NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

LABORATORY TESTING OF THE ONTARIO CONCRETE PRODUCTS ASSOCIATION OIL/GRIT SEPARATOR

G. Larkin and J. Marsalek

Technical Note No. AEP-TN97-005

Laboratory Testing of the Ontario Concrete Pipe Association Oil/Grit Separator

G.A. Larkin and J. Marsalek
National Water Research Institute
867 Lakeshore Road,
Burlington, Ontario, L7R 4A6

NWRI TN #97-005

June 27, 1997

DISCLAIMER

This Technical Report, which was produced through a cost recovery arrangement between the Ontario Concrete Pipe Association (OCPA) and the National Water Research Institute (NWRI), does not imply product endorsement or recommendation for use, and commercial product names are mentioned for identification purposes only. The NWRI does not guarantee or assume any liability for the effectiveness or economic benefits of the technologies described herein or that their use does not infringe privately owned rights. Finally, the NWRI cannot be held liable for any injury or damage to any person or property as a result of implementation of any part of this Technical Report.

MANAGEMENT PERSPECTIVE

One of the goals in Environment Canada's Business Plan calls for providing Canadians with tools to prevent pollution and develop green technologies and capacity that create social, economic, and environmental benefits. Towards this end, the Aquatic Ecosystem Protection Branch of the National Water Research Institute has been providing research and development support to manufacturers of environmental technology, through cost-recovery arrangements. The report that follows presents results of one such project, dealing with the development and testing of an oil/grit separator for enhancing urban stormwater quality and thereby contributing to the protection of receiving waters. At this stage of investigation, hydraulic characteristics of the separator have been established for installations in sewers (slope 0.5% and 1.0%). Further tests dealing with separation efficiency of this device are planned.

This report should be of interest to designers, environmental planners and managers dealing with control of urban non-point sources of pollution.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Le Plan d'affaires d'Environnement Canada prévoit notamment la mise au point d'instruments de prévention de la pollution et d'écotechnologies comme de moyens susceptibles d'engendrer des retombées sociales, économiques et écologiques positives. À cette fin, la Direction de la protection des écosystèmes aquatiques, de l'Institut national de recherche sur les eaux, fournit des services de recherche et développement qui sont offerts aux fabricants de matériel écotechnologique en vertu d'ententes de récupération des coûts. Le rapport qui suit présente les résultats obtenus au terme d'un tel projet, qui portait sur le développement d'un extracteur d'huiles et de sables pour améliorer la qualité des eaux pluviales urbaines et contribuer de la sorte à la protection des masses d'eau réceptrices. À ce point ci des travaux de recherche, on a déterminé les caractéristiques hydrauliques de l'extracteur conçu pour son installation dans des égouts (pentes de 0,5% et de 1,0%). On prévoit la tenue d'autres essais sur l'efficacité de ce dispositif.

Ce rapport s'adresse aux concepteurs, aux planificateurs environnementaux et aux gestionnaires chargés de contrer la pollution urbaine diffuse.

ABSTRACT

The Ontario Concrete Pipe Association designed an oil/grit separator to separate floatables (specifically oils) and sediments from stormwater flow in sewer lines. Low flows are diverted from the main sewer line by a low sill into an off-line separation chamber. Higher flows overflow the sill and bypass the separation chamber, hence not disturbing trapped sediment and floatables. Hydraulic testing on a laboratory scale model was undertaken by the National Water Research Institute. The flow capacity of the separation chamber was determined to be a function of stormwater flow in the sewer line and the diversion sill height. Average detention time in the chamber at low stormwater flows was determined sufficient to settle fine-to-coarse sands. Only medium-to-coarse sands and larger size particulates will be removed in higher stormwater flows. Smaller particles will only be removed during quiescent interevent periods. Head losses created by the device are equivalent to or less than those caused by a 60° bend at sewer manholes dependent on diversion sill height. Sediment retention was determined to be a function of the flow diverted through the separation chamber. Effectively all particles larger than fine sands should be removed during low flow dynamic settling conditions. Qualitative tests with oil demonstrated effective and permanent trapping. Investigation into alternative separation tank inflow pipe configurations are recommended to enhance both sediment and oil trapping of the design. Final evaluation of the oil/grit separator should be conducted in the field on prototype units.

RÉSUMÉ

L'Ontario Concrete Pipe Association a conçu un extracteur d'huiles et de sables qui permet de séparer la fraction flottable (les huiles précisément) et les sédiments charriés par les eaux pluviales dans les égouts. À faible débit, l'eau est déviée de l'égout principal vers une enceinte d'extraction hors circuit par un seuil. À débit plus élevé, l'eau franchit le seuil et évite l'enceinte, ce qui permet d'éviter la perturbation des sédiments et de la fraction flottable interceptés. L'Institut national de recherche sur les eaux a entrepris des essais hydrauliques sur un modèle à l'échelle du laboratoire. On a établi que la capacité de traitement de ce dispositif est fonction du débit des eaux pluviales dans l'égout et de la hauteur du seuil de dérivation. On a également établi que la durée moyenne de retenue à un faible débit des eaux pluviales suffit pour que les sables fins à grossiers puissent sédimenter. À un débit supérieur, seuls les sables grossiers à moyens et les particules de grande taille sont interceptés. Les particules de plus petit diamètre sont éliminées uniquement durant les périodes calmes, c.-à-d. entre deux périodes de débit accru. La perte de charge attribuable au dispositif équivaut sensiblement à l'effet d'un coude de 60 ° à un regard d'égout, selon la hauteur du seuil. Il a été déterminé que l'interception des sédiments est fonction du flux dérivé vers le dispositif. De fait, toutes les particules de granulométrie supérieure à celle des sables fins devraient être interceptées dans des conditions de décantation dynamique à écoulement faible. Des essais qualitatifs sur de l'huile ont montré qu'elle est capturée de façon efficace et permanente. Les chercheurs recommandent d'examiner d'autres configurations pour la conduite d'amenée à l'enceinte, de manière à améliorer l'interception des sédiments et de l'huile. L'évaluation finale du dispositif devrait être faite sur des prototypes employés en conditions réelles.

1. Overview

Urban stormwater is widely recognized as an important non-point source of pollution. Awareness of the harmful impacts of stormwater discharges on receiving waters has resulted in the development of stormwater management measures, supporting the goal of sustainable development of urban areas. Current stormwater management practices, which are applied in both new and existing developments, include both quantity and quality control aspects. Best management practices (BMPs) is the term now commonly used for various water quantity control and water quality enhancement facilities designed to reduce adverse impacts of stormwater on urban ecosystems.

BMPs can be effective in removing specific contaminants from stormwater. Combinations of BMPs are needed to address complex pollution problems as no single type represents a universal solution [Ontario MOEE 1994]. BMPs are not necessarily implemented at the same site (e.g., as done in end-of-the-pipe solutions), but are positioned throughout the catchment in a 'treatment train'. Thus, stormwater management starts with source control in the catchment, and continues through measures implemented along the collection system and in the receiving waters [Marsalek et al. 1992].

The Ontario Concrete Pipe Association (OCPA) has designed a device to separate floatables (specifically oils) and sediments from stormwater flow in sewer lines. This device is an off-line cylindrical separation chamber, with inflow and outflow pipes connected to the main storm sewer line. Low flows are diverted from the sewer line by a low sill into the off-line separation chamber. Higher flows overflow the sill and bypass the separation chamber, hence not disturbing trapped sediment and floatables. Thus, the device fully 'treats' low flows, and allows partial sediment separation from high flows. Stored sediment and oil can be removed from the separation chamber through manhole access.

To evaluate the performance of the off-line oil/grit separator (OGS), the OCPA has commissioned the National Water Research Institute (NWRI) in Burlington, Ontario to conduct testing of the original design in a laboratory scale model. The results dealing with hydraulic testing of the OCPA OGS, installed in a sewer line with slopes of 1% and 0.5%, are described in this report.

2. Stormwater Management

In urban environments, sewer systems have been engineered to take the place of natural drainage routes. Rainwater reaches the catchment surface and is conveyed via multiple inlets to a storm sewer collection system which discharges to receiving waters. En route, the stormwater mobilizes and collects pollutants from the atmosphere and the catchment surface, as either dissolved loads, suspended loads or bed loads.

2.1. Stormwater Characteristics

A wide range of pollutants are transported by stormwater. Light materials such as oil, other hydrocarbons, and debris, may be transported on the flow surface. Soluble nutrients (nitrogen, phosphorus and carbon), and conservative ions (e.g., Cl^-, Na^+) are generally found in the dissolved load. Finer sediment fractions are transported as the suspended load, and usually have significant concentrations of associated hydrophobic contaminants, such as heavy metals, toxic organics and hydrocarbons. Coarser sediment is transported as bed load. The distinction between suspended and bed load transport is given by the particle properties (size, specific weight) and flow characteristics (flow velocity and turbulence).

