Chapter 11

Microcomputer-Based RTC of CSOs in an Industrialized City

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The City of Hamilton is still largely served by combined sewers. During dry weather, and small storm events, combined sewage is conveyed to the Region's Woodward Avenue STP. During larger rainfall events, specifically high intensity thunderstorms, the combined discharge of stormwater runoff and sanitary wastewater may exceed the capacity of the sanitary interceptors and STP. Automatic regulators installed at various points in the system limit flow to the interceptors resulting in CSOs. The advent of inexpensive, computationally powerful microcomputers has introduced the possibility of economically controlling these regulators in real-time to minimize CSOs. While a small number of applications of this technology exist elsewhere, this approach has not been sufficiently tested in Ontario.

In 1989 the Regional Municipality of Hamilton-Wentworth initiated a demonstration project to design, install and evaluate a microcomputer-based real-time control system for managing CSOs.

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This paper reviews the following components of the Royal Avenue RTC Demonstration Project:

1. the design and installation of a real-time rainfall and flow monitoring network and telemetry system;
2. the design and installation of a microcomputer controller for operating the automatic sluice gate in the Royal Avenue CSO Regulator;
3. the estimation of CSO frequencies and volumes at Royal Avenue (with and without RTC) via continuous modelling, using the SWMM RUNOFF and TRANSPORT modules; and
4. the development of software for real-time data acquisition, database management and processing, and RTC of the Royal Avenue CSO regulator.

11.1 Introduction

Hamilton is one of the largest cities in Canada which is still predominantly serviced by combined sewers. The lower City, bounded by the Harbour headline in the north and the Niagara Escarpment in the south, is serviced almost entirely by combined sewers, as are the older, northernmost portions of the Hamilton Mountain. Newer suburban areas, mostly on the Mountain, are serviced by separate sanitary and storm sewer systems.

Two major sanitary interceptors service the City of Hamilton. Combined sewage collected from the lower City, and sanitary sewage from the West Mountain is conveyed to the Woodward Avenue Sewage Treatment Plant (STP) via the Western Sanitary Interceptor (WSI) which runs eastward along Burlington and Barton Streets. The Eastern or Redhill Creek Interceptor (RHCSI) runs parallel to the Redhill Creek, transporting sanitary and combined sewage flows generated by the remainder of the

Mountain to the STP. During dry-weather and small storm events, sanitary and storm flow is conveyed to the STP for treatment. Larger rainfall events, specifically high intensity thunderstorms, often generate flows in the combined sewer system in excess of design capacities. These flows may overload the sanitary interceptors and/or STP. In order to avoid flooding the STP or surcharging the sewer system, flow is diverted to the receiving waters as Combined Sewer Overflow (CSO).

The City's combined sewer system contains approximately 165 diversion structures, with 24 CSOs to local receiving waters (Chedoke Creek, Cootes Paradise, Redhill Creek and Hamilton Harbour).

A number of these diversion structures employ motorized gates which can be automatically opened or closed to regulate flow to the sanitary interceptor. These gates are activated either automatically by local water level sensors, or remotely by operators at the STP. The operator's decision to open or close a gate is frequently based upon prior operating experience using system status indicators including wet-well depth and flow readings upstream of a small number of regulator locations throughout the City. The dynamic spatial and temporal properties of rainfall events, especially thunderstorms, can generate runoff responses in which some sections of the sewer system are overloaded while others, which may be in close proximity, are flowing at only a fraction of their capacity. As a result, gate closure may be initiated well before interceptor capacity is fully utilized and deactivated long after flows subside. While such a procedure results in maximum safety for the STP and a lower probability of local basement flooding, CSO frequencies and volumes are likely greater than necessary. The potential for more precise control of these automatic diversion structures is evident.

Schilling (1985) surveyed several cities in North America which have investigated or installed RTC systems. From his survey it appears that RTC of CSO is feasible for various sizes of combined sewer systems. However, Schilling also identified a wide gap between research and applications of systems control concepts for CSO networks.

Recent technological advances have introduced the possibility of using microcomputers for controlling CSO diversion structures and/or storage in real-time to minimize CSO in wet and dry weather, in lieu of building costly supervisory control systems. While a small number of applications of real-time control (RTC) of CSO exist elsewhere, this approach has not been sufficiently tested to date in Ontario.

