening Action Type of OGS

Screening technologies are different from filtration technologies. Screening refers to the removal of larger particles, gross debris, and trash via flow through a permanent separation element. Filtration refers to removal of finer particles by a replaceable filter media.

The Continuous Deflective Separation (CDS) is similar in some respects to the Downstream Defender^{TM}. It consists of one chamber but the separation of solids is dependent on a separation screen that is installed in the chamber (Figure 2.7). A CDS unit is designed to set up a continual flow of liquids that passes tangentially over the face of a special perforated cylindrical separation screen located in a hydraulically balanced separation chamber. Solids are captured and retained within the central chamber. The fluid then passes through the screen, at which point velocities are reduced (because of the of the screen design) causing further settling before water exits via the outlet pipe. Solid pollutants including trash, debris and sediments are retained in a centrally located solids catchment chamber with the heavier solids ultimately settling into the base of the unit.

2.2.4 Coalescence Action Types of OGS

Coalescence action provides for enhanced gravity separation. Coalescence action will merge the very small oil globules together to form a larger oil droplet. According to Stokes Law, the large oil droplet separates from the water phase much faster than the original small droplets. Hence, the coalescence action types of OGS are able to remove oil droplets larger than 60 microns while the API separators (3 chamber OGS) are only able to remove oil droplets larger than 150 microns.

In the dispersion of two immiscible liquids, immediate coalescence seldom occurs as two droplets collide. If the droplet pair is exposed to turbulent pressure fluctuations, the kinetic energy of oscillations induced in the coalescing droplet pair may be larger than the energy of adhesion between them. As a result, contact may be broken before coalescence is completed.

However, coalescence can be achieved by providing sufficient energy in the system to allow the oil droplets to be brought together. The coalescing action was found to be maximized by installing a series of parallel flat plates at an angle of 45 degrees to the direction flow (Iggleden 1978). The parallel plates provide solid surfaces on which the small oil droplets accumulate. These accumulated oil droplets form a thick oil film, which becomes a source of large drops. When other mechanical forces, such as gravity or fluid forces, overcome the cohesiveness of the oil film, these accumulated oil droplets break loose from the solid surface and rise to the water surface.

Also, the flow through a separator with parallel plates can be two to three times higher than the API separator (3 chamber OGS). Thus, the size of the OGS can be reduced up to twofold in width and tenfold in length when the parallel plate is installed in a separator (Iggleden 1978).

There are different types of parallel plates:

- Inclined plates: The plates are installed in an inclined position, encouraging oil droplets collected on the undersides of the plates to move toward the surface of the separator, and sludge collected on the plates to settle toward the bottom of the separator by gravity.

- Flat corrugated plate: A series of horizontal oleophilic polypropylene plates are stacked on top each another in vertical stacks. The advantages of this system are that the plate packs are modular and relatively small in size compared to the inclined plate modules. Also, the oleophilic nature of the plate attracts oil droplets and encourages them to coalesce into larger ones.

- "MPak®" multiple angle plate: The separator plate has an "M" shape when seen from the end and thus the system is referred to as the "M Paks". The plates are corrugated in both directions, making a sort of "egg carton" shape. The "M" shaped plates are designed to shed solids to a solids collection area at the bottom of the separator thereby avoiding plugging of the device. In inclined plate systems, solids must slide down the entire length of the plates. In the "M" shaped plate, solids only slide a few centimeters before encountering one of a multitude of solids removal holes, where they drop directly to the bottom of the separator.

- Coalescing tube: A series of perforated plastic tubes are utilized for separation. The advantages of this separator are its low cost and enhanced separation due to the oleophilicity of the packing. The disadvantage is that the oil separation from the tubes are uncertain and therefore not optimized.

- Modified crossflow pack: The traditional plate coalescence separator is prone to plugging by solids or biological flocs. A modified plate coalescence is designed to overcome this limitation. In order to increase the coalescence rate, additional energy must be provided to the system to create an oscillatory flow. This type of flow will create turbulence just enough to promote coalescence but not so great as to avoid shearing oil droplets. This flow action can be achieved by applying the shaking-induced flow technique. When the plate pack experiences a vertical motion with 1 cm displacement, it is possible to have different oscillatory flows with Reynolds numbers ranging form 1,500 up to 4,500. Since the Reynolds number of the original laminar flow through a standard crossflow pack was 930, the additional shaking motion accelerates the removal of sediments and solids form the plate pack.

2.2.5 Combined-System Types of OGS

There are various stormwater management technologies available. Each technology has its own benefits and its own limitations. For example, the use of gravitational settling in the OGS can only remove settleable pollutants in stormwater; infiltration sometimes is not an option due to the risk of groundwater contamination. As a result, a treatment-train approach, which combines a variety of stormwater management technologies may be appropriate for stormwater management (e.g. Multi-chambered treatment train (MCTT) and Storm Treat™).

Table 2.2: Specialized Components of the MCTT (Schueler & Holland, 2000)

Chamber	Component	Description	Function
Inlet	Flash aerator	Small column packing balls with counter current air flow	Removes volatile pollutants and traps trash
	Catch basin sump	Conventional catch basin sump	Traps grit and sand-sized particles
Settling	Sorbent pads	Floating absorbent pads	Traps oil and grease
	Find bubble aerator	Generator powered fish farm aeration stone	Enhances aeration
	Inclined tube or plate settlers	Plastic tubes 2" X 2', inclined 30-45 degrees, arranged in rows of opposing direction	Increases surfaces area of settling chamber; enhances sedimentation and prevents scour
Filtration	Gunderboom™ filter fabric	Covers top of filter	Reduces channelization, slows infiltration, sorbs oils
	Peat/sand filter media	50/50 mix, at least 12" depth	Removes small and dissolved particles, provides ion exchange
	Filter fabric	Separates peat/sand layer from gravel and pipe layer	Prevents gravel layer from clogging
	Gravel packed under drain	Perforated PVC pipe and gravel	Provides additional filtration/outlet

Robert Pitt and his colleagues at the University of Alabama-Birmingham (Schueler & Holland, 2000) have developed and tested a prototype known as the multi-chambered treatment train (MCTT). This device employs screening in the first chamber, settling in the next, and filtration in the last (Figure 2.8). It is designed for underground use and sized to contain runoff from various rain events. It typically requires between 0.5 to 1.5% of the paved drainage area.

The MCTT is divided into three main chambers (see Table 2.2 for a description of the various components). Stormwater enters the first chamber where the largest particulates settle out and the bulk of highly volatile materials are removed when they pass over a flash aerator. The stormwater then either flows by gravity or is pumped into the settling chamber. In the second chamber, settling of fine sediment is enhanced through the use of inclined tube or plate settlers while floating hydrocarbons and sorbent pads and bubble diffusers remove additional volatile compounds. The stormwater is subsequently pumped slowly into the filtration chamber containing a sand and peat filter bed for final removal of dissolved toxicants. The filter also provides partial treatment to runoff that may have bypassed prior chambers in the event of excess stormwater flow.

StormTreat™ was developed in 1994 by StormTreat™ Systems, Inc. The system consists of a series of six sedimentation chambers and a constructed wetland, which are contained within a modular 2.9 m diameter tank. Influent is piped into the sedimentation chambers where larger-diameter solids are removed. The internal sedimentation chambers contain a series of skimmers that selectively decant the upper portion of the storm water in the sedimentation basins, leaving behind the more turbid lower waters. An inverted elbow trap serves to collect floatables, such as oils within the inner tank. After moving through the internal chambers, the partially treated storm water passes into the surrounding constructed wetland through a series of slotted PVC pipes.

The wetland is comprised of a gravel substrate planted with bulrushes and other wetland plants. Partially treated storm water is piped into the subsurface of the wetland and through the root zone, where greater pollutant attenuation occurs through such processes as filtration, adsorption and biochemical reactions.

Precipitation of metals and phosphorus occurs within the wetland substrate by biochemical reactions, including microbial decomposition. After stormwater is held within the system for 5 days, the stormwater is released by the outlet control valve.

If the water level in the wetland reaches a depth of 0.9 m, it overtops an internal weir that directs the treated water into the surrounding fill and solids. As a result, the StormTreat™ system is capable of processing storm water beyond the first flush.

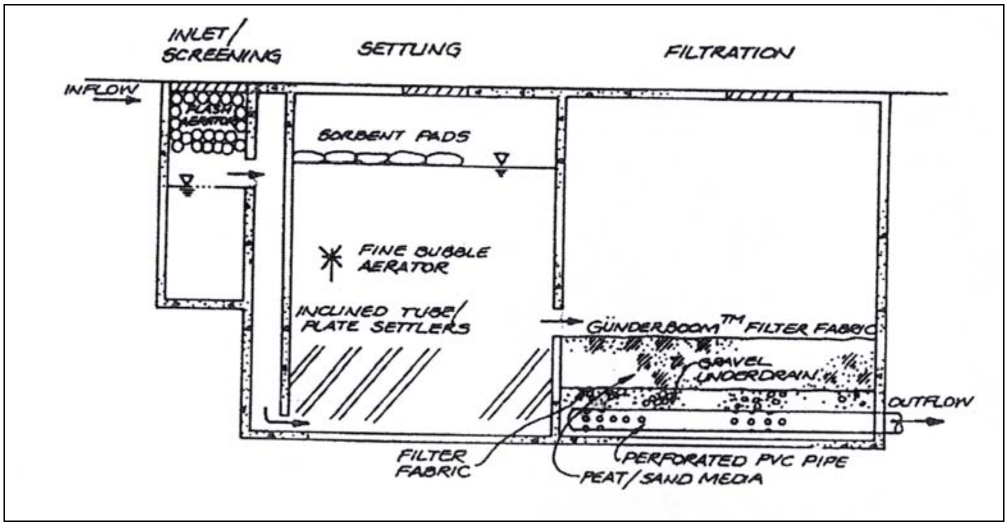


Figure 2.8: Detailed Schematic of the MCTT (Schueler & Holland, 2000)

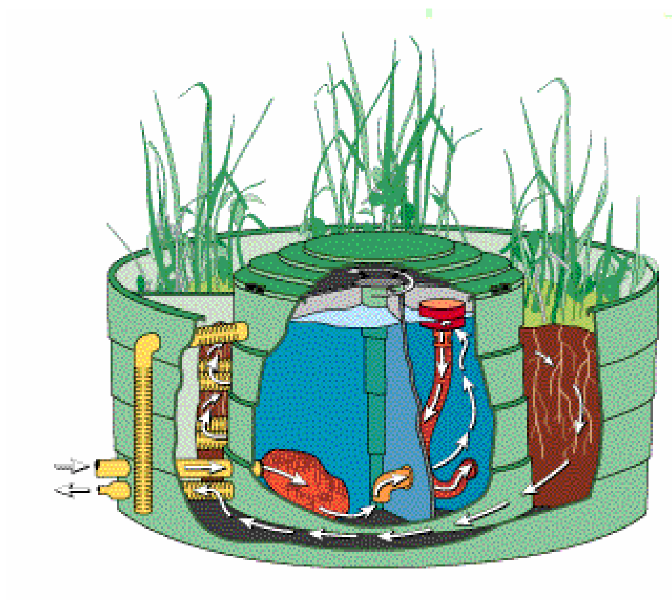


Figure 2.9: StormTreat™ Schematic (www.stormtreat.com)

There are many kinds of oil/grit separator available on the market. Only those separators for which literature and monitoring data were available are reviewed. In subsequent sections, due to the limited information available on the performance of other types of separators, only the API separator (3-chamber), Stormceptor®, BaySaver®, Vortechs™, Downstream Defender™ and Continuous Deflective Separation Unit are reviewed. Other types of separators reviewed but not summarized here in terms of performance and maintenance considerations include the V2B1™, coalescing action (parallel plate) type separators, StormTreat™ and MCTT. Information about these types of OGS can be obtained from the manufacturers.

Table 2.3: Summary of operational principles for selected OGS

Name	Manufacturer	Principle	Web Site
API separator (3-chamber separator)	Not specific	Gravity Separation	----
Stormceptor	Stromceptor Canada Inc.	Gravity Separation, with high flow by-pass weir	www.stormceptor.com
BaySaver	BaySaver Inc.	Gravity Separation, with two pre-cast concrete manholes and a high flow separator unit	www.baysaver.com
Vortechs	Vortechnics Inc.	Hydrodynamic, with tangential inlet that directs the inflow into a swirling flow field to enhance the separation	www.vortechnics.com
Downstream Defender	H.I.L. Technology Inc.	Hydrodynamic, with submerged tangential inlet and cylindrical vessel with a 30^0 sloping base to enhance separation	www.hil-tech.com
Continuous Deflective Separator Unit	CDS Technologies Inc.	Hydrodynamic, with tangential inlet and separation screen to capture solids	www.CDStech.com

2.3 Design and Sizing Criteria of Different Types of OGS

As indicated earlier, OGS separator theory is based on Stokes' Law of gravity separation (API 1990). If an oil globule has a rise rate greater than or equal to the surface-loading rate, it will rise to the surface and be removed. The rise rate of the oil globule can be calculated using Stokes' Law.

$$V_t = (g / 18\mu) (\rho_w - \rho_o) D^2 \qquad \textit{equation 1}$$

Where V_t = rise rate of the design oil globule, in cm/s
g = acceleration due to gravity, 981 cm/s
μ = absolute viscosity of wastewater at the design temperature, t in poise
ρ_w = density of water at the design temperature, t in g/cm^3
ρ_o = density of oil at the design temperature, t in g/cm^3
D = diameter of the oil globule to be remove, in cm

2.3.1 API oil/water separator (3 chamber OGS)

A step-by-step design procedure for the API separator is listed below.

Step 1: Determine the rise rate for the oil globules (V_t)

Since the API separator is designed to treat free oil globules of 150 µm diameter, the rise rate of these globules is determined by

$$V_t = 0.0241 * (S_w - S_o) / \mu \qquad \textit{equation 2}$$

where S_w = specific gravity of fresh clean water at 10^0 C
S_0 = specific gravity of gasoline

Step 2: Determine the maximum allowable mean horizontal Velocity (V_h)

The design mean horizontal velocity (V_h, in feet per minute) is determined by the smallest value of two constraints. One is 15 times of the rise rate for the oil globules, or 3 feet per minute, which is recommended as the upper limit for

$V_h = 15*V_t$ or 3 ft/min (recommend maximum inflow rate of API separator)

Step 3: Determine the minimum vertical cross-section area (A_c)

Given the design flow rate and the horizontal velocity, the cross-sectional area can be determined by the following equation.

$$A_c = Q_m / V_h \qquad \textit{equation 3}$$

where A_c = minimum vertical cross-section area
Q_m = design flow to the separator

V_h = horizontal velocity

Step 4: Determine the channel width and depth

Given the total cross-sectional area of the channel, the width and depth of the channel can be determined by the following equation.

$$d = A_c / B \qquad \textit{equation 4}$$

where d = depth of channel

A_c = cross-section area

B = width of the channel

Since there are two unknowns in this equation, the width and the depth of the separator will be determined by trial and error until the depth-to-width ratio is between 0.3 and 0.5.

Step 5: Determine the separator length, L

After the separator depth and width have been determined, the length of the channel can be calculated by the following equation.

$$L = F * (V_h / V_t) * d \qquad \textit{equation 5}$$

Where L = length of channel

F = turbulence and short-circuiting factor

V_h = horizontal velocity

V_t = rise rate for the design oil globule

d = depth of channel

The turbulence and short-circuiting factor (F) is determined by a short-circuiting factor of 2.1 and a turbulence factor which depends on the ratio of V_h and V_t. A graph of F versus the ration V_h/V_t can be found in the API manual (1990).

Using this step-by-step procedure, an API separator that can treat 120L/s will be 16 m long and 3.9 m wide (Chui 2002).

2.3.2 Stormceptor®

Stormceptor® sizing is based on the removal of total suspended solids estimated by a continuous simulation model using local historical rainfall data. The computer model, the Expert System Sizing Program Version 2.0, was developed based on the USEPA SWMM Version 4.3. Solids build-up, wash-off and settling calculations were added to the hydrology code to estimate the suspended solids captured by the Stormceptor®. Table 2.4 shows the specifications of different Stormceptor® units. Table 2.5 shows the stormwater pollutant removal process modeled by the Expert System 2.0

Table 2.4 : Typical Stormceptor® unit Specifications

Model	Sediment Capacity (l)	Oil Capacity (l)	Total Holding Capacity (l)
STC300I	1450	300	1775
STC750	3000	915	4070
STC1000	3800	915	4871
STC1500	6205	915	7270
STC2000	7700	2890	11000
STC3000	11965	2890	15270
STC4000	16490	3360	20255
STC5000	20940	3360	24710
STC6000	26945	3930	31285
STC9000	32980	10555	44355
STC10000	37415	10555	48791
STC14000	53890	11700	66410

Source: Hanson Canada, 2002

Table 2.5: Modelling of stormceptor during pollutant removal process

Task	Method
Pollutant build-up/wash-off	Exponential decay functions
Hydrology	USEPA SWMM Version 4.3
Mixing in the stormceptor lower chamber	Continuous Flow Stirred-Tank Reactor Equations
Particle Settling	Type I Settling (Stoke's Law) and Flocculated Settling

The model requires 15-minute rainfall data with 1/100th of an inch resolution. The rainfall resolution and time step are important to properly characterize small site hydrology where a Stormceptor® is typically implemented. Daily evaporation rates are assumed constant (2.5mm/day) since catchment areas are typically small (<10ha) and have minimal depression storage.

The particle size distribution used to calculate the removal efficiency of TSS in the Stormceptor® is relatively fine, ranging from 20 um to 2000 um. Research conducted by Ball and Abustan (1995) indicate that there is a high potential for coagulation of smaller particles which would increase settling velocities and TSS removal rates. A flocculation equation is used to simulate the settling velocity for particles equal to or smaller than 20 um.

2.3.3 BaySaver®

The sizing of BaySaver® is dependent on the flow rate that will be conveyed through the system. Table 2.6 lists the flow specifications of the BaySaver® Separation System.

Table 2.6: Typical BaySaver® unit specifications (www.BaySaver.com)

Unit	Max. Treatment Flow (cfs)	Max Capacity Flow (cfs)	Bypass Flow (cfs)	Unit Diameter	Manhole Size	Treatable Drainage Area (acres)
1/2K	1.1	8.5			48”	
1K	2.4	10	8.8	24”	48”	1.2-1.6
3K	7.8	30	24	36”	60”	1.6-4.4
5K	11.1	50	39	48”	72”	4.4-8.0
10K	21.8	100			120”	
XK	Custom	Custom				

The sizing of BaySaver® is based on two design procedures: the peak flow design and the treatment design. For the peak flow design, the flow rate will be calculated by the feasible design storm such as the maximum storm that will be conveyed through the system without backup. By comparing the peak design flow rate with the maximum capacity flow in Table 2.6, the size of BaySaver® for peak design can be selected. For treatment design, the flow rate is calculated using the feasible inches per hour rainfall intensity such as the maximum storm will be treated in the system without by-pass. By comparing the treatment design flow rate to the maximum treatment flow in Table 2.6, the size of BaySaver® can be selected. The following is an example illustrating the sizing of BaySaver® from the BaySaver® website.

A 7.5 acre highly impervious site located in Mt. Airy, Maryland, needs stormwater treatment. Local regulations specify that 80% of the Total Suspended Solids (TSS) must be removed from the yearly runoff by treating an intensity of 1" per hour.

For peak design, the 10-year design storm for this location is calculated to generate 27 cubic feet per second (cfs) of runoff to be carried through the storm drain. Using the sizing table above, we cross-reference this value against the Peak Design Flow Rates. The smallest unit that can convey this peak design flow is the 3K BaySaver® Separator Unit.

For treatment, to remove 80% of the total suspended solids from this site, a flow rate is calculated using the 1" per hour rainfall intensity. This generates the treatment flow rate, which is equal to 8.1 cfs. Again using the sizing table above, we cross-reference this value against the listed Maximum Treatment Flow Rates and find that this rate exceeds that of the 3K unit. Therefore, the next larger size for the BaySaver® Separator Unit is the appropriate choice, that being the 5K BaySaver® Separator Unit with a Maximum Treatment Flow of 11.1 cfs.

The final size of the BaySaver® will be the larger size from both design procedures. The concrete manholes, manufactured to the applicable specifications, can be purchased from local precast concrete suppliers. The separator unit is manufactured by BaySaver® Inc.

2.3.4 Vortechs™

Each Vortechs™ System is custom designed by taking into consideration the site size, site runoff coefficient, regional precipitation intensity distribution and anticipated pollutant characteristics. These factors are incorporated into the Rational Rainfall Method™, developed by Vortechnic® Inc., to estimate net annual pollutant removal efficiency.

<u>The Rational Rainfall Method™</u>
Since the performance of the separator is dependent on the local rainfall intensity distribution and other factors, the Rational Rainfall Method™ combines site-specific information with laboratory generated performance data and local historical precipitation records to estimate the efficiencies of the separator. Short duration rain gauge records from across the United States and Canada were analyzed by Vortechnics to determine the percent of total annual rainfall that fell at a range of intensities. These intensities, along with the total drainage area and runoff coefficient for each specific site are translated into flow rates using the Rational Method. Based on the flow rates calculated from the Rational Method, an operating rate within a proposed Vortechs™ System is determined. Finally, removal efficiency is selected for each operating rate based on the anticipated pollutant characteristics and the full-scale laboratory test results. A full scale Vortechs® Model 2000 had been tested for removal efficiency of different pollutant, such as different particle gradations (50µm, 150µm and typical gradation) and 10w40 motor oil (influent concentrations between 15mg/L and 90mg/L). The relative removal efficiency, based on Model 2000, at each operating rate is incorporated into a model to estimate a net annual pollutant removal efficiency. The following steps are used to determine the minimum Vortechs System model that will meet the treatment objective. (www.vortechnics.com):

1) Determine the net annual removal efficiency target and time of concentration that best match the site.
2) Provide the treatment goal and time of concentration of the site to the local Vortechnics' representatives; they will determine the appropriate maximum design ratio number. The maximum design ratios for different geographic regions across North America have been determined by Vortechnic® Inc through analysis of historical precipitation records archived by the National Climatic Data Center.
3) Calculate the necessary swirl chamber area and the corresponding Vortechs™ system model using the following equation:

Minimum Swirl Chamber Area ≥ $$\frac{C_d * A * 2.77}{\text{Design Ratio}}$$ *equation 6*

Where: A = the drainage area (acres)

C_d = Runoff Coefficient for your site

Design Ratio = Maximum design ratio number provided by Vortechnics in Step 2

4) Based on the required swirl chamber area calculated in Step 3, choose the appropriate Vortechs™ system models from the following table. This is the smallest model that can be expected to achieve the treatment goal.

Table 2.7: Typical Vortechs™ unit specification

Vortechs™ Model	**Swirl Chamber Area (m^3)**	**Design Treatment Capacity (L/s)**	**Grit Chamber Diameter/Area (ft/ft^2)**	**Peak Design Flow (cfs)**	**Sediment Storage (Yds^3)**	**Oil Storage (gals.)**	**Approx. Size L x W (ft)**
1000	0-0.66	45	3/7	1.6	0.75	270	9x3
2000	0.66-1.7	79	4/13	2.8	1.25	350	10x4
3000	1.7-1.8	120	5/20	4.5	1.75	500	11x5
4000	1.8-2.6	180	6/28	6.0	2.5	700	12x6
5000	2.6-3.6	240	7/38	8.5	3.25	900	13x7
7000	3.6-4.7	320	8/50	11.0	4.0	1200	14x8
9000	4.7-5.9	400	9/64	14.0	4.75	1500	15x9
11000	5.9-7.3	500	10/79	17.5	5.5	1800	16x10
16000	7.3-10.5	710	12/113	25.0	7.0	2500	18x12

Vortechnics recommends the selection of systems that will provide an 80% annual TSS load reduction (based on laboratory generated performance curves for 50-micron particles). Other removal efficiencies or particles size targets can be determined using the full-scale laboratory test results and the Rational Rainfall Method™ described above. The procedure can also be used to estimate annual hydrocarbon load reductions. (www.vortechnics.com).

2.3.5 Downstream Defender™

There are four standard sizes available. Each unit is designed to remove 90% of all particles with a specific gravity of 2.65 down to 150 microns, and capture floatable, oil and grease. In order to meet specific performance criteria or for larger flow, the company offers custom designed units up to 40 feet in diameter. The sizing of a Downstream Defender™ is based on North American influent solids grading curves. The solid characteristics in these solids grading curves are from the US EPA Swirl and Helical Bend Pollution Control Device Manual. Table 35 of this manual showed the size of solids found in streets which are potential solids in stormwater runoff, and the materials that will be entering the stormwater system. The capacity through the system is shown in Table 2.8.

Table 2.8: Typical Downstream Defender™ unit specifications

Unit Dia-meter (mm)	Fre-quent Storm Flow (l/s)	Peak Treat-ment Flow (l/s)	Inlet/ Outlet Pipe Diameter (mm)	Headloss at Frequent Storm Flow (mm)	Headloss at Peak Treat-ment Flow (mm)	Oil Storage Capacity (litres)	Spill Contain-ment Capacity (L)	Sedi-ment Storage Capacity (m^3)
1200	20	85	200,300	50	746	265	712	0.916
1800	85	230	300,450	147	1079	870	2400	2.75
2550	200	425	450,600	161	728	1990	5693	6.09
3000	370	700	600,750	175	625	3980	15050	11.40

The company recommends that the Downstream Defender™ be installed as an off-line facility. When the flows are greater than the design capacity, stormwater should be bypassed around the Downstream Defender™ via an upstream manhole.

In order to design a Downstream Defender™, the following site information is required:

- Design flow for a required removal efficiency of 90% of all grit particles with specific gravity 2.65 down to 150 microns.
- Peak flow or hydraulic capacity of the unit
- Top water level downstream of the unit at design peak flow
- Site plan, elevations and topography
- Is a bypass required, and, if so, at what flow?

2.3.6 Continuous Deflective Separation Unit

CDS® offers a range of pre-manufactured units that are sized to process typical drainage flows over a wide range of flow conditions (from 1 cfs to 300 cfs). CDS® also offers design services for larger cast in place units to meet the treatment requirements for more significant runoff flows generated by larger drainage areas.

Table 2.9: Specifications of CDS systems

Model Designation			**Treatment Capacity Range**		**Screen Diameter\Height (ft)**	**Sump Capacity (yd³)**	**Depth Blew Pipe Invert (ft)**
			cfs	MGD			
Precast	Inline	PMIU20_15 (Drop-in Inlet)	0.7	0.5	2.0\1.5	0.5	4.2
Precast	Inline	PMSU20_15_4	0.7	0.5	2.0\1.5	0.5	3.5-4
Precast	Inline	PMSU20_15	0.7	0.5	2.0\1.5	1.1	5.1
Precast	Inline	PMSU20_20	1.1	0.1	2.0\2.0	1.1	5.7
Precast	Inline	PMSU20_25	1.6	0.7	2.0\2.5	1.1	6.0
Precast	Inline	PMSU30_20	2.0	1.3	3.2\2.0	2.1	6.2
Precast	Inline	PMSU30_30	3.0	1.9	3.0\3.0	2.1	7.2
Precast	Inline	PMSU40_30	4.5	3.0	4.0\3.0	5.6	8.6
Precast	Inline	PMSU40_40	6.0	3.9	4.0\4.0	5.6	9.6
Precast	Offline	PSWC30_20	2.0	1.3	3.0\2.0	1.9	6.0
Precast	Offline	PSW30_30	3.0	1.9	3.0\3.0	1.8	7.0
Precast	Offline	PSWC30_30	3.0	1.9	3.0\3.0	2.1	7.0
Precast	Offline	PSWC40_30	4.5	3.0	4.0\3.0	1.9	8.5
Precast	Offline	PSWC30_30	6.0	3.9	4.0\4.0	1.9	9.6
Precast	Offline	PSW50_42	9.0	5.8	5.0\4.2	1.9	9.6
Precast	Offline	PSWC56_40	9.0	5.8	5.6\4.0	1.9	9.6
Precast	Offline	PSW50_50	11.0	7.1	5.0\5.0	1.9	10.3
Precast	Offline	PSWC56-53	14.0	9.0	5.6\5.3	1.9	10.9
Precast	Offline	PSWC56_68	19.0	12.0	5.0\6.8	1.9	12.6
Precast	Offline	PSWC56_78	25.0	16.0	5.6\7.8	1.9	13.6
Precast	Offline	PSW70_70	26.0	17.0	7.0\7.0	3.9	14.0
Precast	Offline	PSW100_60	30.0	19.0	10.0\6.0	6.9	12.0
Precast	Offline	PSW100_80	50.0	32.0	10.0\8.0	6.9	14.0
Precast	Offline	PSW100_100	64.0	41.0	10.0\10.0	6.9	16.0
Cast in Place		CSW150_134	148.0	95.5	15.0\13.4	14.1	19.6
Cast in Place		CSW200_164	270.0	174.0	20.0\16.4	14.1	22.6
Cast in Place		Csw240_160	300.0	194.0	24.0\16.0	14.1	21.2

The recommended design flows for the CDS® units are typically those with a return frequency of 3 to 6 months. These flows are normally in excess of those required to generate movement of pollutants typically associated with "first flush" event. However, should higher flows be identified as movers of pollution in a particular watershed, CDS® capacity should be increased accordingly. Flows that are within the CDS design capacity are treated in the unit. If runoff flows are greater than the design flow, they are split in a weir diversion box, with the CDS capacity flow passing through the processor, while the excess flow spills over the diversion weir and continues downstream. After the CDS® design flow has been determined, the appropriate standard model can be selected from Table 2.9.

Table 2.10: Summary of sizing specifications for selected OGS

Product Name	**Smallest Unit**				**Largest Unit**				**Maximum Treatment Rate, from small to large (cfs)**	**Sizing Criteria**
	Capacity (l)			Size/ model no.	Capacity (l)			Size / model no.		
	Holding	Oil	Sediment		Holding	Oil	Sediment			
3-chamber separator	-	-	-	-	-	-	-	-	-	Inflow rate
Stormceptor	1775	325	1275	STC300	31210	41 50	23445	STC6000	10.56 to 148.38	Historical rainfall data (computer model available)
BaySaver	-	-	-	Two 48" manhole/ 1/2K	-	-	-	Two 120" manhole/ 10K	1.1 to 21.8	Peak/treatment inflow rate
Vortechs	-	1022	573	9 ft X 3ft /1000	-	94 63	5352	18 ft X 12 ft / 16000	1.6 to 25	Site size, site runoff coeff, region rainfall intensity and anticipated pollutant characteristics
Downstream Defender	-	265	916	1200 ft diameter	-	39 80	11400	3000 ft diameter	0.7 to 24.72	Design/Peak flow, Top water level downstream of the unit, site topography
Continuous Deflective Separation Unit	-	-	382	PMIU20_1 5	-	-	10780	Csw240_1 60	0.7 to 300	Hydraulic analysis require, base on the conveyance system and separator performance

2.4 OGS Performance

When applied for wastewater treatment, the performance of gravity oil water separators depends on several factors, including physical characteristics of the oil and wastewater, inflow rate, specific gravity of the water, salinity, temperature, viscosity and the oil/sediment size (API, 1990). Stormwater is more variable than wastewater. Hence, when OGS are used to manage stormwater, performance is affected by several additional factors, such as particle size distribution, land use type, rainfall intensity, upstream storage availability (e.g. roof top, parking lot), road salts and climatic factors.

Other factors that are important in assessing performance relate to the design and execution of the monitoring study. Important questions may include:

- How was the monitoring carried out? For example, was the equipment installed suitable for defining the changes associated with variable inflow rates and concentrations, the potential for surcharging, backwater effects and bypasses? Were samples taken as single point-in-time grabs or were they proportioned according to flow over the duration of the runoff event?

- How were the results interpreted? For example, were influent and effluent concentrations calculated as arithmetic or geometric means, was the quality of bypass flows included in the removal efficiency estimates and was the inherent error associated with the equipment taken into consideration.

The following section discusses the performance of different types of oil/grit separators. The intent of this section is not to compare the performance of one device with another (which would require considerably more information than was available) but to present findings from the literature review. Interpretation of the performance data requires that the reader consider the particular physical characteristics of each study site, the methods used to monitor the technologies and whether the data collected presents an accurate representation of typical conditions under which this technology is usually applied.

The review differentiates between independent or third party studies and those conducted by manufacturers or manufacturer sponsored agencies to indicate potential bias.

2.4.1 Three chamber oil grit separators

Field Monitoring Studies

1. Seat Pleasant, MD (independent study)
Dave Shepp and his colleagues conducted a five-year independent research study on a 3-chamber oil-girt separator (as cited in Schueler, 1998). In the first phases of the study, dye tests indicated that the separator had very short residence times during small storms (often less than 30 minutes). A survey of 109 installed OGS showed an average of only two inches of sediment accumulation in the two pool chambers, and deposition did not increase no matter how long the OGS had been in service. In 17 OGS monitored monthly, sediment depths varied frequently, but rarely accumulated over time. In none of the maintenance agreements for the 109 OGS surveyed was sediment clean-out specified as a requirement.

In the second phase of the study, the pollutant removal efficiency of one OGS was directly measured in the field. The OGS served a one-acre parking lot of a fast food outlet. A total of thirteen storm samples were collected during the monitoring period and the rainfall ranged from 5 to 50 mm in depth. Negative removal efficiency was found for suspended sediment, total organic carbon, hydrocarbons, total phosphorus, organic nitrogen, and extractable and soluble copper. Based on these findings, the study recommended that the use of standard OGS designs (i.e. 3-chamber) should be abandoned at small sites. It was suggested that no practice would likely be effective on small sites unless it was designed to capture 6 to 13 mm of runoff as a bare minimum. In addition, small sites should be designed to be off-line from the major storm water conveyance system.

2. Austin, TX (independent study)
A modified OGS (a two-chamber tank containing oil sorbent pillows) that underwent regular maintenance was monitored. The modified OGS was designed as an off-line pre-treatment device for a peat sand filter. During the study, a total of 17 storm events were monitored. Results showed that the OGS achieved a removal efficiency of 41% for TSS and 22% for total organic carbon (as cited in Schueler, 1998). Unfortunately, details on study design and effluent concentrations cannot be provided here because the full report of this study was not available.

3. Boston, Massachusetts (independent study)
In this study, two units of 2-chamber separators were monitored for 14 months. (April 1999 to June 2000). These two 2-chamber (1,500 gal capacity) oil-grit separators were large precast-concrete containers subdivided by one baffle. They were installed, as an off-line facility, next to a highway, approximately 1.5 m from the edge of the pavement. Via a diversion weir near the inlet of the separator, intense runoff bypasses the facility through a bypass pipe. At each site, automatic instruments were used to collect water samples and measured precipitation, air temperature, water level, flow velocity, turbidity, specific conductance and water temperature in

the separator. Flow-proportional samples were collected for the analysis of suspended-sediment concentrations at the inlet and the outlet of each separator during the monitoring period.

During the study period of 14 months, a total of 75 events were monitored at the sites. The range of suspended-sediment removal efficiencies for individual storms ranged from –98% to 95% for one separator and from –94% to +90% for the second separator. The average sediment-removal efficiency was 35 and 28% for first and second separator, respectively. However, the study did not state the sediment-removal efficiency based on all 75 events. The author also commented that the principal factor affecting the efficiency of the separator was retention time. The average retention time in the separators ranged from about 1 hour to less than a minute. The range of influent and effluent suspended solids concentrations collected from the two separators were 8 to 7,110 mg/L and 5 to 2170 mg/L, respectively.

The settling velocities for highway sediment ranged from 0.009 to 19.8 m/h. Fine-grain sediment requires several days under static conditions to settle out. As a result, the average removal efficiency associated with storms less than 5 mm was only 43%.

The depth of sediment retained in each separator was assessed three times during the project. Results show that the depth of sediment varies from time to time. The rate of sediment accumulation before the monitoring period (3 years operation without maintenance) and the rate of sediment accumulation during the monitoring period (with regular maintenance) were also estimated. The accumulation rate during the monitoring period was found to be 2 times faster than the accumulation rate before the monitoring period indicating that the separator has a higher accumulation rate of sediment when properly maintained than without maintenance.

Samples of suspended sediment were collected after the monitoring program was completed. Most sediment in the primary chamber of the separators (a weighted average of 85%) was coarse-grained (greater than 0.25 mm in diameter), whereas a greater amount of sediment in the secondary chamber of the separators was fine-grained (a weighted average of about 50% was less than 0.25 mm in diameter).

During the study period, there were several events when the outflow sediment load from the separators exceeded the inflow load. The authors commented that the high-intensity rainfall and high storm flows might have resuspended the fine-grained bottom sediment that was previously captured. The authors also commented that the quantity of resuspended sediment might differ from storm to storm, due to differences in prior storm characteristics. For example, a high-intensity storm may mobilize the fine-grained sediment retained in the separator over several small low-intensity storms, but subsequent high-intensity storms may cause no resuspension because little fine-grained sediment was available.

Summary

Table 2.11 summarizes the three field monitoring studies reviewed in this section. In the Seat Pleasant study, only 13 storm events were monitored, which may not be sufficient to adequately characterize the performance of the OGS. Further, the OGS monitored in this study was installed as an on-line facility, which is not current Ontario practice for this type of OGS, and there were no regular sediment clean outs. Consequently, it is not surprising that the OGS performed poorly.

The OGS monitored in the other two studies were both designed as off-line facilities. The OGS in Austin, TX even had regularly sediment clean out during the monitoring period, which may help explain why removal efficiencies were higher than reported in the Seat Pleasant study.

In comparing these studies, the following general conclusions emerge: First, the residence time of stormwater was short during most rainstorms. Second, the off-line technologies had higher performance than the on-line facility. Finally, resuspension appears to be a common feature of this type of OGS, especially when the OGS is not regularly maintained.

Table 2.11: Summary of the 3-chamber field monitoring study

Site Location	Monitoring Period	Site Description	Event Number & Magnitude	Unit Model & Storage	TSS Removal (%)
Seat Pleasant, MD*	Unknown	1 acre parking lot of a fast food joint.	13 events ranging from 5.1 to 49.8 mm.	On-line 3-chamber OGS without regular sediment clean-out	-7.5% for Mean group storm efficiency
Austin, TX*	Unknown	Off-line OGS	17 events	Off-line 2 chamber OGS with regular sediment clean-out	41%
Boston, Massachusetts*	June 1999 to August 2000	1.48, 1.1 from Highway area	75 events monitored but performance assessed on a smaller number of events	Off-line 2 chamber OGS without sediment clean-out	35%, 28%

* Independent Study

2.3.5 Stormceptor®

Several laboratory and field studies have been conducted in Canada and the United States evaluating the performance of Stormceptor®.

Laboratory Testing

1. The initial testing for the Stormceptor® product was performed in 1993 and 1994 at the National Water Research Institute in Burlington, Ontario, Canada (Marsalek et al., 1994). This testing was performed on a 1:4 scale model to determine oil and sediment removal efficiencies. The results of the test indicated that the performance of the Stormceptor® product varied almost linearly with treatment flow rate. The full-scale equivalent of the model was able to treat a maximum of 285 gpm (18 l/s) prior to bypassing at which a TSS removal efficiency (fine to medium sands) was achieved.

2. The School of the Built Environment, Coventry University (1996) assessed the performance of a full scale Stormceptor® under steady flow conditions (9 l/s) with the addition of oil and inorganic/organic sediment in May to August 1996. Two flow tests were performed. Oil was added continuously during each test at a rate of 5 ml/l (4100 mg/l). Tests were conducted to assess the trapping efficiency for sand added at a rate of 210 mg/l and with peat added at a rate of 154 mg/l. These concentrations were thought to be typical of highway stormwater runoff in moderate/highly polluted conditions.

Results showed oil removal of 97.8%, inorganic sediment (sand) removal of 83% and organic sediment (peat) removal of 73%.

Field Monitoring Studies

1. Madison, Wisconsin (Independent study)
Field monitoring was performed on a Stormceptor® unit STC 6000 (total holding capacity is 31.285 m^3) in Madison, Wisconsin from August 1996 through April 1997 by the Wisconsin Department of Natural Resources and the United States Geological Survey (Greb et al, 1998). The 1.7 ha site was a public works yard with a high imperviousness. The works yard was used for yard waste drop-off, fueling, storage and cleaning of city vehicles and storage of sand and salt for road de-icing. Hence, the site was exposed to high pollutant loadings.

A total of 45 storm events ranging from 0.02 to 1.31 inches were monitored. Although 24% of storms (11 out of 45 storms) had some flow by-pass the unit, the total water volume that by-passed equaled only 9%. The other 91% of the runoff was treated by Stormceptor®.

Flow proportional sampling was conducted upstream of the unit, at the by-pass weir, and at the outlet pipe above the lower chamber of the Stormceptor®. The influent TSS EMC for the 45 storms ranged from 43 to 1236 mg/l with a median value of 251 mg/l. And the cumulative influent load for the 45 measured storms was 1670 kg. The effluent TSS concentrations had a median of 151 mg/l and ranged from 45 to 615 mg/l. The total load exiting the treatment tank was 1044 kg, resulting in a removal efficiency for the treatment tank of 26% and an overall removal efficiency (treatment tank + bypass) of 22%. The sampling equipment was not effective in capturing the coarse influent bedload fraction. During the whole monitoring period, the Stormceptor® captured approximately 140 liters of free oil and 536 kg of solids.

Removal efficiencies for other parameters monitored include 18% for Total Phosphorus (TP), 32% for Polycyclic Aromatic Hydrocarbons (PAH), and 18% for dissolved Phosphorus.

The particle size distribution of the influent to the tank was measured with a Coulter counter. The distribution indicated that the majority of influent particles were very fine (92%<50µm). However, the particle size in the tank itself was mainly coarse (95% >63µm), suggesting that the influent sampler, which was located above the bottom of the pipe, missed the coarse bedload fraction. If this fraction were included in the performance calculation, the removal efficiency would increase from 22% to an estimated 29 to 33%.

At the end of the monitoring period, the amount of material retained in the treatment chamber was measured and analyzed. The material had high concentrations of lead and PAH. The report also stated the findings from the study may be atypical due to unique site conditions. Exposed sand and salt piles as well as snowmelt adding to the runoff may have caused this site to have unusually high influent salt concentrations and loads.

2. Edmonton, Alberta (independent study)

The STC 2000 was installed at the parking lot of the Westmount Shopping Center in the city of Edmonton, Alberta (Labatiuk et al., 1997). The area was about 4 ha. Flow samples were taken upstream and downstream of the unit using automatic samplers. Four events occurred on June 18, June 28, July2 and July 15, 1996 and were monitored by the Phoenix Group. The average removal efficiencies were 52.7% for total suspended solids (TSS), 51.2% for lead, 43.2% for oil and grease, 21.5% for copper, 39.1% for zinc, 52.7% for iron, and 40.7% for chromium. A measurement of the accumulated sediment in the unit indicated that 47.5% was sand, 27.5% was silt and 25% was clay. The sediment contained high levels of oil and grease and total organic carbon. Stormceptor® indicated in its study manual that the unit was not sized to achieve 80% TSS removal. TSS influent and effluent concentrations were not reported in the study.

3. Westwood, Massachusetts (study independence unknown)

A field study was done in Westwood, Massachusetts from July 1997 to November 1997. Six storm events were monitored during this period. Only three events produced significant TSS levels and only one event produced significant Total Petroleum Hydrocarbons (TPH) levels where a significant level is defined as a level that typically requires treatment by regulatory permitting criteria. All three rain events were relatively small (<7 mm). The Stormceptor® model STC 1200 was installed at a 0.26 hectare loading area of a local manufacturing facility. The OGS had a permanent pool storage-to-impervious area ratio of approximately 18 m^3/ha, which is larger than the 15 m3/ha recommended in the 1994 Ontario stormwater guidance manual (OMOE, 1994). Environmental Sampling Technology (EST) installed two automatic samplers to collect samples at the inlet and outlet of the Stormceptor®. The average TSS removal efficiency was 93% and the average TPH removal efficiency was 82%. Influent and effluent concentration ranges for the three events were 47 to 400 mg/L and less than 5 to 6.8 mg/L, respectively.

Table 2.12: Summary of the events with significant TSS levels during the study

Event Date	**Precip. Intensity (mm/h)**	**Precip. Depth (mm)**	**Maximum Flow (l/s)**	**Composite Sample Period**	**TSS Inflow Concentration (mg/l)**	**TSS Outflow Concentration (mg/l)**	**Removal Efficiency (%)**
Aug5 1997	1.5	4.6	0.11	3 hours	400	5.3	98
Aug21 1997	2.0	6.4	0.15	3 hours	86	6.8	92
Sep29 1997	0.8	5.6	0.2	3 hours	47	<5.0	90

4. Como Park, Minnesota (independence unknown)

A Stormceptor® unit in Como Park, Minnesota was monitored from August 1998 to September 1999 by Service Environmental and Engineering (Service E&E) of St. Paul, Minnesota. Eight storm events were monitored during this period ranging from 3 to 51 mm with the mean rainfall depth of 15 mm. Storm event durations ranged from 1.3 hours to 10.3 hours with an average duration of 4.2 hours. The study was performed on model STC 1800 serving a 0.4 hectare parking lot in the middle of Como Park, St. Paul and, like the Westwood study, was oversized by Ontario standards (storage-to-impervious drainage area ratio of approximately 21 m^3/ha). Service E & E installed two automatic samplers, one upstream and one downstream from the unit. The samplers collected samples on a time proportional basis. Event mean concentrations for the influent TSS ranged from 13 mg/l to 318 mg/l with the average of 78 mg/l over the 8 events. Effluent values ranged from 3 mg/l to 59 mg/l with the average of 19 mg/l. The overall TSS load reduction for the monitoring period was 76%. Two sludge samples were taken at the end of the monitoring period. Both samples indicated that the material retained consisted of mostly fine particles.

5. Seatac, Washington (independent study)

A Stormceptor® study was carried out in Seatac, Washington from March 1999 to October 1999. Four storm events were monitored during this period ranging from 4 to 20 mm. This study monitored a Stormceptor® model STC 900 located at a Texaco gas station and convenience store site of approximately 0.4 hectare of impervious surface. Associated Earth Sciences Inc. (ASI) of Kirkland, Washington collected the water quality samples for the study. Flow proportional monitoring was conducted using two automatic samplers, one upstream and one downstream from the unit. Each of the constituents was measured as a first flush in and a first flush out as well as composite in and composite out for the first two events. Only the composite in and composite out were measured for the last two events. Removal rates are based on mass reduction over the four events. The removal efficiencies were 87% for TSS, 99% for TPH, 43% for Total Nitrogen (TN), 11% for TP and 28% for copper.

6. Charlottesville, Virginia (independent study)

The Virginia Transportation Research Council (sponsored jointly by the Virginia Department of Transportation and the University of Virginia) conducted a study to monitor the performance of four BMP's, one of which was a Stormceptor® unit (Yu and Stopinski, 2001). The Stormceptor® model STC 3600 was located in a parking lot at the UVA Scott Stadium in Charlottesville, VA. The drainage area was approximately 10,117 m^2 and construction was ongoing during the time of sampling. Six storm events were sampled from November 1999 to April 2000. Two automatic samplers were used, one at the inlet and one at the outlet. The samplers collected continuous flow, rainfall data, and runoff samples at specified time intervals. First flush samples were taken in addition to composites for each storm. Overall removal efficiencies for the constituents tested were 57% for TSS, 28% for COD, 66% for TP, -27% for TN, 22% for copper, 73% for zinc, and 33% for oil and grease. Sediment depths were measured during the monitoring period and the unit was cleaned out halfway through the study. The study stated that the Stormceptor® performed below the design removal efficiency of 80% for TSS because the unit was not sized for construction activity.

7. Orlando, Florida (independence unknown)

A sludge analysis was done on the sediment removed from a Stormceptor® unit in Orlando, Florida in June 2000. The Stormceptor® model STC 900 served a 0.48 hectare parking lot located in downtown Orlando at the Bob Car Auditorium. A particle size analysis was performed using sieve and hydrometer test methods in general accordance with ASTM Standard D 422 "Particle-Size Analysis of Soils". The majority of the sediment was fines with 70% of the solids less than 100 microns in size. Metals found in the sludge were aluminum, barium, copper, iron, lead, magnesium, manganese, nickel, potassium, vanadium, and zinc. Contaminant levels were low enough to be landfilled under EPA guidelines.