Solids in urban stormwater originate from many sources including erosion, construction, road wear, road maintenance, and traffic. Solids concentrations can range from 20 - 10,000 mg·L^{-1}, and include particle sizes from clay to coarse sands and gravel. Hydrocarbons are rather ubiquitous in urban areas and occur in stormwater in significant concentrations. In Ontario, Marsalek and Ng [1989] reported mean concentrations of oil and grease in urban runoff from three industrial cities in the range of 2 to 5 mg·L^{-1}. Even higher concentrations of hydrocarbons can be found in runoff from heavily traveled highways. Oil and grease may be present as free oil on the water surface, in the colloidal or dissolved state [Stenstrom et al. 1984], or associated with sediments.

2.2. Oil/grit separators

The intended function of oil/grit separators is simple - to remove sediment and oils from stormwater by gravity separation. Stormwater flow is introduced to a settling tank where oil and other floatables rise to the water surface, and particulate material settles to the tank bottom. The amount of each that is trapped depends on the relative densities, particle/oil globule size, and detention time in the settling tank.

Settling is not only effective in removing sediments, but also a number of other associated pollutants. Settling experiments with stormwater [Randall et al. 1982] indicate that settling times as short as 2 hours may be adequate to remove 55 - 85% of fine suspended sediment (typical primary particle sizes from 15 to 35 μm), 11 - 54% of COD, 6 - 35% of TOC, 4 - 50% of total phosphorus, 2 - 61% of total nitrogen, 4 - 60% of zinc, and 31 - 83% of lead.

Even though chemical spills may involve a great variety of chemicals of various chemical and densimetric properties, most common spills (addressed here) involve oil or various types of fuels. In general, these materials do not mix with water and, being lighter than water, float on the surface. Motor oil is a typical substance in this group with a specific gravity of 0.879. Spills of soluble chemicals or chemicals of similar densities to water are not retained by conventional settling/skimming devices.

Gravity separation treatment devices, like the OCPA OGS design, should effectively remove medium to coarse size particles and floatables. Soluble constituents or those associated with fine suspended particulates will pass through largely unaffected. Thus for effective protection of the downstream receiving environment, an OGS should be used as part of a comprehensive treatment train, complemented by other BMPs as required by particular local conditions. These devices may also reduce maintenance costs of downstream BMPs such as ponds, by trapping larger sediments and reducing the frequency of costly dredging.

3. OCPA Oil/Grit Separator

3.1. Design and Operation

The OCPA oil/grit separator consists of a diversion chamber, a separation chamber, and a merging chamber (Fig. 1). Flow traveling down the storm sewer first reaches the diversion chamber. A sill in the bottom of the pipe diverts low flows off-line into the cylindrical separation chamber. Higher flows overflow the sill and continue down the main storm sewer line, bypassing the separation chamber. Diverted flows enter the separation chamber via the inflow pipe, which discharges flow downwards into the tank by way of a 90° elbow. At equilibrium, the water level in the separation chamber is slightly higher than that of the pipe invert in the merging chamber, and this head forces outflow at the downstream end through the outflow pipe. The outflow pipe rejoins the main storm sewer line in the merging chamber.

<u>3.1.1. Dynamic Sediment Settling (with flow through the separation chamber)</u>

In low flow conditions, stormwater entering the separation chamber will be detained for a relatively short time, calculated from the inflow rate, the separation chamber volume, and an assumed degree of mixing. The detention time of stormwater in the separation chamber is in the order of several minutes. During this time, any particulate material suspended in the stormwater has the chance to settle out. Under such settling conditions, the OCPA OGS should remove mainly 'sands' (coarse to fine) transported to the separation chamber by stormwater. Silts and clays will pass through with minimum removal. In large storm events, higher flows overflow the sill and bypass the separation chamber. In bypass conditions, the main objective is not to treat the water, but to ensure that previously settled material is not resuspended.

<u>3.1.2. Residual Sediment Settling (with no flow through the separation chamber)</u>

When flows through the storm sewer line drop to zero after storm events, the separation chamber remains filled. This residual volume will be subject to settling during the dry weather period, until the next storm occurs. The detention time thus equals the interevent time. Interevent times are probabilistic parameters which vary from several hours to about two weeks during dry spells, depending on local climatic conditions. With extended detention, fine sands, silts, and possibly even some clay will settle out of the stormwater. Flocculation may also take place in the separation chamber and flocs aggregating clay particles may settle. However, the smallest clay particles (< 2.5 μm) may still be in suspension even after this extended detention, should there be no flocculation. Randall et al. [1982] indicate that certain types of stormwater readily flocculate and this would strongly enhance settling during the interevent time periods.

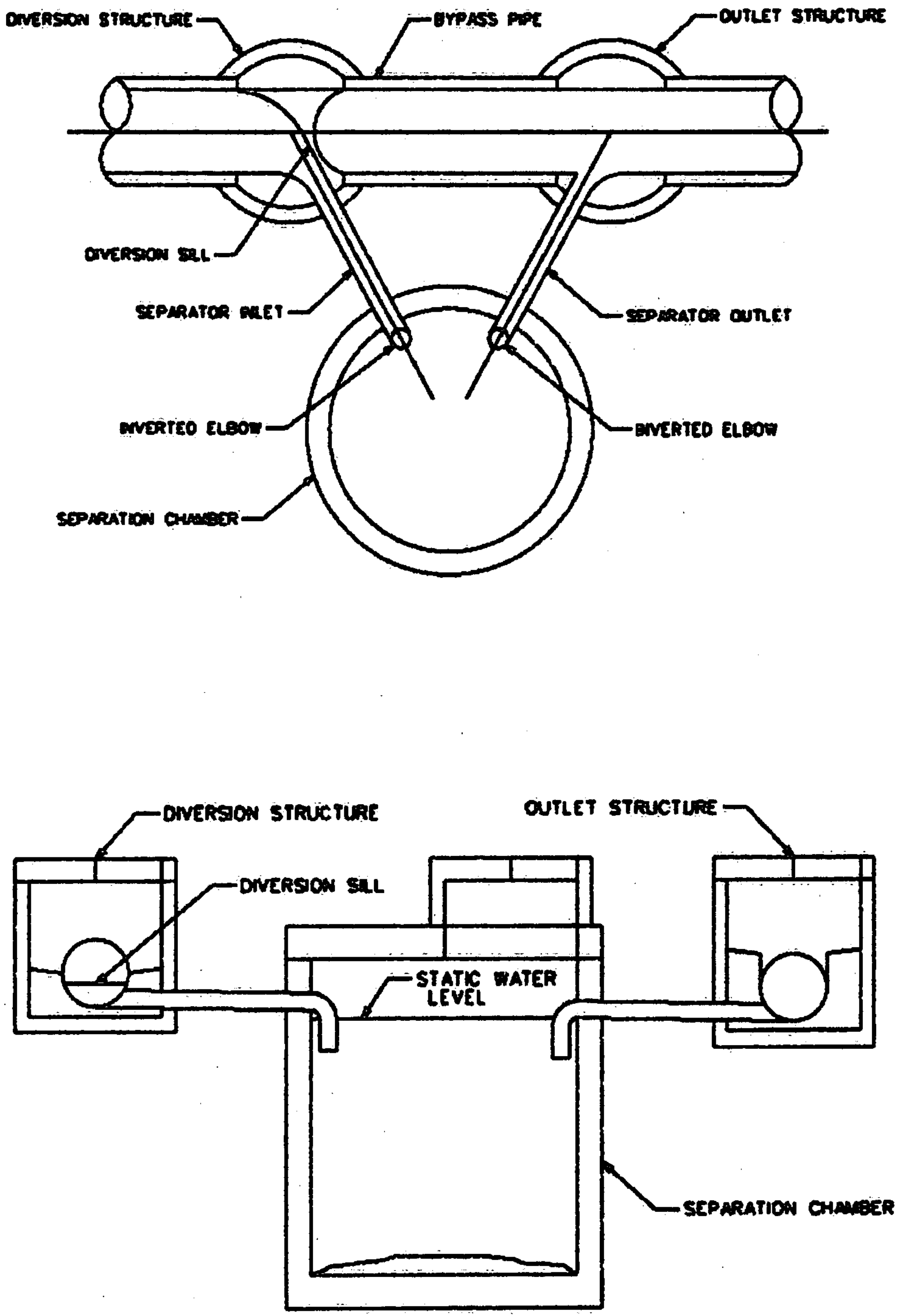


Figure 1. *Ontario Concrete Pipe Association off-line oil/grit separator*

3.2. *Oil Separation and Spill Treatability*

Spills of oil (or other light liquids) during dry weather conditions would flow slowly by gravity along the sewer pipe towards the OGS. With the separation chamber filled with water, oil would collect in the inlet pipe, but would not enter the chamber due to its buoyancy. Oil would accumulate until flow velocities adequate to purge the oil from the inlet into the separation chamber were achieved. Oil may also pool in depressions in the sewer line. Low water flows would dislodge the oil, which would form a slick on the moving water surface. Oil entering the separation chamber of the OGS as a slick should quickly be separated, rising as oil globules to the surface of the water inside the tank. Oil carried on higher stormwater flows will pass over the diversion sill and not enter the separation chamber.

