TORONTO WET WEATHER FLOW PROJECT – THE CHALLENGE OF INTERCEPTORS, TUNNELS AND INFOWORKS

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Introduction

The City of Toronto is embarking on a comprehensive program to construct a Wet Weather Flow (WWF) System to reduce combined sewer overflow (CSO) discharges and improve water quality in the Don River and Inner Harbour of Lake Ontario. The Don River and Central Waterfront (DR&CW) WWF system will provide an optimised storage solution to virtually eliminate untreated sewage (via CSOs) from entering the Don River, Taylor Massey Creek and Central Waterfront through the capture and treatment of flows. The level of bacterial contamination will drop leading to a significant increase in the area meeting Blue Flag swimming standard and the project's ultimate aim is to delist Toronto's waterfront as a Great Lakes Area of Concern.

The solution will comprise 22km of 4.4 to 6.3m diameter tunnel and 14 shafts to store CSO and storm water, with overflow limited to once per typical year. 46 wet weather flow outfalls have been identified as requiring capture and diversion to the tunnel, and the design proposes combining these into 27 connections.

The solution is the largest new CSO interceptor system currently contemplated in North America. This paper will provide an overview of the modelling undertaken for this important infrastructure project in Toronto and will demonstrate how key challenges were overcome through a combined approach integrating InfoWorks modelling, detailed hydraulic calculations and CFD modelling.

During the significant programme of modelling, a number of key challenges have been encountered:

1. Detailed modelling of the tunnel connections to understand system performance and to determine the design flows as accurately as possible.
2. Correction for Preissmann Slot in the modelling of the deep tunnel system to avoid an overestimation of total tunnel storage.
3. Development of a flow regulation strategy to enable the required control on interceptor flows to be achieved.

Project Background

In 1987 the International Joint Commission designated Toronto's waterfront as one of 43 "Areas of Concern" in the Great Lakes, largely because of impaired water quality conditions in the Don River and Inner Harbour. In response, the City of Toronto completed a Municipal Class Environmental Assessment (EA) to look at addressing WWF within the Don River and Inner Harbour sewer catchment areas in addition to carrying out selected sanitary sewer system upgrades.

The DR&CW WWF Project takes forward the preferred solution developed during the EA stage. The project has an estimated capital cost of $1.5bn CAD and is proposed to be implemented in 5 stages, with Stage 1 commencing construction in 2018. Black & Veatch in association with R.V. Anderson Associates has completed predesign work for all 5 stages and has commenced detailed design for Stage 1.

- Stage 1 – Coxwell Bypass Tunnel
- Stage 2 – Taylor Massey Creek Tunnel and connections
- Stage 3 – Offline Storage Tanks
- Stage 4 – Inner Harbour West Tunnel
- Stage 5 – Tunnel Connections on the Inner Harbour and Lower Don

The alignment of the various sections of tunnel is shown in Figure 1. Four of the five stages of the DR&CW Project relate to design and construction of the tunnel system and its connections. Stage 3 involves construction of four storage tanks to alleviate surcharging in upstream sanitary trunk sewers, and construction of three storm water tanks to capture flow from outfalls remote from the tunnel system.

