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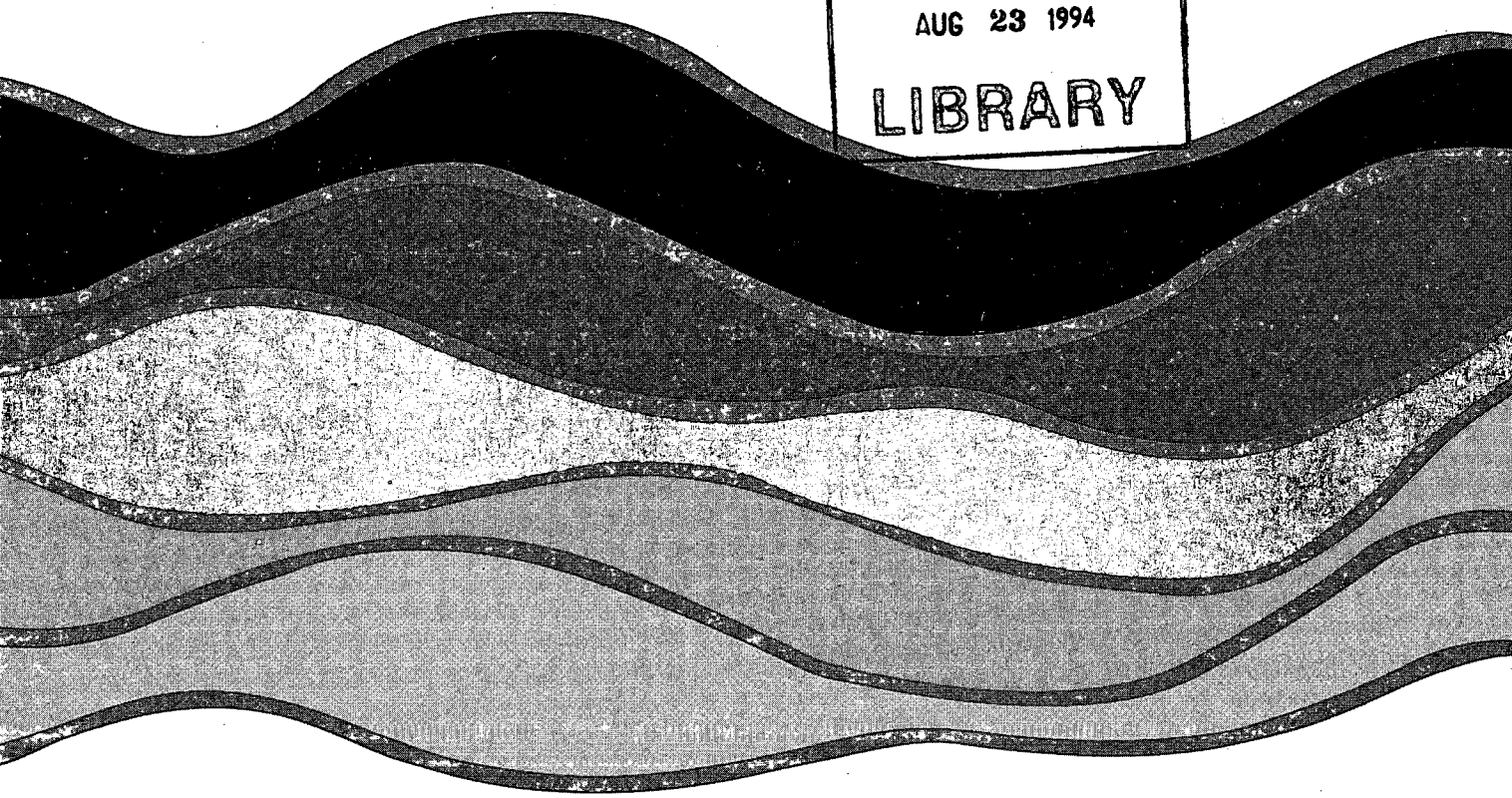

CURRENT TRENDS IN STORMWATER MANAGEMENT

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MANAGEMENT PERSPECTIVE

Uncontrolled stormwater discharges are major contributors to the impairment of local water uses in the Great Lakes' Areas of Concern. Consequently, the Remedial Action Plans for the areas with significant urban populations require the implementation of stormwater management and control measures. Recent advances in this field are reviewed in this paper using two sources of information - the international experience presented at the 6th International Conference on Urban Storm Drainage (Niagara Falls, Canada, 1993), and the current Canadian research in this field.

