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# A Study of methods for Characterization and evaluation of Treatability of CSOs in Great Lakes areas of Concern

BY:

K. Exall, B. Krishnappan, J. Marsalek, Q. Rochfort

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# A Study of Methods for Characterization and Evaluation of Treatability of CSOs in Great Lakes Areas of Concern

K. Exall*, B.G. Krishnappan, J. Marsalek and Q. Rochfort

National Water Research Institute, Environment Canada, 867 Lakeshore Road, P.O. Box 5050, Burlington, Ontario L7R 4A6 (E-mail: Kirsten.Exall@ec.gc.ca)

## Abstract

In a watershed-based approach to water quality management, all pollution sources, including combined sewer overflows (CSOs), need to be addressed. Among the various options for controlling CSO pollution, municipal wastewater authorities throughout Canada are exploring new and innovative treatment technologies specifically designed for CSOs. The effective design of such treatment processes requires good understanding of the CSO characteristics with respect to chemical composition and settleability, with and without chemical additions. In support of the process of delisting a number of Areas of Concern in the Great Lakes Basin, the National Water Research Institute, in conjunction with the Great Lakes Sustainability Fund and four partner municipalities, has conducted a study utilizing various methods for CSO characterization. Settleability of wet-weather and dry-weather samples was assessed by four techniques, including three settling column-based methods (the German UFT column, the U.S. EPA long column, and the Aston column originating in Britain) and a newly proposed elutriation apparatus method. Each method was examined in terms of strengths, limitations and technical challenges, and the results obtained using the four techniques were compared for wet- and dry-weather flows from one municipality.

Treatability of wet- and dry-weather samples with chemical aids was also assessed by jar testing, complemented by a preliminary evaluation of changes in suspended solids settling through modified elutriation tests with polymer addition. Chemical characterization of CSO and municipal sewage samples and the eluted fractions was conducted; the results emphasize the importance of solids removal in reducing levels of associated constituents.

# NWRI RESEARCH SUMMARY

**Plain language title**

A Study of Methods for Characterization and Evaluation of Treatability of Combined Sewer Overflows in Great Lakes Areas of Concern

**What is the problem and what do scientists already know about it?**

The Remedial Action Plans for a number of AOCs in the Great Lakes Basin include control and abatement of combined sewer overflows (CSOs). In this respect, the municipalities involved have recognized the need to examine the environmental impact of CSO discharges on the aquatic environment, and assess the environmental benefit of new and innovative CSO treatment and pollution prevention technologies. For the effective design of a treatment process for CSOs, it is necessary to first understand the CSO characteristics with respect to chemical composition and settleability, with and without chemical additions. A number of different methods have been used in the past to characterize settleability of CSOs and wastewater. Since the testing methods for CSO characterization are not standardized, four such techniques were compared in this study.

**Why did NWRI do this study?**

NWRI has undertaken this study in support of the Great Lakes Action Plan (GLAP) and, specifically, to advance the process of delisting the Niagara River Area of Concern.

**What were the results?**

Characteristics of both wet-weather (CSO) and dry-weather (municipal sewage) flows were determined through laboratory testing of samples; results are presented for a representative municipality. Settleability of both dry-weather and CSO samples was assessed by four methods, the Aston Column Method, UFT Column Method and U.S. EPA Column Method, and a newly proposed elutriation apparatus method. The results indicated some variability in settling velocity distributions as measured by the various methods for individual samples, but considering the variability between samples, any of the four methods would produce comparable designs.

**How will these results be used?**

The data will be used by the study partners for the planning and set-up of a subsequent pilot-scale study, and eventual design of a full-scale CSO treatment facility.

**Who were our main partners in the study?**

Great Lakes Sustainability Fund and City of Niagara Falls

# Étude des méthodes de caractérisation et d'évaluation de la traitabilité des TPEU dans les secteurs préoccupants des Grands Lacs

K. Exall*, B.G. Krishnappan, J. Marsalek et Q. Rochfort

Institut national de recherche sur les eaux, Environnement Canada, 867 Lakeshore Road, C.P. 5050, Burlington (Ontario) L7R 4A6 (Courriel : kirsten.Exall@ec.gc.ca)

