Giving the rivers back to the public. Ten years of Real Time Control in Quebec City

Redonner aux citoyens les cours d'eau de la Ville de Québec. Dix ans de gestion en temps réel des réseaux d'assainissement

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RÉSUMÉ

Après la construction de stations de traitement des eaux usées, la Ville de Québec s'est mise à l'œuvre pour contrôler les débordements par temps de pluie afin qu'il ne se produise pas plus de deux épisodes de débordements par période estivale dans le fleuve St-Laurent et pas plus de quatre dans la rivière St-Charles. Après plusieurs années d'études afin d'identifier les stratégies de gestion les mieux adaptées et de proposer des solutions optimales, un premier projet d'implantation d'une gestion en temps réel optimale et prédictive, appelé « Pilote », naissait en 1999. Des phases de construction ont suivi, se terminant à l'automne 2009 et permettant le respect des exigences de rejet et le retour aux activités aquatiques de deux secteurs, soit la rivière St-Charles et la Plage Jacques-Cartier. Durant la même période, la Ville travaillait à redonner aux citoyens l'accès à leurs cours d'eau en aménageant des sites à la Plage Jacques-Cartier et à la Baie de Beauport, et en réhabilitant les berges de la rivière St-Charles.

ABSTRACT

After the construction of its wastewater treatment plants, the City of Quebec began to implement overflow control in wet weather to ultimately meet the effluent discharge objectives, i.e. no more than two overflows per summer season in the St. Lawrence River and no more than four in the St-Charles River. After several years of studies to determine which management strategies would best suit the purpose, and to propose optimum solutions, a first project to implement optimal and predictive management in real time, called « Pilot », came to life in 1999. Construction in phases soon followed and the work was completed in the fall of 2009. As a result, requirements with regard to environmental rejects were met in two sectors, namely the St-Charles River and the Jacques-Cartier Beach, and aquatic recreational activities could resume. Meanwhile, the City also worked at giving back access to the water courses to the public by developing sites at the Jacques-Cartier Beach and in the Bay of Beauport, and by rehabilitating the banks of the St-Charles River.

KEYWORDS

CSO reduction, real time and optimal control, river pollution control, riverbank rehabilitation

1 INTRODUCTION

These days, the downstream section of the St-Charles River, in Quebec City, is unrecognizable. The banks of this “river in the city” had been set in concrete in the 1970s and until recently, the river was considered “an open dump site”, the lot of many urban water courses. Now, it is a true oasis of nature in the heart of the city. To meet this challenge, the City of Quebec, supported by federal and provincial government agencies, as well as citizen groups has achieved a tremendous engineering feat, i.e. joining combined sewer overflow control and riverbank rehabilitation, with the help of the BPR engineering team and other consulting firms.

At the end of the eighties, BPR was commissioned to conduct studies in order to define a Long Term Control Plan (LTCP) regarding combined sewer overflows (CSO) that occurred in the St. Lawrence River and in the St-Charles River. In the end, these studies, which lasted several years, recommended the implementation of real time control (RTC) to solve the CSO problems in Quebec City. The first phase of implementation began in 1999, and the construction of the infrastructures necessary to meet the environmental goals related to the St-Charles River and to one sector of the St. Laurence River was finally completed in the fall of 2009.

In the mid-nineties, the City knew that they stood at the beginning of a long pollution control process to meet the environmental goals of the St-Charles River. As the City also wished to revitalize downtown Quebec City, they commissioned a project to rehabilitate the riverbanks and to bring back canoeing activities in this urban river. The first phase of renaturalisation began in 1996 and the last was completed in the fall of 2009.

This paper focuses on the key design elements and technologies involved in such RTC implementations. It also outlines the results of the optimal operation of all the storage facilities, and includes an overview of the riverbank rehabilitation project and the engineering behind it. Finally, it features the technical accomplishments of both projects.