The information presented on performance of stormwater exfiltration, water quality inlets, stormwater ponds, biofiltration and wetlands in mitigating stormwater impacts on the receiving waters should be of interest to water managers, urban planners, and researchers dealing with urban nonpoint source pollution.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Les déversements non contrôlés d'eau pluviale contribuent de façon importante à la dégradation des utilisations locales de l'eau dans les secteurs de préoccupation des Grands Lacs. Par conséquent, les plans d'assainissement pour les secteurs où la population urbaine est importante doivent passer par la mise en application de mesures de contrôle et de gestion des eaux pluviales. Le présent article fait état des progrès récents dans ce domaine en fonction de deux sources d'information : l'expérience internationale présentée lors de la sixième Conférence internationale sur la collecte des eaux pluviales urbaines qui s'est tenue à Niagara Falls, Canada en 1993 et les études réalisées à l'heure actuelle au Canada dans ce domaine.

L'information présentée sur la performance de l'exfiltration des eaux pluviales, la qualité des prises d'eau, les bassins de retenue des eaux pluviales, la biofiltration et les milieux humides pour l'atténuation des incidences des eaux pluviales sur les eaux réceptrices devrait intéresser les gestionnaires des eaux, les urbanistes et les chercheurs qui étudient la pollution urbaine non ponctuelle.

ABSTRACT

Review of recent developments in urban stormwater management, presented at the 6th International Conference on Urban Storm Drainage, identified the following promising trends: improvements in spatial and temporary definitions of rainfall data, runoff modelling with a limited number of model parameters and recognition of uncertainties, analytical statistical modelling of runoff quality, advances in the modelling of sewer sediment transport, the use of biomonitoring in assessing drainage impacts on receiving waters, refinement of best management practices (BMPs) for stormwater management, development of new processes for treatment of stormwater, advances in hydroinformatics leading to improvements in the integrated management and modelling of drainage systems, interfacing of drainage models with geographic information systems, and new regulatory programs for drainage effluents. The current Canadian research on BMPs deals with stormwater exfiltration, water quality inlets, stormwater ponds, biofiltration and wetlands. Stormwater exfiltration was found to be economically feasible in a sewer rehabilitation program. Stormwater pond sediments were found marginally-to-significantly polluted, using both chemical testing and ecotoxicological assessments. On-line pond removals ranged from negative removals (various forms of nitrogen) to the high removals of about 40% of solids and associated constituents. Detailed simulation of velocity field in this pond revealed the presence of recirculation zones, which could be eliminated and the settling in the pond improved by retrofitting an inlet skimmer and three pond baffles. Biofilters were found effective in removing 92% of suspended solids, 40% of metals, 25% of PO_4-P and 55% of NH_4-N, with retention times of about 1 hour. Removals of suspended solids, PO_4-P and Cu, in the range of 40-50%, can be attained in wetlands, with a detention time about 24 hours and a low hydraulic loading (0.2 $m^3/m^2/day$).