Summary

The monitoring studies of Stormceptor® reviewed here are not directly comparable because of differences in study design, drainage area, land use, rainfall event characteristics, particle size, the number of events monitored and other factors specific to each study.

In the Madison, Wisconsin study, a large number of events were monitored but influent chloride loads were high because of exposed salt piles within the drainage area. These high chloride levels may reduce the effective storage volume and shorten retention times, both of which negatively impact performance. By comparison, in the Westwood Massachusetts study, which reported impressive removal, monitored only three relatively small events with maximum flow rates between 0.1 and 0.2 L/s, and the OGS was oversized by Ontario standards. Clearly these flow rates are not representative of the full range of events that may occur during any given year.

Although the studies are generally not comparable, results are summarized in Table 2.13 to demonstrate the variability of reported TSS removal efficiencies for this technology.

Table 2.13: Summary of Stormceptor® field monitoring studies

Site Location	Monitoring Period	Site Description	Event Number & Magnitude	Unit Model	TSS Removal (%)
Madison, Wisconsin*	08/1996-04/1997	0.7 ha public works yard with storage of sand and salt for deicing	45 events ranging from 0.51-33.3mm	STC 6000	26% (29-33% including bedload)
Edmonton Alberta*	July 1996	4 ha commercial parking lot	4 events	STC2000	53%
Westwood Massachu-setts	07/1997-11/1997	0.3 ha loading trucking area	6 events monitored, 3 events (4.6 mm,6.4 mm 5.6 mm) with high influent TSS concentration	STC 1200	93%
Como Park Minnesota	08/1998-09/1999	0.4 ha parking lot	8 events ranging from 3.3 mm to 51.3 mm	STC1800	76%
Seatac Washington*	03/1999-10/1999	0.4 ha gas station	4 events ranging from 4.3 mm-20.3 mm	STC900	87%
Charlottesville Virginia*	11/1999-04/2000	1.0 ha parking lot	6 events	STC3600	57%

*Independent Study

2.3.6 BaySaver®

Field Monitoring Study

1. Rockville, Maryland (third party test administrator)
The University of Maryland as the third party test administrator conducted a field study of a 3k BaySaver® Separation System located at a Montgomery county school bus depot in Rockville, Maryland. The unit is being utilized as a hydrodynamic pretreatment device for a detention pond. Samples were taken during storm events over a period from June 30,1998 until June 14,1999. The bus depot has a drainage area of 3.7 acres (composed of approximately 3.5 acres of impervious cover and 0.2 acres of grass). Samples were taken from upstream and downstream of the primary manhole for BaySaver®. Standard Method 209C was followed to measure the Total Suspended Solids of each of the samples. The flow rate was computed using depth and velocity data obtained by an area-velocity meter mounted just inside the inlet to the primary manhole. The rainfall intensity was measured using a tipping bucket rain gauge. In the information package, only the results for three storm events, as indicated in Table 2.14, were shown.

***Table 2.14*:** Summary of the storm events in the Maryland's BaySaver® study

Storm Date	Average In (mg/L)	Average Out (mg/L)	Peak Flow Rate (l /s)	Average Removal %
4-1-99	503	41	13	91
5-22-99	2019	59	179	97
6-14-99	524	122	689	76

(BaySaver® information package)

2. Sparks, Nevada (conducted by the manufacturer)
In April 2002, samples of sediment from each of the manholes in a 3K BaySaver® located in Sparks, Nevada were collected and tested. The information package stated that the results showed the BaySaver® was able to remove fine sediment as small as one micron and 64% of the sediment collected in the storage manhole was smaller than 38 microns (Figure 2.10). It is important to recognize that sampling of sediment accumulated in a device may not be an accurate way to characterize the device's performance.

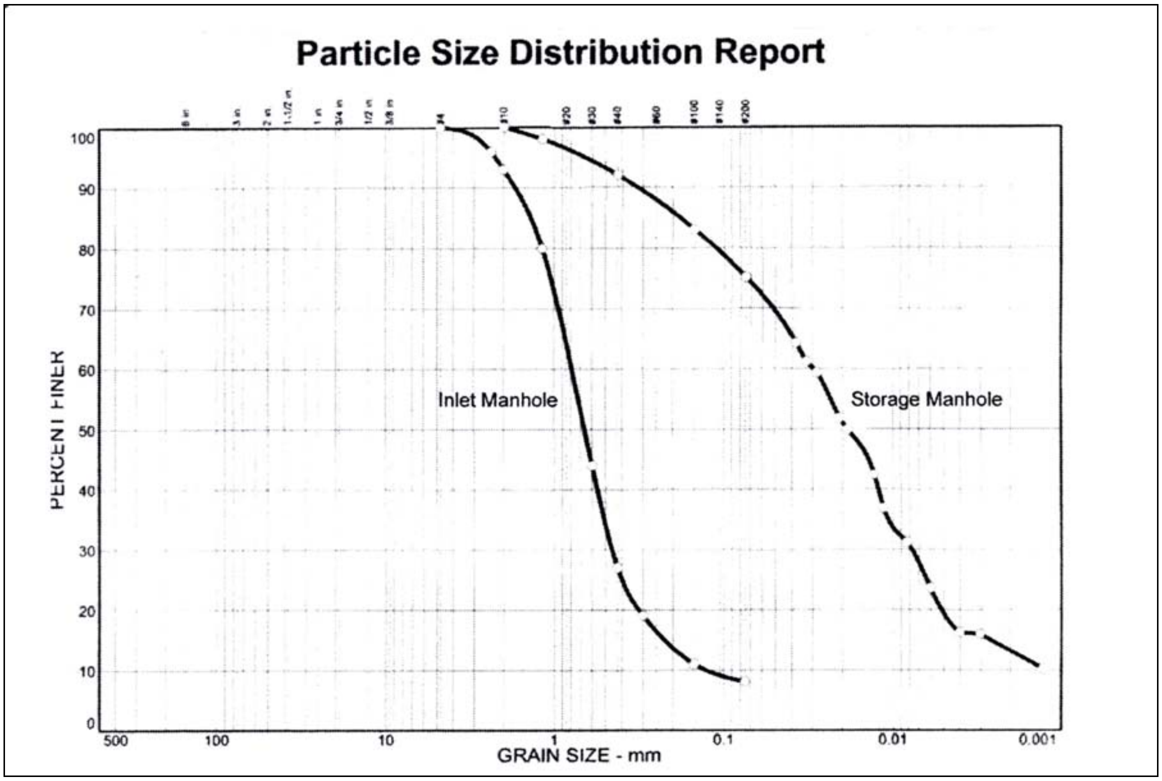


Figure 2.10: Particle size distribution of sediment for the Nevada's BaySaver® study (BaySaver® information package)

3. Olympia, Washington (independent study)

Washington State Department of Transportation incorporated the BaySaver® into their Ultra-Urban Stormwater Technology Test Facility. The BaySaver® was installed and monitored at five locations along SR 101 within the City of Port Angeles, in Clallam Country. The purpose of the monitoring program was to characterize the life cycle maintenance requirements of BaySaver®. The monitoring program started in May 2002. Monitoring activities were performed to determine (1) the depth of sediment accumulation over time at each of the five units; (2) the concentration, volume, and characteristics of floatable pollutants retained in the aqueous phase within the units; (3) the characteristics of the accumulated sediments and water to be removed from the units; and (4) the applicable solid or hazardous waste management requirements for the disposal of sediment. Since the monitoring is still underway, the results of the monitoring are still pending.

Summary

Two field performance studies were found in the BaySaver®'s information package and only one study showed the TSS removal efficiency of BaySaver®. However, the TSS removal efficiency of 88% in the study was based on samples during only three storm events which is insufficient to characterize the overall performance of the technology

.

2.4.4 Vortechs™

Laboratory Testing:

Vortechnics performed extensive laboratory testing of their product in Maine. A full scale Vortechs™ model 2000 was tested with a range of particle sizes, flow rates and sediment loads. The results demonstrate that efficiency decreases as surface overflow rate increases or particle size decreases. The 80% minimum removal efficiency was achieved for particles larger than 75 microns and with surface overflow rates less than 30 gpm/ft^2. Particles smaller than 75 microns were removed at lower efficiencies.

Field Monitoring Testing

1.Yarmouth, Maine Field Study (conducted by the manufacturer)
The study site was located in the Delorme Mapping headquarter, Yarmouth, Maine. A Vortechs™ Model 11000 was installed to treat runoff from a 4-acre parking lot. The runoff coefficient was reported to be about 0.40. A total of twenty events were monitored from May 1999 to Dec. 1999. Mean influent concentration was 328 mg/l and mean effluent concentration was 60 mg/l. The TSS removal efficiency ratio for the entire study was reported to be 82%.

2. Lake George Field Study Evaluation (independent study)
Undertaken by the New York Department of Environmental Conservation, the objective of the Lake George Field Study was to test the effectiveness of the device in treating stormwater entering Lake George. A Vortechs™ model 11000 was installed in 1997 to treat the runoff from a 3.8 hectare area with 95% imperviousness. The monitoring program began in Feb. 2000 and ended in Dec. 2000. A total of 13 events ranging from 1 to 55 mm were monitored. The data analysis focused on calculation of the TSS event mean concentration. The average inflow EMC was 801 mg/l and the average outflow EMC was 105 mg/l. No information on the sampling protocol was provided in the report. The average TSS removal efficiency was 88%.

3. Harding Township Rest Area, New Jersey (independent study)
This study was performed under a U.S. Environmental Protection Agency grant, administered by the New Jersey Department of Environmental Protection. The Vortechs™ Model 4000 was sized to handle a 100-year storm from the 3-acre paved parking area at the Harding Rest Stop. The OGS was followed by a horizontal sand filter to provide additional treatment. Five storm events were monitored from May 1999 to Nov 2000. The average TSS removal efficiency was 93%, with a mean influent concentration of 493 mg/l and a mean effluent concentration of 35 mg/L (OGS only). The sand filter removed an additional 5% of TSS. The Vortechnics unit and sand filter removed 96% of total petroleum hydrocarbons, of which 67% was removed by the OGS unit alone. There were no data reported on the size of the storm events monitored.

4. South Windsor, Connecticut (independent study)

The 0.8 hectare school parking lot for the Timothy Edwards Middle School in South Windsor, Connecticut was selected as a monitoring site in this study. The monitoring of the Vortechs™ model 5000 at the site began in January of 1999 and ended in April of 2001. The catchment was estimated to be 80% impervious. The monitoring was done on a continuous basis for the duration of the project. Flow-weighted composite samples at the inlet and outlet were taken each week for TSS and nutrient parameters (Figure 2.11). Based on the mass balance, the average TSS removal efficiency at this site was 77%.

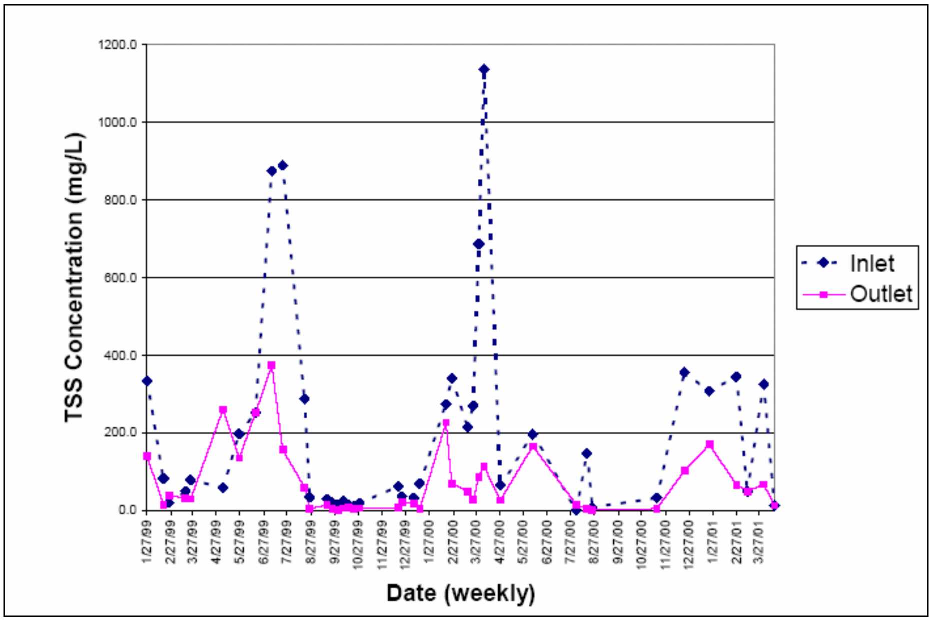


Figure 2.11: TSS concentrations for the Connecticut's Vortechs™ study

It is interesting to note that this site was monitored continuously over two years as it offered some perspective on the annual pollution trend. The high peaks of TSS in the winter and spring influent were due to sand application and de-icing on the road. These additional inputs of sand increase the total influent mass and help to increase the overall removal efficiency above that which would occur if only summer events were monitored.

5. King County, Washington Field Study (independent study)

Washington State Department of Transportation performed a water quality assessment of the Vortechs™ system installed along State Route 405 in King County. The removal efficiency and maintenance needs of a Vortechs™ system installed for a highway catchment were assessed. The Vortechs™ system was located in a subcatchment area of 28 acres with 66% impervious area. Rainfall and stormwater flow were monitored from March 2001 to February 2002. The flow was measured upstream and downstream of the Vortechs™ unit and water samples were collected as flow-weighted composites. Rainfall was measured on-site with a tipping bucket rain gauge. The composite samples were analyzed for TSS, turbidity, pH, hardness, total Zinc, dissolved zinc, total phosphorus, orthophosphorus and particle size distribution. Results show average TSS removal efficiency of 20% for the Vortechs™ system.

Summary

As with other studies, caution must be exercised in interpreting the results because of differences in study design and other site specific influences. Several studies indicated impressive performance with TSS removal rates generally above 75% and mean effluent concentrations ranging from 35 mg/L in the Harding Township study to 105 mg/L in the Lake George Field Study. High influent concentrations likely contributed to the higher effluent concentrations observed in the latter study. The King County showed dramatically different results than the other studies, possibly due to low influent concentrations (and fine particle sizes) associated with low intensity rain events. Monitoring results of the Vortechs™ studies reviewed are presented in Table 2.15

Table 2.15: Summary of field monitoring studies of Vortechs™

Site Location	**Monitoring Period**	**Site Description**	**Events**	**Flow measured (Pack 2003)**	**Sampling (Pack 2003)**	**Vortechs™ Model**	**TSS Removal Efficiency**
Yarmouth Maine	05/1999-12/1999	1.6 ha parking lot, runoff coefficient 0.4	20 events with influent EMC 328mg/l	Yes, but flow meter under reported flow	Discrete sample (Time-weighted)	11000	82%
Lake George*	02/2000-12/2000	3.8 ha subcatchment with 95% impervious	13 events with inflow EMC 801 mg/l	Yes	Discrete Sample	11000	88%
Harding Township, New Jersey*	05/1999-11/2000	1.2 ha paved parking area	5 events with inflow EMC 493mg/l	No	Time-weighted sample	4000	93%
South Windsor, Connecticut*	01/1999-04/2001	0.8 ha parking lot with 80% impervious	Samples were taken every week	Yes	Composite sample (flow-weighted)	5000	77%
King Country, Washington Field Study*	03/2001-02/2002	Highway subcatchment area of 11.3 ha with 66% of impervious area	11 events	Yes	Composite sample (flow weighted)	11000	20%

*Independent Study

2.4.5 Downstream Defender^{TM}

Laboratory Testing

1. Conventry University (sponsored by the manufacturer)
In 2002, the School of The Built Environment, Conventry University assessed the performance of a 1.2 diameter Downstream Defender^{TM} under a number of steady flow conditions with the addition of oil, sand and peat. For the oil input testing, six constant flow rates were used (3.0, 5.0, 10.0, 15.0, 20.0 and 25.0 L/s). For the sand and peat input testing, five constant flow rates were used (5.0 through to 25.0 L/s). Inputs were added separately and continuously throughout the 20-minute tests. Sampling of effluent concentrations was undertaken at 1-minute intervals in the last 5 minutes of each test.

Results showed that the removal efficiencies of the Downstream Defender^{TM} decreased with increasing flow rates for all three types of pollutants. At a flow rate of 5 L/s, the removal efficiencies for oil, sand and peat were 94, 99 and 91% respectively. At a flow rate of 25 L/s, the removal efficiencies were 82, 68 and 18% respectively.

2. H.I.L. Technology Inc. performed two laboratory tests of Downstream Defender^{TM} in May 1997 and September 2001(sponsored by the manufacturer).

May 1997
A freestanding 1800mm diameter Downstream Defender^{TM} was tested at flows of 20 to 85 L/s. The material used for the test was from the local government sand pile. Thirty to fifty piles of sand were used for each test, weighted to achieve an influent solids content of 300mg/l. The measured quantity of influent sand was fed into the influent flow stream of the Downstream Defender^{TM} via a "T" pipe located approximately 20 feet from the unit. Following solids feeding, the flow rate was maintained for two minutes. The feed pipe valves were closed and the pump turned off. The underflow valve was opened and the contents of the collection facility and the unit discharged into the decanter unit. The solids removal efficiency was determined by comparing the influent and underflow gradings. The results showed that the 1800mm diameter of Downstream Defender^{TM} was able to achieve a solids removal efficiency of 98% under 20 l/s and 84% under 85 l/s respectively.

September 2001
H.I.L. Technology Inc. (Hydro International) conducted a test of a 4-ft diameter Downstream Defender^{TM} at their testing facility using the Marine Department of Environmental Protection Protocol. The Marine Department of Environmental Protection laboratory testing protocol included flow calibration, system equilibrium and sampling. For the flow calibration, a number of iterations of the test sequence were performed to identify the loading rate that provides the required removal. Flow was measured using the ISCO UniMag Magnetic Flowmeter System

which has an accuracy of plus/minus 0.5% of flow rate for mean velocities of 1 ft/s and greater. The appropriate flow rate to achieve the desired minimum removals of 80% was found to be 630 gpm (with an inlet velocity of 4.0 ft/s).

The theoretical residence time is equal to the amount of time it takes one unit volume to pass through the system at a given flow rate assuming plug flow condition (no underflow). The residence time for the experiments was calculated by dividing the effective treatment volume by the flow rate through the system. For a flow rate of 630 gpm, the residence time was 20.9 sec. To ensure that equilibrium conditions had been established, sampling commenced when four residence times passed. The time difference between the end of influent sampling and the beginning of the effluent sampling was 20.9 sec. The unit had undergone nine tests at 630 gpm flow rate. The observed removal efficiency range was 80.3% to 88.8% with an average influent concentration of 245 mg/l.

<u>Field Monitoring Study</u>

1. Onondaga County, New York (independent study)
A Downstream Defender™ Unit was monitored from March 2001 until May 2002 for Onondaga Lake Environmental Benefit Project Final Report. A 4-ft diameter Downstream Defender™ with a design flow rate of 0.75 cfs and a maximum capacity of 3.0 cfs was installed at the East Seneca Turnpike site, which has a catchment area of approximately 1.2 acres.

Water quality sampling was conducted on six storm events beginning in July of 2001 and ending in April of 2002. However, due to non-representative sampling procedures and laboratory methods only samples collected during the sixth event are considered appropriate for influent versus effluent comparisons. Three influent/effluent samples pairs were taken at flow rates ranging from 0.4 to 0.75 cfs during the sixth event. Samples were taken as 1) the first flows were observed; 2) the flow rate peaked near the design flow; 3) the falling limb of the hydrograph. The TSS percent removals for each pair of samples are 93%, 26% and 43%, respectively. The first sample appeared to be representative of a first flush. High removals are often associated with the first flush because this flush conveys water laden with heavy solids and associated pollutants.

The particle size distribution of the accumulated sediment was tested twice. Results show 9% of the sample was characterized as coarse sand, 53% of the sample was characterized as medium sand and 38% characterized was as fine sand, silt and clay.

The sediment sample from September 3, 2002 was also analyzed for metals and phosphorus. Result shows the copper, lead and total phosphorus removed by Downstream Defender™ were 31 mg/kg, 170 mg/kg and 210 mg/kg, respectively. It is expected that the mass of total phosphorus captured would be significantly higher if the samples were collected during the autumn when leaves on the ground are readily washed into the OGS units..

2. City of Belleville, Ontario (Analysis done by the manufacturer)
This study only involved sediment analysis for a Downstream Defender^{TM} that acted as a pre-treatment for a perforated pipe infiltration system. A 2-meter Downstream Defender^{TM} was part of the stormwater management plan for a redevelopment plan of 40 non-profit housing units on a site on Station Road in Belleville, which is adjacent to the Moira River. The total drainage area to the stormwater treatment system is 2 ha, of which the new development area is 0.5 ha and the remainder are the existing roads and impervious surface. The 2 meter Downstream Defender^{TM} was designed to remove 95% of grit particles greater than 150 microns for flow rates equal to 200L/s; 95% of grit particles greater than 250 microns for flow rate equal to 250L/s; and 95% of grit particles greater than 300 microns for flow rate equal to 300L/s.

A 4-liter sediment sample was collected after two years of operation. The sample was taken during an annual inspection and shipped to H.I.L. Technology Inc for analysis. The sample was divided into two equal parts; one sample was sent to a laboratory to determine the particle size distribution and the second was sent to an environmental laboratory for chemical analysis. The results from the standard sieve analysis showed that 95% of the sediment in the sample was finer than 75 microns, which corresponds to silt and clay particles. For the chemical analysis, it was found that the copper, lead and total phosphorus removed by Downstream Defender^{TM} were 101 mg/kg, 242 mg/kg and 1500 mg/kg, respectively.

<u>Summary</u>

Results from the two field monitoring studies indicate that the Downstream Defender^{TM} technology is able to settle a certain amount of fine sand, silt and clay from stormwater and that the chemical pollutants and heavy metals in the stormwater tend to be associated with the finer particles.

The two laboratory studies showed that Downstream Defender^{TM} could achieve approximate 80% of TSS removal under a flow rate of 85 l/s. However, this flow rate was maintained for only 2 to 3.5 minutes (ten times the 20.9 sec of residence time) during the testing, which does not adequately mimic storm flow conditions or the potential for re-suspension, which is common in many oil/grit separators.

Six events were monitored in the independent field monitoring study, but only one event was considered appropriate for comparing influent and effluent loads/concentrations. Overall, there is a need for more monitoring to effectively quantify the water quality benefits of this technology.

2.4.6 Continuous Deflective Separation Unit

Laboratory Testing (independence of the study is not known)

1. .Monash University, Caulfield
Dr. Tony Wong, Monash University, Caulfield, Victoria, Australia was the first to evaluate and verify CDS® efficiency at removing gross pollutants and coarse sediment. The following is a summary of the extensive work by Monash University.

Laboratory experiments were conducted using a CDS® unit with screen openings of 4700 µm. The removal efficiency of different sand particles is shown in Table 2.16. There was no reduction in removal efficiencies or blocking of the screen face as the flow rate was increased up to the design treatment flow of a given CDS® unit.

Table 2.16: Removal efficiency of different sand particles in CDS

Particle Size (µm)	Screening Removal Efficiency (%)
>4700	100
2350-4700	100
1551-2350	93
940-1551	50

2. Portland State University, Portland (unknown)
Professor Scott Wells of Portland State University and Professor Michael Stenstrom of UCLA also carried out experiments to evaluate the fine sediment removal efficiency of CDS. The following table lists the removal efficiencies as determined by Professors Wells and Stenstrom for a CDS® unit equipped with a 1200 µm screen using sand particles.

Table 2.17: Removal efficiency of different sand particles in CDS

Particle Size (µm)	Screening Removal Efficiency (%)
>1200	100
425-600	93
300-425	85
150-300	30
75-150	22

3. UCLA (independence of the study is not known)
Professor Michael Stenstrom and Sim-lin Lau of UCLA completed a study for CDS® Technologies which evaluated the effectiveness of four different sorbent materials in removing used motor oil at concentrations typically found in stormwater runoff. They applied the sorbents in a CDS® unit separation chamber and reported captures of 80-90% of the oil. The tests found polypropylene or co-polymer sorbents to be the most effective in capturing used motor oil.

Field Monitoring Study

1. Brevard County (independence of the study is not known)
In July 1997, Brevard County's Stormwater Utility Program installed a CDS® unit. This was the first American installation of the unit. The CDS® unit was installed on July 17, 1997 at a cost of approximately $55,000. It took two days to install the precast structures. A large crane was required to lift the chambers into place. A 4.57 meter deep hole was excavated and the structure was placed inside.

This location served a drainage basin of 24.9 hectares of mixed industrial, commercial, and vacant land. Over an 18 month period 5 storm events were monitored. The 10 year flow was 1,557 L/sec and the mean annual flow was 1,177 L/s. In Brevard County, the 10 year storm is 201 mm of rainfall and the mean annual storm is 139 mm of rainfall. There is no base flow at this location. A diversion weir was placed in front of the culvert giving an off-line design which effectively diverted flows under 254 L/sec (9 cfs) through the CDS® unit.

It was estimated that the CDS® unit provided an average removal efficiency of 52% for total suspended solids and 31% for phosphorus respectively.

Summary

Performance data for the CDS unit were available for only one field monitoring study. Hence, a study comparison could not be conducted. During this study, there were only 5 events monitored, which is not sufficient to represent the overall performance of the CDS unit. Also, the study does not state whether or not the by-passed flow is included in the calculation of the average concentration.

2.4.7 Conclusion

Six different types of OGS were reviewed in this chapter. Most laboratory and field monitoring performance assessments cited in this literature review were conducted by the manufacturer or by manufacturer sponsored organizations, although there were also several independent third party studies. New studies continue to be conducted on various OGS technologies. The reader should consult with individual manufacturers for new studies and for complete reports of past studies either cited in this review or for other studies that were not available at the time of writing.

Perhaps the most striking finding of this literature review is the dramatic variation among study results conducted for each of the OGS technologies reviewed. Various factors contribute to discrepancies among studies, including differences in site characteristics, climatic regime and study design. These factors are briefly discussed below.

<u>Study site characteristics</u>

Land use

Clearly land use is a very important factor that can influence chemical loading rates, particle size distribution, and sediment generation. Studies reviewed were conducted for a wide range of land uses, included parking lots, highways, a public works yard, a school bus depot and sites in which there was construction activity. Pollutant loading rates and other land use specific factors need to be carefully considered in evaluating results.

Particle size distribution

Oil grit separators rely on gravity settling (sedimentation) to remove sediment particles. Thus, removal efficiencies and effluent concentrations will be influenced by the particle size distribution characteristic of a given site. In general, sediment removal efficiencies rise as the particle size distribution becomes more coarse, and vice versa. The relatively small median particle size (37 microns) in the Washington study of the Vortechs OGS, which reported average suspended solids removal of only 20%, provides an example of how removal efficiency may be affected by particle size (section 2.4.4). Conversely in a laboratory study using sand only (*i.e*. a coarse particle size distribution), Downstream Defender reported a removal efficiency of 84 to 98%, depending on the flow rate. Caution should be exercised in comparing particle size results among studies because different analytical methods can yield very different results.

Influent concentrations

Removal efficiency has been shown to be a biased indicator of performance because it varies with influent suspended solids concentrations, even in the absence of intra-event variations in particle size distributions (GeoSyntec Consultants et al.,2002). Below a certain threshold, which varies with technology, low influent concentrations are associated with low removal efficiencies and vice versa. Unfortunately, removal efficiency is often the only parameter reported in performance assessments, making it difficult, if not impossible, to interpret the data. Recognizing this problem, the United States National Stormwater BMP Database recommends that stormwater BMP removal efficiencies be evaluated only in conjunction with a statistical analysis of influent and effluent water quality (GeoSyntec Consultants et al., 2002). …

Upstream storage

Additional storage upstream of OGS installations is occasionally provided on rooftops, parking lots or underground in catchbasins and contributing drainage networks. Upstream storage reduces flow rates and increases system residence times, thereby enhancing performance. Conversely, if larger particles settle out upstream and are never flushed into the OGS unit (as may be the case if runoff is infiltrated or upstream sediment is manually removed), the average particle size distribution may be finer and the influent concentration lower than would be the case without upstream storage. This may result in lower removal efficiencies. It was not always clear in the studies reviewed whether upstream storage was provided and if so, to what extent it may have influenced results.

Salt loading

Salt in road runoff has been shown to cause densimetric stratification in OGS systems (see section 6.2.4), which may reduce residence times by inhibiting vertical mixing and decreasing the effective volume of water quality storage. Results of the Wisconsin field study of a Stormceptor® system, which showed unusually low removal rates, may have been influenced by stratification because the study was conducted in a public works yard in which there were exposed piles of road salt and sand (section 2.4.2). Other studies conducted downstream of transportation corridors or in large parking lots may also be subject to unusually high road salt loading.

Offline/online systems

OGS systems without bypass are affected by the configuration of drainage. Offline systems generally show better performance than online systems because high flows by-pass the system, reducing the incidence of sediment re-suspension in the OGS. Low performance in the Seat Pleasant study relative to other studies of 3-chamber OGS systems may be in part explained by the absence of bypass (section 2.4.1).

Climatic factors

Rainfall regime

The size and intensity of rainfall events affects inflow rates and the wash off potential of sediment and other contaminants. These factors can, in turn, affect performance by, for instance, increasing the number of bypasses, contributing to sediment re-suspension or increasing influent concentrations. Consequently, a study conducted in a region where large, intense storms are relatively common may yield significantly different performance results than a study conducted in a region where storms are smaller and of longer duration.

Seasonal factors
Variations in climate throughout the year can produce easily treated heavy sediment loads in winter and spring; hard-to-treat loadings, such as pollen and grass clippings, in summer; and moderately treatable loading (leaves etc.) in the fall (Adams, 2000). Inflow rates and dry weather inter-event duration may also vary considerably during the year, depending on the seasonal pattern of snow and rainfall in different geographic regions. To adequately characterize OGS performance over the full range of seasonal climatic conditions, monitoring studies should be conducted over a period of no less than two years (Adams, 2000).

Study design

There are many factors associated with the design of the study that can dramatically influence study results. These include the selection of sites for monitoring, quality control/assurance procedures, equipment set-up (e.g. sampling intervals, triggering mechanisms), duration of study and number of events monitored, laboratory analytical procedures, statistical analysis protocols and reporting methods. In many of the studies reviewed, methods were not reported in sufficient detail to interpret results. It is beyond the scope of this literature review to recommend guidelines for designing and conducting monitoring studies. The ASCE/EPA BMP performance monitoring manual (GeoSyntec Consultants et al, 2002) provides a useful summary of this topic. Selected examples from the literature review of how analysis protocols may affect results are provided below.

Removal efficiency calculations
As mentioned earlier, removal efficiencies have been shown to be a poor indicator of performance in the absence of information on influent/effluent concentrations and other factors that may influence removal rates. This problem is compounded when different methods are used to calculate removal efficiencies. In some studies reviewed, percent removal rates were averaged over all events monitored such that each event, whether large or small, is given the same weight in the overall calculation. In other studies, removal efficiencies were calculated as the total sum of loads (or total mass), whereby larger events are weighted more heavily than small events (*i.e.* according to their relative contribution of pollutant loads to receiving waters). Results of the two methods may differ considerably, especially if only a few events are monitored.

By pass flow
Flow that bypasses the OGS system is typically dirtier because it does not receive treatment. However, some studies reported results only for events that did not cause bypass, while others included these larger events in their assessments. To accurately assess and compare performance

among studies, it is essential that the number of bypasses and the volume of flow that bypassed be reported.

Flow proportioned sampling

Performance calculations in most studies are based on influent and effluent Event Mean Concentrations (EMC), ideally represented by flow weighted or flow proportioned composite samples collected at the inlet and outlet over the duration of the event. These are typically obtained using automatic samplers, a flow meter and a flow totalizer that arithmetically converts the flow rate measured by the flow meter to flow volume over time, and keeps track of the volume. The sampler receives a signal that causes it to take a sub-sample when a programmed volume of flow is measured.

Error enters in setting the volume to be used in a monitoring study. One study may set the programmed volume as 200 m3/s, while another may set the programmed volume as 500 m3/s. If a small storm event occurs, the study with the large programmed volume will take the sample after the high concentration, 'first flush' occurs, resulting in a lower EMC. Conversely, if the event is large, the sampler with the smaller programmed volume may collect all bottles in the carousel (typically 24) before event flow subsides, thereby missing the usually cleaner water at the end of the event. Unfortunately, studies rarely report the sampling interval and duration of storm runoff, or provide an analysis of potential errors inherent in the study design.

In sum, technology comparisons require careful consideration of the various factors that influence study results. However, these considerations can only be incorporated into decisions if the information are provided. This information may include, but is not limited to the following:

- unit and drainage area size (is it sized according to manufacturer specifications);
- land use;
- number/volume of bypasses;
- influent/effluent concentrations (summary statistics may need to be log transformed);
- performance (see ASCE guidelines on reporting performance);
- meteorological data (number, size, intensity of rainfall events monitored);
- inter-event periods;
- upstream storage type and capacity;
- field monitoring protocols (including QA/QC, sampling intervals, sampling durations, etc.);
- data analysis protocols;
- lab sample analysis procedures (especially particle size analysis); and
- field monitoring assumptions

2.5 Maintenance Issues

2.51. Recommendations from government agencies

1. U.S. EPA

The U.S. EPA Stormwater Technology Fact Sheet on Hydrodynamic Separators emphasizes the importance of maintaining oil/grit separators as a means of ensuring that the separator functions according to design. Proper maintenance involves frequent inspections throughout the first year of installation. The unit is considered full when the sediment level comes within one foot (0.3 m) of the unit's top. This can be recognized through experience or the use of a "dip stick" or rod for measuring the sediment depth. When the unit is full, a sump vac or vacuum truck should be used to clean out the unit.

2. City of Portland, Oregon

The City of Portland has listed a detailed procedure to maintain oil/grit separators in their Stormwater Management Manual (Sept 2002). They suggest that the separator be inspected and cleaned quarterly and within 48 hours after each major storm event. The facility owner must keep a log, recording all inspection dates, observations, and maintenance activities. The following items should be inspected and maintained as stated:

- **Stormwater Drain Inlet/Outlet pipe** should be inspected for clogging or leaks during every inspection and clean out. Debris/sediment that is found to clog the inlet shall be removed, tested, and disposed of in accordance with applicable federal and state requirements.

- **Separation Chamber** should be inspected for cracks or damage during each inspection. The cleanout should be done in a manner to minimize the amount of trapped oil entering the outlet pipe. If there is a valve on the outlet pipe, it should be closed otherwise the outlet will be plugged prior to cleanout. Water and oil in the separation chamber should be removed, tested, and disposed of in accordance with regulations. Grit and sediment from the bottom of chamber should be removed during each cleaning. Cleaning should be done without use of detergents or surfactants. A pressure washer may be used if necessary.

- **Vegetation** such as trees should not be located in or around the separator because roots from trees can penetrate the unit body, and leaves from deciduous trees and shrubs can increase the risk of clogging the intake pipe. Large shrubs or trees that are likely to interfere with separator operation will be identified at each inspection and removed.

- **Insects & Rodents** should not be harbored in the separator; Pest control measures should be taken when insects/rodents are found to be present.

3. City of Tacoma, Washington

In the city of Tacoma surface water management manual, vol. 5 Runoff Treatment BMPs, Tacoma Public Works recommend an operation and maintenance procedure for oil/grit separators similar to those discussed above. However, they refine the maintenance procedure according to local climatic conditions. For instance, they suggest that separators should be inspected monthly during the wet season from October 1 to April 30 to ensure proper operation, and, during and immediately after a large storm event of 1 inch or more per 24 hours. Also, separators should be cleaned regularly to keep accumulated oil from escaping during the storm. They must be cleaned by October 15 to remove materials that are accumulated during the dry season, after all spills, and after a significant storm. When the thickness of accumulated oil reaches 1-inch and the thickness of sludge deposits reaches 6 inches, they should be removed from the separator.

4. Canadian Petroleum Products Institute

The Canadian Petroleum Products Institute (CPPI) prepared a "Best Management Practices Stormwater Runoff from Petroleum Facilities" in March 2003. This manual outlines a detailed procedure to measure the sludge depth and oil layer thickness in the separator. Immediately after the separator has been installed, a calibrated gauge stick should be used to determine water level. In order to measure sludge and oil layer thickness during monitoring, the following procedure should be followed:

1. Apply a coating of water detection paste extending to 30 cm below the expected top liquid level mark
2. Insert the stick through the inspection port, keeping the stick vertical, slowly lower the stick into the separator. Do not drop the stick into the separator as this could cause a misreading of sludge depth and/or cause damage to the bottom of the vessel.
3. Lower the stick until a slight resistance is encountered. This represents the top surface of the sludge layer. Note and record the reading at a convenient reference point.
4. The difference between the liquid depth measured now and that when the separator was new, is the sludge thickness.
5. Withdraw the gauge stick and observe the water detection paste. The distance between the point where the paste has changed colour (the oil/water interface) and the total wetted liquid level is the thickness of the oil layer. If the paste does not change colour, repeat the measurement using a new coating of water detection paste, but extend the paste to 60 cm below the expected top liquid level mark.

All records should be retained for a minimum of two years at a location for future inspection. The records should contain the employee name and training dates, inspection dates plus the measured thickness of oil and sludge, clean-out date and copies of waste manifests showing name of waste removal company, spill details including date, time, spill volume, to who was it reported and by whom, clean up information, analytical results of any effluent sampling.

5. Ontario

In the Stormwater Management Planning and Design Manual (MOE, 2003), the suggested operation and maintenance requirements for oil/grit separators are similar to other manuals discussed earlier. More specific recommendations are provided for operation and maintenance of separators under winter conditions than other manuals. Depending on the depth and location of the installation, the concern in the winter is that the permanent pool in the separator may freeze, which would reduce the storage capacity of the separator and significantly reduce its effectiveness (*e.g.,* by causing more frequent by-pass or overflow). The retained water in the separator between events may also be susceptible to salt stratification. The manual notes that more research is required to quantify the performance impacts of salt stratification, but as a precaution, more frequent maintenance (e.g., removal of retained water) is recommended in the winter to avoid potential reductions in performance.

6. Alberta

In the Stormwater Management Guidelines for the Province of Alberta (January 1999), specific maintenance guidelines are recommended for 3-chamber separators and bypass separators. The manual indicates that 3-chamber separators are difficult to maintain and, therefore, may be prohibitive from a maintenance and operation standpoint. Manual cleaning with shovels is often required. Cleaning frequencies are higher (three to four times per year and after any known spills) than other types of OGS. Sediment accumulation can be measured using a graduated pole with a flat plate attached to the bottom. Oil accumulation may be inspected from the surface for trash/debris and the presence of an oil spill. Bypass type separators are easier to maintain than 3-chamber separators. A vacuum truck is typically used for this purpose. No entry into the unit is required for maintenance. Cleaning of the Bypass Separator is usually carried out once per year or after any known spills have occurred. Sediment depth could be measured from the surface via a dipstick tube equipped with a ball valve (sludge judge). Oil accumulation can also be determined by inserting a dipstick tube into the separator.

7. British Columbia

The Urban Runoff Quality Control Guidelines for the province of British Columbia (June 1992), recommend that the 3-chamber separator be cleaned at least twice per year. If a 3-chamber separator does not employ automatic oil skimmers, it may require cleaning as often as every two weeks, depending on the application. The oil/grit separator should be cleaned before the onset of the rainy season, and again after the first significant storm.

Table 2.18: Summary of government agency guidelines for OGS maintenance

Name	Maintenance Period	Criteria for determining the need for maintenance	Maintenance Equipment
U.S. EPA	• Frequent inspections throughout the first year	• Sediment level reaches within 0.3 m of the top of the unit	• "dip stick" or rod for sediment depth measurement • sump vac or vacuum truck for clean up
City of Portland, Oregon	• Quarterly and within 48 hrs after major storm event		• Pressure washer for chamber cleaning • No use of detergents and surfactants
City of Tacoma, Washington	• Monthly during wet season and immediately after a large storm event of >1 inch per 24 hours	• Accumulated oil > 2.5cm • Sludge deposits> 15 cm	
Canadian Petroleum Products Institute	---	• According to Manufacturer's specification or the following • Sludge depth > 15 cm • Oil thickness > 2.5cm • Floating depth > 5 cm	• "dip stick" and water detection paste (see section 4.4.1 for detailed procedure)
Ontario	• Annually and after any known spills occurred. • More frequent maintenance for winter operation due to the potential for freezing and salt stratification		• Sediment remove by vacuum truck
Alberta	• 3-chamber separator - three to four time per years and after any known spills • By-pass type separator – once per years and after any known spills		• 3-chamber separator – manual cleaning with shovels • By-pass type separator – cleaning via vacuum truck • "dip stick" tube equipped with a ball valve (sludge Judge) for sediment depth and oil thickness
British Columbia	• Twice per year, before the onset of wet season and after the first significant storm • Every two weeks if separator does not have automatic oil skimmers (applies to 3 chamber only)	• According to manufacturer's recommendations	

2.5.2. Recommendations from manufacturers

- Stormceptor®

Stormceptor® recommends maintenance when sediment occupies 15% of the unit capacity. Annual maintenance is generally acceptable if the units are sized based on guidelines provided by the manufacturer. However, more frequent maintenance may be needed depending on local conditions.

- Vortechnics

Vortechnics recommends quarterly inspection of the accumulated sediment. Additionally, inspections should be performed more often in the winter months and in areas where sanding operations may lead to rapid accumulation. The Vortechs™ System should be cleaned when inspection reveals that the sediment depth has accumulated to within 15 cm of the dry-weather water surface elevation. Cleanout should not occur within 6 hours of a rain event to allow the entire collection system to drain down.

- BaySaver®

It is generally recommended that the system be maintained (full pump-out) once per year. This frequency may have to be adjusted to a shorter interval based on site specific measurements of pollutant loading. Regular inspections will help determine the required frequency of cleaning. More frequent inspections are appropriate where oil spills occur regularly or a large volume of trash and debris is expected.

- Downstream Defender™

A commercially or municipally owned sump-vacuum truck is used to remove captured sediment and floatables. The frequency of the sump-vacuum procedure is determined in the field after installation. During the first year of operation, the unit should be inspected every six months to determine the rate of sediment and floatables accumulation. A probe can be used to determine the level of solids in the sediment storage facility. This information can then be used to establish a maintenance schedule. When sediment depth has accumulated to the specified depth, the contents should be removed by sump-vacuum. In most situations, it is recommended that the unit be cleaned annually.

- Continuous Deflective Separation System

Clean out frequency or schedules are site specific and depend on particular land use activities and the amount of gross pollutants and sediment generated within a given catchment. Experience in Australia, Florida and California have indicated that CDS® units typically need to be cleaned out approximately 2 to 4 times per year.

CDS Technologies recommends the following maintenance procedure:

New installations:
The condition of the unit should be checked after every runoff event during the first 30 days of operation. The visual inspection should ascertain whether the unit is functioning properly. At the same time, the amount of sediment accumulated should be measured.

Ongoing operation:
During the heavy rain season, the unit should be inspected at least once every 30 days. The floatable should be removed and the sump cleaned when the sump is 85% full. Cleanout of the unit at the end of a rainfall season is recommended to prevent the potential for odor generation.

The unit should be pumped down at least once a year. The screen should be carefully inspected for damage and to ensure that it is properly fastened. Ideally, the screen should be power washed for the inspection.

Table 2.19 Summary of manufacturer guidelines for OGS maintenance

Name	**Maintenance Frequency**	**Criteria for determining the need for maintenance**	**Maintenance Equipment**
3-chamber Separator	The 3-chamber separator is not manufactured by a single company, and therefore does not have a single set of maintenance guidelines. General maintenance guidelines for this type of separator are provided in Table 2.19.		
Stormceptor	• Annually	• When sediment reaches 15% of Stormceptor sediment capacity	• Vacuum truck
BaySaver	• Annually • Regular inspections determine the required frequency of cleaning		
Vortechnics	• Quarterly • More frequency during winter operation	• Sediment depth > 15 cm of dry-weather water surface elevation • Do not clean out within 6 hours of a rain event	
Downstream Defender	• Annually • Frequency determined during the first year of bi-annual inspections		• A probe to measure sediment depth. • Sump-vacuum to removal sediment
Continuous Deflective Separation Unit	• Depends on particular land use activities. • Inspect every runoff event for the first 30 days installation, after which inspections should occur monthly during the wet season.	• Sump is 85% full	

2.5.3 Summary of Maintenance Requirements

Most government agencies and manufacturers of oil/grit separator recommend that oil/grit separators undergo annual maintenance with inspections at more regular intervals, especially during the first year of operation and after periods of heavy rain or snow. The depth of accumulated sediment and oil should be recorded during each inspection and these records should be retained for a minimum of two years. A dipstick was most often recommended to measure the sediment depth and oil thickness. Local site characteristics and climatic conditions must be considered in developing any maintenance program. Older 3-chamber type separators are generally thought to be more likely to resuspend trapped sediment, and therefore manuals often recommend more frequent maintenance for this type of separator. A vacuum truck is generally regarded as the best tool to remove accumulated oil and sediment from OGS.

Maintenance schedules should be based on the sludge depth observed during the first year of inspection. If not specified, the accumulated sediment should not exceed 15 cm or 15% of the unit's sediment capacity. Accumulated oil should not exceed 2.5 cm and the depth of floating debris should not exceed 5 cm.

3.0 STUDY SITES

3.1 Site Selection and Site Comparability

Several locations were investigated as part of the site selection process. Sites were selected based on the intended purpose of the technology (i.e. stormwater management vs. spills control), appropriateness of design relative to the drainage area, monitoring considerations and whether or not the sites were similar enough to permit meaningful comparisons of technologies between sites. Based on these general criteria, and after evaluating several sites, two locations were selected for the study as follows:

- Three-chamber OGS installed as a part of the stormwater management plan for a commercial development in Markham, Ontario, which included a large Home Depot store;
- Stormceptor® OGS installed as a part of the stormwater management plan for a single Home Depot store located in Etobicoke, Ontario.

Drainage area characteristics and OGS design parameters for each site are presented in Table 3.1. The two sites are comparable in terms of land use and percent impervious cover. The 1994 version of the Province of Ontario's *Stormwater Management Practices Planning and Design Manual*, which was current at the time the units were installed, recommends a minimum permanent pool storage of 30 m^3 per impervious hectare for 3-chamber OGS, and 15 m^3 per impervious hectare for manhole type OGS (such as Stormceptor®). The total permanent pool storage provided was 21.3[1] and 14.0 m^3/impervious ha for the 3-chamber and Stormceptor® OGS, which is below the minimum recommended in the 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 performance than would have been the case if the flow were equally distributed. These factors are not considered in the MOE sizing guidelines.

Stormceptor® provides sizing guidelines for its OGS units according to different levels of desired treatment. For a unit providing approximately 12 m^3 of storage per impervious hectare, approximately 80% TSS removal would be expected (Stormceptor® Canada, 1996). Once again,

---

[1] The actual storage provided is probably much lower because, based on monitored data, the actual drainage area contributing to the monitored units is considerably larger (see section 3.2.2)

however, the criteria do not strictly apply under conditions of unequal flow distribution and where additional temporary pipe and surface storage capacity is provided upstream of the OGS because of the effect these factors may have on removal efficiencies.

Table 3.1: Overview of drainage area characteristics, design parameters and provincial guidelines

Site and OGS design attributes and MOE guidelines	Three-chamber OGS, Markham	Stormceptor® OGS, Etobicoke
Total drainage area	8.9 ha	5.2 ha
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
Total number of units installed	7	2
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**
Design criteria per MOE SWMP	-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
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)

*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 probably less than stated because flows were not evenly distributed to the two units of equal size.

3.2 Three-chamber OGS, Markham, Ontario

3.2.1 Drainage Area

The three-chamber OGS selected for monitoring under this study was installed as a part of the stormwater management plan for the Woodside Commercial Development (Highway 7 and Woodbine Avenue) in the Town of Markham, Ontario. Total site area is 8.9 hectares, of which 1.1 hectares is flat roof area.