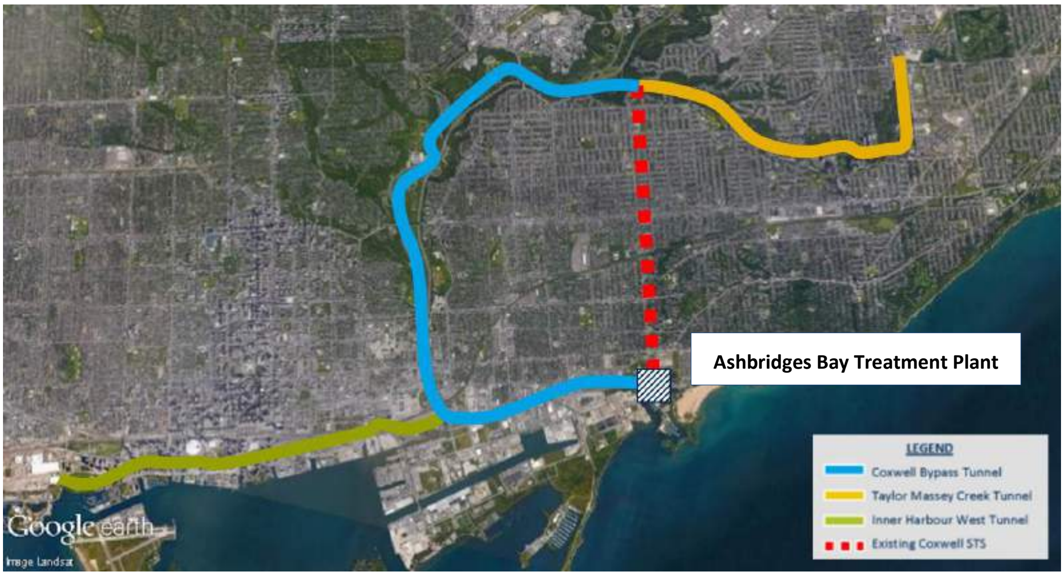


Figure 1 – DR&CW Tunnel Alignment

Study Area

The study area (shown in Figure 2) includes the entirety of the Ashbridges Bay Treatment Plant (ABTP) sewer shed, covering an area of about 270km^2. The sewer shed is served by the Don Sanitary Trunk Sewer System and the Waterfront Interceptor Sewer System. The ABTP is the City's largest treatment plant, serving around 1.4 million people.

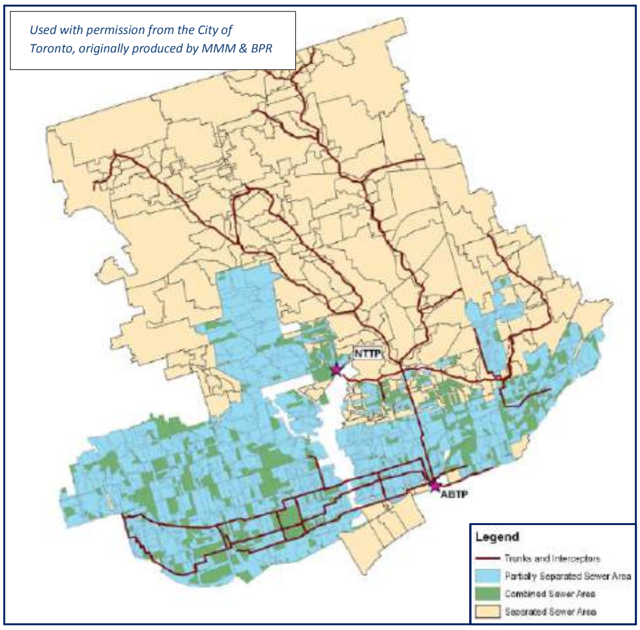


Figure 2 – Study Area

The Don Trunk system serves an area of about 160 km^2 and a population exceeding 750,000 people. The West Don, East Don, North Toronto and Massey Creek trunk sewers all converge at the Coxwell STS, which runs south and enters the ABTP by gravity. Approximately 10% of the ABTP Sewershed is served by combined sewers. During wet weather, sewer flows exceed the capacity of the system resulting in spills at CSO locations within the network.

The Waterfront system consists of three main interceptors running west to east; the Low Level Interceptor (LLI), High Level Interceptor (HLI) and the Mid-Toronto Interceptor (MTI). These are linked by four interconnecting transfer sewers (Strachan, Simcoe, Victoria/Scott and Carlaw). Two branches run east to west in the eastern part of the lakefront; the Lakefront Interceptor (LFI) and the Queen Street Interceptor (QSI).

Network Model

The InfoWorks model used for the EA stage and for our subsequent design work is developed from a calibrated trunk main model with about 17,000 conduits and around 750 weirs, gates and flap valves. The key outputs of the network modelling undertaken were to determine:

- ✓ How much storage is required?
- ✓ What are the connection design flows?

Figure 3 shows the outline of the InfoWorks model, including the modelled tunnel system.

The InfoWorks modelling carried out during the EA process determined the storage volume required to achieve the performance target of one CSO spill per typical year.

