Chapter 12

Application of the SWMM4 Model for the Real Time Control of a Storm Trunk Sewer

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Recent plans for new subdivision development in North Edmonton will significantly increase the burden on the currently stressed Kennedale storm drainage system. In July 1991, the City retained Stanley Associates Engineering Ltd. to re-evaluate the hydraulic and structural performance of the Kennedale storm trunk. The study was to develop a calibrated stormwater model, to identify the critical storm events, to identify the flood prone areas within the Kennedale storm basin and to define servicing alternatives for both the present and future development areas. The assessment resulted in the recommendation of utilizing real time control to maximize the use of the existing trunk system.

12.1 Introduction

The Kennedale storm trunk contains a north trunk and a south

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trunk which join to form the main trunk downstream before discharging into the North Saskatchewan River (Figure 12.1). The south trunk was constructed during the late 1950's and comprises 11 km of pipe ranging in size from 1200 mm to 2400 mm. The north trunk was constructed during the mid 1970's and comprises 10 km of pipe ranging in size from 1650 mm to 2250 mm. The main trunk was constructed in 1980 and comprises 4 km of piping ranging in size from a 3000 mm circular pipe to a 4900 mm x 3050 mm concrete box. The Kennedale storm trunk presently services 3213 ha of directly

Figure 12.1: Kennedale storm trunk system configuration and capacities.

connected area with an additional 774 ha of lake-regulated area. The lake-regulated designation is for the portion of the service area where the storm runoff will be drained to storage lakes. The discharge from these lakes will be regulated. The future development of North Edmonton will all be lake-regulated and will increase the lake-regulated area to 4249 ha for the Kennedale storm system (Figure 12.2).

Included in the directly connected areas, there is 170 ha of combined sewer area which discharges to the south trunk. Normal dry weather flows are intercepted and conveyed to the City's sewage treatment facilities by means of other combined and sanitary sewer trunks. However, during rainfall events, a portion of the higher wet weather flow overflows into the south trunk.

12.2 Model Development

The Stormwater Management Model (SWMM) is a comprehensive computer model which can simulate rainfall/runoff and dynamic flow conditions (including surcharging) in pipe systems. Version 4 (i.e. SWMM4) was chosen for the analysis of the Kennedale system. Since the off-the-shelf version of SWMM4 can only handle a network of 150 conduits in a personal computer environment, SWMM4 was re-compiled on an HP-UNIX 400 series computer for increased computing efficiency and network capacity (1000 catchments in RUNOFF and 1500 pipe in EXTRAN). The basic system data came from an existing SWMM2 input data file developed by the City of Edmonton in a 1979 study. It was necessary to convert the data to the SWMM4 format while additional data for new areas were added as required. The resulting stormwater model is a lumped hydraulic model for the Kennedale system with approximately 210 conduits representing all piping 1050 mm in diameter and larger. Run times for a six day storm event (with a 5 minute time-step in RUNOFF and a 30 second time-step in EXTRAN) were in the order of two to three hours.

Figure 12.2: Kennedale storm trunk service areas.

The assessment of the Kennedale system included short duration, high intensity design storms as well as long duration, high volume historical storms. Short duration, high intensity storms have put the Kennedale storm trunk into highly surcharged conditions and has resulted in some localized flooding. The long duration, high volume storms have shown that there is a long drawdown period for lake storage. As a result, the modelling concepts for the Kennedale system were divided into short and long storms. The short storms utilized the EXTRAN BLOCK's dynamic routing procedure while the long storms were simulated using the TRANSPORT BLOCK. Both the EXTRAN and TRANSPORT blocks use similar input data and interface with the results from RUNOFF BLOCK (Figure 12.3).

Figure 12.3: Kennedale storm trunk model structure.

Another consideration was the selection of rainfall events. The City of Edmonton has adopted the most severe one and two day rainfall events of 1937, 1978 and 1988 in their City Standards for analysis. However, these events may not be the critical in multiple day rainfall events for lake systems with long drawdown times. Analysis of multiple day rainfall events indicated events which occurred over thirty day periods during 1953, 1983 and 1990 should also be considered in multiple day rainfall event simulations (Figure 12.4).