Permanent stormwater quality control is provided by precast concrete OGSs units. The Woodside Commercial Centre includes 7.8 hectares of parking lot draining to the OGS (Cosburn, Patterson Wardman Ltd., 1993). The facilities were sized to provide 28 m^3/ha of wet storage (note that

MOE recommends 30 m^3/ha of wet storage) and 14 m^3/ha of dry storage, in accordance with guidelines suggested by the Ministry of Natural Resources (MNR)[2] A total of seven separators were installed, because construction of a single large facility was discouraged by the MNR. The distribution of the OGS into four locations was based on the storm sewer layout. This arrangement was deemed necessary to minimize the suspension and flushing of sediment trapped in the separators during previous events. At three locations, the two OGS were installed in parallel and fed by a "Y" connection to divide the flows between the units[3]. The monitoring study was carried out at one of these locations (Figure 3.1). The location that was selected for monitoring incorporates one 35 m^3 unit and one 17 m^3 unit installed in parallel, with the design contributing drainage area of 2.2 hectares.

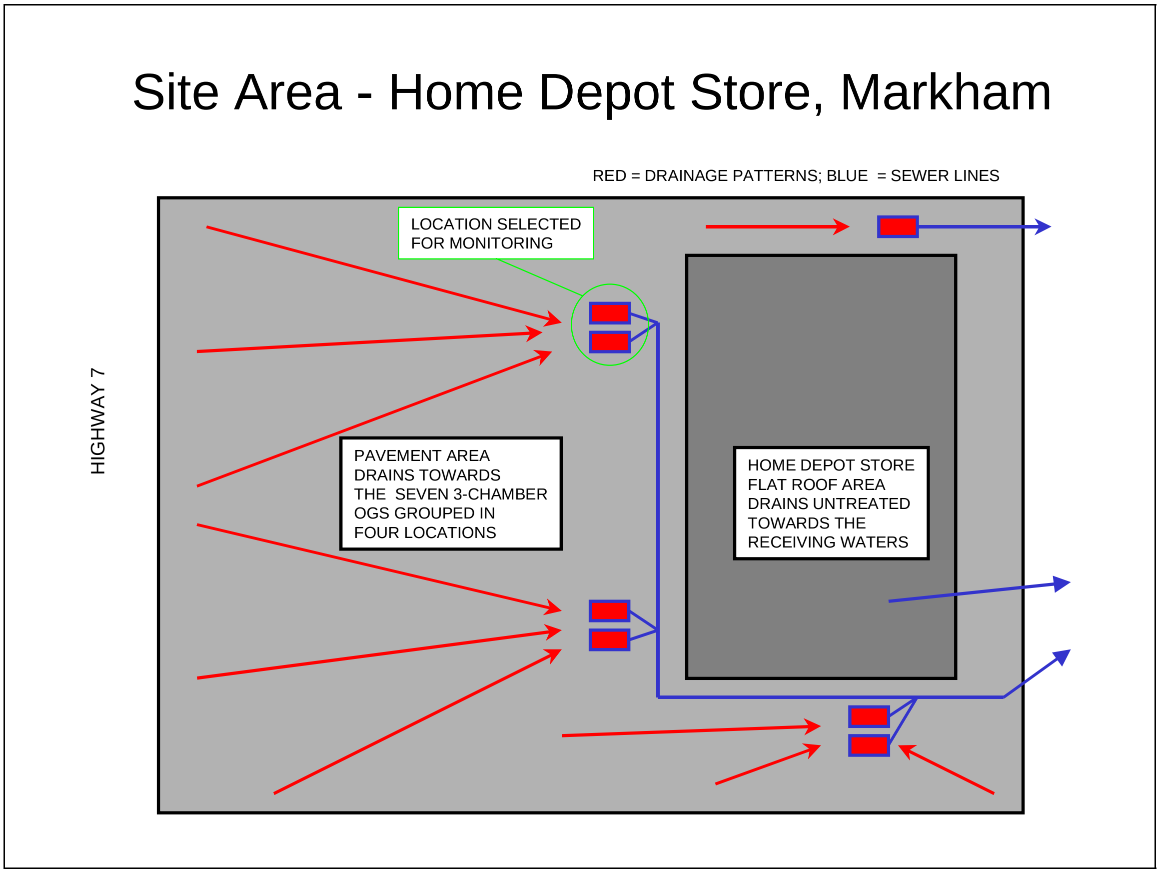


Figure 3.1: Layout of the study area in Markham

3.2.2 Three-chamber OGS Design and Operations

---

[2] This was a general sizing guideline for all 7 units installed. The two units monitored in this study had less than the recommended storage (see Table 3.1)

[3] The "Y" consisted of a straight section of pipe leading to the larger unit, and an angled section leading to the smaller unit.

General design of the three-chamber OGS is presented in Figure 3.2. The three-chamber design is located on-line in the storm sewer and is subject to both low and high flow discharges. The unit is a precast concrete tank that is used to separate water from most insoluble materials having a specific gravity different than water (Wilkinson Heavy Precast Ltd.). The invert of the inlet pipe is about 75 mm above the permanent pool level for the larger unit and 63 mm for the smaller unit. As runoff enters into the first chamber, the water level in this chamber rises and the increase in head pushes flow to the second chamber through the trash rack in the wall between the chambers. The trash rack is located approximately one meter from the bottom of the tank.

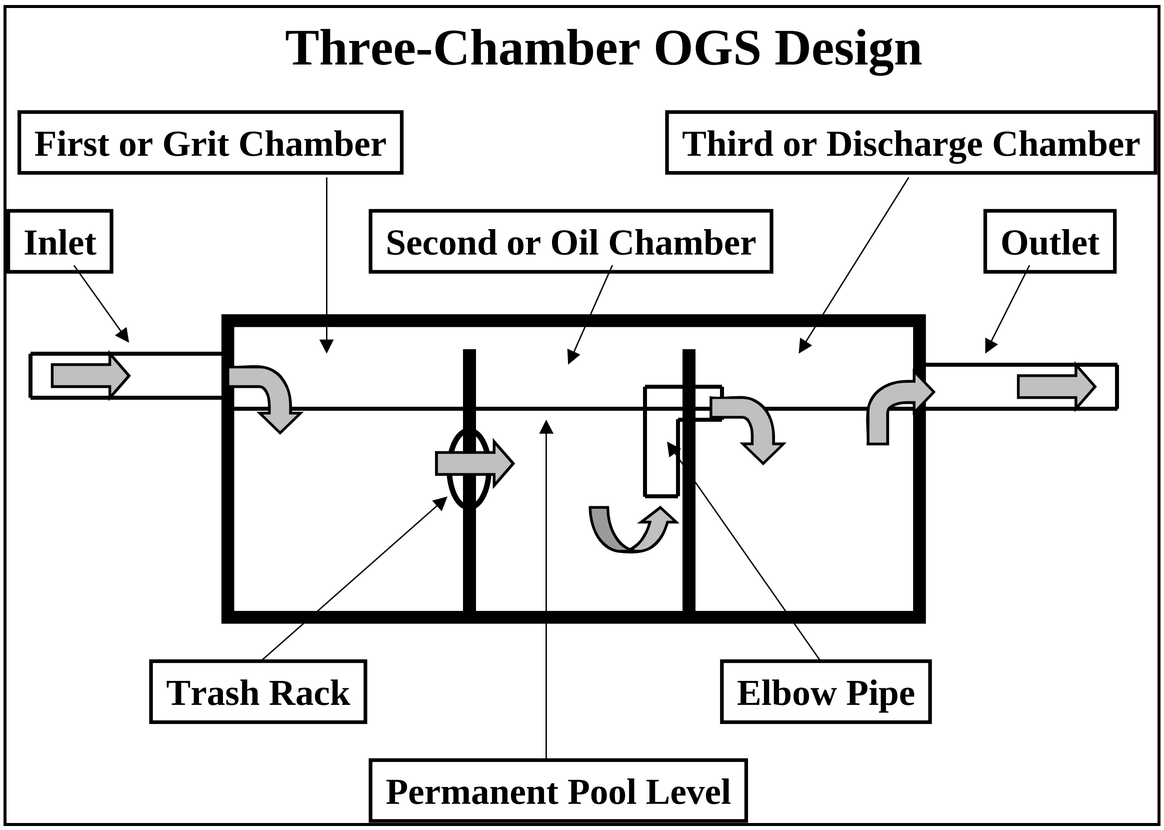


Figure 3.2 : General Design of the Three-chamber OGS

The first chamber is known as the sediment chamber and is designed to trap the heavier grits and large floating trash washed off from the parking lot. As the water level in the second chamber rises, water is forced through the two elbow pipes (375 mm and 300 mm diameter for larger and smaller unit, respectively) into the third chamber. The intakes of the elbow pipes are submerged and located one meter from the bottom of the second chamber. This configuration is efficient in trapping free oil from the stormwater runoff, for which reason the second chamber is called the oil chamber. The third chamber is primarily used to discharge treated runoff from the OGS, although some opportunity to settle suspended particles exists. The opening that discharges the treated runoff to the sewer (800 mm and 600 mm diameter for the larger and smaller units, respectively) also determines the permanent pool level. Once the hydraulic capacity of the trash rack or elbow pipes is exceeded, an overflow will occur through the openings located at the top of the interior walls (Figure3.2). The permanent pool level is set at about 1.8 m and 1.5 m from the bottom of the tank for the larger and smaller unit, respectively. This permanent pool is an important feature for pollutant removal. It serves to dilute pollutant concentrations, slow down incoming flows, thus improving the settling of suspended particles, and provide extended detention time for runoff volume captured in the permanent pool.

Table 3.2: Permanent Pool Volumes for the Three-chamber OGS

Chamber / Unit	**Larger 3-chamber OGS**		**Smaller 3-chamber OGS**	
	L x W x H [m]	Volume [m^3]	L x W x H [m]	Volume [m^3]
First (Grit) Chamber	2.53 x 2.69 x 1.76	12.0	1.54 x 2.34 x 1.53	5.5
Second (Oil) Chamber	1.87 x 2.69 x 1.76	8.9	1.40 x 2.34 x 1.53	5.0
Third (Discharge) Chamber	2.23 x 2.69 x 1.76	10.6	1.40 x 2.34 x 1.53	5.0
Total Volume [m^3]	31.5		15.5	

In addition to the combined permanent pool of 47 m^3, there is approximately 26 m^3 of combined dry storage in the both units. The units were sized in accordance to MNR criteria, which are slightly different from the MOE criteria. According to the stormwater management plan (Cosburn, 1992), the contributing area to these two units was supposed to be approximately 2.2 hectares. As per MNR guidelines, the OGS should have been designed to provide 28 m^3 of permanent pool volume and 14 m^3 of dry volume per one hectare impervious. However, comparing flow volumes from the combined outlet station to the rainfall volumes measured at the Buttonville Airport (3 km away) over the whole monitoring period yielded a significantly larger contributing drainage area of approximately 3.9 hectares. A possible reason for this could be the difference in rainfall distribution at the site and at the Buttonville gauging station. It is also possible that the additional drainage area was introduced into the sewer system after the stormwater management plan had been completed. This could not be confirmed, since no as-built drawings were available, but it is believed that the drainage area contributing to the monitored units was larger than was assumed in the stormwater management plan and, that the units were undersized according to MNR and MOE guidelines. Assuming that the runoff was generated from the total drainage area of 3.9 hectares with 100% imperviousness, then approximately 12 m^3 of permanent pool volume would be available per one impervious hectare.

3.3 Stormceptor® OGS, Etobicoke, Ontario

3.3.1 Drainage Area

The Stormceptor® unit selected for monitoring in this study was installed as part of the stormwater management plan for the Home Depot store (Hwy 427 and Queensway) in Etobicoke, Ontario. The stormwater management report prepared by PVA Consultants Ltd. contains all relevant details related to stormwater quality and quantity control (PVA, 1996). Design criteria for stormwater management at the site were established by the City of Toronto (Etobicoke District). They are given as (a) quantity controls for the drainage area should provide runoff coefficients less than 0.70; and (b) potentially contaminated stormwater should be treated up to the "first flush", defined as the first 15 mm of rainfall. However, there was no explicit criterion pertaining to the level of treatment that was to be provided for the first 15 mm of rainfall. The drainage area is shown in Figure 3.3. A general schematic of the 5.2 ha drainage area is shown in Figure 3.4. Runoff management was considered separately for each component of the development as follows:

- Future development of 1.0 ha

This area was not included in the system when the monitoring study initially started in 1997, but it did become a part of the adjacent sewer system in 1998. According to available information and field inspections, the runoff from this area is not conveyed to the sewer system draining to the Stormceptor® units monitored in this study.

- Flat roof building area of 1.03 ha

Roof drains provide water quantity control for this area. Rain falling on the roof is not considered to be contaminated and does not require any treatment. Runoff is collected separately and conveyed directly through a separate storm sewer to the main storm collector.

- Uncontrolled roof area of 0.105 ha

Runoff generated from the roofs of the greenhouses and canopies is also not contaminated and does not require treatment. This component is conveyed together with the runoff from the flat roof area directly into the separate sewer that drains into the main storm collector.

- Soft landscaping area of 0.54 ha

Runoff from the grassed area contributing to catch basin CB-1 (just east of the hardware store) does not require any treatment. Water that does not infiltrate eventually enters the separate storm sewer from the roof areas and is routed directly to the main storm collector. The runoff from the soft landscaped areas does not require any treatment and is routed through grassed swales towards the manholes to promote groundwater recharge. The manholes in the swales are connected to the roof drainage system as well. According to the design, a high percentage of the "first flush" (80-100%) is expected to infiltrate, unless very wet antecedent moisture conditions are present.

- Pavement area of 2.55 ha

Stormwater from the hard pavement areas is expected to be contaminated with sediment and oils. Most of the pollutants that are deposited on the paved areas are washed off into the storm sewer. The "first flush" is treated by installing catchbasin sumps which capture the larger grit particles before the stormwater flows through the two Stormceptor® units (model STC 4000).

Figure 3.3: Drainage Area for Etobicoke Stormceptor®

The two Stormceptor® units have a maximum treatment flow rate, before bypassing, of 50 L/s per unit. In order to ensure that the maximum combined treatment rate of 100 L/s is not exceeded, and that the water volume of the "first flush" is contained on site with minimum nuisance to customers, the following additional measures were applied at the site:

- A 150 mm diameter section was installed at the last 2.5 meters of the pipe entering MH-11, upstream of the "Y" type splitter to the two Stormceptor® units; and
- Runoff from the pavement areas is temporarily stored in the storm sewer system (90 m^3), loading dock area (280 m^3) and pavement area west of the store (10 m^3).

The temporary storage was designed so that almost 100% of the first flush runoff is retained in the storm sewer system and loading dock area, thus minimizing ponding in the parking areas.

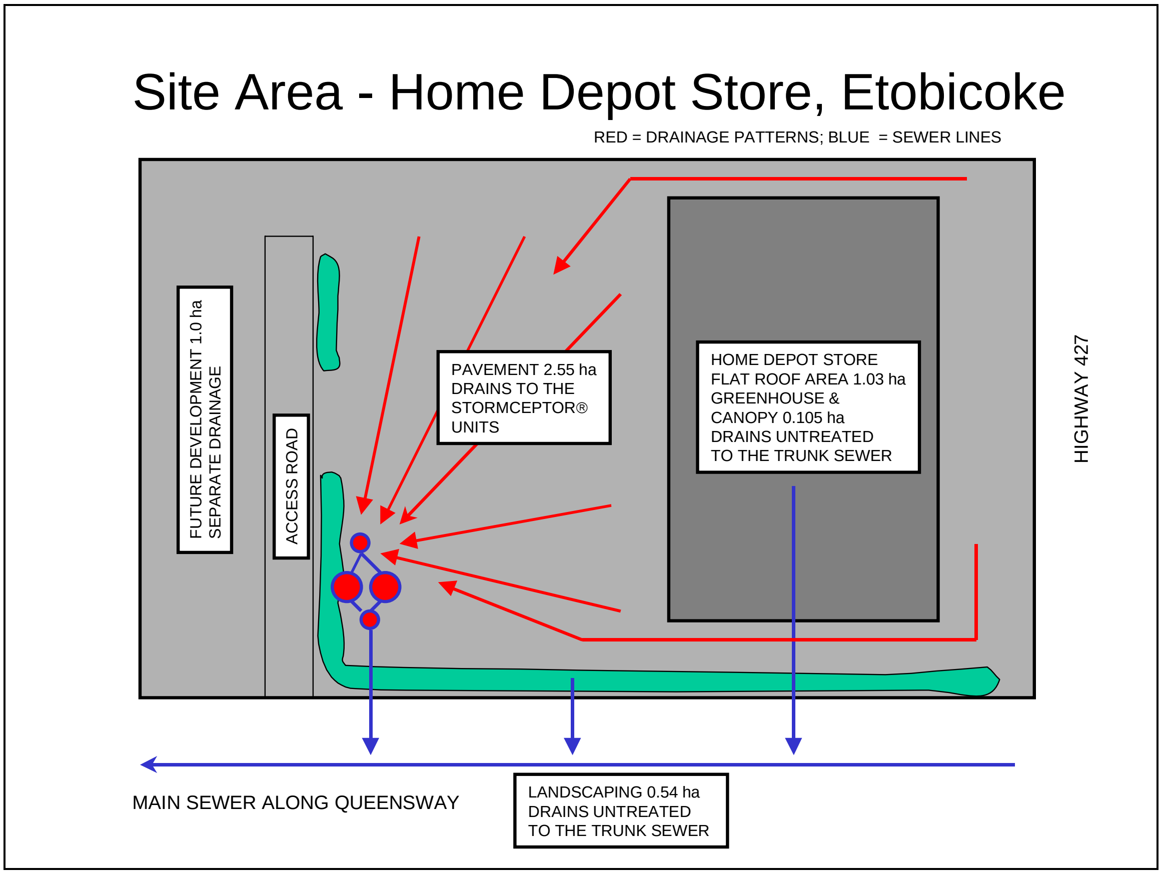


Figure 3.4: Layout of the study area in Etobicoke

3.3.2 Stormceptor® OGS Design and Operations

Stormceptor® STC 4000 is a concrete precast unit with fiberglass insert and with oil holding capacity of 3,490 L and a sediment holding capacity of 14,060 L. General features and of the unit are presented in Figure 3.5. Each Stormceptor® unit has two components:

- Treatment chamber; and
- By-pass chamber

Stormwater influent flows are distributed into the by-pass chamber of each unit via a "Y" type splitter[4]. 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 since the outlet riser pipe is submerged. Sediment will settle at the bottom of the chamber by gravity forces. According to the manufacturer, the circular design of the treatment chamber is critical to prevent turbulent eddy currents and to promote settling (Stormceptor®, 1998). During high flow conditions, stormwater in the by-pass chamber will overtop the weir and be conveyed untreated 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. This design, as suggested by the manufacturer (Stormceptor®, 1998), ensures that excessive flows will not be forced into the treatment chamber and re-suspend the settled material.

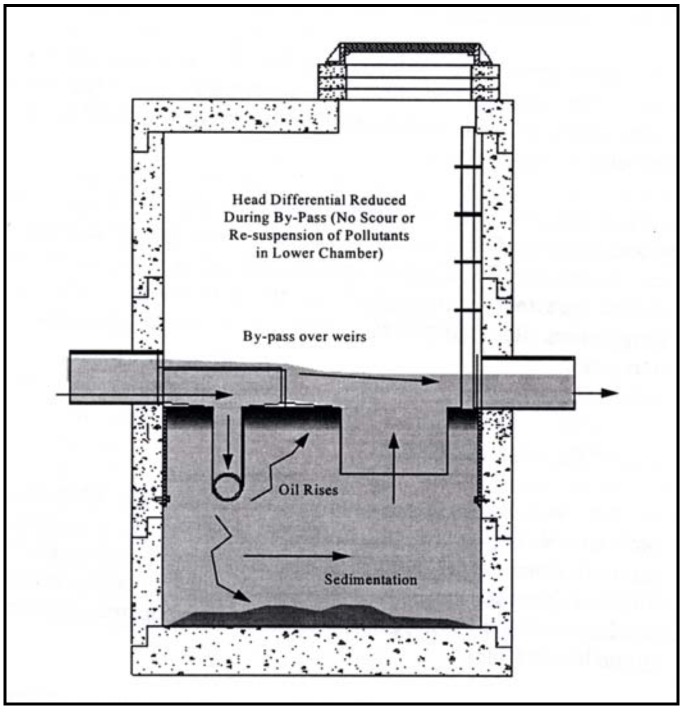


Figure 3.5: Stormceptor® Operation During High Flow Conditions (Stormceptor®, 1996)

[4] Unlike the 3-chamber site, the "Y" splitter consists of an inflow pipe that discharges to a manhole, the bottom of which is level with the pipes that distribute flow into the two parallel units. One side of the "Y" splitter is straight, the other connects to the manhole at an angle. Although greater flows would be expected to enter the unit downstream of the straight section, the two Stormceptor® units are the same size.

4.0 STUDY APPROACH

4.1 Monitoring Approach and Data Requirements

4.1.1 General considerations

The monitoring program was based on co-ordinated measurements of rainfall, runoff and water quality. Pollutant loads were calculated based on the event mean concentration (EMC) for a range of parameters and the associated flow volumes. Two methods are commonly employed to characterize the event mean concentration:

- A single composite sample

In this approach, the EMC is based on a single sample composited from a number of samples proportioned according to flow. A composite sample based on samples collected at regular time intervals (called time weighted or time proportioned) also provides a reasonable approximation of the EMC if collection intervals are 5 minutes or less.[1]

- A set of discrete samples

Most automatic wastewater samples allow for collection of a set of discrete samples, usually up to 24 separate containers, using either flow or water level to initiate the collection. Discrete sampling allows for characterization of the event pollutograph, which shows how pollutant concentrations vary during a given event. A flow proportionate EMC can also be determined from discrete samples and event flow data. The major disadvantage of this approach is that there is less volume available for each separate analysis, limiting the number of parameters that can be analyzed. Moreover, if the parameter selected for analysis requires a complex laboratory procedure, this approach may be very time consuming and expensive.

Regardless of the method, it is usually difficult to collect enough samples for an event of short duration and high rainfall intensity, and to collect a representative sample for an event of low intensity and very long duration. In this study, since only the pollutant removal efficiency and influent/effluent EMCs were of interest, a single composite sample was adopted as an appropriate method to determine the EMC.

---

[1] The sampling interval for an automated sampler that is programmed to collected samples according to flow would collect only slightly more quickly during the high flow period because it takes 2-3 minutes to complete the sampler rinse-pump-purge cycle.

4.1.2 Data requirements

Urbonas (1995) suggested that stormwater BMP data should be reported as paired inflow and outflow EMC for all the events samples, along with the runoff volume. He also listed a number of parameters to report when monitoring different BMPs. In contrast, Adams (1990) recommended collection of discrete samples for a much smaller number of constituents and to correlate performance to the operating flow rate. According to this approach, influent and effluent concentrations can be correlated based on the retention time, which is influenced by the storm size and intensity. The monitoring protocol for this study was developed in recognition of the following:

- Drainage areas for the selected OGS were relatively small and highly impervious, resulting in a very short time lag between the beginning of an event and the start of the inlet hydrograph;
- Available storage volumes for the selected OGS were relatively small, resulting in negligible influent peak flow reduction; and
- Given the enclosed watertight design of the OGS, no infiltration or evaporation losses were expected (*i.e*. a perfect water balance was assumed).

Monitoring was conducted using portable automated equipment. An overview of data required for the purpose of assessing the performance of the selected technologies is given in Table 4.1. Precipitation data at a nearby station were obtained using standard tipping bucket rain gauge in order to monitor the time of occurrence, duration and intensity of the storm events. Flow measurement was only conducted at the combined outlet. The combined outlet was preferred over the inlet of one unit because of much better accessibility and fewer problems with fouling and silting of the probe, given that only treated flows were to be measured. A recording interval of two minutes was required to accurately record flow rates because of the short travel time expected for the small and very impervious area. Water quality samples were collected both at the inlet of one unit and the combined outlet locations and submitted to the Ministry of Environment and Energy laboratory in Toronto for analysis of the constituents given in Table 4.2.

Maintenance of equipment was carried out at a two week intervals to determine whether or not:

- batteries were running low;
- flow probes and depth sensors were buried or washed loose;
- sampling lines were clogged;
- equipment was vandalized; and/or
- equipment was malfunctioning.

Table 4.1: Overview of data requirements for the OGS study

Data Requirements	Location	Data Collection	Recording Interval
Precipitation measurement	Study catchment	Standard tipping bucket rain gauge	1 minute
Continuous flow through the device	Outlet	Area velocity flow meter	2 minutes
Water quality sampling	Single Inlet and combined outlet	Automatic wastewater sampler	Time (5-min interval) and flow proportioned, respectively
Sediment sampling	From the bottom of the device	Manual grab	As appropriate
Conductivity measurement	Permanent pool of the device	Portable conductivity probe	As appropriate

Table 4.2: Water quality constituents analyzed in the OGS study

Constituent Group	Constituent
Solids	Suspended, dissolved and total solids
Solvent extractable	Organic solvent extractable substances, including non-volatile petroleum hydrocarbons and their derivatives, vegetable oils, animal fats, soaps, greases and waxes
Metals	Aluminum, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, molybdenum, mercury, nickel, lead, strontium, titanium, vanadium, zinc

4.2 Monitoring Protocol for the Three-chamber OGS

4.2.1 Site conditions

The monitoring set-up for the three-chamber OGS is presented in Figure 4.1, showing the two units connected in parallel and general flow directions. Two monitoring stations were established to accommodate equipment, one at the inlet of one unit and one at the combined outlet of both units. Monitoring at these stations commenced in May 1997 and was continued until December 1998. Site observations relevant to the monitoring program are as follows:

- The selected OGS were next to the entrance of the hardware store, where vehicular and pedestrian traffic were heavy, causing some difficulties in equipment installation and maintenance, and, in some instances, rendering the OGS inaccessible during field visits;

- No major sediment deposition was found in the sewer system at the beginning of the program;

- Both of the three-chamber OGS units were completely drained and thoroughly cleaned of oil and sediment prior to the beginning of the study;

- A fiber-like material was discovered in the inlet pipe when the monitoring commenced, creating significant problems with regards to clogging of the sampling lines and the liquid actuator.

- Flow splitter, which incorporates a “Y” connection to distribute flows to the two units, was built as an underground structure, without any access from the surface. This arrangement complicated the collection of the inlet water quality samples. In addition, the configuration of the splitter with one straight end and the other angled resulted in greater flows diverted into the larger OGS unit.

- Level of the permanent pool of water [Figure 3.2] is defined by the invert elevation of the outlet pipe. The difference in elevations between inverts of the inlet and outlet pipe was 75 and 63 mm for the larger and smaller OGS units, respectively.

- A continuous baseflow, likely originating from groundwater discharge into the sewer network, was present in the system under dry weather conditions.

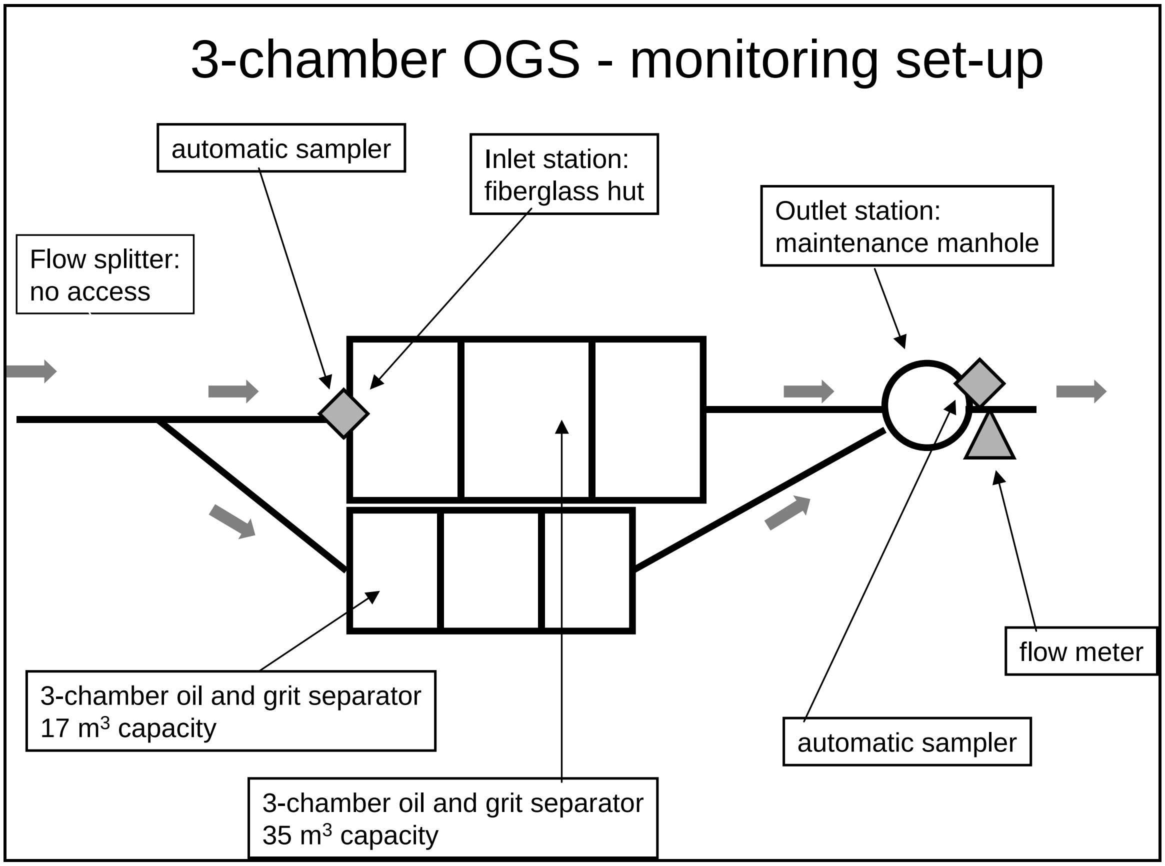


Figure 4.1: Monitoring Set-up for the Three-chamber OGS

4.2.2 Precipitation measurement

Precipitation data were collected from the Environment Canada AES weather station at the Buttonville Markham Airport, approximately 3 km from the study site. Due to its close proximity to the study area, it was assumed that data from the AES station would provide a reasonable approximation of the rainfall distribution at the study site. In 1997, rainfall data from May to November were available. In 1998, due to malfunctioning of the equipment maintained at the station, only data from April to August were available. Precipitation was not measured during the winter period.

4.2.3 Flow measurement

For the purpose of flow monitoring and level measurement, the outlet manhole (Figure 4.1) was equipped with an area velocity flow meter. The probe was installed downstream from the manhole at the outflow pipe, measuring the combined flow from the two units. As previously stated, no losses were expected in the system. Furthermore, numerous field observations indicated that the permanent pool in the chambers was maintained at constant level during dry weather conditions, which confirmed the assumption. In terms of wet weather flow, response time of the system and time needed to route runoff from the inlet to the outlet sewer were measured in the order of minutes. Therefore, a single flow meter was assumed to be sufficient to monitor the flow through the system. Very little debris or irregularities in flow were observed, resulting in a well developed stage-discharge curve for this location (Figure 4.3).

Figure 4.2: Fiberglass Shelter for Equipment, Three-chamber OGS

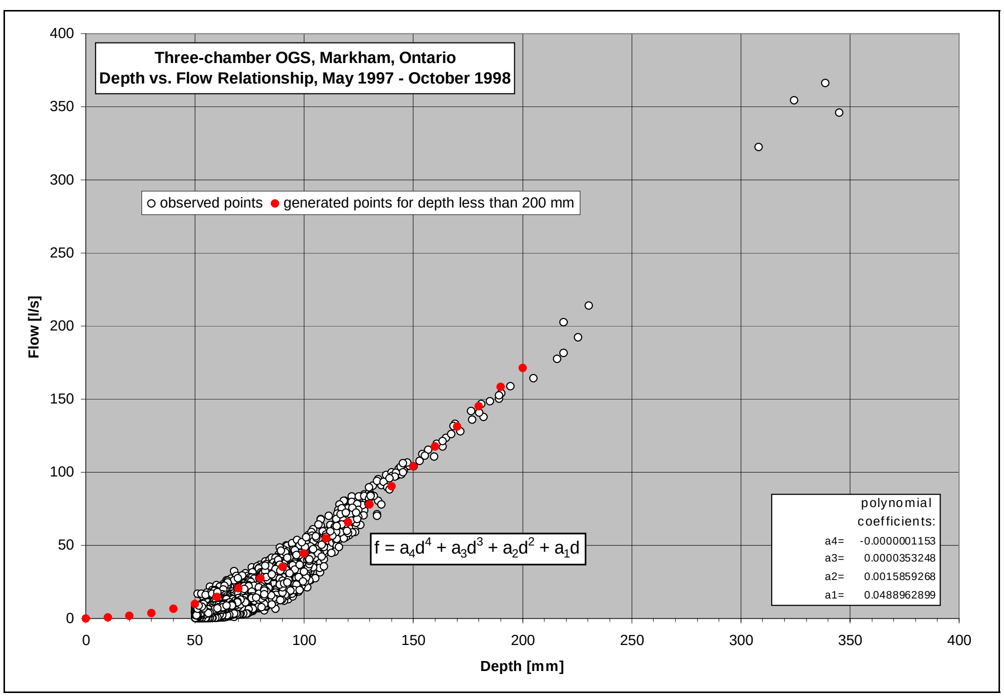


Figure 4.3: Stage-Discharge Curve for the Three-chamber Flow Measurement

4.2.4 Water quality sampling

Water samples for chemical analysis were collected at the inlet of one unit and the combined outlet location. The inlet sampler of one unit was accommodated inside a fiberglass hut (Figure 4.2), and the combined outlet sampler was installed in the outlet manhole (Figure 4.1), along with the flow meter. The inlet sampler was triggered by a liquid level actuator positioned just slightly above the level of the sampler intake, close to the end of the incoming pipe to the larger OGS unit.

Ideally it would have been best to sample water quality upstream of where the flow splits to the two units, but this pipe was completely inaccessible from the upstream end because of the underground design of the "Y" type flow splitter. The next accessible upstream manhole was further up in the system. Flow passing through that manhole would not include the flows from the two additional catchbasins connected in between, and was therefore judged to be inappropriate for sampling. Under the circumstances, monitoring water quality at the inlet of only one of the two parallel units was thought to be a reasonable compromise because: (i) the larger unit receives the majority of runoff (due to the configuration of the splitter) and is therefore more representative of total inflow; and (ii) runoff was expected to be relatively well mixed before the split, resulting in similar influent pollutant concentrations in each of the two units.[2] Analysis of the potential errors in removal efficiencies associated with this monitoring set-up is provided in chapter 6.

Once the monitoring program was underway, runoff entering the first chamber was observed to back up to the inlet line during rainfall events. As a result, samples would reflect not only the influent water quality of one unit, but also quality of the supernatant from the first chamber. In order to rectify this problem, a steel weir (Figure 4.4) was built at the end of the inlet pipe and the samples were collected upstream of the weir. The weir design incorporated perforations which prevented accumulation of water at the inlet pipe. Sample collected at this location were thought to provide a reasonable estimate of influent quality.

[2] In the absence of a well mixed flow stream, the configuration of the "Y" splitter would be expected to favour discharge of heavier solids to the monitored unit, resulting in an overestimate of removal efficiencies (since heavier solids are more easily removed by OGS than smaller particles). This potential bias should be considered when interpreting study results.

Figure 4.4: Inlet Sewer to the First Chamber, Three-chamber OGS

The outlet sampler was triggered by a flow meter to collect flow proportional samples and no major difficulties were encountered with this sampling station throughout the study.

4.2.5 Conductivity measurement

Depth profile measurements of conductivity were undertaken to assess whether or not chloride stratification was occurring. Chloride is highly soluble and is, therefore, not removed by gravity settling. The storage and release of chloride from stormwater BMPs has important implications for receiving water quality and may adversely affect OGS pollutant removal processes.

4.3 Monitoring protocol for the Stormceptor® OGS

4.3.1 Site conditions

A schematic of the monitoring set-up for the Stormceptor® OGS, including flow directions, is presented in Figure 4.5. As at the Markham site, the two OGS units were installed in parallel. Monitoring stations were set up at the outlet manhole (STMH-12) and inside Stormceptor® unit #2. Field operations commenced in August 1997 and continued until December 1998. Some observations related to the study area are as follows:

- The selected location was at the corner of the parking lot, far from the entrance to the store, resulting in very few problems with traffic and access to the system;

- Preliminary site inspections were conducted before the sewer system was completed. Monitoring commenced soon after construction. The position of the two Stormceptor® units could not be identified during the initial site inspections due to large earth deposits in the area. It is unclear whether appropriate erosion control measures were in place during the final phase of the construction and installation of the units;

- Field observations revealed that the flow restrictor caused back-up of flow during rain events, which helped to maintain a small pool of standing water in upstream manholes STMH-10 and STMH-7.

- At the maintenance manhole STMH-11, two outflow pipes distribute flows to the Stormceptor® units. Flows would be expected to follow the path of least resistance, and discharge preferentially to the monitored unit (unit #2). A hydrant test and further monitoring of both units conducted in 2000 confirmed this assumption.

- Construction activities on 1.0 hectare of the total area, which is referred to as a "future development" in Section 3.3.1, were completed by the beginning of summer 1998. Runoff from this area is not conveyed to the sewer system draining to the Stormceptor® unit.

- The stormwater management concept for this site utilizes the whole sewer network, the loading dock and pavement to store runoff during rain events. As a result, the pipes are regularly surcharged throughout the system, which rendered the whole system upstream from the OGS inappropriate for flow measurement;

- A small baseflow was observed entering the Stormceptor® units at all times.

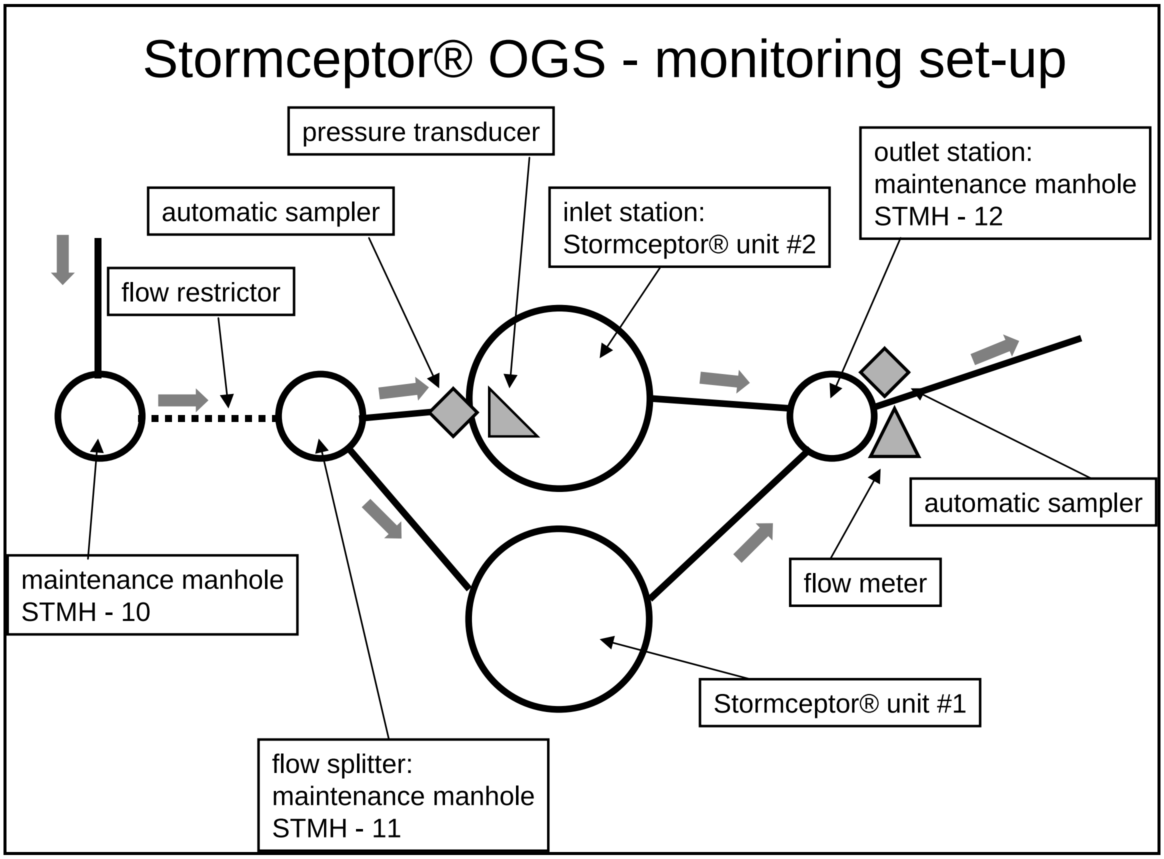


Figure 4.5: Monitoring layout for the Stormceptor® OGS

4.3.2 Precipitation measurement

In 1997, precipitation data were obtained from a station set up in the vicinity of Princess Margaret Blvd, approximately 5 km from the site. Precipitation data for 1998 were obtained from a station maintained by the Etobicoke District Works Department at 7th street and Lakeshore Blvd, approximately 3 km from the study site. Standard tipping bucket rain gauges were used and no winter data were available.

4.3.3 Flow and level measurement

As noted earlier, the use of the sewer network upstream of the OGS units as storage imposed severe constrains on flow measurements. Hence, the following options were investigated in order to determine the optimal method and location for flow measurement. These options included:

Upstream measurement:

- Primary device and level measurement upstream of the Stormceptor® units

Flow restrictor designed as a reduced diameter pipe installed between the manhole STMH-11 and manhole STMH-10 creates backwater conditions upstream of the manhole STMH-11

(Figure 4.5). As a result, the application of a weir or flume was not possible, for the primary structure would often be submerged.

- Direct flow measurement upstream of the Stormceptor® units

Similar to the previous option, backwater effect in the sewer during an event would distort velocity sensor readings. Direct flow measurement was only theoretically possible

(a) inside the 150 mm restrictor pipe, where the probe itself and the mounting hardware would likely interfere with measurements due to the small size of the pipe;

(b) upstream from the manhole STMH-7, where two or more flow meters would have to be used with no real guarantee that either of them would be affected by backwater; and

(c) inside the manhole STMH-11, where non-uniform geometry of the conduit and supercritical flow conditions would have impact on velocity readings as well.

Downstream Measurement:

- Primary device and level measurement downstream of the Stormceptor® units

Difference in invert elevations between the inlet and outlet pipe is about 25 mm, according to Stormceptor® specifications [Stormceptor 1996]. Even the smallest weir or flume installed in STMH-12 would affect head differentials and alter system hydraulics.

- Direct flow measurement downstream of the system

The probe could not be installed in manhole STMH-12 due to non-uniform geometry of the conduit, but the sewer downstream from the manhole was relatively straight and flow was uniform. This option was eventually selected as the most appropriate for flow measurement (Figure4.5).

Figure 4.6: Monitoring Equipment Installed at the Stormceptor Weir

Figure 4.7: Area-velocity Probe and Sampling Intake at the Outlet, Stormceptor®

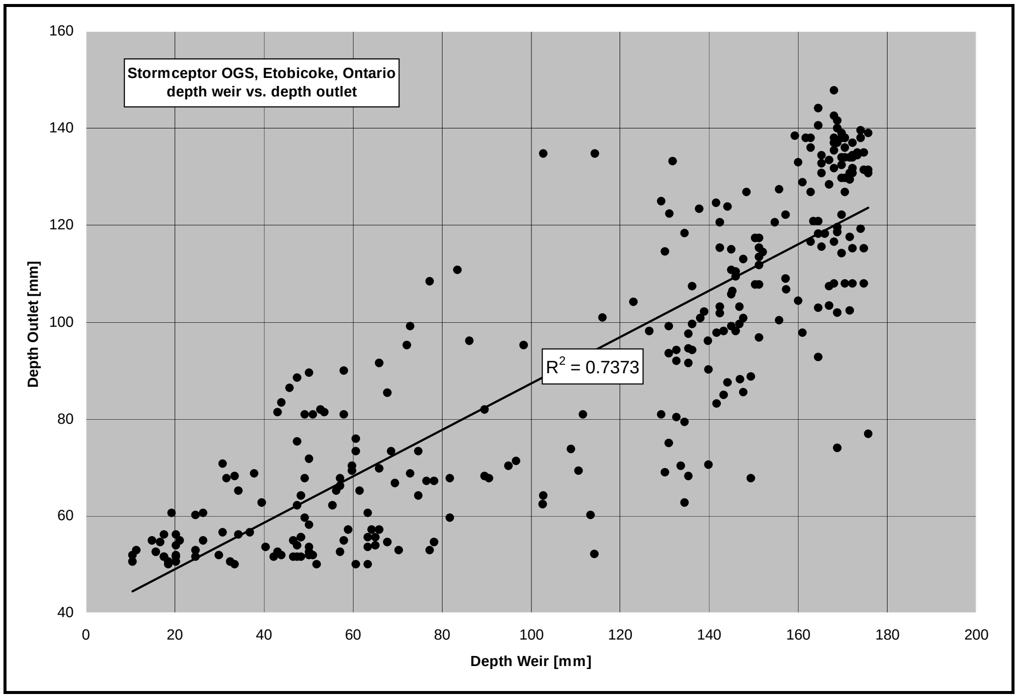


Figure 4.8: Water level at weir vs. water level at outlet, Stormceptor® OGS

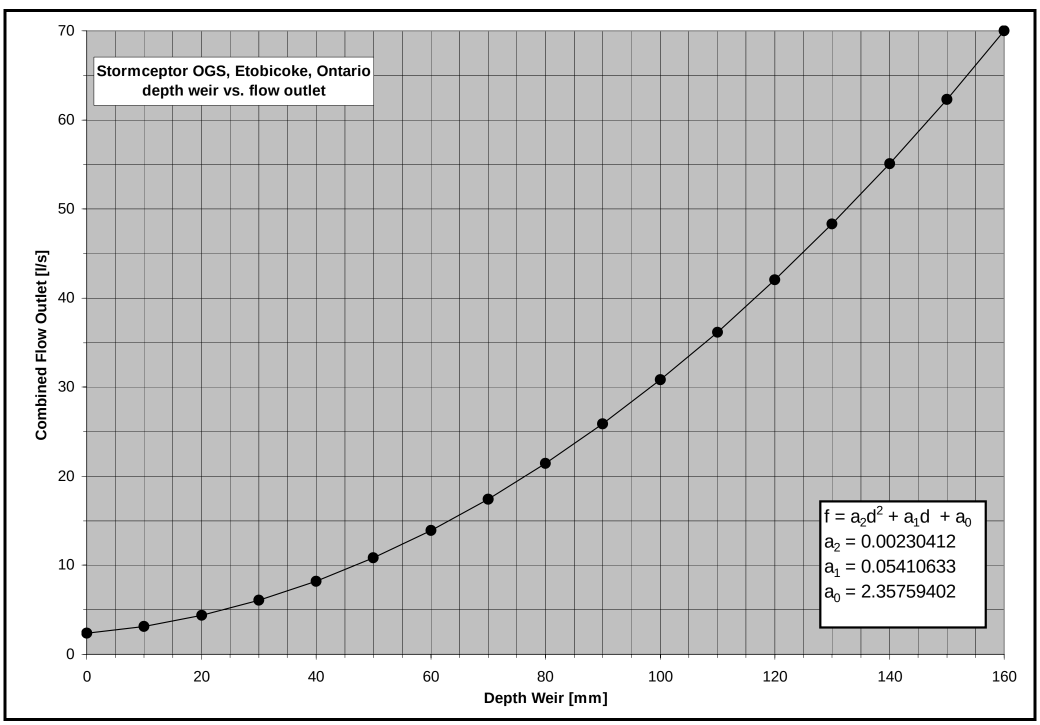


Figure 4.9: Depth Weir vs. Combined Flow Outlet, Stormceptor® OGS

Unfortunately, when the remaining 1.0 hectare of land at the site was developed at the beginning of the summer in 1998 (roughly half way through the monitoring period), additional flows were introduced into the main storm sewer, downstream from the discharge point for the two Stormceptor® units. This may have caused an increase in depth in the main storm sewer resulting in back flow to the probe. To help overcome this problem, the flow rate through the system was calculated using the depth readings from the pressure transducer installed upstream from the weir within unit #2. To determine flow rates by this method, the Stormceptor unit was described in hydraulic terms as a submerged orifice. The flow rate was defined by (a) a non-dimensional coefficient (**C**), depending on the shape and size of the orifice; (b) a combination of the diameters of the drop ($\mathbf{D_D}$) and riser ($\mathbf{D_R}$) pipes; and (c) available head (**H**). The difference in water levels upstream ($\mathbf{H_U}$) and downstream ($\mathbf{H_D}$) from the weir defines the available head, so it can be written:

$$\textit{Flow Outlet} = f(\mathbf{C}, \mathbf{D_D}, \mathbf{D_R}, \mathbf{H_U}\text{-}\mathbf{H_D}) \ldots\ldots\ldots\ldots\text{(Equation 1)}$$

Since the first three factors are constant ($\mathbf{C}$, $\mathbf{D_D}$, $\mathbf{D_R}$ = const.) for the whole range of flows, it is possible to calculate the flow rate as a uniform function of the difference in levels upstream and downstream of the weir. Given the moderately good relationship between the depth at the weir and depth at the outlet (Figure 4.8), equation 1 can be modified as:

$$\textit{Flow Outlet} = f(\mathbf{C}, \mathbf{D_D}, \mathbf{D_R}, \mathbf{H_U}) \ldots\ldots\ldots\ldots\ldots\text{(Equation 2)}$$

However, in practical terms it is difficult to define and verify the described coefficient **C** and representative orifice area [$\mathbf{D_D}$, $\mathbf{D_R}$]. Thus, this relationship was instead deduced from the two sets of readings measured at the weir and at the outlet for those events for which good flow data were available. The resulting relationship is provided in Figure 4.9. Of course, the relationship is not valid during overflow, which occurred infrequently and was often of very short duration.

