Chapter 5

Operational Model Development for a Regional Municipality

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The Regional Municipality of Ottawa Carleton (RMOC) initiated the development of an operational model as part of the wastewater system Pollution Control Planning Strategy and the Master Planning process to give them a powerful tool for the integrated analysis of the Regional wastewater collection and treatment systems.

It was recognized, with the recent upgrade to the wastewater treatment plant, that an opportunity existed to review the operation of the Regional sewerage facilities to identify system configurations and control strategies that would provide cost-effective pollution control. The Region found limited information was available on the hydraulic operation of the interceptor sewers and regulating chambers, leaving them in a position of not being able to make informed operational decisions. As well, the Region was unable to identify remedial or operational measures that would complement the upgraded capacity of the wastewater treatment plant. To this end, the Region undertook the Operational Review Study that included the development of an operational model with the goal of developing an analytical tool to be used in developing operational and long term strategies.

The primary function of the operational model is to simulate the behaviour of the collection system and treatment facilities. The model will also have ancillary data management, user interface and data analysis functions. XP-SWMM program was selected as the collection system model and the GPS-X program to model the treatment plant process.

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The objective of the chapter is to describe the steps taken to develop, calibrate and apply an operation model in the Region of Ottawa-Carleton. An overview of the model selection process is presented, however, the main focus is on the definition of the collection system, development of hydrologic parameters for summer, spring and snowmelt conditions, the calibration process, and the application of the operational model to evaluate various overflow control measures and operational changes to the collection system.

5.1 Background

In Ottawa Carleton, wastewater is collected by seven local municipalities and conveyed by the Regional trunk system to the central Regional treatment plant. Figure 5.1 shows the key collection system facilities in the Region.

The service area is approximately 16,000 hectares of mixed residential, industrial and commercial land use, with a population of nearly 600,000. Most of this area is served by separated sanitary and storm sewers. Portions of the separated area are nevertheless significantly influenced by inflow/infiltration (I/I). The downtown core area of the City of Ottawa collection system remains combined and is linked to the Regional system via flow regulating structures. Areas adjoining the combined area are partially separated in that road drainage has been redirected to a separated storm sewer. These areas are also subject to significant I/I flows. Table 5.1 summarizes the Regional wastewater facilities.

The newly upgraded R.O. Pickard Environmental Centre provides wastewater treatment for the Region and will meet the Regional needs in the foreseeable future. The main pumping station is operated so that a substantial length of the Ottawa Interceptor, Ottawa Outfall and Orleans-Cumberland Collector are continually operating under surcharged conditions. A portion of the flow from the Green Creek Collector can enter the plant by gravity. In 1995 it is expected that the construction of the South Ottawa Collector will be completed to convey flows from the South Ottawa drainage area to the treatment plant by gravity, eliminating the need for the Watts Creek WPCP facility.

The important Regional wastewater system features and processes identified that were incorporated into the operational model include:

- interceptor and collector sewers in a range of diameters,
- flow regulating structures,
- pumping facilities,
- treatment facilities,
- inflow/infiltration and combined sewer flow,
- combined sewer overflow,
- sewer surcharge and backwater, and
- flow routing effects.

Figure 5.1 Collection system features.

Table 5.1 Summary of regional wastewater facilities.

Trunk and Interceptor Sewers	Total of 142.5 km of sewers in a diameter range from 250 mm to 2,743 mm.
Pumping Stations	Fifteen pumping stations in a range of capacities. Two pumping stations (Richmond and Acres Road) are of the varispeed type, the remainders are fixed speed.
Flow Regulators	Six regulators are located along the main interceptor sewer. The purpose of the regulators is to control the quantity of combined sewage flow entering the Regional trunk interceptor system. (Note: the City of Ottawa system has a number of local overflows upstream of the major regulators).
Wastewater Treatment Facilities	<p>Region operates two treatment facilities:</p> <ul style="list-style-type: none"> • R.O. Pickard Centre: <ul style="list-style-type: none"> - average capacity 545 MLD - peak capacity 1,350 - current flow 430 MLD • Watts Creek WPCP: <ul style="list-style-type: none"> - 30,700 m³/d <p>Both facilities are secondary treatment plants. The Watts Creek plant will be decommissioned within the next five years.</p>

5.2 Operational Model Selection

The operational model is a decision support tool, for attaining environmental objectives, engineering planning of Regional wastewater facilities, as well as supporting the operation of Regional Wastewater facilities and training of Division staff.