3.3. *Internal Configuration*

Efficiency of oil and sediment removal from stormwater will be affected by the internal configuration of the separation chamber. Effective sediment removal requires discharge fairly close to the chamber bottom (without disturbing previously trapped materials). Oil separation requires discharge close to the ceiling, both to reduce oil accumulation in the inflow pipe and to reduce the distance oil particles need to rise in order to be trapped. The original configuration of the OCPA oil/grit separator is a simple cylindrical tank with inlet and outlet pipes at nearly identical elevations (outlet is slightly lower). Inlet and outlet pipes both have 90° elbows and discharge/draw at approximately 85 % of the resting water height. Trapped oils and sediments should be protected from washout, given regular maintenance to prevent buildup of material in the separation tank. It was of interest to note that one of the recent designs in this field [Geiger and Dreiseitl 1995] uses three chambers to achieve oil and grit separation - a settling chamber, an oil separation chamber, and a coalescence chamber. In this arrangement, very simple layouts of inlets/outlets are used.

4. Testing

4.1. *Laboratory model*

For quick and economic evaluation of the OCPA OGS, testing was conducted with a laboratory 1:5.58 scale model (Fig. 2). Such a model was large enough (diameter of the model base D = 43.18 cm = 17"; total height H = 83.82 cm = 33"; separation chamber inflow and outflow pipe diameter = 3.81 cm = 1.5") to produce reliable hydraulic data and be viewed as a small prototype unit. The testing system, comprising a 0.15 m (6") diameter pipe line with the inserted OGS, is fed by a large head tank which provides constant flow rates. The 0.15 m diameter main sewer line feeds and drains the OGS, with 4 m of length on both the upstream and downstream sides. The model itself is made of clear acrylic to allow flows, sediment and oil transport to be easily viewed. The separation chamber was designed to allow the interchange of diversion sills of various heights. The system can also run with no diversion sill. Water exits the downstream end of the sewer line into a baffled weir box, which empties via a calibrated V-notch weir. The main sewer line on the downstream side of the OGS is equipped with a flow gate for throttling the flow and thereby pressurizing the testing system.

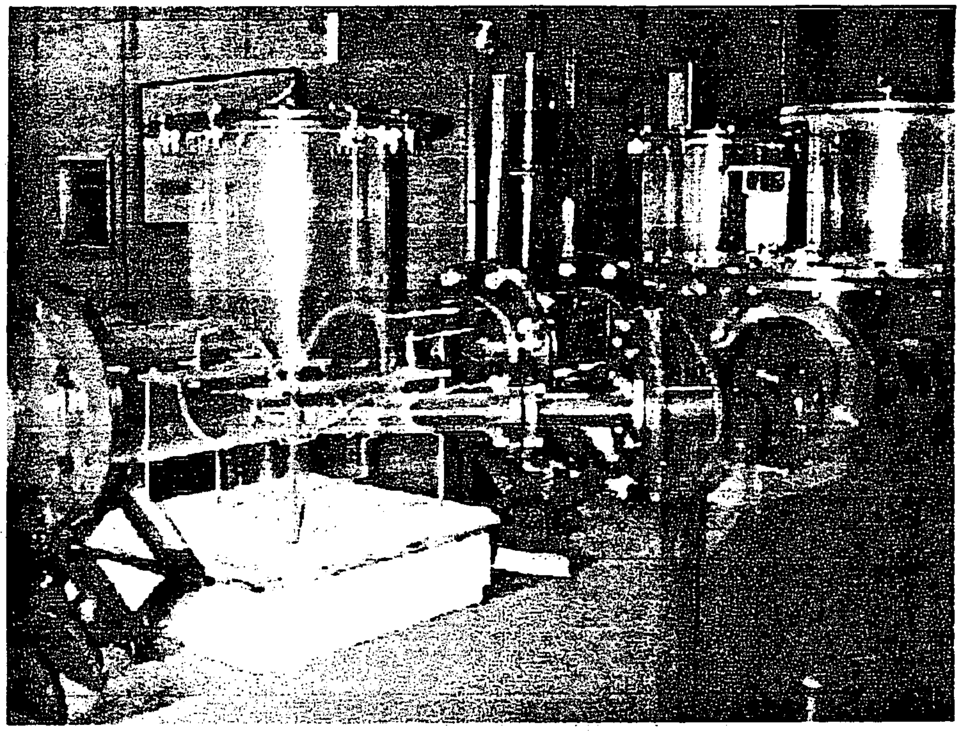


Figure 2. *Laboratory model of the OCPA oil/grit separator.*

The first phase of the OCPA OGS laboratory testing dealt with its hydraulic operation. The interest in the OGS's hydraulic performance is twofold:

1. To provide OGS hydraulic characteristics, which are needed for design applications.
2. To provide data on effects of the OGS on the operation of the sewer system in which it is installed.

Tests were conducted to determine treatment capacity (i.e., without bypassing), flow distribution between the main line and separation chamber (i.e., during bypassing), and head losses caused by the OGS in pressurized flow.

Hydraulic features of the OGS were modelled according to Froudian similitude which yields the following scales for basic hydraulic quantities:

Length scale	$\lambda_l = 1:5.58$	[1]
Velocity scale	$\lambda_v = \lambda_l^{0.5} = 1:2.36$	[2]
Time (duration) scale	$\lambda_t = \lambda_l^{0.5} = 1:2.36$	[3]
Discharge scale	$\lambda_Q = \lambda_l^{2.5} = 1:73.55$	[4]

Results from hydraulic tests on the scale model were recalculated to prototype values using the above scaling relationships. Tests were performed with sewer system gradients of 0.5 % and 1.0 %.

4.2. Separation chamber full treatment capacity for diversion sills of various heights

The first hydraulic design parameter of the OCPA OGS studied was the separation chamber full treatment capacity for diversion sills of various heights. This capacity equals that maximum discharge which passes through the separation chamber, without any bypassing in the main sewer line. For this purpose, flows in the main sewer line were gradually increased until a critical point was reached (when the first bypassing of the diversion sill was noted). This maximum flow was then denoted as the separation treatment capacity under the "full treatment" condition. In this context, the term full treatment means that all inflow is subject to gravity separation in the separation chamber, without any references to specific efficiencies of such treatment.

Maximum separation chamber capacities are plotted in Fig. 3 for diversion sills of various heights. Such capacities varied from 16 $L \cdot s^{-1}$ to 35 $L \cdot s^{-1}$ for the system at 1.0 % slope, and from 12 $L \cdot s^{-1}$ to 26 $L \cdot s^{-1}$ for the system at 0.5 % slope. Thus, the first step in applying the OGS at a particular location would be to decide which flow rate should be fully treated and then the diversion sill height could be selected accordingly.

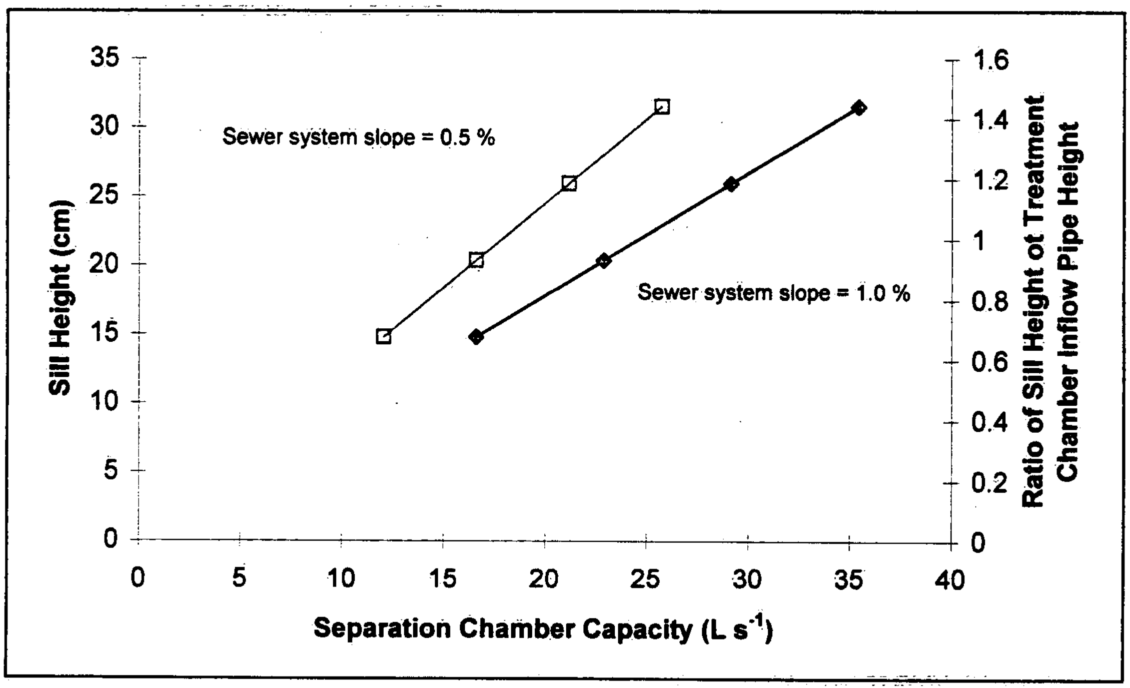


Figure 3. *Separation chamber capacity.*

4.3. Flow Distribution During Bypassing

Flow distribution between the main storm sewer line and the separation chamber was investigated to determine detention time in the separation chamber during high flows. To obtain accurate measurements of discharge through the separation chamber, a small velocity meter was inserted into the chamber's outflow pipe and used to measure flow velocities, from which the discharge was calculated.

