

Wet-Weather Flow Management in the Great Lakes Areas of Concern

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Under the Government of Canada's Great Lakes Program, the Great Lakes Sustainability Fund and its predecessor programs (the Great Lakes Cleanup Fund and the Great Lakes 2000 Cleanup Fund) were established to implement cleanup actions and strategies that would contribute to the restoration of beneficial uses in environmentally degraded areas (known as Areas of Concern) in the Great Lakes basin. The Great Lakes Sustainability Fund is administered by Environment Canada on behalf of eight Government of Canada departments. Contributing to impaired beneficial uses are municipal wastewaters generated from the urban centres in the Great Lakes Areas of Concern. These municipal wastewaters include treated sewage and wet-weather discharges of combined sewer overflows and stormwater runoff. This paper provides an overview of the Municipal Wastewater Program of the federal government's Great Lakes Sustainability Fund and highlights the progress made to date under the program towards wet-weather flow management and the Program's role in developing and demonstrating sustainable approaches and technologies in the Great Lakes Areas of Concern.

Key words: wet-weather flow management, stormwater, combined sewer overflows, Great Lakes

Introduction

The Great Lakes – St. Lawrence River system is one of the world's largest freshwater ecosystems, comprising approximately 20% of the global freshwater supply. This ecosystem is the source of drinking water for approximately 9 million people in Canada. Together with the bordering United States, the Great Lakes – St. Lawrence basin is not only home to more than 46 million people but is also habitat for a wide diversity of plants and animals. By 2020, more than half of Canada's growth is forecasted for this Great Lakes – St. Lawrence ecosystem. This population growth is already evidenced in the Golden Horseshoe region, an area stretching from Port Hope in the east around Lake Ontario to Niagara, where more than 90% of Ontario's population growth between 1996 and 2001 occurred.

Past and present economic activities supported by the Great Lakes – St. Lawrence basin have presented and continue to present environmental challenges. Municipal wastewaters from the urban centres in the Great Lakes contribute to these environmental challenges and cause impairments to beneficial uses of the Great Lakes. These municipal wastewaters include treated sewage and wet-weather related discharges, primarily combined sewer overflows and stormwater runoff. This paper provides an overview of the Municipal Wastewater Program of the Government of Canada's Great Lakes Sustainability Fund and highlights the progress made to date under the program towards sustainable wet-weather flow management in the Great Lakes Areas of Concern.

Origins of the Great Lakes Program

The degraded environmental legacy from historical pollution is recognized in the Great Lakes Water Quality Agreement. This Agreement was first signed in 1972 and renewed in 1978 when the Governments of Canada and the United States committed to restore and maintain the chemical, physical and biological integrity of the Great Lakes basin ecosystem. In 1987, a Protocol was signed amending the 1978 Agreement to make a maximum effort to develop programs, practices and technology necessary for a better understanding of the Great Lakes basin ecosystem and to eliminate or reduce, to the maximum extent practicable, the discharge of pollutants into the Great Lakes system (International Joint Commission 1989).

The International Joint Commission identified and called for the restoration of 43 specific Areas of Concern (AOCs) around the Great Lakes, of which 12 were wholly in Canada. Five AOCs, being on connecting water bodies, were shared with the U.S. The Canada-Ontario Agreement, as amended in 1986, committed both governments to develop Remedial Action Plans (RAPs) for restoring water quality in the AOCs. Subsequent Canada-Ontario Agreements in 1994 and 2002 (Canada-Ontario 1994, 2002), established firm targets for meeting the environmental priorities for the Great Lakes. The federal Great Lakes program was first launched in 1989, and was renewed in 1994 and 2000 to restore environmental quality in the Great Lakes AOCs.

Of the original 17 Canadian AOCs, 14 remain listed as such. Two AOCs (Collingwood Harbour and Severn Sound) have been delisted. An AOC is delisted when ecosystem monitoring tracking the results of restoration

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actions indicates that the beneficial uses have been restored. Table 1 lists the 14 impairments to beneficial uses that were used to characterize an AOC. Spanish Harbour is designated as an Area in Recovery, meaning all recommended RAP cleanup actions have been completed. Ecosystem health of this AOC is being monitored before it can be delisted. Causes of these the impairments to beneficial uses include contaminated sediments, pollution from agricultural activities and municipal sources, and degraded fish and wildlife habitat (Environment Canada 2003).

It is interesting to note that while the issue of sustainability has never been more pressing than now, the communities that form the Remedial Action Plan teams in the Great Lakes Areas of Concern have always embraced the tenets of sustainability. Such a vision has always stemmed from a serious concern about the nature of the environmental legacy that will be left for future generations. Implementation actions, aided by ecological monitoring and assessment, to restore and protect these AOCs have been guided by this vision.

Great Lakes Sustainability Fund— Municipal Wastewater Program

Under the Government of Canada's Great Lakes Program, the Great Lakes Sustainability Fund and its predecessor programs (the Great Lakes Cleanup Fund and the Great Lakes 2000 Cleanup Fund) were established to implement cleanup actions and strategies that would contribute to the restoration of the impaired beneficial uses in the AOCs, and ultimately, result in the delisting of the AOC. The Great Lakes Sustainability Fund (GLSF) is administered by Environment Canada on behalf of eight Government of Canada departments.