The operational model includes two major functional elements each with its own interface, data analysis and management capabilities:

- collection system analysis sub-model, and
- treatment plant analysis sub-model.

Early in the selection process it was necessary to define the functions of the collection and treatment sub-models. The specific functions of the collection system sub-model include:

- Flow generation for separated, partially separated and combined areas for summer, spring and snowmelt conditions.
- Network analysis including detailed hydraulic analysis of the collection system (interceptors, regulators, pump stations, diversions) which operate under open channel and surcharged conditions, as well as, continuous overflow analysis.
- Graphical and statistical analysis of observed and simulated results.
- Graphical User Interface (GUI) and compatibility with existing computing systems and with future GIS or other information systems (e.g. SCADA).

After defining the functions of the operational model, the next task was to select a model or group of models that would best meet all of the Regional requirements. A review of existing commercially-available models associated with hydrologic and collection system analysis was undertaken to identify candidate models.

The long list of potential operational model models was shortened through a process that addressed several basic factors such as cost and technical support. Essentially, models that were costly to purchase and maintain were not considered (i.e. Dorsch, Spida). Technical support was very important to the Region concerning technical transfer, model development and ongoing timely support. A short list of models that were considered to make up the core of the collection system model included SEWHYMO, QUALHYMO, RUNSTDY, and SWMM among others. Each model reviewed was evaluated based on their individual advantages and limitations. It was recognized throughout the selection process that one model may not be appropriate but several models integrated would be necessary to satisfy the objectives.

The end result of the extensive assessment process was the selection of XP-SWMM as the collection system sub-model. XP-SWMM was selected as it satisfied the present and future analytical needs of the Region, is based on the widely accepted and documented EPA SWMM 4.2, has a GUI and the modeling system is expandable. For the wastewater treatment sub-model, GPS-X, fully met or exceeded all the Regional requirements. GPS-X is a dynamic modeling system for the design, operation and control of wastewater treatment plants under dynamic conditions.

5.3 Collection System Sub-Model Development

The development of the operational model required data from many sources including, both historical and current records. The process of development followed these basic steps:

1. define collection system networks,
2. assemble collection system physical data,

3. load collection system information into XP-SWMM,
4. delineate the drainage areas to each system node and assemble catchment information,
5. define system elements for each mode of operation, and
6. calibration/verification using flow data.

5.3.1 Define Collection System Network

The modeled collection system network is a simplified version of the Regional Lotus database and CAD plan. The database and plan were reviewed in detail to verify data as well as to identify key points in the network to be included as nodes in the model. A node was identified if any of the following conditions existed:

- change in pipe diameters,
- significant change in pipe grades,
- regulating structures (pump stations, overflows, diversions, gates, etc.),
- confluence points of major interceptor and collector sewers,
- outfall locations,
- identified problem areas,
- potential location of remedial measures (i.e., storage), or
- to subdivide a long continuous section.

The resulting simplified network formed the basis for the operational model development.

5.3.2 Assemble Collection System Physical Data

The Regional database was used to compile the physical and spatial information of the network. The database was simplified to include only the key nodes and link elements previously identified. The simplification was done in Lotus such that a change to the original database would translate in a change to the simplified version.

5.3.3 Load Collection System Information into XP

XP utility programs were used to load the basic physical information, such as maintenance hatch x-y coordinates, maintenance hatch inverts, pipe length, diameters and inverts, into the XP-SWMM database for the entire network. Detailed physical information on all regulating structures and overflows were compiled separately and entered manually.