2 QUEBEC CSO CONTROL PROJECT

2.1 The Quebec territory

Located on the North shore of the St. Lawrence River, Quebec City spreads over a 500 km^2 area with a population of more than 500,000. The City manages 100 km of pipe interceptors serving two independent catchment areas, the Easterly and the Westerly, each with its own wastewater treatment plant (WWTP). The Easterly WWTP has dry and wet weather capacities of 375,000 and 719,000 m^3/d (4.34 to 8.04 m^3/s) respectively, while the capacities of the Westerly WWTP range between 302,400 and 504,000 m^3/d (3.5 to 5.83 m^3/s). Both plants provide primary treatment using bar screens, degritters and lamellar clarifiers, and secondary treatment using biofilter. UV disinfection is also used as tertiary treatment in summer time. Figure 1 shows the Quebec City territory and the locations of the elements mentioned above.

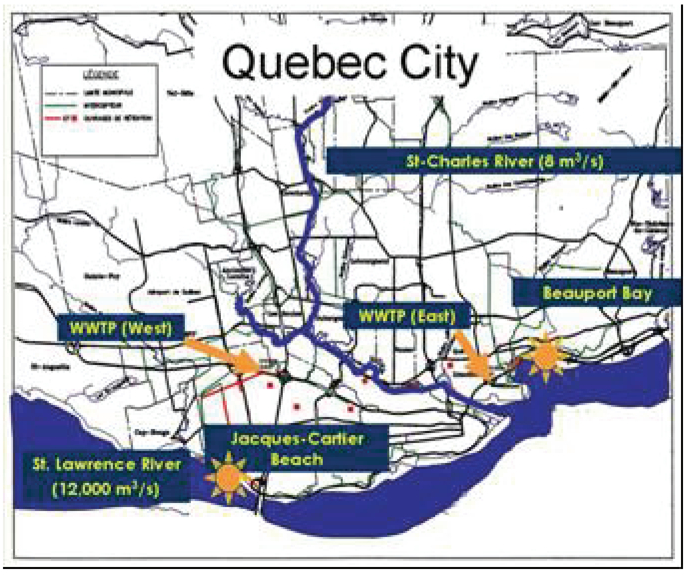

Figure 1: Map of Quebec City’s Territory

The combined sewers of these two networks are located almost exclusively in the southern part of the city. They also form the oldest urbanized sectors. In the Westerly network, water overflows in the St. Lawrence River, near the Jacques-Cartier Beach (left sun icon in Figure 1) and in the St-Charles River. In the Easterly network, all the densely populated sector of Quebec City is served by combined networks that overflow in the downstream section of the St-Charles river, whereas the combined sewers of the most eastern part of the city overflow to the Beauport Bay (left sun icon in Figure 1) of the St. Lawrence River.

2.2 Environmental Objectives

Before the modifications dedicated to CSO abatement began, the St-Charles River had been identified as the most contaminated by fecal coliforms (downstream end) in the Province of Quebec. Studies based on measurements showed that the concentration of bacteria in the river could exceed 50,000 coliforms/100 ml after rain events. As a reference, the maximum allowable concentration of coliforms for swimming is 200 coliforms/100 ml. In the summer (i.e. between May 15th and September 15th), more than one CSO event every five days occurred on average (Villeneuve *et al.*, 1992)..

The Jacques-Cartier Beach and the Beauport Bay are recognized as important recreational sites. The former is dedicated to swimming and the latter to wind surfing. The objective of the City consisted in regaining the primary contact recreational uses of these sites during the summer season. As for the Saint-Charles River, the objective was to regain its use for secondary contact activities like canoeing or fishing.

Based on diffusion and dilution studies conducted in the eighties for the two receiving water bodies, the Quebec Province environmental authorities established the effluent discharge objectives at no more than two overflows between May 15th and September 15th in the St. Lawrence River and at no more than four in the St-Charles River (Pleau *et al.*, 2005) during the same period of the year.

2.3 CSO Project Implementation

Between 1988 and 1997, studies were conducted to define a CSO LTCP for Quebec City. This study included a measurement campaign, the hydrological and hydraulic modeling of the sewer network and simulation studies to propose solutions that would permit to achieve the environmental objectives at the lowest cost and over a short period of time.

A measurement campaign was conducted at the end of the eighties. The objective consisted in better characterizing the hydraulic behaviour of the sewer network, and to calibrate the sewer model. The campaign lasted for more than five months and recorded 25 rainfall events. Six sites were added to the 19 permanent flow monitoring sites and 54 sanitary sewer overflow (SSO) sites were monitored. In addition, 700 samples were taken and more than twelve rainfall events were analysed to assess the water quality at the main CSO sites (Villeneuve *et al.*, 1992).