Municipal wastewaters (sewage treatment plant effluents, combined sewer overflows (CSOs) and

stormwater runoff) contribute to the impairments to beneficial uses (IBUs). Relevant IBUs include beach closures, excessive nutrient levels that could lead to eutrophication and undesirable algae, degradation of benthos, degradation of phytoplankton and zooplankton populations, and the loss of fish and wildlife habitat. Projects supported under the GLSF address the development and implementation of sustainable approaches and technologies to control municipal wastewaters. GLSF projects also address the clean up of contaminated sediments, the reduction of pollution from agricultural activities and the rehabilitation of fish and wildlife habitat. Since 1990, the GLSF and its predecessor programs have provided \$87 million in funding and technical support to 700 projects. With support from partners, these projects value \$213 million.

At the start of the RAP program, it was recognized that the costs for addressing municipal wastewater would be substantial to meet RAP targets for water quality. The Municipal Wastewater Program of the GLSF therefore set one of its objectives to be the development of innovative, cost-effective sustainable approaches and technologies to reduce the cost of implementing the municipal wastewater-related recommendations of the RAPs. Working in partnership with the Province of Ontario (particularly the Ministry of the Environment), municipalities, conservation authorities, academia, other federal groups such as Environment Canada's National Water Research Institute, and non-government organizations, projects addressed the following aspects: (1) pollution prevention and control planning, (2) development and demonstration of sustainable cost-effective approaches and treatment technologies, and (3) technology transfer. Since 1990, the GLSF and its predecessor programs have provided \$10.3 million in funding and technical support to 129 projects related to wet-weather flow management in AOCs. Together with support from partners, these projects are valued at \$39.5 million.

The GLSF's Municipal Wastewater Program activities related to wet-weather flows have been highlighted previously (Kok et al. 1998, 2000). As shown in Table 2, work has continued on some of these projects and new projects have been initiated.

Pollution Prevention and Control Plans in AOCs

Kok et al. (1998) and Hill (2004) have provided a summary of Pollution Prevention and Control Plans (PPCPs) in the Great Lakes municipalities in the AOCs. Table 3 compiles the current status of key recommendations from PPCPs conducted in the AOCs. In some instances, the PPCPs reflect an integrated watershed management approach, addressing all sources of pollutant loadings (i.e., municipal and agricultural nonpoint sources), as applied in the Severn Sound and the Bay of Quinte. Inte-

TABLE 1. Impairments of beneficial uses in Great Lakes Areas of Concern

Impairment of beneficial use(s), as defined in the GLWQA, means a change in the chemical, physical or biological integrity of the Great Lakes system sufficient to cause

Restrictions on fish and wildlife consumption
Tainting of fish and wildlife flavour
Degradation of fish and wildlife populations
Fish tumours or other deformities
Bird or animal deformities or reproduction problems
Degradation of benthos
Restrictions on dredging activities
Eutrophication and undesirable algae
Restrictions on drinking water consumption, or taste and odour problems
Beach closings
Degradation of aesthetics
Added costs to agriculture or industry
Degradation of phytoplankton and zooplankton populations
Loss of fish and wildlife habitat

TABLE 2. Implementation status of municipal pollution prevention and control plans

<i>AOC and municipality</i>	<i>Status of PPCP</i>	<i>Key implementation actions and status</i>
Severn Sound municipalities	Completed Severn Sound Remedial Action Plan (2002)	AOC was delisted in 2002. Sewage treatment improvements had major impact towards achieving RAP phosphorus targets/ecosystem response. Stormwater management plan being implemented.
Thunder Bay Thunder Bay	Completed XCG Consultants, Wardrop Engineering (1999)	All municipal RAP actions will be completed within the next few years. Infrastructure funding obtained in 2002. Upgrade of primary sewage treatment plant underway; no major CSO works needed.
St. Marys River Sault Ste. Marie	Completed Wm. R. Walker Engineering Inc. (2000)	All municipal RAP actions will be completed within next few years. Infrastructure funding obtained in 2001. Underway are upgrade of primary sewage treatment plant and CSO tank.
Bay of Quinte Quinte West, Picton, Belleville, Napanee,	Completed for Belleville, Trenton (now Quinte West) Review of Belleville underway	Ecosystem/water quality monitoring show P to be at RAP target due to sewage treatment plant improvements, agricultural pollution reduction program. Stormwater discharges a bacterial concern. Action initiated for Napanee, Picton; Quinte West has eliminated bacterial problem.
Detroit River Windsor	Completed Stantec (1998)	Upgrading primary sewage treatment plant. Infrastructure funding received in 2003. Chemically aided settling studies underway.
St. Clair River Sarnia	Completed UMA (1993) SWM plan completed Li (2004)	Upgrade of primary sewage treatment completed, 1 CSO tank of 3 installed; source controls identified in SWM plan eliminate need for end-of-pipe stormwater pond.
Niagara River Niagara Falls, Fort Erie, Welland	PPCP underway for Fort Erie; PPCP completed for Welland	High-rate treatment recommended for Welland. CSO characterization completed for Niagara Falls, Welland. Demonstration of high-rate treatment in Niagara Falls in planning.
St. Lawrence River Cornwall	Completed CH2M Hill Engineering Ltd. (1995); to be updated in 2004.	Environmental Study Report for upgrading primary STP completed.
Metro Toronto	Completed City of Toronto (2004)	Estimated cost for 25-year implementation plan is \$1.025 billion. Optimization of high rate treatment at North Toronto CSO tank underway; evaluating innovative stormwater treatment systems.