5.3.4 Delineate the Drainage Areas and Assemble Catchment Information

From the Regional database and plan the drainage areas to each of the network nodes were defined. The result is a lumped catchment model. The database contains information about the total drainage area and a breakdown of land use (institutional, commercial, industrial, utility, recreational, open, vacant and residential). As well, the database defines the percentage of the area that is combined, partially separated and separated.

In preparing the data for XP-SWMM, the drainage area was broken down to reflect the different sanitary service types (combined, partially separated and separated). The subdivision of the drainage area into its service type would make it easier in the future to assess the impact of source controls and separation programs by re-allocating the area from one service type to another.

The model parameters associated with runoff flow generation were determined in the calibration and verification process.

5.3.5 Define System Elements for Each Mode of Operation

XP-SWMM has internal data verification routines that force the user to display and approve each dialogue screen where data has been entered. This forces the user to review and verify both the data bulk loaded and the manually entered data. At this stage of the operational model development the individual system elements were defined in the appropriate computational mode or modes (i.e. RUNOFF, TRANSPORT and EXTRAN).

5.3.6 Calibration/Verification

The calibration/verification process was considered to be an essential part of the operational model development and implementation to ensure confidence in the analytical results. To this end, an extensive calibration effort was undertaken to characterize system response for summer, spring and snowmelt conditions.

The complex nature of the collection system required a systematic calibration process to reduce the iterations required to achieve good agreement between monitored data and simulation results.

The initial activity in the calibration process was to identify the available collection system monitoring data. As part of the Operational Review Study, a flow monitoring program was conducted to provide flow and rainfall data to calibrate the operational model. The program was designed to measure system response at the following key locations:

- total flows reaching R.O. Pickard Environmental Centre,
- flows in major sub-basins (i.e. Rideau River, Mooney's Bay, Green Creek, etc.),
- overflows, and the
- Hydraulic Grade Line (HGL) in the West Nepean, Ottawa Interceptor and Ottawa Outfall.

The program was divided into two periods, summer and fall 1992, and winter and spring 1993. Historical flow data was used to provide additional flow information throughout the system, based on annual flow monitoring programs that have been ongoing since 1987. The Region and City of Ottawa maintain fifteen rainfall monitoring stations used for collecting rainfall data throughout the Region. The stations are geographically distributed throughout the Region, providing excellent spatial coverage.

The flow data and rainfall records were reviewed for each site to isolate suitable wet weather events for model calibration. Identified as suitable calibration events were five summer, two spring and one snowmelt events.

Only one sub-drainage area was calibrated to simplify and start the calibration process. The Rideau River basin was selected over other basins given the consistent flow monitoring data set, that the catchment area comprises all service types (combined, partially separated, separated) and that the drainage basin is one of the largest in the Region with a CSO regulator controlling flows into the Regional interceptor system. The objective of using the Rideau River drainage basin for the initial model calibration was to develop some guidelines in establishing representative model runoff and infiltration parameters as well as to isolate parameters that could be reasonably fixed. The verification of the runoff and infiltration parameters was achieved by applying the same guidelines to calibrate the remaining drainage basins and having good agreement between monitored flow and simulation results.

The guidelines developed for the operational model set up and calibration include:

1. Drainage Area

The net drainage area is the gross drainage area less the sum of the open space, vacant space and utility area. The three areas are subtracted from the gross area as they are considered to be unserved. The net drainage area is separated into three separate drainage areas, combined, partially separated and separated based on the percentage of each service type.

2. % Imperviousness

The % imperviousness is fixed for combined areas at 30%. Partially separated areas range from 1.5% to 3% imperviousness. For separated areas, the % impervious range between 0.5% and 1%.

The %imperviousness is based on historical flow monitoring and modeling work conducted by the Region. In these studies the runoff coefficients were calculated to be approximately 30%, 3% and 1% for combined, partially separated and separated areas respectively. The runoff coefficients were converted into an effective %imperviousness for the operational model. An effective %imperviousness was selected and used over an effective area in order to maintain the drainage areas measured. By using the effective %imperviousness and the measured areas, sewer separation could be more easily evaluated without having to recalculate an effective area.

