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Global optimal real-time control of the Quebec urban drainage system

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Abstract

A global optimal control (GOC) system was implemented in 1999 on the Quebec Urban Community's (QUC) Westerly sewer network to manage flows and water levels in real-time in order to, among others, reduce the frequency and volumes of combined sewer overflows discharged into the St. Charles River and St. Lawrence River. This paper presents some of the salient results of the first three years of operation. The configuration of the GOC system is discussed and operational observations are made about the reliability of some of the major components. Furthermore, an economical analysis presents how cost-effective the real-time control system is for the QUC.

Keywords: Combined sewer overflow; Global optimal control; Real-time control; Sewer networks; Urban drainage

1. Introduction

For many municipalities, combined sewer overflows (CSOs) are a major source of river pollution. During CSO-generating rainfall events and sometimes for up to several days after, CSOs cause an increase in pollutant loads such as suspended solids, fecal coliforms, phosphorus, ammonia–nitrogen and heavy metals in receiving water bodies. Water uses in the vicinity of CSO discharge points may be significantly threatened. Consequently, swimming and fishing may be forbidden for health and safety reasons.

Alerted by scientists and environmental groups about the devastating effects of CSOs on the river and riverbank habitats of an ever-growing number of water bodies, many American and European governments have strengthened their regulations aimed at reducing urban pollution over the past two decades. In the USA, the Environmental Protection Agency (EPA) has instituted the "nine minimum controls" (US EPA, 1995), which water companies are required to implement. In essence, municipalities must maximize the use of their existing sewer facilities, implement proper management practices and effectively characterize CSO impacts. For larger cities, a CSO long-term control plan (CSO-LTCP) that complies with the clean water act must also be submitted using either an explicit presumptive approach or an explicit demonstrative approach. In the presumptive approach, the water company must reduce the frequency of overflow events in urban areas to an average of 4 or less annually and treat a minimum of 85% of the average annual wet-weather volume of combined sewage. Under the demonstrative approach, the water company must demonstrate that the applied CSO control measures allow to meet water quality standards at all times.

The EPA has estimated that over US$ 60 billion will be spent over the next years in order to implement the nine minimum controls and CSO-LTCPs. Wastewater treatment plants (WWTPs) and satellite treatment facilities will either need to be built or upgraded. Storage facilities will also be needed to store excess flows generated during rainfall events and, in some cases, relief or separate sewers will be required.

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In Europe, the European Community issued a new urban waste water treatment directive in May 1991 (91/271/EEC) which sets the main principles for the collection and treatment of both dry-weather and wet-weather wastewater (CEC, 1992). This directive was then interpreted and translated by each European country into a respective law. Most European countries chose to establish specific dry- and wet-weather water quality objectives rather than discharge limits such as is mostly the case in North America (Agences de l'eau, 1994; OTV, 1994).

In the Province of Quebec (Canada), the Ministry of Environment set discharge limits linked to downstream water usage, such as water supply, activities with primary or secondary water contact, which translate into an allowable number of overflows per year. This approach is well adapted to retention-type solutions where wastewater has to be stored before being released for treatment but ill-adapted to satellite treatment solutions (Meunier et al., 2000). At the Quebec Urban Community (QUC), the environmental goals set by the Ministry of Environment are to decrease the frequency of sewer overflows to two per year in the St. Lawrence River and to four per year in the St. Charles River.

Due to budgetary constraints, many municipalities will not be able to implement their CSO-LTCP on schedule and some are proposing an implicit approach based on a reasonable level of control in order to reduce the investment needed to comply with the level of performance of the presumptive and demonstrative approaches. For this reason, the government agencies, as well as municipalities, are now seeking cost-effective solutions to eliminate or reduce pollution related to CSOs such as real-time control (RTC) schemes. The main objective under RTC is to maximize using regulating devices, such as mobile gates, inflatable dams, variable speed pumps and variable crest weirs, existing treatment, storage and conveyance capacities of sewer networks. The regulating device set points are defined according to local or system-wide rules calculated by computers or set by human operators according to the sewer network's hydraulics and rainfall characteristics. A recent study published by the EPA (USEPA; Draft Final Report, Contract No. 8C-R057-NTSX) has demonstrated the potential of RTC to decrease the cost of QUC LTCP. In this study, it is shown that US$ 41.3 million is needed to meet the environmental objectives set by the Ministry of Environment if RTC is not considered. That money would serve to build seven storage tanks totalling 9.6 million gallons. Using a global optimal control (GOC) scheme, an investment of US$ 32.3 million is needed for the construction of four storage tanks totalling 6.13 million gallons.

As early as the 1970s and 1980s, RTC has been studied and implemented in numerous American and European cities (Schilling, 1989; Gonwa and Novotny, 1993). With a few exceptions, local reactive control (LRC) or supervisory control (SC) was implemented (Colas et al., 1998). Many American cities had planned to implement some type of centralized scheme but only Seattle operated its sewer network using a GOC strategy from 1992 to 1995 (CH2M HILL, 1986; Vitasovic et al., 1990; Speer et al., 1992; Gelormino and Ricker, 1994). While theoretical results were extremely promising, the reasons for not going forward with global control were mainly related to the reliability of sensors, gate motors and communication systems, the limited computational speed of personal and programmable computers, the availability and accuracy of hydrological and hydraulic models and the ability of the control system to react to emergency situations.

Today, the hardware and software technologies needed to implemented efficient GOC schemes are available (Schütze et al., 2002). Accurate and reliable water level sensors and flowmeters developed for sewer applications can be purchased at a reasonable cost. Robust gate motors allow more than 1000 gate displacements per hour and powerful computers can perform billions of operations per second. GOC can significantly reduce the cost of a CSO-LTCP when compared to LRC strategies.

This paper presents the QUC RTC implementation project that took place in 1999 and the performance obtained during the first three years of operation. For the QUC, this system is an important step towards the achievement of integrated urban water management since it takes into account the contributing urban watersheds, flow in the controlled portion of the sewer network, the varying treatment capacity of the WWTP and the hydraulic capacity of the diffuser, which is influenced by the St. Lawrence River's tide. The RTC scheme also permits the spatial and temporal distribution of inevitable overflows, thus alleviating the impact on the water quality of the receiving water bodies.

2. QUC's Westerly sewer network

Located on the North shore of the St. Lawrence River, the QUC covers 500 km^2 with a population of approximately 500,000 inhabitants. The QUC manages 130 km of pipes in two independent catchment areas, the Easterly and the Westerly, each with their own WWTP. Pipe diameters in both catchments range from 0.25 to 2.44 m. The Easterly WWTP has dry- and wet-weather capacities ranging from 375,000 to 719,000 m^2/day, while the Westerly WWTP capacities range from 316,000 to 505,000 m^2/day. The wet-weather hydraulic capacity of both WWTPs is influenced by the St. Lawrence River's tide. Both plants have primary treatment using bar screens, degritters and lamellar clarifiers and secondary treatment using biofiltration. A