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## Environnement Canada

Feasibility of stormwater treatment by conventional  
and lamellar setting with and without polymeric  
flocculant addition

By:

J. Wood, M. Yang, Q. Rochfort, P. Chessie...

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## **Feasibility of stormwater treatment by conventional and lamellar settling with and without polymeric flocculant addition**

J. Wood, M. Yang, Q. Rochfort, P. Chessie, J. Marsalek, P. Seto and S. Kok

### **ABSTRACT**

Stormwater treatment by lamellar and conventional clarification, with and without flocculant addition, was investigated in Toronto, Ontario, Canada using a pilot-scale rectangular clarifier vessel with removable lamellar plates. During the 2001 field season, 51 stormwater runoff events were characterized with respect to flow and quality, and further investigated for stormwater treatment. The stormwater at this site was significantly polluted, with most constituent concentrations exceeding those for the US NURP median urban site. A polymeric flocculant dosage of 4 mg/L with lamellar clarification provided the best results with total suspended solids (TSS) removal of 84% at a total vessel surface load of 15 m/h. The clarifier sludge was strongly polluted by heavy metals and would require special disposal procedures.

## **La faisabilité du traitement de l'eau pluviale par décantation lamellaire avec ou sans addition de floculants polymériques**

J. Wood, M. Yang, Q. Rochfort, P. Chessie, J. Marsalek, P. Seto and S. Kok

### **RÉSUMÉ**

La décantation lamellaire et classique des eaux pluviales, avec ou sans addition de floculants, a été examinée à Toronto (Ontario) Canada au moyen d'un décanteur rectangulaire pilote muni de lamelles amovibles. Durant la saison de terrain 2001, 51 épisodes de ruissellement pluvial ont été caractérisés (écoulement et qualité des eaux) et ont été étudiés aux fins du traitement. À cet endroit, les eaux pluviales étaient très polluées, la concentration de la plupart des paramètres étant supérieure à celle du site urbain médian du NURP américain. Un dosage de floculants polymériques de 4 mg/L avec décantation lamellaire a donné les meilleurs résultats (enlèvement des MES de 84 % pour une charge superficielle totale de 15 m/h). Les boues produites étaient fortement polluées par les métaux lourds et devaient être éliminées de façon appropriée.

## **NWRI RESEARCH SUMMARY**

### **Plain language title**

Feasibility of stormwater treatment by plain and plate settling with and without chemical addition

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

Concerns about impacts of stormwater discharges on receiving waters have led to the development of stormwater management practices, which strive to prevent or reduce such impacts by reducing runoff and enhancing stormwater quality by passive treatment processes. There are however circumstances, when more intensive treatment may be required, such as chemically aided settling, which has been so far investigated mostly for combined sewer overflows, or in small facilities with short residence times. The feasibility of stormwater treatment by chemically aided settling was addressed in this study, which besides the treatment efficiency also addressed the risk of effluent toxicity caused by polymer addition and the quality of sludge produced.

### **Why did NWRI do this study?**

NWRI has been working with the City of Toronto on developing various measures for controlling urban stormwater pollution, in support of the Toronto Wet-Weather Flow Management Master Plan and remediation of the Toronto Waterfront. This study is one of the activities designed to develop technologies for wet-weather flow pollution control.

### **What were the results?**

Lamellar clarification with polymeric flocculant addition was found effective in total suspended solids (TSS) removal from stormwater, at a polymer dosage of 4 mg/L and total vessel surface overflow rates up to 15 m/h (TSS removal 84%). Significantly lower contaminant removals were obtained for other constituents (c.BOD<sub>5</sub>, COD, nutrients and metals). The use of a high molecular weight polymeric flocculant did not increase the stormwater toxicity, as determined in this study by tests on the stormwater and process effluents, using both the Microtox<sup>TM</sup> test and rainbow trout fish bioassays. The combination of lamellar clarification and polymeric flocculant addition improved the treatment efficiency and could be well applied in other stormwater management projects requiring intensive stormwater treatment in a compact area.