4.3.4 Water quality sampling

Water quality samples were collected at the inlet of one unit and the combined outlet locations using automatic wastewater samplers. The inlet sampler was triggered using a liquid level actuator, and the outlet sampler by the existing flow meter. The inlet samples were collected from the incoming pipe to the Stormceptor® unit #2, and the outlet flow proportioned samples from the outlet pipe downstream from the outlet manhole (Figure 4.1). No major problems were experienced with regards to clogging and fouling of the intake lines.

As at the Markham site, it would have been preferable to sample the combined inlet flow, but an appropriate location upstream could not be found. Under the circumstances, monitoring water quality at the inlet of only one of the two parallel units was thought to be a reasonable compromise for the same reasons provided earlier in section 4.2.4. Analysis of the potential errors in removal efficiencies associated with this monitoring set-up is provided in chapter 6.

4.3.5 Conductivity measurement

Conductivity measurements were taken in both OGS units at the treatment chamber as appropriate. In some cases the range of the portable conductivity (20,000 µS/cm) was exceeded. In these instances, a sample was collected and submitted for conductivity analysis to the MOE laboratory.

4.4 Monitoring Protocol for Trapped Sediment

4.4.1 Introduction

The physical and chemical characteristics of the trapped sediment were assessed by cleaning out both devices of oil and sediment prior to the beginning of the monitoring program, and removing the trapped sediment to offline holding tanks for analysis at the end of the field study. Sediment analysis was considered to be a major enhancement of the monitoring program, for the following could be achieved:

- Assess the physical and chemical characteristics of the trapped material;
- Recommend maintenance frequency and disposal options; and
- Verify removal efficiency results by comparing measured sediment accumulation to model simulations from a calibrated hydrologic model (see section __).

The various steps involved in the analysis of trapped sediment were as follows:

- Initial dewatering of the OGS units by pumping the supernatant from the units and discharging it to the sanitary sewer; a representative sample of the supernatant was collected for chemical analysis;

- Transfer of the remaining sludge and liquid content into the two separate off-line holding tanks;

- Secondary settling within the off-line tanks for another week;

- Secondary dewatering by pumping the supernatant from the off-line tanks into sanitary sewer; another composite sample was collected for the supernatant from the off-line tank;

- Solidification of the sediment content by exposing it to cold weather conditions; and

- Measuring the volume of frozen content and extracting representative core samples for sediment analysis.

Figure 4.10: Installation of the Off-line Sediment Holding Tanks

The storage tanks (Figure 4.10) used to hold the contents of the OGS units were installed at the Toronto Works Yard (Disco Rd. in Etobicoke) on December 4, 1998. The tanks were identical concrete two-chamber design, the dimensions of which are provided in Table 4.3. The total surface area and volume were 13.2 m^2 and 18.4 m^3 per tank, respectively. A small hole approximately 10 cm in diameter was made at the base of the concrete partition wall between chambers to facilitate uniform filling of the chambers during pumping.

Table 4.3: Dimensions of the Sediment Holding Tanks

Parameter / Chamber	Larger Chamber	Smaller Chamber
Base Dimensions, L x W x H	3.82 x 1.98 m	2.85 x 1.98 m
Surface Area	7.57 m^2	5.64 m^2
Depth	1.4 m	1.4 m

A wooden frame was constructed over the tanks and fitted with industrial grade tarpaulin to prevent the precipitation from entering the tanks and to allow for internal tank heating (Figure 4.11). Sufficient number of electrical outlets was located at the rear of the tanks to provide adequate power supply for the equipment set-up.

Figure 4.11: Holding Tanks for the Sediment Study

4.4.2 Primary dewatering and transfer phase

The three-chamber OGS at Markham was pumped out on December 8, 1998 by a vacuum pumping truck having a total storage volume of 8 m^3. Extra care was taken to ensure that the truck pumping lines and tank were clean prior to and after the transfer of the sludge. Supernatant was carefully evacuated from the chambers by pumping it very slowly from the surface level to the vacuum truck. This transfer process was conducted under supervision of the SWAMP field staff to ensure trapped sediment was not inadvertently pumped with the supernatant. The content from the truck was then discharged to the sanitary sewer. Composite samples of the supernatant discharged from the truck were also collected. An identical procedure was also applied to the other chambers. When all the chambers were properly dewatered in the described manner, the remaining content from the chambers, consisting of a mixture of liquid and sludge, was pumped to the vacuum truck. A small portion that could not be pumped out was transferred manually. Collected samples were composited and submitted for chemistry analysis. As expected, the largest content of sediment was found in the first chamber. When the operation was completed, some 15% of the total volume of the permanent pool (7 m^3) was transferred to the vacuum truck, and eventually to one of the holding tanks at the Toronto Works Yard for sediment analysis. The sludge material filled the holding tank to a depth of 0.53m.

The Stormceptor® units underwent a similar procedure in terms of initial dewatering, sampling and transfer of the tank content on December 9, 1998. The combined volume of the permanent pool in this case was 35.6 m^3. A total of 21.4 m^3 was pumped off each unit. The remaining 14.1 m^3 of liquid and sludge was removed and transferred into the other holding tank at the Toronto Works Yard and filled the tank to an average depth of 1.07 m. When the operation was completed, some 39% of the total permanent pool volume was transferred from the Stormceptor® units to the holding tank. Due to the capacity of the vacuum truck (8 m^3), two trips were needed to transfer the content.

4.4.3 Secondary settling and dewatering phase

The sludge mass in the two holding tanks was permitted to settle under quiescent conditions until December 17, 1998. During this period the sludge material was kept from freezing by electric heat cables laid on the bottom of the tanks and by forced air electric heaters warming the ambient air in the tanks under the tarpaulin roof structure. A plywood platform (Figure 4.12) was built over the holding tanks to accommodate the electric heaters and automatic water samplers. One pair of samplers was used to collect the water quality samples, and another pair to gradually dewater the tanks.

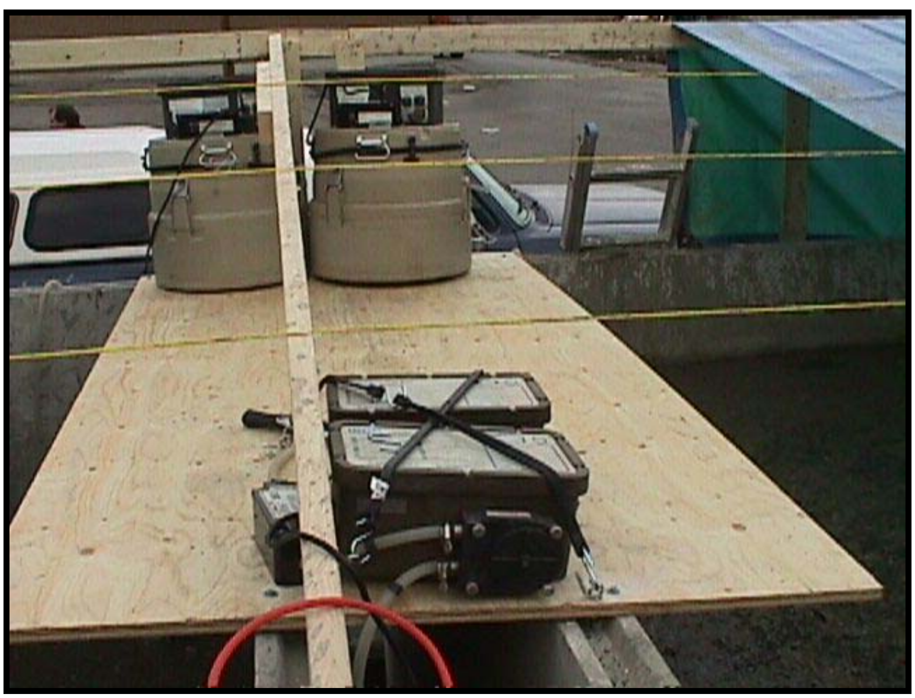


Figure 4.12: Sampling Platform Built Over the Sediment Tanks

On December 17, 1999, after 9 days of settling, pumps were activated in each tank to draw off the upper layer of liquid in the tank. The intake ports of the pumps were suspended by floats at about 10 cm below the liquid surface and pumping was undertaken slowly to avoid collecting surface oils and floatables and disturbing the settled sediments. Water samples were collected at the same depth in the tank over the length of the dewatering period at 6 hours intervals and composited at the end of sampling.

The samples were collected for the three-chamber OGS on December 21, 1998 and for the Stormceptor® on December 23 and 29, 1998. After six days of pumping, the dewatering exercise had lowered the level in the tanks as much as possible without disturbing the settled sediment and pumping was terminated. Composite water quality samples collected over the pumping period were submitted to the MOE laboratory for analysis. After dewatering and sampling were complete, the heating cables and forced air heaters were turned off to permit the remaining sludge to freeze under the low external ambient temperatures.

4.4.4 Sediment solidification and sample extraction phase

By January 7, 1999 the sludge from the tank holding the three-chamber OGS content had frozen completely to the bottom (Figure 4.13). Transects were set up across each chamber and three discrete columns of material were collected from each transect. Each column was approximately 32 x 32 cm in area and reached to the bottom of the tank. The thickness of the samples varied from 9 to 14 cm. Columns were cut and extracted as blocks of frozen material. An overview of sampling quantities is given in Table 4.4.

Table 4.4: Sediment Sampling Quantities for the Three-chamber OGS

Parameter / Chamber	**Small Chamber**	**Large Chamber**
Sample volume (liters)	30.6	37.8
Sample mass (kg)	33.3	50.6
Sample density (kg/m^3)	1,090.2	1,338.2

The sludge samples from each transect were composited into two discrete samples and placed in 100-liter vats. The two composite samples were then incubated at 50^o C for four weeks in a ventilated bulk oven until the sludge mass was dry enough for sediment sample handling and submission.

Figure 4.13: Content in the Sediment Tank Subject to Freezing

The sludge in the tank holding the Stormceptor® content had a much greater depth when dewatering and water sampling were conducted, and a longer period was needed to adequately freeze the content. By January 13, 1999, 6 days after collection of the samples from the three-chamber OGS, the Stormceptor® unit mass had still not frozen adequately for solid phase extraction. Consequently, a different method of sample column collection was adopted. Again transects were established in both the large and small chambers and three discrete samples were collected from each transect. At each sampling point along the transect, a 10 cm circle was cut into the ice layer, which was about 10 cm in thickness, and removed. The 10-cm cylindrical tube was inserted vertically through the hole to the bottom of the tank. Then the entire sludge content within the tube was drawn up to a sampling bucket by a vacuum pump. The tube was subsequently retracted from the sludge to minimize disturbance of settled sediment. This procedure was continued for the remaining five column samples. An overview of sampling quantities is given in Table 4.5.

Table 4.5: Sediment Sampling Quantities for the Stormceptor® OGS

Parameter / Chamber	**Small Chamber**	**Large Chamber**
Sample volume [liters]	17.05	17.29
Sample mass [kg]	20.55	19.15
Sample density [kg/m^3]	1,205.00	1,107.00

The samples from each transect were composited into two discrete samples and placed in the ventilated incubation oven at 50^{o} C for 32 days until the sample was dry enough for sediment handling and submission.

4.5 Computer Modelling

The hydrologic and water quality performance of the two OGS were modelled using PC-SWMM 98, a version of the EPA SWMM model. The model simulates influent and effluent hydrographs and predicts sediment accumulation rates with the facility based on measured flow volumes, TSS loads and precipitation records for the entire study period. Estimates of sediment accumulation rates over the study period were compared to actual sediment accumulation measured in the offline tanks at the end of the study to help assess potential errors in field monitoring results.

5.0 STUDY RESULTS: WATER QUANTITY

5.1 Rainfall and Runoff Analysis for the Three-chamber OGS, Markham, Ontario

During the period from May 1997 to December 1998, a total of sixty events were monitored at the site. Rainfall data at Buttonville Airport were available for thirty events occurring during the growing season. Average rainfall for these events was 11.4 mm, with a range between 1.8 and 28.6 mm. Mean rainfall intensities averaged 2.1 and ranged from 0.5 to 6.8 mm/hour. Twenty out of thirty rainfall events resulted in significant runoff volumes. Although the Buttonville Airport is approximately 3 km away from the site, it was assumed that, on average, rainfall was similar at the site. Significant runoff was recorded for twenty monitored events. An overview of rainfall data for selected events (i.e. events for which flow and rainfall data were available) is provided in Appendix B, Table B1. The table includes storm date; rainfall volume, average and maximum hourly rainfall intensity recorded at Buttonville Airport, the measured runoff volumes at the site and estimated volumetric runoff coefficients.

A stage-discharge equation developed from measured data (Figure 4.3) was used to calculate runoff. Runoff determined by this method provides a more consistent and less variable measurement of flow than could be obtained by using observed data for individual events because flow measurement anomalies due to, for example, debris in the flow stream or temporary sensor malfunction, are averaged out over a number of events.

The average volumetric runoff coefficient was 0.85, indicating that 85% of the total volume of rainfall falling within the drainage area passes through the system as stormwater runoff. This is a reasonable runoff coefficient given the high level of catchment imperviousness.

Figure 5.1 shows the correlation between rainfall depth and the observed and calculated runoff volume. As expected, a strong correlation (R^2=0.81) exists between the rainfall depth and runoff volumes calculated using the stage-discharge curve, suggesting that the rainfall recorded at Buttonville airport provided a reasonable estimate of actual rainfall at the site.

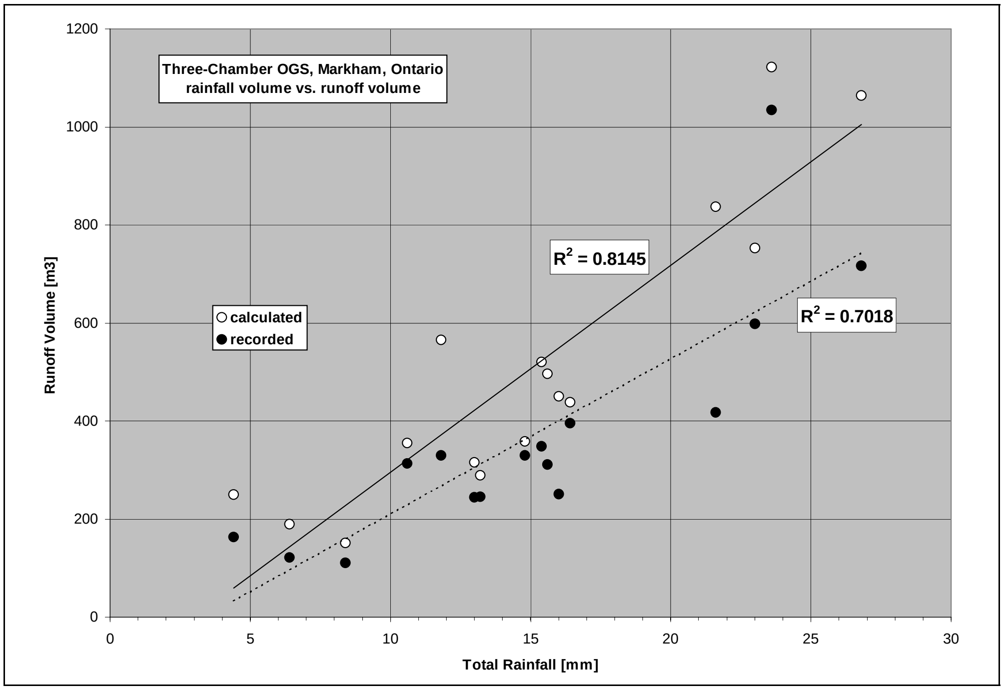


Figure 5.1: Total rainfall depth vs. runoff volume, Three-chamber OGS

Hydrographs for four characteristic events are presented in Appendix B (Figures B2 to B5). These events represent large and small runoff events monitored during the study. The response of the system to rainfall was almost instantaneous, as may be expected from a small and highly impervious area. Outflow peaks rapidly as the storm progresses, and recedes very soon after the precipitation subsides, indicating that the drawdown time and peak flow attenuation capacity of the OGS are negligible. The absence of significant flow control is not surprising in view of the relatively low storage-to-drainage area ratio and lack of extended detention capability. Similar findings have been reported in other studies of OGS (see chapter 2).

5.2 Rainfall and Runoff Analysis for the Stormceptor® OGS

At the Etobicoke site, a total of 44 events were monitored from August 1997 to December 1998 at two gauging stations 3 and 5 km from the site. Rainfall data were available for only 24 of these events because rainfall was not measured at the gauging stations during the winter. Rainfall depths for these 24 events averaged 11.8 mm, ranging between 2.3 and 36.8 mm. Mean rainfall intensities averaged 2.3 mm and ranged between 0.4 and 8.6 mm. An overview of rainfall data for selected events (i.e. events for which flow and rainfall data were available) is provided in Appendix B, Table B2. As at the Markham site, the table includes storm date; rainfall volume, average and maximum hourly rainfall intensity, the measured runoff volumes at the site and estimated volumetric runoff coefficients.

As discussed in section 4.3.3, runoff volumes were calculated from weir and outflow measurements. The wide variation in runoff coefficients (Table B2) and the relatively poor relationship between rainfall depths and runoff (Figure 5.2) reflects the relatively coarse method used to estimate runoff (see section 4.3.3).and potential differences between rainfall measured at the gauging station (approximately 3-5 km away) and actual rainfall occurring at the site. The average runoff coefficient for all events monitored was 0.98, indicating that the majority of rainfall falling within the drainage area passed through the OGS as stormwater runoff.

Figure B6 shows the frequency and water level (in unit #2) at which overflow occurred (i.e. runoff bypassed the system). In general, there were few overflows and those that did occur were of relatively short duration. Hence, effluent concentration and removal efficiency estimates provided in this study are based largely on flows that passed through the treatment chamber of both units.

An interesting observation relates to the flow rate at which overflow was activated. The maximum design treatment capacity of each unit was 50 L/s without overflow, meaning that the combined treatment capacity for both units was 100 L/s. However, as shown in Appendix B, Figure B6, overflow actually occurs at a depth of 160 mm, corresponding to a flow rate of only 70 L/s. This result is a consequence of the asymmetrical "Y" splitter configuration, which distributes larger flows to the monitored unit[1]. It should be noted that if flow had been equally distributed to the two parallel units, there would have been fewer overflows and more similar flow rates in the two units, which may have improved the overall capacity of the system to treat stormwater pollutants.

The hydrographs for four typical small and large events are presented in Appendix B, figures B7 to B10. The system responded in a manner similar to the 3-chamber OGS site (i.e. quickly and with minimum drawdown), but higher rainfall intensities were generally required to generate runoff, probably due to the surface storage available in the loading and parking areas, although differences between on-site rainfall and that measured at the gauging station may also be a factor. On May 10, 1998 (Appendix B, Figure B7), low intensity precipitation was recorded for more than six hours before any measurable runoff at the site was observed.

The similarity in precipitation and outflow durations indicated that detention times were generally short and, as expected, the OGS units provided little benefits in terms of runoff control. During large events, some peak shaving may have occurred due to upstream storage provided in the sewer network.

[1] This hypothesis was confirmed by a hydrant test and further flow monitoring of water levels in both units in 2000.

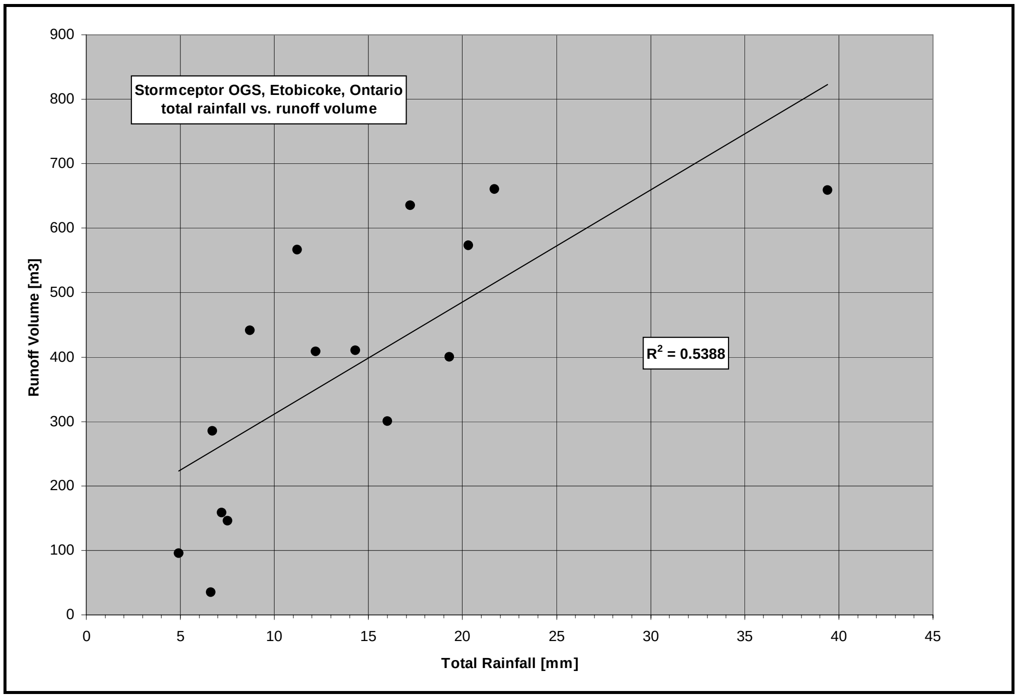


Figure 5.2: Rainfall depths (mm) at the gauging station vs. runoff volumes, Etobicoke, Stormceptor® OGS

6.0 STUDY RESULTS: WATER QUALITY AND SEDIMENT

6.1 Three-chamber OGS, Markham, Ontario

6.1.1 Water Chemistry

Water quality results are summarized in Appendix C, Table C1. The table includes: (i) number of samples, (ii) arithmetic average, minimum, maximum and median value, (iii) upper and lower 95% confidence intervals, and (iv) the correlation between TSS and other parameters.

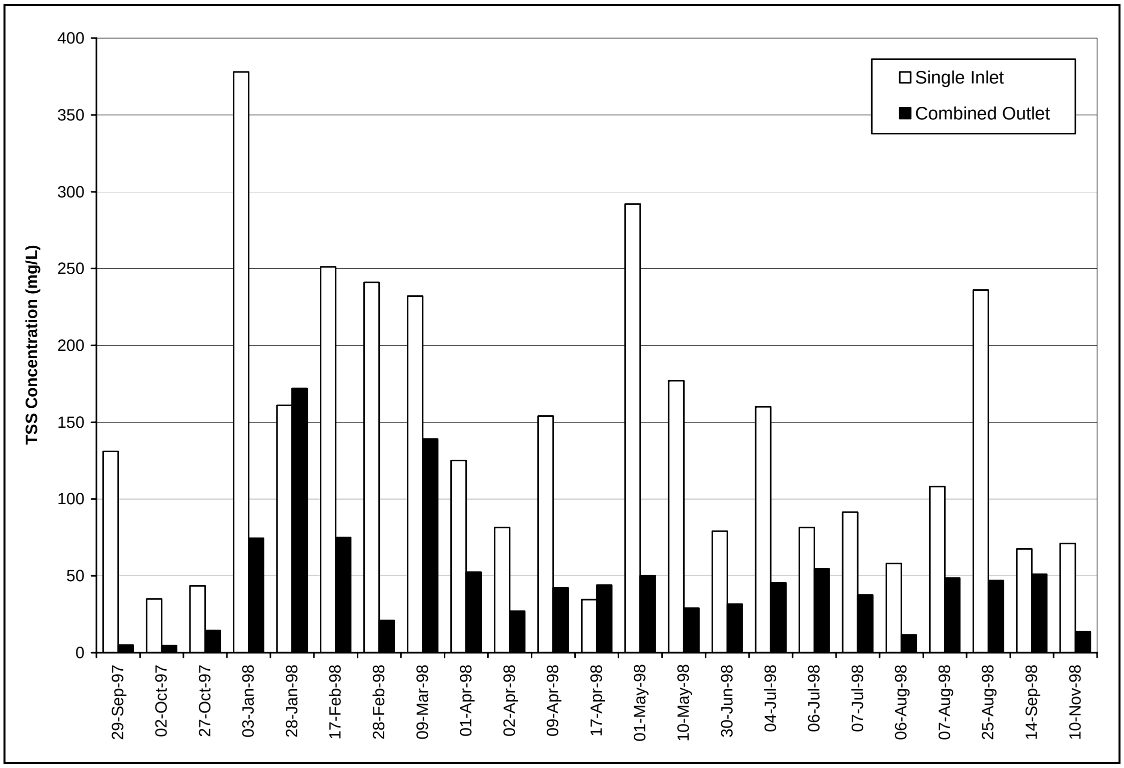
Probability distribution analysis revealed that the influent TSS and oil and grease (O&G) data were log normally distributed, but the effluent TSS data were not (Appendix C, Figures C3 to C4). To facilitate comparison between influent and effluent results, the median value, which is not influenced by probability distributions (i.e. it is a nonparametric or distribution free statistic), is reported here as a best estimate of the true mean value of the influent and effluent data sets.

Based on 26 samples (Appendix C, Table C1), the TSS concentrations at the inlet had a median value of 109 mg/L, with a range between 34 and 378 mg/l. By comparison, the median effluent concentration for 54 events was 40 mg/L, with a range between 4 and 268 mg/L. Figure 6.1 shows TSS and O&G concentrations at the inlet and outlet during individual events.

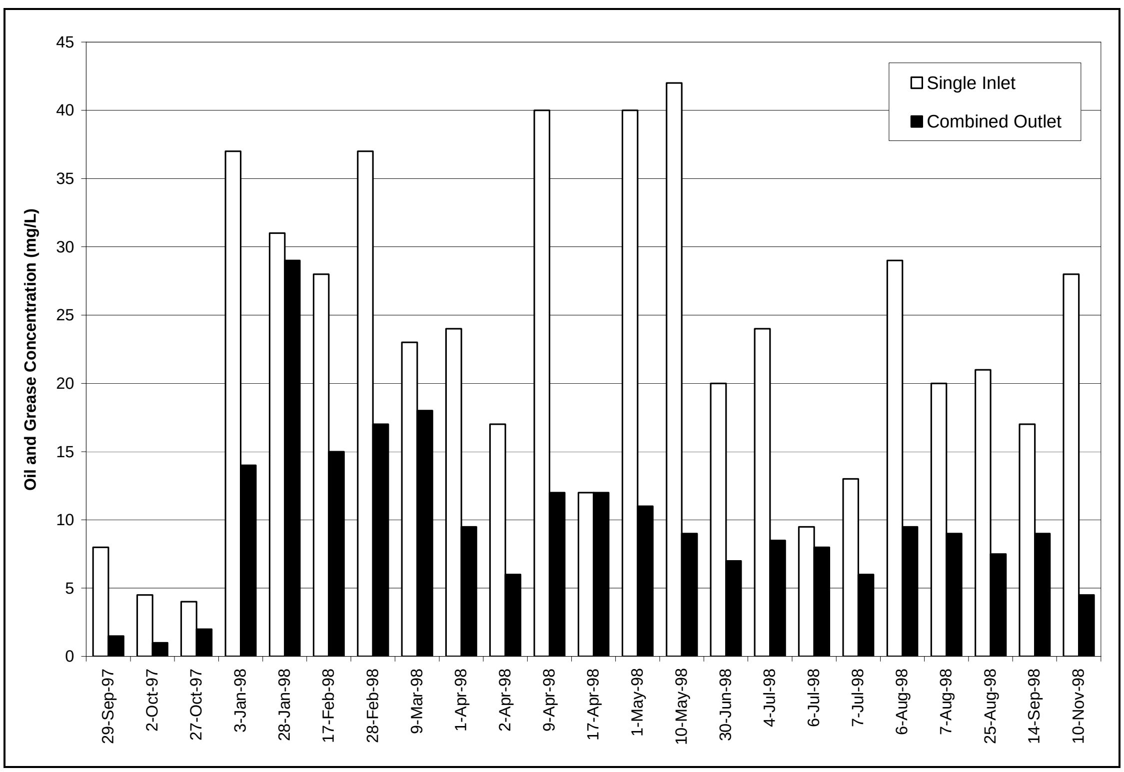
Most metal concentrations were strongly correlated with TSS. Coefficients of determination (R^2) indicated that between 50 and 80% of the variation in heavy metal concentrations were explained by variations in TSS. O&G was similarly well correlated with most metals. The highest concentrations were measured in winter and early spring, approximately from January 1998 to April 1998, corresponding to winter road maintenance activities.

Figure 6.2 shows the relationship between influent and effluent concentrations for two main parameters of interest, TSS and O&G. The relationship, albeit weak, indicates that, in general, dirtier catchments will produce dirtier effluents. Other stormwater BMPs, such as ponds and wetlands, do not show a similar influent/effluent correlation because these systems have larger storage-to-drainage area ratios resulting in all but the smallest of particles settling out, regardless of influent loading (see other SWAMP studies in this series).

Figure 6.2 also shows that, based on influent/effluent concentrations alone, the level of solids treatment provided varies widely between less than 0 to greater than 80%. Part of the observed variation in treatment is explained by variations in influent concentrations, which are, in turn, affected by storm size, storm intensity, interevent duration (i.e. length of time for solids to build-up between events) and land use activities. The combined effect of these and other factors on system performance requires further research.

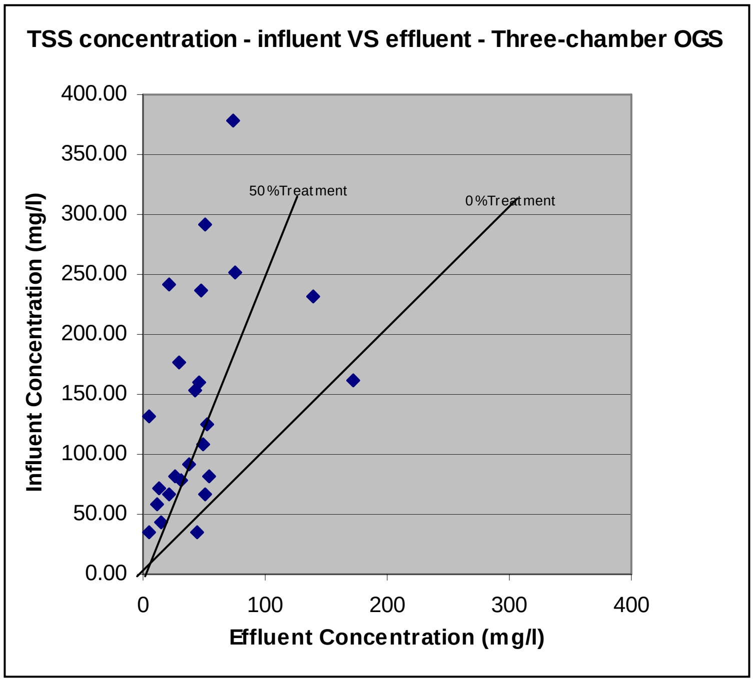


(a)

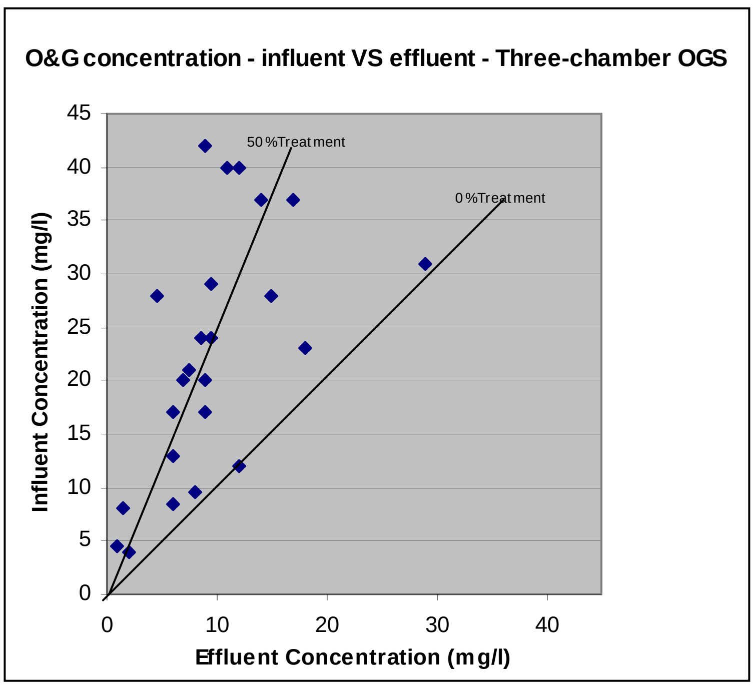


(b)

Figure 6.1: TSS (a) and Oil and Grease (b) concentrations, Three-chamber OGS



(a)



(b)

Figure 6.2: Influent vs. effluent concentration for a) TSS and b) O&G**,** Three-chamber OGS

6.1.2 Particle Size Analysis

The particle size distribution of samples collected at the inlet and outlet stations were analyzed by the MOE laboratory. The lab analytical method is a destructive method in which suspended particles are ground before an optical instrument is used to scan their sizes.

Figure 6.3 presents the average distribution (n=18) and 95% confidence intervals for the inlet and outlet stations. The influent and effluent median particle sizes were 8.7 and 3.8 um, respectively. Although effluent particle size distributions varied widely among events, the median particle sizes were significantly different at the 95% level of confidence.

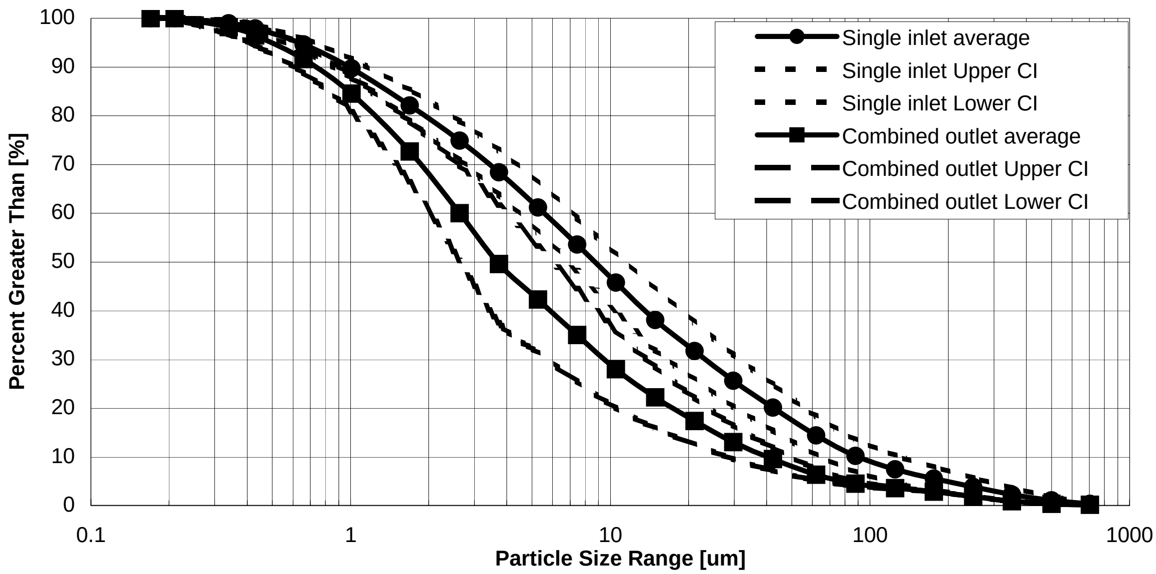


Figure 6.3: Inlet and outlet average particle size distributions and 95% confidence intervals for the Three-chamber OGS

6.1.3 Sediment Accumulation and Sediment Quality

As presented in Section 4.4.4, all the sludge and liquid content of the OGS units was transferred into two separate off-line holding tanks after the OGS units had undergone the dewatering process. In the off-line holding tanks, the sludge settled for one week before undergoing a second dewatering. After the sediment was exposed to freezing temperatures, core sediment samples were extracted from the off-line holding tank, dried for four weeks and then analyzed. An overview of the sediment analysis is given in Table 6.1.

Table 6.1: Sediment Analysis in the Off-line Tank, Three-chamber OGS

Code	Balance component	Formula	Small chamber in the off-line tank	Large chamber in the off-line tank	Sum or average
A	Permanent pool [m^3]		31.4		
B	Transferred to the off-line tanks [m^3]		7.0		
C	Percentage transferred [%]	B/A=	15.6		
D	Wet core sediment Sample volume [L]		30.6	37.8	68.4
E	Wet core sediment Sample mass [kg]		33.3	50.6	83.9
F	Wet core sediment Sample density [kg/m^3]	E/D=	1090.2	1338.2	1214.2
G	Total frozen content volume of accumulated sediment [m^3]		0.68	0.97	1.64
H	Total frozen content mass of accumulated sediment[kg]	F*G=	744.6	1,297.4	2,041.9
I	Dry core sediment sample mass after 4 weeks [kg]		10.7	28.0	
J	Dry sediment content as mass [%]	I/E=	32.1	55.4	43.7
K	*Total sediment mass in the tank [kg]*	*J*H=*	*239.2*	*718.1*	*957.2*

The dry sample mass after four weeks was 10.7 and 28.0 kg for the samples collected from the small and large chambers in the off-line tank, respectively. These dry masses represent 32.1 and 55.4% of total wet mass in samples from the small and large chamber, respectively. Volumetric measurements of the remaining dry content (after the sample was taken) were deliberately excluded from the calculation in order to avoid problems associated with compactness of the material. It has been observed that, especially for fine particles, compactness of the material can cause a change in bulk density of between 40% and 50%. Based on the dry mass, the small and large chambers held 239.2 and 718.1 kg of sediment, respectively.

In total, approximately 957 kg of sediment was transferred from the 3 chamber OGS units to the offline holding tanks. This compares well to the 922 kg of sediment accumulation generated over the same period by the calibrated water quantity/quality model (see chapter 8).

Table 6.2: Sediment quality analysis, Three-chamber OGS

Parameter /sampling date	Units	May 29,97. Three samples collected from large unit of OGS			Dec 02, 97 collected from two units of OGS		Jan 7,99 collected from off-line holding tank		Ontario Sediment Quality Guidelines (ug/g)	
					Larger unit	Smaller unit	Large chamber	Small chamber	Low effect level	Severe high effect level
Organic Carbon	mg/g	63	43	51	84	22	29	92	1%	10%
Chloride	µg/g	No data	No data	No data	No data	No data	130	290		
Mercury	µg/g	0.06	0.04	0.03	0.07	0.02	0.03	0.06	0.2	2
Beryllium	µg/g	0.6	0.6	0.6	0.5	0.5	0.5	0.7		
Magnesium	µg/g	20000	13000	15000	20000	19000	13000	17000		
Aluminum	µg/g	13000	14000	13000	9100	10000	7500	15000		
Calcium	µg/g	130000	110000	120000	120000	150000	120000	120000	0.6	10
Vanadium	µg/g	39	38	36	34	27	27	46		
Chromium	µg/g	74	37	36	59	35	40	77	26	110
Manganese	µg/g	470	470	420	390	560	350	540	460	1100
Iron	µg/g	17000	17000	16000	15000	16000	13000	20000	2%	4%
Cobalt	µg/g	7	7	5.9	5.3	5	13	11		50*
Nickel	µg/g	21	19	17	22	14	14	27		
Copper	µg/g	98	54	57	140	38	62	120	16	110
Zinc	µg/g	360	210	210	600	180	220	540	120	820
Molybdenum	µg/g	1.5	1.1	0.9	2.4	0.7	2.2	2.6		
Cadmium	µg/g	1.9	0.9	1.8	6.3	1.1	0.8	2.2	0.6	10
Barium	µg/g	95	100	90	110	67	56	120		
Lead	µg/g	67	57	53	110	35	55	120	31	250
Strontium	µg/g	280	200	240	170	230	210	230		
Titanium	µg/g	460	460	480	310	330	440	360		
Nitrogen, Kjeld.	mg/g	1	1.4	1.5	1.3	0.4	0.8	0.8	5.5 mg/g	4.8 mg/g
Total Phosphorus	mg/g	0.64	0.52	0.8	0.72	0.56	0.54	0.54	0.6 mg/g	2 mg/g
Total Solids Loss	mg/g	88	78	78	160	44	44	44		
Oil and Grease	mg/g	1.2	9.7	21	35	15	7.4	7.4		0.15%*

* From the Open Water Disposal Guidelines (OWDG)

Sediment quality analysis was based both on the samples collected from the off-line holding tank and samples collected directly from the three-chamber OGS during the study. An overview of sediment quality parameters is given in Table 6.2. The three samples collected on May 29, 1997 were collected as aliquots from the first chamber in the 35 m^3 unit. The two samples collected on

December 2, 1997 were collected from the first chambers of the 35 and 17 m^3 units. The samples collected on January 7, 1999 were the actual samples taken from the small and large chamber in the off-line holding tank.

As indicated in Table 6.2, there were relatively minor differences in sediment quality between the samples collected from the chambers during the study and the samples collected from the off-line holding tank. Metal concentrations in sediments at the OGS sites were above the lowest effect level guidelines for aquatic life, as defined by the province. This is not a specific issue of concern because OGS are not meant as habitat for aquatic life, but it does provide a general sense of the danger to receiving water if sediment is resuspended (due to, for instance, inadequate maintenance) and deposited in rivers or water bodies downstream of the facility. Oil and grease were also very high indicating that special considerations may be required for sediment disposal.

6.1.4 Conductivity Measurement

Conductivity readings were taken using a manual portable meter from all three chambers in both units. These measurements did not reveal any spatial stratification with depth or temporal fluctuations in conductivity by season. This finding indicated that the permanent pool is well mixed, and that there is a high potential for periodic flushing of previously trapped sediments.

6.2 Stormceptor® OGS, Etobicoke, Ontario

6.2.1 Water Chemistry

Water quality results are summarized in Appendix C, Table C2. The table includes: (i) number of samples, (ii) arithmetic average, minimum, maximum and median value, (iii) upper and lower 95% confidence intervals, and (iv) the correlation between TSS and other parameters.

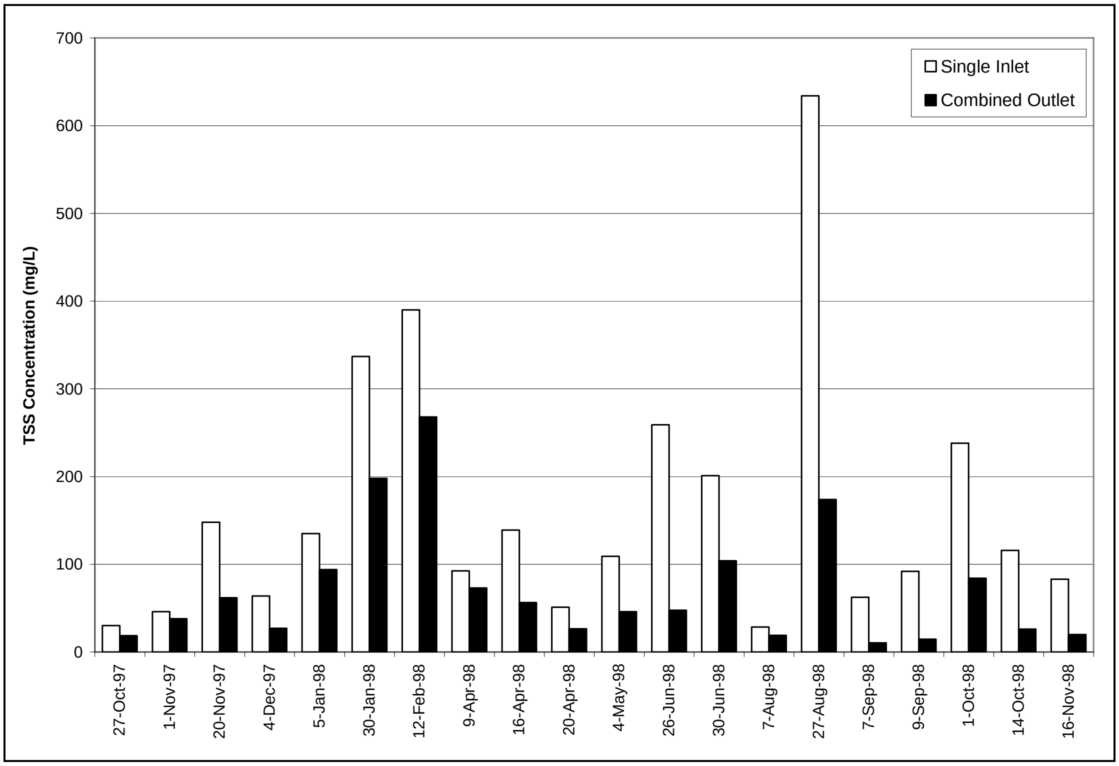
Probability distribution analysis revealed that both the influent and effluent TSS and oil and grease (O&G) data were log normally distributed (Appendix C, Figures C5 to C6). Under these circumstances, the geometric mean would typically serve as the best representation of the true mean of the influent and effluent data sets. However, the median value, a distribution free summary statistic, and also a reasonable estimate of the true mean, was selected for reporting purposes to permit ready comparison of results to the three chamber study.

Based on 20 influent samples and 37 effluent samples, median concentrations were 112 and 48 mg/L, respectively. Influent TSS concentrations ranged from 28 to 634 mg/L, compared to an effluent concentration range of 10 to 451 mg/L. These ranges are considerably wider than at the 3-chamber site in Markham. O&G median concentrations were 17 and 7 mg/L, respectively. Figure 6.4 shows TSS and O&G concentrations at the inlet and outlet during individual events.