3. Width

The definition of catchment width in SWMM is applicable to smaller drainage areas. In most instances the operational model was structured with large lumped catchments that inherently provide collection system storage, distorting the definition of catchment width. To overcome this the width was re-defined, based on the catchment type. Combined areas have immediate response to wet weather events, thus the combined area width was measured from the drainage area maps and represents the average length of overland flow for the entire drainage area. The width factor for the partially separated and separated areas was taken to be 10% of the overall catchment width. This reduction in the width is possible because the effective drainage area for a separated or partially separated area is less than the actual drainage area. Secondly, the mechanism by which surface runoff infiltrates into a separated or partially separated system is different from the immediate response of a combined system. A reduction in width reduces a hydrograph peak flow and prolongs the response time.

The percent imperviousness and width factors initially employed were all evaluated in the calibration and verification process.

4. Land Slope

The slope is generally fixed at 1% for all service area types as the ground slope in the Ottawa-Carleton Region is reasonably consistent. The slope was reduced in some areas to 0.5% during flow data calibration.

5. Manning n

The Manning n for pervious and impervious areas was initially set at 0.25 and 0.15 respectfully. In some areas the Manning n was increased for pervious areas to 0.30 during flow data calibration

(this was done with reducing the slope from 1% to 0.5%). The Manning n for pervious and impervious areas was adjusted for spring time calibrations.

6. Depression Storage

The percentage of impervious area with no depression storage was found to be not sensitive and is fixed at 25%. Depression storage for pervious and impervious areas were fixed at 3.0 mm and 2.0 mm respectively across the entire area. Depression storage parameters were changed for spring time calibrations.

7. Infiltration

The Horton infiltration routine was used for the operational model. The maximum infiltration rates were set at 38.1 mm/hr, the minimum rate at 7.62 mm/hr and the decay rate at .0015 1/s. The infiltration parameters were adjusted for spring time.

In the calibration process, the above guidelines were developed and found applicable across the entire collection system. However, one limitation became apparent that could not be addressed in the calibration of each sub-basin using the runoff and infiltration parameters. The RUNOFF routine is limited in accounting for sewer Rainfall Derived Infiltration (RDI) which occurs after a rainfall event and can last several days. During the calibration of the sub-basins RDI was apparently an important component of the wet weather response in the collection system. Several methods were investigated to determine the best approach to introduce RDI.

XP-SWMM has a global sewer infiltration routine that applies to the entire collection system. In this routine, infiltration flow varies with the antecedent conditions and the infiltration rates. The RDI flow is distributed throughout the collection system based on a pipe diameter and pipe length function. This method was found not to be an effective way to introduce RDI given the variation of RDI rates across each sub-basin.

The second method investigated used the XP-SWMM groundwater routine. The groundwater routine was effective in introducing flow into the collection system at the individual catchment level accounting for the differences between sub-basins. However, there are many input parameters associated with groundwater that cannot be systematically determined across the collection system. As well, the groundwater routine is extremely dependent on the groundwater elevation that fluctuates during a simulation based on the antecedent conditions, infiltration rates and precipitation.

Using an additional sub-catchment to introduce the RDI at each runoff node was investigated as an alternative to using the XP-SWMM global sewer infiltration or groundwater routine. This technique allowed the model to reflect the RDI

characteristics of each drainage basin. The runoff parameters for each drainage sub-basin were developed through the calibration process to achieve the best fit for RDI. A RDI drainage area was not introduced in those sub-basins with no local flow monitoring data. Given the variability of RDI in each sub-basin, it was felt that the RDI for one area could not be assumed to be the same as for another area. This method was found to be the best overall and was used throughout the collection system.

Calibrations were initially completed for summer time wet weather events. A second calibration exercise was conducted to adjust the operational model for the spring freshet period. Flow monitoring data collected in Phase II of the monitoring program showed a significant increase in dry weather flow in the spring. Historically, the elevated flows start at the end of May and last through to the end of April, as observed in the 1993 data. The elevated flows are a combination of increased infiltration and inflow caused by saturated ground conditions and snowmelt.