### **How will these results be used?**

The information on stormwater treatment by chemically aided settling will be used by the City of Toronto in the implementation of their Wet-Weather Flow Management Master Plan and also in other locations, where stormwater treatment is required.

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

This study was conducted in co-operation with the City of Toronto and the Great Lakes Sustainability Fund.

## **Sommaire des recherches de l'INRE**

### **Titre en langage clair**

Étude de la faisabilité du traitement d'eaux pluviales par décantation statique et décantation anodique avec et sans apport de substances chimiques

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

À la suite de préoccupations concernant les effets des rejets d'eau de pluie dans des eaux réceptrices, on a établi des pratiques de gestion des eaux pluviales dans le but de prévenir ou de réduire ces effets en réduisant le ruissellement et en augmentant la qualité des eaux pluviales au moyen de procédés de traitement passif. Il existe cependant des circonstances justifiant un traitement plus intensif, dont la décantation stimulée chimiquement, qu'on a étudiée jusqu'à maintenant surtout pour application aux déversoirs d'eaux excédentaires ou aux petites installations où le temps de séjour de l'eau pluviale est court. L'étude visait à déterminer la faisabilité du traitement d'eaux pluviales par décantation stimulée chimiquement, ainsi qu'à évaluer le risque de toxicité de l'effluent due à l'addition de polymères et la qualité des boues produites.

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

L'INRE a collaboré avec la Ville de Toronto à l'élaboration de diverses mesures de lutte contre la pollution des eaux pluviales urbaines à l'appui du Plan directeur pour la gestion des débits par temps pluvieux de cette municipalité et des efforts de restauration du secteur riverain de Toronto. Cette étude est une des activités conçues pour la mise au point de technologies de lutte contre la pollution des eaux de ruissellement par temps pluvieux.

### **Quels sont les résultats?**

La clarification lamellaire avec apport de flocculant polymérique s'est révélée efficace pour la suppression des solides en suspension dans les eaux pluviales, à une dose de polymères de 4 mg/L et à des vitesses de déversement calculées sur la surface totale du bassin pouvant atteindre 15 m/h (suppression de 84 % des solides en suspension). Des taux de suppression de contaminants très inférieurs ont été obtenus pour d'autres paramètres (DBO<sub>5</sub>, DCO, teneur en nutriments et teneur en métaux). L'emploi d'un flocculant polymérique à masse moléculaire élevée n'a pas augmenté la toxicité des eaux pluviales selon les analyses des eaux pluviales et des effluents de procédé effectuées au moyen du test Microtox<sup>MC</sup> et de bio-essais sur truite arc-en-ciel. La combinaison de la clarification lamellaire et de l'introduction d'un flocculant polymérique a rendu le traitement plus efficace, et elle pourrait bien être utile dans d'autres projets de traitement d'eaux pluviales exigeant un traitement intensif des eaux dans des milieux peu étendus.

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

La Ville de Toronto utilisera l'information sur le traitement d'eaux pluviales par décantation stimulée chimiquement pour la mise en œuvre de son Plan directeur pour la gestion des débits par temps pluvieux et à d'autres endroits où il faut traiter des eaux pluviales.

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

L'étude a été effectuée en collaboration avec la Ville de Toronto et avec le soutien du Fonds de durabilité des Grands Lacs.

## **Feasibility of stormwater treatment by conventional and lamellar settling with and without polymeric flocculant addition**

La faisabilité du traitement de l'eau pluviale par décantation lamellaire avec ou sans addition de flocculants polymériques

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### **RÉSUMÉ**

La décantation lamellaire et classique des eaux pluviales, avec ou sans addition de flocculants, a été examinée à Toronto (Ontario) Canada au moyen d'un décanteur rectangulaire pilote muni de lamelles amovibles. Durant la saison de terrain 2001, 51 épisodes de ruissellement pluvial ont été caractérisés (écoulement et qualité des eaux) et ont été étudiés aux fins du traitement. À cet endroit, les eaux pluviales étaient très polluées, la concentration de la plupart des paramètres étant supérieure à celle du site urbain médian du NURP américain. Un dosage de flocculants polymériques de 4 mg/L avec décantation lamellaire a donné les meilleurs résultats (enlèvement des MES de 84 % pour une charge superficielle totale de 15 m/h). Les boues produites étaient fortement polluées par les métaux lourds et devaient être éliminées de façon appropriée.