In 1987 the Region made application to the Ontario Ministry of the Environment (MOE) for funding of a demonstration project to evaluate microcomputer-based RTC of CSOs. Funding was provided equally by the Region through its Capital Budget and the MOE under the Province's Pollution Control Planning (PCP) Studies Program.

The main objectives of this project were to demonstrate microcomputer-based RTC at the Royal Avenue CSO Regulator, located near the intersection of Royal Avenue and Stroud Road, in West Hamilton and determine whether wider application of this new technology is feasible. The design, installation and evaluation of the proposed RTC system constituted the bulk of the project which was begun in 1989 and has been conducted entirely in-house by Regional staff.

This paper reviews the following components of the Royal Avenue RTC Demonstration Project:

1. the design and installation of a real-time rainfall and flow monitoring network, telemetry system, and microcomputer controller for operating the automatic sluice gate in the Royal Avenue CSO Regulator;
2. the development of software for real-time data acquisition, data processing and database management and RTC of the Royal Avenue CSO regulator; and
3. the estimation of CSO frequencies and volumes at Royal Avenue (with and without RTC) via continuous modelling, using the PCSWMM3 RUNOFF and TRANSPORT modules.

11.2 Real-Time Control of CSOs

The objective of a RTC system is to operate CSO regulators to make most efficient use of system storage, and to take full advantage of treatment facilities. RTC can eliminate unnecessary or premature diversions of combined sewage by utilizing in-line storage, and by controlling off-line storage facilities, detaining CSO until the sanitary interceptor and STP can accommodate it. RTC systems may also be able to divert unavoidable overflows to less sensitive receiving areas, and may reduce future storage requirements for CSO control.

Remote monitoring and control techniques are aimed at enhancing the operator's knowledge of the performance of the combined sewer system during a storm event and providing a means for effecting its operation. A computerized RTC system would continuously monitor the combined sewer system and use the data collected in real-time to operate CSO regulators and/or storage/treatment facilities within the system to minimize CSO.

A RTC system gathers and analyzes data acquired from monitoring stations and flow regulators in the combined sewer system. This data may include wind speed and direction, rainfall intensities, sewer depths and discharges, storage levels, regulator settings or positions and pollutant concentrations. Information is generally transmitted to a central computing facility, which controls the affected portion of the sewer system. The data is then immediately available for use by an operator, in a supervisory mode, or as input to an operational computer model, which usually comprises techniques for flow forecasting and optimization, in an automatic mode.

Combined sewer systems are particularly suited to RTC since they are seldom fully utilized, carrying less than 10% of capacity for roughly 90% of the time (Schilling, 1985). During most storms there will be unused volume within some major conduits. Furthermore, the design of storm and combined sewer systems has traditionally been based upon design storms derived from rainfall intensity-duration-frequency (IDF) curves. The limitations of this design methodology have been summarized by James and

Robinson (1982):

1. the procedure used to construct the design storm's synthetic hyetograph does not differentiate between storm types, and as a result, the design storm represents an amalgamation of many storm types (thunderstorms, cyclonic rains, etc.);
2. design storms specify a single rainfall distribution (i.e. hyetograph shape), and thus do not accurately reflect the real spatial and temporal variations of rainfall during storm events; and
3. current practice specifies a design storm with a particular return period, but does not specify a design antecedent dry period. Antecedent conditions can greatly affect the runoff and pollutant loads generated by a rainfall event. Consequently, the recurrence interval of the design rainfall event cannot be transferred to runoff or pollutant volume.

Without RTC, a combined sewer system designed in this manner can only be expected to perform optimally when it is loaded with its design storm (Schilling, 1990). The likelihood of such an event occurring in nature is minimal. During real storms, spatial and temporal rainfall variations may result in surcharging in some portions of the combined sewer system, while others are significantly underutilized. For example, small localized storms might generate CSOs even though storage is available elsewhere in the system.

