# Preventative Rehabilitation of the Fairfield CTS to allow undermining for the Eglinton Crosstown LRT

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## ABSTRACT

Metrolinx, a Government of Ontario Agency, is currently undertaking construction for the Eglinton Crosstown Light Rail Transit (ECLRT) project which is, in total, 19 km long, 10 km of which are constructed in tunnels.

Eglinton Avenue, a major arterial road in Toronto, accommodates four (4) lanes of traffic. The area has been developed approximately 100 years ago. The ECLRT tunnels run primarily under the Eglinton Avenue Right of Way (RoW) and are passing under significant existing infrastructure including trunk brick sewers which have been deemed to be at risk of failure due to losing ring compression as a result of ground settlement due to the tunneling operations. As a precaution, to mitigate the risk of catastrophic failure, these brick sewers were lined using Cured in Place Pipe (CIPP).

One tunneled section passes directly under the Fairfield Combined Trunk Sewer (CTS) – a 1200 mm (48 inch) diameter brick sewer consisting of two or three ring brick cross sections (depending on depth), likely constructed in a hand mined tunnel. The undermined section of the sewer varies in depth from ~7 m to near ~21 m (to invert). A jet grouted station headwall had to be constructed in the upper reaches of the sewer, creating a sub-section where differential settlement would occur. It was therefore anticipated that the Fairfield CTS would likely loose compressive ring forces and collapse catastrophically.

The City of Toronto (the City) requires CIPP liners to be designed to the “Fully Deteriorated State”, meaning that the host pipe will not provide/contribute any structural support. The City had, due to the high risk impacts from failure (100’s of flooded basements), mandated that a Safety Factor of 3.0 be used for the design. The depth of the sewer, high water table and restrictions on the Structural Dimension Ratio of CIPP liners meant that the Safety Factor could not be achieved in the design using a single pass liner installation.

Relining of combined sewers requires approval from the Ministry of the Environment and Climate Change (MOECC) to ensure that relining does not cause additional combined sewer overflows. The City’s model showed significant flows surcharging in the upper reaches of the sewer. An extended period of flow monitoring and calibration was required to confirm the existing and projected hydraulics to show how the sewer would perform following relining.

The hydraulic capacity of the sewer was in the range of up to 2.3 $m^3/s$. Given the depth of the sewer of up to 20 m, bypass pumping the full capacity of the sewer was deemed not economically feasible; this would have required a long-term full closure of Eglinton Avenue and significant excavation to allow pumping access to the sewer.

This paper summarizes how these challenges were addressed using an innovative way to minimize flooding and construction risks.

## INTRODUCTION

Metrolinx, an Agency of the Government of Ontario, is currently undertaking construction for the Eglinton Crosstown Light Rail Transit (ECLRT) project (http://www.thecrosstown.ca/) that will ultimately provide for Light Rail Transit along Eglinton Avenue from Mount Dennis (Weston Road) in the west to Kennedy Road in the east, in the City of Toronto. The ECLRT will connect to the Union-Pearson Express (UPE), the existing Yonge-University-Spadina Subway, the existing Bloor-Danforth Subway and the future Scarborough Subway Extension. The total length of the ECLRT will be approximately 19 km, 10 km of which are being constructed in tunnels. The tunneling operation was using four Earth Pressure Balance Tunnel Boring Machines (EPTBM), two each for the West and East tunnel sections respectively. An overview of the extent of the tunneled portion of the project is depicted in **Figure 1** below.[2]


**Figure 1:** Eglinton Crosstown LRT Overview – showing tunneled / underground section

The Eglinton Right of Way (RoW), generally ~ 20 m wide in the (tunnel) project area, is a major arterial road in Toronto, accommodating four lanes of traffic as well as sidewalks on both sides of the street. The project area has generally been initially developed in excess of 100 years ago, resulting in sparse information pertaining to underground infrastructure, and especially construction details.