grated municipal PPCPs, as carried out in Sarnia, Thunder Bay, Windsor and Cornwall, address all municipal wastewater discharges (sewage, combined sewer overflows and stormwater runoff). There are also PPCPs solely focussed on stormwater and/or CSOs, which have also been conducted for municipalities in the Bay of Quinte, Toronto and Niagara AOCs.

Current activity is focussed on stand-alone PPCPs and updating PPCPs done many years ago, assessing the status of recommendations (Hamilton, Cornwall, Belleville and Quinte West) and initiating new PPCPs as for Napanee and Picton in the Bay of Quinte. Development and application of decision-making support tools, based on expert systems that provide linkages between various watershed resource management models (green-space conservation and protection, hydrogeological mapping and groundwater resources) and cultural and heritage issues is underway in the Duffins Creek watershed outside of the Toronto AOC for potential application to

selected watersheds in the Toronto AOC (Toronto and Region Conservation Authority 2003a). Other PPCPs such as the City of Toronto Wet Weather Flow Master Plan reflect the use of advanced modelling tools for more accurate estimation of the benefits of control technologies and approaches.

Status of implementation of PPCP recommendations. A key benefit of completing comprehensive municipal PPCPs to the municipalities is their ability to be in a position to demonstrate to infrastructure funding agencies that they have a well-defined plan of action based on a sound technical analysis of their wastewater system. The PPCP addresses some of the criteria for infrastructure funding since it defines the expected environmental benefits from reductions in pollutant loadings from municipal discharges; recommends pollution prevention measures to reduce the sources of pollution; takes into account overall watershed goals and objectives (such as

TABLE 3. Wet-weather flow projects supported under the Great Lakes Sustainability Fund

Pollution prevention and control planning	
Sarnia, Welland, Fort Erie, Hamilton, Toronto, Belleville, Trenton, Napanee, Picton, Cornwall	
Development and demonstration of approaches and technologies—CSO high-rate treatment	
Chemically aided settling of CSOs	North Toronto CSO Tank, Toronto
Chemically aided retention treatment basins	Windsor
Demonstration of high-rate treatment—Vortex, CDS	Niagara Falls
Characterization and feasibility study	Niagara Falls, Welland
Elutriation method development	Niagara Falls, Welland
Development and demonstration of approaches and technologies—stormwater	
Evaluation of street sweepers	Toronto
Green roofs	York University, Toronto
Infiltration, Etobicoke exfiltration	Sarnia, Toronto
Benthic community assessment of stormwater treatment	Toronto
Evaluation of construction sediment ponds	Richmond Hill, Markham
Oil spill management	Richmond Hill, Markham, Vaughn, Toronto
Chemically aided settling of stormwater	Toronto
SWAMP—Dunkers Flow Balancing; Beaches Storage Tank	Toronto
Technology transfer—workshops, guidance documents, Salon des technologies environnementales du Québec 2004, RÉSEAU environnement, Québec City, Québec	
26 ^e Symposium on wastewater and the 15th annual workshop on potable water, RÉSEAU environnement, Laval, Québec	
Stormwater Pollution Prevention Manual; Stormwater Management Planning and Design Manual; Guidance Manual for the Treatment of Combined Sewer Overflows	

those of the RAP); and generates a preferred management option based on consideration of technical and socio-economic considerations and the willingness to adopt innovative, cost-effective technologies.

Between 2001 and 2003, infrastructure funding amounting to \$250 million has been announced towards the implementation of major capital projects recommended in PPCPs (Infrastructure Canada 2004; Ministry of Public Infrastructure Renewal 2004). Specifically, upgrading of primary sewage treatment plants to secondary treatment standards is underway in Thunder Bay, Sault Ste. Marie and Windsor. CSO storage tanks in Sault Ste. Marie and Hamilton have also been approved for infrastructure funding from provincial and federal governments. Addressing wet-weather flows at Hamilton's main sewage treatment plant has also been supported under the Canada-Ontario Infrastructure Program. With this infrastructure funding, municipal actions recommended under the RAP for the Thunder Bay and Sault Ste. Marie AOCs will be completed within the next few years.

Impact of short-term implementation plans. The PPCP also generates a short-term implementation action plan which is readily achieved within the municipality's typical annual capital and operating budget and within a shorter time frame (5 to 10 years) compared to the more capital-intensive longer term 20- to 25-year implementation plan. These short-term plan measures include operating and maintenance practices and pollution prevention measures such as downspout disconnection.