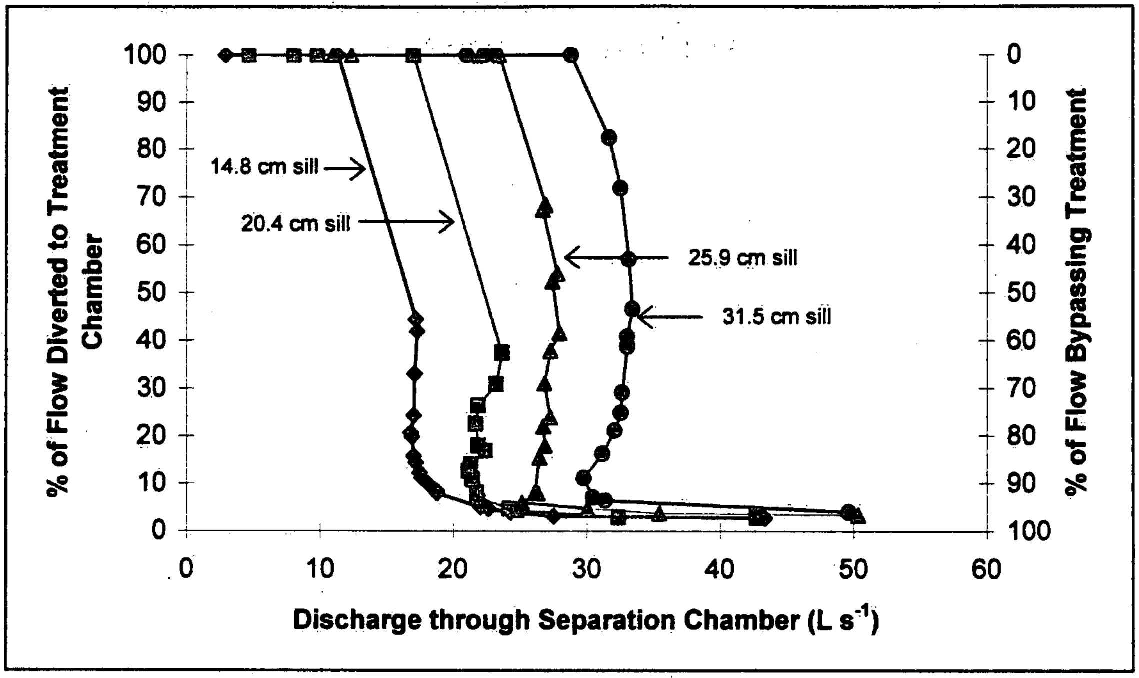
A range of flows were introduced to the OGS system to investigate their division between the main sewer line and separation chamber. Figure 4 shows that 100 percent of the flow is treated (i.e., directed to the separation chamber) until the depth of inflow equals the sill height. The drop from 100 % treatment to less than 10 % treatment is quite abrupt, and occurs between 15 and 35 $L \cdot s^{-1}$ at a system slope of 0.5 %, and between 20 and 40 $L \cdot s^{-1}$ at a system slope of 1.0 %, for the four sill heights tested.

Discharges through the separation chamber were of particular interest, since high flow through rates may disturb or flush out trapped material. At low flows, separation chamber discharge equals the total discharge through the OGS installation. When the depth of the sewer pipe flow exceeds the sill height and bypassing occurs, the separation chamber discharge reaches a peak, then drops slightly before climbing to even higher values (Fig. 5). Even if the maximum diverted flow reached 50 to 70 $L \cdot s^{-1}$, flow diverted through the separation chamber would still be subject to a detention time of 3.9 to 5.4 minutes (assuming plug flow and an approximate separation tank volume of 16.3 m^3). Whether such flows diverted to the separation chamber would pose any threat of flushing out previously accumulated sediments and oils is addressed in subsequent sections.

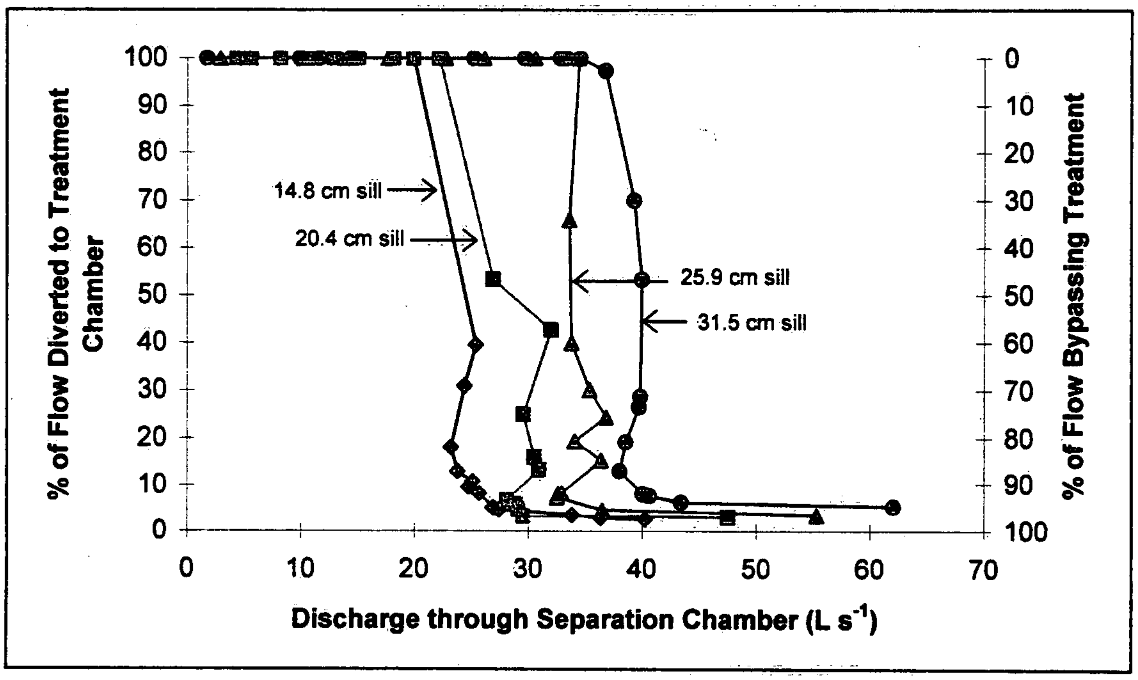
From simple relationships established between inflow water height, total discharge through the system, discharge through the separation chamber, and separation tank volume, detention time in the separation tank can be predicted for various discharges through the system (before bypassing) (Figs. 6a (0.5 %) and b (1.0 %)). The resting water depth in the separation chamber is approximately 3.6 m when based on the scale model proportions. Based on the relationships found for the scale model, similar curves are presented for water depths in the separation chamber of 2.0, 2.5 and 3.0 m, since these are more realistic depths for a prototype unit.

Detention time in the chamber at critical flows (i.e., just before bypass) was determined for the four trial sill heights to be 22.4, 16.3, 12.8 and 10.5 minutes respectively (low sill to high sill) for a water depth of 3.6 m, and a system slope of 0.5 %. Corresponding detention times with a system slope of 1.0 % were 16.5, 11.9, 9.4 and 7.7 minutes. When flows through the separation chamber increase at high flow rates (after bypass), detention times are reduced to 6.2 to 5.4 minutes at 0.5 %, and to 6.8 to 4.4 minutes at 1.0%, at the maximum discharges observed. These minimum detention times will decrease if the volume of the separation chamber is reduced. For a separation chamber with a water depth of 3 m, minimum detention times would range from 5.2 to 4.4 minutes (0.5 %) and from 5.6 to 3.6 minutes (1.0 %) for the 4 trial sill heights. For a chamber with a water depth of 2.5 m, minimum detention times would range from 4.2 to 3.6 minutes (0.5 %) and from 4.5 to 2.9 minutes (1.0 %). And for a chamber with a water depth of 2 m, minimum detention times would range from 3.2 to 2.8 minutes (0.5 %) and from 3.5 to 2.3 minutes (1.0 %).