The ECLRT tunnels are passing under significant existing infrastructure in the RoW including several trunk sewers. A [settlement] analysis of the tunneling effects on these sewers was undertaken and resulted in the brick sewers being deemed at risk of failure due to a high probability of losing ring compression. As a result, all brick sewers were recommended to be lined as a precaution; this was done using Cured in Place Pipe (CIPP). Most of these CIPP installations, although fairly large, were moderately complex and completed without significant challenges. In contrast, the Fairfield Combined Trunk Sewer (CTS) provided significant challenges.

## THE FAIRFIELD CTS AND RISKS OF UNDERMINING.

Just west of Bayview Avenue, the west bound tunnel section passes directly under the Fairfield CTS – a 1200 mm diameter brick sewer owned and operated by the City of Toronto (the City). This sewer was built approximately

[2] The tunneling operations using the EPTBMs has been completed.

90 years ago, and the top half consists of a two-ring brick cross section, and, for the deeper section a three-ring brick cross section. The bottom half of the sewer consists of a single brick ring embedded in concrete fill. The overall sewer is called a 2 (or 3) ring, Square Base Sewer[3]. There is an indication in the records that the sewer was constructed using tunneling techniques (indicating on the drawings, for example: "Air Pressure 16 to 22 lbs"), however none of the temporary works, nor details of the backfill surrounding the sewer were recorded.

Since the EPTBMs were to pass directly under the sewer at a minimum distance of 3.9 m (less than a tunnel diameter), settlements of the sewer were to be expected (refer to drawings ECLC1-17-G3005 & G3006 for a general alignment of the tunnel in relation to the sewer). It was anticipated that the sewer, due to the method of construction and age, had very little, if any, remaining tensile strength capacity. This meant that if the sewer was subjected to settlement it would likely lose the compressive ring forces and collapse catastrophically. Since the high risk impacts from failure (100's of flooded basements) was significant, the sewer had to be lined to ensure that a failure was not catastrophic in nature.

## TECHNICAL CHALLENGES

The preventative lining of the Fairfield CTS provided for several interdependent challenges that had to be solved concurrently to provide an acceptable outcome. These challenges can be broadly categorized as listed below:

- Bypass Pumping and impact on the overall project;
- Liner Design Options and bypass pumping requirements to allow installation of liners;
- Sewer Hydraulics pre- and post-lining;
- Timeline; and
- Final Liner Design and Environmental Compliance Approval Process.

A decision flow diagram was prepared in the initial phase of the project to highlight interdependence of [some] of the technical challenges.

### Bypass Pumping and Impacts on the Overall Project

An initial review of the hydraulic capacity of the sewer indicated that it was in the range of up to 2.3 $m^3/s$ under free flowing (gravity) conditions (based on a Manning N Value of n=0.013). The City had, for all other sewers that were to be lined prior to the Fairfield CTS, generally required a bypass capacity for a 1:2 year storm event, and provided the flow rates for a 1:2 year storm as well as 1:5 year storm. A review of these flows indicated that based on the hydraulic model, the Fairfield CTS was surcharging significantly at flow rates of the above noted estimated sewer capacity. Although most of the inflows (at the east end of the sewer) were from local sewers, there was no logical point to pump from. Interception of the local sewer would have meant a number of different pumping systems as well as challenging logistics pertaining to bypass pumping. In summary, bypass pumping the flows associated with a 1:2 year storm would have required a long-term full closure of Eglinton Avenue and significant excavation to allow pumping access to the sewer which was overall undesirable to both Metrolinx and the City.

### Liner Design Options and Bypass Pumping Requirements to Allow Installation of Liners

The City generally requires all sewer liners to be designed to the "Fully Deteriorated State", meaning that the host pipe will not provide/contribute any structural support. The City, in their "Specification for the Cured–In-Place Pipe Lining of Sewers" (Toronto Specification 4.10) generally requires all Cured-In-Place-Pipe (CIPP) to be designed with a safety factor of 2.0. However, the City had, due to the high risk impacts from failure of this sewer, required a safety factor of 3.0 for this design. Due to the depth of the sewer, the high water table and the restrictions on the Structural Dimension Ratio of the liner for installation reasons, this meant that the Safety

[3] For the purpose of the remainder of this paper the Fairfield CTS will be referred to as a brick sewer.