RÉSUMÉ

L'étude des récents développements dans le domaine de la gestion des eaux pluviales urbaines, présentés lors de la sixième Conférence internationale sur la collecte des eaux pluviales urbaines, a identifié les tendances prometteuses suivantes : les améliorations au niveau des définitions spatiales et temporelles des données sur les pluies, la modélisation du ruissellement avec un nombre limité de paramètres et la reconnaissance des incertitudes, la modélisation statistique et analytique de la qualité du ruissellement, les progrès en modélisation du transport des sédiments dans les égouts, l'utilisation de la surveillance biologique dans l'évaluation des impacts du drainage sur les eaux réceptrices, le raffinement des meilleures pratiques de gestion (MPG) des eaux pluviales, la mise au point de nouveaux procédés pour le traitement des eaux pluviales, les progrès en hydro-informatique qui ont donné lieu à des améliorations de la gestion intégrée et la modélisation des réseaux de drainage, l'interfaçage des modèles de drainage avec les systèmes d'information géographique et les nouveaux programmes de réglementation des effluents des réseaux de drainage. La recherche canadienne actuelle sur les MPG porte sur l'exfiltration des eaux pluviales, la qualité des prises d'eau, les bassins de retenue des eaux pluviales, la biofiltration et les milieux humides. On a trouvé que l'exfiltration des eaux pluviales était économiquement possible dans un programme d'assainissement des égouts. À l'aide de tests chimiques et d'évaluations écotoxicologiques, on a trouvé les sédiments du bassin de retenue des eaux pluviales peu à très pollués. L'élimination en ligne dans les bassins allait d'une élimination négative (diverses formes d'azote) à une élimination élevée d'environ 40 % des solides et de leurs constituants. Une simulation détaillée du champ de vitesse dans ce bassin a révélé la présence de zones de remise en circulation qui pourraient être éliminées et la décantation dans le bassin qui pourrait être améliorée en ajoutant un écrémeur d'entrée et trois chicanes. Les biofiltres se sont avérés efficaces en éliminant 92 % des solides en suspension, 40 % des métaux, 25 % du PO_4-P et 55 % du NH_4-N, avec des temps de séjour d'environ une heure. On peut atteindre une élimination de 40 à 50 % des solides en suspension, du PO_4-P et du Cu dans les milieux humides, avec un temps de séjour d'environ 24 heures et une faible charge hydraulique (0,2 m^3/m^2/jour).

INTRODUCTION

Advances in the understanding of urban runoff processes indicate that the cumulative impacts of increased flows, erosion, and discharges of pollutants (solids, nutrients, heavy metals, hydrocarbons, bacteria and toxicants) result in degradation of urban receiving waters (1). Consequently, the need for stormwater control and management is now recognized and promulgated in government policies (2). For implementation of such policies, stormwater Best Management Practices (BMPs) have been proposed and the performance of selected BMPs has been reported (3,4). The purpose of this paper is to provide an overview of stormwater management based on the proceedings of the 6th International Conference on Urban Storm Drainage (6th ICUSD), held in Niagara Falls, Canada, in 1993, and to supplement this overview by more detailed information on the current Canadian research on BMPs.

TRENDS IN STORMWATER MANAGEMENT REPORTED AT THE 6th ICUSD(4)

Rainfall/runoff processes and modelling - referring to rainfall data, the needs of adequate characterization of rainfall spatial and temporal variabilities in measurements and definitions of rainfall data continue to be a challenge. An increasing density of rain gauges does not guarantee accurate data and further development of radar rainfall measurements is needed. In runoff modelling, two trends are apparent - the need to compromise between the requirements on model input data and lack of such data, and the recognition of modelling uncertainties. To bridge the gap between the demands of complex models on input data and the data available to practising engineers, the number of model parameters should be reduced to a few important ones and some measure of uncertainty with respect to rain events and catchment characteristics. New results were presented on unsteady flow routing through sewer manholes and junctions. Some existing

flow routing models have been enhanced by a graphical decision support, or modifications for applications in real-time control.

Runoff quality characterization continues at widely varying scales - ranging from chemodynamics of micropollutants running off roads and roofs to the assessment of loads of micropollutants in runoff by sewer outfall monitoring. In quality modelling, refinements of physically-based approaches focused on improved sediment transport modelling. Among statistical models, analytical probabilistic models, suitable for prediction of long-term pollution control, offer a good alternative to planning simulation models.