The effect of storm speed and direction on the response of Hamilton's storm and combined sewer system to thunderstorms has been found to be significant. In Hamilton, storms coming from the southwest, and thus following the general direction of the drainage network, can result in significantly higher peak flows than storms of similar magnitude travelling in other directions. A critical storm speed has been found to exist for a drainage

basin, where storm travel time over the basin is comparable to its characteristic runoff response time (Scheckenberger, 1983). A given storm will yield the highest peak flows when travelling at this speed, in the direction of the drainage network.

A combined sewer system is said to be controlled in real-time if monitored data is used to operate CSO regulators during actual events. Generally a RTC system consists of the following components:

1. a regulator which can be manipulated to affect system performance (eg. a sluice gate);
2. one or more sensors to monitor the state of the system (eg. raingauges and/or flowmeters);
3. a controller to activate (i.e. open or close) the regulator;
4. a telemetry system which retrieves measured data from the sensors and transmits signals to the controller to actuate the gate; and
5. software to analyze the collected data, estimate future conditions and direct control of the regulator in real-time.

Regulator control strategies are generally classified as either reactive or adaptive. Reactive strategies are generally developed off-line, and simply react to the current discharge and storage conditions. Adaptive strategies comprise on-line forecasting and optimization. Control is based on continuous updating of flow forecasts in real-time. Real-time data acquisition is an essential component of an adaptive control scheme. The observed data is used to update forecast model parameters, thereby improving system performance.

Large scale deterministic computer models such as SWMM (Huber et al., 1983) are not presently suited to running in real-time at fine timesteps (5 to 15 minutes), on 286 and 386-based microcomputers. Such models do not provide updates of

forecasts in a computationally simple manner (O'Connell, 1980), although some methods have been suggested (O'Connell and Clarke, 1981). On the other hand, simple input-output methods, such as transfer function (TF) models, can provide accurate forecasts with very little computational effort. Patry (1983) provided a comprehensive analysis of water quantity and quality forecasting for urban catchments and developed both statistical and simple conceptual models based on deterministic and stochastic concepts.

In developing an optimization model, the objective function, whatever it may be, should penalize overflows and credit direct (and stored) throughflows to the STP (Bradford, 1976). By assigning different weights to overflows in the optimization model, based on their pollutant concentrations or their expected impacts on receiving waters, overflow sites could be selectively chosen so as to minimize their overall impact on the environment.

11.3 Real-Time Rainfall and Flow Monitoring

The design and operation of an RTC system relies heavily on telemetred rainfall data. Appropriate knowledge of rainfall intensity and storm dynamics is essential for hydrologic modelling and system forecasting.

Accurate measurement of depth and/or discharge in sewers and at control structures is also essential for the implementation of RTC of CSO. Real-time measurements can be used on their own as a decision variable for control purposes, or used to update or correct for errors in the performance of rainfall-runoff forecasting models.

A monitoring network consisting of ten electronic dataloggers and tipping bucket raingauges (TBRGs), and two ultrasonic flow monitors was installed in 1989 and has been operated continuously.

Independent, multi-channel electronic dataloggers were utilized to receive signals from these sensors, translate them into numerical quantities and temporarily store the values. Permanent

storage of this data was felt to be best suited to a central computing facility with high capacity, high speed access storage and system backup. By having the dataloggers independent from the sensors, monitoring system components could be interchanged which provided greater flexibility and reduced down time when taking equipment out of service for repair.

At present, the two flow sensors and three of the raingauges are connected to a Central Microcomputer Controller (CMC) by modem and dial-up telephone lines to permit real-time collection of rainfall and flow data. Data is currently transmitted at 1200 baud. The feasibility of using dial-up lines was evaluated during the project.

Raingauge locations were selected to encircle the Royal Avenue CSO regulator and hence provide advance information pertaining to storms coming from the main cardinal directions in particular the southwest, the prevailing storm direction in the area. The TBRG at Royal Avenue provides the detailed information required to forecast flows at the Royal Avenue CSO regulator.

The monitoring network provides the following information:

1. historical rainfall and flow data for the calibration and validation of the PCSWMM3 model of the combined sewer system;
2. historical rainfall and flow data for the continuous PCSWMM3 simulations; and
3. real-time rainfall and flow data for operating the Royal Avenue RTC Demonstration System.