Factor could not be achieved in the design using a single pass liner installation. The liner installation timeframe, as result of the projected CIPP wall thickness required and host pipe diameter, was initially projected in the range of up to 60 hours.

### Sewer Hydraulics Pre- and Post-Lining

In Ontario, all lining works pertaining to combined sewers have to be approved by the Ministry of the Environment and Climate Change (MOECC). The underlying reason is to prevent additional Combined Sewer Overflows (CSOs) over those occurring in the pre-lining state. In discussion with the City, the City informed Hatch that generally an improvement of the hydraulics resulting from a smoother liner is an acceptable post lining state which shows that additional CSOs will not occur. For most sewer lining designs, this approval process does not pose a significant hurdle, as the Manning's N-value is reduced as a result of the new liner to compensate for the reduced pipe diameter post-lining. Ven Te Chow (1959) provides a table with suggested Manning N values for use in sewer designs covering a variety of different materials including brick, concrete pipe and smooth pipes. CIPP liner reference information generally indicates a post lining Manning N value for use, which usually is the basis for improved hydraulic capacity in the lined sewer. However, these values are lower than the MOECC Design Guidelines for Sewage Works (MOE 2008) recommended Manning N values (N=0.013).

### Timeline

The preventative lining of the Fairfield CTS had to be completed in advance of the TBMs passing under the sewer. Since access to the tunneled portion of the ECLRT was to be granted to the follow-on Station Design Build Contractors, tunneling was to advance at an accelerated pace to ensure that there were no delays (and associated penalties) that were the responsibility of Metrolinx. The overall project timelines did not leave an extended design/approval timeframe normally associated with projects of this complexity.

### Final Liner Design and Environmental Compliance Approval Process

Since CIPP contractors all use somewhat specialised/customised installation processes and have developed relationships with liner and resin suppliers, the final design of the CIPP liner is usually completed by the contractor. As noted above, this process does not pose an issue for most CIPP lining projects as an approval can be sought based on preliminary liner thicknesses and hence preliminary hydraulics: this being because the liner thickness falls within the range between the current sewer diameter and the minimum acceptable sewer diameter. However, in this case, the projected liner thickness resulted in a reduction of capacity and hence the final approval could only be sought once the final liner design had been completed. This sequence made the owner vulnerable to delay claims as the final MOECC approval was required before the liner could be installed.

## PROJECT APPROACH

After review of the above noted technical challenges, a proactive project approach was developed to cover all of these issues. The following actions were initiated to ensure that all of the technical challenges could be solved in the appropriate timelines for the project:

- Confirm the hydraulic capacity of the existing sewer, to ensure that the pre- and post-lining hydraulic conditions could be equated.
    - Conduct flow monitoring for a period of 6 months. This was done to provide information on the existing flow rates as well as to confirm the existing Manning's N value;
    - Complete a desktop study to confirm the theoretical existing hydraulic conditions and to confirm reasonable post-lining hydraulic conditions;
    - Provide additional information on bypass pumping requirements.
- Confirm if suitable alternate lining methods exist that would allow lining of the sewer without a need for bypass pumping.

- Determine if there are periods during the year in which the weather forecasting is more reliable than during other periods of the year. The intent of this was to confirm if reliable weather forecasting could be used to reduce the bypass pumping requirements for the period during which the CIPP liner was to be installed.
- Determine under which circumstances the City would allow for a reduction in the Safety Factor for the overall design of the CIPP (and other suitable liners if any).
    - Carry out discussions with the contractor (and his designer) to determine what would improve the reliability of the design;
    - Carry out discussions with the City to determine under what circumstances a reduction in the Safety Factor would be allowed.

The flow chart showing the interdependencies of the various project task was developed early in the project with the purpose of ensuring that all parties involved in the project understood the complexities and interdependencies and is included as **Figure 2** below. However, as evident from this paper, not all processes originally laid out were pursued as several originally conceived interdependencies were relatively easy to avoid.

