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Final Report for

# Wood Group / City of Hamilton

## Quantification of Volume and Contaminant Loadings

September 28, 2018

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Wood Group / City of Hamilton
Quantification of Volume and Contaminant Loadings

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## 1. Introduction and Background

On August 2, 2018, the Ministry of Environment, Conservation and Parks (MECP) issued Provincial Officer's Order #1-J25YB (hereinafter referred to as the Order) to the City in relation to the discharge of untreated wastewater to the environment. The Order requires the City to retain the services of a qualified consultant to complete certain work.

This report addresses MECP Order Item 1(a), which requires the quantification of spill volume and contaminant loadings associated with the sewage discharged from the Main/King Combined Sewer Overflow (CSO) facility to Chedoke Creek between January 28, 2014 and July 18, 2018.

## 2. Quantification of Spill Volume

The first part of MECP Order Item 1(a) involves the quantification of the spill volume.

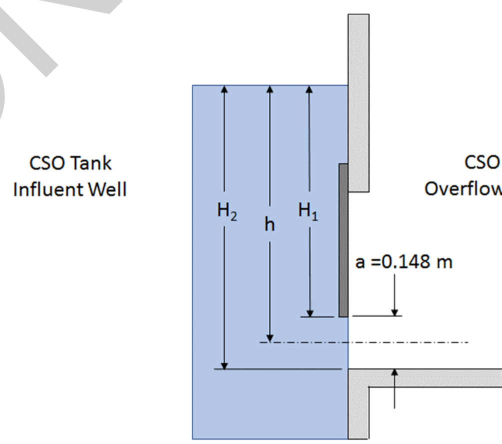
The discharge to the creek was the result of CSO tank inflows passing through a partially open maintenance by-pass gate in the CSO tank influent well[1]. It is assumed, for the purposes of these calculations, that sometime in January 2018, a second flow control gate located outside the CSO tank influent well failed in the closed position. The failure of this second gate increased the amount of flow diverted towards and under the first gate, increasing the volume of the discharge to the creek.

Prior to the second gate failure, historical data from the City's Supervisory Control and Data Acquisition System (SCADA) and a review of historical rainfall data indicate that the discharge to the creek occurred only during wet weather flow (WWF) conditions, mainly due to rainfall events, or in some cases (in late winter/early spring), due to snowmelt and/or elevated groundwater infiltration entering the contributing sewage collection system. After the second gate failure, the SCADA records and a review of historical rainfall data indicate that discharges to the creek began to also occur during dry weather flow (DWF) conditions.

### 2.1 Methodology

The key piece of information to allow estimation of the spill volume is the historical sewage level data collected in the CSO tank wet well by the City's SCADA system. This data can be used to estimate the sewage level in the adjacent CSO tank influent well where the first gate is located, since the two chambers are hydraulically interconnected and the levels will be the same.

The discharge under the maintenance by-pass gate comprises three different types of flow.




[1] *The gate was found to be 4.94% open, which equates to a 0.148 m high gate opening. This measurement is being used for purposes of the calculations set out in this report.*

Referring to the figure above:

1) When the upstream depth of sewage above the bottom of the gate opening ($H_2$) is greater than 5 times the gate opening height (a = 0.148 m, so $H_2$ > 0.740 m), the opening acts as a Small Rectangular Orifice, and Bernoulli's equation applies, as described by the following equation:

$$Q = C_d a b (2gh)^{1/2}$$

*Where:* $C_d$ = Orifice Discharge Coefficient = $0.6 \dfrac{(H_2 - a)^{0.072}}{(H_2 + 15a)^{0.072}}$ (1)

$a$ = Gate Opening Height = 0.148 m

$b$ = Gate Opening Width = 3.0 m

$h$ = Depth of Sewage above centerline of Gate Opening (m)

$H_2$ = Depth of Sewage above bottom of Gate Opening (m)

$g$ = Gravitational Constant = 9.81 m/sec$^2$

2) When the upstream depth of sewage above the bottom of the gate opening ($H_2$) is between the top of the gate opening and 5 times the gate opening height (so 0.148 m < $H_2$ < 0.740 m), the opening acts as a Large Rectangular Orifice, and the following variation of Bernoulli's equation applies:

$$Q = \frac{2}{3} C_d b (2g)^{1/2} (H_2^{3/2} - H_1^{3/2}) \quad (2)$$

*Where:* $C_d$ = Orifice Discharge Coefficient = $0.6 \dfrac{(H_2 - a)^{0.072}}{(H_2 + 15a)^{0.072}}$

$b$ = Gate Opening Width = 3.0 m

$H_2$ = Depth of Sewage above bottom of Gate Opening (m)

$H_1$ = Depth of Sewage above top of Gate Opening (m)