Detention times will determine the particle size that will be trapped in the separation chamber. In order to settle 0.5 m, different sediment size fractions require different times (Table 1).

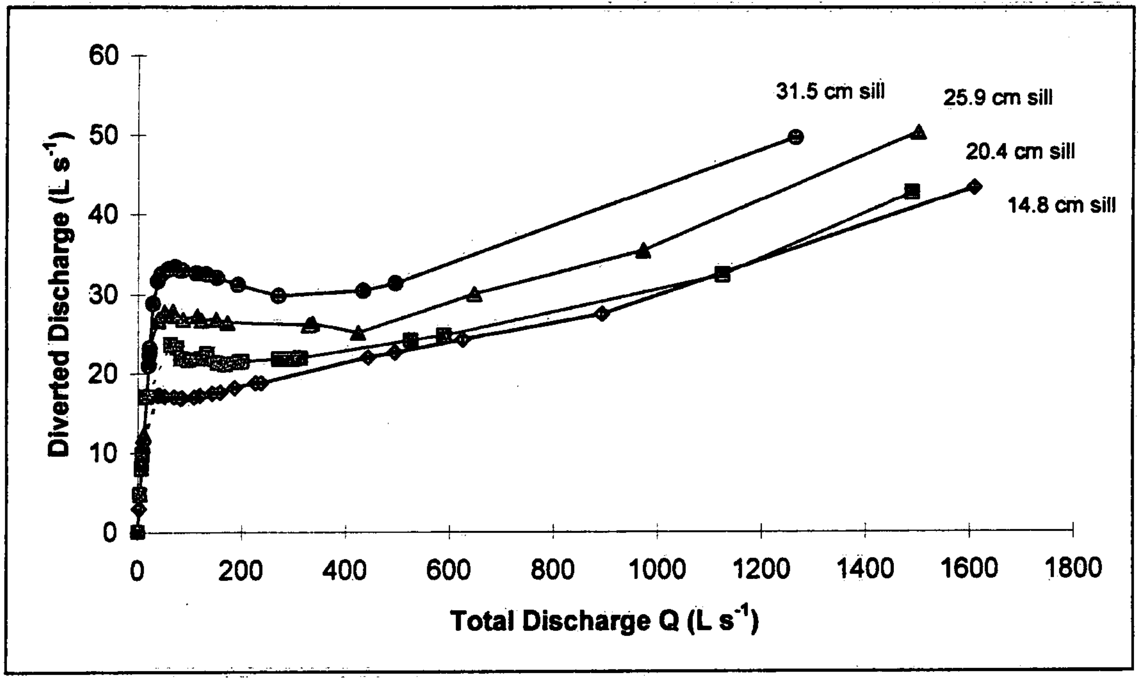


(a) Sewer system slope of 0.5 %

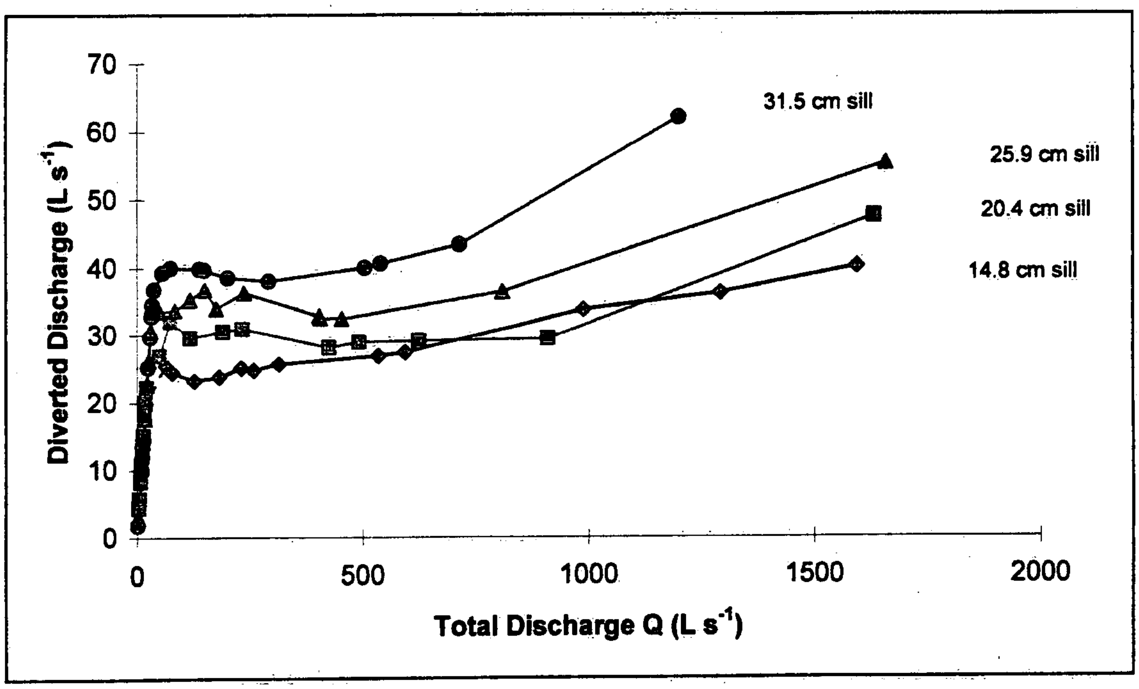


(b) Sewer system slope of 1.0 %

Figure 4. *Percent flow distribution through the OCPA oil/grit separator.*

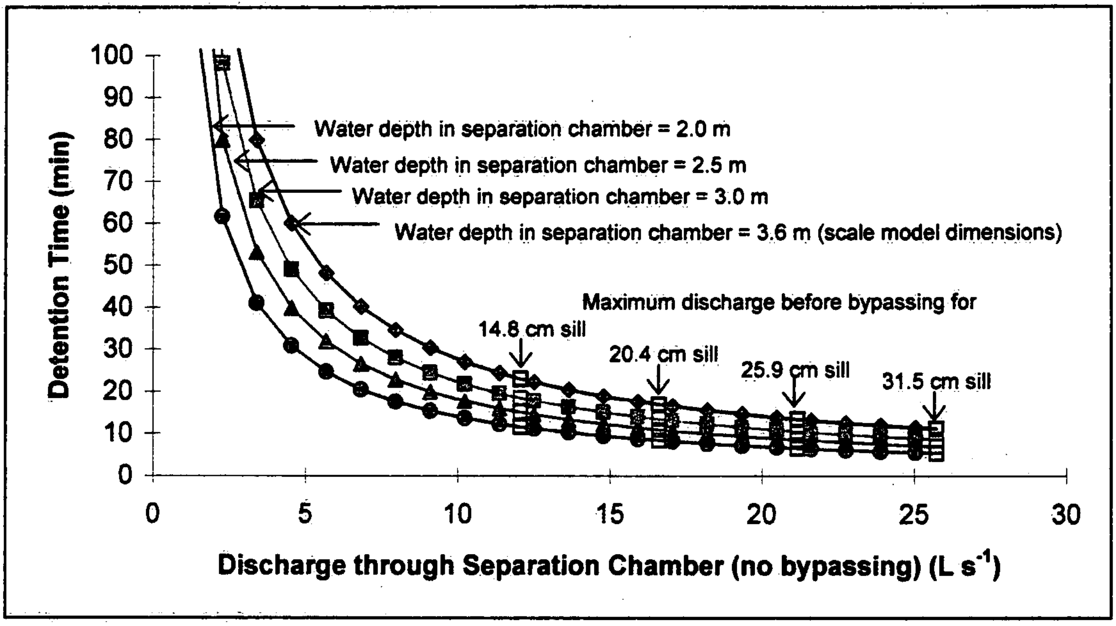


(a) Sewer system slope of 0.5 %

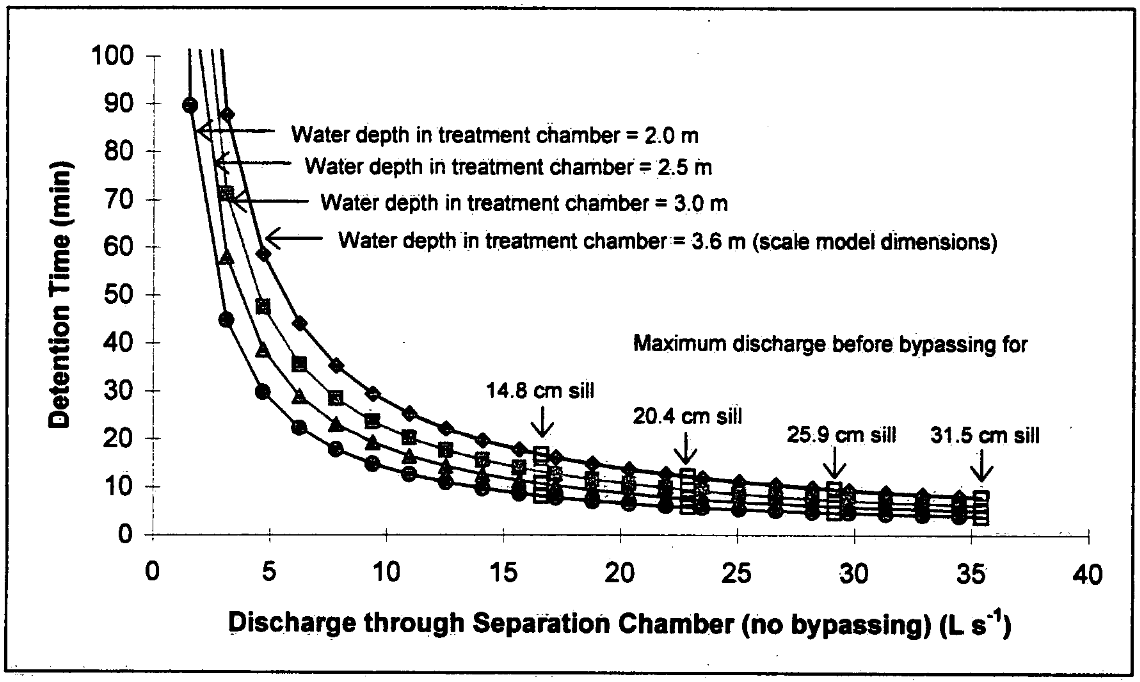


(b) Sewer system slope of 1.0 %

Figure 5. *Maximum discharges through the separation chamber.*



(a) Sewer system slope of 0.5 %



(b) Sewer system slope of 1.0 %

Figure 6. *Detention time in the separation chamber.*

Table 1. *Settling time for five particle size fractions in stormwater (determined from Stokes' law at 20 °C).*

Sediment classification	Particle diameter (mm)	Time to settle 0.5 m (mins)
Very coarse sand	1.0	0.6
Coarse sand	0.5	2.2
Medium sand	0.25	8.9
Fine sand	0.125	35.6
Silt	0.0625	142.5

At critical flows, most coarse and medium sands should be removed. Only coarse sands and larger sized particulates will be removed after the system begins to bypass. Fine sands and silts will only be trapped with much longer detention times, such as after storms when the flows through the system are well below the height of the sill.

4.4. Head Losses

Flow obstacles inserted into sewers contribute to head losses and may potentially cause sewer surcharging and flooding upstream of their installation. It is therefore necessary to know the head losses caused by the OGS and to account for them in new designs, or to evaluate the potential impact in retrofit situations.