### **ABSTRACT**

Stormwater treatment by lamellar and conventional clarification, with and without flocculant addition, was investigated in Toronto, Ontario, Canada using a pilot-scale rectangular clarifier vessel with removable lamellar plates. During the 2001 field season, 51 stormwater runoff events were characterized with respect to flow and quality, and further investigated for stormwater treatment. The stormwater at this site was significantly polluted, with most constituent concentrations exceeding those for the US NURP median urban site. A polymeric flocculant dosage of 4 mg/L with lamellar clarification provided the best results with total suspended solids (TSS) removal of 84% at a total vessel surface load of 15 m/h. The clarifier sludge was strongly polluted by heavy metals and would require special disposal procedures.

### **KEYWORDS**

Clarification, lamellar settling, polymer flocculant, stormwater treatment, sludge

## 1. INTRODUCTION

Concerns about impacts of urban stormwater discharges on receiving waters have led to the development of stormwater best management practices, which strive to prevent or mitigate such impacts by reducing runoff and enhancing stormwater quality mostly by passive treatment processes. In Canada, stormwater ponds and constructed wetlands are prevalently used for stormwater quality enhancement and serve well many municipalities by providing a range of environmental benefits and amenities (MOE, 2003). Limitations of such facilities may include land availability, heating of stored runoff in summer months, accumulation of polluted sediment contributing to habitat degradation and possible health concerns with mosquitoes breeding. Where such limitations are of concern, they can be addressed by implementing a more compact intensive treatment, including lamellar settling with flocculant addition at facilities that could be located underground (Bridoux et al., 1998; Ekvall, 1998; Plum et al., 1998; Vetter et al., 2001). Some of these measures were addressed in this study striving to develop technologies for the implementation of the Toronto Wet-Weather Flow Master Plan and for remediation of the Toronto Waterfront.

## 2. OBJECTIVES

The objective of the stormwater treatment investigation was to demonstrate the reliability of polymeric flocculant aided clarification processes, which were earlier successfully applied to treatment of combined sewer overflows (CSO) in Toronto (WTI, 1999). The target performance criteria were adopted from the Ontario Ministry of the Environment (MOE) stormwater management manual requiring TSS removals in the range from 60 to 80% (MOE, 2003). In addition the benefit or requirement of lamellar over conventional clarification was also to be determined. Effluent toxicity, sludge characterization and sludge disposal requirements were identified as environmental concerns for this treatment process.

## 3. EXPERIMENTAL APPARATUS AND METHODS

Stormwater treatment by constant rate clarification was studied during the 2001 field season (7 April – 13 December 2001) at a site in Toronto, Ontario. The clarifier was fed with a submersible pump from a 2.5 m diameter storm sewer draining an area of almost 300 ha, comprising industrial, commercial, and residential land. A temporary compound weir constructed from plywood and angle iron was installed in the storm sewer downstream of the feed pump to measure stormwater flow.

The rectangular clarifier was 3 m long, 1.4 m wide and 2 m deep. The features of the clarifier including inlet flow streamlining baffles and scum baffles designed to retain floating solids are depicted in Figure 1. The clarifier total surface area of 4.1 m<sup>2</sup> was used solely to determine the surface loads for a direct comparison between lamellar and conventional clarification. The lamella pack had a projected surface area of 6.5 m<sup>2</sup>. Sludge was not wasted from the clarifier until the end of the stormwater event. The clarifier was drained and cleaned when time permitted between successive events with the sludge and wastewater discharged to a sanitary sewer.