A 286-based machine currently functions as the CMC, handling real-time data retrieval. To date, this machine has performed adequately as the CMC for the Royal Avenue RTC Demonstration System. Results of the study evaluation indicate that the use of a 286-based machine as the CMC for a large-scale RTC system would not be feasible due to hardware limitations and that 386 or 486-based equipment is more appropriate.

Data from the raingauge stations not equipped with modems is collected during site visits using a laptop microcomputer. This machine can also be used to program the data loggers (eg. select timestep, communications protocols, etc.) and perform some simple data processing on site. This approach facilitates prompt identification of instrument difficulties and allows in-situ bucket calibration. Minor maintenance problems can be addressed immediately and the laptop can be used to verify their resolution before departing the site. Instruments in need of more major repairs can be immediately replaced with working spares. This avoids the situation in which an inoperative sensor remains in the field undetected until data is processed and analyzed; often at a much later date.

In operating the system for the three year period it has been observed that the availability and quality of the dial-up lines are not sufficient for real-time data acquisition. Transmission errors would limit the performance of the RTC system. In future work only dedicated telephone lines will be utilized. It should be noted however, that for bulk retrieval of data, dial-up lines were adequate.

11.4 Data Acquisition and Management

Specialized software was required to provide a means of communicating with the remote electronic dataloggers for programming and reconfiguring the dataloggers, retrieving the recorded rainfall and flow data, processing the recorded raw data and displaying it in a more understandable format. A centralized database management system (DBMS) was required to archive the large volumes of collected data and to provide facilities for online querying and retrieval of archived data.

The HWRTC (**H**amilton-**W**entworth **R**eaL-Time **C**ontrol) software package was developed by the project team for operating the Royal Avenue RTC Demonstration System. The Data Acquisition and Management component of the HWRTC provides access to the following utilities:

1. HWCOMM
2. HWDPRO
3. HWDBMS

HWCOMM (**H**amilton-**W**entworth **D**atalogger **C**ommunications) is a collection of utilities developed to provide a means of communicating with the project's electronic dataloggers. **HWCOMM** supports RS232 serial communications with IBM-PC compatibles through a 4800 baud direct connection or via a 1200 baud modem on dedicated or dial-up telephone lines. These utilities are used to program or reconfigure certain characteristics of the dataloggers, and to retrieve recorded data from the logger's memory. Data from the three telemetered monitoring stations is retrieved by the CMC. Data from the remaining remote sites is retrieved on-site with a small laptop PC.

The data contained in the datafiles retrieved by **HWCOMM** is stored in a compressed format. **HWDPRO** (**H**amilton-**W**entworth **D**ata **P**rocessor) performs two main tasks: processing the data contained in the raw datafiles collected by **HWCOMM**, prior to appending to the central database; and converting the raw datafiles into the format needed to append the data to the central database. **HWDPRO** facilitates viewing acquired data in the field to check for station problems and generates a summary of the recorded rainfall and/or flow events contained in the raw datafiles.

HWDBMS (**H**amilton-**W**entworth **D**ata**B**ase **M**anagement **S**ystem) is a permanent, centralized database management system, created by the project team to archive, retrieve, and process the time-series data acquired by the rainfall and flow monitoring network. Rainfall and flow data can be retrieved and displayed in a number of formats, at any user-specified timestep, for any user-specified time period. Data may be displayed in either metric or imperial units, as selected by the user. Available data formats include rainfall event summaries, flow event summaries, daily and monthly rainfall volumes, and daily and monthly flow volumes. Rainfall intensities may also be written in **SWMM** **RUNOFF** module format (E1 and E2 data groups), and subsequently imported into a **RUNOFF** module datafile. This

option is especially useful for creating datafiles for continuous modelling, and was used to prepare datafiles for the continuous simulations conducted during the study.