**Résumé**

Dans le cadre d'une approche par bassin de la gestion de la qualité de l'eau, toutes les sources de pollution, y compris les trop-pleins d'égouts unitaires (TPEU) doivent être prises en compte. Parmi les multiples options visant le contrôle de la pollution due aux TPEU, les responsables municipaux du traitement des eaux usées de partout au Canada analysent de nouvelles technologies novatrices de traitement, conçues spécialement pour les TPEU. Pour concevoir des procédés de traitement efficace, il faut bien comprendre les caractéristiques des TPEU, comme leur composition chimique et leur décantabilité, avec ou sans ajout chimique. Dans le cadre du processus de réduction du nombre de secteurs préoccupants dans le bassin des Grands Lacs, l'Institut national de recherche sur les eaux a réalisé une étude à l'aide de différentes méthodes de caractérisation des TPEU, en collaboration avec le Fonds de durabilité des Grands Lacs et en partenariat avec quatre municipalités. La décantabilité des échantillons prélevés par temps de pluie et par temps sec a été évaluée au moyen de quatre techniques, comprenant trois méthodes de décantation en colonne (colonne de l'UFT d'Allemagne, colonne longue de l'EPA des États-Unis et colonne Aston de Grande-Bretagne) et une toute nouvelle méthode utilisant un dispositif d'élutriation. Les points forts, les limites et les défis techniques de chaque méthode ont été examinés, et les résultats obtenus à l'aide de ces quatre techniques ont été comparés pour les écoulements par temps de pluie et par temps sec provenant d'une seule municipalité.

La traitabilité des échantillons prélevés par temps de pluie et par temps sec à l'aide de produits chimiques a également été évaluée au moyen d'essais de floculation, complétés par une évaluation préliminaire des changements des matières solides en suspension par des tests d'élutriation modifiés et avec l'ajout de polymères. La caractérisation chimique des échantillons des eaux usées municipales et des TPEU, ainsi que des fractions éluées, a été effectuée; les résultats soulignent l'intérêt de la suppression des matières solides pour la réduction des taux de constituants connexes.

## Sommaire des recherches de l'INRE

**Titre en langage clair**

Étude des méthodes de caractérisation et d'évaluation de la traitabilité des trop-pleins d'égouts unitaires dans les secteurs préoccupants des Grands Lacs.

**Quel est le problème et que savent les chercheurs à ce sujet?**

Les plans de mesures correctives pour un certain nombre de secteurs préoccupants du bassin des Grands Lacs comprennent le contrôle et la réduction des trop-pleins d'égouts unitaires (TPEU). À cet égard, les municipalités impliquées ont reconnu la nécessité d'analyser l'effet des TPEU sur le milieu aquatique et d'évaluer l'avantage environnemental des nouvelles technologies novatrices en matière de traitement des TPEU et de prévention de la pollution. Avant de concevoir un procédé de traitement efficace pour les TPEU, il faut d'abord comprendre les caractéristiques des TPEU, comme leur composition chimique et leur décantabilité, avec ou sans ajout chimique. Une certain nombre de méthodes différentes ont déjà été utilisées afin de caractériser la décantabilité des TPEU et des eaux usées. Comme les méthodes d'essai de caractérisation des TPEU ne sont pas normalisées, quatre de ces méthodes ont été comparées dans cette étude.

**Pourquoi l'INRE a-t-il effectué cette étude?**

L'INRE a mené cette étude dans le cadre du Plan d'action des Grands Lacs et, plus particulièrement, pour faire avancer le dossier du retrait de la rivière Niagara de la liste des secteurs préoccupants.

**Quels sont les résultats?**

Les caractéristiques des écoulements par temps de pluie (TPEU) et par temps sec (eaux usées municipales) ont été déterminées par des essais en laboratoire sur les échantillons; les résultats sont présentés pour une municipalité représentative. La décantabilité des échantillons par temps sec et par temps de pluie a été évaluée à l'aide de quatre méthodes, la colonne Aston, la colonne de l'UFT, la colonne de l'EPA, ainsi qu'une toute nouvelle méthode à l'aide d'un dispositif d'élutriation. Les résultats ont fait ressortir une certaine variabilité dans les distributions des vitesses de décantation obtenues avec les différentes méthodes pour chacun des échantillons, mais, étant donné la variabilité entre les échantillons eux-mêmes, n'importe laquelle des méthodes aurait donné des résultats comparables.

**Comment ces résultats seront-ils utilisés?**

Les données seront utilisées par les partenaires de l'étude pour la planification et la mise en place d'une étude pilote ultérieure et pour la conception éventuelle d'une véritable installation de traitement des PTEU.