$g$ = Gravitational Constant = 9.81 m/sec$^2$

3) When the upstream depth of sewage above the bottom of the gate opening ($H_2$) is less than the top of the gate opening (so $H_2$ < 0.148 m), the opening no longer acts as an orifice, but acts as a Sharp-nosed Broad-crested Weir, and the following equation applies:

$$Q = C_d b g^{1/2} H_2^{3/2} \quad (3)$$

*Where:* $C_d$ = Weir Discharge Coefficient = 0.462

$b$ = Gate Opening Width = 3.0 m

$H_2$ = Depth of Sewage above bottom of Gate Opening (m)

$g$ = Gravitational Constant = 9.81 m/sec$^2$

## 2.2 Results

The historical CSO tank wet well sewage level data from SCADA, and the above equations and parameters, were entered into an Excel spreadsheet, and discharge volumes were calculated for the period from January 28, 2014 to July 18, 2018. The results of the spill volume calculations are presented in Table 1 below.

**Table 1: Estimated Spill Volume for Period from January 28, 2014 to July 18, 2018**

| Gate Flow Component | WWF Spill Volume 2014 - 2018 (GL) | DWF Spill Volume 2018 (GL) | Total Spill Volume 2014 - 2018 (GL) |
|---|---|---|---|
| From Equation (1) For $H_2 > 0.740$ m | 11.7 | 0.1 | 11.8 |
| From Equation (2) For $0.148 \text{ m} < H_2 < 0.740$ m | 8.8 | 2.6 | 11.4 |
| From Equation (3) For $H_2 < 0.148$ m | 0.6 | 0.2 | 0.8 |
| Total Spill Volume | 21.1 | 2.9 | 24.0 |

The Total Spill Volume for the period from January 28, 2014 to July 18, 2018 is therefore estimated to be 24.0 GL (Giga-Litres), and of this total, 21.1 GL is estimated to have occurred during WWF conditions, and 2.9 GL during DWF conditions.

We understand that this amount is greater than that reported by the City of Hamilton to the MECP on July 27, 2018, but that calculation did not have the benefit of the detailed analysis applied in this report; and this analysis is more conservative and likely overestimates the volume.

## 2.3 Key Assumptions and Limitations

Some key assumptions and limitations related to the estimated spill volume include:

+ The Main/King CSO tank is designed to overflow in significant events once the tank is filled to capacity. Approved CSO tank overflows that might otherwise have happened during significant WWF events from January 28, 2014 to July 18, 2018 (i.e. if the flows under the gate had instead entered and filled the tank to capacity) have not been subtracted from the estimated total spill volume presented above. Accounting for such approved CSO tank overflows would reduce the estimated total spill volume presented in this report.
+ Small openings such as the one under the maintenance bypass gate can become blocked by floating debris in the sewage on the upstream side of the gate, which can at least temporarily reduce the rate of flow under the gate. The total spill volume estimate presented above assumes no such blockages occurred during the period from January 28, 2014 to July 18, 2018. Accounting for such blockages would reduce the estimated total spill volume presented in this report.

+ The spill volume calculations assume free flow through the gate opening with no controlling water level on the downstream side of the gate. This is a reasonable assumption given that there were no measured overflows from the CSO tank contributing flows to the overflow chamber on the downstream side of the gate. Having said this, there is a possibility that very high water levels in Chedoke Creek (e.g. occurring during significant WWF events) could create some level of backwater on the downstream side of the gate, which would reduce the flow rate under the gate. The estimated total spill volume presented above assumes this did not occur during the period from January 28, 2014 to July 18, 2018. Accounting for such obstructions to the flow would reduce the estimated total spill volume presented in this report.

## 3. Quantification of Contaminant Loadings from Spill

The second part of MECP Order Item 1(a) involves the quantification of contaminant loadings associated with the spill, based upon the estimated DWF and WWF spill volumes and available DWF and WWF water quality sampling data.

### 3.1 Methodology

Contaminant loadings have been estimated by multiplying the DWF and WWF spill volume estimates above by representative event mean concentrations (EMCs) for each selected pollutant parameter, developed using historical water quality data collected by the City.

Since some of the spill volume occurred during DWF conditions and some during WWF, and since the strength of the sewage entering the CSO tank wet well would be expected to vary significantly between DWF and WWF (where the latter will typically be more dilute, at least for organic and bacterial pollutant parameters), we determined two separate EMCs for each pollutant parameter, one to represent average DWF conditions, and one to represent average WWF/CSO conditions.

For DWF conditions, the following information was used:

+ Daily historical pollutant concentration data for the Woodward Avenue Wastewater Treatment Plant (WWTP) influent stream, covering the period from January 28, 2014 to July 18, 2018; including the following parameters: Total Suspended Solids (TSS), Total Phosphorus (TP), Ammonia ($NH_3$), Total Kjeldahl Nitrogen (TKN), and Carbonaceous Biochemical Oxygen Demand (cBOD).
+ Single DWF water quality sample taken just upstream of the Main/King CSO Tank on September 6, 2018, including the same parameters as listed above (TSS, TP, Ammonia, TKN, and cBOD).