Impacts on receiving waters - impacts of drainage effluents on receiving waters, demonstrated by the impairment of water uses and ecosystem health, are determined from field measurements and modelling. The constituents causing most concerns include indicator bacteria, low dissolved oxygen and toxic metals. Biomonitoring indicates bioaccumulation of toxicants in indicator organisms and thereby provides a time-integrated measure of contaminant bioavailability rather than its abundance. Ecological evaluation of stormwater should be based on multifactorial matrices considering a number of parameters (varying in time and space) reflecting basic ecological principals of aquatic community structures. It should be recognized that urban drainage also contributes to groundwater pollution by leaching of in-situ pollutants, exfiltration from leaky sewers, and uncontrolled infiltration of polluted runoff.

Impact mitigation: stormwater control and management - among the BMPs, stormwater infiltration/percolation and on-site detention/retention are generally preferred in the European practice, while stormwater ponds seem more common in Australia and North America.

Common infiltration structures include porous pavements and infiltration trenches.

Porous pavements control runoff peaks and reduce pollutant concentrations in percolating water. To prevent clogging, these pavements have to be regularly cleaned by high pressure water jet and/or vacuum sweeping. The widespread use of infiltration pits and trenches follows from their ease of construction, low maintenance, efficiency in reducing the inflow to sewers, and applicability in areas with no other means of drainage. The main disadvantage is their dependence on soil conditions. The design of infiltration structures still has some weak points - uncertainties in the determination of design infiltration parameters and in determination of the operational lifetime of infiltration structures.

Wet stormwater ponds, particularly with extended detention periods, are recognized among the most effective BMPs. These ponds, which can be readily applied in new developments with available land, are effective in removal of particulate pollutants, but less effective in removal of dissolved materials through biological action during extended detention. Wetlands are used either as "stand alone" facilities or in combination with other BMPs. The most widely used are reed bed wetlands which under favourable conditions trap sediment, nutrients, bacteria and toxins, and also promote oxygen recovery. Maintenance requirements, including regular plant harvesting, and seasonal variations in removals are the most obvious disadvantages.

Promising processes for stormwater treatment include solid-liquid separation by settling with inclined plates, degritting and a flotation reactor, and UV disinfection of stormwater pond effluents discharged upstream from recreational waters. The treatment train applied in stormwater management extends into the receiving waters and takes advantage of their self-purification capacity which may have to be renewed by renaturalization of such waters.

Implementation of stormwater management - at the technical level, implementation is greatly aided by computer modelling, which tends to be dominated by a limited number

of well-supported and continuously updated modelling packages incorporating some aspects of hydroinformatics and merging environmental modelling with information technology. At the political level, successful implementation of stormwater management is enhanced by supporting environmental regulatory programs. Recently introduced regulations include a Swiss law requiring infiltration of unpolluted stormwater; the Interim Stormwater Quality Control Guidelines For New Development in Ontario (adopting the concept that "stormwater is a resource to be managed in support of societal benefits"); and the US EPA's National Pollutant Discharge Elimination System (NPDES) for the regulation of municipal and industrial stormwater discharges.

CANADIAN RESEARCH ON STORMWATER MANAGEMENT

Much of the current Canadian research on stormwater management is sponsored under the Great Lakes Water Quality Agreement and the associated Cleanup Fund Program, which strives to develop remedial measures in support of this agreement (5). The discussion that follows focuses on field research on stormwater management in the areas with separate sewer systems. The specific measures addressed include exfiltration of stormwater from sewers, water quality inlets, stormwater ponds, filters, and miniwetlands.

Stormwater Exfiltration - a stormwater exfiltration systems was used in rehabilitation of aging storm sewers. This system is only 10 to 20% more costly than conventional sewer replacement, and is less costly than alternate storage or treatment schemes. It appears to be an attractive measure for controlling existing problems in built-up urban areas. The system performance will be evaluated over several years, including pollutant removal, groundwater impacts, and maintenance requirements (5).