**Quels étaient nos principaux partenaires dans cette étude?**

Fonds de durabilité des Grands Lacs et ville de Niagara Falls.

# A Study of Methods for Characterization and Evaluation of Treatability of CSOs in Great Lakes Areas of Concern

K. Exall*, B.G. Krishnappan, J. Marsalek and Q. Rochfort

National Water Research Institute, Environment Canada, 867 Lakeshore Road, P.O. Box 5050, Burlington, Ontario L7R 4A6 (E-mail: Kirsten.Exall@ec.gc.ca)

**Abstract**
In a watershed-based approach to water quality management, all pollution sources, including combined sewer overflows (CSOs), need to be addressed. Among the various options for controlling CSO pollution, municipal wastewater authorities throughout Canada are exploring new and innovative treatment technologies specifically designed for CSOs. The effective design of such treatment processes requires good understanding of the CSO characteristics with respect to chemical composition and settleability, with and without chemical additions. In support of the process of delisting a number of Areas of Concern in the Great Lakes Basin, the National Water Research Institute, in conjunction with the Great Lakes Sustainability Fund and four partner municipalities, has conducted a study utilizing various methods for CSO characterization. Settleability of wet-weather and dry-weather samples was assessed by four techniques, including three settling column-based methods (the German UFT column, the U.S. EPA long column, and the Aston column originating in Britain) and a newly proposed elutriation apparatus method. Each method was examined in terms of strengths, limitations and technical challenges, and the results obtained using the four techniques were compared for wet- and dry-weather flows from one municipality.

Treatability of wet- and dry-weather samples with chemical aids was also assessed by jar testing, complemented by a preliminary evaluation of changes in suspended solids settling through modified elutriation tests with polymer addition. Chemical characterization of CSO and municipal sewage samples and the eluted fractions was conducted; the results emphasize the importance of solids removal in reducing levels of associated constituents.

**Keywords**
Combined sewer overflows; CSO characterization; settling tests; suspended solids; treatability.

## INTRODUCTION

In 1973, the International Joint Commission identified 43 Areas of Concern (AOCs) throughout the Great Lakes basin where water quality impairment prevents full beneficial use of the local receiving waters (Kok, 2004). The Remedial Action Plans for a number of these AOCs include control and abatement of combined sewer overflows (CSOs). In this respect, the municipalities involved have recognized the need to examine the environmental impact of CSO discharges on the aquatic environment, and assess the environmental benefit of new and innovative CSO treatment and pollution prevention technologies.

A number of municipalities are undertaking studies to fully evaluate the hydraulics, performance and pollutant removal efficiency of various physical screening/settling devices, as well as chemical coagulation technology, for the high-rate treatment of CSOs at specific sewer outfall sites. It is envisaged that these new satellite treatment technologies, if implemented successfully, could significantly reduce the requirement for large storage tanks and their associated costs. As a preliminary requisite phase of the technology evaluation, it is imperative to first understand the CSO characteristics of the specific discharges with respect to chemical composition and settleability, and the effects of chemical addition. Towards that end, four municipalities have carried out a joint study with the National Water Research Institute (NWRI) to characterize the

CSOs, and to conduct bench-scale treatability studies of CSO using polymer coagulation technology.

A number of different methods have been used in the past to characterize settleability of CSOs and wastewater (e.g., Michelbach and Wöhrle, 1994; Pisano and Brombach, 1996; Rasmussen and Larsen, 1996). Several researchers have compared the traditional and alternative methods in order to determine which technique is the most suitable for assessing the treatability of wet-weather flows (Tyack *et al.*, 1993; Aiguier *et al.*, 1998; O'Connor *et al.*, 2002). Since the testing methods for CSO characterization are not standardized, four such methods were included in this study. Three of the methods use settling columns, including the Aston column, the UFT column and the U.S. EPA multi-port long column; the fourth technique is a new method using an elutriation apparatus.

## EXPERIMENTAL METHODS

### Sample Collection and Preparation

Between May 21st, 2003 and January 28th, 2005 a total of 53 wet-weather samples and 51 dry-weather samples were tested, including 19 wet-weather and 12 dry-weather samples from the City of Niagara Falls, Ontario, Canada. Wet-weather samples were collected using an autosampler, while dry-weather grab samples were collected using a bucket. Samples were stored at 4°C in the dark until tested. Prior to testing, the sample was well mixed, divided into several 20-L carboys, and then warmed to 20 ± 2°C in hot water baths. Analyses for total suspended solids (TSS) and volatile suspended solids (VSS) were performed in accordance with Standard Methods (1998); all other chemical analyses were performed by CAEAL-certified, third-party laboratories.