From interrogation of the rainfall series used for analysis, the typical year was identified as 1991.

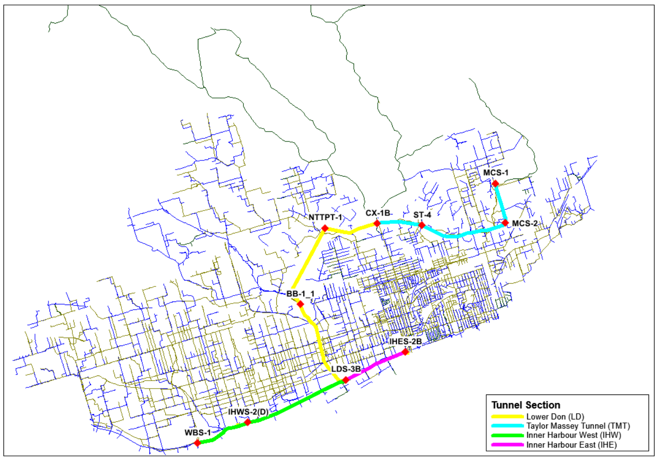


Figure 3 – Modelled Tunnel Sections

From this typical year, representative events were identified as follows:

- "Sizing" event for Inner Harbour Lower Don Tunnels and Taylor Massey Tunnel: July 6-7, 1991
- "One CSO" event for Inner Harbour Lower Don Tunnels: August 2-3, 1991
- "One CSO" event for Taylor Massey Tunnel: July 22, 1991

To determine the storage volume required, the "Sizing" event was used and flow volumes entering the modelled tunnel system were determined. The design storage volume included a 30% safety factor to account for uncertainties: primarily those associated with reference rainfall data, climate change and modelling accuracy.

Results from the InfoWorks modelling were used at the EA stage in conjunction with the water quality modelling of the receiving waters to confirm that the proposed storage solution would meet the overall project objectives. The storage volume identified in the EA is now exceeded by the finalised design providing confidence that the overall objectives will be met.

Detailed Connection Modelling

The first of three key challenges encountered was that of the tunnel connection design and the associated modelling that was undertaken. Three different types of tunnel connection are proposed, including baffle, vortex and simple drops. The connections required detailed modelling to allow system performance to be fully understood, to determine the design flows as accurately as possible and to determine what proportion of flow would enter the tunnel during events above the design storm. The system will rely on passive flow control, using an orifice and relatively small gates, to limit flows into the system to close to the design flows. Flow control is necessary to prevent the system from filling too fast which could cause significant transient oscillations and flooding from shafts or connections.

The tunnel connections were modelled using different components within InfoWorks to achieve a good rating curve match compared to Computational Fluid Dynamic (CFD) modelling and detailed spreadsheet calculations.