Water Quality Inlets - water quality inlets are multi-cell chambers with sedimentation compartments retaining sediment and skimmers retaining oil. In European practice, these

inlets, with a sediment storage capacity of 1.5 m^3 per impervious hectare, were recommended for risk areas on heavily travelled highways as well as for commercial vehicle and large car parks (6). Preliminary results from the U.K. and France indicate removals of 15-25% of sediment, 10% of metals and nutrients, and 30 - 40% of oil (6). This lower-than-expected performance can be explained by limited wet storage, 7 - 8 mm of runoff per impervious hectare (70 - 80 m^3/impervious ha), which allows for relatively short settling times measured in minutes. Furthermore, sediment and pollutants deposited during small storms may be resuspended and washed out during large storms. To maintain satisfactory performance of these inlets and prevent odours, they should be cleaned out at least twice a year.

A new water quality inlet design, Stormceptor™, has been tested in the laboratory (7). This inlet resembles a cylindrical manhole, divided by a horizontal plane into two chambers - the lower separation chamber (with a volume of about 3 m^3) and the upper bypass chamber. Flow enters the lower chamber through a drop pipe in the dividing wall and exits through a riser pipe at the opposite end. The main advantage of this design should be improved protection of the separation chamber against washout. Tests in a scale model indicate that in wet weather, the detention time in the separation chamber is so short that only larger particles could be removed (say $D > 0.2$ mm). However, during dry weather, extended settling of stormwater left in the separator takes place and even fine particles, silt and clay, settle. For the design tested, about 10% of the annual runoff would be subject to settling over extended time periods, but this proportion could be increased by increasing the device storage volume. Field testing at a highway truck station will start later in 1994.

Stormwater ponds - studies of stormwater ponds focused on characteristics of sediment deposited in ponds, with reference to maintenance and sediment disposal, and on pollutant removal processes.

Characteristics of pond sediments were studied at four stormwater ponds in the Toronto area. Two approaches were taken to assess sediment contamination - a chemically based approach using sediment quality guidelines (8) and an ecotoxicological approach. The chemical testing used 35 constituents from four categories - metals, nutrients, organic compounds (pesticides plus PAHs), and additional parameters (oil and grease, cyanide, ammonia, cobalt and silver). Pond sediments were sampled four times a year, collecting surficial bottom samples, core samples and suspended solids samples by centrifugation.

The preliminary results indicate widely varying contamination - ranging from relatively clean materials (i.e. no effect level), to severe effect levels (grossly polluted) reported in a limited number of cases for five metals - Cu, Pb, Mn, Ni and Zn. A vast majority of data falls into the lowest effect level - recognized as "marginally-to-significantly polluted" sediments. The highest concentrations were found in a pond serving an older industrial area and could be caused by illicit discharges, or in situ pollutants. The results indicate that resuspension and washout of grossly polluted sediment should be avoided and, according to the sediment quality guidelines, special methods of sediment disposal may be required in areas with industrial pollution.

In ecotoxicological studies, suspended particulate and benthic pond sediments and their extracts were subjected to a battery of bioassay tests for toxicant/genotoxicant presence (9). Promutagens were found in both pore water and solvent extracts from a large number of samples from all the ponds studied and suspended particulate showed greater concentrations of toxicants than the benthic sediment (9). Lack of bioassay response to metals and the presence of herbicides (Triazine and Metolachlor) suggest that the toxicity of pond sediment was caused by trace organics rather than metals.

Pond Processes - to improve the understanding of stormwater ponds, a comprehensive study of an on-line pond near Kingston, Ontario has been conducted, focusing on water,

sediment and chemical mass balances, and identification of chemical sources, sinks, and transport and transformation processes (10). This pond was constructed in 1982 to reduce stormwater peak flows from a 12.6 ha parking lot of a shopping mall. The two-cell pond consists of a permanent wet cell and a dry cell, which floods when the water level in the wet pond exceeds the normal water level by 0.2 m.