Operating and maintenance measures have been found to be effective in resolving municipal wastewater

pollution in some AOCs. For example, in 1997, a PPCP was conducted to address bacterial pollution from stormwater runoff from the municipality of Trenton (now Quinte West) into the Trent River, a tributary to the Bay of Quinte (XCG Consultants Ltd. 1998). The PPCP recommended an intensive sewer investigation and reduction of cross connections from sanitary to storm sewers. By 2002, these actions had been carried out and bacterial pollution from stormwater runoff were eliminated (XCG Consultants Ltd. 2003). Quinte West has also adopted a stormwater drainage policy developed from the 1998 PPCP and remains committed to adhering to its policy. Other examples are found in the City of Hamilton where minor adjustments to one existing regulator at a CSO tank within the City's combined sewer system resulted in an 80% decrease in CSO annual volume at that location (Stirrup et al. 2002). Thunder Bay's PPCP identified that the City's system was capable of capturing more than the 90% CSO volume requirement under the MOE CSO Procedure F-5-5 with improvements in operating and maintenance measures, such as adjustment and/or replacement of CSO regulators (XCG Consultants, Wardrop Engineering 1999).

Short-term implementation actions include pollution prevention measures such as downspout disconnection. Upon completion of a PPCP in 1992, the City of Sarnia implemented downspout disconnection for one of its catchment areas. In 2003, a study supported by the City of Sarnia, GLSF, Ministry of the Environment (MOE) and Ryerson University was conducted to evaluate the impact of this downspout disconnection on future CSO storage required (Li 2004). It was found that this measure would

save the City approximately \$450,000 because of the reduction of the ultimate size (by 930 m³) of the future CSO tanks. The number of overflows would be reduced from 15 to 14 for a 90% volumetric control, and the TSS loadings to the St. Clair River would be reduced by 5% or 500 kg/year.

A stormwater management implementation plan was also generated in the Sarnia project using the stormwater retrofit model demonstrated under the GLSF by Ryerson University and municipalities in the Severn Sound AOC (Mattson 1998), Mimico Creek (Li and Banting 1999) and Centennial Creek (Li 1997). This implementation plan for Sarnia consisted of downspout disconnection, oil-grit separators, exfiltration and infiltration. The need for the end-of-pipe stormwater pond previously recommended in the 1992 PPCP was eliminated based on this plan.

Summary of review of PPCPs. Pollution Control and Prevention Plans have helped municipalities identify their wastewater pollution problems, set priorities for remediation, and plan the most cost-effective way of meeting their remediation goals. These plans encourage communities to consider new technologies and optimization procedures that are under evaluation by the GLSF's Municipal Wastewater Program.

PPCPs have played a significant role in addressing infrastructure funding criteria as evidenced by major capital projects in several AOCs. In two AOCs, all RAP recommendations related to municipal wastewaters will be completed within the next few years, having project infrastructure funding commitments in place. The PPCPs have identified the present status of CSO volume control in AOCs as ranging from 50 to 97% CSO volume control (based on 5 municipalities). Municipalities need to track the impact of their short-term implementation actions to determine any increase in CSO volume control and any corresponding decrease in the requirement for major capital projects, such as tunnels and detention tanks. Likewise, municipalities should monitor the impact of source controls on controlling their stormwater runoff against the predicted results from planning models, and adjust their implementation accordingly.

Pollutant loadings for total suspended solids and BOD (biochemical oxygen demand) and other components from upstream sources can contribute to the majority of loadings in some of the receivers in the AOCs where municipal discharges were less than 5% of the total loadings. Such high contributions stress the need to address pollution control planning from a watershed perspective.

Issues such as algal blooms resulting in aesthetic issues, taste and odour concerns in drinking water and potential health risks from toxins, as well as health risks related to bacterial contamination at beaches (U.S. EPA 2004) were not as well identified at the beginning of the

RAP program. To date, there has been more emphasis on implementing recommendations related to sewage treatment compared to that related to CSO and stormwater runoff. With the advances in the knowledge of the impacts of CSOs and stormwater runoff, along with a more informed public, wet-weather flow management is becoming more important along with demands for implementation actions. The completion of the PPCPs in most of the AOCs empowers the municipalities in AOCs to initiate implementation and it also provides the basis for applying for infrastructure funding for long-term implementation actions. The GLSF's Municipal Wastewater Program continues to support the initiation and updating of PPCPs in the remaining AOCs.

Development and Demonstration of Sustainable Approaches and Technologies for CSOs and Stormwater

The PPCPs carried out in the AOCs identify the need for evaluating innovative approaches and technologies for managing the municipalities' wastewaters. The Municipal Wastewater Program has been evaluating such state-of-the-art treatment technologies for CSOs and stormwater under various initiatives. These initiatives include the Stormwater Assessment and Monitoring Program under which many stormwater management technologies, such as ponds (Stormwater Assessment and Monitoring Program 2003a), wetlands and perforated pipes (Stormwater Assessment and Monitoring Program 2003b) were evaluated. More recently, projects have focussed on re-evaluation of methods used for performance evaluation of stormwater treatment (e.g., benthic community assessment), promotion and testing of promising technologies at more municipalities (characterization and testing of high-rate treatment of CSOs), increasing attention to source control technologies for wet-weather flow management (green roofs), and population growth issues such as control of sediments in runoff from construction sites. Described below are highlights of these projects.