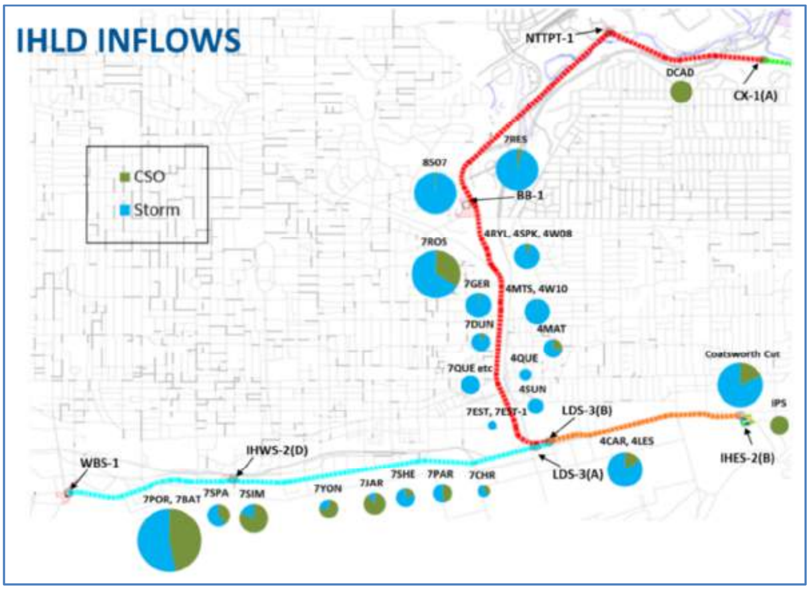


Figure 4 – Storm water versus CSO

As part of the initial analysis carried out, an assessment of the proportion of CSO versus storm water contribution was undertaken to determine the return period to be used for connection design. For the connections with a very low proportion of CSO contribution but a high peak flow and volume contribution to the tunnel, the connection itself was designed for a 1 year return period rather than the 5 year return period used at other connections. 6 of the 46 proposed outfall connections were designed to a 1 year return period flow, with the remaining 39 connections designed to a 5 year return period peak flow. This approach noticeably reduced the peak flow which could enter the tunnel system, reducing the speed of filling and amount of expensive shaft storage required to control transient oscillations.

Flows in excess of the design arriving at the connection location continue to flow down the existing storm water outfall to the river/lake. An indication of CSO versus storm flow proportion is shown in Figure 4.

There are three different types of tunnel connections proposed:

- Baffle drop
- Vortex drop
- Simple drop

The vortex drop connection was the most common, used at 20 of the 27 proposed connection locations. To represent the arrangement at a particular connection, a number of model elements were used (as shown in Figure 5) with adjustments made to the discharge coefficients as necessary.

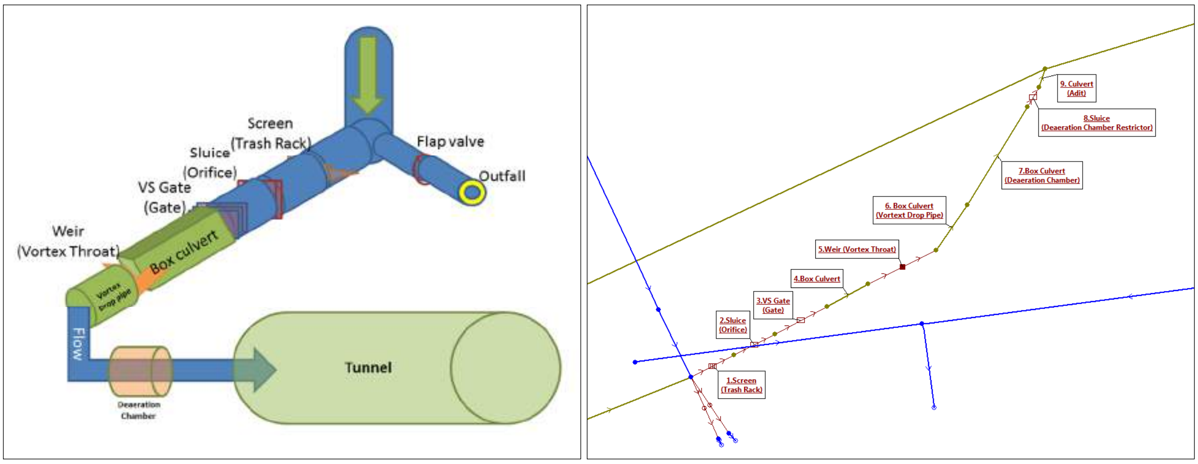
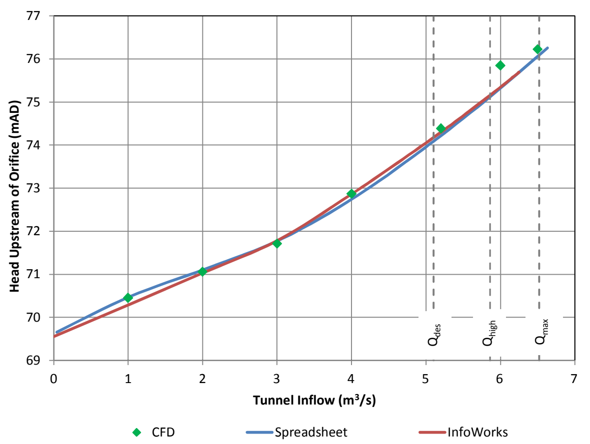