11.5 Royal Avenue CSO Regulator Controller

The 2325 mm x 2850 mm Royal Avenue Box Sewer collects combined sewage from a catchment approximately 444 ha in area, located above and below the Niagara Escarpment, and conveys it to the Royal Avenue CSO regulator. The area below the Escarpment is serviced predominantly by combined sewers, while the drainage network above the Escarpment is separated. The Royal Avenue sewer receives separated stormwater at four inlet points from a total drainage area of 142 ha on the West Mountain. Stormwater entering at the most downstream inlet and combined sewage being conveyed in the Royal Avenue sewer from the west are prevented from mixing under low flow conditions by a 670 mm high wall which extends about 40 m west from the outlet (i.e. to a point which is upstream of the stormwater inlet).

Located just upstream of the outfall are two pipes, connecting the combined sewer to the Royal Avenue CSO Regulator Chamber. The larger 525 mm sewer conveys flow to the regulator chamber. The smaller 300 mm 'tell-tale' pipe, connected to a stilling well in the regulator chamber, was installed to allow measurement of the water level in the combined sewer, via a float recorder housed in the stilling well.

A motorized gate is located over the end of the 525 mm pipe leading from the combined sewer. This gate controls the flow of sewage into the 900 mm sanitary interceptor, which in turn conveys combined sewage to the STP via the WSI.

During dry-weather and smaller runoff events, sewage collected in the northern portion of the Royal Avenue catchment, and stormwater entering at the three upstream inlets is conveyed through the open CSO regulator to the 900 mm sanitary interceptor, to be treated at the STP. Separated stormwater runoff

from the southern portion of the basin, above the Escarpment and entering at the most downstream inlet, is discharged to the Chedoke Creek.

When the capacity of the regulator (i.e. the 525 mm sewer) is exceeded, excess flow will be diverted to the Chedoke Creek. If the gate is left open, approximately 0.6 cms of combined sewage will be intercepted and conveyed to the 900 mm sanitary interceptor. However, if the gate is closed, all flow will be diverted to the Chedoke Creek.

The motorized gate at Royal Avenue is an example of an automatic CSO regulator, and was felt to be well-suited for use in development of RTC technology. Originally constructed around 1969, the regulator was equipped with a remote measurement and control system, supplied by Bristol Babcock Inc, consisting of a float-type liquid level gauge, liquid level transmitter and receiver, and gate control panel. The installed system allowed the gate to be operated remotely by staff at the STP, or automatically actuated by the float recorder when it reached predetermined open or close setpoints. By the time this project began, the automatic gate control had been abandoned in favour of remote operation from the STP. The float gauge and transmitter were located inside the Royal Avenue regulator chamber. The recording flow receiver, gate control panel and power supplies for the transmitter and receiver were installed at the STP. The transmitter and receiver are connected by two dedicated Bell Canada telephone lines. A manually operated switch on the gate control panel determines how the regulator at Royal Avenue is controlled. The gate switch has three positions; AUTO, OPEN and CLOSE.

In the AUTO position, the operation of the gate was originally driven by the float gauge. The gate was set to close as soon as CSO to the Chedoke Creek began, and to reopen five minutes after overflow ceased. This level is approximately equivalent to the capacity of the inlet to the regulator. As long as the switch was set to AUTO, the gate would be operated in this manner. The gate's position was monitored with the aid of indicator lights on the control panel. Automatic operation of the gate can be

overridden by an operator at any time by moving the switch to either the OPEN or CLOSE position.

Under automatic control the level at which the gate was opened and closed remained constant from event to event. This system lacked the capability to adapt to changing conditions, because it relied on a single piece of information which did not accurately reflect conditions elsewhere in the combined sewer system.

In the RTC system developed, the CMC decides to open or close the gate after analyzing real-time rainfall and flow data from selected sites in and around the Royal Avenue CSO catchment. The status of other regulators in the system and the inflows to the STP should also be considered for future modifications of the system. The conditions which warrant opening or closing the gate will vary from event to event.

The CMC must generate a signal which will actuate the motorized gate at Royal Avenue. This interface is provided by the electronic datalogger, through its Auxiliary (AUX) Output Channel, a software selectable 12 volt DC (switched) signal. The datalogger is connected directly to the CMC through its serial port.