Pond instrumentation was designed to continuously measure rainfall, inflow, outflow and pond water level; with water quality sampled on an event basis. Continuous monitoring has been supplemented by bottom sediment surveys, velocity measurements and dye tracing to verify simulated flow patterns, the sampling of suspended particulate manually and by centrifuging (particles ranging from 0.24 to 62.5 μm), and the sampling of submergent plants. A summary of interim results follows.

Pond hydrology - pond inflow is largely generated by the creek flowing through, rather than by the shopping plaza. Even with calibrated weirs at all inflows, uncertainties in measured flows are the main sources of uncertainties in calculations of mass loadings to the pond. Flow patterns in the pond were simulated by a commercial software package which provides a solution of flow equations in three dimensions (11). The modelling results, partly verified by dye tracing and current meter measurements, indicate that a large recirculation zone forms in the pond and reduces its effectiveness in sediment removal.

Effective sedimentation can be achieved by inducing good mixing of the influent at the pond inlet, a uniform flow velocity distribution in the pond (which favours quiescent settling), and prevention of short-circuiting and sediment resuspension by high flow velocities or secondary currents (12,13). Following these recommendations, improvements of flow patterns in this pond will be achieved (summer 1994) by installing an inlet skimmer and flow baffles.

Sediment surveys focused on two types of sediments - the sediments deposited on the bottom and suspended particulate. Core samples indicated that the thickness of bottom sediment varied from 0.15 to 0.2 m. This layer of sediment was accumulated over a 10-year period, with an average rate of accretion of about 0.02 m/year. The bottom sediments were composed mostly of silt (35%) and clay (61%). Metals found in this sediment generally exceeded the provincial sediment quality guideline (8), at the lowest effect level, defined as 16, 31 and 120 μg/g for Cu, Pb and Zn, respectively. Thus, this sediment would be classified as "marginally-significantly" polluted and its disposal, according to the guidelines, would require certain precautions.

Manually collected samples of suspended particulate were obtained by dipping a short (50 mm) cylinder in the pond water. After slow decantation, geometrical characteristics of particulates in such samples were examined. It was observed that the suspended particulate represented flocculated aggregates combining primary particles. The sizes of such flocs can be appreciable - with an equivalent diameter of about 0.25 mm (10). The use of fractal analysis to establish physical and chemical properties of floc particles is planned.

Chemical fluxes are monitored at two inflow points and the outflow points. Water quality is determined by analysis of water samples and additional data are obtained from two HYDROLAB SURVEYOR 3 water quality probes, installed close to the inlet and outlet, respectively. These probes measure continuously temperature, specific conductance, dissolved oxygen, pH and redox. High costs of sample analyses restrict the number of samples to be analyzed. Consequently, pollutant fluxes in unmonitored events are approximated by computer simulations using regression approximations for various constituents.

Pollutant removals - Mass balances were used to establish pollutant removals for various constituents. Two removal regimes were noted - during baseflow and event flows. The

highest removals were found for suspended solids, total phosphorus, nitrate, oil and grease, phenol and zinc - about 40%. Removals were insignificant for total dissolved solids, chloride, copper and lead. For sulphate, nitrite, ammonia and TKN, there were negative removals - these constituents were produced by transformations (14). Removals of chemicals by biota in the studied pond were insignificant.

Stormwater biofiltration - treatment of stormwater by submerged aerated biological filtration was studied, at a laboratory scale, focusing on removal of selected constituents (organic carbon, suspended solids, phosphorus, ammonia and Cu, Pb and Zn) under various hydraulic retention times, aeration and media depths (15). Results indicate that a metabolising biofilm could be established on a granular medium fed from the stormwater pond. For hydraulic retention time of 60 minutes, 92% of suspended solids, 40% of metals, 24% of PO_4-P, and 55% of NH_4-N were removed. The supplemental air supply did not significantly improve filter performance and most removal occurred in the upper 0.45 m of 1.1 m column. Laboratory results were used in design of a field facility (filter volume = 1 m^3) which will be tested in the summer of 1994.