High-rate treatment of CSOs. Planning studies (CH2MHill 1992) done under the Municipal Wastewater Program estimated the costs of high-rate satellite treatment to be about one-quarter of that of the conventional option of storage and central treatment. Specifically, \$107 million was estimated for satellite treatment using high-rate processes, \$441 million using the storage and central treatment option, and \$3.7 to \$5.9 billion for sewer separation for municipalities in AOCs. High-rate treatment processes include vortex separators, microscreening, and physical/chemical treatment processes in retrofitted conventional storage tanks, primary clarifiers or retention treatment basins, or ballasted flocculation processes.

With these potential cost savings, and the lack of performance data on state-of-the-art processes for addressing CSOs in Ontario, a field development and demonstration project of high-rate satellite treatment was launched in 1994 in the Scarborough District, City of Toronto, and continued until 1998. The results of the Scarborough project have been reported previously (Water Technology Inc. 1999). The main conclusion was that because of the relatively low settleability of this particular CSO, the vortex separator tested would achieve the MOE's CSO Procedure F-5-5 effluent objective of 90 mg/L total suspended solids (TSS) at relatively low loading rates similar to that of a primary clarifier. Loading rates could be improved at least fourfold using a polymeric coagulant to assist settling of the solids using simpler conventional tanks. These results led to the demonstration of the chemically aided settling process at an existing full-scale CSO tank at the North Toronto Water Pollution Control Plant. The use of computational fluid dynamic modelling coupled with a physical scale model of the North Toronto CSO tank has been invaluable in designing the modifications for the full-scale tank. Under steady surface loading rates of 15 m/h, 75% removal of TSS and 53% removal of CBOD₅ have been achieved (Marsalek et al. 2004), along with effluent TSS concentrations below 90 mg/L as required under the MOE's CSO Procedure F-5-5. The procedure also requires 50% removal of TSS and 30% removal of CBOD₅. Further activities are focussed on automating the addition of polymer using turbidity and flows to trigger polymer addition, and on modifying the tank to accommodate higher loading rates. Partners in this project include the City of Toronto, Environment Canada's National Water Research Institute (NWRI) and the MOE.

This chemically aided settling process is also being considered for proposed retention treatment basins for the City of Windsor. Since 1999, the GLSF has supported pilot investigations to determine the technical and economic feasibility of this chemically aided settling process for CSO storage tanks recommended under the 1999 Windsor Riverfront PPCP (Li et al. 2002, 2003). Results so far indicate that the tank could be three times smaller in volume (and much less costly) compared to a conventional detention tank. Partners in the project are the City of Windsor, the University of Windsor and the MOE. The City plans to apply this information to the design of its full-scale tank, and potentially to consolidate all three CSO tanks recommended from the PPCP into one tank (Horneck 2003). Elements of the study include: treatability of Windsor's CSO using jar testing (Guo 2003), pilot testing of chemically aided settling of CSOs (Guo 2003), modelling to refine sizing (Schraa et al. 2004) and functional design aspects related to sludge accumulation and removal.

Fundamental to the application of any high-rate treatment process is a sound knowledge of the character-

istics of the CSOs, and in particular, its settling characteristics. CSOs with high settleability can potentially be treated using vortex separators. If the CSO is not highly settleable, chemicals may be needed as is the case in North Toronto and Windsor. Settleability tests provide such characterization information. There are several test protocols for measuring the settleability of CSOs under static conditions and with no chemical addition (Exall et al. 2004). Given the promising results of chemically aided settling for reducing the size of CSO storage tanks, a test to determine the settling rates under chemical addition was developed by the NWRI, with support from the GLSF and the cities of Niagara Falls, Welland and Toronto (Marsalek et al. 2004, Krishnappan et al. 2004).

The CSO projects in Toronto and Windsor represent the most advanced demonstration projects on the application of chemically aided settling to attain the MOE's CSO Procedure F-5-5 effluent objectives. Further work is needed to address the life cycle costs of the process and to refine the design for the full-scale application in the City of Windsor. Such an analysis also needs to be applied to potential sites identified in the various pollution prevention and control plans.

Stormwater management—green roofs. Rooftops in some urban areas can cover as much as 30% of the land surface with impervious cover, adding to the negative impacts of stormwater runoff (Liptan and Strecker 2002). In Toronto, roofs occupy anywhere from 30 to 50% of most properties and percentages increase with increasing densities. To reduce the volume of runoff and discharge rate of stormwater from these surfaces, green roofs are increasingly being considered as a source control technique for managing stormwater runoff. Roofs are covered with an engineered system of vegetation and its underlying media which capture rain. Green roofs are also being considered as a low-impact development technology and are commanding attention as a sustainable technology for their potential multi-benefits including energy conservation, greenhouse gas reductions, improved air quality and contaminant removal. However, while there is considerable interest in the technology, actual hard data on their effectiveness do not exist for the Canadian situation.