The process equipment and refrigerated auto-samplers were started automatically when stormwater flow in the sewer exceeded a pre-selected threshold. Stormwater level and clarifier flow data were logged at a two minute frequency using a dedicated computer. The process controller was a SCADAPack™ unit from Control Microsystems Inc. A custom ladder logic process control program received input from

a user interface terminal screen and controlled the pilot scale apparatus. The user interface for entering experimental variables was prepared with Lookout™ software and resided on the data logging computer. The process controller provided stormwater event notification to the operator with a telephone auto-dialer.

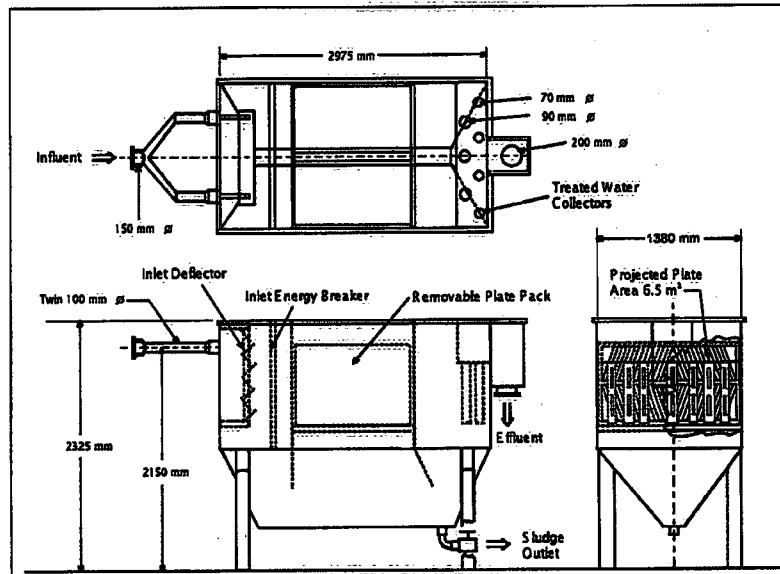


Figure 1: Commercial Clarifier supplied by John Meunier Inc. (after modification)

A 14-m highway trailer and the clarifier were located outdoors in a fenced enclosure. The highway trailer contained the process controller, data storage computer, effluent samplers, liquid polymeric flocculant storage tank, polymer metering pump and a control air compressor. A 37 mm ID pipeline from a nearby water hydrant, fitted with a backflow preventer valve, provided potable water for rinsing the clarifier and for diluting a commercial concentrated liquid polymer flocculant. In-line static mixers were used for blending the tap water and concentrated liquid polymer and also for mixing the diluted flocculant solution and stormwater prior to clarification. The diluted polymer flocculant solution was prepared on-line and directly injected to the clarifier inlet as required without maturation. The clarifier hydraulic residence time at a surface load of 15 m/h was less than 6 minutes.

Stormwater inflow to the clarifier was measured by a magnetic flowmeter and controlled by a full bore diaphragm valve. For the polymer pump flow control, a set-point control strategy and a calibrated line equation were used to provide a polymer pump control signal proportional to the clarifier inlet flow. The volume of polymer consumed during each event was measured in a calibrated tank to confirm that the design polymer flocculant dosage was achieved.

Discrete samples of the influent and effluent were usually collected with American Sigma Inc. auto samplers at a 10-minute frequency during the first hour of an event, and subsequently every 20 minutes during the rest of the event.



#### 4. RESULTS AND DISCUSSION

Study findings are presented first for stormwater characterization, followed by clarification results and discussion.

##### 4.1 Stormwater Characterization

All events were characterized with respect to runoff quantity. The seasonal mean event duration was 2.64 h, average stormwater flow 0.71 m<sup>3</sup>/s, mean peak stormwater flow 1.67 m<sup>3</sup>/s, mean event volume 8,500 m<sup>3</sup>, and the mean temperature of stormwater was 15.1 °C. The total field season volume of stormwater from the drainage area served by the storm sewer studied was 548,000 m<sup>3</sup>.