Simulation studies were also conducted using two management modes, i.e. static and global optimal RTC (see Schutze *et al*. (2004) for definitions). MED, a new software based on nonlinear programming (which later became Csoft™), was developed for global optimal RTC of sewers through the 1990s (Pleau *et al.* 1996 and Colas *et al.*, 1998). For each of these management modes, a LTCP that met the environmental objectives was designed. Based on a traditional approach in which regulators were static, site simulations showed that five storage tanks and one tunnel, for a total storage volume of 34,000 m^3, were needed on the Westerly territory to meet the CSO objectives defined by the environmental government authorities. For the Easterly Territory, twelve storage tanks and one tunnel, for a total storage volume of 198,000 m^3, were needed. The total cost was estimated at $250M (US). Based on an optimal and predictive approach, only 14 storage tanks, for a total storage volume of 132,000 m^3, were needed. The total cost for the CSO LTCP under this management strategy, including the cost for the RTC system, was estimated at $130M (US) (see Figure 2). As the results showed huge potential for the implementation of a sewer network under optimal and predictive control, the City decided to go forward with a Long Term Control Plan that included the optimal predictive control scheme. (Pleau *et al.*, 2001, Pleau *et al.*, 2005).

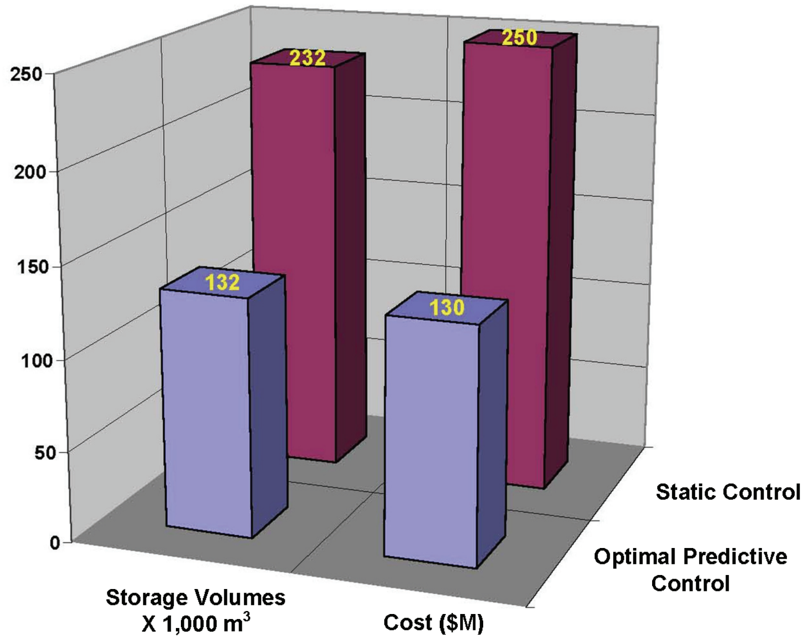

Figure 2: Comparison of Costs between a CSO LTCP Using Static Management versus a CSO LTCP with Optimal Predictive Control for Quebec City

The CSO LTCP was scheduled in three main phases, i.e. the pilot project, Phase 1, and Phases 2 and 3. The pilot project lasted from 1998 to 2001, and aimed to confirm the results presented in the simulation studies. Although this phase did not involve the construction of storage tanks, dynamic flow regulators were implemented to fully use the storage capacity available in two existing tunnels (i.e., Versant-Sud and Affluent Tunnels), a total storage capacity of approximately 18,000 m^3. Phase 1 began when the efficiency of the RTC technology to minimize CSOs was confirmed. It aimed mainly at reducing CSOs in the St. Lawrence River from the Westerly sewer Network. Finally, Phases 2 and 3 took place simultaneously so the CSO plan could be completed by the end of 2008, in time for the 400th anniversary of Quebec City. Table 1 summarizes the implementation phases of the Quebec City CSO LTCP.