Figure 5 – Schematic and Modelled Representation of Vortex Drop

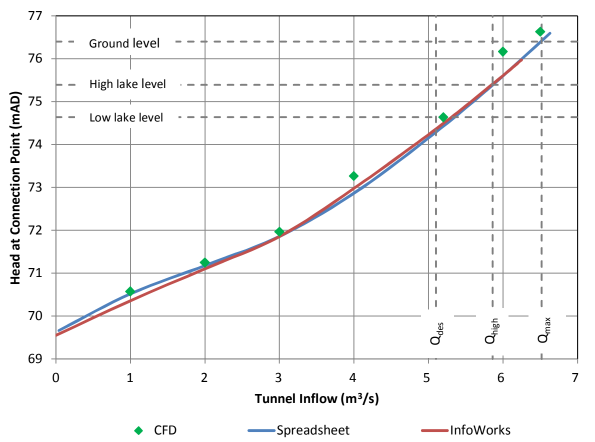
As an example, the elements used for the vortex drop arrangement are as follows:

- Screen: representing a trash rack with 50mm bars and 100mm gaps with 25% blinding.
- Sluice gate: representing a rectangular orifice. At the connection design flows, these generally operate under drowned orifice hydraulic control, and the primary discharge coefficient was set to give a similar headloss to that obtained via CFD modelling and detailed spreadsheet calculations. The secondary discharge coefficient (used for weir hydraulic control) was set to equal the primary discharge coefficient to maximise model stability.
- VS gate (sluice gate with controllable opening height): representing the connection isolation / RTC gate. At the connection design flows, the sluices generally operate under drowned orifice hydraulic control, and the primary discharge coefficient was set to give a similar headloss to that obtained via CFD modelling and detailed spreadsheet calculations. For most sites, the secondary discharge coefficient (used for weir hydraulic control) was set to 1 which gave slightly too low a headloss at low flows, but couldn't be reduced further without causing model instability.
- Conduit: representing the box culvert proposed between the gate and the vortex generator. A downstream fixed headloss coefficient was entered, determined from detailed spreadsheet calculations.
- Weir: representing the vortex throat. A weir coefficient of 0.60 was used for the 1.4m diameter vortices and 0.62m for the larger ones to give similar headloss to that obtained via CFD modelling, detailed spreadsheet calculations and empirical methods.
- Conduits: representing the vortex drop pipe, the deaeration chamber and adit. Fixed headloss coefficients were used throughout.
- Flap gate: representing the proposed flap gates. A discharge coefficient of 1.41 was used to give twice the default InfoWorks flap gate headloss as two flap gates are proposed in series. The flap gate diameter was set to give the same cross sectional area as the existing outfall sewers.

Figure 6 below shows an example of the InfoWorks rating curves obtained at different points of the connection chamber, compared to CFD and spreadsheet results.



Upstream of orifice – Good match at design flow, slight underestimate of headloss in InfoWorks at low flows.



At sewer diversion (overall rating curve) – Good match at design flow. Slight underestimate at higher flows compared to CFD.

Figure 6 – Example rating curves

An example of the CFD modelling carried out for the connection design is shown in Figure 7 below. The CFD model results were used to optimise the chamber configurations and also to validate the InfoWorks model representation of the tunnel connections.

The vortex connections were standardised into 6 different sizes ranging from 1.4m diameter to 4.0m diameter, with changes made to invert levels and orifice openings to achieve the required design flows at all sites. This will reduce the number of sizes of vortex drops to be drilled during construction and also reduced the required modelling input, increasing overall efficiency within the design process and reducing modelling time input in the project programme.