The gate is actuated by the RX relay in the transmitter in the Royal Avenue Regulator Chamber. To operate this relay, a signal voltage of 120 volts is required. The 120 volt signal is derived from the datalogger's 12 volt DC auxiliary output (AUX) with the assistance of a Gate Control Interface Module designed by the project team. The AUX signal is fed through this interface, which is connected to one of the spare card slots offered by the logger, and is used to operate any 120 volt AC device placed across the interface module, including the RX relay which operates the gate at Royal Avenue. The AUX signal is activated by the CMC via software. When AUX is turned on (and left on), the gate motor's RX relay is energized and the gate is closed. Conversely, if AUX is turned off, the RX relay is deactivated and the gate reopens.

11.6 Analysis of Royal Avenue CSO

Analysis of a combined sewer system, to determine CSO frequencies and volumes, should be carried out using a continuous hydrologic simulation package, for as long a term as practical given the available rainfall record. Continuous simulation provides more accurate estimates of antecedent moisture conditions and surface pollutant buildup. If the combined sewer system being modeled includes off-line storage tanks, initial levels of storage in these facilities are also known. Accurate accounting of antecedent conditions is required if reliable estimates of CSO frequencies and volume are to be obtained.

A suite of water quantity models was assembled with the following objectives:

1. estimation of current (i.e. no RTC) CSO frequencies and volumes;
2. generation of continuous rainfall-runoff time-series to provide a basis for development of real-time flow forecasting software; and
3. development of a RTC simulation model for estimation of future (i.e. with RTC) CSO frequencies and volumes.

These models are capable of simulating rainfall-runoff processes, flow routing, in-line and off-line storage, and the hydraulic operation of diversion structures, in continuous mode. The RUNOFF and TRANSPORT modules of PCSWMM3, a microcomputer version of the United States Environmental Protection Agency's (USEPA) Stormwater Management Model (SWMM), Version III, form the basis for the model simulations. The estimation of current CSO frequencies and volumes at the Royal Avenue Regulator, using PCSWMM3, indicates how the combined sewer system currently functions, without RTC, and provides a basis for the subsequent theoretical evaluation of proposed RTC strategies.

In addition, the rainfall-runoff time-series generated by the continuous SWMM simulations could be used to develop simplified flow forecasting models to predict the response of the Royal Avenue combined sewer system to recorded rainfall.

The RUNOFF model for the Royal Avenue catchment was calibrated using observed rainfall and flow data collected at the Royal Avenue CSO in 1990. Each calibration run consisted of a continuous simulation for May to July inclusive. Eight events during this period were calibrated. Original parameters were taken from an earlier RUNOFF model of the Chedoke Creek Drainage Basin. The Royal Avenue CSO Regulator is situated within this larger basin. The original Chedoke Creek model was calibrated using flow records collected downstream of Royal Avenue. The rainfall and flow data collected at Royal Avenue in 1990 allowed recalibration of the RUNOFF model for this drainage basin. The results of the Royal Avenue RUNOFF model calibration are presented in Figure 11.1.

Total volumes and peak flows for all eight calibration events fall within 20% of observed values. The adequacy of the calibrated Royal Avenue RUNOFF model was then checked using an independent data set of eight events, observed during July to October, 1990. Simulated volumes for all eight events fell within 20% of observed volumes and peak flows for seven of the eight events were within 20% of observed peaks.

The calibrated, validated SWMM model was run to estimate CSO frequencies and volumes at the Royal Avenue Regulator for 1989, 1990 and 1991. These estimates provide a basis for the evaluation of proposed strategies for controlling the gate in the Royal Avenue CSO Regulator.

The large volumes of rainfall data required for these analyses were handled by HWDBMS, the centralized database management system described previously. With HWDBMS, data from any of these gauges can be quickly retrieved and converted to the SWMM RUNOFF rainfall input format (E1 and E2 data groups). This greatly reduced the time and effort required to create datafiles for continuous simulation.

The TRANSPORT model of the box sewer in the vicinity of

Figure 11.1: Runoff calibration model results.

the outfall and regulator was constructed assuming the gate in the Royal Avenue CSO Regulator was always open and intercepting the maximum volume of combined sewage. Intercepted flows would be conveyed to the STP, unless diverted to local receiving waters by some other downstream CSO regulator. The model provides the following information:

1. the total inflow of combined sewage to the Royal Avenue Box Sewer;
2. the CSO which is diverted over the central dividing wall, from the combined sewer to the separate storm sewer, and subsequently discharged to the Chedoke Creek;
3. the total CSO discharged to Chedoke Creek; and
4. the combined sewage which is intercepted by the Royal Avenue CSO Regulator (when gate is open), for conveyance to the STP.