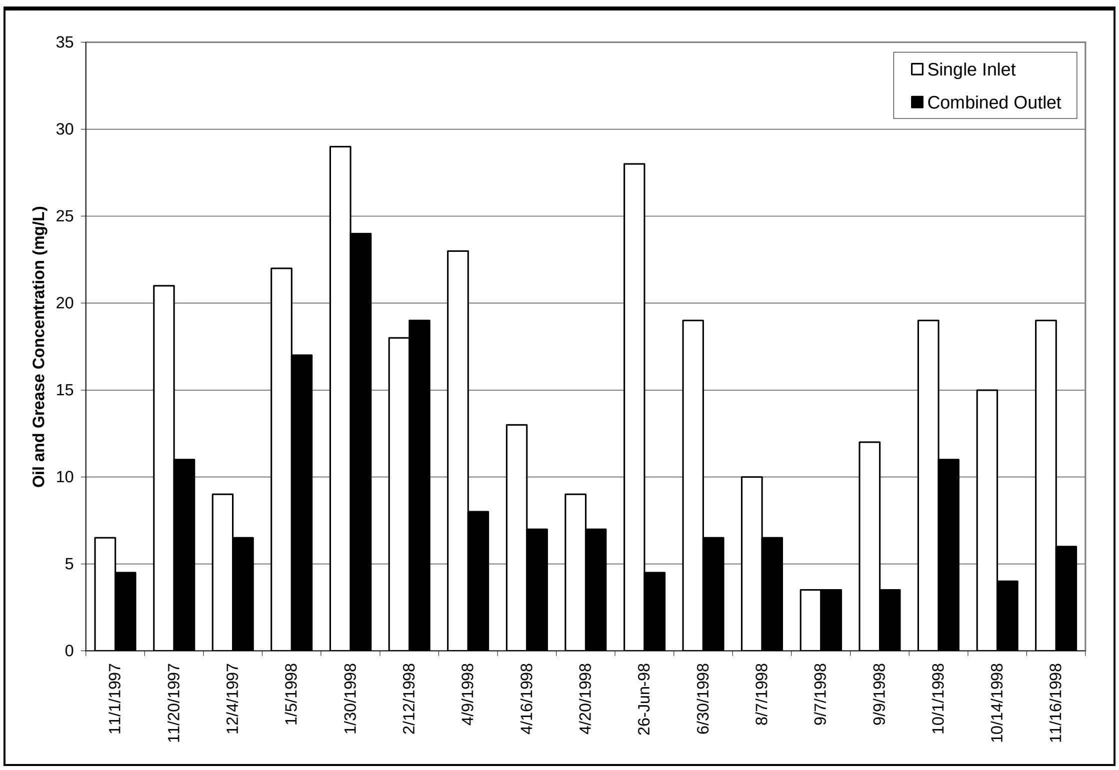
As at the Markham site, most metal concentrations were strongly correlated with TSS. Coefficients of determination (R^2) for most metals ranged between .60 and .90. O&G was similarly well correlated with most metals.

Figure 6.5 shows the relationship between influent and effluent concentrations for two main parameters of interest, TSS and O&G. The relationship, which is stronger (R^2 = 0.7 for TSS) than at the 3 chamber site, suggests that unit sizing should be based not only on the size of the drainage area and level of imperviousness, but also on land use specific pollutant loading potentials. As noted earlier, this has not been a concern for other end-of-pipe facilities, such as wet ponds or wetlands, because the large storage volumes (permanent pool and active storage) in these facilities reduce TSS over the full range of influent concentrations to a level approaching what may be considered a non-settleable or irreducible fraction (between 15 and 40 mg/L) (see other SWAMP studies in this series).

Figure 6.4 also shows that, based on influent/effluent concentrations alone, the level of solids treatment provided varies widely during individual events. Although influent pollutant concentrations/loads explain part of the observed variation in treatment, further investigation is required to identify other event specific causal factors.

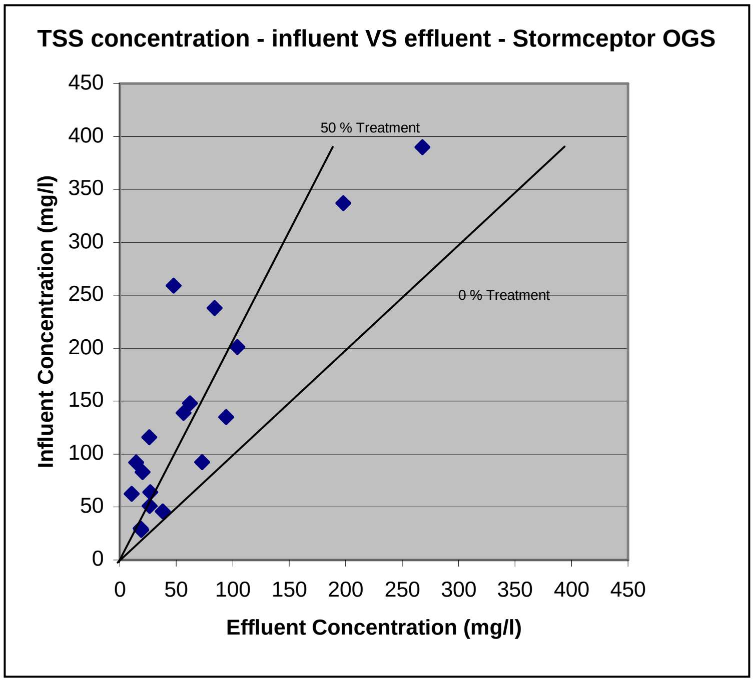


(a)

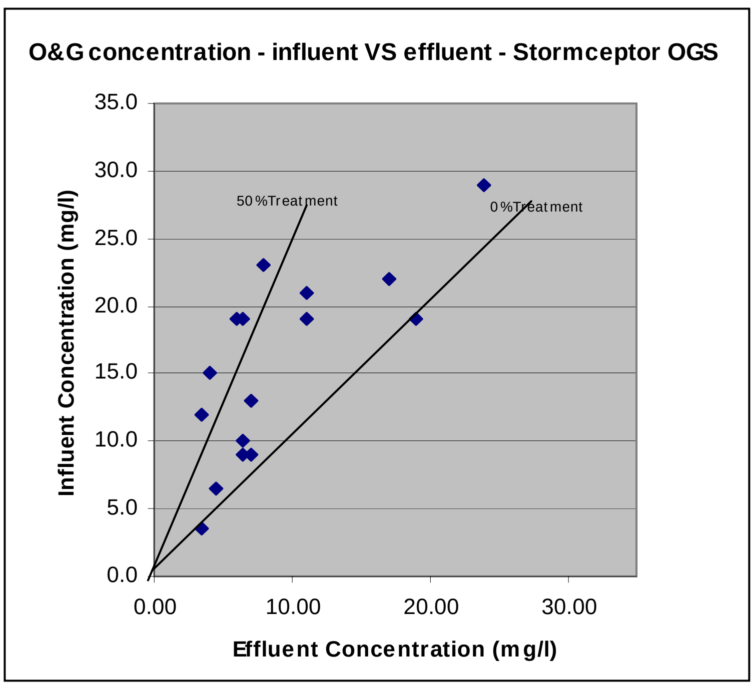


(b)

Figure 6.4: TSS (a) and Oil and Grease (b) concentrations, Stormceptor OGS



(a)



(b)

Figure 6.5: Influent vs. Effluent concentration for a) TSS and b) O&G, Stormceptor OGS

6.2.2 Particle Size Analysis

Figure 6.6 presents the average influent and effluent particle size distribution (n=14) and 95% confidence intervals. The influent and effluent median particle sizes were surprisingly similar; 6.5 and 5.8 µm, respectively. The median particle sizes were not significantly different at the 95% level of confidence.

The finer average influent particle size distribution, relative to the 3-chamber site, may be explained by the availability of temporary storage upstream of the facility on the road surface, settling of coarser solids in catchbasin sumps, and/or finer soil types in the catchment. Further investigation would be required to identify causal factors.

The factors contributing to an average effluent particle size distribution coarser than that of the 3 chamber site are more difficult to identify. Intuitively, the phenomenon of re-suspension of previously trapped sediment, which was observed to be a defining feature of the on-line 3 chamber OGS, would produce a coarser effluent particle size distribution than was observed in the off-line Stormceptor OGS. But this appears not to have been the case. Coarser particles would be expected when overflow occurs, but these were generally infrequent and of short duration. Again, further research and monitoring is required to identify factors that may have contributed to this unexpected result.

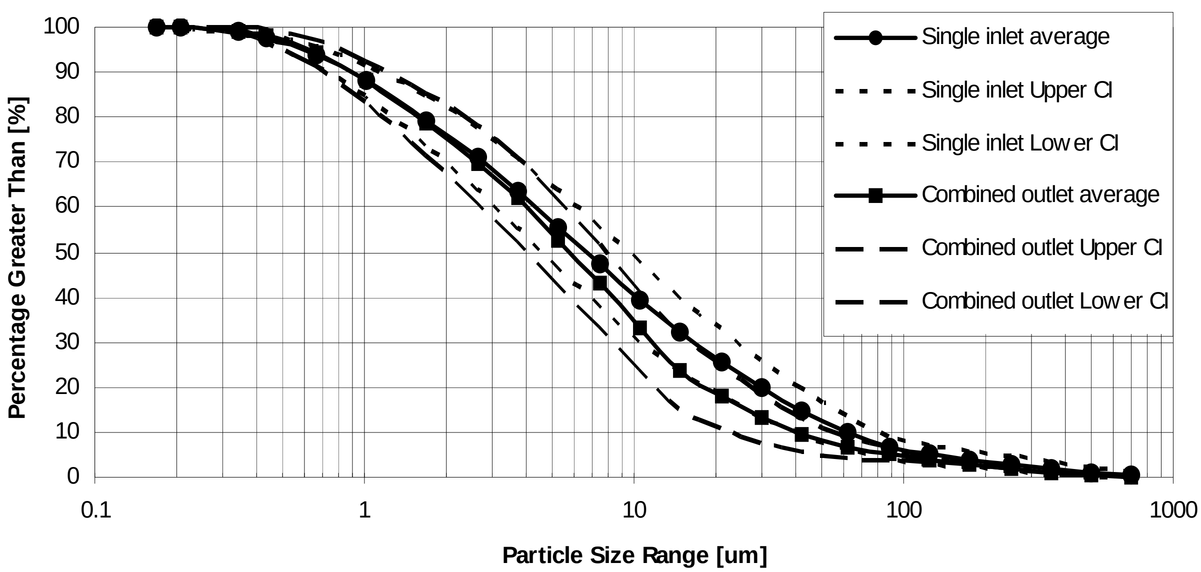


Figure 6.6: Inlet and outlet average particles size distributions and 95% confidence intervals for the Stormceptor®, Etobicoke, Ontario

6.2.3 Sediment Accumulation and Sediment Quality

An overview of the sediment analysis in the two OGS units is given in Table 6.3. The dry sample mass after four weeks was 5.6 kg and 0.65 kg for the small and large chamber, respectively. This resulted in 328.4 kg and 37.6 kg of dry mass per cubic meter of sample, leading to the conclusion that 925.08 kg and 142.28 kg of sediment were transferred to the small and large chamber, respectively. The non-uniformity in sediment content between the two chambers was expected, for the sludge was pumped directly from the vacuum truck into the smaller chamber. The fluid content found its way through the small opening to the larger chamber much easier than heavier and less mobile sludge. In total, approximately 1,067.4 kg of sediment was estimated to have been captured in the two monitored units, which compares well to the 1142 kg of sediment mass generated over the same period by the calibrated water quantity/quality model (see chapter 8).

Table 6.3: Sediment® Analysis in the Off-line Tank, Stormceptor, Etobicoke, Ontario

Code	**Balance component**	**Formula**	**Small chamber in the off-line tank**	**Large chamber in the off-line tank**	**Sum**
A	Permanent pool [m^3]		35.56		
B	Transferred to the off-line tanks [m^3]		14.12		
C	Percentage transferred [%]	B/A=	39.71		
D	Wet core sediment Sample volume [L]		17.05	17.29	34.34
E	Wet core sediment Sample mass [kg]		20.55	19.15	39.70
F	Wet core sediment Sample density [kg/m^3]	E/D=	1,205.28	1,107.58	
G	Total frozen content volume of accumulated sediment [m^3]		2.8166	3.7848	6.6013
H	Total frozen content mass of accumulated sediment[kg]	F*G=	3,394.73	4,191.92	7,586.65
I	Dry core sediment sample mass after 4 weeks [kg]		5.60	0.65	
J	Dry sediment content as mass [%]	I/D=	328.4	37.6	
K	Total sediment mass in the tank [kg]	J*H=	925.08	142.28	1067.37

Sediment quality analysis was based on the samples collected from the small and large chamber in the off-line holding tank during the final phase of the study. The collection of representative sediment samples directly from the treatment chamber was not feasible. An overview of the results is given in Table 6.4. There was a remarkable difference in chloride and O&G content in the sediment samples from the two systems. As shown in Table 6.2 and Table 6.4, chloride content in the Stormceptor® OGS sediment was several orders of magnitude higher than for the three-chamber system, which agrees with earlier observations provided in section 6.2.1. In contrast, considerably higher sediment concentrations of O&G were observed in the three-chamber OGS. This finding was consistent with slightly higher influent O&G concentrations at the 3- chamber site (22 mg/L in Markham vs 16 mg/L in Etobicoke).

Table 6.4: Sediment Quality Analysis, Stormceptor® OGS

Parameter /sampling Date	Units	Jan 13,99 collected from off-line holding tank		Ontario Sediment Quality Guidelines (ug/g)	
		Small chamber	Large chamber	Low effect level	Severe high effect level
Organic Carbon	mg/g	36	11	1%	10%
Chloride	µg/g	8500	50000		
Mercury	µg/g	0.07	0.04	0.2	2
Beryllium	µg/g	0.8	0.5		
Magnesium	µg/g	26000	9100		
Aluminum	µg/g	17000	5600		
Calcium	µg/g	79000	29000	0.6	10
Vanadium	µg/g	41	15		
Chromium	µg/g	41	15	26	110
Manganese	µg/g	850	320	460	1100
Iron	µg/g	26000	9000	2%	4%
Cobalt	µg/g	14	5.1		50*
Nickel	µg/g	26	9.2		
Copper	µg/g	71	26	16	110
Zinc	µg/g	290	110	120	820
Molybdenum	µg/g	1.2	1		
Cadmium	µg/g	1.4	0.5	0.6	10
Barium	µg/g	120	51		
Lead	µg/g	73	35	31	250
Strontium	µg/g	130	80		
Titanium	µg/g	210	100		
Nitrogen, Kjeld.	mg/g	1.2	0.6	5.5 mg/g	4.8 mg/g
Tot. Phosphorus	mg/g	0.82	0.24	0.6 mg/g	2 mg/g
Total Solids Loss	mg/g	94	51		
Oil and Grease	mg/g	2.8	3.7		15%*

*From the Open Water Disposal Guidelines (OWDG)

6.2.4 Conductivity Measurement

Conductivity readings were taken from the treatment chamber in unit #2 using a manual portable meter on several occasions during the study. The results are presented in Figure 6.7. On February 26, 1998, conductivity was constant at approximately 2000 µS/cm to a depth of 1.5 m. Beyond this depth the maximum range of the instrument (20,000 µS/cm) was exceeded. Water samples collected from a depth of 2.0 m were later identified in the laboratory as having a conductivity of 72,700 µS/cm, which corresponds to a chloride concentration of approximately 36,500 mg/L. The depth of the salty layer tended to decrease towards the end of the summer and dissipated entirely by November, just prior to the new salting and sanding season.

The existence of a stratified layer of chloride suggests that turbulent flows causing re-suspension of accumulated solids were minimized in the Stormceptor® OGS. However, the stratification also raised concerns as reduced vertical mixing may decrease the effective storage available for treatment, resulting in poorer pollutant removal during the winter and spring.

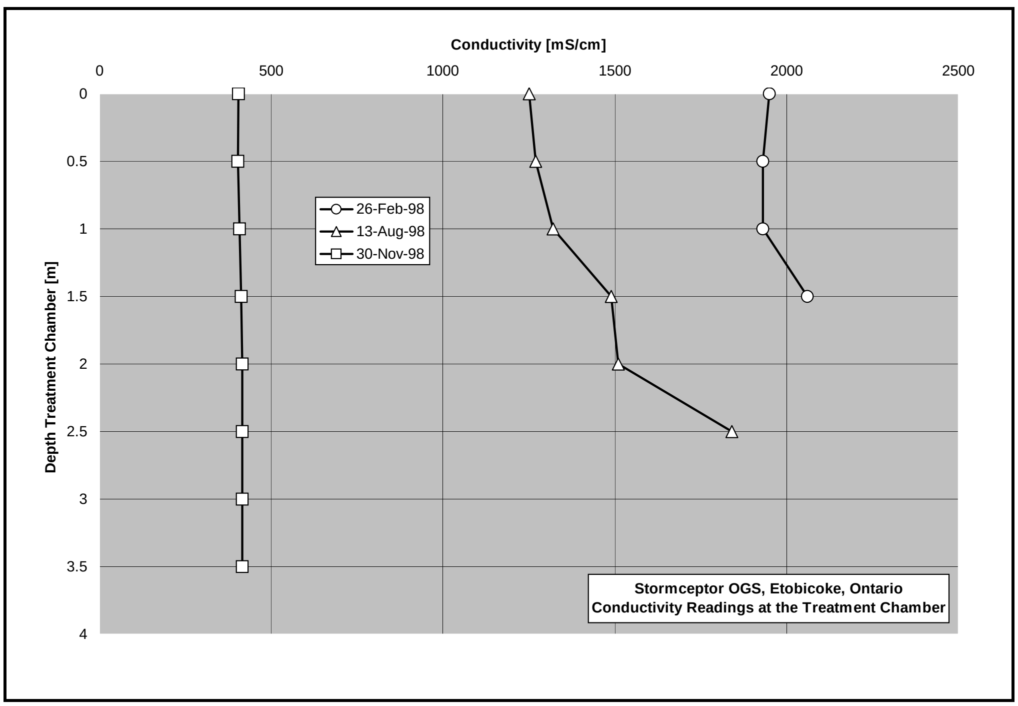


Figure 6.7: Conductivity Readings at the treatment chamber, Stormceptor OGS.

Note that the reading at 1.5 m depth on February 26 exceeded the maximum limit of the instrument (20,000 mS/cm). Lab analysis of a sample taken at this location revealed the actual conductivity to be 72,700 mS/cm.

7.0 STUDY RESULTS: REMOVAL EFFICIENCIES

7.1 Introduction

In this study, OGS performance is assessed based on effluent concentrations and load based removal efficiencies for TSS, heavy metals and oil and grease. Removal efficiencies, which are the focus of this chapter, are assessed for the entire study period based on the total mass of pollutants entering and exiting the OGS units, as follows:

$$\textit{Total Load [\%]} = \frac{\sum_{i=1}^{n}(EMCin_i * V_i) \;-\; \sum_{i=1}^{n}(EMCout_i * V_i)}{\sum_{i=1}^{n}(EMCin_i * V_i)} \quad \text{…(Equation 4)}$$

Where *V* represents the total volume of runoff passing through the system and EMC refers to an approximation of the event mean concentration at the inlet and outlet of the facility for selected water quality variables. As noted in chapter 4, the influent EMC is measured at the inlet of only one of the two parallel units based on the assumption that the flow stream is well mixed, resulting in similar concentrations entering both units. Note that this assumption was never verified. An analysis of the potential error associated with this assumption is provided at the end of this chapter.

7.2 Three-chamber OGS Removal Efficiencies

The total load based removal efficiencies for TSS, O&G and selected metals typically found in stormwater runoff are presented in Figure 7.1. Removal efficiencies ranged from 29% for cobalt to 62% for zinc. TSS and O&G had removal efficiencies of 57 and 51%. Continuous model simulation results for all storms occurring over the study period indicated a total load TSS removal efficiency (62%) marginally higher than field monitoring results (see chapter 8). Note from chapter 6 that the metals of particular concern with respect to effluent concentrations include iron, lead, zinc and copper. These contaminants had removal efficiencies ranging from 40 to 62%.

Total suspended solids and oil/grease removal efficiencies during individual events are presented in Appendix D, Table D1. Results show a large variation among events (n=19), with a range for TSS between –81 and 96%, and a range for O&G between –200 and 84%. The cause of these wide variations is unknown. Further analysis showed no relationship between removal efficiencies and runoff volumes (Figure 7.2), or removal efficiencies and the date of sampling (Figure 7.3). Other climatic and site factors that, alone or in combination, would be expected to influence removal efficiencies include the average and maximum rainfall intensity, the particle size and mass of sediment within the drainage area prior to the storm, as well as the volume and particle size distribution of sediment in the chambers (the latter of which may influence the potential for resuspension of trapped sediment).

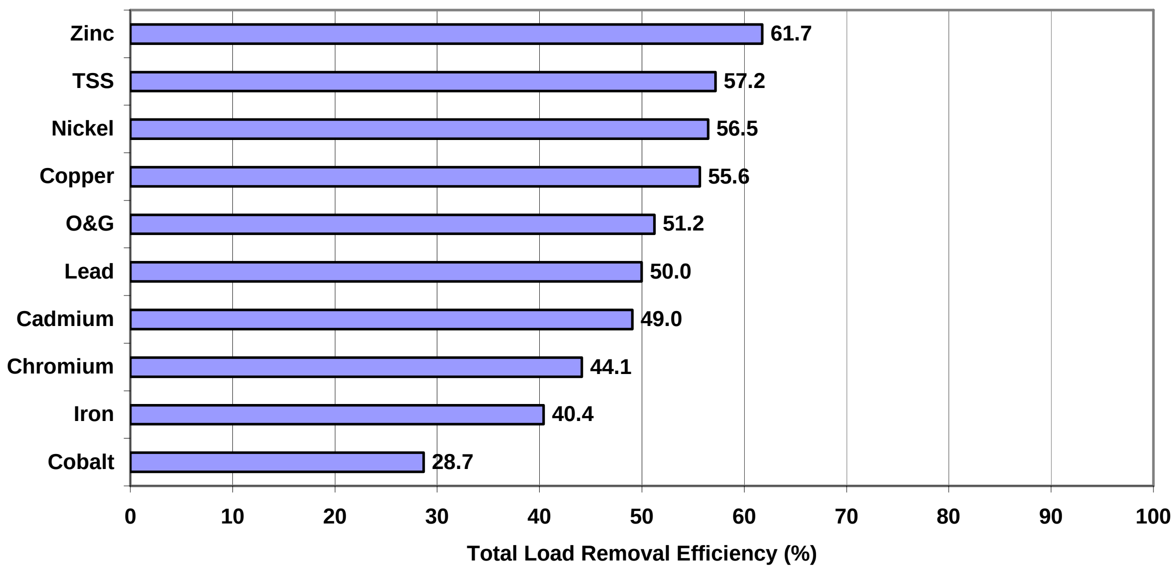


Figure 7.1: Load based removal efficiencies for TSS, O&G and selected metals, Three chamber OGS, Markham.

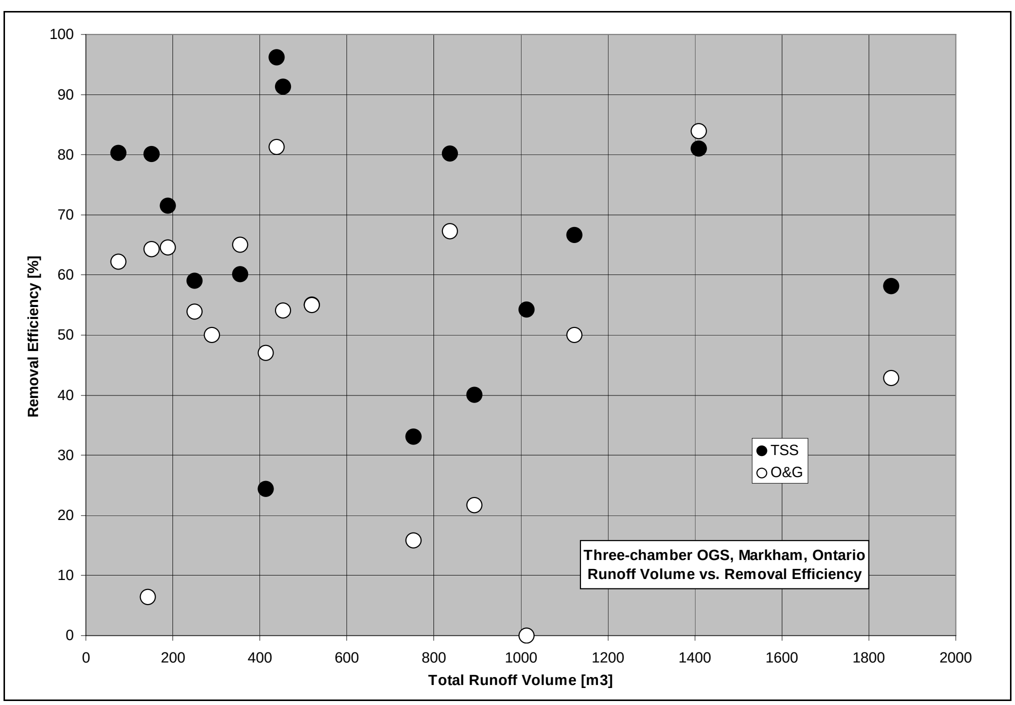


Figure 7.2: Total runoff volume vs. removal efficiency, Three-chamber OGS, Markham

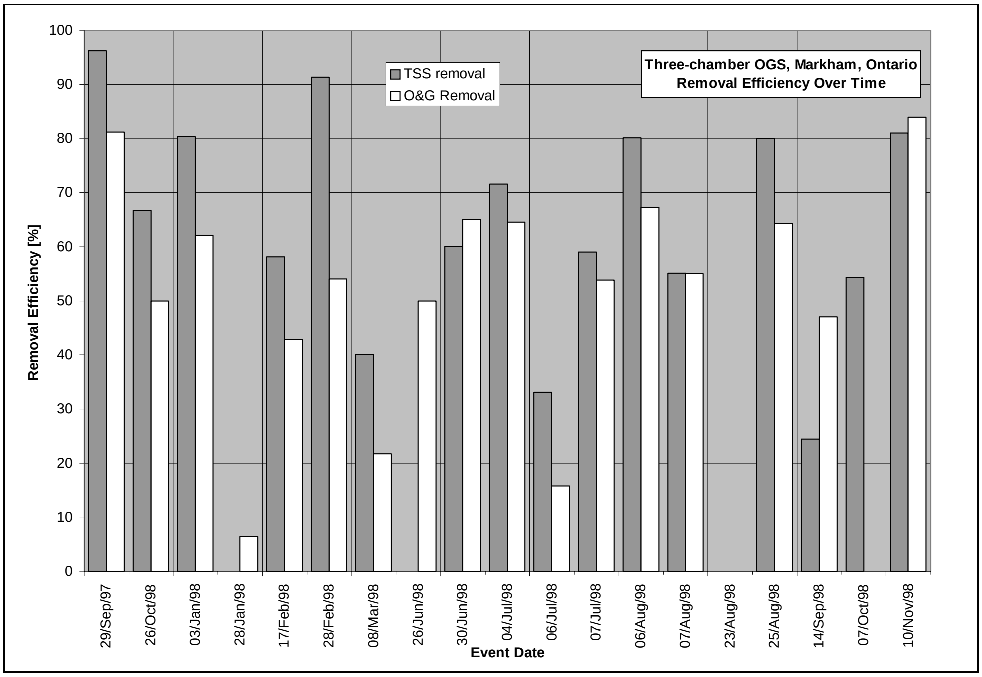


Figure 7.3: Event removal Efficiency over Time, Three-chamber OGS

Influent TSS concentrations above 200 mg/L were typically associated with removal efficiencies of at least 40%. However, over the full range of observations, influent concentrations were not well correlated to removal rates (Figure 7.4). O&G influent concentrations were also not well correlated with removal efficiencies. In this context, it should be noted that while dirtier influents do not result in poorer pollutant removal rates, dirtier influents do generally produce dirtier effluents (see section 6.1.1), and thus the overall capacity of the OGS to reduce contaminant levels to desired levels is typically compromised when pollutants within the catchment are elevated.

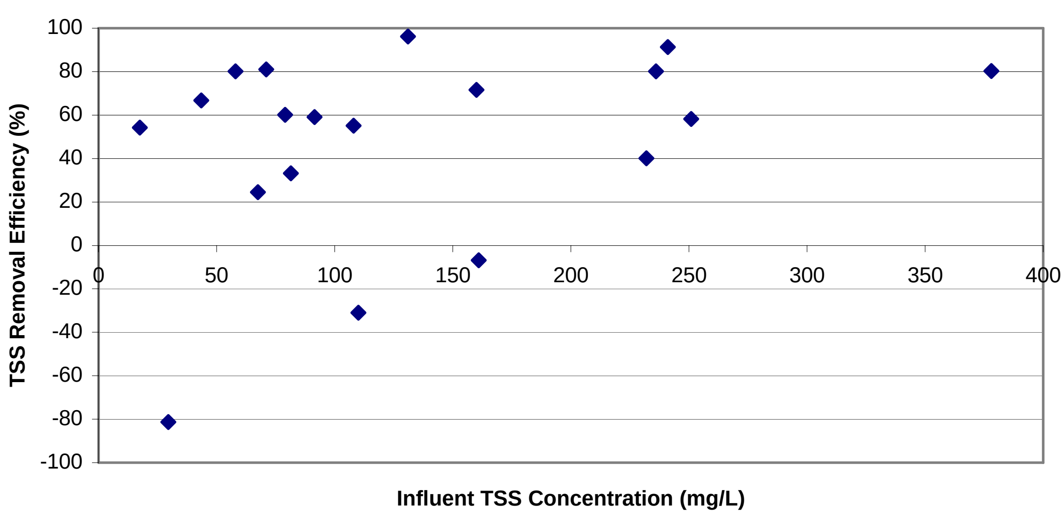


Figure 7.4: Influent TSS concentration vs TSS removal efficiency, 3-chamber OGS, Markham

7.3 Stormceptor® OGS Removal Efficiencies

Figure 7.5 presents total load based removal efficiencies for TSS, O&G and selected metals at the Stormceptor® site. Removal efficiencies ranged from 42% for lead to 61% for TSS. Continuous simulation results for all storms occurring over the 16-month study period also indicated a total load TSS removal efficiency of 60% (see chapter 8). O&G had a removal efficiency of 44%, which lies roughly within the middle of the removal efficiency range for metals. Analysis of effluent concentrations in chapter 6 indicated that iron, lead, zinc and copper were the metals of particular concern with respect to the protection of receiving waters.

Individual event removal efficiencies for TSS and oil/grease are presented in Appendix D, Table D2. Results show less variation among events than observed at the 3-chamber site, with a range for TSS between 4 and 83% (n=16), and a range for O&G between –6 and 84% (n=13). Removal efficiencies were not related to runoff volumes (Figure 7.6), which is not surprising given the stormwater management concept for the Etobicoke site includes flow control (*i.e.* upstream storage) and other factors, such as interevent duration, can influence removal rates.

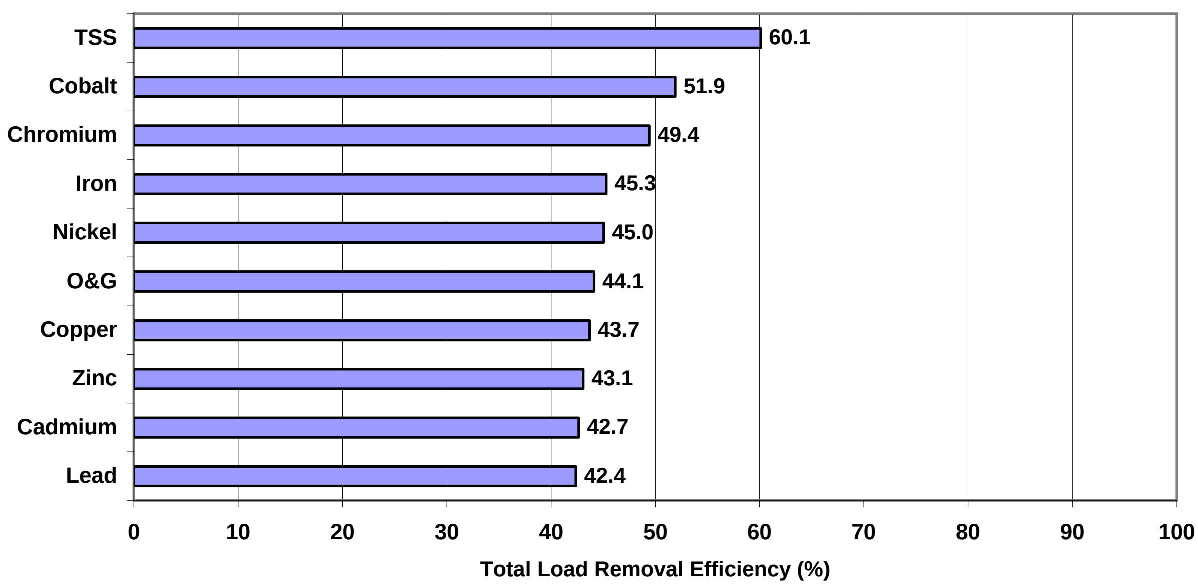


Figure 7.5: Load based removal efficiencies for TSS, O&G and selected metals, Stormceptor OGS, Etobicoke.

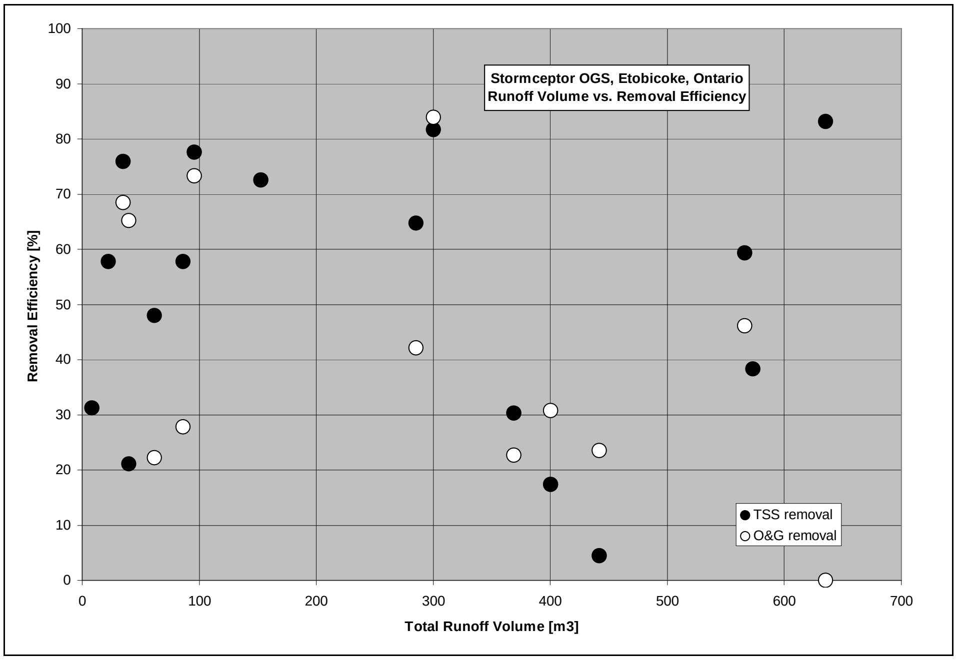


Figure 7.6: Runoff volume vs. removal efficiency, Stormceptor® OGS, Etobicoke.

Better removal for TSS and O&G generally occurred during the summer and fall (Figure 7.7), although this was not always reflected in lower summer/fall effluent concentrations (see Figure 6.4). Chloride stratification during the winter and spring (see section 6.2.4) and longer interevent durations (due to the snow and melt cycle) may influence removal efficiencies, but further research is required to identify the extent of this effect. .

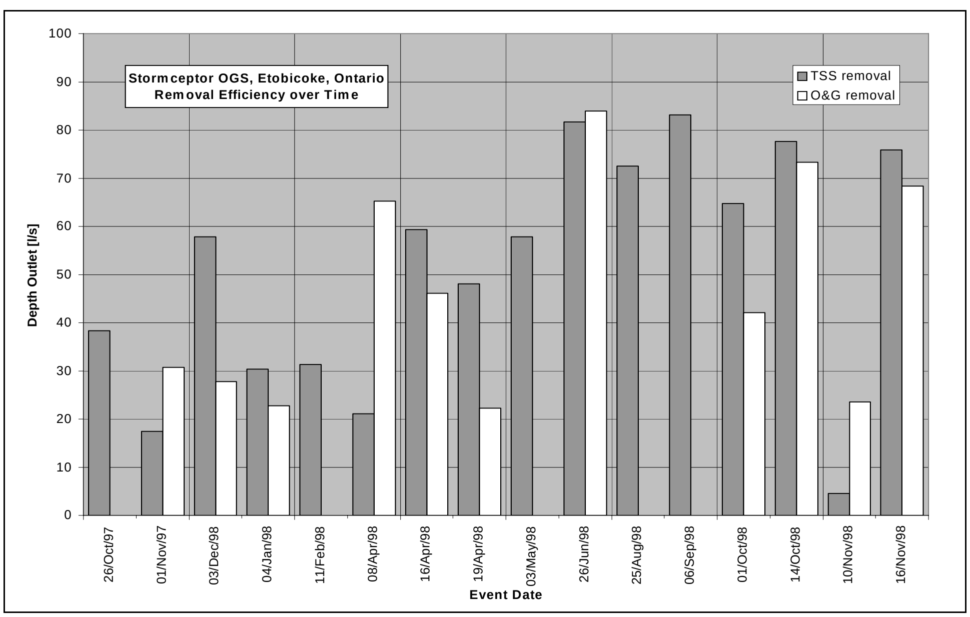


Figure 7.7: Removal efficiency over time, Stormceptor® OGS, Etobicoke

Influent TSS concentrations and removal efficiencies were not well correlated (Figure 7.8), although the lowest removal rates generally did occur at lower influent concentrations, as observed in other studies of stormwater BMPs (GeoSyntec Consultants et al., 2002). The same observation did not hold true for O&G. As noted earlier, good removal rates can occur in combination with elevated effluent concentrations. Therefore, performance should be based on an evaluation of both the removal efficiency and effluent quality.

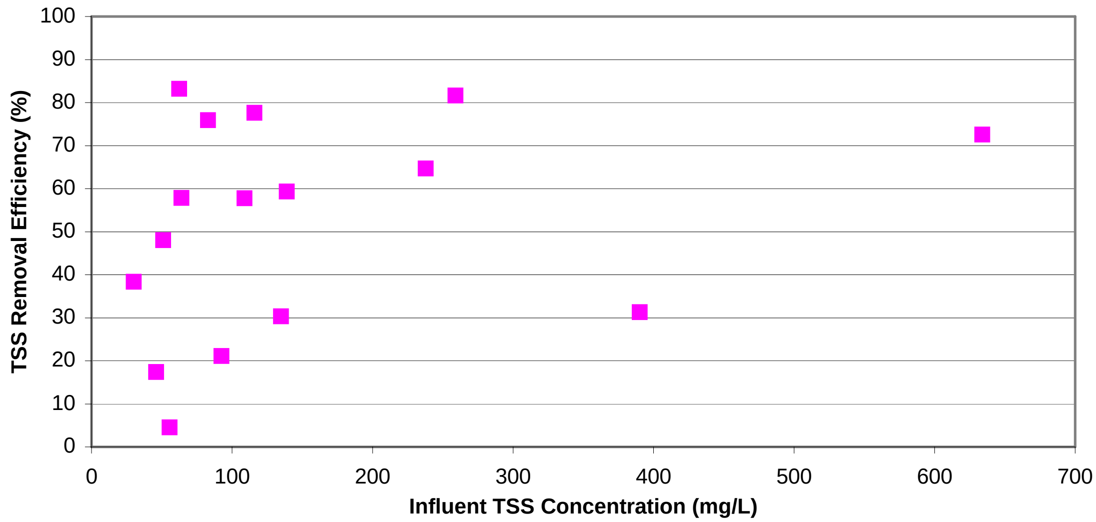


Figure 7.8: Influent TSS concentration vs TSS removal efficiency, Stormceptor OGS, Etobicoke

7.4 Analysis of Potential Errors

There was some concern that the performance results for both OGS types may be biased because influent concentrations were measured at only one of the two inlets, whereas effluent concentrations were measured from the combined discharge of both units. To estimate the potential error associated with unequal influent TSS concentrations, total TSS load calculations were repeated assuming that: (i) inflow was equally distributed between the two units; and (ii) influent TSS concentrations in the unmonitored unit differed consistently (*i.e.* during all events) by ±20% and ±40% from that measured in the monitored unit. Results of these scenarios for the 3-chamber OGS indicated a total load TSS removal efficiency range of between 52 and 61% for the ±20% scenario and between 46 and 61% for the ±40% scenario. For the Stormceptor® OGS, the removal efficiency ranges were 56 to 64% and 50 to 67% for the same two scenarios. These ranges narrow slightly if the error calculations account for larger flow volumes entering the monitored unit, which is known to occur at both sites.

The potential error associated with flow measurement inaccuracies were estimated by randomly varying the measured flow rate among events by ±20%. This exercise was repeated for several randomly generated combinations resulting in an error range in TSS removal efficiencies at both sites of approximately ±3%. A consistent increase or decrease in flow volumes by exactly the same magnitude for all events would, of course, have no impact on removal efficiencies because a perfect flow balance through the OGS is assumed.

Another source of error relates to the use of removal efficiencies as an indicator of performance. Removal efficiency is a biased indicator of performance because the fraction of pollutants removed by hydrodynamic separators (and stormwater BMPs generally) is partly a function of the influent concentration (Geosyntec consultants et al., 2002). Thus a performance evaluation based solely on removal efficiencies can lead to misleading conclusions, especially when additional water quality storage or treatment provided upstream of the OGS facility contributes to cleaner influents. Effluent concentrations or loads are a more reliable indicator (*i.e*. not subject to the errors noted above) and in any assessment of OGS performance, should be evaluated in combination with removal efficiencies, and in relation to effluent concentration ranges of other similar technologies.

7.5 Comparison to the other studies

7.5.1 Three chamber OGS, Markham

The performance of the Markham 3-chamber OGS (average TSS removal of 48%) was marginally better than the 2-chamber OGS in Austin, Texas (average removal of 41%), reported in section 2.4.1. The Seat Pleasant study showed lower removal possibly because the facility was not subject to regular sediment clean-outs. The study in Boston of a two chamber OGS also showed poorer performance than the Markham 3-chamber OGS, although the range of removal efficiencies during individual events was similar, suggesting that the differences in average performance may not be statistically significant.

7.5.2 Stormceptor®, Etobicoke

The performance of the Etobicoke study lie within the range of results reported in studies of Stormceptor® OGS provided in section 2.3.5. The Madison Wisconsin study, which monitored 45 events, reported an average removal efficiency of 29 to 33% (including bedload), which is less than the 51% average load based removal (60% total load) reported in the Etobicoke study. The Madison study was conducted in a public works yard with exposed salt and sand piles, which would typically be expected to improve removal (although effluent concentrations would be higher) by increasing the amount of coarse material that readily settles out in Stormceptor® OGS. However, this appears not to have been the case, suggesting that other factors related to the design or maintenance of the unit relative to the catchment may have influenced performance.

Other studies reported in section 2.3.5 included very few events, or monitored only a limited range of event sizes, calling into question the credibility of results. Two of the studies –in Edmonton, Alberta and Charlottesville, Virginia - reported removal efficiencies of 53 and 57%, which closely mirror the findings of the Etobicoke study. Three other studies reported higher removal efficiencies, ranging between 76 and 93%, although the sample size in each case was very small. In general, the level of information provided in the studies reviewed in section 2.3.5 on system design characteristics, monitoring protocols, effluent concentrations and other factors was insufficient to allow for meaningful inter-study comparisons.

8.0 COMPUTER MODELLING

The relevant information gathered at both study sites was used to initialize, calibrate and apply a mathematical model. The main purpose of the modeling exercise was to:

- Generate estimates of TSS loading and performance for the entire study period, including events for which field data at one or more monitoring stations were not available;
- Verify field performance results, and
- Estimate the total mass of sediment captured in the OGS units during the study period

The modeling package selected for this study was PC-SWMM 98, a version of the EPA SWMM model. The SWMM model is well known and widely accepted as an industrial standard for stormwater management. The PC-SWMM package supports different modules, which incorporate all the features needed to address the specific modeling requirements for this study.

8.1 Model Initialization

As discussed earlier, the drainage areas at both study sites were relatively small and highly impervious, resulting in short concentration times and low infiltration potential. These conditions allowed for a simplified model approach in which : (i) routing effects did not require simulation; (ii) the whole drainage area could be simulated as one lumped catchment; and (iii) accurate information on infiltration was not required. The small storage capacities and very short retention times of the OGS units allowed for substitution of the structures, which were complex in hydraulic terms, for single detention units.

The RUNOFF and STORAGE/TREATMENT modules were used to simulate the two catchments and OGS technologies monitored in this study. The RUNOFF module was developed to simulate both the quantity and quality of runoff in a drainage basin, including the routing of flows and contaminants to the major sewer lines. It represents the basin by an aggregate of idealized catchments and channels or pipes. The program accepts arbitrary rainfall hyetographs and makes a step by step calculation of infiltration losses, surface detention, overland flow, channel flow, as well as the constituents washed into inlets or nodes. Hydrographs and pollutographs are subsequently calculated for each node. In this instance, the drainage area for both systems was simulated as a single catchment, draining to a single node. The node represented the inlet to the OGS unit and no channels or pipes were simulated.

It is fairly simple to initialize and calibrate the quantity component of this module. Simulation of urban runoff quality is more complicated because uncertainties arise both in the representation of processes and in the acquisition of data. To simplify, calibration and verification are ordinarily performed on total loads only, which is much easier task than trying to match a detailed pollutograph throughout an event. Output from the RUNOFF block, given as paired values of time, flow and concentration, was used as input for the STORAGE/TREATMENT block. The time interval for rainfall simulation was ten-minutes for the single event simulation, and one-hour for the continuous simulation.

The STORAGE/TREATMENT module has been developed to simulate the routing of flows and pollutants through a storage/treatment plant. The units in the plant may be modeled as having detention or non-detention characteristics. The module will route up to three pollutants. In this case, only TSS removal was simulated. Pollutants may be characterized by their concentrations only, or by their concentrations and a settling velocity distribution.

When the particles are classified by a settling velocity distribution, their removal is simulated by settling. When they are characterized by concentrations alone, removal is simulated through removal equations. The manner in which pollutants are routed in a detention unit can be specified as (a) perfect plug flow, or (b) complete mixing reactor. Perfect plug flow is expected in long, rectangular tanks where settling is the most important removal mechanism. Complete mixing is most applicable to small tanks where the primary purpose is to thoroughly mix the content. For the plug flow, the inflow during each time step is queued through the detention unit and the transfer of pollutants between plugs is not permitted. Either way, detention time is the most important indicator of removal efficiency. In this module, settling is only available as a removal mechanism for a detention unit with plug-flow.

Instead of simulating two separate build-up and wash-off processes, the TSS loads were, in this case, generated using the rating curve method, which gives a direct relationship between rainfall and loads. Given that the objective of this study was to characterize water quality entering and leaving the OGS, and not to provide a detailed characterization of the drainage area, the rating curve method was found to be most appropriate. Sensitivity analysis revealed that the two coefficients defining the rating curve (WASHPO and RCOEF) were the most sensitive calibration parameters. The observed stage-discharge curve at the outlet and known depth versus storage dependence were used to simulate the depth-storage-outflow relationship.

8.2 Three-chamber OGS, Markham, Ontario

8.2.1 Model Calibration and Verification

As described in the previous section, only one catchment draining directly to the node representing the inlet to the three-chamber OGS was simulated, without any channels or pipes. Field observations indicated that there was no significant sediment accumulation in the sewer lines. The quantity segment of the RUNOFF block was calibrated and verified using six storm events (Appendix E, Table E1). Sensitivity analysis revealed that the size of the drainage area

(AREA) was the determining factor for this calibration. In terms of water quantity, the model was calibrated using (a) combined total runoff volume for the six storm events, (b) peak flow rate, and (c) time between the beginning of the storm and peak occurrence. The calibration and verification resulted in a 10.1% difference in total runoff volumes and a 9.1% difference in peak flow rates. When observed vs. modeled values were compared for individual events, differences ranged from –9.7 to 37.3% for total volumes and between –30.4 and 47.6% for peak flow rates, with average differences of 8.7% for volumes and 9.3% for peak flows.

Quality calibration was performed using the four events given in Table E1. Differences in average load for those events was 12.7%. Difference between observed and modeled loads for individual events ranged between –30.3% and 31.2%, resulting in an average difference of 6.7%. The observed and modeled hydrographs for two events (Appendix E, Figure E1) show good agreement.

The same four events used for quality calibration in the RUNOFF block were used to calibrate the STORAGE TREATMENT Block (Appendix E, Table E1). The two units of 35 m^3 and 17 m^3 were combined into a single unit with no cells. The detention unit was simulated with a permanent pool of 50 m^3, and a perfect plug flow was selected as a routing method. This method is generally recommended for larger and longer units. However, in this case the flows are divided into the two units and then transferred through a series of chambers, with low mixing potential among the chambers. Consequently, the perfect plug approach is a reasonably accurate representation of stormwater flow through the units. This suggested the selection of a settling velocity distribution as a calibration parameter. Difference between observed vs. modeled total loads was 7.2%. For individual events that difference ranged from –28.5 to 29.6%, resulting in an average difference of 1.8%.