Over the 2001 season, 51 of 64 events were characterized for stormwater quality at this site. Table 1 contains a summary of all stormwater quality data for 51 events and constituent concentrations above the corresponding analytical method detection limits.

Table 1: Overall Stormwater Characterization (7 April to 13 December 2001)

	US NURP Median site	Toronto Stormwater					
		Mean	Std. Deviation	Minimum	Maximum	n	MDL
pH	---	7.32	0.26	6.41	8.11	453	0.045
TSS (mg/L)	100	183	225	5	2,510	567	5
TSS Volatility	---	26%	10%	0%	100%	520	
c.BOD <sub>5</sub> (mg/L)	9	15	16	1.5	222	457	1
COD (mg/L)	75	133	138	24	2,010	409	6
TP (mg/L)	0.33	0.54	0.52	0.18	5.61	322	0.18
NH <sub>3</sub> -N (mg/L)	---	0.40	0.28	0.03	1.68	450	0.029
TKN (mg/L)	2.92	2.47	2.61	0.21	27	442	0.13
Cd (µg/L)	---	9.0	10.7	2.99	54.7	50	2.93
Cr (µg/L)	---	24.1	40.7	5.9	718	340	5.96
Cu (µg/L)	34	60	191	6.52	3,940	440	6.52
Mn (µg/L)	---	315	475	19.4	7,590	451	1.19
Pb (µg/L)	144	86	570	7.1	10,400	335	7.1
Zn (µg/L)	160	293	1,020	7.4	21,300	451	2.52

MDL – Method detection limit: --- not reported by NURP

n – Indicates the number of samples quantified above the MDL

Total metal analyses were conducted on stormwater and process effluents

The mean constituent concentrations observed were generally 1.6 times greater than those reported in the US NURP program (US EPA, 1983) for the median urban site shown in column 2, of Table 1, but less than those reported for the 90<sup>th</sup> percentile site. Thus, for most constituents the stormwater at this site was significantly more polluted than that of the NURP median site. Note that the NURP Pb concentration reflects the situation prior to phasing lead out of gasoline.

#### 4.2 Clarification Results

In total, 51 lamellar and conventional clarification tests were completed. Polymeric flocculant dosages ranged from 0 to 4 mg/L in 47 tests conducted at a total vessel surface load of 15 m/h.

The dosage of 4 mg/L was found the most effective for removal of total suspended solids and other pollutants, followed by 2 mg/L, and unaided clarification. The corresponding average TSS removals for lamellar clarification were 84, 61, and 26%, respectively, as shown in Table 2. TSS removals for individual events were relatively consistent with the coefficient of variation of 1.07; for the polymer dosage of 4 mg/L, the removals ranged from 75 to 95%. It was further noted that these removals did not depend on the event mean concentration (EMC) of TSS. Average removals of other constituents were lower, e.g., 25% for c.BOD<sub>5</sub>, 48% for COD, and 48-60% for the metals studied. Removals of c.BOD<sub>5</sub> and COD were weakly correlated with TSS concentrations; the higher TSS EMCs produced higher removals of both c.BOD<sub>5</sub> and COD.

Table 2: Lamellar Clarification Constituent Removal Efficiencies for Event Mean Concentrations

Design Polymer Dosage (mg/L)	Constituent Removal Efficiencies (%)										
	TSS	c.BOD <sub>5</sub>	COD	TP	NH <sub>3</sub> -N	TKN	Cr	Cu	Mn	Pb	Zn
0 (6 tests)	26	8	16	31	5	26	15	15	27	31	16
2 (7 tests)	61	27	37	69	7	30	25	29	51	35	47
4 (16 tests)	84	25	48	58	4	37	54	54	65	46	60

In conventional clarification tests, the flocculant dosage of 4 mg/L again produced the highest removal of TSS 52%, as presented in Table 3, but such a removal was not significantly different from that the 47% removal obtained with the 2 mg/L dosage, which was coincident with lower stormwater TSS concentrations.