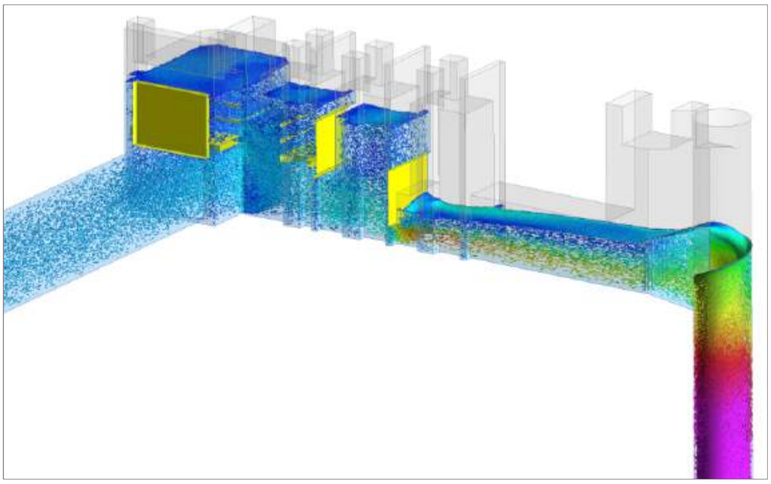


Figure 7 – CFD Modelling of Vortex Drop Connection

Modelling the Deep Tunnel

The second key challenge was the modelling of the deep tunnel. As with all major design projects, reaching the final proposed solution typically incorporates a number of design iterations. The overall route and depth of the tunnel has remained reasonably constant but with some changes to connection locations, grouping and detailed drop arrangements. On completion of initial system analysis, the storage volume was agreed and the detailed tunnel layout was incorporated into the updated InfoWorks Design Model.

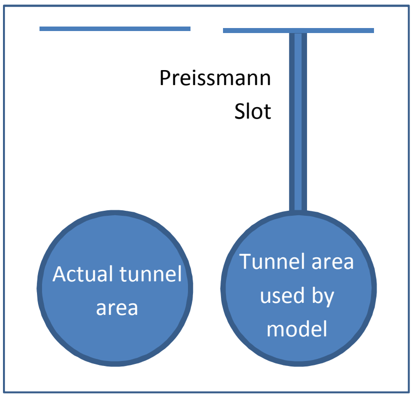


Figure 8 – Preissman Slot

During initial model analysis undertaken for the detailed connection arrangements, it was noted that the tunnel filling operation evident in model simulations was not in line with expectations. It was identified that the Preissmann Slot was contributing to this inaccuracy through an overestimation of total tunnel storage. To maintain the stability of the hydraulic calculations, InfoWorks assumes a slot of additional cross-sectional area above the pipe (as shown in Figure 8). Normally the effect is minimal but in this case the effect was significant due to the depth of the tunnel and large diameter of the conduits being modelled.

The Preissmann slot width was reduced to 1% of conduit diameter by changing the celerity ratio in the model simulation parameters. Manual reduction of plan area at modelled tunnel shafts was still required to ensure that the tunnel storage was accurately represented. This manual adjustment was used in preference to the automated compensation function within the software since achieving accurate adjustments at all levels was considered critical to the tunnel design. Corrected areas for the large diameter tunnel shafts were applied using storage nodes, as shown in Figure 9 and Figure 10 below. A total area correction of 1300m^2 was required.