To simulate these conditions three adjustments to the operational model were required with regard to:

1. the average dry weather flow,
2. infiltration parameters, and
3. the introduction of snowmelt.

Average dry weather flow values were increased across the collection system to reflect the spring flows observed in the recent flow monitoring program and the treatment plant flows. To achieve a suitable comparison between the monitored flows and the computed flows, adjustments were made to the Manning n for pervious and impervious areas, depression storage and infiltration parameters, all of which have the effect of increasing runoff volume and prolonging the runoff event while not increasing the peak flow.

XP-SWMM has a snowmelt routine for single event or continuous simulation. During the development of the operational model the single event analysis component of XP-SWMM, which was used, was not capable of simulations greater than 24 hours; this has since been rectified. Calibrating the operational model was conducted only for single event analysis at three separate monitoring locations and verified using flow data for the R.O. Pickard treatment facility. Temperature and snow pack data for the March 26, 1993 calibration event was extracted from the flow monitoring report. Calibrating the snowmelt component of the operational model required that assumptions be made with respect to the percent snow coverage, the initial free water, percent free water holding capacity and monthly wind speeds. The assumptions made remained fixed in the calibration process. The only model parameter adjusted was the snowmelt coefficient that was found to vary between 0.25 and 0.38. Although the snowmelt calibration is limited to one event, March 26, 1993, where temperature, snow pack and flow data were available, future monitoring programs can be tailored to collect additional snow melt data suitable to refine the initial calibration.

Figure 5.2 shows reasonably good agreement between monitored flows and simulation results for the summer, spring and snowmelt calibration curves for the Rideau River monitoring location between (the snowmelt simulation was limited to 24 hours).

5.4 Operational Model Analysis

The application of operational model will assist the Region in developing operational controls and long term strategies. Operational measures evaluated include:

- main pumping station operating level and capacity,
- collection system storage,
- diversions,
- source controls,
- regulator settings, and
- storage facilities.

The operational model was used to evaluate the hydraulic performance as well as the CSO control for each operational measure proposed. Initial conditions were established for the existing collection system under summer time conditions with the Watts Creek WPCP decommissioned and the new South Ottawa Collector in operation.

Hydraulic analysis was conducted using a 2-year design storm event and a historical event that occurred on September 12, 1986. Both events cause surcharge to occur in the collection system at various points and were considered suitable for evaluating the effect of operational changes on the collection system hydraulic performance.

Overflow analysis was conducted using a typical year determined from an analysis of the long term AES rainfall records. From hourly data collected at the Ottawa International Airport, 1980 was selected as the typical year. The effect of operational improvements on CSO control was an important goal in this project as it was determined that conveying wet weather flows to the treatment plant for primary treatment was more cost effective than other CSO abatement options.

Figure 5.3 shows the normal operating HGL for the main interceptor in the Regional collection system under dry weather conditions and at the peak of the 2-year design storm event. To determine the effectiveness of each operational change the same HGL profile was reviewed to identify hydraulic benefits. As well, a continuous analysis was conducted to determine if there was a CSO reduction possible by the operational change. The final stage in evaluating each operational measure was the cost-effectiveness.

Figure 5.2 Flow calibration.

Figure 5.3 Hydraulic grade line profile.

5.5 Operational Changes

5.5.1 Main Pumping Station Operation

The operation of the Main pumping station was found to have an immediate impact on both the hydraulic performance and CSO control by maximizing flows to the treatment plant. The operational model confirmed that the wet well operating elevations at the Main pump station greatly influence the capacity of the interceptor during wet weather. Pump station operations have been modified to optimize capacity in the interceptor during wet weather. Plant operators now draw down the wet well prior to wet weather events to reduce surcharging in the interceptor and run more pumps to increase the carrying capacity of the interceptor. This change in operations maximizes flows to the treatment plant and provides treatment for combined flows that would have otherwise overflowed to the Ottawa River. The integration of the treatment plant model allowed Regional staff to assess the impact of increased flows to the plant over a prolonged period. The result is an estimated 25% reduction in CSO volume to the Ottawa River on an annual basis.