An obvious deficiency of this approach is that the model does not consider the effect of sediment accumulation and periodical flushing. For modelling purposes, it is assumed that the sludge volume has no effect on available storage volume and that no re-suspension occurs. This deficiency did not have a major impact on the continuous simulation because re-distribution of sediment trapped in the chambers over time is reflected in the samples collected at the outlet station.

8.2.2 Continuous Simulation

The model predicted total volumes and TSS loads over the period of sixteen months. Rainfall data were available from the Buttonville Airport AES station for ten months. For the RUNOFF block, a time step of 120 seconds was used constantly both for single event and continuous simulation. For the STORAGE/TREATMENT block, it was necessary to increase the time step to 1800 seconds for continuous simulation to improve the stability of the model. An overview of modeling results is given in Table 8.1.

Table 8.1: An overview of measured and modeled sediment accumulation, Three-chamber OGS

Code	Balance component	Formula	Amount
A	modeled inlet volume [m3]		16011.0
B	modeled* inlet load [kg]		933.9
C	modeled inlet EMC [mg/l]	B/A=	58.3
D	modeled outlet volume [m3]		15992.0
E	modeled outlet load [kg]		357.7
F	modeled outlet EMC [mg/l]	E/D=	22.4
G	modeled removal efficiency [%]	(B-E)/B=	61.7
H	modeled remaining in the OGS [kg]	B-E=	576.1
I	estimated** remaining amount Oct 97 - Mar 98 [kg]		345.7
J	total simulated sediment accumulation July 97 - Aug 98 [kg]	H+I=	921.8
K	total captured sediment accumulation July 97 - Aug 98 [kg]		957.2
L	difference between simulated and captured accumulation [%]	(J-K)/J=	-3.8

Simulated total inlet runoff volume and TSS loads were 16,011 m^3 and 933.9 kg, respectively. When these flows and TSS load were routed through the detention unit, the outflow volume and load fell to of 15,992 m^3 and 357.7 kg, respectively, indicating that 576.1 kg of TSS was captured in the OGS over the 10 month simulation period for which rainfall data from the AES station were available. Since the study period was 6 months longer, it was necessary to estimate the sediment accumulation in the unit for the period from October 1997 to March 1998. The amount captured between October 1997 and March 1998 was estimated using the average sediment accumulation rate as modeled in the continuous simulation. The average rate was 57.6 kg/month, indicating that over six months approximately 345.7 kg of sediment accumulated. Thus, total sediment accumulation in the OGS unit over the entire study period was 921.8 kg (576.1 kg +345.7 kg), and there was very little difference (-3.9%) between the modeled (921.8 kg) and observed (957.2 kg) values. Thus the modelling results support the findings from the field monitoring program.

8.3 Stormceptor® OGS, Etobicoke, Ontario

8.3.1 Model Calibration and Verification

As in section 8.2, one catchment draining directly to the inlet node was simulated in the RUNOFF block, without any channels or pipes. The treatment plant in the STORAGE/TREATMENT block was again simulated as a single unit, combining the storage volumes of the two units. In this modeling exercise, the overflow feature of the Stormceptor® unit was not specifically modeled. Although overflow rates were not simulated, the impact of overflow on the outflow water quality was considered, for the collected quality data were used for the calibration. Overflow conditions in general did not last very long and most of the runoff was routed through the treatment chamber. Therefore, for the model calibration, it was not necessary to simulate overflows.

The quantity segment of the RUNOFF block was calibrated and verified using eight individual events (Appendix E, Table E2). The model was calibrated using (a) combined total runoff volumes for the eight events and (b) peak flow rates. The calibration resulted in 0.22% difference in average for volumes and 17.5% difference in average peak flows. For individual events, differences ranged from –37.3% to 45.2% for volumes and from –14.9% to 57.2% for peak flows, with an average difference of –0.73% for the volumes and 15.3% for the peak flows. The quality segment of the RUNOFF block was calibrated using seven individual events (Appendix E, Table E2). The difference in average load was –0.32%, with individual events having differences ranging from –78.3% to 66.2%, resulting in an average difference of 2.4%. A comparison between observed and modeled hydrographs is given in Appendix E, Figure E2.

The same seven events used for the quality calibration in the RUNOFF block were used to calibrate the STORAGE/TREATMENT block. The two units of 20.2 m^3 were combined into a single large unit. A detention unit with a permanent pool of 35.6 m^3 was simulated, and complete mixing was selected as a routing method. This method is generally recommended for smaller tanks and it requires the application of removal equations to simulate pollutant removal. Consequently, coefficients in these equations were the most important calibration parameters. The model did not consider either the reduction in storage volume due to sediment accumulation within the unit, or the re-suspension and periodic flushing of trapped sediment. Since the OGS units were cleaned out at the beginning of the monitoring program, the effect of reduced storage volume was not a concern. The same thing applies for re-suspension because the by-pass feature was designed to prevent periodic flushing.

8.3.2 Continuous Simulation

The model was used to predict the total volumes and TSS loads over the study period of sixteen months. Rainfall data were available for twelve months. The approach described in the previous section was used to simulate loads for the remaining four months. An overview of modeling results is given in Table 8.2.

The continuous simulation resulted in a total inlet volume and load of 10,650 m^3 and 1,416kg, respectively. Routing the flows through the detention unit resulted in total outlet volume and load of 10,641 m^3 and 559.7 kg, respectively. In order to estimate the amount of sediment captured during the months for which no rainfall data were available, the simulated monthly sediment accumulation rate was used. As a result, the total sediment accumulation was estimated to be 1,142.16 kg. A total of 1,067.37 kg of sediment was measured in the off-line holding tank (see section 6.2.3, which is 6.6% less than the modeled TSS load. Thus the modelling results agree closely with field monitoring program findings.

Table 8.2: An overview of measured and modeled sediment accumulation, Stormceptor OGS

Code	Balance component	Formula	Amount
A	modeled inlet volume [m3]		10650.00
B	modeled* inlet load [kg]		1416.30
C	modeled inlet EMC [mg/l]	B/A=	132.99
D	modeled outlet volume [m3]		10641.00
E	modeled outlet load [kg]		559.68
F	modeled outlet EMC [mg/l]	E/D=	52.60
G	modeled removal efficiency [%]	(B-E)/B=	60.48
H	modeled sediment mass remaining in the OGS [kg]	B-E=	856.62
I	modeled sediment mass remaining in the OGS May 97 - Sep 97, Apr 98 - Aug 98 [kg]		856.62
J	estimated** sediment mass remaining amount Oct 97 - Mar 98 [kg]		285.54
K	total simulated sediment accumulation July 97 - Aug 98 [kg]	I+J=	1142.16
L	sediment captured in the off line tank [kg]		1067.37
M	difference between simulated and captured accumulation [%]	(K-L)/K=	6.55

9.0 STUDY SUMMARY AND RECOMMENDATIONS

This report reviews the literature on various OGS technologies and provides a detailed field study evaluation of two types of OGS commonly used in Ontario. As reports of OGS water quality performance vary widely among studies, the monitoring results should be reviewed carefully in relation to other studies of similar technologies and with full consideration of the technology/site design (e.g. unit sizing, provision of upstream storage), the drainage area characteristics (e.g. runoff quality, influent particle sizes) of the sites selected for the study, and the monitoring protocols used to generate results. The following sections summarize the main findings of the literature review and field monitoring study.

9.1 Literature Review

The literature review provides a general overview of the theory and application of Oil Grit Separators (OGS). Various commercially available OGS designs are grouped and discussed for the purposes of the review with respect to their respective functional attributes, such as high flow bypass, swirl action, screening action, coalescence action and combined system types. Only those devices with sufficient documentation on performance and monitoring data were reviewed in detail. These devices include the traditional 3 chamber OGS, Stormceptor, Bay Saver, Vortechs, Downstream Defender and Continuous Deflective Separation Unit. Coalescing Plate separators and combined system type OGS (Multi-chambered Treatment Train and Storm Treat™) are discussed but not reviewed in terms of performance or maintenance requirements.

Most laboratory and field monitoring performance assessments cited in this literature review were conducted by the manufacturer or by manufacturer sponsored organizations. There were considerably fewer independent third party studies available. A review of all these studies revealed a wide variation in site conditions (e.g. climate, soil texture, land use) and field monitoring and data analysis protocols, making it difficult to compare performance results among studies, even for the same device. In some studies, essential information (e.g. effluent concentrations, design specifications) required to interpret results was not provided. Although performance results are provided for each technology, it was not possible to rate the technologies in terms of overall effectiveness based on the limited information available.

Like other stormwater technologies, the water quality performance of OGS declines significantly if they are not regularly maintained. Most guidelines from government agencies and manufacturers suggest that the maintenance frequency for OGS be at least once or twice per year, or when the accumulated sediment reaches 15% of the sediment capacity.

9.2 Monitoring Study

The main objective of the monitoring study was to better understand the performance and maintenance requirements for two types of OGS applied under typical conditions for stormwater management in southern Ontario. This objective was achieved by (a) implementing a full-scale field monitoring program of the two OGS technologies, and (b) verifying field monitoring results by comparing the measured dry mass of sediment that accumulated over the monitoring period with sediment accumulation simulated using a continuous water quantity/quality model.

The following provides a summary of the main findings of the two monitoring studies with respect to hydrology, water quality treatment, and sediment.

9.2.1 Water Quantity

Three-chamber OGS

A total of 60 runoff events were monitored at the Markham site from May 1997 to December 1998. Rainfall measurements were available for 30 events occurring during the spring, summer and fall. Average rainfall was 11.4 mm, with a range between 1.8 and 28.6 mm. Mean rainfall intensities averaged 2.1 mm/hour and ranged from 0.5 to 6.8 mm/hour. Twenty out of thirty rainfall events resulted in significant runoff volumes.

The average volumetric runoff coefficient was 0.85, indicating that, on average, 85% of the runoff volume that fell within the drainage area during monitored rain events passed through the OGS as stormwater runoff. As expected, rainfall depths were well correlated with runoff volumes (R^2=0.81).

The capacity of the system to control water quantity (i.e. attenuate peak flows and extend release times) was assumed to be very limited because the storage-to-drainage area ratio is small and the technology is not designed with extended detention storage. This assumption is further corroborated by hydrologic data showing that effluent runoff and rainfall extended over similar time intervals during individual storm events.

Stormceptor®

A total of 44 events were monitored at the Etobicoke site during the period from August 1997 to December 1998. The absence of winter rainfall measurements meant that only 24 of the 44 runoff events were monitored for rainfall. Rainfall depths averaged 11.8 mm, ranging between 2.3 and 36.8 mm. Mean rainfall intensities averaged 2.3 mm/hour, with a range between 0.4 and 8.6 mm/hour.

The volumetric runoff coefficient averaged 0.98. There were substantial variations in the runoff coefficient among individual events, suggesting possible discrepancies between the rainfall gauging stations, located 3 to 5 km away, and actual rainfall at the site. The relatively weak correlation between runoff volumes and rainfall depths (R^2 = 0.54) lends additional support to this hypothesis.

As at the Markham site, the duration of rainfall and outflow were similar during rain events, indicating that stormwater runoff was not detained for significant time periods within the OGS units. Although not monitored in this study, additional storage provided upstream of the OGS units (via a flow restrictor) may have helped to reduce peak flow during large events.

There were few overflows and those that did occur were of relatively short duration. Hence, effluent concentration and removal efficiency estimates provided in this study are based largely on flows that passed through the treatment chamber of both units.

9.2.2 Water Quality

<u>Three-chamber OGS</u>

A total of 26 influent and 54 effluent water samples were collected and analyzed for particle size, total dissolved and suspended solids, heavy metals and oil and grease from May 1997 to December 1998. There were fewer influent than effluent samples because in the early stages of the study, runoff backed up from the first chamber. After the problem was detected, a small weir was installed at the inlet to prevent re-occurrence of this problem.

The median influent and effluent TSS concentrations were 109 and 40 mg/L, respectively. Concentrations during individual events ranged widely from 34 to 378 mg/L at the inlet and 4 to 268 mg/L at the outlet. Median concentrations of oil and grease (solvent extractable) were 22 and 8 mg/L at the inlet and outlet, respectively. The highest concentrations of TSS and O&G were measured in winter and early spring, approximately from January to April 1998.

Total suspended solids were well correlated with most heavy metals, indicating that these contaminants are removed with suspended solids through sedimentation processes.

Load based removal efficiencies for metals ranged from 42 to 60%. Median effluent concentrations of copper (17 μg/L), lead (11 μg/L), zinc (77 μg/L), and iron (383 μg/L) exceeded provincial receiving water standards. Although effluent concentrations are not expected to meet receiving water criteria, comparisons made against the provincial standards are helpful in identifying water quality variables of potential concern.

The size of particles entering the OGS units was significantly lower than those exiting the units. Average influent and effluent particle size distributions (n=18) had median particle sizes of 8.7 and 3.8 microns, respectively. These were significantly different at the 95% level of confidence. Particle size distributions in the warm and cold seasons were similar.

On-site depth profiles of electrical conductivity in all three chambers did not show any signs of stratification, suggesting well mixed conditions and periodic re-suspension of previously settled solids. The tendency for resuspension may partly explain the wide range of removal efficiencies observed among storm events.

The total load based TSS removal efficiency for 19 events was 57%, with individual event removal efficiencies ranging from –81 to 91%. In comparison, the total load-based removal of oil and grease was 51%, with a range between -200 and 84%. Total runoff volumes were not well correlated with removal efficiencies either for TSS or oil and grease. There also was no discernible seasonal variation in removal.

Stormceptor®

A total of 20 influent samples and 37 effluent samples were collected from the Stormceptor® OGS between August 1997 and December 1998. As at the Markham site, collection of reliable samples was more challenging at the inlet than at the outlet, hence fewer influent samples were collected.

Median influent and effluent TSS concentrations were 112 and 48 mg/L, respectively. Influent TSS concentrations ranged from 28 to 634 mg/L, compared to an effluent concentration range of 10 to 451 mg/L. These ranges are considerably wider than at the 3-chamber site in Markham. Median concentrations of oil and grease (solvent extractable) were 17 and 7 mg/L at the inlet and outlet, respectively.

Load based removal efficiencies for heavy metals commonly found in urban runoff ranged from 42 to 52%. Median effluent concentrations of the following metals exceeded provincial receiving water standards: copper (22 μg/L), lead (19 μg/L), zinc (120 μg/L), and iron (515 μg/L). As at the3 chamber site in Markham, total suspended solids were strongly correlated with most heavy metals.

Influent and effluent concentrations were well correlated for the two main parameters of interest, TSS and O&G. The relationship ($R^2 = 0.7$ for TSS), which is also observed at the 3 chamber site, suggests that unit sizing should be based not only on the size of the drainage area and level of imperviousness, but also on pollutant loading potentials associated with specific land use types.

Average influent and effluent particle size distributions were similar. The median particle size at the inlet was 6.5 um, compared to a median size of 5.8 um at the outlet. The low influent particle size relative to the 3-chamber OGS site may be partly explained by the presence of upstream storage and catchbasin sumps, where coarser particles may have settled out of suspension before reaching the OGS units. The cause of the unexpectedly coarse effluent particle size distributions requires further investigation.

Depth profiles of electrical conductivity showed a distinct stratified layer in the winter and summer, starting at 0.5 to 1 m depth below the permanent pool surface in the treatment chamber. The stratified layer had completely dissipated by the fall, when a third measurement was taken. Winter conductivity levels reached a maximum of 72,700 mS/cm at 1.5 m below the water surface, which is roughly equivalent to a chloride concentration of 36,500 mg/L. The existence of a stratified layer of chloride suggests that turbulent flows causing re-suspension of accumulated solids were minimized. However, the stratification also raised concerns as reduced vertical mixing may decrease the effective storage available for treatment, resulting in poorer pollutant removal during the winter and spring.

The total load based TSS removal efficiency for events with co-ordinated inlet and outlet sampling (n=16) was 60%, with individual event removal efficiencies ranging from 4.5 to 83%. Total load-based removal for oil and grease was 44%, with a range between -6 and 84%. Both of the ranges are less than observed at the 3-chamber site, although the total load results are similar. Runoff volumes were not well correlated with removal efficiencies either for TSS or oil and grease, but unlike the 3-chamber site, TSS removal was generally better during the summer.

9.2.3 Analysis of potential errors

There was some concern that the performance results may be biased because influent concentrations were measured at only one of the two inlets, whereas effluent concentrations were measured from the combined discharge of both units. To estimate the potential error associated with unequal influent TSS concentrations, total TSS load calculations were repeated assuming that: (i) inflow was equally distributed between the two units; and (ii) influent TSS concentrations in the unmonitored unit differed consistently (*i.e.* during all events) from that measured in the monitored unit by ±20%. Results of this scenario indicated a total load TSS removal efficiency range of between 52 and 61% for the 3-chamber OGS and between 56 and 64% for the Stormceptor® OGS. These ranges narrow when differences in influent concentration were combined with larger flow volumes entering the monitored unit (the latter of which is known to occur at both sites).

The potential error associated with flow measurement inaccuracies were estimated by randomly varying the measured flow rate among events by ±20%. This exercise was repeated for several randomly generated combinations resulting in an error range in TSS removal efficiencies at both sites of approximately ±3%. A consistent increase or decrease in flow volumes by exactly the same magnitude for all events would, of course, have no impact on removal efficiencies because a perfect flow balance through the OGS is assumed.

The reader should note that removal efficiency is a biased indicator of performance because influent concentrations below a minimum threshold have a statistical propensity to produce low removal efficiencies. Thus a performance evaluation based solely on this indicator can lead to misleading conclusions, especially when additional water quality storage or treatment provided upstream of the OGS facility contributes to cleaner influents. Effluent concentrations or loads are a more reliable indicator (*i.e*. not subject to the errors noted above) and in any assessment of OGS performance, should be evaluated in combination with removal efficiencies, and in relation to effluent concentration ranges of other similar technologies.

9.2.4 Sediment Analysis

The total dry mass of sediment measured in the two parallel three chamber OGS units from July 1997 to August 1998 was 957 kg and 1067 kg in the 3 chamber and Stormceptor OGS, respectively.

The concentrations of several metals in the trapped sediment of both OGS types were above the lowest effect level guidelines defined by the Province for the protection of aquatic life. High concentrations of oil and grease in the sediment suggest that special considerations may be required in the disposal of sediment.

9.2.5 Modelling

Continuous simulation results for all storms occurring over the 16-month study period indicated a total load TSS removal efficiency of 62% at the Markham 3-chamber site and 60% at the Etobicoke Stormceptor site. In both cases, simulated TSS load-based removal efficiencies match results from the monitoring study within ±5%.

The measured and simulated total dry mass of sediment accumulation over the study period was 922 and 957 kg in the 3-chamber OGS, and 1067 and 1142 kg in the Stormceptor OGS, respectively. The good correspondence between accumulated sediment measured from the holding tanks and model simulations based on influent and effluent measurements lends confidence to the monitored results.

9.3 Recommendations

Maintenance issues

- To avoid re-suspension of trapped oil and sediment, an aggressive maintenance schedule/plan for inspections and clean-out should be established upon the installation of any and all OGS. High oil and grease concentrations may limit disposal options.

- To help prevent adverse effects on performance due to chloride stratification, annual or bi-annual maintenance of OGS units should be timed to correspond with the end of the snow melt season, when concentrations of chloride in the treatment chamber are at a maximum.

Site/Technology design improvements

- Three chamber OGS should include a high flow bypass design feature to avoid re-suspension of accumulated pollutants.

- The asymmetrical "Y" splitter at both sites consisted of one straight and one angled pipe section that distributed flows unequally to the two parallel units. The two 3-chamber units were sized differently to accommodate variable flows, but the Stormceptor units were the same size. The storage treatment capacity of the two Stormceptor units could be better utilized if either the splitter did not distribute flows preferentially to one of the two units (i.e. it was shaped like a true "Y"), or the units were sized to compensate for unequal flow distribution.

- The correlation between influent and effluent concentrations for TSS and O&G suggests that unit sizing should be based not only on the size of the drainage area and level of imperviousness, but also on estimates of how much O&G and sediment are likely to be generated by land use activities within the drainage area.

Further Research

- Removal efficiencies and effluent concentrations varied widely among events for both types of OGS monitored in this study. Factors contributing to this variability may include resuspension of settled solids (especially in the 3- chamber OGS), varying inter-event periods, storm sizes and intensities, chloride stratification (Stormceptor), presence of upstream storage (Stormceptor), and bypass events (Stormceptor). Detailed research into the inter-relationships between these and other potential contributing factors needs to be done to quantify their effects on performance and better understand how application of the technology or maintenance procedures may be modified to minimize adverse effects.

- Oil Grit Separators require regular maintenance if they are to function according to design. However, discharge regulations are not currently enforced to the degree necessary to ensure that the required maintenance is indeed being undertaken. A detailed field assessment of accumulated sediment in previously installed units would help to show whether or not owners and operators are actually 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.

- OGS are often recommended in provincial and state stormwater guidance documents as best applied in conjunction with other treatment technologies (i.e. as part of a treatment train) or as part of a 'multi-component' approach to stormwater management. The effectiveness of separators when installed together with other control measures, both from a quantity and quality perspective, needs further study.

- This study showed strong stratification of chloride in the Stormceptor units. It has been suggested that this stratified layer may inhibit mixing and reduce the effective permanent pool storage available for treatment. Further research is required to quantify the effect (if any) of chloride buildup and stratification in the treatment chamber on water quality performance.

10.0 REFERENCES

Adams, T.R. 1998. *An Approach to Monitoring Stormwater Treatment Facilities*. University of Hampshire Volunteer Monitoring Conference – Proceedings, June 1998.

Adams, T.R. 1997. *A Method for the Consistent and Uniform Evaluation of Stormwater BMP*. Computational Hydraulic Conference – Proceedings, Toronto February 1997.

Adams T.R., P. Raikko and A. Perley, 2000. By any Measure…National Conference on Tools for Urban Water Resource Management and Protection proceedings, Feb 7-10, 2000, Chicago, IL, pp 362-370. <http://www.epa.gov/ord/WebPubs/nctuw/625r00001.pdf>

Adams, T.R. and S.P. True. *Designing Facilities for Ultra-Urban Stormwater Treatment Applications in the Pacific Northwest.* Online document. <http://www.vortechnics.com/techbulletins/05%20Design%20Facilities%20Pacific%20NW.pdf>

American Petroleum Institute, 1990. *Monographs on Refinery Environmental Control Management of Water Discharges: Design and Operation of Oil Water Separators.* Refining Department, API Publication 421.

Ball, J.E., and I. Abustan, 1995. An *investigation of particle size distribution during stormevents from an urban catchment*. The Second International Symposium of Urban Stormwater Management, Melbourne, Australia, 531-535.

BaySaver, 2003. BaySaver Information Package.

Berg, H., 1991. Water Quality Inlets (oil/grit separators). Maryland Department of the Environment Sediment and Stormwater Administration.

Brater E.F., H.W. King, J.E. Lindell and C.Y. Wei, 1996. Handbook of Hydraulics. McGraw-Hill Washington, D.C., USA, ISBN 0-07-007247-7.

British Columbia Environment, 1992. Urban *runoff quality control guidelines for the province of British Columbia*. Municipal Waste Reduction Branch, Environmental Protection Division.

Brown W. and T. Schuler, 1997. *National Pollutant Removal Performance Database for*

Stormwater BMPs. Chesapeake Research Consortium, Inc. Edgewater, Maryland, August 1997.

Bryant, G., R. Grant, D. Weatherbe, V. Berg, 2000. *Stormceptor Hydrology and Non-point source pollution removal estimates.* National Conference on Tools for Urban Water Resource Management and Protection – Proceedings, Chicago, IL, February 2000

Canadian Petroleum Products Institute, 2003. *Best Management Practices Stormwater Runoff from Petroleum Facilities,* CPPI, March 2003.

CDS Technologies Inc, 2004 <http://www.cdstech.com>

Chavez, F., C. Cunningham, 2002. *Enhancing stormwater management with sediment removal boxes.* Public Works, 133, 1, Wilson Applied Science & Technology Abstracts Plus Text, pg. 38 <http://www.pwmag.com>

Chui, J., 2002. Control of oil spills in urban areas. M.Sc. Thesis, Program of Environmental and Applied Science and Management, Ryerson University, Toronto, Ontario, Canada.

City of Portland, 2002. *Stormwater Management Manual*. Environmental Services, City of Portland, Clean River Works.

Claytor, R., 2000. *Performance of a Proprietary Stormwater Treatment Device: The Stormceptor Technical Note #104,* Watershed Protection Techniques. 3(1): 605-608

Coventry University, 1999. *Laboratory Tests conducted in the School of the Built Environment, Coventry University on X-Ceptor Concrete Bypass Interceptor, also known as Stormceptor in North America,* UK.

Csuros, M. 1994. *Environmental Sampling and Analysis for Technicians*. CRC Press, Boca Raton, Florida USA. ISBN 0-87371-835-6.

England, G. and J. Royal, 2002. *Using Baffle Boxes for Stormwater Treatment*. Computational Hydraulic Conference – Proceedings, Toronto February 1997.

Environment 21™ homepage <www.env21.com>

Geosyntech Consultants et al. 2002. *Urban Stormwater BMP Performance Monitoring.* Office of Water, US EPA, Washington, D.C. EPA-821-B-02-001

Grant, M.D. and B.D. Dawson, 1995. *ISCO Open Channel Flow Measurement Handbook*. ISCO Environmental Division, Lincoln, Nebraska USA

Greb, S., S. Corsi, and R. Waschbusch, 1998. *Evaluation of Stormceptor and Multi-Chamber Treatment Train as Urban Retrofit Strategies*. Presented at Retrofit Opportunities for Water Resource Protection in Urban Environments, A National Conference. The Westin Hotel. Chicago, Il. February 10-12, 1998.

Greenway, R.A., 2001. *Stormwater Treatment Demonstration Project Oil Water/Grit Separator followed by a sand filter*. Paper WM-668, RTP Environmental Associates Inc., New Jersey.

Haan, C.T., B.J. Barfield and J.C. Hayes, 1997. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press, New York City, 1997.

Henry, D., W.Y. Liang and S. Ristic, 1999. *Comparison of Year Round Performance for Two Types of Oil and Grit Separators*. The International Congress on Local Government Engineering and Public Works, Sydney, Australia – Proceedings, August 1999.

Herschy R.W., 1978. *Hydrometry – Principles and Practices*. John Wiley and Sons, New York City, 1998.

Hynds Environmental 2002 Downstream Defender Brochures.

Hynds Environmental, 1997. Hynds Downstream Defender Performance Data, May 1997.

Hynds Environmental, 2002. Downstream Defender Advanced Hydrodynamic Vortex Separation.

Iggleden, G., 1978. The design and application of tilted plate separator oil interceptors. *Chemistry and Industry*, Nov. 4, pp. 826-831

Labatiuk, C., V. Nataly and V. Bhardwaj, 1997. Field Evaluation of a Pollution Abatement Device for Stormwater Quality Improvement. *Proceedings of the 1997 CSCE-ASCE Environmental Engineering Conference.* July 22-26, Edmonton, Alberta.

Liang, W.Y. and M.K. Thompson, 1996. *Performance Assessment of an Off-line Stormwater Management Pond*. Ontario Ministry of Environment and Energy, Toronto, Ontario

Marsalek, J. and J. Hedit. *Performance of Ontario Concrete Pipe Association Oil/Grit Separator,* *OGER, In Trapping Sediment* National Water Research Institute NWRI Contribution No. AEP-TN99-004

Marsalek, J., R. Long and D. Doede, 1994. *Laboratory Development of Stormceptor II*; National Water Research Institute, Report for Stormceptor, Burlington, Ontario.

Montgomery Country Maryland, 2002. *Flow Splitting Design Criteria* Department of Permitting Services, Water resources section.

National Pollutant Discharge Elimination System, 2002. *NPDES Progress Report.* Washington State Department of Transportation, Environmental Affairs Office, Water Quality Program, Olympia, Washington. <http://www.wsdot.wa.gov/environment/eao/wgec/docs/2002NPESProgressReprot.pdf>

Ontario Ministry of Environment and Energy, 1994. *Stormwater Management Practices Planning and Design Manual*. Queen's Printer for Ontario, Toronto, Ontario PIBS 3150.

Ontario Ministry of Environment and Energy, 1994. *Water Management Policies, Guidelines and Provincial Water Quality Objectives of the Ministry of Environment and Energy*. Queen's Printer for Ontario, Toronto, Ontario, ISBN 0-7778-3493-4.

Ontario Ministry of Environment and Energy, 2003. *Stormwater Management Planning and Design Manual.* Queen's Printer for Ontario, Toronto, Ontario PIBS 3150

Oswald, G.E. and R. Mattison, 1995. *Monitoring the Effectiveness of Structural BMP*. Stormwater NPDES Related Monitoring Needs: Proceedings of and Engineering Foundation conference, ISBN 0-7844-00652.

Pack, A., 2003. *Literature Review & Evaluation of the Vortechs Stormwater Treatment Device,* University of Colorado at Boulder.

Province of Alberta, 1999. *Stormwater Management Guidelines for the Province of Alberta.* Municipal Program Development Branch, Environmental Sciences Division, Environmental Services.

Rapp, D., 2003. *Evaluation of Stormceptor Studies for Intra-Storm Water Quality and Quantity Data,* University of Colorado at Boulder.

Rinker Materials Corporation homepage, 2003-2004. *Stormceptor Testing Summaries* <http://www.rinkermaterials.com/stormceptor/SS_TestingSumm.htm>

Schueler T., 1997. *Bacterial Levels in Urban Stormwater*. Watershed Protection Techniques 3(1).

Schueler, T., 1997. *Performance of Oil/Grit Separators in Removing Pollutants at Small Sites, Technical Note #101*, Watershed Protection Techniques. 2(4): 539-542.

Schueler T. and D. Shepp, 1993. *The Quality of Trapped Sediments and Pool Water Within Oil and Grit Separators in Suburban Maryland*. Maryland Department of Environment, April 1993.

Schueler T. and H. Holland, 2000. *The Practice of Watershed Protection.* Center for Watershed Protection 551-555pp.

Shaw, L. and D. Monika, 2001. *Testing of ultra-urban stormwater best management practices* Virginia Transportation Research Council in cooperation with the U.S. Department of Transportation Federal Highway Administration, Charlottesville, Virginia, January 2001.

Shepp, D., 1995. *Petroleum Hydrocarbons in Urban Runoff: A Stud Overview*. Prepared for Maryland Department of Environment, Department of Environmental Programs, Metropolitan Washington Council of Governments. Washington, D.C. 160 pp.

Shepp, D., 1995. *A Performance Assessment of an Oil-Grit separator in Suburban Maryland*. Final Report prepared for Maryland Department of Environment, Metropolitan Washington Council of Governments, Washington, D.C. 124 pp

Smith, K.P., 2002. *Effectiveness of Three Best Management Practices for Highway-Runoff Quality along the Southeast Expressway, Boston Massachusetts:* U.S. Geological Survey Water-Resources Investigations Report 02-4059, 62 p. + 1 CD-ROM.

Stahre P., and B. Urbonas, 1990. *Stormwater Detention for Drainage, Water Quality and CSO Management*. Prentice Hall, Englewood Cliffs, New Jersey USA ISBN 0-13-849837.

Stormceptor Canada Inc., 1996. *Stormceptor Technical Manual*, Toronto.

Stormceptor Canada Inc, 2003. Study Binder.

StormTreat System Inc. <http://www.stormtreat.com>

Strecker, E.W., 1995. *Constituents and Methods for Assessing BMP's* Stormwater NPDES

Related Monitoring Needs: Proceedings of and Engineering Foundation conference, ISBN 0-7844-00652.

Tacoma Public Works, 2003. *City of Tacoma Surface water management manual, vol. 5 Runoff Treatment BMPs.* Tacoma Public Works, Environmental Services.

Tran, J., D. Henry and D. Hui, 1996. *Myth and Facts about OGS (oil/grit separator)* 31st Central Canadian Symposium on Water Pollution, Wilkinson Heavy Precast limited.

Transportation Research Board, 1993. *Stormwater Management for Transportation Facilities.* National Research Council, Washington D.C. USA.

Tschantz, A., R. Gangaware, G. Morton, 2002. *Guide to the Selection and Design of Stormwater Best Management Practices (BMPs).* Tennessee Water Resources Research Center, The University of Tennessee, Knoxville, Tennessee <http://eerc.ra.utk.edu/divisions/wrrc/>

Urbonas, B.R., 1995. *Parameters to Report with BMP Monitoring Data*. Stormwater NPDES Related Monitoring Needs: Proceedings of and Engineering Foundation conference, ISBN 0-7844-00652.

U.S. Environmental Protection Agency, Region 1: New England, CEIT virtual show: stormwater <http://www.epa.gov/region1/assistance/ceitts/stormwater/techs/>

U.S. Environmental Protection Agency, Region 1: New England, CEIT virtual show: stormwater: StormTreat. <http://www.epa.gov/region1/assistance/ceitts/stormwater/techs/stormtreat.html>

U.S. Environmental Protection Agency, Region 1: New England, CEIT virtual show: stormwater: V2B1 Stormwater Treatment System <http://www.epa.gov/region1/assistance/ceitts/stormwater/techs/v2b1.html>

U.S. Environmental Protection Agency 1999 *Stormwater Technology Fact Sheet: Water Quality Inlets* Office of Water, Washington, D.C. EPA 832-F-99-029.

U.S. Environmental Protection Agency 2001 *Stormwater Technology Fact Sheet: Baffle Box* Office of Water, Washington, D.C. EPA 832-F-01-004.

U.S. Environmental Protection Agency 1999 *Stormwater Technology Fact Sheet: Hydrodynamic Separators* Office of Water, Washington, D.C. EPA 832-F-99-017.

U.S. Environmental Protection Agency 1999 *Preliminary Data Summary of Urban Storm Water Best Management* Practices Office of Water Washington, D.C. EPA-821-R-99-012.

Vortechnics Inc, 2004 <www.vortechnics.com>

Winkler, E., 1997. *Technology Assessment Report Stormceptor CSR New England Pipe prepared for The Massachusetts Strategic Envirotechnology Partnership (STEP)* Center for Energy Efficiency and Renewable Energy, University of Massachusetts Amherst.

Yu, L., X. Zhang, A. Earles, and M. Sivers, 2001. *Field Testing of Ultra-urban BMP's.*

Yu, L., and D. Stopinski, 2001. *Testing of Ultra-Urban Stormwater Best Management Practices* Virginia Transportation Research Council.

Zhang, X., 1998. *A Review on Space-limited Stormwater BMPs* University of Virginia Appendices.

APPENDIX A

Historical Context of the SWAMP Program

HISTORICAL CONTEXT OF THE SWAMP PROGRAM

Over the past 15 years, the Great Lakes Basin has experienced rapid urban growth. Stormwater runoff associated with this growth has been identified as a major contributor to the degradation of water quality and the destruction of fish habitats. In response to these concerns, a variety of stormwater management 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 fo 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 substance. 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 substance. 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 Actions Plans (RAP's) were to be prepared by various levels of government for the AOC's. The plans would contain strategies to clean up problems 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 ACO'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 communities 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 has 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 effects since 1971. The last version of the Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem (COA) was signed in 1994. The agreement expired in 2000 and is currently being renegotiated. 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 Environment and Energy

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

SWAMP

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

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

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

The objectives of the SWAMP Program are:

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

Technologies that have been addressed by the SWAMP program include:

- Wet ponds and constructed wetlands,
- Underground storage tanks,
- Flow balancing systems,
- Oil and grit separators,
- Conveyance exfiltration systems.

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

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

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

Contacts

Weng-Yau Liang
Pollution Control Engineer Advisor
Ministry of the Environment
Phone: 416-327-6409
Fax: 416-327-9091
Email: WengYau.Liang@ene.gov.on.ca

Tim Van Seters
Water Quality and Monitoring Supervisor
Toronto and Region Conservation Authority
Phone: 416-661-6600 ext.5337
Fax: 416-661-6898
Email: Tim_Van_Seters@trca.on.ca

Sandra Kok
Senior Project Engineer
Environment Canada
Great lakes Sustainability Fund
Phone: 905-336-6281
Fax: 905-336-6272
Email: Sandra.Kok@ec.gc.ca

APPENDIX B

Detailed Results: Water Quantity

Table B1: Rainfall/runoff summary for selected events, May 1997 - Dec 1998, Three-chamber OGS

storm #	date	runoff starts	runoff ends	runoff duration [hours]	rainfall [mm]	average rainfall intensity [mm/h]	maximum hourly intensity [mm/h]	rainfall volume [m3]	runoff calculated [m3]	runoff coefficient calculated [-]	runoff recorded [m3]	runoff coefficient recorded [-]
1	8-Jul-97	8/7/97 15:10	9/7/97 10:30	19.33	16.0	1.8	6.2	632.0	449.9	0.71	250.9	0.40
2	15-Aug-97	15/8/97 16:00	15/8/97 21:04	5.07	14.8	3.7	10.2	584.6	358.2	0.61	329.8	0.56
3	20-Aug-97	20/8/97 19:35	21/8/97 15:50	20.25	26.8	1.5	5.4	1058.6	1064.5	1.01	716.6	0.68
4	6-Sep-97	6/9/97 18:05	7/9/97 2:00	7.92	13.0	4.3	7.2	513.5	316.1	0.62	244.6	0.48
5	10-Sep-97	10/9/97 8:20	11/9/97 8:20	24.00	11.8	0.8	2.8	466.1	565.1	1.21	329.8	0.71
6	29-Sep-97	29/9/97 1:55	30/9/97 12:35	34.67	16.4	1.3	4.0	647.8	437.9	0.68	395.6	0.61
7	26-Oct-97	26/10/97 16:50	28/10/97 6:00	37.17	23.6	1.3	6.2	932.2	1122.6	1.20	1035.0	1.11
8	25-Jun-98	26/6/98 0:50	26/6/98 5:50	5.00	13.2	4.4	5.6	521.4	289.5	0.56	245.8	0.47
9	30-Jun-98	30/6/98 5:45	30/6/98 10:55	5.17	10.6	3.5	7.0	418.7	355.1	0.85	312.9	0.75
10	4-Jul-98	4/7/98 6:10	4/7/98 18:15	12.08	6.4	0.9	3.6	252.8	189.1	0.75	121.7	0.48
11	6-Jul-98	6/7/98 23:00	7/7/98 13:15	14.25	23.0	1.9	10.0	908.5	753.1	0.83	598.2	0.66
12	7-Jul-98	7/7/98 13:20	7/7/98 22:00	8.67	4.4	2.2	4.0	173.8	250.3	1.44	163.7	0.94
13	6-Aug-98	6/8/98 2:00	7/8/98 2:00	24.00	21.6	1.1	4.8	853.2	837.2	0.98	417.0	0.49
14	7-Aug-98	7/8/98 2:20	7/8/98 13:45	11.42	15.4	1.7	5.4	608.3	520.2	0.86	348.9	0.57
15	23-Aug-98	23/8/98 8:55	24/8/98 10:20	25.42	15.6	2.0	10.6	616.2	496.1	0.81	311.7	0.51
16	25-Aug-98	25/8/98 14:50	25/8/98 19:10	4.33	8.4	4.2	8.2	331.8	151.5	0.46	110.4	0.33