### Confirm the hydraulic capacity of the existing sewer

Hatch retained a sub-consultant (Civica Infrastructure Inc.) experienced in flow monitoring and model calibration to complete the following work:

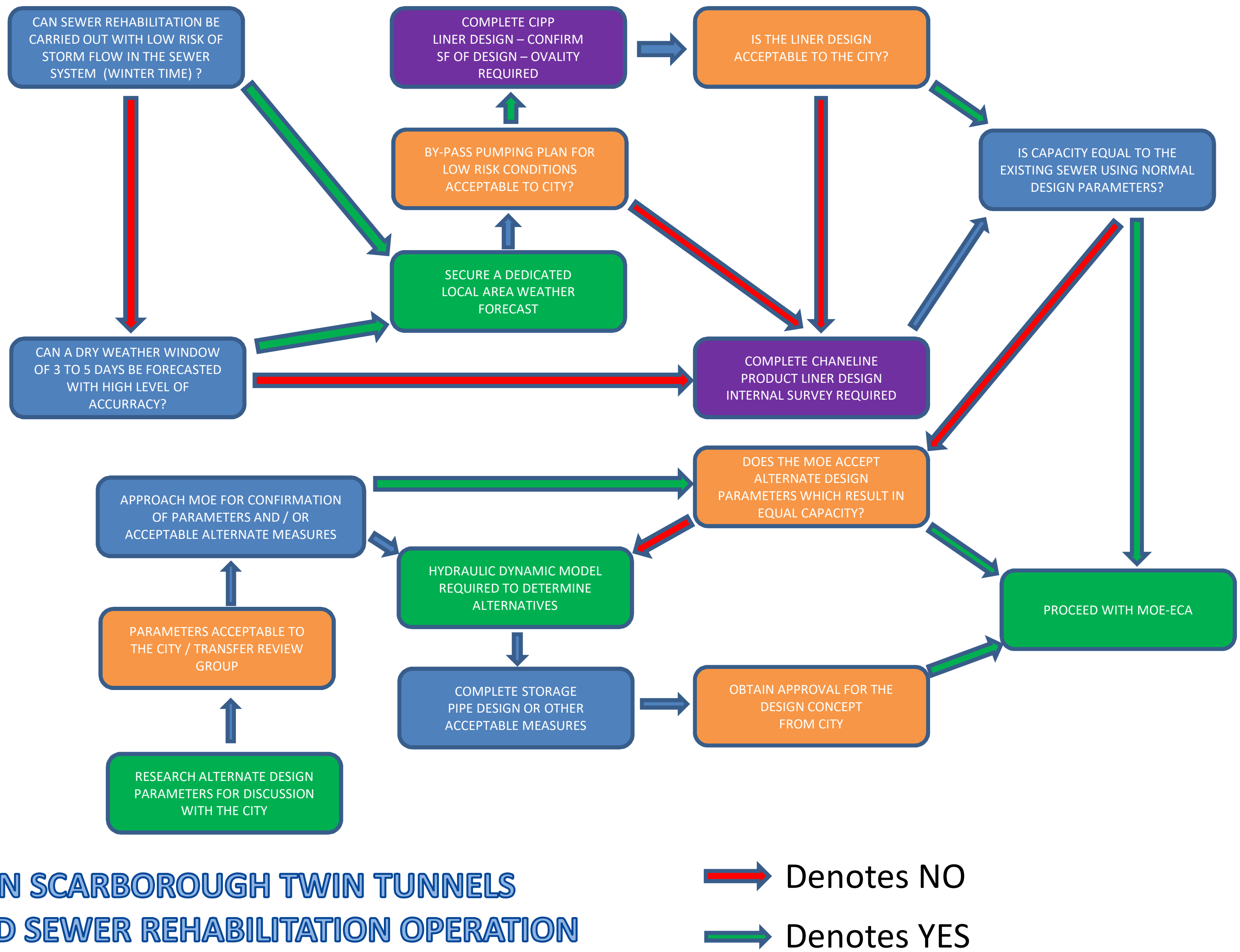
- Review the partial sewer model made available by the City for completeness and suitability;
- Complete flow monitoring for six months;
- Calibrate the hydraulic model specifically to determine the actual Manning's N value for the existing brick sewer; and
- Review and provide comments on the desktop study completed by Hatch.