For WWF conditions, the following information was used:

+ Pollutant concentration data for the Main/King CSO tank influent stream, collected during the period from 2002 to 2006, including the following parameters: Total Suspended Solids (TSS), Total Phosphorus (TP), Ammonia ($NH_3$), Total Kjeldahl Nitrogen (TKN), and Carbonaceous Biochemical Oxygen Demand (cBOD).
+ Pollutant concentration data for other nearby CSO facilities (including the Royal Avenue, McMaster/Ewen, Bayfront Park, and Eastwood Park CSO tanks), for the period from January 28, 2014 to July 18, 2018, including the same parameters as listed above (TSS, TP, Ammonia, TKN, and cBOD).

To develop the contaminant loading estimates, a series of analyses and calculations were performed. First, historical rainfall records, Woodward WWTP inflows, and Main/King CSO tank wet well levels were analyzed and corroborated to identify periods of DWF and WWF occurring at the Woodward WWTP and Main/King CSO tank from January 28, 2014 to July 18, 2018. The identified DWF and WWF periods were then used to develop separate representative average pollutant concentrations (EMCs) for both DWF and WWF conditions, which are highlighted in green in Table 2. The table also presents some other available DWF and WWF pollutant data, which were used to confirm the applicability of the final selected DWF and WWF EMC values for each pollutant.

Woodward WWTP influent data were used to develop the EMCs for the Main/King DWF conditions since DWF data is not collected in the Main/King CSO tank influent well, nor is it required to be. The single DWF sample taken on a dry day just upstream of the Main/King CSO tank on September 6, 2018 was used simply to confirm the applicability of the Woodward WWTP DWF influent data. As evident from Table 2, the results of this single DWF sample are consistent with the average DWF EMCs developed from the Woodward WWTP influent data.

In our opinion, it is more accurate to use the 2002-2006 WWF Main/King CSO tank data instead of the time-specific data from the other CSO facilities, to quantify the contaminant loadings. Having said this, the selected WWF EMCs for the Main/King CSO tank were compared to those from the other facilities. The EMCs for the Main/King CSO tank are consistent with those from the Eastwood Park CSO Tank (which is intuitive when considering the more commercial/ industrial land uses within their contributing catchments), but are generally higher than those for the other three CSO tanks (with at least the Royal and McMaster facilities generally serving more residential catchments). Based on the above, the final contaminant loading estimates presented below are likely overestimated.

**Table 2: Estimated Average DWF/WWF Pollutant Concentrations**

| Sample Description | TSS (mg/L) | TP (mg/L) | Ammonia (mg/L) | TKN (mg/L) | cBOD (mg/L) |
|---|---|---|---|---|---|
| DWF Data | | | | | |
| Average DWF Conc. From WWTP Influent | 266 | 4.52 | 21.6 | 34.7 | 173 |
| Main/King DWF Single Sample | 154 | 3.86 | 22.2 | 45.4 | 135 |
| WWF Data | | | | | |
| Average WWF Conc. Main/King CSO Influent | 76 | 1.61 | 4.58 | 10.0 | 41.3 |
| Average WWF Conc. Royal CSO Influent | 229 | 0.64 | 0.41 | 2.5 | 15.7 |
| Average WWF Conc. McMaster CSO Influent | 73 | 0.99 | 2.00 | 4.9 | 29.2 |
| Average WWF Conc. Bayfront CSO Influent | 66 | 0.67 | 1.22 | 4.0 | 29.9 |
| Average WWF Conc. Eastwood CSO Influent | 113 | 2.06 | 5.64 | 11.9 | 78.1 |

## 3.2 Results

Finally, the selected DWF and WWF EMC values from Table 2 were multiplied by their respective estimated DWF and WWF spill volumes from Table 1, to develop estimates of Total Contaminant Loadings for each selected pollutant parameter. The results of this final calculation are presented in Table 3.

**Table 3: Estimated Contaminant Loadings for Period from January 28, 2014 to July 18, 2018**

| Flow Component | Spill Volume (GL) | Estimated Total Contaminant Loading (Tonnes) | | | | |
|---|---|---|---|---|---|---|
| | | TSS | TP | Ammonia | TKN | cBOD |
| DWF (2018) | 2.9 | 771 | 13 | 63 | 101 | 502 |
| WWF (2014-2018) | 21.1 | 1,604 | 34 | 96 | 211 | 871 |
| TOTAL (2014-2018) | 24.0 | 2,375 | 47 | 159 | 312 | 1,373 |