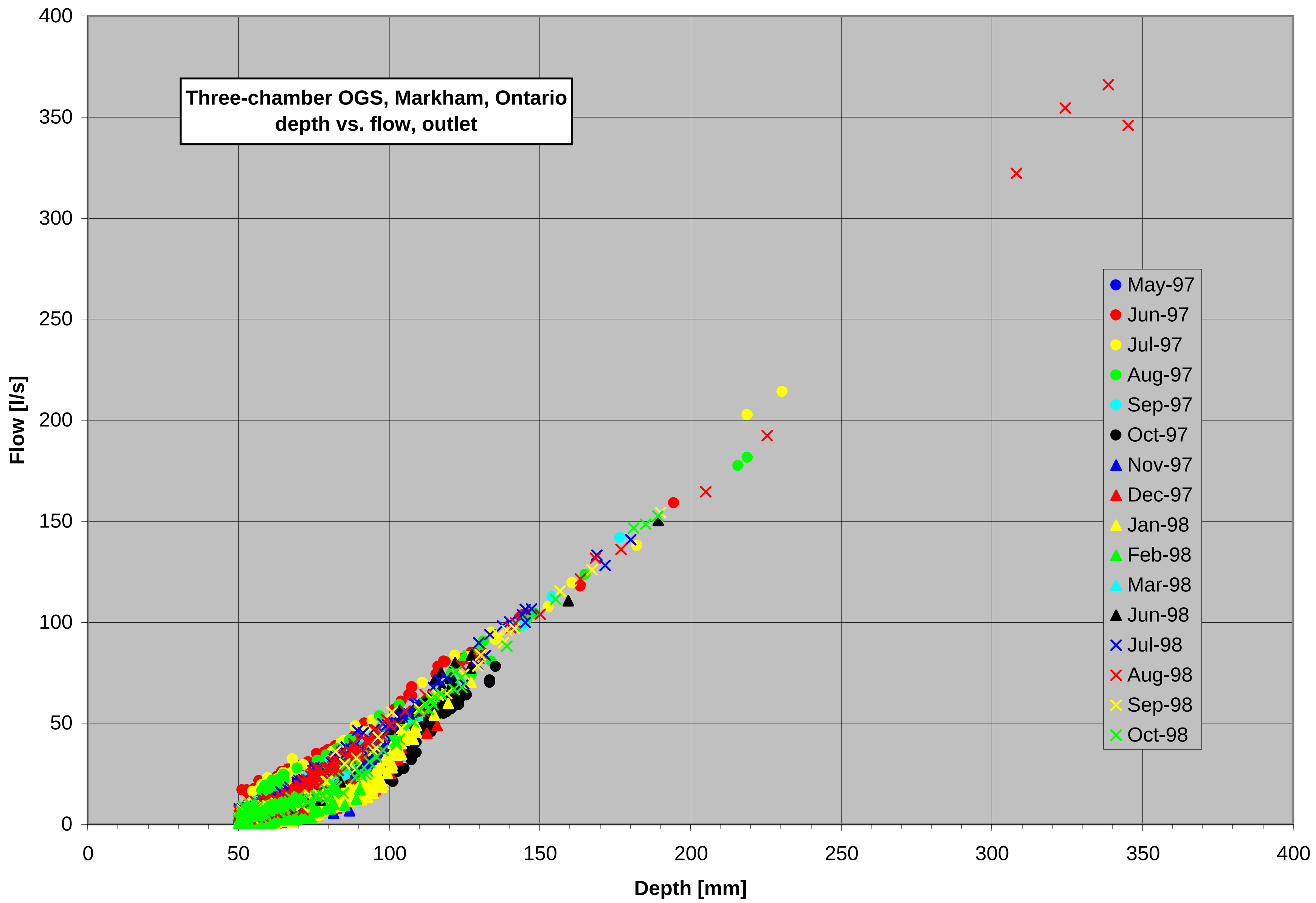


Figure B1: Depth vs. flow, combined outlet, Three-chamber OGS

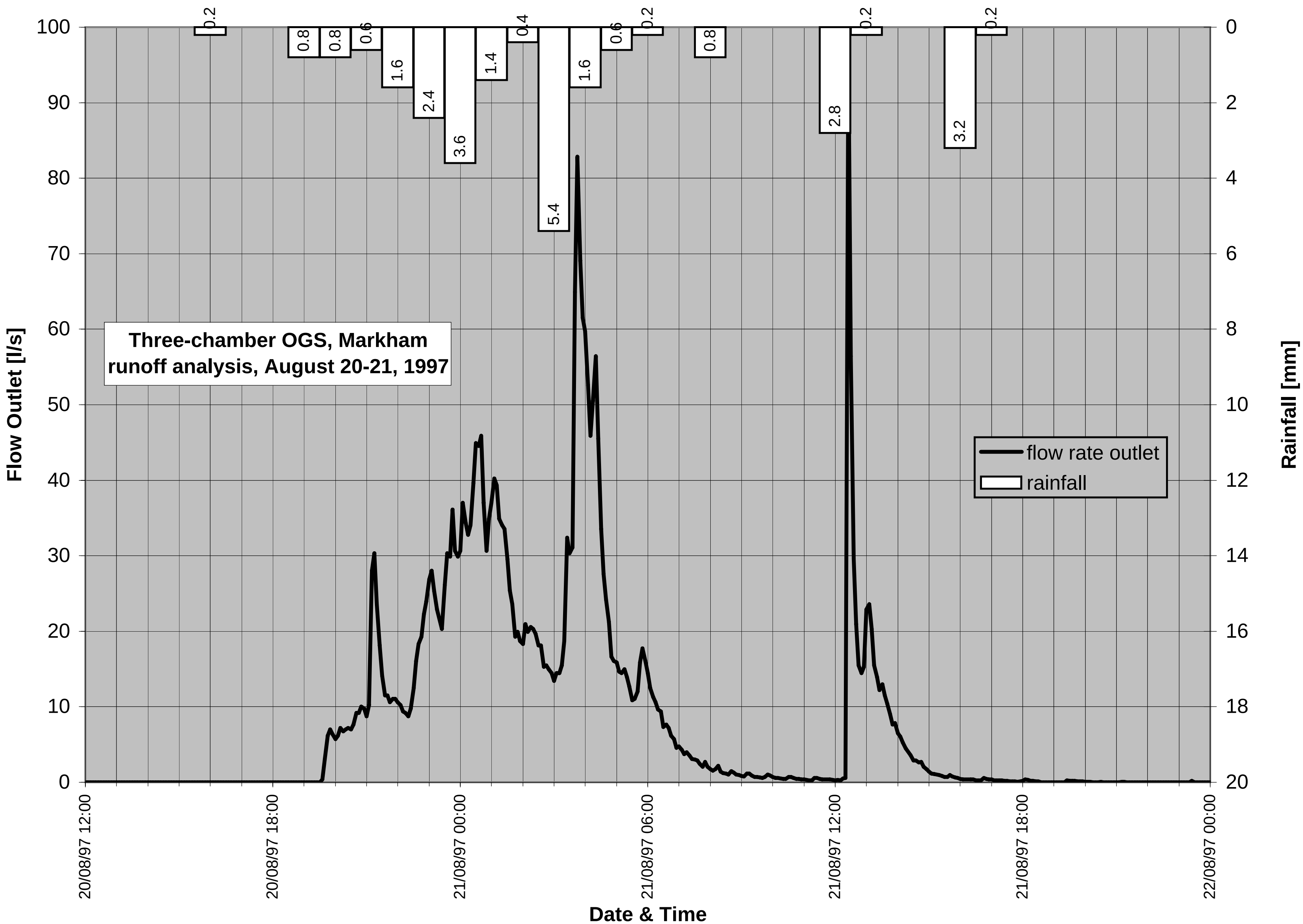


Figure B2: Runoff analysis, August 20-21, 1997, Three-chamber OGS

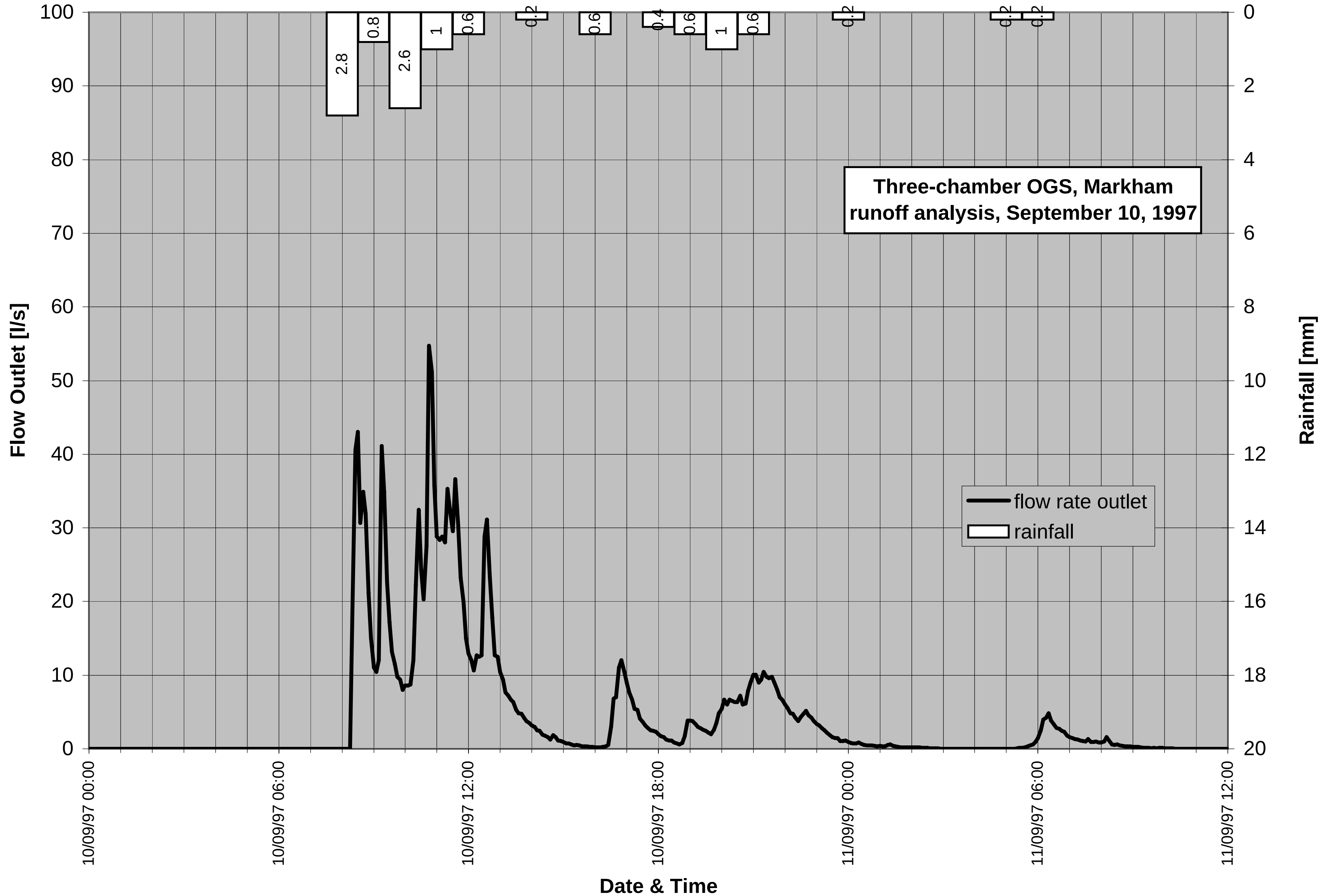


Figure B3: Runoff analysis, September 10, 1997, Three-chamber OGS

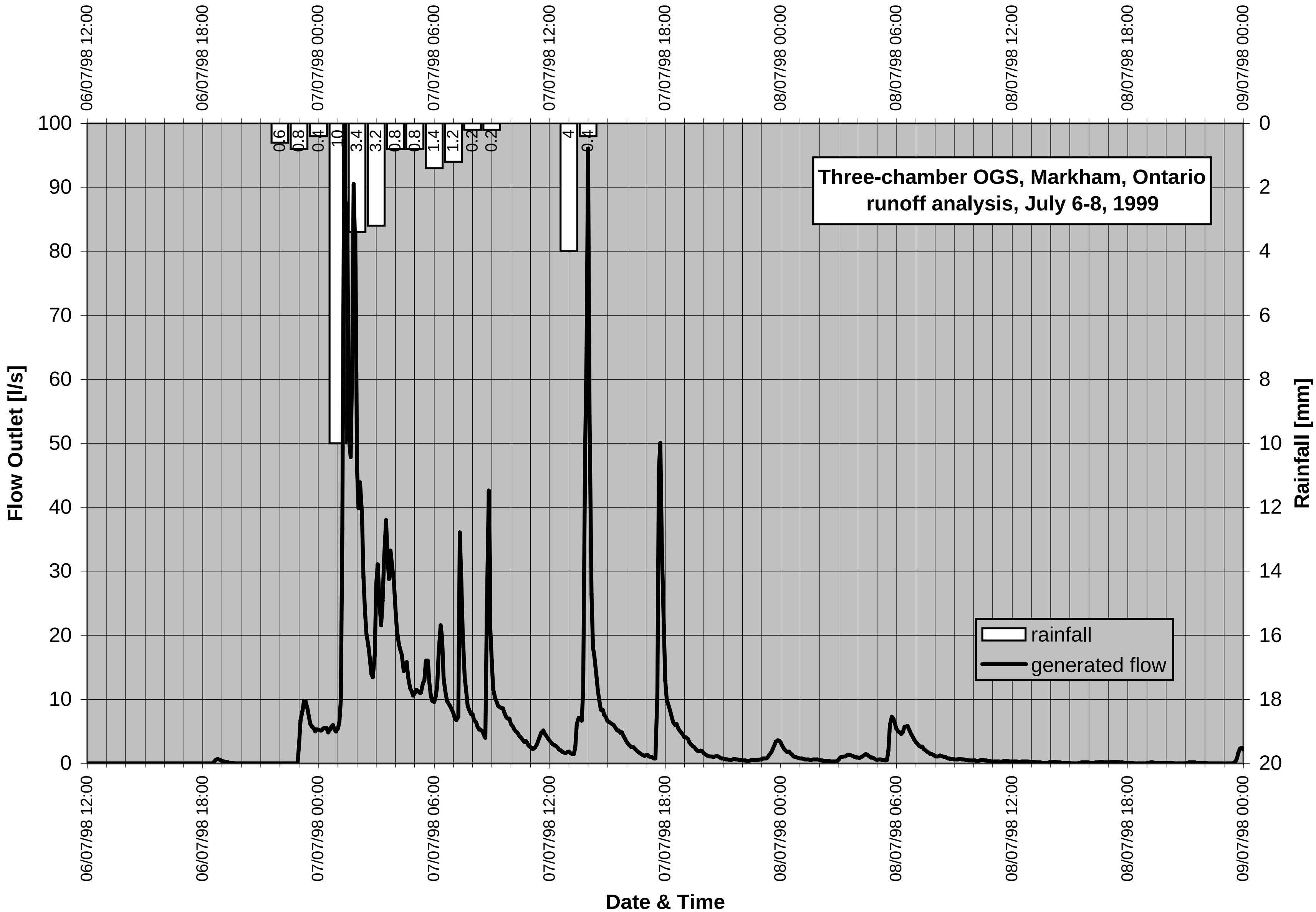


Figure B4: Runoff analysis, July 7 1998, Three-chamber OGS

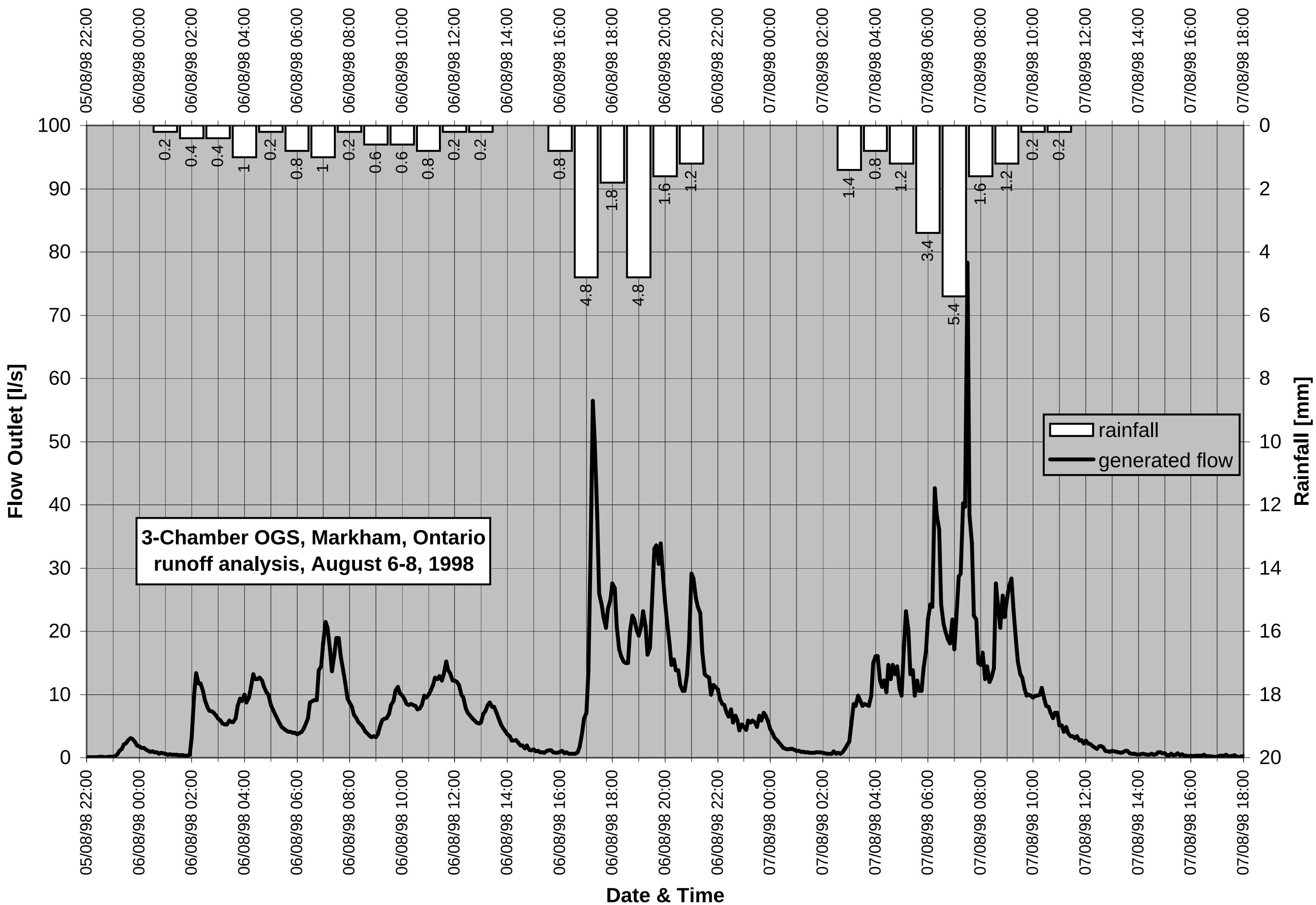


Figure B5: Runoff analysis from August 6 to August 8, 1998, Three-chamber OGS

Table B2: Rainfall/runoff summary for selected events from August 1997 to December 1998, Stormceptor OGS

storm #	storm date	runoff starts	runoff ends	runoff duration [hours]	total rainfall [mm]	average rainfall intensity [mm/h]	maximum hourly intensity [mm/h]	rainfall volume [m3]	runoff volume calculated [m3]	runoff coefficient [-]	overflow duration [min]
1	26-Oct-97	26/10/97 19:59	27/10/97 8:37	12.633	20.3	1.8	3.2	582.6	573.0	0.98	n/a
2	01-Nov-97	1/11/97 12:15	1/11/97 21:01	8.767	19.3	1.4	4.7	553.9	400.1	0.72	n/a
3	16-Apr-98	16/4/98 10:03	16/4/98 14:47	4.733	11.2	2.0	5.1	321.4	566.3	1.76	n/a
4	10-May-87	10/5/98 18:37	11/5/98 11:59	17.367	39.4	1.2	2.9	1130.8	659.2	0.58	n/a
5	11-Jun-98	11/6/98 22:55	12/6/98 6:37	7.700	14.3	1.6	3.2	410.4	410.5	1.00	n/a
6	16-Jun-98	16/6/98 8:41	16/6/98 11:21	2.667	7.2	2.1	2.9	206.6	158.4	0.77	n/a
7	17-Jun-98	17/6/98 14:57	17/6/98 18:53	3.933	12.2	3.1	7.1	350.1	409.2	1.17	24
8	26-Jun-98	26/6/98 1:56	26/6/98 3:22	1.433	16.0	7.8	14.7	459.2	300.3	0.65	44
9	07-Jul-98	7/7/98 2:12	7/7/98 15:04	12.867	21.7	2.0	6.3	622.8	660.6	1.06	24
10	06-Sep-98	6/9/98 22:09	7/9/98 0:57	2.800	17.2	8.6	9.5	493.6	635.2	1.29	104
11	01-Oct-98	1/10/98 0:24	1/10/98 2:08	1.733	6.7	3.4	3.7	192.3	285.2	1.48	n/a
12	07-Oct-98	7/10/98 13:30	7/10/98 20:34	7.067	7.5	0.7	2.2	215.3	146.1	0.68	n/a
13	14-Oct-98	14/10/98 4:51	14/10/98 6:29	1.633	4.9	1.3	2.9	140.6	95.8	0.68	n/a
14	10-Nov-98	10/11/98 11:10	10/11/98 15:10	4.000	8.7	1.5	4.1	249.7	441.8	1.77	n/a
15	16-Nov-98	16/11/98 12:28	16/11/98 20:42	8.233	6.6	0.4	1.1	189.4	35.2	0.19	n/a

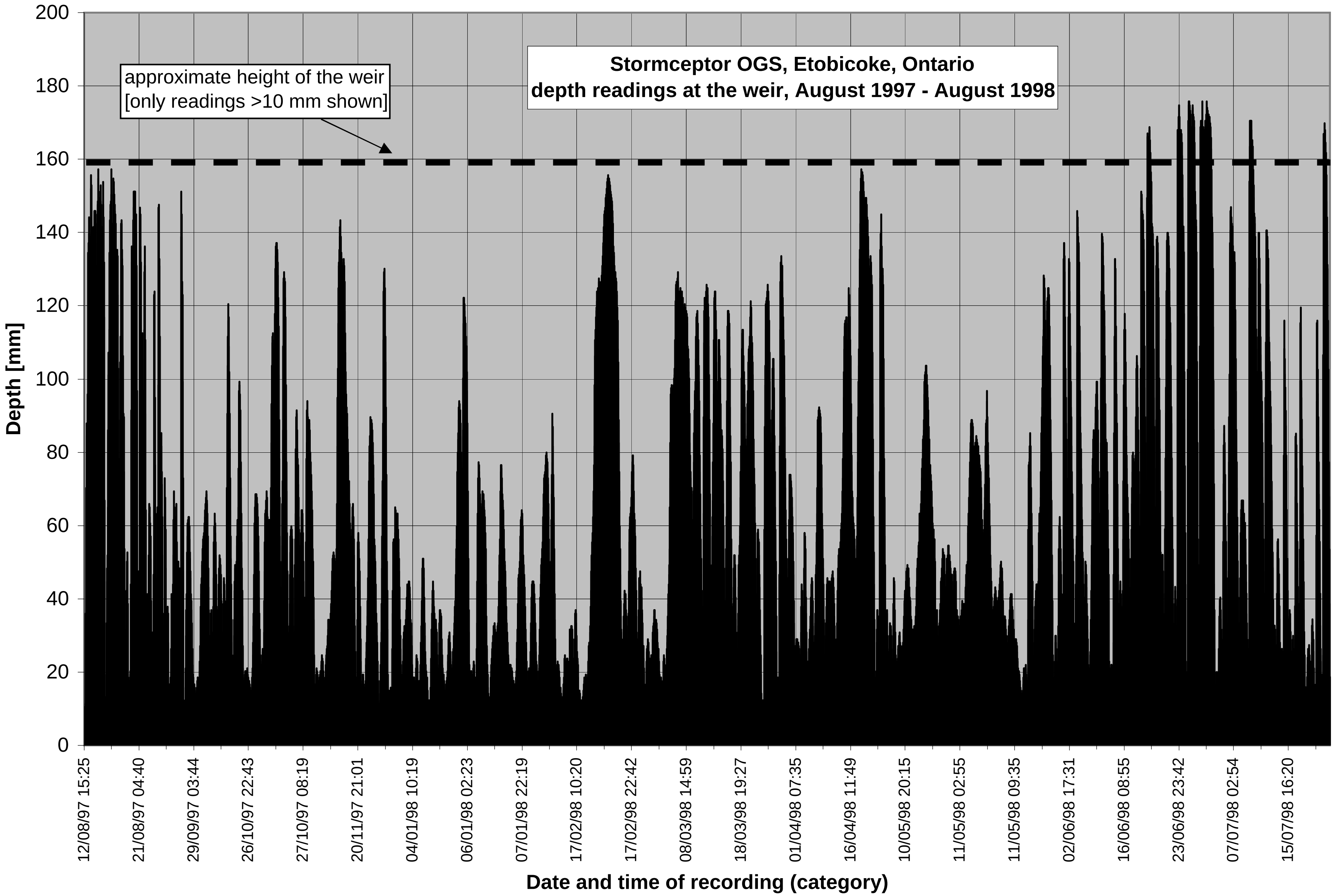


Figure B6: Depth readings at the weir from August 1997 to August 1998, Stormceptor OGS

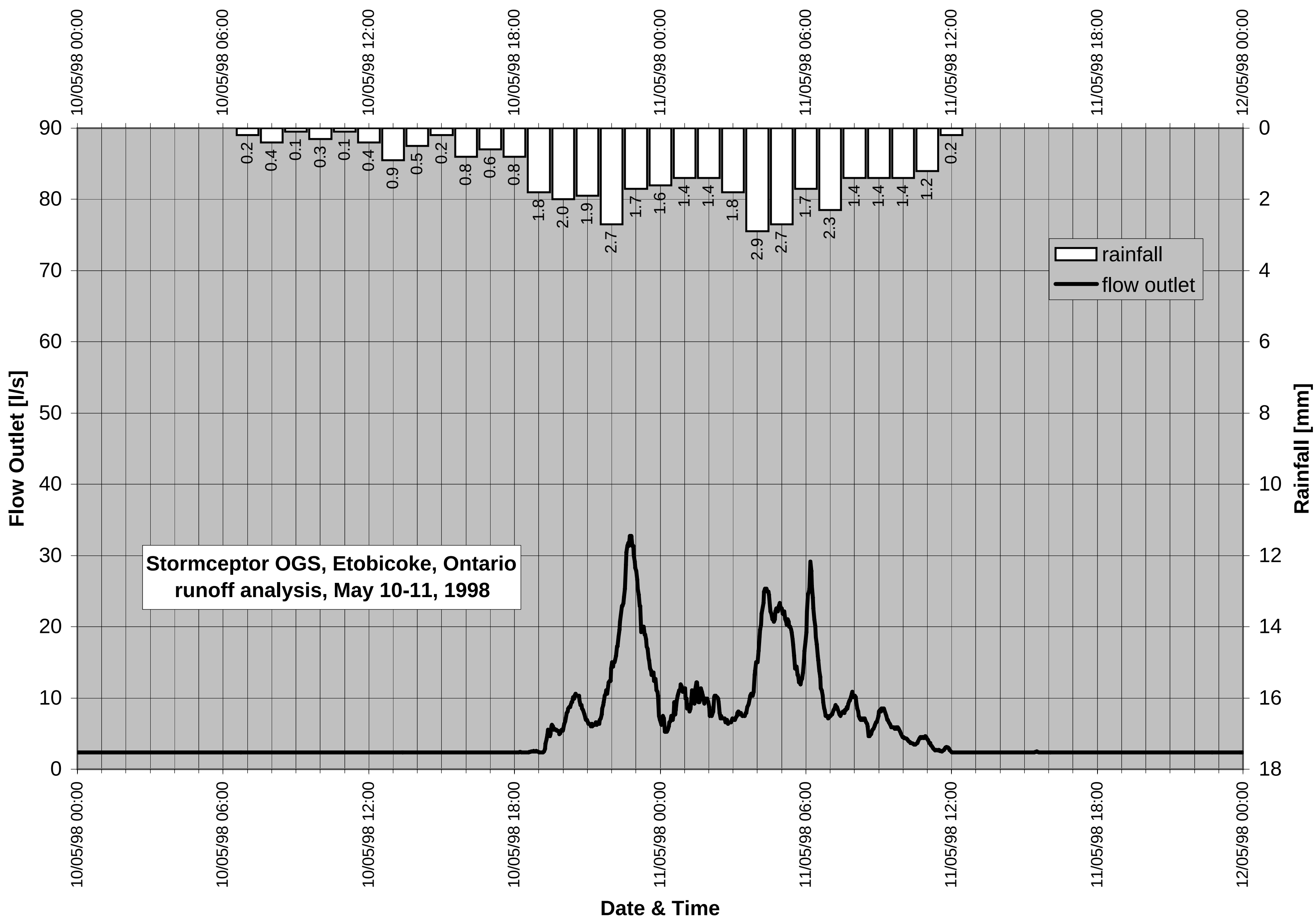


Figure B7: Runoff analysis from May 10 to May 11, 1998, Stormceptor OGS

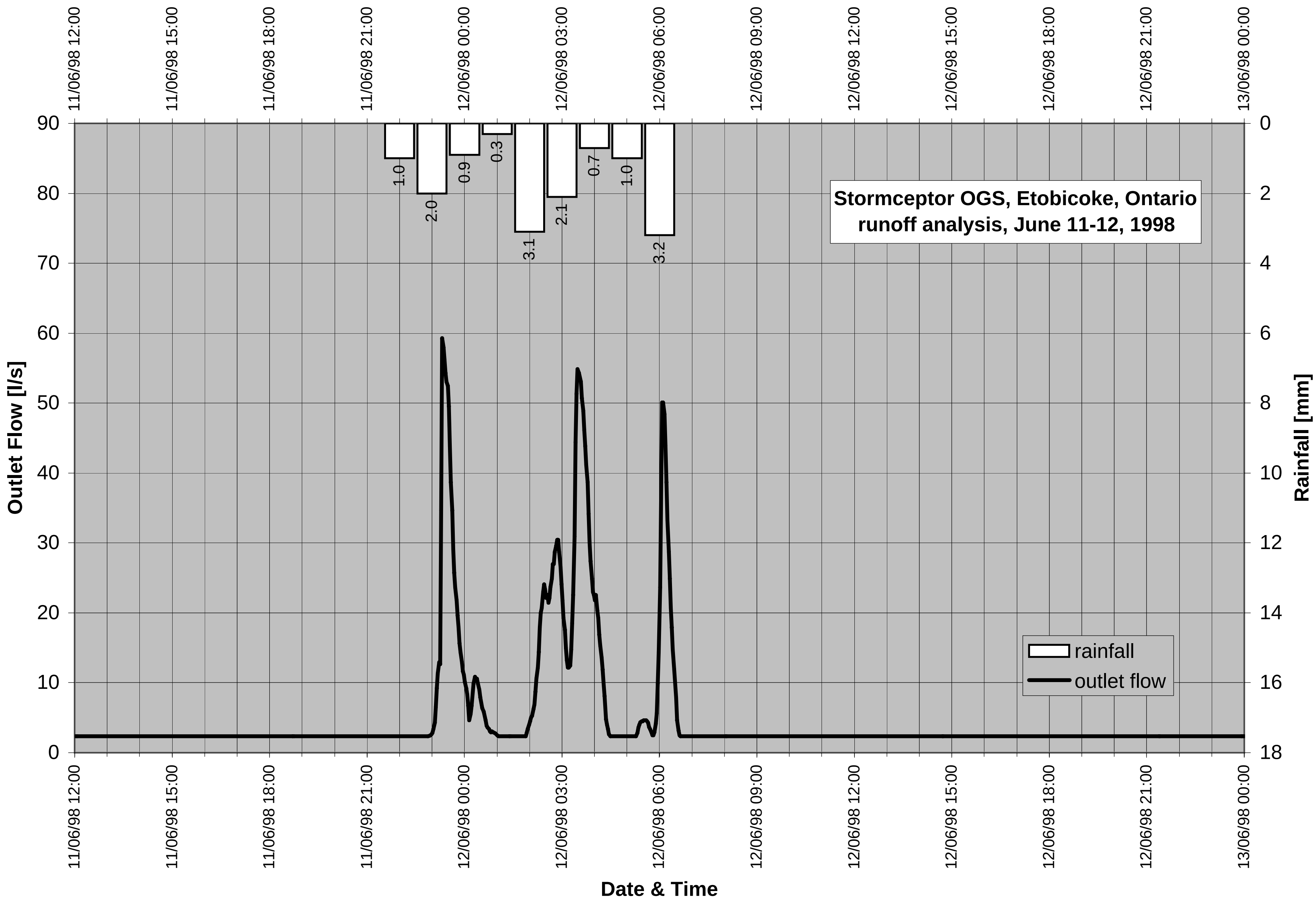


Figure B8: Runoff analysis from June 11 to June 12, 1998, Stormceptor OGS

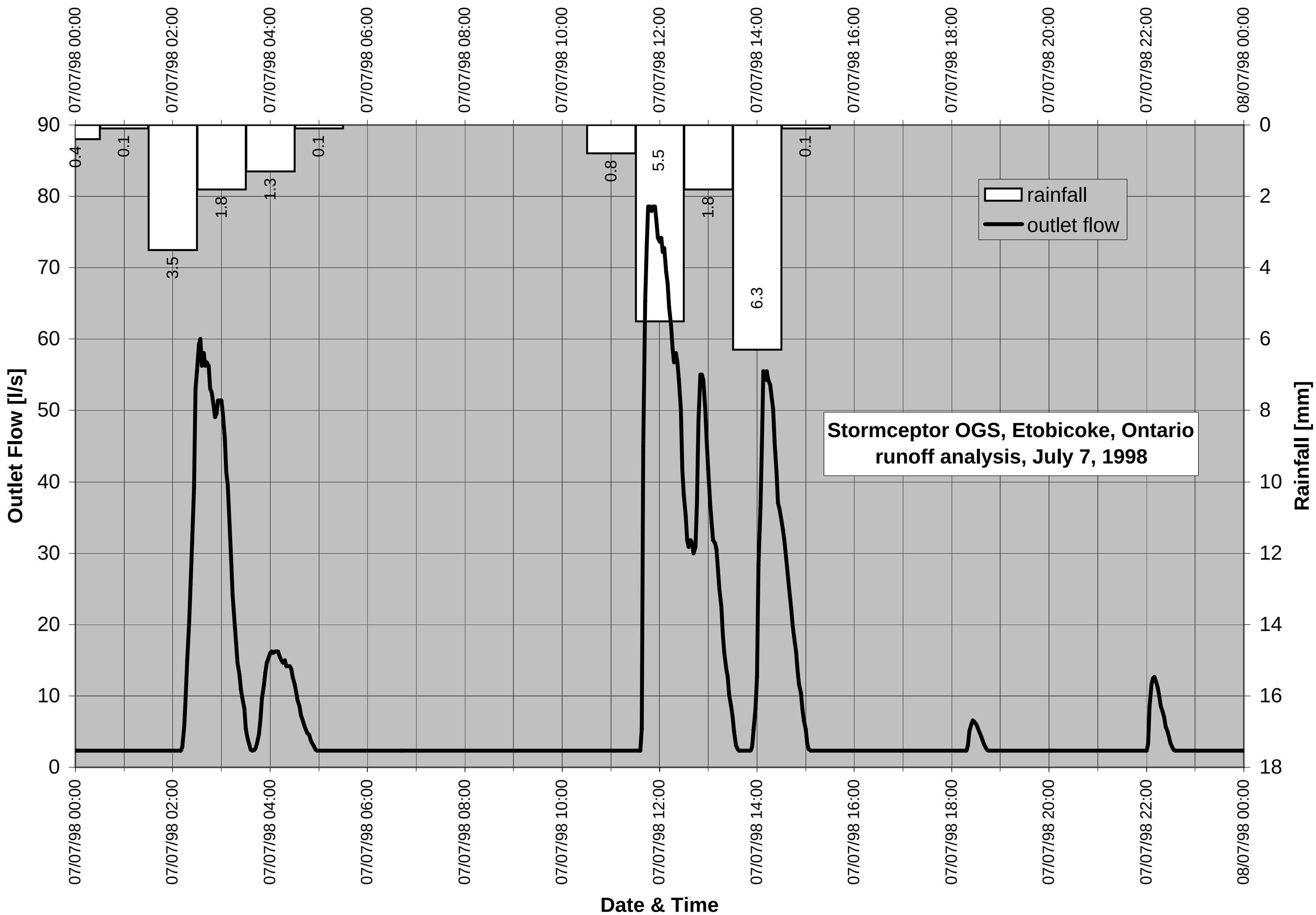


Figure B9: Runoff analysis for July 7, 1998, Stormceptor OGS

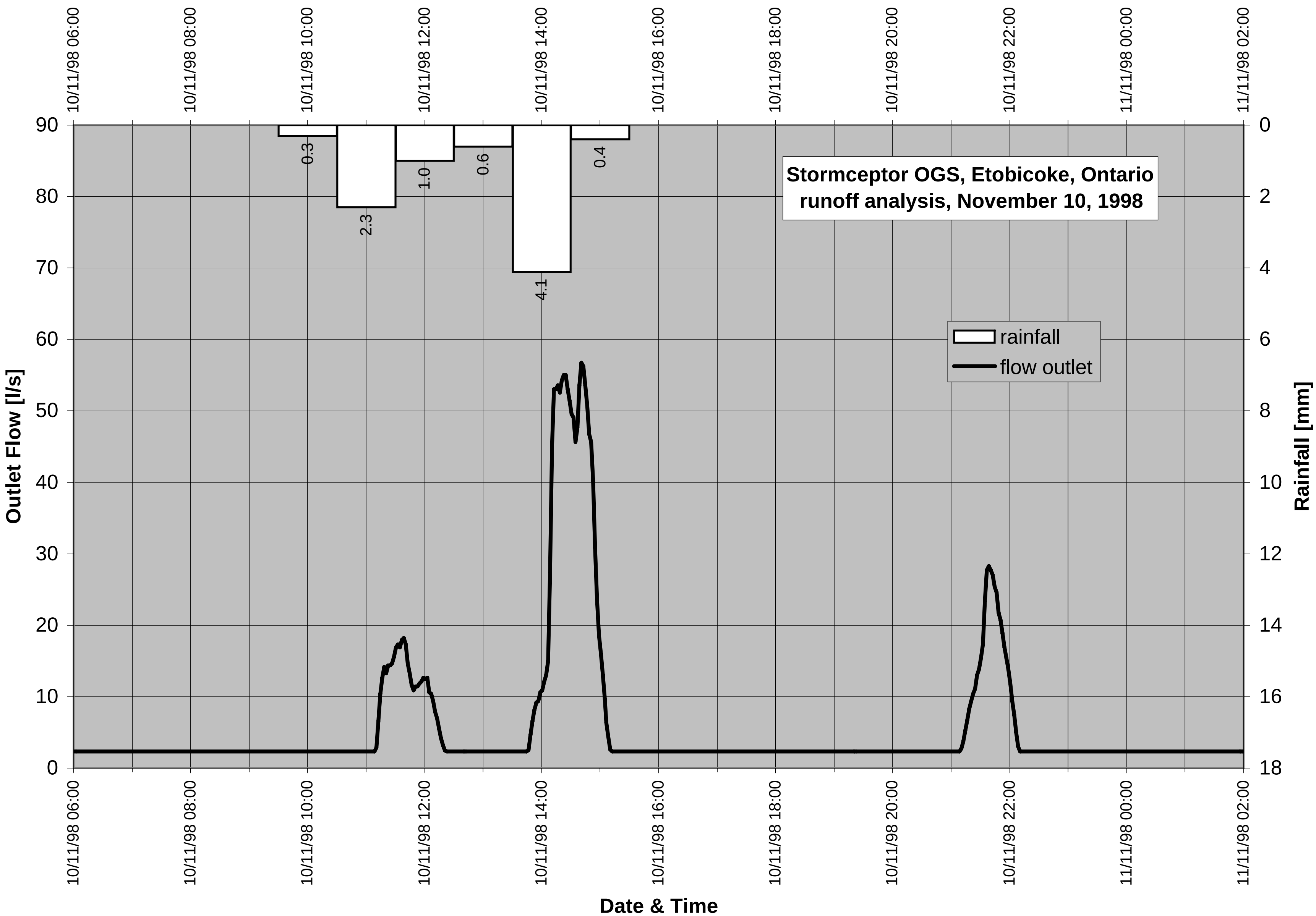


Figure B10: Runoff analysis for November 10, 1998, Stormceptor OGS

APPENDIX C

Detailed Results: Water Quality

Table C1: Statistical summary of water quality results, Three-chamber OGS

storm date/ parameter	units	detection limit	provincial water quality objectives	inlet								outlet							
				number of samples	average	max	min	median	95%LL	95%UL	TSS vs. parameter correlation	number of samples	average	max	min	median	95%LL	95&UL	TSS vs. parameter correlation
Mercury	ug/l	0.02	0.2 ug/l	26	0.03	0.09	0.02	0.02	0.02	0.04	0.49	54	0.02	0.10	0.02	0.02	0.02	0.03	0.13
Suspended Solids	**mg/l**	**2.5**		**26**	**136.1**	**378.0**	**34.5**	**109.0**	**102.2**	**170.1**	**1.00**	**54**	**54.4**	**268.0**	**4.5**	**40.0**	**40.0**	**68.9**	**1.00**
Solids; total	mg/l			26	1567.8	13400.0	118.0	427.0	308.1	2827.4	0.38	54	478.3	4000.0	74.0	266.0	280.3	676.2	0.51
Solids; dissolved	mg/l			26	1429.4	13000.0	44.0	331.0	184.9	2673.8	0.36	54	423.9	3930.0	58.0	225.0	232.8	614.9	0.46
Oil and Grease	**mg/l**	**1.0**		**26**	**22.0**	**42.0**	**4.0**	**22.0**	**17.4**	**26.5**	**0.67**	**54**	**8.5**	**34.0**	**1.0**	**7.8**	**6.8**	**10.2**	**0.76**
Aluminum	ug/l	11	15-75 ug/l	26	568	1540	128	599	438	698	0.78	54	292	922	41	216	232	352	0.57
Barium	ug/l	0.2	n/a	26	53.9	236.0	10.3	46.0	35.9	71.8	0.53	54	28.7	93.4	13.3	24.9	24.6	32.8	0.59
Beryllium	ug/l	0.02000	11-1100 ug/l	26	0.05068	0.10700	0.00935	0.05425	0.04050	0.06085	0.81	53	0.03391	0.39600	0.00144	0.02020	0.01797	0.04985	0.34
Calcium	mg/l	0	n/a	26	64	256	14	55	46	82	0.72	54	39	111	19	35	34	43	0.47
Cadmium	ug/l	0.600	0.1-0.5 ug/l	23	1.108	6.530	0.199	0.673	0.582	1.634	0.58	44	0.452	1.510	0.000	0.365	0.347	0.557	0.48
Cobalt	ug/l	1.30	0.6 ug/l	23	1.36	2.69	0.15	1.40	1.07	1.66	0.53	45	0.78	2.22	0.00	0.69	0.62	0.93	0.50
Chromium	ug/l	1.40	100 ug/l	26	11.30	35.90	1.52	9.46	8.12	14.48	0.77	53	6.24	29.80	0.18	4.67	4.68	7.81	0.59
Copper	ug/l	1.6	1-5 ug/l	26	55.2	199.0	6.6	46.2	38.9	71.5	0.72	54	21.1	83.3	5.8	17.0	17.4	24.7	0.48
Iron	ug/l	1	300 ug/l	26	831	1930	125	762	641	1022	0.70	54	500	1660	65	383	398	602	0.70
Magnesium	mg/l	0.01	n/a	26	4.90	13.90	0.92	4.63	3.81	5.99	0.62	54	3.64	9.10	0.95	3.37	3.16	4.13	0.13
Manganese	ug/l	0.2	n/a	26	165.1	549.0	29.6	154.5	122.1	208.2	0.85	54	85.2	258.0	6.0	72.7	70.1	100.3	0.70
Molybdenum	ug/l	1.60	10 ug/l	21	2.46	6.84	0.08	1.95	1.61	3.32	-0.15	47	1.37	6.56	0.00	0.94	0.95	1.80	-0.05
Nickel	ug/l	1.30	25 ug/l	26	6.96	21.30	0.91	6.23	5.25	8.67	0.73	54	3.09	8.77	0.36	2.93	2.64	3.54	0.56
Lead	ug/l	10.0	1-5 ug/l	26	39.6	167.0	2.5	28.7	24.8	54.4	0.78	49	19.2	123.0	0.8	11.1	12.2	26.2	0.73
Strontium	ug/l	0.1	n/a	26	292.6	1450.0	32.9	209.0	177.7	407.4	0.64	54	168.4	660.0	59.7	148.5	141.6	195.2	0.38
Titanium	ug/l	0.50	n/a	25	7.55	17.90	1.32	6.83	5.86	9.24	-0.05	53	5.52	25.00	0.00	4.94	4.38	6.66	0.51
Vanadium	ug/l	1.50	7 ug/l	26	6.96	13.70	1.42	6.80	5.65	8.27	0.32	54	3.73	9.28	0.57	3.45	3.27	4.19	0.51
Zinc	ug/l	6.0	20 ug/l	26	305.3	960.0	48.9	217.0	211.5	399.1	0.47	54	89.4	360.0	15.0	77.2	72.1	106.7	0.65

Table C2: Statistical summary of water quality results, Stormceptor OGS

parameter/ date	units	detection limit	provincial water quality objectives	inlet								outlet							
				number of samples	average	max	min	median	95%LL	95%UL	TSS vs. parameter correlation	number of samples	average	max	min	median	95%LL	95%UL	TSS vs. parameter correlation
Mercury	ug/l	0.02	0.2 ug/l	17	0.03	0.06	0.02	0.02	0.02	0.04	0.75	35	0.02	0.05	0.02	0.02	0.02	0.03	0.45
Suspended Solids	**mg/l**	**2.5**		**20**	**162.8**	**634.0**	**28.5**	**112.5**	**94.4**	**219.0**	**1.00**	**37**	**79.5**	**451.0**	**10.5**	**47.5**	**49.6**	**207.7**	**1.00**
Total Solids	mg/l			20	978.2	6540.0	60.0	424.0	297.3	1659.1	0.25	37	700.3	3610.0	86.0	608.0	475.4	1667.8	0.56
Dissolved Solids	mg/l			20	797.6	6390.0	44.0	286.0	138.9	1456.3	0.13	37	619.9	3340.0	68.0	394.0	410.2	1521.9	0.46
Oil and Grease	**mg/l**	**1.0**		**18**	**15.7**	**29.0**	**3.5**	**17.0**	**12.2**	**19.2**	**0.79**	**36**	**9.0**	**24.0**	**1.0**	**6.8**	**7.1**	**17.1**	**0.66**
Aluminum	ug/l	11	15-75 ug/l	18	648	1750	143	455	437	858	0.84	36	424	1910	36	290	282	1027	0.91
Barium	ug/l	0.2	n/a	18	47.9	106.0	12.9	45.6	34.5	61.2	0.79	36	42.3	83.2	12.3	39.0	35.6	70.9	0.56
Beryllium	ug/l	0.02000	11-1100 ug/l	18	0.05963	0.17000	0.01180	0.04255	0.03870	0.08056	0.87	36	0.03950	0.16100	0.00741	0.02705	0.02816	0.08764	0.93
Calcium	mg/l	0	n/a	18	52	141	11	41	36	68	0.75	36	57	127	15	45	46	104	0.30
Cadmium	ug/l	0.600	0.1-0.5 ug/l	18	1.208	4.560	0.000	0.556	0.577	1.839	0.54	36	0.669	2.500	0.000	0.470	0.464	1.540	0.53
Cobalt	ug/l	1.30	0.6 ug/l	18	1.43	3.23	0.01	1.27	0.96	1.90	0.71	36	0.96	2.61	0.00	0.82	0.72	1.95	0.70
Chromium	ug/l	1.4	100 ug/l	18	11.10	25.30	2.78	10.80	8.77	13.43	0.39	36	9.34	71.50	0.79	6.11	5.10	27.34	0.16
Copper	ug/l	1.6	1-5 ug/l	18	61.0	253.0	9.1	46.7	33.4	88.5	0.77	36	30.9	145.0	5.8	22.0	21.4	71.6	0.66
Iron	mg/l	1	300 ug/l	18	1032	2020	204	923	760	1303	0.78	36	655	2960	123	516	468	1446	0.81
Magnesium	ug/l	0.008	n/a	18	8.57	18.10	1.98	8.37	6.31	10.84	0.89	36	9.39	23.10	2.19	7.61	7.48	17.45	0.52
Manganese	ug/l	0.2	n/a	18	219.5	511.0	38.2	229.5	153.7	285.2	0.87	36	146.4	442.0	33.7	115.0	112.9	288.3	0.82
Molybdenum	ug/l	1.6	10 ug/l	18	1.32	6.71	0.01	0.60	0.51	2.14	0.11	36	0.46	2.60	0.00	0.34	0.26	1.32	-0.24
Nickel	ug/l	1.3	25 ug/l	18	8.33	26.00	1.29	6.80	5.24	11.42	0.79	36	4.20	11.40	0.71	2.91	3.29	8.02	0.69
Lead	ug/l	10	1-5 ug/l	18	58.43	249.00	0.75	35.45	28.16	88.70	0.72	36	32.74	165.00	0.00	18.80	19.70	88.07	0.79
Strontium	ug/l	0.1	n/a	18	238.76	983.00	28.00	136.50	132.79	344.72	0.57	36	253.95	632.00	59.50	166.00	198.32	489.98	0.16
Titanium	ug/l	0.5	n/a	18	6.21	11.00	2.57	6.61	5.28	7.14	0.14	36	5.74	51.20	0.00	4.82	3.05	17.16	0.15
Vanadium	ug/l	1.5	7 ug/l	18	5.67	9.98	2.39	5.98	4.56	6.78	0.59	36	3.72	9.33	1.07	3.16	3.06	6.52	0.60
Zinc	ug/l	6.0	20 ug/l	18	266.9	754.0	55.6	247.5	186.8	346.9	0.76	36	159.5	548.0	32.1	120.5	119.9	327.9	0.89

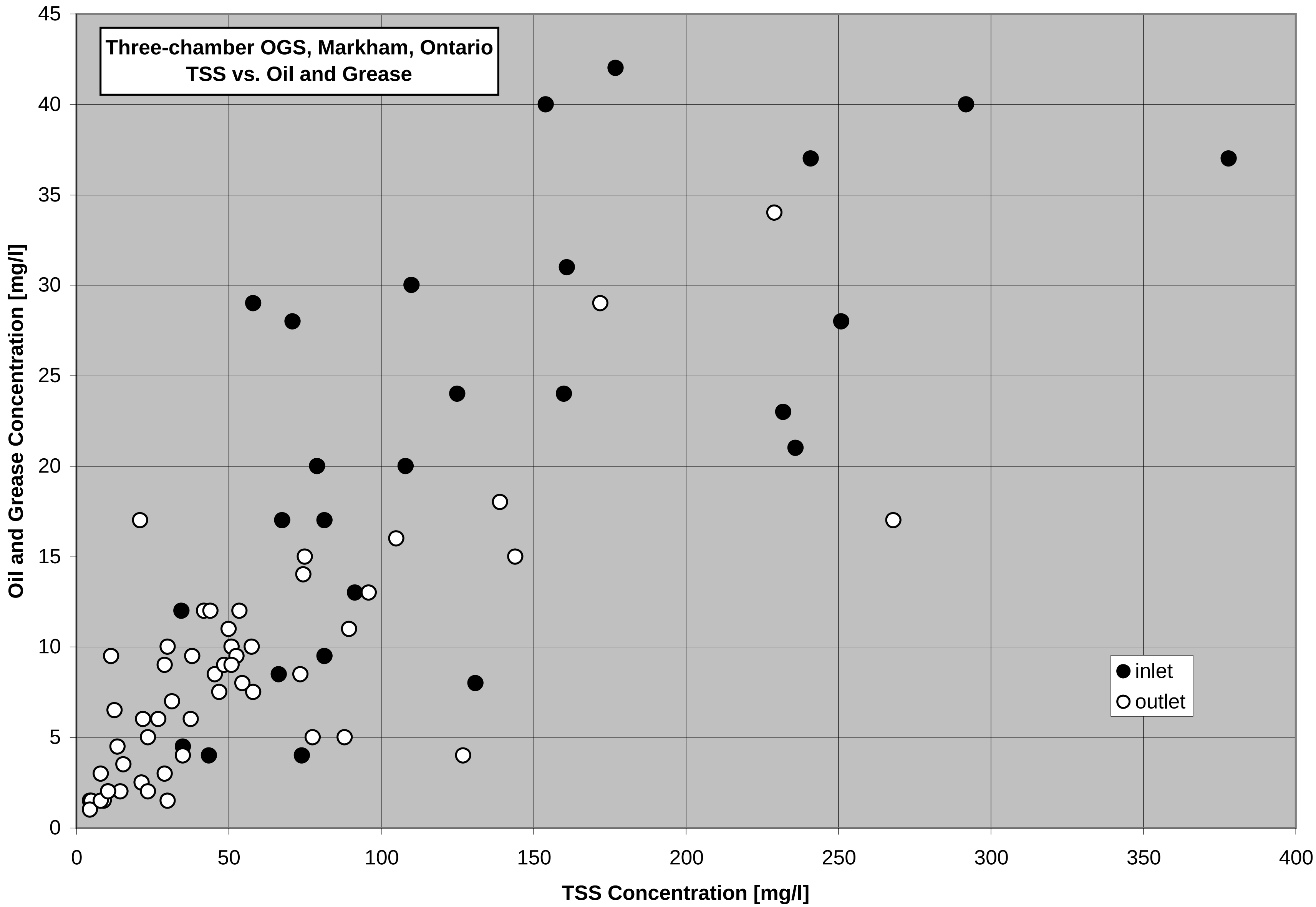


Figure C1: TSS vs. oil and grease, Three-chamber OGS

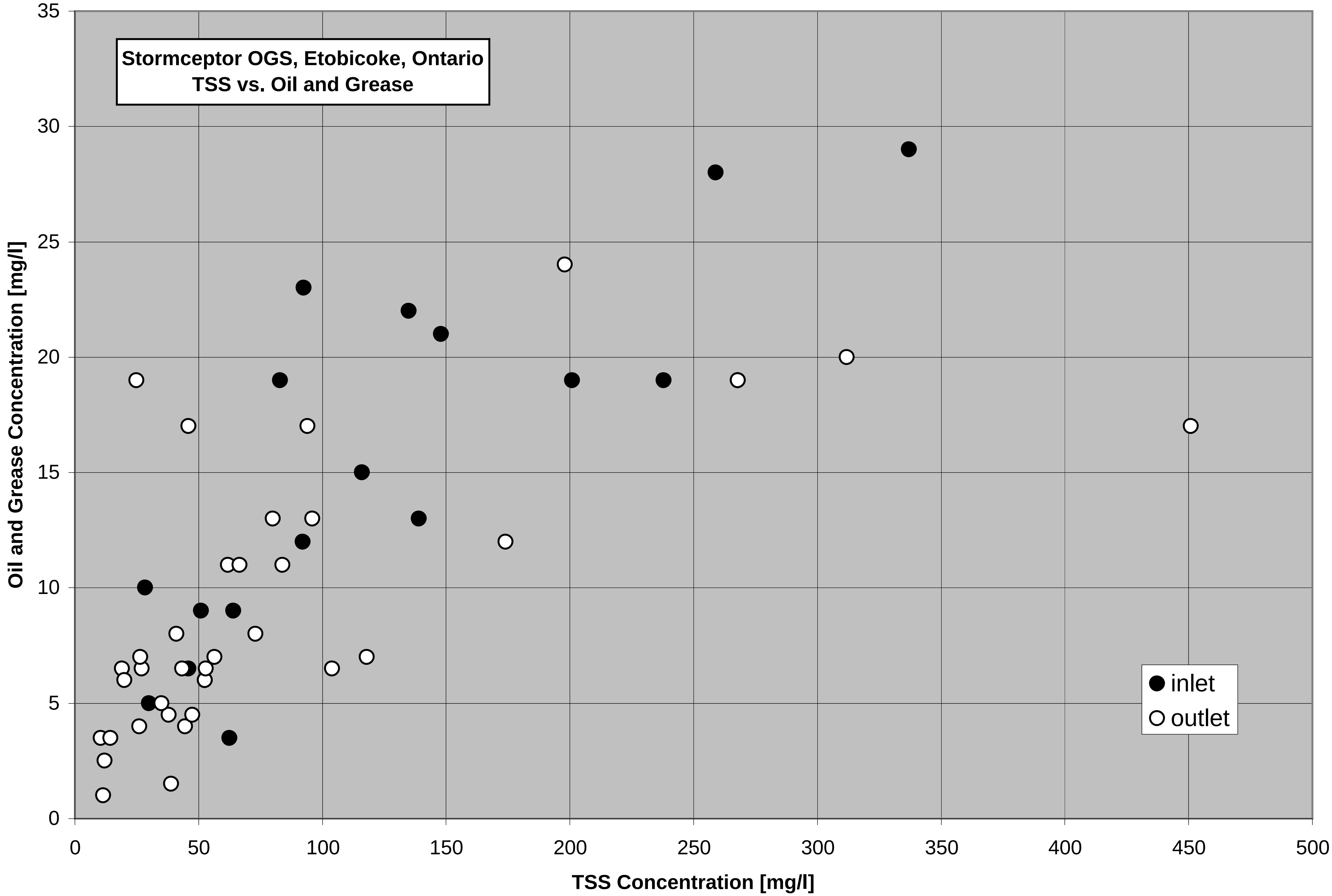
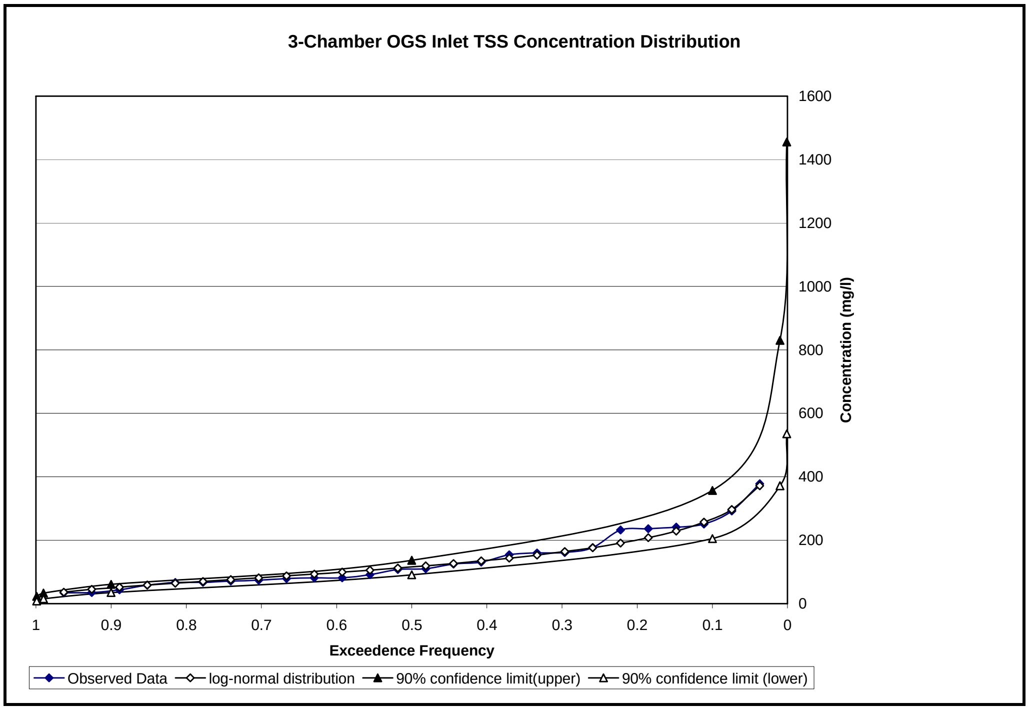
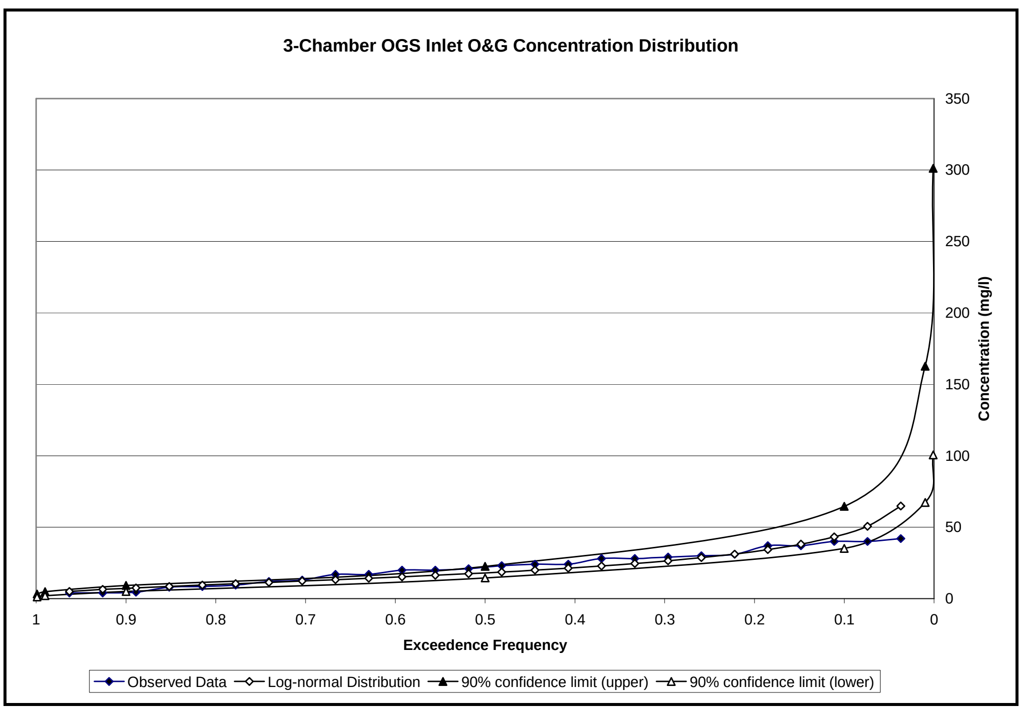