Head losses in sewers are customarily expressed as

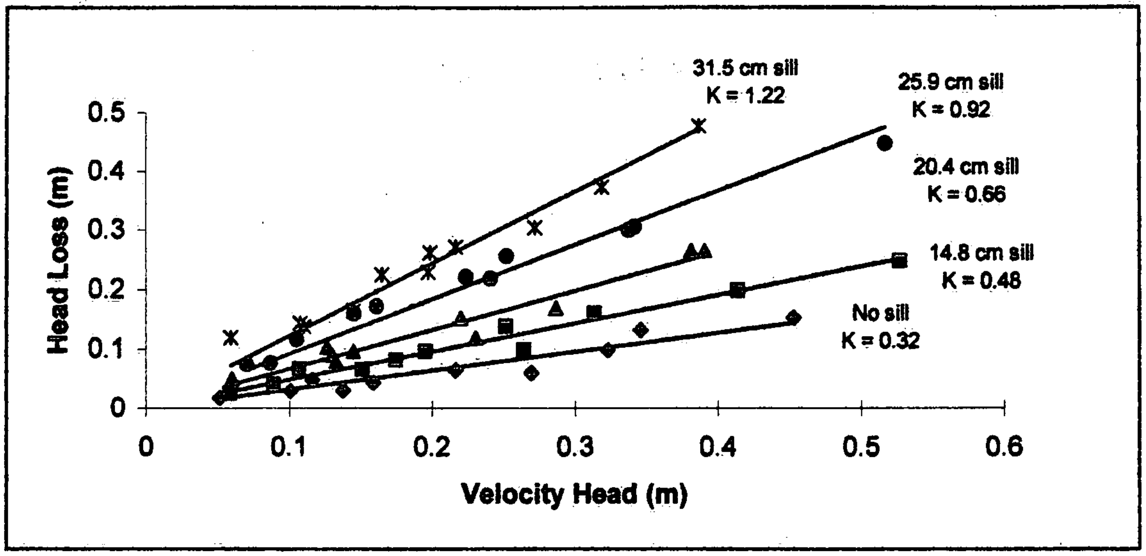
$$\Delta E = K\left(\frac{v^2}{2g}\right) \qquad [5]$$

where ΔE is the head loss (m), K is the head loss coefficient (dimensionless), v is the mean flow velocity ($m \cdot s^{-1}$) and g is the acceleration due to gravity ($m \cdot s^{-2}$).

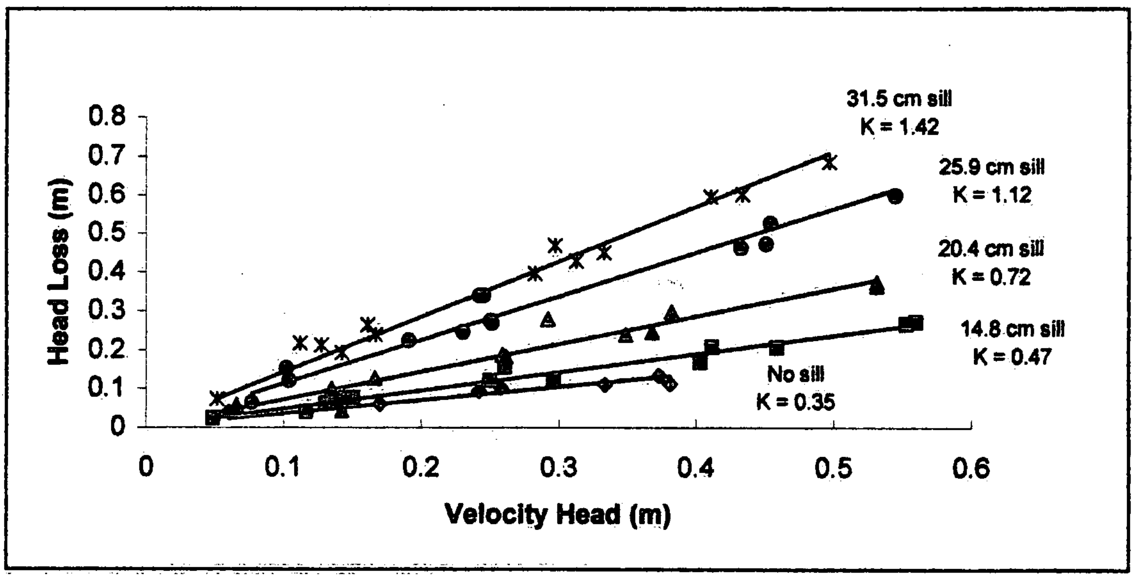
Head losses were determined in pressurized flow, with hydraulic gradients measured on a manometer board from piezometric openings installed in pipe inverts upstream and downstream from the OGS. For various flow rates, energy grade lines were determined upstream and downstream from the separator and the difference in these two lines, above the separator centre, was taken as the head loss.

Head losses determined this way were then plotted against the velocity heads. The head loss coefficient, which represents the slope of the fitted lines in Figures 7a (0.5%) and b (1.0 %), was determined for each of the four trial sill heights.

As expected, the head loss caused by the OGS increases with the size of the diversion sill. The OGS does not create a large head loss in the system. The largest of the 4 weirs tested (31.5 cm) resulted in a K of only 1.22 at a 0.5 % system slope, and 1.42 at a 1.0 % system slope. This approximately corresponds to a 60° bend at sewer manholes (K = 1.4, no benching) [Marsalek and Greck 1988]. Figure 8 can be used to predict head losses for any sill height between those tested. Note that the height of the separation chamber inflow pipe (i.e., leaving the diversion chamber) is 21.3 cm.