### Settling Columns

Four types of settling tests were conducted, including three settling column-based methods (the British Aston column, the German UFT column, and the U.S. EPA long column) and a newly proposed Elutriation Apparatus Method. Each method is described in general terms in the following paragraphs. Details of test procedures can be found in project reports (e.g., Exall *et al.*, 2005) or in the references cited for each method.

*Aston Column.* The Aston column method was developed at Aston University, UK (Tyack *et al.*, 1993) with the objective of characterizing not only settling solids (sinkers), but also floating solids (floaters). The column used in this study was constructed of acrylic (2.2 m long and 5 cm ID), had a volume of approximately 5 L, and was supported by central gimbals allowing 180° rotation in the vertical plane to facilitate sampling of settled and floating solids. At each end of the column, ball valves isolate terminal cells, which separate the sampling volume from the rest of the column. After an initial, 2-h settling period, water with floaters and sinkers collected during the initial period was removed from the outer cells A and B, respectively. The initial floaters (cell A) were saved for further analysis; the sinkers from cell B were thoroughly mixed and poured into the top cell A, the bottom cell B was filled with tap water, and the column was returned to the starting position. The inner valves were then opened, releasing the re-introduced sinkers into the central column section for settling over a 2.5 hour period. Settled solids were collected from cell B at pre-selected times.

*UFT Settling Column.* The UFT column (Umwelt- und Fluid-Technik, also known as the Brombach column) has been used extensively in Germany to characterize the settleability of CSOs, and such data were used to design CSO storage tanks (Pisano and Brombach, 1996). The column used in this study had a total volume of approximately 1 L, and consisted of an upper reservoir (500 mL) with an offset sample delivery cylinder, a middle cylindrical section (approximately 5 cm ID x 49 cm), and an Imhoff cone (100 mL) attached to the column bottom. In this procedure, a sewage sample was pre-settled in the column, the settled solids were collected, the column was drained and refilled

with tap water, and the settled solids were reintroduced at the top of the column. Subsequently, samples were withdrawn from the bottom of the column at timed intervals and analyzed for total suspended solids.

*U.S. Environmental Protection Agency (EPA) Settling Column.* The U.S. EPA column is also known as the 'long' column and was described in general terms by O'Connor *et al.* (2002). It is usually constructed of clear acrylic, in lengths ranging from 1.8 to 2.5 m, and fitted with evenly spaced side ports for sample withdrawal and a drain valve at the bottom. The column used in the current study was 1.5 m long, 12.7 cm in diameter and had side ports spaced at 25.3 cm. A well mixed sample was poured rapidly into the column. Sampling was performed at timed intervals, in a sequential fashion from the top to the bottom port. As successive samples were withdrawn, the total depth of sewage in the column was reduced, which necessitated corrections of calculated settling rates for these changes.

*Elutriation Apparatus.* An experimental elutriation apparatus method was included in this battery of settleability tests to provide an alternative approach to conventional quiescent settling column tests. In the elutriation method, the particles are exposed to dynamic interaction while settling, and this more realistically reflects the type of settling which would occur in a conventional full-size flow-through settling basin. The method was adapted from a water elutriation process which was originally proposed by Walling and Woodward (1993) to measure particle size distribution of riverine suspended sediment. Krishnappan *et al.* (2004) developed a protocol for measuring the settling velocity distribution of CSO solids using a related system. The elutriation apparatus method used in this study was based on this protocol. The apparatus consisted of eight cylinders, arranged sequentially in ascending order of their diameters. In the present test procedure, CSO samples were split into two 25-L carboys (a total of 50 L of sample was eluted) and mixed by impellers. A Y-connector combined the delivery lines from the two carboys, so that their streams became completely mixed prior to entering the first column. This configuration was designed to duplicate the effect of an online mixing process such as polymer addition, which is often used to improve settleability of CSOs. Sample was drawn through these cylinders by a pump, which was placed at the downstream end of the apparatus. The CSO was routed through these cylinders in such a way that it entered the cylinders near the bottom and exited near the top. As the CSO sample entered the column at the bottom, it began to rise towards the outflow tube located at the top of the column. Particles or flocs with settling velocities greater than the upward flow velocity were retained within the column, and particles with settling velocities smaller than the upward flow velocity were carried through into the next column. As the upward flow velocities in each successive column became progressively slower, finer and finer solids settled. All other materials with settling velocities smaller than those collected in column 7 and 8 passed through to the effluent carboys.