On average, there were 41 runoff events per year for the period 1989-91 (May through October), generating an average annual flow volume of approximately 454,000 m³ in the Royal Avenue Combined Sewer. Assuming the gate in the regulator is open, this results in 25 CSOs per year, on average, and approximately 83,000 m³ of CSO annually. About 82% of the combined sewage reaching the regulator is intercepted. The other 18% is discharged to the Chedoke Creek. The CSO frequencies and volumes generated by these SWMM simulations are in close agreement with those produced by a longer term analysis performed using 20 years of hourly rainfall recorded at the Mount Hope Airport and RBG AES stations. On average the simulations generated 22 CSOs per year for the 1970-89 period (May through October).

As stated earlier, these analyses assumed the gate in the Royal Avenue Regulator Chamber was open at all times. Records of gate operation kept at the STP indicate that the gate was closed

a number of times by operators during this three year period. These closures are generally initiated to decrease the hydraulic load on the STP during severe rainfall events, and prevent pumphouse flooding. While the reasons for the aforementioned gate closures is understood, it is also apparent that they have a significant impact on the total duration and volume of CSO at Royal Avenue, and that there are likely significant benefits to be gained from more precise operation of the gates.

In order to examine the impacts of a control strategy at Royal Avenue, the May to October, 1990 period was simulated assuming the gate closed when the flow reached the following levels: the threshold capacity of the regulator (0.6 cms), 1.25, 1.5 and 2.0 times the threshold capacity. Table 11.1 presents the intercepted flow, CSO volume and duration of gate closure for the above noted conditions as well as for the actual operation of the gate.

Table 11.1: Impact of control strategies on CSO volume.

Control Strategy	Intercept Flow (1000 m ³)	(%)	Total CSO (1000 m ³)	(%)	Gate Closure (hours)
1	409	82	88	18	0
2	285	57	211	43	142
3	229	46	268	54	83
4	320	65	176	35	41
5	361	73	136	27	22
6	388	78	109	22	10

Note: Strategy 1: Gate open all the time

Strategy 2: STP operation of gate in 1990

Strategy 3: Gate closed when flow = 0.6 cms

Strategy 4: Gate closed when flow = 0.75 cms

Strategy 5: Gate closed when flow = 0.9 cms

Strategy 6: Gate closed when flow = 1.2 cms

As can be seen from the table, the minimum amount of CSO is generated by leaving the gate open under all conditions. However, this also generates the maximum amount of flow to the STP. It is evident that this volume of flow is unacceptable for operation of the plant since the gate is frequently closed by operators. It is interesting to note that closing the gate at the threshold level of the regulator actually produces more total overflow for the full year than the rather imprecise method of operation currently practised. This indicates that there is likely a better setpoint, in excess of the 0.6 cms, which increases the intercepted flow while not adversely affecting the STP. In the absence of information about levels at other regulators in the system, such a setpoint could form a viable operating strategy for the Royal Avenue regulator.

11.7 RTC Demonstration System

The RTCDEMO (Real-Time Control Demonstration) component of the HWRTC is the operational software utility for the Royal Avenue RTC Demonstration System. RTCDEMO retrieves real-time rainfall and flow data from monitoring stations in and around the Royal Avenue catchment, analyzes and displays this information, and directs control of the gate in the regulator chamber. The proposed RTC system is shown schematically in Figure 11.2.

For the purposes of testing and demonstration of the RTC, the CMC was installed at the STP. It is likely that any permanent RTC system installation will be centered there. A datalogger containing the Gate Control Interface Module described previously was connected directly to the CMC via a 4800 baud serial interface. The dataloggers at the three remote stations

Figure 11.2: Hardware for proposed RTC system.

outfitted with 1200 baud modems, were linked to the CMC via dial-up telephone lines. RTCDEMO accesses the dataloggers at these three stations, retrieves and displays the latest recorded rainfall and flow information. Rainfall recorded by the TBRGs during the previous four time intervals (20 minutes), is presented as five-minute average intensities in mm/hr. Flow-related information for the Royal Avenue Box Sewer which may be displayed includes measured flow depths (m), measured flowrates (m^3/sec), forecasted flow depths (m), and/or forecasted flowrates (m^3/sec).