(a) Sewer system slope of 0.5 %



(b) Sewer system slope of 1.0 %

Figure 7. *Head losses in pressurized flow.*

Head loss testing at 1.0 % was also conducted with a small roof attached to the diversion sill (for all 4 sizes). The roof was suggested as a design improvement which would trap sediment that may otherwise escape over the sill. There was concern that the roof would introduce additional resistance, but its incorporation had a negligible effect on the head loss of the system.

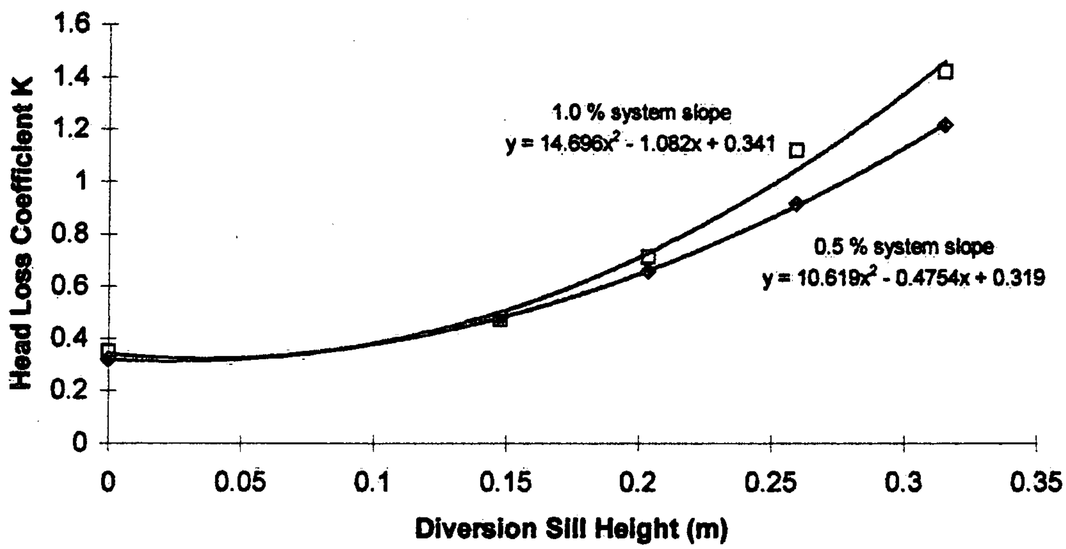


Figure 8. *Head loss coefficient K for various diversion sill heights.*

4.5. Sediment trapping efficiency

The performance of the design in removing sediment from stormwater was evaluated qualitatively in the scale model, at various sill heights, flows and treatment chamber configurations. All sediment testing was conducted at a system slope of 0.5%.

Halliwell and Saul [1980] recommend that the scaling of solids separation should be based on the Froudian similarity of models. The essential requirement is to properly model the particle settling velocity — the velocity scale for the OCPA model can be calculated as $\lambda_v = \lambda_l^{0.5} = 2.36$. Thus, the particle settling velocity is the model should be slightly less than one half of that in the prototype. Reduced settling velocities can be achieved in the model either by using smaller particles of the same density as the prototype materials (not practical), or by using particles of comparable sizes, but lower density (common in hydraulic laboratory studies).

A styrene acrylonitrile copolymer product (LUSTRAN) from Monsanto Chemical was used as a synthetic sediment to evaluate the trapping efficiency of the model. The particle size distribution and density of this white 'bead' mixture is provided in Table 2. The middle two size fractions (0.50ϕ and 1.0ϕ) were selected for sediment testing since they represented the majority of the size mixture, and demonstrated the more consistent settling behavior than both larger and smaller sizes. These two size fractions are equivalent to fine to very fine sands in the prototype [Ponce 1989].

Table 2. *Synthetic sediment particle size distribution and density.*

Particle Diameter		Class frequency	Cumulative coarser	Density	Prototype size[1]
ϕ	(μm)	(%)	(%)	($g \cdot cm^{-3}$)	(μm)
-0.50	1414.21	3.4	3.41	1.017	218
0.00	1000.00	14.66	18.06	1.024	184
0.50	707.11	36.31	54.37	1.032	150
1.00	500.00	25.60	79.97	1.041	121
1.50	353.55	15.38	95.35	1.059	103
2.00	250.00	3.68	99.02	1.086	88

[1] Determined from hydraulic similarity of settling velocities

For a selected flow, 20 g of beads were introduced to the system immediately upstream of the diversion sill. The 20 g comprised 10 g of each of the two chosen particle sizes, and was pretreated with a dilute solution of Ilfotol™ [Ilford Ltd.] (a photographic wetting agent used as an anti-static treatment) to aid in settling. Any imperfect beads which persisted in floating (e.g., with air trapped during the polymerization process) were removed during pretreatment. The remaining beads were introduced to the model in a slurry, either by pouring from a beaker (flows below sill height) or with a large syringe (flows above sill height), ensuring that all beads were directed into the separation chamber.

Flow was discontinued after 15 minutes, a time considerably longer than the detention time in the chamber for any of the flows tested. The quantities of beads trapped in the separation chamber, as well as those captured downstream of the model (i.e that had been flushed out of the separation chamber), were determined. Average sample mass recovery was 98.5 %. The beads retained in the separation chamber were expressed in percent of the total sediment introduced and termed "trapped" sediment.

The efficiency of the OCPA model in trapping the synthetic sediment was determined at a variety of flows both above and below diversion sill heights (Fig. 9). A relationship was determined between flow diverted through the separation chamber and the amount of material trapped. Higher flows through the chamber created more disturbance and resulted in more sediment held in suspension and flushed out. Large downward velocities from the inflow pipe dispersed settled sediment to the edges of the separation tank floor. Vertical circulation currents in the separation chamber were evident, and may even have been responsible for some resuspension of settled particles. At the maximum sewer pipe flows tested (pipe full; 1 $m^3 \cdot s^{-1}$), 25 % of the introduced material was retained in the separation chamber.

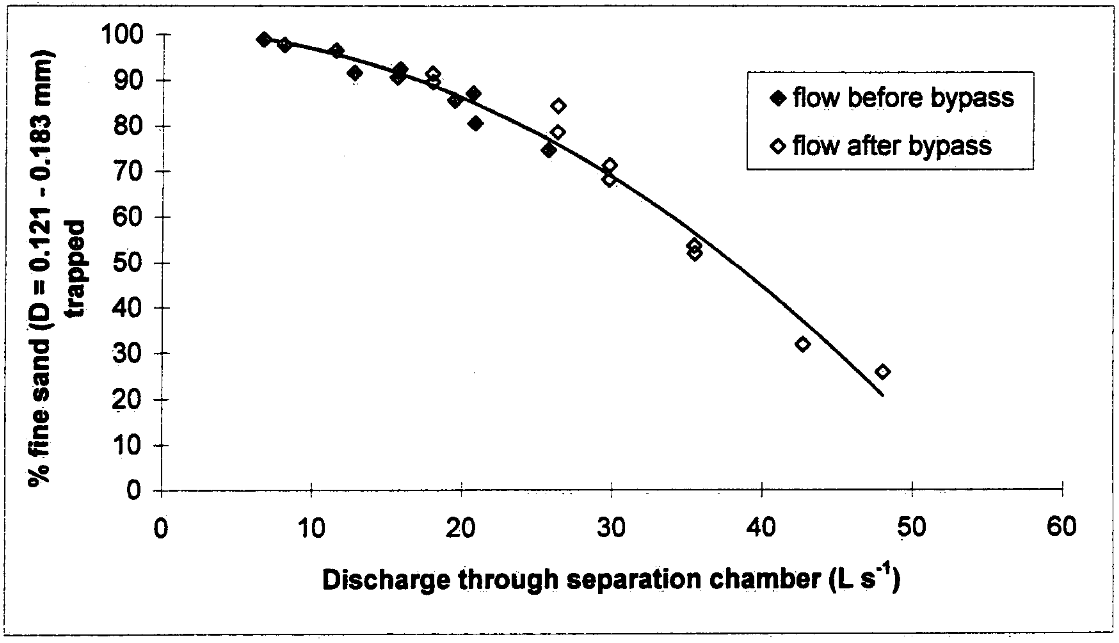


Figure 9. *Sediment trapping efficiency.*

The model was able to trap large percentages of the introduced material, especially at flow rates before bypass. The findings suggest that for a prototype separator in field conditions, effectively all particles larger than fine sands should be removed during low flow dynamic settling conditions. Smaller percentages will be removed at large storm flows. Reduced sediment removals at higher flows are inevitable, and should be acceptable as long as the sediment already deposited in the separation chamber is not scoured and washed out. Scouring tests were not pursued with the model and synthetic sediment since scouring is a complex process and can only be properly addressed at the prototype scale with actual field materials.