**Coagulant addition**

The addition of coagulants and flocculants during primary treatment of wastewater aids in the removal of suspended solids, and therefore in the removal of associated contaminants. Jar tests were conducted with alum, chitosan or a high molecular weight, cationic polymer flocculant to determine dosage requirements for wet- and dry-weather samples. A somewhat modified jar test procedure (2 min rapid mix, 15 min slow mix for alum only, and 20 min settling) was followed in an effort to better reflect rapid treatment conditions. The effects of coagulant addition were also evaluated for selected samples through a modified elutriation apparatus test. In this procedure, a dilute polymer solution was placed in one of the 25-L carboys and sample in the other. A static mixer was included in the delivery line before the first column to thoroughly mix the polymer solution and sample.

## RESULTS AND DISCUSSION

Table 1 compares characteristics of the four methods employed in this study for assessment of solids settling. Each method can be seen to have both operational advantages and limitations.

Table 1: Comparison of four settleability assessment methods used in the Niagara Falls study

| | Method | | | |
|---|---|---|---|---|
| Method characteristics | Aston column | Elutriation apparatus | UFT column | U.S. EPA column |
| Sample volume (L) | 5 | 50 | 1 | 20 |
| Duration of test (h) | 5.5 | 1.5 | 4 | 2 |
| Pre-separation of solids | Yes | No | Yes | No |
| Flow conditions | Quiescent | Dynamic | Quiescent | Quiescent |
| Measurement of sinkers | Yes | Yes | Yes | Yes |
| Measurement of floatables | Yes | Yes (with limitations) | No | No |
| Chemical additions | No | Yes | No | No |

To compare the settling velocity distributions from all four methods, the measured distributions were fitted to an analytical expression of the form shown below:

$$y = \frac{x}{\beta x + \alpha} \tag{1}$$

where y is the ordinate representing the percent of the particles by weight that have settling velocity less than a prescribed value (percent slower), x is the abscissa representing the settling velocity, and $\alpha$ and $\beta$ are empirical constants. Typical results for all four methods can be seen in Fig. 1.

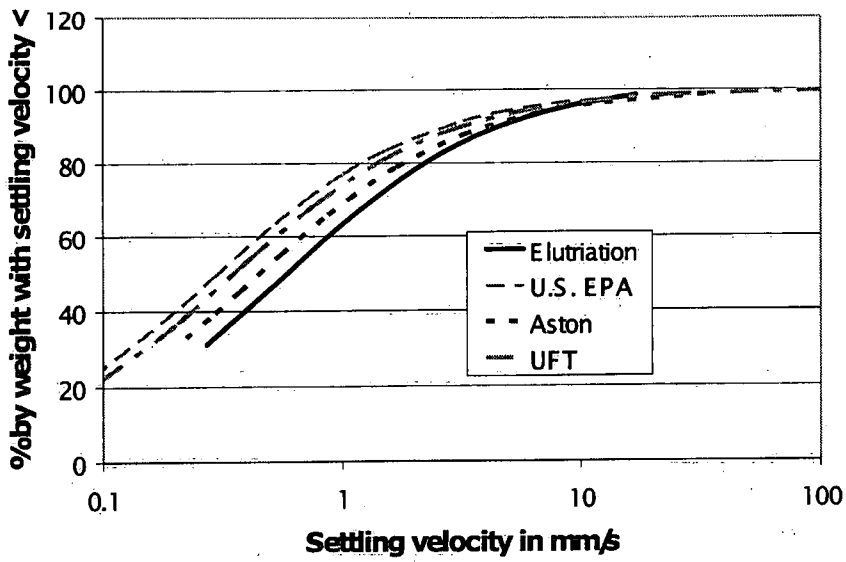


Fig. 1: Comparison of settling velocity distributions given by various methods.