Together with the Toronto and Region Conservation Authority (TRCA), the City of Toronto, academia and many other partners, the GLSF is supporting an evaluation of two green roofs in Toronto to quantify their stormwater management benefits. The green roof at site 1 is situated at a newly constructed building at a local university (York University). Site 2 is a community centre roof retrofitted with a green roof. Both roofs have a control plot along with the test plot. The York University's control roof area is 162 m² and the green roof area is 241 m². The other site has two test plots (each 200 m²) and 1 control plot (100 m²). To date, two full

seasons (April 2002 to November 2004) of data have been collected, including flow, water quality, rainfall, air temperature, soil temperature, soil moisture and relative humidity. The monitoring results will be used to evaluate the potential benefits of implementing rooftop gardens through a modelling exercise for a subwatershed in the Toronto Area of Concern (Toronto and Region Conservation Authority 2003c).

Results from the York University site indicate that the green roof garden effectively slows runoff (increases runoff lag time) during an event when the soil is dry and is most effective for events that are less than 20 mm. With more closely spaced rainfall events, the roof garden soil reaches its saturation point. At this stage, the runoff from the garden becomes similar to the control roof. Once the garden becomes heavily saturated and during intense storms, runoff volume and flow rate from the garden can be greater than the control roof. There is a steady release of soil water rather than a flush effect, which occurs on the control roof. Further details are on a web-based monitoring system (www.sustainabletechnologies.ca).

Benthic community assessment of stormwater management facilities. The Terraview Willowfield Stormwater Management project in the City of Toronto's Scarborough District is a demonstration project that had its origins in the 40 Steps to a New Don; recommendations of a Task Force to save the Don River in 1994 (Metropolitan Toronto and Region Conservation Authority 1994). One of the recommendations from this community-driven subwatershed plan was the need for sites where innovative concepts in multifunctional stormwater management and ecosystem restoration could be demonstrated (Todhunter, Schollen & Associates et al. 1995).

The stormwater treatment facilities of this project manage runoff from two catchment areas (of which highway runoff from a multilane divided highway is a major component for one catchment while the other catchment receives runoff from an adjacent residential area). There are a number of stormwater controls, including oil-grit separators, a sand filter, extended detention ponds in series and finally, a downstream drainage ditch. The sand filter system is sited under a soccer field as part of the multifunctional design philosophy for this stormwater management site.

Ecosystem restoration in the Terraview Willowfield project included planting native trees and shrubs around the stormwater management facilities, and naturalizing a previous concrete drainage channel which receives the treated stormwater runoff. Such naturalized features can potentially cause a risk created by uptake of contaminants from stormwater pond sediments to the wildlife that is attracted to these sites (Environment Canada, Canadian Wildlife Service 1999). Additional data is needed on the ecological status within such stormwater treatment systems to provide guidance on removal frequency of accu-

mulated sediments and on minimizing inputs of contaminants into the stormwater management system.

For a number of years, the National Water Research Institute (Environment Canada) has been working on developing a methodology for evaluating the impacts of stormwater discharges on receiving water ecosystems by benthic community assessments (Grapentine et al. 2004). Since 2001, these activities, conducted with support from the GLSF and the City of Toronto, have focused on the ecological status within the Terraview Willowfield stormwater management system to develop such guidance for municipalities. Preliminary results indicate chemical contamination of sediments contributing to some toxic effects on benthic communities.

Addressing population growth—construction sediment ponds. Many jurisdictions in Canada are undergoing rapid urban expansion. As development proceeds, significant portions of watersheds are subject to urban runoff discharges from construction sites. In many cases, limited water quality controls, particularly during large rainfall events, has led to widespread water quality concerns concerning urban runoff and sediment loading associated with construction activities. The Toronto Remedial Action Plan (RAP) has identified actions relating to the control of construction sediments aimed at improving watershed ecosystem health. In 1999, the Toronto and Region Conservation Authority (TRCA), with support from the GLSF, initiated the Sediment Awareness Study as a means of addressing excess sediment generated from urban construction sites, particularly in the sensitive headwater streams in the Great Lakes basin. One element of this study has been the performance evaluation of sediment ponds used at construction sites. These ponds are designed based on the existing TRCA criteria (enhanced level of protection and extended detention storage for the runoff from a 25-mm storm released over a minimum of 24 hours). The study is supported by many partners, including the towns of Richmond Hill and Markham, the Department of Fisheries and Oceans, Ryerson University, the University of Guelph and the Ministry of the Environment.

The results of the performance evaluation indicated that based on monitoring and long-term simulation modelling of a construction sediment pond in the Town of Richmond Hill, an 82% TSS removal (loading-based) could be expected. However, effluent TSS concentrations could be very high (up to 2600 mg/L) due to extremely high inflow concentrations (e.g., 34,000 mg/L). On average, the pond detention time was estimated at about 46 hours with a range from 14 to 101 hours. The particle size distribution from the construction site was skewed towards the finer particles. At the inlet, about 99% of suspended solids particles were smaller than 62 microns. Approximately 50% of particles were smaller than 2.3 microns. Similar observations were made at the outlet (Toronto and Region Conservation Authority 2003b).