Figure C2: TSS vs. oil and grease, Stormceptor OGS

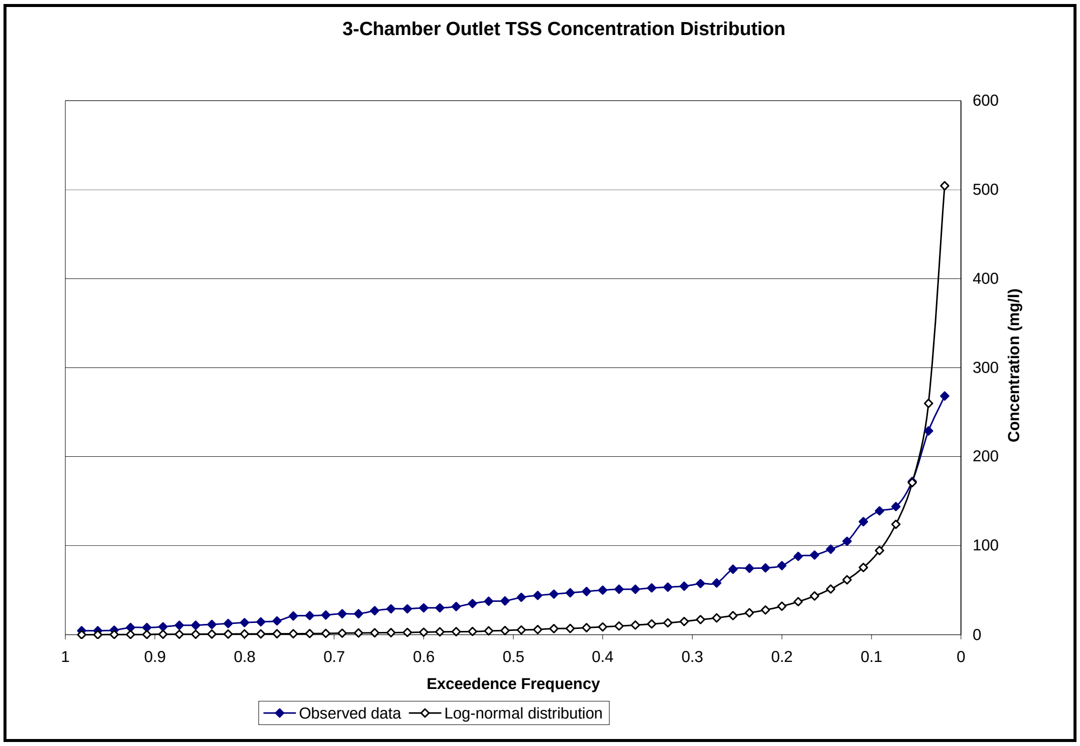


(a)

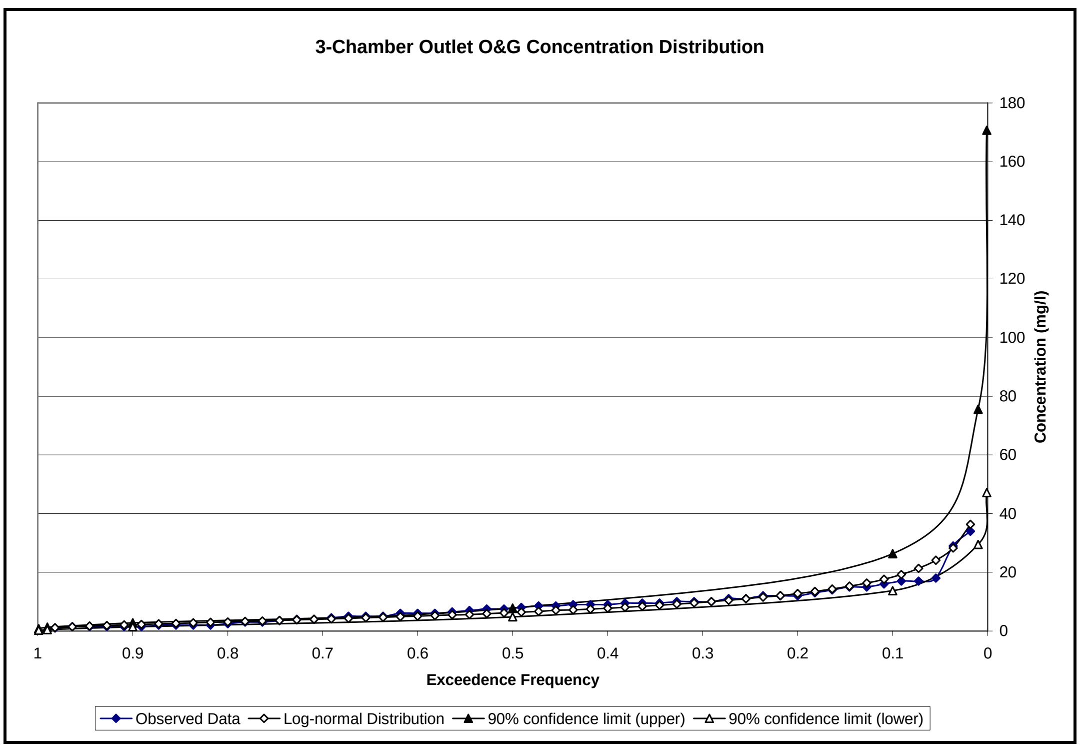


(b)

Figure C3: Log-normal distribution for inlet TSS and inlet O&G, three-chamber OGS

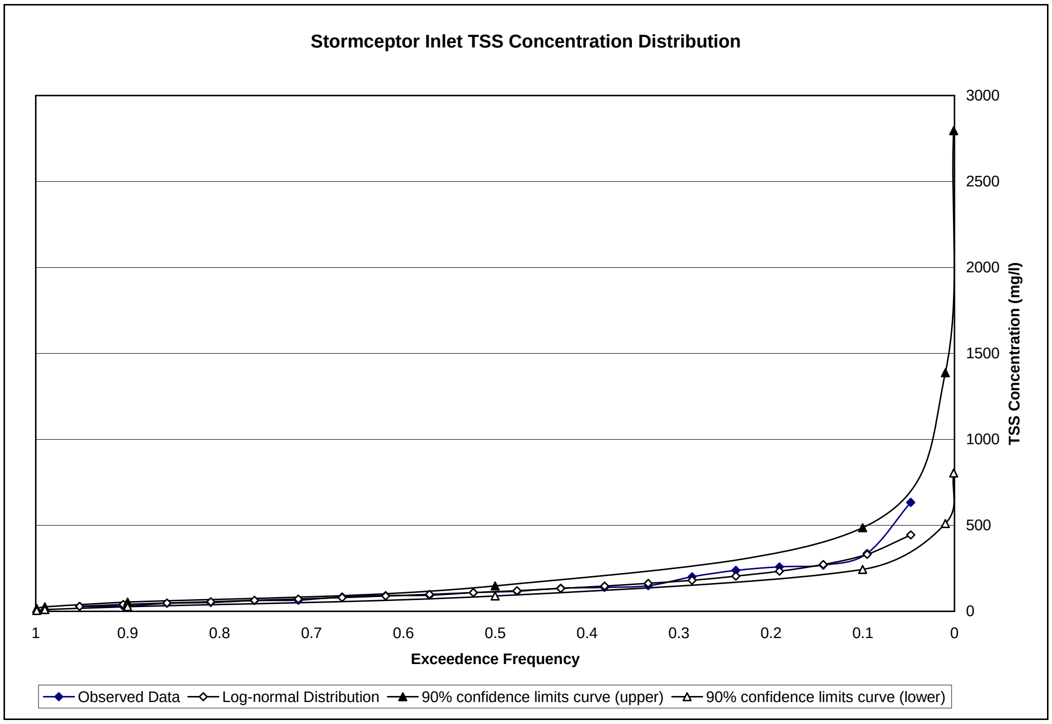


(a)

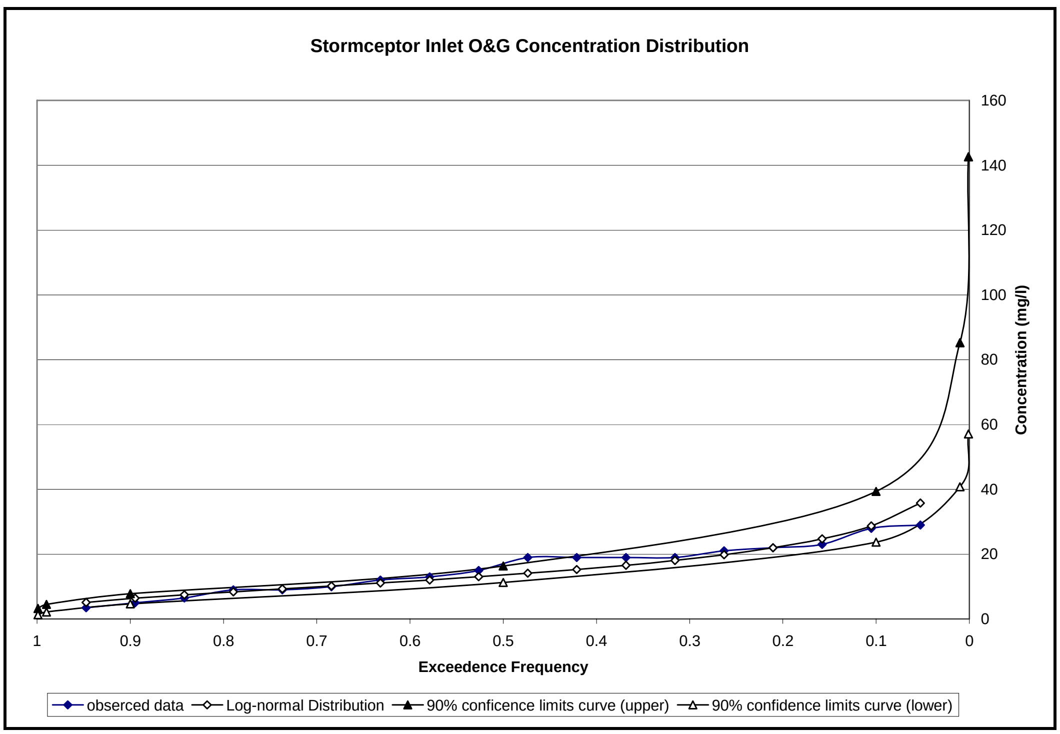


(b)

Figure C4: Log-normal distribution for outlet TSS and outlet O&G, three-chamber OGS

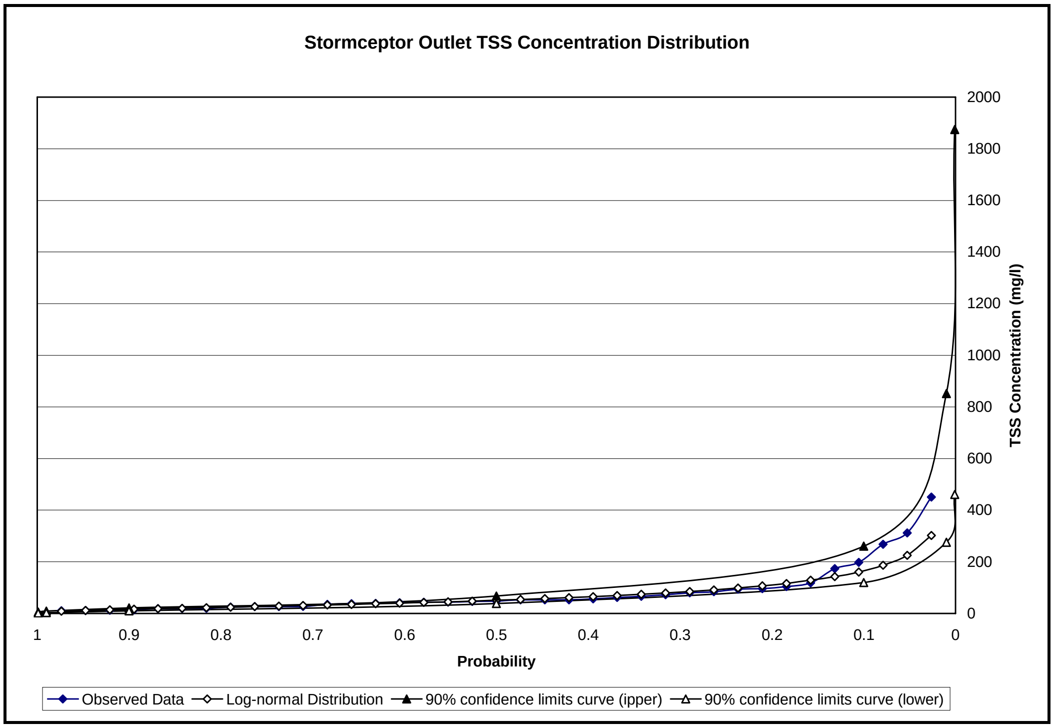


(a)

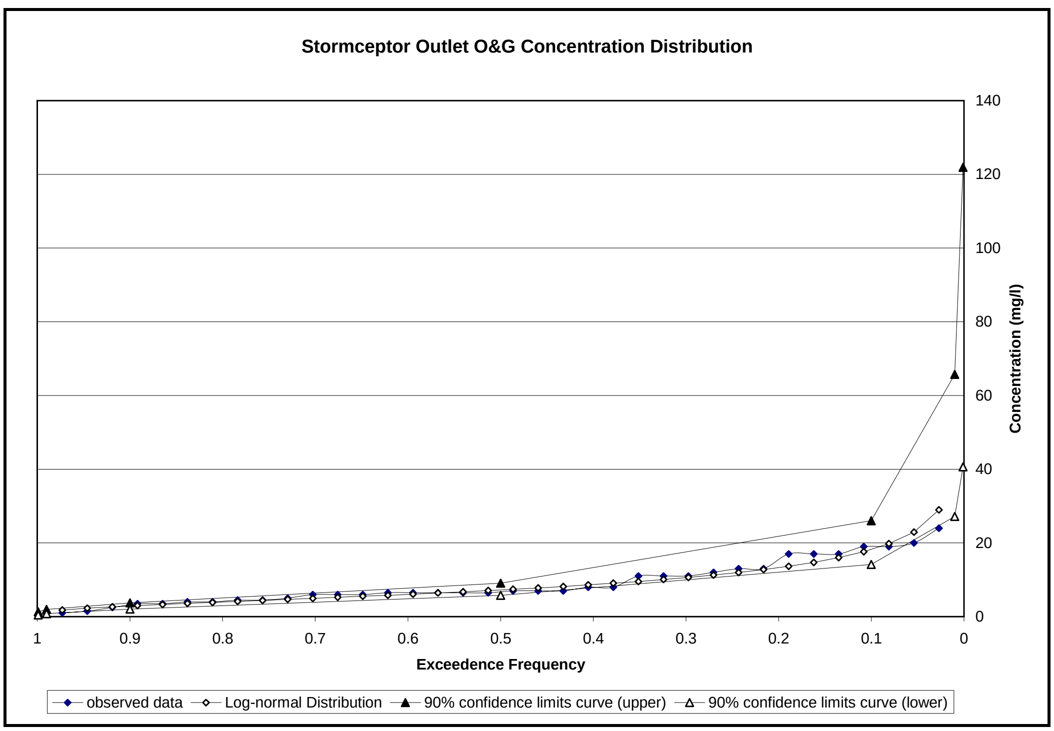


(b)

Figure C5: Log-normal distribution for inlet TSS and inlet O&G, stormceptor OGS



(a)



(b)

Figure C6: Log-normal distribution for the combined outlet TSS and O&G, stormceptor OGS

APPENDIX D

Detailed Results: Removal Efficiencies

Table D1: Removal Efficiency for selected events from August 1997 to December 1998, Three-chamber OGS

storm #	storm date	sampling date	total rainfall [mm]	average rainfall intensity [mm/h]	runoff volume observed [m3]	runoff volume generated [m3]	TSS inlet [mg/l]	TSS outlet [mg/l]	O&G inlet [mg/l]	O&G outlet [mg/l]	TSS removal [%]	TSS load inlet [kg]	TSS load outlet [kg]	O&G removal [%]	O&G load inlet [kg]	O&G load outlet [kg]
1	29-Sep-97	30-Sep-97	16.4	1.26	395.6	437.9	131.0	5.0	8.0	1.5	96	57.365	2.190	81.25	3.50	0.66
2	26-Oct-98	27-Oct-97	23.6	1.31	1035.0	1122.6	43.5	14.5	4.0	2.0	67	48.833	16.278	50.00	4.49	2.25
3	03-Jan-98	03-Jan-98	n/a	n/a	49.5	75.3	378.0	74.5	37.0	14.0	80	28.448	5.607	62.16	2.78	1.05
4	28-Jan-98	28-Jan-98	n/a	n/a	98.7	142.2	161.0	172.0	31.0	29.0	-7	22.893	24.457	6.45	4.41	4.12
5	17-Feb-98	18-Feb-98	n/a	n/a	863.6	1851.4	251.0	105.0	28.0	16.0	58	464.709	194.400	42.86	51.84	29.62
6	28-Feb-98	02-Mar-98	n/a	n/a	133.5	453.4	241.0	21.0	37.0	17.0	91	109.267	9.521	54.05	16.78	7.71
7	08-Mar-98	09-Mar-98	n/a	n/a	n/d	893.5	232.0	139.0	23.0	18.0	40	207.292	124.197	21.74	20.55	16.08
8	26-Jun-98	29-Jun-98	13.2	4.40	245.8	289.5	110.0	144.0	30.0	15.0	-31	31.846	41.689	50.00	8.69	4.34
9	30-Jun-98	02-Jul-98	10.6	3.53	312.9	355.0	79.0	31.5	20.0	7.0	60	28.045	11.183	65.00	7.10	2.49
10	04-Jul-98	06-Jul-98	6.4	0.91	121.7	189.1	160.0	45.5	24.0	8.5	72	30.253	8.603	64.58	4.54	1.61
11	06-Jul-98	07-Jul-98	23.0	1.91	598.2	753.1	81.5	54.5	9.5	8.0	33	61.376	41.043	15.79	7.15	6.02
12	07-Jul-98	08-Jul-98	4.4	2.20	163.7	250.3	91.5	37.5	13.0	6.0	59	22.903	9.387	53.85	3.25	1.50
13	06-Aug-98	06-Aug-98	21.6	1.13	417.0	837.2	58.0	11.5	29.0	9.5	80	48.559	9.628	67.24	24.28	7.95
14	07-Aug-98	07-Aug-98	15.4	1.71	348.9	520.2	108.0	48.5	20.0	9.0	55	56.184	25.231	55.00	10.40	4.68
15	23-Aug-98	24-Aug-98	15.6	1.95	311.7	496.1	29.5	53.5	4.0	12.0	-81	14.635	26.542	-200.00	1.98	5.95
16	25-Aug-98	27-Aug-98	8.4	4.20	110.4	151.5	236.0	47.0	21.0	7.5	80	35.763	7.122	64.29	3.18	1.14
17	14-Sep-98	15-Sep-98	n/a	n/a	178.8	413.9	67.5	51.0	17.0	9.0	24	27.936	21.107	47.06	7.04	3.72
18	07-Oct-98	08-Oct-98	n/a	n/a	564.0	1013.1	17.5	8.0	1.5	1.5	54	17.730	8.105	0.00	1.52	1.52
19	10-Nov-98	12-Nov-98	n/a	n/a	698.9	1408.7	71.0	13.5	28.0	4.5	81	100.020	19.018	83.93	39.44	6.34
										average	48.03		average	36.07		
										total load	57.19		total load	51.21		

Table D2: Removal efficiency for selected events from August 1997 to December 1998, Stormceptor OGS

storm #	storm date	sampling date	total rainfall [mm]	average rainfall intensity [mm/h]	maximum hourly intensity [mm/h]	runoff volume generated [m3]	TSS inlet [mg\l]	TSS outlet [mg/l]	TSS removal [%]	TSS load inlet [kg]	TSS load outlet [kg]	O&G inlet [mg/l]	O&G outlet [mg/l	O&G removal [%]	O&G load inlet [kg]	O&G load outlet [kg]
1	26-Oct-97	27-Oct-97	20.3	1.8	3.2	573.0	30.0	18.5	38.3	17.19	10.60	n/a	n/a			
2	01-Nov-97	03-Nov-97	19.3	1.4	4.7	400.1	46.0	38.0	17.4	18.40	15.20	6.5	4.5	30.77	2.60	1.80
3	03-Dec-98	04-Dec-97	n/a	n/a	n/a	86.3	64.0	27.0	57.8	5.52	2.33	9.0	6.5	27.78	0.78	0.56
4	04-Jan-98	05-Jan-98	n/a	n/a	n/a	368.7	135.0	94.0	30.4	49.77	34.66	22.0	17.0	22.73	8.11	6.27
5	11-Feb-98	12-Feb-98	n/a	n/a	n/a	8.2	390.0	268.0	31.3	3.20	2.20	18.0	19.0	-5.56	0.15	0.16
6	08-Apr-98	09-Apr-98	n/a	n/a	n/a	40.0	92.5	73.0	21.1	3.70	2.92	23.0	8.0	65.22	0.92	0.32
7	16-Apr-98	17-Apr-98	11.2	2.0	5.1	566.3	139.0	56.5	59.4	78.72	32.00	13.0	7.0	46.15	7.36	3.96
8	19-Apr-98	20-Apr-98	7.4	0.6	1.0	61.6	51.0	26.5	48.0	3.14	1.63	9.0	7.0	22.22	0.55	0.43
9	03-May-98	04-May-98	n/a	n/a	n/a	22.2	109.0	46.0	57.8	2.42	1.02	n/a	n/a			
10	26-Jun-98	29-Jun-98	16.0	7.8	14.7	300.3	259.0	47.5	81.7	77.78	14.26	28.0	4.5	83.93	8.41	1.35
11	25-Aug-98	27-Aug-98	n/a	n/a	n/a	152.8	634.0	174.0	72.6	96.88	26.59	n/a	n/a			
12	06-Sep-98	07-Sep-98	17.2	8.6	9.5	635.2	62.5	10.5	83.2	39.70	6.67	3.5	3.5	0.00	2.22	2.22
13	01-Oct-98	01-Oct-98	6.7	3.4	3.7	285.2	238.0	84.0	64.7	67.88	23.96	19.0	11.0	42.11	5.42	3.14
14	14-Oct-98	14-Oct-98	4.9	1.3	2.9	95.8	116.0	26.0	77.6	11.11	2.49	15.0	4.0	73.33	1.44	0.38
15	10-Nov-98	12-Nov-98	8.7	1.5	4.1	441.8	55.5	53.0	4.5	24.52	23.42	8.5	6.5	23.53	3.76	2.87
16	16-Nov-98	16-Nov-98	6.6	0.4	1.1	35.2	83.0	20.0	75.9	2.92	0.70	19.0	6.0	68.42	0.67	0.21
								average	51.35				average	38.51		
								total load	60.10				total load	44.13		

APPENDIX E

Detailed Results: Modelling

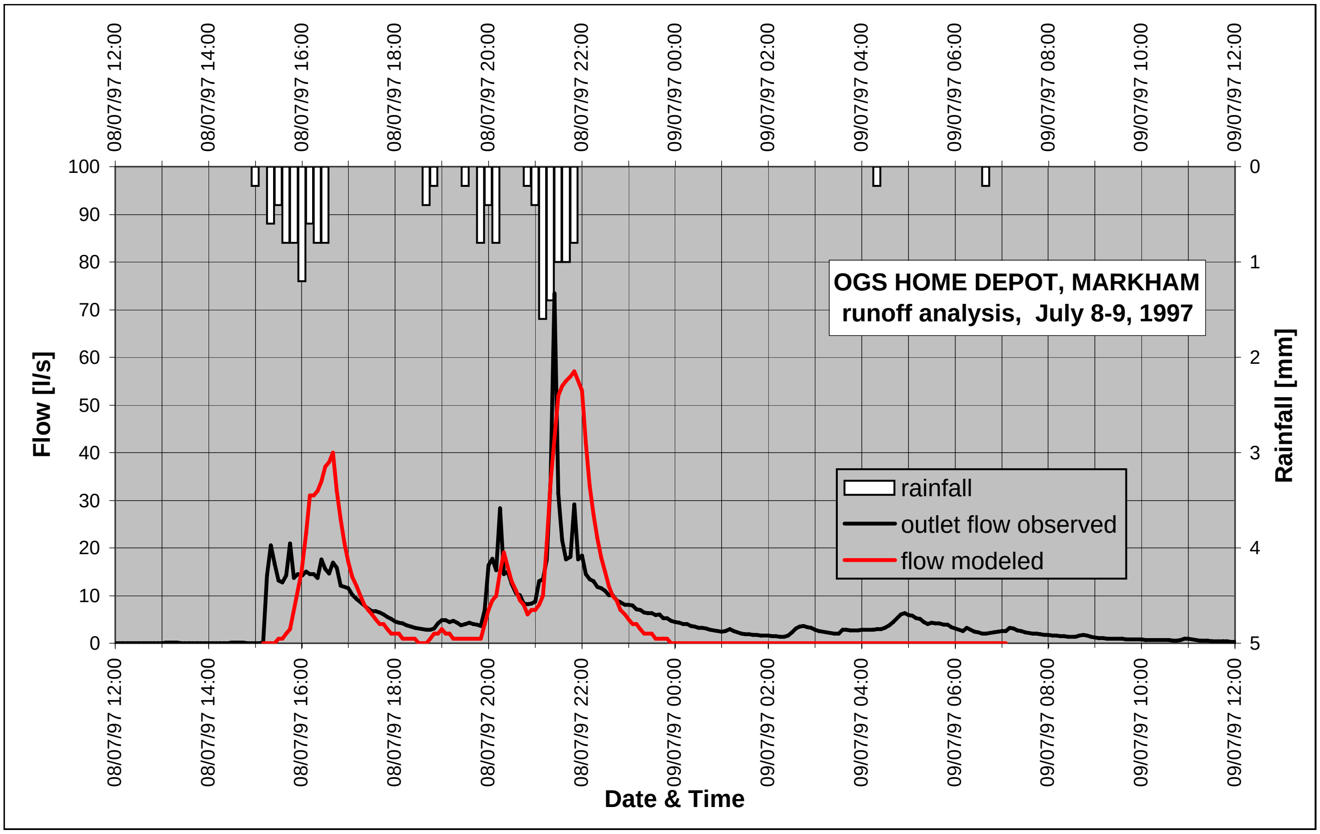
Table E1: Comparison between observed and modelled events, Three-chamber OGS

Water Quantity

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
storm #	storm date	storm starts [date/time]	total rainfall [mm]	flow recorded [m3]	flow modelled [m3]	difference (E-F)/E [%]	peak recorded [l/s]	peak modelled [l/s]	difference (H-I)/H [%]	peak occurrence recorded	time to peak recorded [hours]	peak occurrence modelled	time to peak modelled [hours]	difference (L-N)/L [%]
1	08-Jul-97	8/7/97 15:00	15.8	374.70	411.00	-9.69	73.40	57.10	22.21	8/7/97 21:25	6.42	8/7/97 21:30	6.50	-1.30
2	20-Aug-97	20/8/97 16:20	18.8	922.00	578.00	37.31	82.80	43.40	47.58	21/8/97 3:45	11.42	21/8/97 4:10	11.83	-3.65
3	10-Sep-97	10/9/97 8:00	14.0	566.10	489.00	13.62	54.70	40.20	26.51	10/9/97 10:45	2.75	10/9/97 11:00	3.00	-9.09
4	26-Oct-97	26/10/97 17:00	25.2	1036.70	920.00	11.26	60.60	79.00	-30.36	27/10/97 1:55	8.92	27/10/97 1:50	8.83	0.93
5	06-Jul-98	6/7/98 18:00	25.4	743.61	752.00	-1.13	100.10	112.90	-12.79	7/7/98 1:20	7.33	7/7/98 1:30	7.50	-2.27
6	09-Aug-98	6/8/98 1:40	42.2	1363.21	1350.00	0.97	78.33	76.40	2.47	7/8/98 7:30	29.83	7/8/98 7:20	29.67	0.56
	average			834.39	750.00	8.72	74.99	68.17	9.27					-2.47
	difference in average [%]				10.11			9.10						

Water Quality and Removal Efficiency

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
storm #	storm date	storm starts [date/time]	total rainfall [mm]	flow recorded [m3]	flow modelled [m3]	difference (E-F)/E [%]	peak recorded [l/s]	peak modelled [l/s]	difference (H-I)/H [%]	total load IN observed [kg]	total load IN modelled [kg]	difference (K-L)/K [%]	total load OUT observed [kg]	total load OUT modelled [kg]	removal observed (K-N)/K [%]	removal modelled (L-O)/L [%]	difference (P-Q)/P [%]
1	26-Oct-97	26/10/97 17:00	25.2	1036.7	919.8	11.28	60.6	79	-30.36	45.10	58.77	-30.31	15.03	31.20	66.67	46.91	29.63
2	06-Jul-98	6/7/98 18:00	25.4	743.61	750.90	-0.98	100.10	112.90	-12.79	60.60	53.80	11.22	40.53	30.89	33.13	42.58	-28.53
3	06-Aug-98	6/8/98 1:40	42.2	1363.21	1353.00	0.75	78.33	76.40	2.47	104.97	72.24	31.18	34.84	27.17	66.81	62.39	6.61
4	23-Aug-98	23/8/98 8:10	16.2	496.11	465.50	6.17	164.47	113.00	31.29	40.25	34.34	14.67	25.74	21.90	36.06	36.24	-0.52
	average			909.9095	872.30	4.30	100.87	95.33	-2.35	62.73	54.79	6.69			50.66	47.03	1.80
	difference in average [%]				4.13			5.50			12.66					7.17	



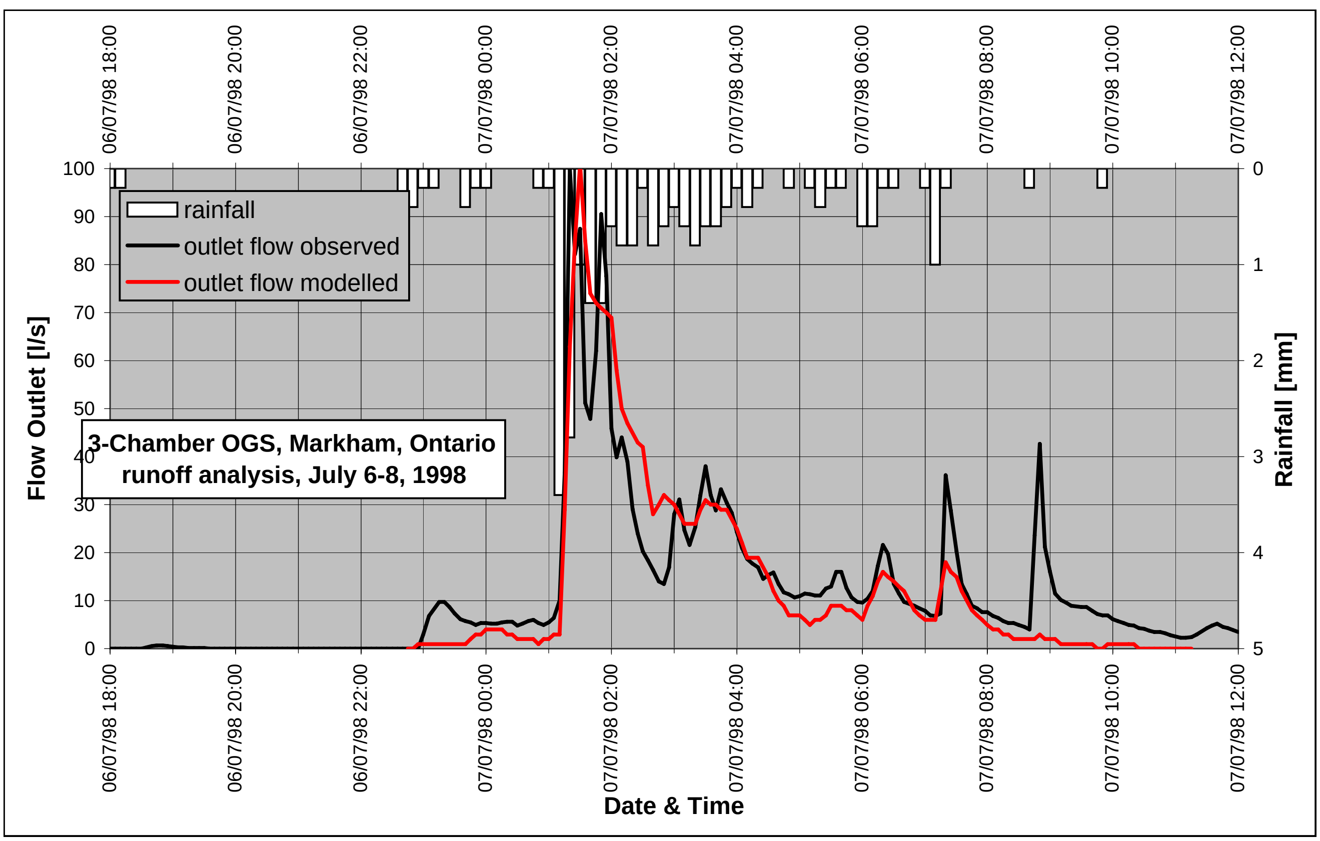


Figure E1: Hydrograph comparison of observed vs modelled events, Three-chamber OGS

Table E2: Comparison between observed and modelled events, Stormceptor OGS

Water Quantity

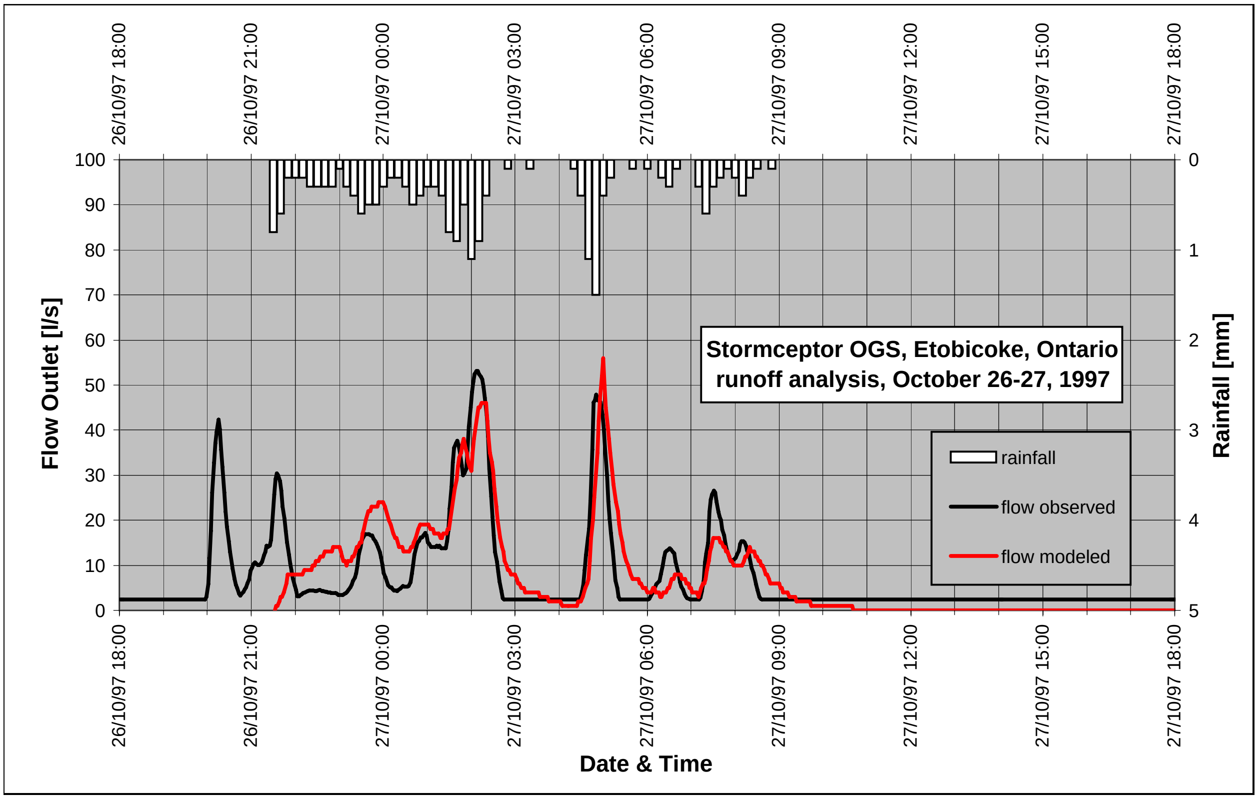
A	B	C	D	E	F	G	H	I
storm #	storm date	total rainfall [mm]	flow recorded [m3]	flow modelled [m3]	difference (D-E)/D [%]	peak recorded [l/s]	peak modelled [l/s]	difference (G-H)/G [%]
1	26-Oct-97	20.3	573.00	580.60	-1.33	53.08	56.00	-5.50
2	01-Nov-97	19.3	400.10	549.30	-37.29	57.43	66.00	-14.92
3	16-Apr-98	11.2	566.30	310.60	45.15	67.88	57.00	16.03
4	10-May-98	39.4	659.20	893.20	-35.50	32.74	25.00	23.64
5	11-Jun-98	14.3	410.50	344.00	16.20	59.30	63.00	-6.24
6	16-Jun-98	7.2	158.40	166.30	-4.99	77.05	33.00	57.17
7	01-Oct-98	6.7	285.20	176.60	38.08	72.75	45.00	38.14
8	14-Oct-98	4.9	95.80	120.90	-26.20	41.73	36.00	13.73
	average		393.56	392.69	-0.73	57.75	47.63	15.26
	difference in average [%]			0.22			17.53	

Water Quality

A	B	C	D	E	F	G	H	I	J
storm #	storm date	total rainfall [mm]	flow observed [m3]	EMC inlet observed [mg/l]	total load inlet observed [kg]	flow modelled [m3]	EMC inlet	inlet load modelled [kg]	difference (F-I)/F [%]
1	16-Apr-98	11.2	566.3	139.0	78.7	310.6	118.2	36.7	53.4
2	19-Apr-98	7.1	200.0	51.0	10.2	185.7	56.3	10.5	-2.5
3	26-Jun-98	16.0	300.3	259.0	77.8	434.7	319.0	138.7	-78.3
4	30-Jun-98	13.2	444.8	201.0	89.4	363.9	288.9	105.1	-17.6
5	01-Oct-98	6.7	285.2	238.0	67.9	176.6	129.8	22.9	66.2
6	14-Oct-98	4.9	95.8	116.0	11.1	120.9	99.5	12.0	-8.3
7	16-Nov-98	6.6	88.4	83.0	7.3	168.1	50.2	8.4	-15.1
		average			48.9			47.8	-0.32
	difference in average [%]								2.35

Removal Efficiency

A	B	C	D	E	F	G	H	I	J
storm #	storm date	total rainfall [mm]	EMC inlet observed [mg/l]	EMC outlet [mg/l]	observed removal efficiency [%]	modelled load inlet [kg]	modelled load outlet [kg]	modelled removal efficiency [%]	difference (F-I)/F [%]
1	16-Apr-98	11.2	139.0	56.5	59.35	36.6	11.4	68.90	-16.09
2	19-Apr-98	7.1	51.0	26.5	48.04	10.5	0.9	91.07	-89.57
3	26-Jun-98	16.0	259.0	47.5	81.66	140.2	101.0	27.98	65.74
4	30-Jun-98	13.2	201.0	104.0	48.26	107.0	72.5	32.26	33.14
5	01-Oct-98	6.7	238.0	84.0	64.71	22.9	7.7	66.30	-2.46
6	14-Oct-98	4.9	116.0	26.0	77.59	12.1	3.0	75.20	3.07
7	16-Nov-98	6.6	83.0	20.0	75.90	8.4	0.8	90.92	-19.79
		average			65.07			64.66	-3.71
	difference in average [%]								0.63



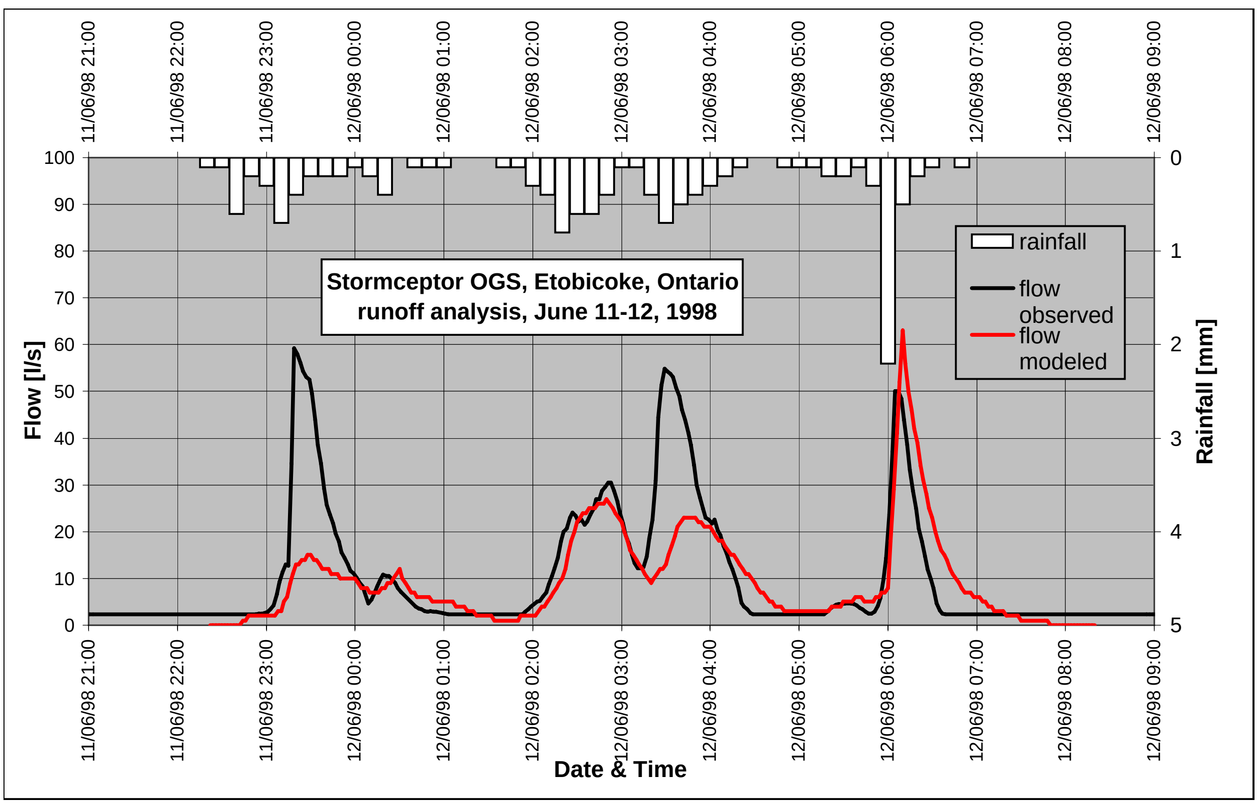


Figure E2: Comparison of observed and modelled hydrographs, Stormceptor OGS