Phase	Site	Storage (m^3)	Schedule
Pilot project	2 tunnels 5 RTC sites 17 monitoring sites	17,600 (existing in-line storage)	1998 to 2001
Phase 1	7 storage tanks 9 RTC sites 15 monitoring sites	40,300	2002 to 2005
Phases 2 and 3	7 storage tanks 4 control sites	81,000	2004 to 2008

Table 1: Implementation Phases of Quebec City's CSO LTCP

8,100 m^3 out of the total 121,300 m^3 of new storage is distributed in two distinct reservoirs solely dedicated to pollution control at the Jacques-Cartier Beach. The other 113,200 m^3 of new storage is distributed in twelve distinct reservoirs dedicated to pollution control in the St-Charles River. The largest tank can store 32,000 m^3 of wastewater. All of the storage facilities are located in densely populated areas, often only a few meters from private residences. The construction of these storage tanks took place while the rehabilitation of the riverbanks was underway.

2.3.1 Pilot project

Combined sewer overflow control began in 1998, when the City of Quebec commissioned an optimal, predictive real time control system (OP RTC) in the Westerly territory. The objectives pursued included:

- The validation of the performance and concept of the optimal predictive RTC scheme proposed before the construction of the storage tanks;
- The use of the in-line storage capacity of two existing tunnels (18,000 m^3) for CSO reduction at minimum cost;
- 60% reduction in the CSO frequency and 50% reduction of the CSO volume from five majors overflow sites.

During the implementation of RTC, 22 local stations were built or modified in the Westerly territory. These local stations include 4 flow monitoring stations, 13 rain gauge stations and 5 RTC stations. All these monitoring and control sites are linked to the Easterly WWTP via a radio telecommunication network, which uses both public and private frequency bands. At the WWTP, a supervisory system, a weather forecasting system and a model-based optimal and predictive decision-making system (i.e., Csoft™) have been installed (see Figure 3). The entire pilot project was made a reality with a budget of $3.2M (US).

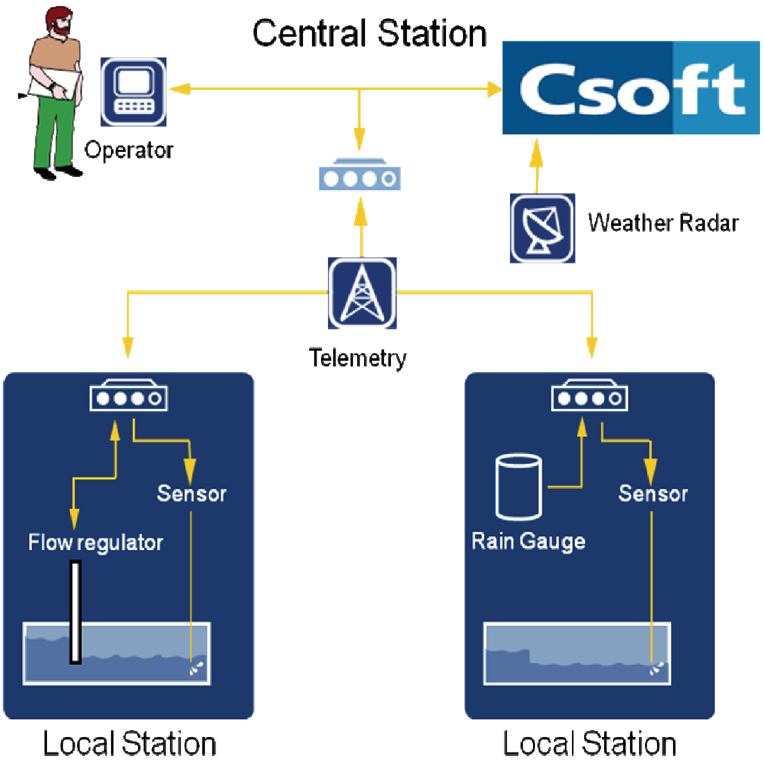

Figure 3: Architecture of the RTC System Implemented in the Context of the Pilot Project

Each of the system's components was designed and configured to achieve high system performance in normal and degraded conditions of operation. The control scheme works as follows: measurements from the monitoring and control stations are processed to the supervisory, weather forecasting and decision making systems via the radio telecommunication network. The weather forecasting system, using rainfall measurements and Radar images, computes rainfall predictions two hours ahead on pixels of 1 km^2 that cover the entire watershed of the Quebec City sewer system. These weather predictions, along with local flow and water level measurements and alarms, are used by the Csoft™ decision-making system to compute the optimal flow set points to be applied at the local flow regulators. Before being sent locally, these optimal flow set points are displayed on a Human Machine Interface (HMI) along with field measurements. If the sewer system operator acknowledges these set points, they are sent to the local control stations, where local controllers convert the optimal flow set points into gate openings. At all times, the operator can take full control of the local flow regulator through the HMI, by switching the control mode from optimal and predictive to supervisory or manual. All the components of the RTC system were designed for high performance, robustness, reliability and adaptability in all circumstances as shown in Table 2.