The desktop study yielded the following outcomes:

- Hatch and the City agreed to use a Manning's N value of N=0.013 for the post-lining condition of the sewer. While a better (lower) Manning's N value may have been indicated by the desktop study and especially lining suppliers, it was thought prudent to follow the MOECC Guidelines for this value in order to avoid questions during the MOECC review / approval process;
- It was concluded that a Manning's N-Value for the existing brick sewer of N=0.018 was a reasonable value (Rüsch & Graham 2015). The City accepted that the capacity of the existing sewer be calculated using this value.

The flow measurements and model calibration yielded the following results:

- The Peak Dry Weather Flow (PDWF) in the Fairfield CTS was ~35 L/s. This value was surprisingly low, yet a closer analysis of the data yielded a clear diurnal pattern normally associated with sewers for the dry weather periods;
- Further review of the data and associated rainfall events indicated that the Fairfield CTS responded with significant flows once the rainfall intensity increased above 3 mm/hour. It was anticipated that this value could be used to determine a hold-point if it was found that a dedicated weather forecast was feasible for this project;
- The actual calibrated Manning N value for the existing brick sewer was determined to be 0.030 for the bottom 1/3 of the sewer and 0.035 for the top 2/3 of the sewer (Civica, 2017). This means that the actual hydraulic conditions were not as favourable as shown by the desktop study.




**EGLINTON SCARBOROUGH TWIN TUNNELS**
**FAIRFIELD SEWER REHABILITATION OPERATION**
**DECISION MAKING PROCESS**

Figure 2

The actual values derived for the Manning's N value are not normally expected for brick sewers, however deteriorated they may be. Although area/velocity meters were used for the flow measurement, the project team concluded that for approval purposes, the Manning's N value as derived under the desktop study would be used to determine the existing conditions. While it seems to summarily dismiss the actual flow measurements and model calibration, this was done to avoid questions during approval.

The above indicates that the model could be used to determine the pre- and post-lining capacity:

- The existing conditions (pre-lining) would be modelled using a Manning's N value of N=0.018 and the original sewer diameter; and
- The final conditions (post-lining) would be modelled using a Manning's N value of N=0.013 and the sewer diameter based on the final liner design.

### Confirm if suitable alternate lining methods exist

The project team undertook an investigation of alternate lining methods. After extensive discussion with lining contractors on the subject, it was concluded that alternate lining systems that would have avoided the need to bypass pump were not practically feasible. This was because on closer inspection of the existing manholes of the Fairfield CTS, the proposed liner alternative (which was a propriety segmental sliplining liner) could not be installed through the existing manholes without extensive work. In addition, preliminary wall thickness information provided by the supplier showed that the capacity would be significantly reduced. As a result, the alternative lining methods were thought to be not feasible and not considered any further.

### Determine if weather forecasting is more reliable during certain periods of the year

The City (Brian Worsley[4], 2015a), in an early response, had referred the project team to a paper written by Ripley and Archibold (2002) which dealt with weather forecasting reliability. A review of the paper by the project team revealed that the paper was written more than 10 years prior to this project being undertaken. The project team attempted to contact the authors of the paper (and could only find Dr. Archibold) to confirm if any work had been completed since the paper was initially published and if so to confirm if forecasting has improved. Dr. Archibold responded that he had retired and to the best of his knowledge no further work had been completed by his original team since the paper was published.

The project team then approached The Weather Network to gain information on the predictability of weather forecasting. The project team's discussions with this commercial supplier of weather forecasts and further information provided by the City (Brian Worsley, 2015b) yielded the following general understanding of weather forecasting:

"During the period from October to March, when Synoptic (frontal) storms are the predominate weather engine, the prediction we're (the project team) after may be possible, HOWEVER, in the Summer months, when Meso-scale convective events, (Thunderstorms) are likely (June to August in particular), accurately forecasting a no runoff event, is improbable."[5]

The discussions with The Weather Network revealed that this was largely due to limitations in the forecasting models used as they all currently (at the time of discussion) have grid sizes of 10 x 10 km which are typically larger than pop-up thunderstorms that may develop during humid, warm summer days. However, the discussions also revealed that access to a meteorologist would help with interpretation of the forecast, and that much more information could be provided to the project team, improving the go/no-go decision framework for the bypass pumping and liner installation operations.