Miniwetlands - while the benefits of use of constructed wetlands in stormwater treatment have been documented, more information is needed on removals as a function of hydraulic and pollutant loadings, seasonal variations in removals, and the performance in Canadian climate. Consequently, two miniwetlands were established in metal tanks installed in the field. Each of the two tanks is 5 m long, 1 m wide and the depth is 0.55 m. The tanks were made of galvanized sheet metal and lined with a polyethylene sheeting. Stormwater from the pond is pumped into these installations at a loading rate of about 0.2 $m^3/m^2/day$. The planted species include Broad and narrow-leafed cattail, Arrowhead, Common reed and Spike rush. Detention times in miniwetlands are closely controlled and the plant growth monitored. Detention of at least one day is needed to remove 40% of total suspended solids and PO_4-P, and about 50% of Cu (16). Pulse loading investigations are planned for the forthcoming field season.

CONCLUSIONS

Developments in the field of urban drainage continue at a rapid pace, with emphasis on integrated considerations of all drainage components and implementation of stormwater management employing the best management practices (BMPs). New improvements in BMPs have been facilitated by analysis of experience from the earlier installations. Among the various practices, most attention currently focuses on stormwater infiltration, stormwater ponds and wetlands. These priorities are also reflected by the current Canadian research on BMPs.

REFERENCES

1. U.S.Environmental Protection Agency: Results of the Nationwide Urban Runoff Program, Volume I - Final Report, U.S. EPA, Washington, DC., 1983.

2. G. Bowen, D. Henry and Z. Novak: Interim stormwater quality control guidelines for new development - results to date, Proc. 6th ICUSD, pp. 1689-1694, 1993.

3. T.R. Schueler: Controlling urban runoff: a practical manual for planning and designing urban BMPs, Washington Metropolitan Water Resources Planning Board, 1987.

4. J. Marsalek and D. Sztruhar: Urban drainage: review of contemporary approaches, Water Science and Technology, 28(1-2), pp.1-10, 1994.

5. D.G. Weatherbe and I.G. Sherbin: Combined sewer overflow control and stormwater management in Canada's Great Lakes Cleanup Fund, Water Science and Technology, Vol.28 (in press), 1994.

6. J.B. Ellis: Drainage from roads: control and treatment of highway runoff, Middlesex University report No. NRA 43804/MID.012, London, U.K., 1991.

7. J. Marsalek: Stormceptor: a new stormwater management tool for controlling sediment and oil in sewers, Proc. of the PCAO Conference, Toronto, 1993.

8. Environment Ontario: Guidelines for the protection and management of aquatic sediment quality in Ontario, Toronto, 1992.

9. B.J. Dutka, J. Marsalek, A. Jurkovic, K.K. Kwan and R. McInnis: Ecotoxicological study of stormwater ponds under winter conditions, Angew. Zoologie 1/94, 1994.

10. E.W. Watt and J. Marsalek: Comprehensive stormwater pond monitoring, Water Science and Technology, Vol.28(1-2), pp.337-346, 1994.