Transposing equation 1 to express the settling velocity (x) in terms of percent by weight of solids with settling velocity less than a specified value (percent slower, y), we get:

$$x = \frac{\alpha y}{1 - \beta y} \tag{2}$$

From this equation, a relationship between the surface loading rate and the percent removal can be established as the settling velocity gives a measure of the surface loading rate, and the percent of solids with settling velocity less than a specified value can be related to percent retained and hence to percent removal. Using Equation 2, the surface loading rate in m/hr was calculated for different removal rates for all the samples as shown in Fig. 2.

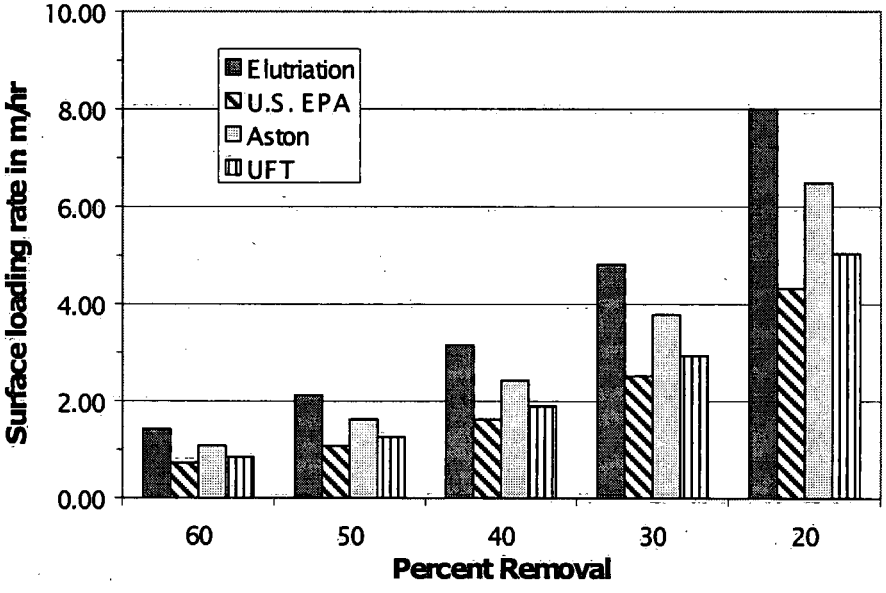


Fig. 2: Comparison of surface loading rates given by various methods.

Visual comparisons of settling velocity distributions for the four methods show clear differences in the results obtained with various methods. Comparing settling velocity distributions and surface load estimates for all samples, however, indicates that the variability inherent to different samples is of the same order of magnitude as the variability due to measurement methods. Overall, the differences among the mean required surface loads produced by these four methods were not statistically significant at a 95% level of confidence. For the samples from this municipality, the results indicate that any of the four methods would be acceptable and produce comparable designs.

Chemical analysis of all samples indicated that the municipal sewage at this particular site was characterized by weak to medium strength for all measured parameters except chloride, which was generally elevated to the "strong sewage" level. Combined sewer overflow samples related well to the composition of municipal sewage, with lower concentrations of organic carbon, oxygen-demanding substances and nutrients typically associated with sewage. Analysis of fractions separated by elutriation indicated that the removal of trace metals and nutrients by settling closely tracked the removal of suspended solids in the elutriation apparatus, while removal of organics required slightly lower surface loading rates.

Treatability of a number of the dry-weather and CSO samples with chemical aids was assessed by jar testing and a modified elutriation apparatus method test. The data indicate that relatively inexpensive low dosages of a polymer flocculant can substantially increase the settleability of solids and associated contaminants. Use of the modified elutriation apparatus method allowed the measurement of changes in settling velocity distributions upon the addition of the polymer.

## CONCLUSIONS

Characteristics of both wet-weather (CSO) and dry-weather (municipal sewage) flows collected between May 2003 and January 2005 were determined through laboratory testing of samples. Settleability of both dry-weather and CSO samples was assessed by four methods, the Aston Column Method, UFT Column Method and U.S. EPA Column Method, and a newly proposed elutriation apparatus method. The results indicate some variability in settling velocity distributions as measured by the various methods for individual samples, but considering the variability between samples, any of the four methods would produce comparable designs. The final choice within this group would depend on other considerations.

## ACKNOWLEDGEMENTS

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**National Water Research Institute**
**Environment Canada**
**Canada Centre for Inland Waters**
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

**National Hydrology Research Centre**
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

**Institut national de recherche sur les eaux**
**Environnement Canada**
**Centre canadien des eaux intérieures**
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

**Centre national de recherche en hydrologie**
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

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