Effects of minor modifications to the separation chamber on sediment trapping were also evaluated. Pipes of two lengths were fitted into the outflow elbow in the separation tank to achieve downward extensions of 0.32 and 0.50 m. Sediment trapping efficiencies were determined for the original elbow, short extension and long extension of the outflow pipe at a variety of detention times in the chamber. The length of outflow pipe did not have any significant effect on the sediment trapping efficiency of the chamber. Changes to the inflow pipe configuration were not undertaken at this time.

The trapping efficiency of the separation chamber was also evaluated at 4 tank volumes representing prototype standing water depths of 3.6, 3.0, 2.5 and 2.0 m. Volumes were altered by raising the floor of the separation tank to the appropriate height. Trapping efficiency for each of the 4 depths was determined at 3 flows rates, all below bypass conditions. Intermediate tank depths proved to create better conditions for settling, specifically in the ranking 2.5 m > 3.0 m > 2.0 m = 3.6 m. The optimum intermediate configuration with a water depth of 2.5 m corresponds to a prototype resting tank volume of

10.9 m^3. A boundary layer was evident, as even at the higher flow rates, sediment resting on the tank bottom floor was not disturbed.

4.6. *Oil trapping efficiency*

The separation and retention of oil in the treatment device was also qualitatively evaluated in the OGS. All oil tests were performed with the original model configuration, and a system slope of 0.5 %. Olive oil, dyed to improve its visibility, was used in these experiments. The specific gravity of the olive oil was previously determined to by 0.916, slightly greater than that of motor oil (0.879), which would more frequently be detected in urban runoff. The experiments with oil were not properly scaled and it should be understood that they serve for qualitative evaluations only. However, the results are still useful from a practical point of view as they illustrate the behavior of oil in the separator design. Since the device is designed to separate oil at flows before bypass, oil was only introduced to the system at flows below the diversion sill.

Oil was introduced into the sewer pipe (during low flows) immediately upstream of the diversion sill. For each test, 500 mL of oil was introduced over a 2 minute interval, and the system observed for a total of 15 minutes. Oil movement through the system was observed at three different flow rates (9.2, 16.2, 24.4 $L{\cdot}s^{-1}$). The prevailing behavior of the oil was common to all three. After oil was introduced to the water surface, it flowed as a slick down the separation inflow pipe to the downward elbow where it emerged into the tank was globules. For the highest of the three flow rates tested, it was noted that some oil pooled on the water surface in the corner created by the sill and the side of the main sewer line above the treatment chamber inflow pipe. This oil did not get directed into the treatment chamber, even after considerable time passed. Weirs of heights large enough to create this problem are not likely to be used in prototypes, and hence this small amount of pooled oil was not of particular concern. For the lowest of the three flow rates tested, there was a considerable delay between the time that the oil was first introduced just upstream of the diversion sill and the time the first oil appeared in the separation chamber; oil was collecting in the inflow pipe elbow due to buoyancy. Oil globules that emerged from the bottom of the elbow rose rapidly to the water surface directly around the inflow pipe, i.e., with very little lateral displacement in the tank. Oil continued to seep from the inflow elbow for well into the 15 minute observation period at each of the three flows. At the conclusion of each test, flow rates through the inflow pipe were increased and any remaining oil purged from the inflow pipe elbow; flows of approximately 30 $L{\cdot}s^{-1}$ seemed adequate to purge remaining oil into the separation chamber. Purged oil was often forced all the way to the floor of the separation tank by the downward velocities. Despite this, the oil rose quickly to the water surface, with little lateral displacement thus avoiding any draw by the outflow pipe. Increases in flow through the separation tank had no effect on oil collected on the water surface, which was considered permanently trapped.

On the whole, oil was quickly transported down the treatment chamber inflow pipe, down the inverted elbow and into the treatment chamber. However, there were some problems with transporting oil out of the inflow pipe elbow and into the chamber itself. Free oil found in stormwater is conveyed as oil slicks. Consequently, as it enters the inflow pipe elbow, a significant downward velocity is needed to overcome oil buoyancy and entrain it into the separation chamber. However, once in the treatment chamber, oil is effectively and permanently trapped.

5. Conclusions

5.1. Hydraulic characteristics

At low flow rates (i.e., without bypassing), the separation chamber flow capacity is a function of the flow through the sewer line and the height of the diversion sill. For prototypes, sill size can be selected after determination of the desired flow capacity of the separation chamber. After bypassing occurs, flow through the chamber decreases slightly before increasing to a maximum value greater than the capacity at the time of bypass (greatest increase seen in the smaller sill sizes).

Average detention time in the chamber at critical flows (i.e., assuming plug flow, just before bypass) was determined to range from 16.5 to 7.7 minutes (low sill to high sill) for a water depth of 3.6 m in the separation chamber and a system slope of 1.0 %. Corresponding detention times at a system slope of 0.5 % ranged from 22.4 to 10.5 minutes.

The head loss caused by the OCPA OGS was determined under pressurized flows, and described by a head loss coefficient 'K'. K values for the four trial sill heights ranged from 0.47 to 1.42 (low sill to high sill) at a system slope of 1.0 %, and 0.48 to 1.22 at a system slope of 0.5 %. Maximum head losses observed (for the largest sill) correspond to the head loss of a 60° bend in a sewer line without benching. Figures have been provided to predict head losses for any sill height between those tested, at both of the system slopes.

The hydraulic characteristics of the OCPA OGS provided in this report should be sufficient for its incorporation into the design of sewer systems with slopes of 0.5 to 1.0 %.

5.2. Sediment retention

Sediment trapping efficiency of the OGS was determined to be a function of the flow diverted through the separation chamber. Effectively all particles larger than fine sands should be removed during low flow dynamic settling conditions. As determined from tests with the synthetic sediment, more than 80% of fine and very fine sands that enter the separation chamber will be trapped, at discharges through the chamber of below 20 $L \cdot s^{-1}$. Smaller percentages will be removed at large storm flows, down to 25 % for full sewer pipe flows. During dry weather periods, even fine particles, including silts and clays incorporated in larger flocs, may settle out.

Changes to the separation chamber outflow pipe length did not significantly affect sediment separation efficiency. Tank depth did affect trapping efficiency, with the optimum arrangement having a water depth of 2.5 m, corresponding to a resting tank volume of 10.9 m^3. Less than idea settling conditions in the chamber were indicated by vertical circulation currents and large downward inflow velocities dispersing settled sediment on the floor of the separation chamber.

5.3. *Oil retention*

Qualitative tests demonstrated transport of oil down the treatment chamber inflow pipe, through the inverted elbow, and into the treatment chamber. There were some problems noted with transporting oil out of the inflow pipe elbow and into the chamber itself. Significant downward velocities are needed to overcome oil buoyancy and entrain it into the separation chamber. However, once in the separation chamber, oil is effectively and permanently trapped.

6. Recommendations

- Investigate alternative inflow pipe configurations and/or use of baffles to reduce vertical circulation and enhance sediment settling.
- Investigate alternate treatment chamber inflow pipe configuration to prevent oil accumulation in the elbow.
- Demonstrate sediment scouring using synthetic sediment.
- Final evaluation of the OGS should be conducted in the field on prototype units.

7. References

Geiger, W. and H. Dreiseitl. 1995. Neue Wege fuer das Regenwasser (in German; New methods for stormwater drainage). R. Oldenbourg Verlag, Muenchen.

Halliwell, A. R. and A. J. Saul. 1980. The use of hydraulic models to examine the performance of storm-sewage overflows. Proc. Instn. Civ. Engrs. Part 2, 69:245-259.

Ilford Ltd. ILFOTOL™ Cat. 758744. Mobberly, Cheshire, England.

Marsalek, J. and H.Y.F. Ng. 1989. Evaluation of pollution loadings from urban nonpoint sources: methodology and applications. J. Great Lakes Res. 15(3): 444-451.

Marsalek, J. and B.J. Greck. 1988. Head losses at manholes with a 90° bend. Canadian Journal of Civil Engineering 15(5):851-858.

Marsalek, J., W.E. Watt, and D. Henry. 1992. Retrofitting stormwater ponds for water quality control. Water Poll. Res. J. Canada 27(2): 403-422.

Ontario Ministry of Environment and Energy (MOEE). 1994. Stormwater management practices planning and design manual. Queen's Printer for Ontario, Toronto, Ontario.

Ponce, V. M. 1989. Engineering hydrology: principles and practices. Prentice Hall, New Jersey.

Randall, C.W., K. Ellis, T.J. Grizzard and W.R. Knocke. 1982. Urban runoff pollutant removal by sedimentation. Pages 205-219 *in* W. DeGroot [ed.], Stormwater detention facilities. Proc. Eng. Found. Conf., ASCE, New York, NY.

Stenstrom, M.K., G.S. Silverman and T.A. Bursztynsky. 1984. Oil and grease in urban stormwaters. Journal of the Environmental Engineering Division, ASCE, 10(1): 58-72.

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Canada Environnement Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6

Think Recycling!

Pensez à recycler !