System	Performance	Robustness	Reliability	Adaptability
Monitoring	Strategic Localization	Data Validation Algorithms	Sensor Redundancies	
Local Control	Adaptive Integrative (AI) Controllers	Data Validation RTC Alarms Degraded Management	Sensor Redundancies Power supplies	Standard Programming Language (Ladder)
Telemetry	Polling < 1 minute	Robust Communication Protocol	Detection of Communication Failures	Open architecture TCP/IP Communication Protocol
Supervisory		Manual Data Validation RAID-5 Computers		Supervisory Flow Control Manual Control
Weather Forecasting	Prediction horizon of 2 hours	Data Calibration using Rain Gauges	Rainfall Intensity Redundancy	
Decision-making	Csoft™ Optimizer	On-line Calibration of the Hydraulic Model On-line Update of the Gates, Pumps and WWTP Status	Oracle Database	Flexible Control Objectives Reporting Capabilities

Table 2: Design Specifications of the Quebec City Optimal Predictive RTC System

The "objective function" defined in the Csoft™ optimization problem for the computation of the optimal flow set points establishes priorities, such as the reduction of flooding risks, the minimization of overflow volumes, the optimization of the pumping station capacities, the maximization of flows conveyed at the WWTP, the minimization of the sewer's dewatering time, and the reduction of operating costs. (Pleau *et al.* 1996)

The performances at the five major overflow sites where dynamic flow control was implemented were recorded during the pilot project to verify if the environmental objectives were attainted in terms of frequency and CSO volume reductions. In two years of monitoring (2000 and 2001), results confirmed the capability of the optimal and predictive decision-making system to achieve the objectives pursued, as shown in Table 3.

		2000 (53 rainfall events)		2001 (45 rainfall events)	
CSO Volume	Global RTC	47,300	m^3	22,000	m^3
	Static	185,400	m^3	129,000	m^3
	Reduction	75	%	83	%
CSO Frequency	Global RTC	23		25	
	Static	40		44	
	Reduction	43	%	43	%

Table 3: Reduction Achieved at the 5 Major CSO Sites with the RTC Pilot Project Implemented

2.3.2 Phase 1

Following the successful implementation of the OP RTC pilot system, the City decided to go ahead with the full CSO LTCP to give the St. Lawrence River and the St-Charles River back to the residents of Quebec City. During Phase 1, which took place from 2002 to 2005, the City built seven storage tanks, for a total water storage capacity of 40,300 m^3, and implemented nine new local control stations and 15 monitoring sites. The total budget for Phase 1 amounted to $45M (US).

Figure 4 shows the location and storage volume of the seven storage tanks built during that phase. The Suète (5,500 m^3) and Jones (2,600 m^3) storage tanks, along with the Versant Sud and Affluent Tunnel, provide the storage capacity needed to control the CSOs discharged at the Jacques-Cartier Beach and meet the requirement of no more than two CSOs per summer season in the St. Lawrence River. The other five storage tanks built during this phase contribute to the reduction of CSOs in the St-Charles River. The total storage volume of these five tanks (32,200 m^3 of storage) corresponds to one third of the total storage volume required to achieve the environmental objective of no more than four CSOs per summer season in the St-Charles River.