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[4] Brian Worsley, P.Eng left the City of Toronto during the project.

[5] Quoted from an email from Brian Worsley, P.Eng. The author accepts all responsibility for any misquotation.

While Metrolinx originally wanted to have the work completed at the earliest convenience, the costs of a full bypass system, the better forecasting probability during the colder month (or Synoptic weather events period), overall reduced bypass pumping requirements for Dry Weather Periods was sufficient reason to allow postponing the actual lining of sewer to the (from a weather perspective) preferred period between late October and March of the next year.

### Determine under which circumstances the City would allow for a reduction in the Safety Factor (SF)

The City had originally noted that a SF of 3.0 was required based on a fully deteriorated existing pipe condition. The City's major concern with the sewer was not the Risk of Failure but the Risk from Failure. The project team investigated under which circumstances the safety factor could be reduced, and if so, to what value. The importance of the safety factor played a role in the final liner design, as the thickness, and therefore instability was a direct function of the SF. The project team prepared a detailed technical memorandum describing the likely existing bedding conditions surrounding the sewer and water table above the sewer. In addition, detailed ovality measurements were taken to ensure that the existing out-of-roundness of the Fairfield CTS was accurately incorporated into the design. The project team also reviewed options to ensure that the tunneling process could produce better than expected/allowed for loss of ground; one of these options included mining through the Fairfield CTS section non-stop to reduce loss of ground from the TBM restarting.

As a result of this work, the City allowed for a reduction in the SF to 2.5, which helped with the following, all due to the reduction in wall thickness:

- Hydraulics;
- Liner curing times; and
- Installation times.

### PUTTING IT ALL TOGETHER / APPROVAL AND INSTALLATION

At this stage, the project team had the following information/tools to complete the final For-Approval package:

- A hydraulic model for the sewer including specific agreed upon Manning's N values for "Before" and "After" hydraulic conditions;
- A detailed information package on which the final liner design was to be based; and
- A good understanding of when and how detailed weather forecasting could be used to reduce the peak bypass pumping requirements to ~ 3 times the Peak Dry Weather Flow, which was a fraction (~7%) of the original bypass pumping requirements (1:2 year storm event).

The project team then proceeded to put the final package in place for approval where the City was required to initially approve the overall package, including the following:

- Detailed design of the sewer liner, to be provided by the contractor:
    - Review of the liner design to confirm conformity to the required design;
    - Updated capacity comparison (pre-lining vs post-lining).
- A proposed workplan on how the project team (which now included the overall construction team) proposed to implement the interaction between the construction team, design lead and the weather forecasters:
    - The project team proposed to impose a bypass pumping capacity on the contractor, on the understanding that the project team would also provide the contractor with a detailed weather forecast 3 times per day, at 6:00 am, noon, and 6:00 pm. It was decided to forego an scheduled weather update at midnight, as it was thought to be of little use.
- A full design report and design drawings.

The City reviewed the overall package, and provided approval. Once the City had approved the package, it was sent to the MOECC (via the City transfer review group) for approval.

On obtaining approval, the project team retained the specialist weather forecasting company and provided a detailed briefing to the forecasters. This was to ensure their team understood the aim of the project and how the sewer was anticipated to respond to rainfall events, based on the flow monitoring results. The dedicated weather forecast was distributed to the following overall project team members:

- The general contractor;
- The specialist lining sub-contractor;
- The construction administration team (CA team); and
- The design team.

The contractors jointly discussed the weather forecast and provided feedback to the remainder of the team. The CA team and design team provided input into the decisions as required to ensure that the project went ahead smoothly. Installation proceeded over four installation sessions, of which one session was delayed due to weather. There was no flooding of any subsection of the sewer and no complaints related to the installation process.