12.3 Model Calibration

The City of Edmonton operated an extensive monitoring network of rainfall gauges (five), flow monitors (six) and surcharge level gauges (fifteen) in the Kennedale basin during 1991. Some of the stations are part of the City's permanent network. Based on the magnitude of the events and the completeness of the data collected, the rainfall event of 20 to 23 August 1991 was chosen as the calibration event. During this storm event, the surcharge

Figure 12.4: Hourly rainfall for 17 June to 16 July 1983.

gauges did not record surcharge at the tributary locations. However, the main trunk and both the north and south trunks did record surcharge. Of the six flow monitors in the Kennedale system, the flow monitor at the outfall was inoperational during the storm event. Therefore, the calibration effort was concentrated on matching the runoff volume and peak flow rates to the five available flow monitors as well as the surcharge level of the surcharge gauges.

Initially, the volume and peak flow parameters were modelled quite accurately with the monitored results. However, the resulting surcharge levels would be significantly lower in the north trunk than indicated by the surcharge gauges. In order to match the surcharge levels, a significantly higher Manning's n would have to be placed at the downstream end of the north

Figure 12.5: North trunk calibration for 20 to 23 August 1991.

Figure 12.6: South trunk calibration for 20 to 23 August 1991.

Figure 12.7: North trunk surcharge levels for 20 to 23 Aug. 1991.

Figure 12.8: South trunk surcharge levels for 20 to 23 Aug. 1991.

trunk. In doing so, the modelled peak flow was less than the monitored flow (Figure 12.5, 12.6, 12.7 and 12.8). A temporary "choke" at the downstream end of the north trunk was believed to be the reason for the inaccuracy of the calibration. Field inspection of the trunk was recommended to confirm if a constriction existed. The subsequent analysis of the Kennedale storm trunk then continued without the 'choke' situation (assuming it would be found and remedied).

A single rainfall event is not sufficient to accurately calibrate a system as big as Kennedale. More calibration work was recommended in order to improve the accuracy of the Kennedale storm system model.

12.4 Structural Assessment

Structural assessment of the Kennedale system has been carried out by inspecting fourteen various locations on the north trunk and the main trunk. The structural condition (i.e. physical characteristics such as cracks, joint separation, etc.) of the trunk was found to be very good. The service condition (i.e. operational characteristics such as debris deposits, seepage, etc.) of the trunk was also good except in some areas at the upstream end of the north trunk.

12.5 Storm Assessment

The hydraulic assessment of the Kennedale system was performed using the calibrated model without the 'choke' situation. Two factors are important in the hydraulic assessment. They are the loading factor rating and the hydraulic gradeline ratings. The loading factor ratings are a measure of the trunk capacity while the hydraulic gradeline ratings are a measure of the surcharge level. Both ratings go from zero to five as the condition is rated from excellent to poor (Table 12.1).

The Kennedale system was first examined with the synthetic

design hyetographs for the two and five year events with the existing system without any lake-regulated inflows. The system performed reasonably well during the two year event (only 4% of the pipe rated poor). However, during the five year event, 60% of the system was found to have poor hydraulic gradeline ratings.

Table 12.1: Hydraulic rating criteria.

Rating	Rating Range	TLF ¹	(m below street level)
1	0 to 1.5	0 to 0.75	> 5.25
2	1.5 to 2.5	0.75 to 1.25	3.75 to 5.25
3	2.5 to 3.5	1.25 to 1.75	2.25 to 3.75
4	3.5 to 4.5	1.75 to 2.25	0.75 to 2.25
5	4.5 and up	> 2.25	0 to 0.75

- Notes: 1. TLF is the theoretical load factor: $TLF \propto (Q_p/Q)^2$, where Q_p is the peak flow rate and Q is the pipe non-surcharged full flow capacity.
2. HGF is the hydraulic gradeline factor.
3. From the City of Edmonton Standard Sewer Condition Rating System report.

These findings are consistent with the earlier investigation by the City of Edmonton.

Two relief alternatives were investigated for the Kennedale system. They were the construction of a large relief trunk from the North Saskatchewan River and, alternatively, the construction of storage ponds to control the flow at strategic points within the Kennedale system.