Table 3: Conventional Clarification Constituent Removal Efficiencies for Event Mean Concentrations

Design Polymer Dosage (mg/L)	Constituent Removal efficiencies (%)										
	TSS	c.BOD <sub>5</sub>	COD	TP	NH <sub>3</sub> -N	TKN	Cr	Cu	Mn	Pb	Zn
0 (5 tests)	5	8	5	8	11	8	4	6	6	13	7
2 (6 tests)	47	12	17	37	2	20	18	27	35	0	26
4 (7 tests)	52	15	36	36	3	21	45	35	43	27	34

The stormwater TSS concentrations depicted as influents for the lamellar and conventional clarifiers are compared in Fig. 2 with the corresponding clarifier effluents at a constant surface load of 15 m/h and a polymer flocculant dosage of 4 mg/L. For

each curve in Fig. 2 the legend value of  $n$  represents the number of TSS samples analyzed. The stormwater influent TSS mean of 189 mg/L for lamellar clarification was higher than the corresponding influent TSS mean of 124 mg/L for conventional clarification. The lamellar clarification data presented in Fig. 2 represented a total of 42.7 h of operation during 16 stormwater events. Similarly the conventional clarification data represented a total of 24 h of operation during 7 stormwater events.

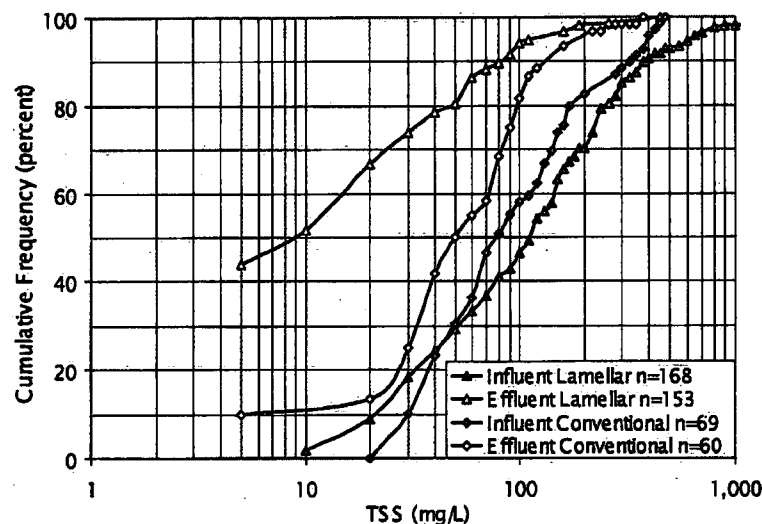


Figure 2: Comparison of lamellar and conventional clarification results for polymer flocculant addition of 4 mg/L and a total vessel surface load of 15 m/h

#### 4.3. Discussion

Typically the highest stormwater pollutant concentrations corresponded with the highest flows in the storm sewer, however, often during extended rainfall events the TSS pollutant concentrations decreased with event duration. Therefore significant savings in polymer flocculant may be realized if on-line turbidity instrumentation were included and a solids-mass-flux proportional flocculant dosage implemented.

At a surface load of 15 m/h and an economical polymer flocculant dosage of 4 mg/L, the lamellar clarifier slightly exceeded the 80% TSS removal required for enhanced protection of sensitive aquatic habitat (MOE, 2003). Thus, further testing with increased surface loads and if necessary higher polymer dosages would be warranted. The flocculant aided lamellar clarification results with stormwater from this study agreed well with the performance data for similar processes used to treat CSOs in Toronto (WTI, 1999) and Stuttgart-Buesnau (Vetter et al., 2001).