In summary, the following is noteworthy in the overall project:

- The City approved a bypass pumping system based on extended flow measurements, and a detailed weather forecast; this bypass system had ~7% of the capacity of a bypass system that the City would have mandated under normal circumstances;
- The design team imposed a bypass pumping capacity on the contractor, with the associated risks. The construction team accepted the imposed limits, with the specialised weather forecasting.
- Discussions with the construction team revealed that the overall method reduced their construction risks; they felt that they had more control because they had more information available.
- The City has since updated / revised the bypass pumping specifications detailing that additional modelling is to be completed for trunk sewers, and that bypass pumping installations are to be supported with a weather forecast.

## REFERENCES


1. Chow, Ven Te, 1959: *Open Channel Hydraulics*, Development of Uniform Flows and its Formulas (Table 5.6);
2. Ministry of the Environment (Ontario), 2008: *Design Guidelines for Sewage Works,* Details of Design and Construction of Sewers (Section 5.7). Note: The Ministry of the Environment (Ontario) has, since publishing this guideline, changed its name to The Ministry of Environment and Climate Change.
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7. Worsely, Brian, 2015: *Comment in an E-mail dated March 24, 2015*

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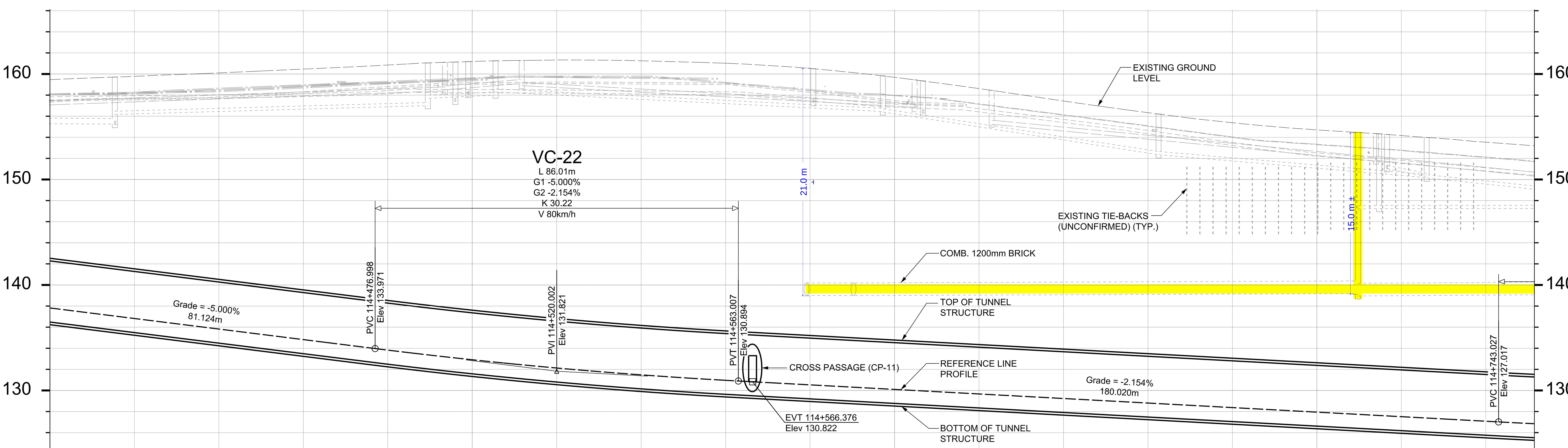


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Hatch Mott MacDonald

DESIGNED
DRAWN
CHECKED
APPROVED

EGLINTON-SCARBOROUGH CROSSTOWN

TWIN TUNNELS
GENERAL ARRANGEMENT
PLAN AND PROFILE
STA. 114+400 TO STA. 114+750

Plot Date: 16-Oct-2013

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SCALE (VERT) 0 1 2 3 4 5 8m

Hatch Mott MacDonald

DESIGNED

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EGLINTON-SCARBOROUGH CROSSTOWN

TWIN TUNNELS
GENERAL ARRANGEMENT
PLAN AND PROFILE
STA. 114+750 TO STA. 115+100

Plot Date: 18-Oct-2013

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Sheet No. 044