The current status of the gate in the Royal Avenue Regulator Chamber is displayed; OPEN or CLOSED, or in the process of OPENING or CLOSING.

The information retrieval cycle requires approximately 2 minutes and is repeated every 5 minutes. The remaining 3 minutes of each data acquisition cycle is available to determine gate setting. Field measurements indicate that the gate takes approximately 100 seconds to open (or close) after the appropriate signal is sent.

The current version of RTCDEMO offers two distinct operating modes; supervisory and automatic control. Supervisory control is the default mode of operation for the gate, and is enabled when RTCDEMO commences. In this mode, RTCDEMO acts as a decision support tool providing information on system conditions to an operator. The operator has responsibility for analyzing available information, deciding on the appropriate gate setting and transmitting the signal which opens or closes the gate. In automatic control mode RTCDEMO provides several algorithms for local control of the Royal Avenue gate. An operator must initially change the RTCDEMO's control mode to automatic from supervisory. At this point, the operator is required to select the algorithm which is to be used for gate control. RTCDEMO will use this algorithm to automatically determine gate setting until supervisory mode is reestablished or until another automatic algorithm is selected.

The structure of RTCDEMO is such that control algorithms can be added, deleted or modified off-line and RTCDEMO reinstalled. The control algorithms can be mathematical equations for rainfall or flow forecasting evaluated using real-time data, actuation setpoints dependent on real-time rainfall or flow data or knowledge-based rules. These options were included to demonstrate some of the parameters and techniques which might be used to direct automatic RTC of Royal Avenue and similar regulators. The design of the software provides a general tool which can be adapted to other regulators within the combined sewer system.

Investigation has shown that control points in the combined

sewer system must be operated as a complete system accounting for treatment plant conditions. It was beyond the scope of this phase of the study to monitor and model the entire city-wide system. The current status of RTCDEMO limits its use to improvement of local control of a regulator. Until a City-wide RTC system is developed, the overall benefits of such local control strategies will be unknown as will requirements for modification to these strategies.

11.8 Conclusions

The Regional Municipality of Hamilton-Wentworth has recently completed a demonstration project to develop and evaluate technology for microcomputer-based real-time control of CSOs. The project was conducted at the Royal Avenue CSO regulator in West Hamilton. The study has found that it is feasible to implement low-cost microcomputer-based control at regulators and control points in a combined sewer system in order to reduce the frequency and volume of combined sewer overflow through more precise operation. 286-based machines were found to be satisfactory for single site operation but it is expected that 386 or 486-based machines will be necessary for a city-wide system.

1. A real-time rainfall and flow monitoring network and telemetry system was installed and operated for three years. Appropriate hardware was evaluated and selected and software was developed for real-time data acquisition, data processing and database management. Dial-up telephone lines were found to be satisfactory for operating a data collection system off-line using periodic bulk retrieval of data but were found to lack the reliability necessary for real-time data acquisition.
2. The PCSWMM3 RUNOFF and TRANSPORT modules were used for continuous modelling of the Royal Avenue catchment to investigate the impact of proposed RTC strategies on CSO frequencies and volumes at the Royal Avenue regulator.

3. A microcomputer-based controller for actuating an automatic sluice gate in the Royal Avenue CSO Regulator in real-time was built, installed and successfully tested.
4. Software for real-time control of the Royal Avenue CSO Regulator in either a supervisory (operator-controlled) or automatic (algorithmic-controlled) mode was developed and tested. The software has been structured for flexibility in adding or deleting algorithms to allow adaptation to other regulators in Hamilton's combined sewer system.
5. A second phase of the study to develop a real-time control system for the complete combined sewer system has begun. This project will require the interaction of all regulators and control points together with the operation of the treatment plant be accounted for. The toolkit of techniques, hardware and software for local control developed in the first phase of the work will be used.

11.9 References

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