To address concerns about possible toxicity of polymer treated stormwater (Marsalek et al., 1999), both the influent and treated effluent were tested with two toxicity tests, Microtox™ and the 96-h acute toxicity rainbow trout bioassay. In 20 stormwater event tests of fish toxicity, only one event with acutely toxic influent and effluent was observed for a lamellar clarification test without polymer addition. During three other

events with the polymeric flocculant, some influent stormwater fish toxicity was noted in warm weather and for elevated concentrations of TSS, COD, Cu, Mn and Zn. Two of the tests with polymer flocculant addition reduced the level of fish toxicity in the process effluent as compared to the stormwater influent.

One of the stormwater treatment considerations was the recovery of residual sludge and its quality. The separated stormwater sludge may be recovered more economically from the clarifier than from stormwater settling ponds. On a seasonal basis less than 5% of the separated solids were observed to float in the clarifier during operation. Floating sludge formed primarily during the vessel filling when the elevated clarifier inlet caused a brief waterfall effect and some foaming was noted. Clarifier bottom sludge was sampled and its quality was determined for 14 constituents and assessed against the Canadian freshwater aquatic sediment quality guidelines listed in Table 4. The Canadian Sediment Quality Guidelines, which are shown in Table 4 for selected metals, were recommended by the Canadian Council of Ministers of the Environment (CCME, 2002). The Ontario Guidelines for aquatic sediment quality (MOE, 1992) were selected for Table 4 instead of guidelines for municipal sewage sludge, because in urban drainage, stormwater with sediment is typically discharged untreated into receiving waters.

Table 4: Comparison of Metal Concentrations in Sediments and Clarifier Sludge

Metal ( $\mu\text{g/g}$ )	(CCME, 2002)		(MOE, 1992)	Stormwater	Mean Stormwater Clarifier Sludge <sup>1</sup>
	Interim Sediment Quality Guideline	Sediment Probable Effect Level	Aquatic Sediment Severe Effect Level	Pond Sediment (Mayer et al., 1996)	
Cadmium	0.6	3.5	10	4.16	1.7
Chromium	37.3	90	110	45.3	61
Copper	35.7	197	110	151	196
Lead	35	91.3	250	202	200
Manganese			1,100	693	1,259
Zinc	123	315	820	610	1,116

<sup>1</sup> Mean of all clarifier sludge characterization analyses from this study (n = 36)

Clarifier sludge concentrations of Cu, Mn and Zn exceeded the severe effect levels in the MOE guidelines (MOE, 1992) and would necessitate special disposal considerations.

The total phosphorus content in lamellar clarification sludge was on average 150  $\mu\text{g/g}$  and all samples were well below the lowest effect level of 600  $\mu\text{g/g}$  in MOE guidelines (MOE, 1992). The TKN content in the lamellar clarification sludge was on average 851  $\mu\text{g/g}$  and eight event sludge samples were below the lowest effect level of 550  $\mu\text{g/g}$  in the MOE guidelines (MOE, 1992).

Near the Toronto study site, the studied storm sewer discharges to the Colonel Samuel Smith stormwater pond with approximate surface dimensions of 38 x 75 m (width x length). The mean observed metal concentrations in pond sediment were reported by Mayer et al. (1996) and are shown in column 5 of Table 4.

## 5. CONCLUSIONS

Lamellar clarification with polymeric flocculant addition was found effective in TSS removal from stormwater, at a polymer dosage of 4 mg/L and total vessel surface overflow rates up to 15 m/h (TSS removal 84%). Significantly lower contaminant removals were obtained for other constituents (c.BOD<sub>5</sub>, COD, nutrients and metals).

The use of a high molecular weight polymeric flocculant did not increase the stormwater toxicity, as determined in this study by tests on the stormwater and process effluents, using both the Microtox<sup>TM</sup> test and rainbow trout fish bioassays.

The combination of lamellar clarification and polymeric flocculant addition improved the treatment efficiency and could be well applied in other stormwater management projects requiring intensive stormwater treatment in a compact area. Future work will examine treatment efficiency with higher surface overflow rates and the use of flocculant dosing proportional to the suspended solids flux.

## 6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial sponsorship of this study by the Government of Canada's Great Lakes Sustainability Fund.

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