Recommendations for improving erosion sediment control (ESC) effectiveness included: considering the ultimate stormwater management facility as a sediment control pond during construction; designing to facilitate the removal of accumulated sediment, including the ability to draw down the permanent pool; and, stabilizing the slopes of the pond soon after the pond is constructed since the banks of the sediment-control ponds can be significant sources of soil erosion and sediment contributions to the storage facility. Slope stabilization should be a high priority after pond construction. Outflow polishing of the pond's effluent should be considered to capture the predominantly slow-settling smaller particles that reduce treatment effectiveness. Receiving water impacts should also be investigated, as well as ways to reduce at-source generation of sediments entering the pond (such as early revegetation of the site). Annual surveying of the pond to verify its effectiveness, particularly after runoff events along with the generation of inspection records to document the inspection and repairs should be implemented.

This project has evolved into monitoring investigations in the Town of Markham of a pond that has been designed using increased storage to see whether this design will provide sufficient sediment control for the protection of downstream aquatic life. Data collected from both sites will subsequently be used in a hydrodynamic model to identify specific conditions under which ponds are effective sediment control practices, as well as to assist in the development of pond design guidelines for water quality control during the construction period. The study period for monitoring will extend from the stripping of land through to the end of the construction period to ensure that the full range of construction impacts is adequately considered.

Technology Transfer

Over the past 15 years, the Great Lakes Sustainability Fund has generated a wealth of information on the characteristics of combined sewer overflows and stormwater; performance evaluation of state-of-the-art CSO and stormwater treatment technologies; development and demonstration of sustainable cost-effective CSO treatment processes; incorporation of advances in modelling and technologies used for addressing CSO and stormwater management into pollution prevention and control plans, and design of treatment systems; and research on CSOs and stormwater related issues (e.g., toxicity, potential risks to wildlife). The projects reflect the evolution of the CSO and stormwater management field in Ontario as well as in North America. Over this time, many approaches evaluated under the program are now being adopted widely in Ontario, in part, as a result of the confidence provided to the municipal community by the data generated from the program in what was a relatively new area in the early 1990s.

Information from the Municipal Wastewater Program is widely disseminated through various avenues. These include (1) guidance documents (Totten Sims Hubicki Associates et al. 2001); (2) specialized CSO and stormwater management workshops to encourage networking between municipalities, consultants and government and to disseminate the latest findings on projects; (3) transfer of information to other provinces and internationally, such as the International Conference on Innovative Technologies in Urban Drainage, NOVATECH, France; (4) presentations by project proponents and engineering consultants at technical symposia hosted by key municipal wastewater associations, such as the Water Environment Association of Ontario, the Canadian Association of Water Quality and RÉSEAU environnement (Québec); and (5) peer-reviewed publications in scientific and engineering journals, including special issues on abatement of urban wet-weather pollution and urban stormwater management for ecosystem protection (Water Quality Research Journal of Canada, Vol. 32, No. 1 and Vol. 35, No. 3, respectively).

Guidance Manual for the Treatment of Combined Sewer Overflows. In partnership with the City of Welland, the Regional Municipality of Niagara and the National Water Research Institute, the Government of Canada's Great Lakes Sustainability Fund produced a Guidance Manual for the Treatment of Combined Sewer Overflows (Zukovs and Marsalek 2004; XCG Consultants 2004). During the preparation of the guidance manual, two workshops were held with municipalities in Ontario to seek their input. The aim of the guidance manual is to provide options and costs for treating and managing combined sewer overflows (CSOs) to municipal engineers and plant managers facing costly decisions on managing their municipality's CSOs in Great Lakes AOCs and elsewhere. The manual includes a basic primer on treatment systems for CSOs, regulatory framework for CSO treatment in Ontario, the current approach to the treatment and management of CSOs in other jurisdictions (including the U.S., Europe and other parts of Canada), costs and performance data on new technologies for CSO treatment (including chemically assisted settling, vortex separators, screens, etc.), and the implications of results from key CSO demonstration projects in the Great Lakes AOCs and other jurisdictions.

Workshop on Integrated Urban Water Pollution Control. The GLSF, together with the National Water Research Institute, supports workshops that bring together program managers from provincial and federal departments, municipalities and non-government organizations to share the state-of-the-art in approaches in watershed management and municipal wastewater management and treatment. In 2004, the GLSF and the

NWRI hosted a workshop on Integrated Urban Water Pollution Control Planning (Environment Canada, National Water Research Institute 2004). Municipal leaders from Canada, U.S. and the United Kingdom contributed to a review of approaches to developing and implementing integrated urban water pollution control planning. Presentations highlighted the experiences in the Great Lakes Areas of Concern, such as the focus on control of critical pollutants in Severn Sound and the hierarchical approach to stormwater/CSO management in Toronto. Other presentations reflected trends in wastewater recycling (Edmonton, Los Angeles), biological risk assessment for establishing pollution control strategies (Greater Vancouver Regional District), integration of groundwater, surface water and green cover management for water quality protection in rapidly urbanizing watersheds (Duffins and Carruthers Creek watershed planning) and water quality trading (U.S. Environmental Protection Agency). Conclusions from the workshop highlighted the importance of leadership as a primary factor in making progress in implementation of the plans presented in the workshop. Sustainable funding of pollution control was also identified to be a major challenge.