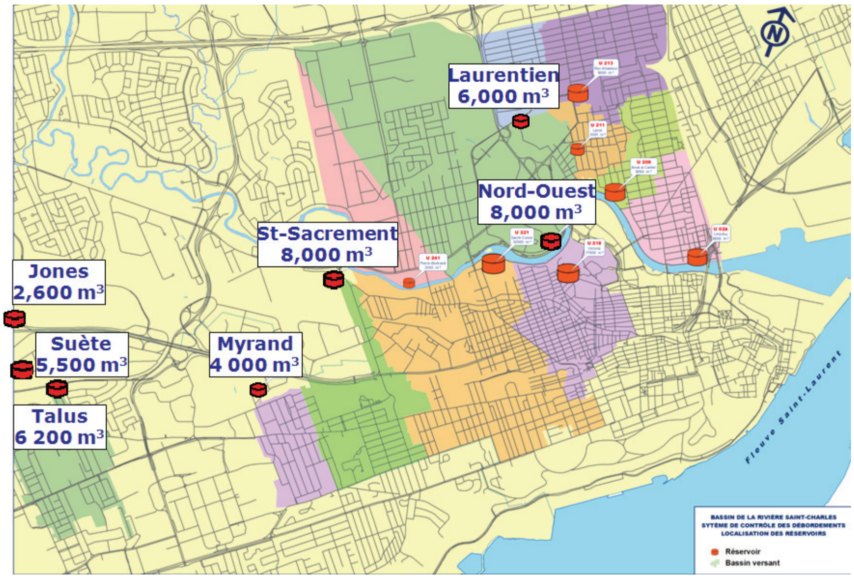

Figure 4: Storage Tanks Built During Phase 1 of the CSO LTCP

The four storage tanks located along the Versant-Nord Interceptor (i.e., Jones, Suète, Talus and Myrand) are filled and dewatered by gravity. The Laurentian and St-Sacrement storage tanks are filled by gravity, but are dewatered by pumps, whereas the Nord-Ouest tank is filled by pumps and is dewatered by gravity. All storage tank facilities consist of an upstream and downstream chamber, a weir and several aisles. The cleaning system consists of cleaning cells that can be flushed clean with sewer or tap water. These cells are equipped with flap gates controlled either automatically using the water level in the tanks or remotely by the operator at the WWTP.

The construction of the tanks was completed by the fall of 2004. The start-up of the RTC scheme was initiated during the spring of 2005. During the summer of 2005, the performance of the optimal RTC decision-making system was evaluated (Pleau and Simoneau, 2005). Four rainfall events with return periods ranging between one month and 5 years were analysed in details. As expected, based on the RTC simulation study conducted to size the storage tank, the rainfall events with returning periods smaller than six months did not create CSOs in the St. Lawrence River (see Table 4).

CSO Site	CSO Volume (m^3)			
	August 30th	**August 31st**	**September 22nd**	**September 29th**
	6-month Return Period	**5-year Return Period**	**6-month Return Period**	**2-month Return Period**
Affluent Tunnel	0.0	85,300	0.0	0.0
Versant Sud Tunnel	0.0	0.0	0.0	0.0
Jones	0.0	19,900	0.0	0.0
Suète	0.0	28,900	0.0	0.0
TOTAL	**0.0**	**134,000**	**0.0**	**0.0**

Table 4:
CSOs Recorded at the RTC CSO Sites Discharging in the St-Lawrence River
for 4 Rainfall Events Analyzed During the Summer of 2005

To achieve this performance in CSO abatement, the dynamic regulators were operated under the optimal predictive RTC scheme. The optimal flow set points were computed to maximize the use of the WWTP capacities available. When the upcoming flow to the sewer system reaches and exceeds the treatment capacity, the OP RTC scheme begins to accumulate the exceeding flows in the storage tanks and in the two tunnels. As shown in Table 5, CSOs appear only when all the storage capacity available is completely used. Thus, CSO volumes are minimized.. The dewatering of the sewer system starts when the upcoming flow amounts to less than the capacity of the secondary treatment plant. The optimal predictive RTC scheme behaves to maintain the flow at the treatment plant equal to the capacity of the secondary treatment plant until all storage facilities are fully dewatered. Hence, all of the water accumulated in the storage facilities receives full treatment.