5.5.2 Collection System Storage

A complete analysis of existing pipe capacity was carried out to identify hydraulic restrictions and potential in-line storage opportunities. Unfortunately, no significant in-line storage was found in the collection system. However, the analysis revealed a significant hydraulic restriction at the Booth Street diversion structure. The restriction routinely surcharges upstream tributary trunks that contribute to basement flooding and surface failures. Capital improvements will be made in the near future to remove the restriction and regulate flow into the interceptor as part of the proposed new central off-line storage scheme. In the meantime, the operating practice of this regulator has been changed and linked to the flow levels in the tributary collector sewers. Once the HGL reaches a critical level in the tributary sewers the overflow gate will be opened providing relief.

5.5.3 Diversions

Three diversions were considered to divert flow from the upstream end of Woodroffe, Mooney's Bay, and Rideau River collection systems to the new South Ottawa Collector, away from the main Ottawa Interceptor/Outfall. Hydraulically, the diversions had minimal impact for the 2 year design event. However, CSO control was improved by a 14% reduction in annual overflow

volumes. In addition to the CSO control, this operational change can provide the Region with some flexibility in routing flows for improved maintenance of downstream facilities.

5.5.4 Regulator Settings

The Region had limited information on the operation of the regulators. Using the operational model, the Region was able to quantify the annual overflow volume of 845,300 m³/d and on a regulator basis determine the frequency of overflow and volumetric control. Changing the regulator settings was considered for each of the operational measures evaluated with the goal of increasing the intercepted volume. The operational model allowed the Region to consider several changes to the present regulator settings in conjunction with changing the operation of the Main pumping station. Presently, the Region is evaluating the physical condition of the regulators to determine if newer technology needs to be employed to achieve the control required. As well, to address their combined sewer area, the City of Ottawa is in the process of planning a central storage tunnel that will influence the flows at each regulator in the central part of the collection system. The operational model will be used to assist the Region in setting new regulator capacities to reduce CSO volumes.

5.5.5 Source Controls

Although source controls may not be considered an operational change, the operational model was used to evaluate the impact of reduced inflow and infiltration into the system. Because of the structure of the runoff catchment model it was possible to simulate separation of the combined sewer system to a partially separated system. In effect, the inflow and infiltration was reduced into the collection system. Hydraulically, there was an improvement in the Ottawa Interceptor/Outfall performance, however, the greatest improvement was in CSO control with a 95% reduction in overflow volumes. The drawback of separation as a source control is the overall cost.

5.5.6 Central Storage

The largest combined sewer area is in the City of Ottawa. In a Combined Sewer Area Pollution Control Planning Study conducted for the City of Ottawa a storage tunnel option was identified as the most cost effective pollution control method available. The planned tunnel will intercept excess combined sewer flow during wet weather periods. The operational model has allowed the Region to assess the impact of the Ottawa Tunnel project on the Regional collection system and treatment plant facilities. As well, the operational model was used to evaluate

the possible extension of the tunnel to include wet weather flow volumes from other areas to form an integrated Regional solution to wet weather flow management. Presently, the operational model is being expanded to include additional collection system details in the City of Ottawa combined sewer area and to assist in the pre-engineering design of the storage tunnel facility. Hydraulically, the central storage facility, if extended by the Region, will have the positive effect of lowering the HGL in the West Nepean Collector. As well, a CSO control level of 90% volumetric control would be achieved at each regulator with the implementation of the tunnel storage. The extension to the City of Ottawa storage tunnel is presently under consideration by the Region as part of a Regional pollution control strategy.

5.6 Conclusions

The operational model was designed to assist the Region in making informed operational decisions and to assist in facilities planning. To this end, the operational model has been a successful decision tool allowing the Region to make operational changes that will provide immediate environmental benefits and to plan future operational changes and capital facilities. As the operational model evolves it is anticipated that it will take on a greater role in the Master planning process as additional details are built into the model.