Impact of the Great Lakes Sustainability Fund

Over the past 15 years, the Great Lakes Sustainability Fund and its partners have made significant progress in addressing Remedial Action Plan recommendations related to municipal wastewater management, including CSOs and stormwater issues. As well, the GLSF has provided many sustainable approaches and tools that provide cost-effective solutions to municipalities, as shown by savings gained from integrated municipal pollution and prevention control planning, development of high-rate chemically assisted high-rate treatment of combined sewer overflows and stormwater and the use of pollution prevention approaches such as downspout disconnection. Working from the principles of demonstrating best management practices for sustainable cities, the GLSF projects on the evaluation of low impact development techniques such as green roofs, and better designed sediment control systems from construction sites will provide defensible scientific data for guiding technology vendors, developers and regulators and will build environmental expertise and knowledge at all levels of society.

Management decisions and actions have occurred to ensure a sustained program within municipalities in AOCs, as evidenced by municipal council commitment to implementation of plans, implementation of major works on upgrading sewage treatment, limited capital projects related to CSOs and implementation of pollution prevention measures for wet-weather flow management. Projects spanning many years have positioned municipalities to provide the necessary scientific and engineering rationale to support infrastructure funding

applications. Major milestones will be reached in the two AOCs of Thunder Bay and St. Marys. RAP recommendations related to municipal wastewater treatment from the cities of Thunder Bay and Sault Ste. Marie, respectively, will be completed within the next few years. In the remaining AOCs, municipalities such as Sarnia, Hamilton, Toronto and Niagara continue to investigate cost-effective options for their complex wet-weather flow systems. In the Bay of Quinte AOC and the now-delisted Severn Sound, where ecosystem recovery related to phosphorus controls has been positive, stormwater runoff threatens these environmental gains in the face of anticipated population growth and other stressors.

Many approaches evaluated under the program are now being adopted in Ontario, in part as a result of the confidence provided to the municipal community by the data generated from the program in what was a relatively new area in the early 1990s. Although there has been substantial progress in stormwater and CSO management in the Great Lakes AOCs, there are issues that have emerged or have become more pressing since the beginning of the RAP program. These include climate change, West Nile virus, pharmaceuticals and personal care products (Environment Canada 2004a), taste, odour and aesthetic problems caused by algal growth (Environment Canada 2004c), all exacerbated by population growth. Outside of the GLSF Municipal Wastewater Program, scientific and engineering tools are being developed to assist in addressing such issues. Bacterial fingerprinting (Environment Canada 2004d) to determine exact sources of beach closures, and environmental decision support systems (Environment Canada 2004b) for providing management options to deal with impacts to water quality and quantity, are some tools being developed in municipalities in AOCs.

Partnerships have been critical in ensuring projects remain relevant to the community. The role of partners includes provision of regulatory advice and direction; conduct of detailed scientific investigations in the laboratory and the field to develop improved ways to characterize, treat and address potential environmental issues; provision of demonstration facilities and field support staff; building of environmental expertise in Canada; and, technology transfer. The GLSF's network with other agencies such as academia, Environment Canada's research facilities, and the private sector consultants and technology vendors provides connections with municipalities in applying such tools in addressing RAP recommendations by municipalities in the Great Lakes AOCs. Resulting from these partnerships has been increased competitiveness of the private sector in ecological restoration and municipal wastewater management and treatment. Also, there has been a shift in perception of cities historically labelled as degraded to revitalized as a result of enhanced quality of life stemming from ecological restoration, better municipal servicing and attractive shorelines. Federal

expertise in municipal wastewater research, management and treatment have also been welcomed by municipalities in providing scientific direction on pressing municipal issues, such as lower cost options for CSO treatment.

Conclusions

From its inception in 1990 as the Great Lakes Cleanup Fund to the Great Lakes Sustainability Fund in 2004, the Municipal Wastewater Program now epitomizes an effective model of sustainable communities among municipalities. The communities of practices formed under the Municipal Wastewater Program and its overarching management framework, the Remedial Action Plan for the Great Lakes Areas of Concern, have always embraced the tenets of sustainable development and sustainable communities. The Municipal Wastewater Program of the Great Lakes Sustainability Fund manifests such tenets through its leadership in the provision and delivery of: best management practices; communities of practice within municipalities in the Great Lakes AOCs; integration of perspectives from varied disciplines of community stakeholders (including other federal departments); increased competitiveness of Canadian consultants and technology vendors; enhanced competitiveness of cities through improvements to quality of life from ecological restoration; and the adoption of adaptive management philosophies focussed on continuous improvement in response to the vision of communities in the Great Lakes AOCs. Such a vision has always stemmed from a serious concern about the nature of the environmental legacy that will be left for future generations. Federal leadership through programs such as the Great Lakes Sustainability Fund can contribute significantly towards achieving the realization of this fundamental vision.

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