Storage Site	August 30th		August 31st		September 22nd		September 29th	
	% of Stored Volume	Dewatering Time (h)	% of Stored Volume	Dewatering Time (h)	% of Stored Volume	Dewatering Time (h)	% of Stored Volume	Dewatering Time (h)
Versant Sud Tunnel	63.0	6.20	100	12.8	59.0	1.80	47.0	1.10
Affluent Tunnel	20.0	6.80	100	12.8	11.0	4.70	9.0	1.30
Jones	22.0	0.80	100	4.30	9.0	2.80	15.0	0.40
Suète	52.0	1.30	100	10.0	14.0	2.80	69.0	1.40
Talus	61.0	5.20	100	N/D	78.0	2.60	75.0	N/D
Myrand	19.0	0.80	100	9.90	18.0	2.60	35.0	1.80

Table 5: Stored Volumes and Dewatering Times for the 4 Rainfall Events Analyzed During the Summer of 2005

2.3.3 Phases 2 and 3

Phases 2 and 3 were executed together and aimed at completing the CSO LTCP to meet the effluent discharge requirement of no more than four overflows per summer season in the St-Charles River. To achieve this, four new control sites and seven storage tanks were built along the St-Charles River and integrated into the OP RTC scheme. These new storage sites create a total storage capacity of 87,000 m^3. The storage capacity of the largest storage tank, namely Sacré-Coeur, amounts to 32,000 m^3 (see Figure 5). These new structures are currently under start-up, and will be fully operational in time for the 2010 summer season. The total budget for Phases 2 and 3 amounts to $75M (US).

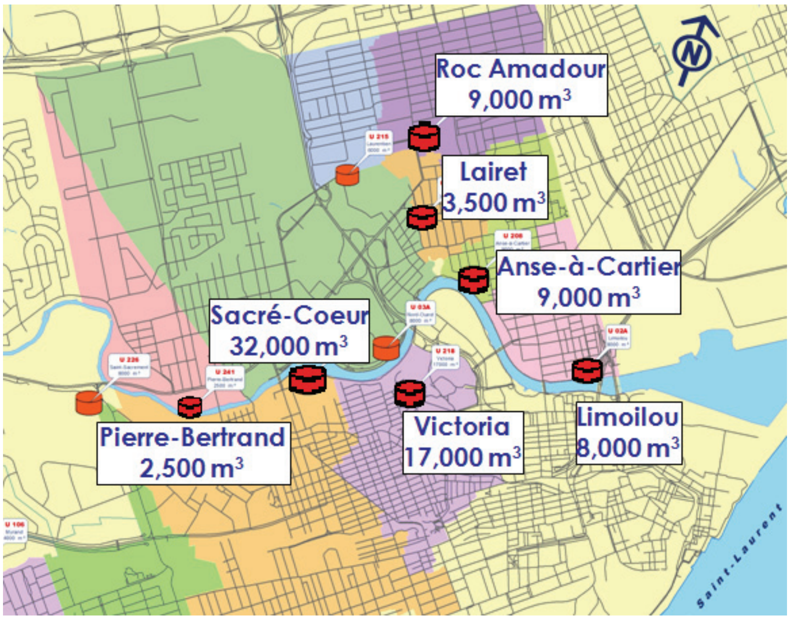

Figure 5: Storage Tanks Built During Phases 2 & 3 of the CSO LTCP

Unlike several storage tanks built in Phase 1, which are filled and dewatered by gravity, all storage tanks constructed in Phases 2 and 3 are either filled by pumping (e.g. the Limoilou storage tank) or dewatered by pumping.

3 RIVERBANK REHABILITATION FOR THE ST-CHARLES RIVER

The St-Charles River flows in the heart of Quebec City in a densely populated area. Until recently, however, secondary contact recreational water activities could not take place in the river because it was highly contaminated with fecal coliforms. In addition, the banks of the river were encased in high concrete and granite walls that restricted access to the river since the 1970s. Consequently, the river was seen by many as an open sewer rather than a playground were activities such as canoeing could take place. Each year, the City, with the help of volunteers, had to remove all kinds of trash from the banks and the river bed.

The St-Charles River Rehabilitation Project was initiated in 1996 and completed in the fall of 2009. The objectives of the project consisted in improving the recreational vocation of the land as well as to develop various wildlife habitats and in integrating bicycle paths and hiking trails along the linear park (see Figure 6). The project involved over 8,000 linear meters of riverbank located in a very densely populated area of the city. Some 600 trees, 1,500 shrubs and 20,000 herbaceous plants were planted to create 65,000 m² of wildlife habitat.