12.6 Relief Trunk Alternative

The relief trunk alternative would involve building a relief tunnel

along 132 Avenue. This relief trunk would take flows from both the north and south trunk at strategic locations. An overflow outfall system would be constructed parallel to the existing main trunk beginning at the top of the Kennedale ravine. This alternative would relieve most of the system during the five year event with only 11% of the system piping having poor hydraulic gradeline ratings. The total cost for the relief trunk is, however, in the order of \$60 million.

12.7 Storage Pond Alternative

The storage pond alternative involves the combination of a connecting tunnel and a system of eleven different storage units. For this alternative, a short (0.65 km) length of tunnel is proposed to connect the existing north trunk at 137 Avenue and 58 Street to the 2400 mm diameter tunnel at Fort Road. In addition, three dry ponds and one buried storage unit would be used in the north trunk service area, while six dry ponds would be located in the south trunk service area. Another dry pond would be utilized in the main trunk service area as well. This alternative would also relieve most of the system during the five year event with 17% of the system piping having poor hydraulic gradeline ratings. The total cost for this alternative is in the order of \$15 million.

12.8 Real Time Control for the Trunk

Real time control of all the proposed lake-regulated inflows was found to be necessary for the Kennedale system. As the Kennedale system is already overloaded under the existing conditions, adding lake-regulated inflows would only increase the burden on the existing system. Therefore, a real time control system was proposed which would require no lake outflow to the Kennedale system during any significant storm event. Thus, each lake-regulated system had to store all of the runoff for the design

event. The allowable discharge rate for each lake system after the storm event would then be pro-rated according to the respective service areas. The magnitude of flows was determined subject to the constraint that no more than 50% of the Kennedale trunk's capacity was utilized at any point. This provided room to control the system with set points far enough apart not to be affected by fluctuations in flow.

The most difficult aspect of real time control is to accurately forecast the runoff event within the critical time period. Initial calculations showed that the critical time period for the Kennedale system from one end to the other is about 46 minutes. However, a more detailed analysis evaluating the critical reach (draining the flow from the Lake Beaumaris outlet about 10 km along 137 Avenue) indicated a travel time of about 25 minutes. This would be in line with the amount of advanced warning available from rain gauges within the Kennedale System.

At this stage, only a simple response-to-rainfall system is being proposed. Gates will close when a significant rainfall occurs or when downstream water level monitors rise above a set-point. Gates will open when downstream water level monitors drop below their set-points. The benefits of a storm forecast system using gauges outside the Kennedale system will be investigated during the course of system implementation.

12.9 Real Time Control for the Lake Outlets

Lake outlets were proposed to be configured using a system of two weirs and one outlet valve (Figure 12.9). A weir placed at normal water level would maintain lake elevation at a pre-determined level prior to the storm events. During a significant storm event, the outlet valve would be closed in response to either the monitored rainfall or the surcharge levels downstream in the Kennedale system. Within a multiple lake system, a lake's control valve will close when a high water level (HWL) is indicated in downstream lakes. This would detain all subsequent flow, and the lake level would rise as the stored volume of water

increases. If the stored storm volume exceeded the available storage and the lake level rose above HWL, the emergency overflow weir would allow water to spill and flow into the pipe leading to the downstream lake or to the trunk. Closure of the outlet valve would not affect overflow from the emergency overflow weir, therefore, a fail-safe outlet would be provided for each lake. Any flow capacity control devices would be located in the second weir wall in order to ensure unrestricted emergency overflow. Under normal operating conditions, the valve would remain closed until the receiving trunk below the downstream lakes had cleared. Once the downstream trunk was clear, all valves would be opened and the lakes would drain to the trunk.

Figure 12.9: Lake outlet configuration.

12.10 Conclusions

The Kennedale storm trunk is a complex system with many unique features. A lumped hydraulic model was developed for the Kennedale storm system using the SWMM4 model. Although the calibration effort was far from comprehensive, some degree of calibration was achieved using the only significant rainfall event available. The structural condition of the trunk was found to be satisfactory while the hydraulic assessment clearly showed the over-stressed condition of the Kennedale system.

Initial investigation showed that a relief trunk would significantly improve the hydraulic condition of the system. Another alternative investigated involved the construction of eleven storage units and a short tunnel. In addition, real time control of all lake-regulated inflows was found to be necessary for the Kennedale storm system. The use of storage and real time control allowed for the addition of runoff from a considerable amount of new development north of the existing service area.

12.11 Acknowledgements

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