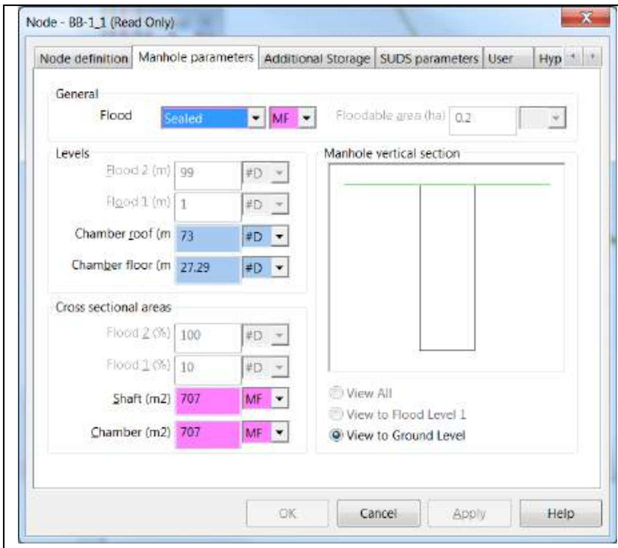


Figure 9 – Shaft BB-1 before manual correction

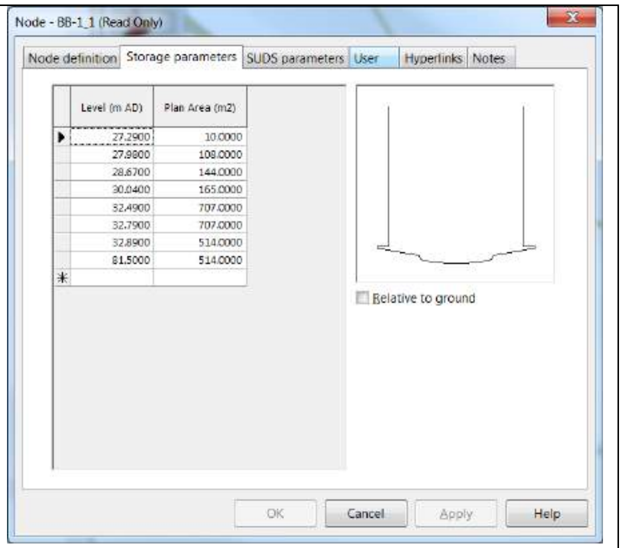


Figure 10 – Shaft BB-1 following manual correction and representation of shaft benching

Once resolved, tunnel filling simulated in line with expectations, with the overall storage volume correctly represented. Whilst manual correction for Preissmann Slot was more time consuming than utilising automated routines embedded in the software, particularly during the evolution of the overall design and changes to modelled pipe diameters, the manual correction was most accurate and provided the highest confidence in model results. The results taken from the InfoWorks model were used to inform wider design calculations and decisions, such as sediment transport calculations and associated operating regime arrangements. The additional input was time well spent and enabled the design team to make decisions with confidence.

Regulation of Interceptors

The third key challenge was the development of a strategy to achieve a reduction in Wet Weather Flows (WWF) arriving at Ashbridges Bay Treatment Plant (ABTP). This was to be achieved through making iterative adjustments to control settings at selected gates on the main interceptor sewers.

The overall aim of the regulation strategy is to prevent the interceptor sewers from becoming heavily surcharged during severe rainfall events and achieve specified water levels on the Mid Toronto Interceptor (MTI). The interceptor sewers and gate locations are shown in Figure 11.

The detailed Real Time Control (RTC) strategy made use of 9 automated gates and will provide a system balancing act, maximising the flow within the existing interceptor sewers during low flow conditions whilst implementing controls to prevent high water levels within the interceptor system in high flow conditions during wet weather. Maximising the flow within the existing interceptor sewers in dry weather maximises the proportion of flow that passes to full treatment, but when levels of service start to become threatened by excessive surcharging it is better to spill excess flow to the tunnel. Flows which pass into the tunnel will be treated by the new high rate treatment plant at ABTP.