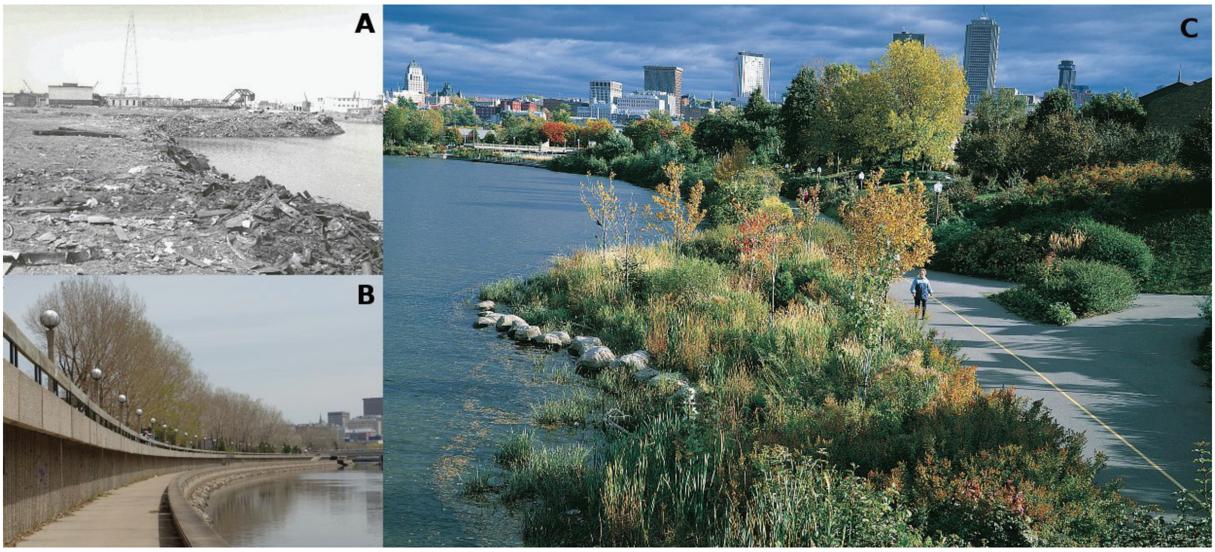

Figure 6: The St-Charles Riverbanks (A) in the 1950s, (B) before rehabilitation and (C) after rehabilitation

The riverbank restoration works took place while Phases 2 and 3 of the storage tanks project was underway. Most of the storage tanks are located very close to the riverbanks. As a result, substantial savings were achieved because the excavated material was distributed at the various construction sites. 85,000 m^3 out of 150,000 m^3 of cutting from the storage tanks was used as filling material in the river. Also, parts of the concrete and granite walls were reused as buttresses, abutments and retaining walls in various construction projects throughout the City during the same period.

4 CONCLUSION

The CSO LTCPs of the City of Quebec for its two main receiving water bodies, namely the St. Lawrence River and the St-Charles River, will be completed in 2010 and the performance analysis of the fully operational global optimal RTC scheme will take place in the summer of 2011. The entire project cost $125M, and both the construction schedule and cost estimates have been respected. The global optimal RTC of the fourteen storage tanks allowed the reduction of the size of the structures by 43% and of the construction fees by 50% when compared with a conventional static management approach.

The design and operation of a real time control system in Quebec City over the last nine years made the following achievements possible:

- A better understanding of the behaviour of the sewer system under various operational conditions;
- The improvement, integration and planning of other engineering works related to urban pollution control, such as the rehabilitation of the St-Charles riverbanks;
- The optimisation of the management of the sewer system even outside the required summer control period, i.e. in winter wet weather and in the snow melt period;
- Improved operation and maintenance of the sanitation works.

Over the years, the operators have become familiar with the RTC system, and can now propose ways to constantly improve it. In addition, the City has always kept improving the components of the RTC system, either by adding flowmeters, rain gauges or by adapting telemetry.

The Csoft™ dynamic model is not only at the heart of the RTC system, it is also used to study other issues in differed time. The solutions are then optimized because the dynamic management of the sewer networks in real time has been taken into consideration.

Most of all, the CSO abatement efforts made it possible to give the rivers back to the public through a rehabilitation of the riverbanks. The public now greatly enjoys these new spaces and the City won two prizes for their project.

Through experience and the success of its achievements, the City of Quebec has begun the next phase, i.e. the depollution of the Beauport Bay and the most eastern part of the City. Based on the feasibility studies, approximately 15,000 m^3 in retention volume will be required. Construction has been scheduled for 2010-2011.

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