11. PHOENICS: PHOENICS course notes T/300, Concentration Heat and Momentum (CAM) Limited, London, UK, 1993.

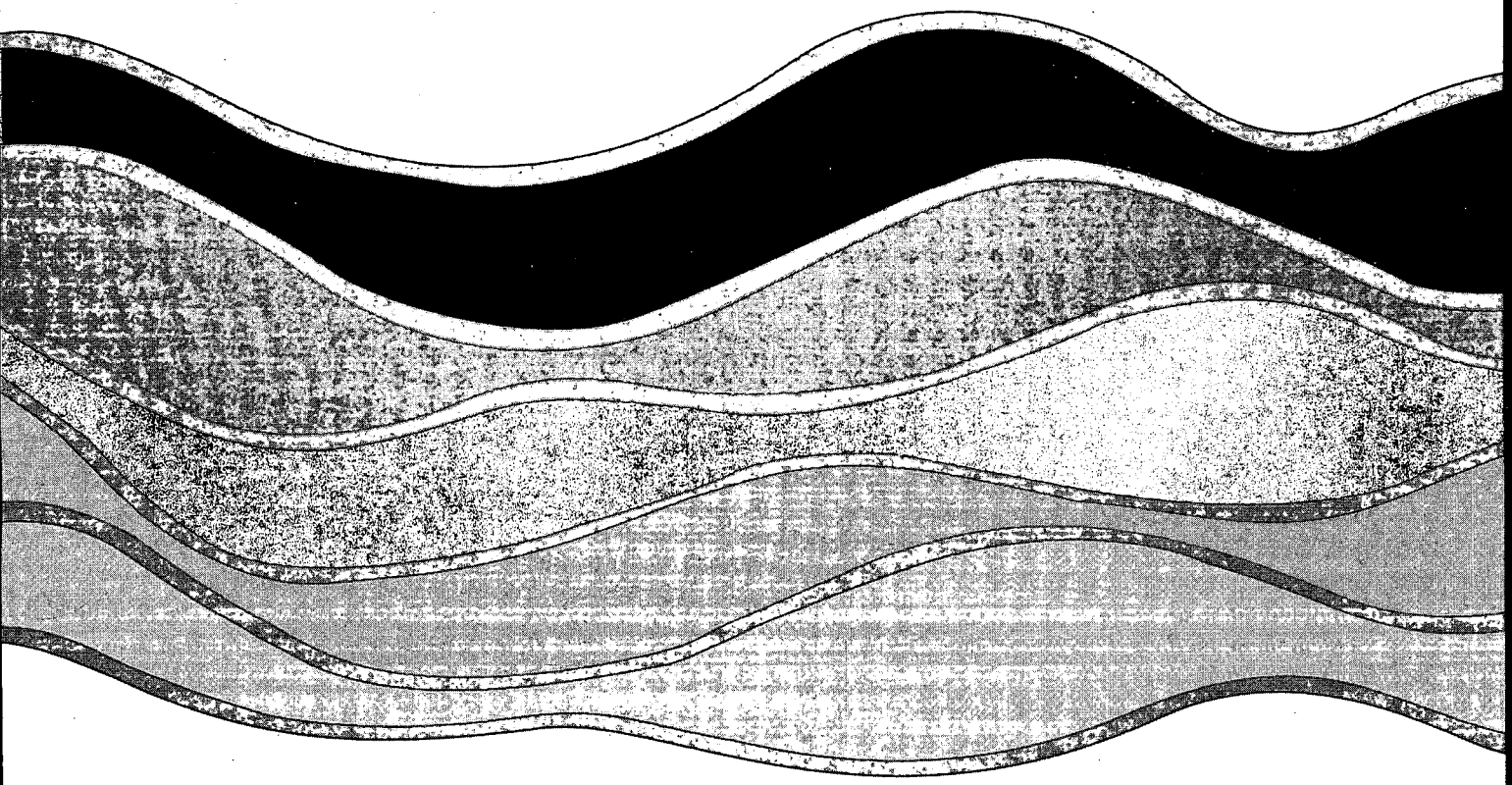
12. T. Hvitved-Jacobsen: Design criteria for detention pond quality, In: H.C. Torno (Ed.), Urban Stormwater Quality Enhancement - Source Control, Retrofitting and Combined Sewer Technology, Proc. Eng. Found. Conf., ASCE, New York, 1990, p.111-130.

13. J. Marsalek, W.E. Watt, D. Henry: Retrofitting stormwater ponds for water quality control, Water Poll. Re. J. Canada, Vol. 27(2), pp.403-422.

14. M. Van Buren: Constituent mass balance for an urban stormwater detention pond in Kingston Township, MSc Thesis, Queen's University , Kingston, Ontario, 1994.

15. M. Seaman: Remediation of urban runoff pollution by submerged aerated biological filtration: lab scale studies, MSc Thesis, Queen's University , Kingston, Ontario, 1994.

16. Q. J. Rochfort (Dept. of Civil Engineering, Queen's University, Kingston, Ontario): Personal communication, 1994.



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