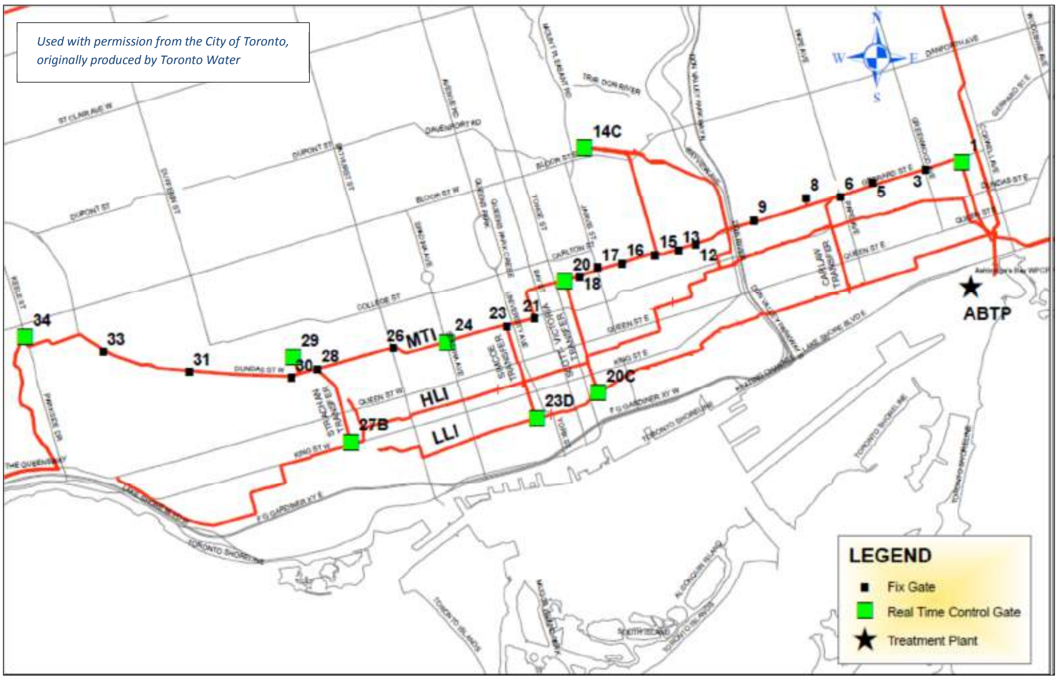


Figure 11 – Interceptor and Gate Locations

The long time lag within the system means that two different controls are required for the gates:

- Modulation to achieve target level in the MTI close to gate location; and
- Over-ride to close gates if level in local sewer is very high, indicating severe storm is occurring.

This RTC set-up maximises flows in the MTI until levels rise too high, at which point storm flow is transferred to the proposed tunnel system to protect the interceptor sewers, maintaining the levels required at target locations along the interceptor system.

A number of gates within the interceptor system were controlled by an RTC file within InfoWorks to achieve the overall strategy objectives. This RTC set-up includes controllers that incrementally open or close the gates in order to maintain a target level in the MTI. The gates therefore might not fully open or close but rather they have a continually changing opening height to let the required amount of flow through. Where there is a large distance between the gate and the sensor location in the MTI this can result in over-adjustments to the gate height and this was a challenge when developing the RTC.

The proposed gate control system achieves the required water levels in the MTI for events up to a 50 year design storm. However, as observed during the initial testing, the resulting re-distribution of flows in the system would have effects on the DR&CW project in particular. Flows arriving at many of the connection locations were affected by the application of the control strategy within the model, with some connection sizes needing to be increased to accommodate increased peak flow rates.

As a final check on overall performance, sensitivity tests were carried out to assess the impact of failure of gate control. The proposed control closes gates in response to high MTI water levels, so only the effect of a gate failing to open was modelled. This represents the worst case for overall system performance.

Now that a suitable strategy has been developed to achieve the required flow rates at ABTP and water levels within the interceptor system, the next stage of the physical implementation of the control strategy will be challenging, with retrofit to existing chambers being needed in a number of locations across the City. Investigation and detailed survey of structures will be required to ensure that the necessary equipment can be successfully installed.

Lessons Learned and Conclusions

A number of factors have contributed to the successful delivery of the project so far. The modelling undertaken has been both challenging and rewarding, with success achieved through the combined approach integrating InfoWorks modelling, detailed hydraulic calculations and CFD modelling.

We have undertaken a significant programme of modelling to understand system performance, quantify storage volumes and designs flow to enable the design of the overall system and connections to be completed. We have successfully modelled the deep tunnel system, accurately modelling the system volume and developing confidence in the results used for a wide range of design decisions. We have also developed a flow regulation strategy to achieve the required control on interceptor flows and peak flows arriving at ABTP.

Key factors that we believe are fundamental to the successful delivery of the hydraulic design are:

- A collaborative approach to the design is fundamental to achieving the optimum solutions as all hydraulic aspects are interlinked
- Drawing on a global workforce to provide the best person for the job and to bring together good practice and a knowledge sharing culture
- Utilising multiple modelling techniques and software packages to meet the design requirements and to ensure that system performance was fully understood and optimised

There is a long journey ahead to achieve our ultimate aim to delist Toronto's waterfront as a Great Lakes Area of Concern. We will continue to work as a collaborative team to meet the overall objectives of this important infrastructure project for the City of Toronto. It will be a challenging and fun experience.

Acknowledgements

Thank you to the team at the City of Toronto for a challenging project and their support of this paper and to the entire design team at Black & Veatch and R.V. Anderson Associates.