EVALUATION OF ETOBICOKE EXFILTRATION SYSTEM APPLICATIONS IN THE CITY OF BARRIE

by

Parto Peyvandisani

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Abstract

Evaluation of Etobicoke Exfiltration System Applications in the City of Barrie

Parto Peyvandisani

Master of Engineering

Civil Engineering

Ryerson University

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These days engineers reduce the adverse effects of urbanizations using Low Impact Developments (LID) on their municipal design. Etobicoke Exfiltration System (EES) as a LID Best Management Practice (BMP) was demonstrated in 1993 and is being implemented at a hospital rehabilitation project in Toronto. To evaluate EES through modeling, a methodology was used to implement EES in SWMM 5.1.012, and the outcome was applied for a case study in Barrie. The primary components of EES include inlets, void space storage of granular material laid beneath the main sewer system. These components were modeled by orifices and a storage unit to simulate the exfiltration of water from the stone trench into the surrounding native soil. The model was applied in a case study in Barrie regarding hydrologic performance analysis. The results indicated a significant reduction of runoff volume and peak flow reduction for a single design storm. However, some challenges revealed by these results regarding the case study.

Acknowledgements

I would like to express my sincere gratitude to my Supervisors Prof. James Li and Dr. Darko Joksimovic for the continuous support of my MEng Project and related research, for their patience, motivation, and immense knowledge. Their guidance helped me in all the time of research and writing of this project.

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1 Introduction

1.1 Background

Intensification of urban development changes the hydrologic cycle, resulting in increased flooding, deterioration of receiving water quality and ecological change of receiving water. Sustainable Low Impact development (LID), is a hot topic aims at reduction of the adverse hydrologic impacts of urbanization. Etobicoke exfiltration system (EES) was proposed and constructed as a LID in 1993 in the City of Etobicoke. The EES would reduce both the runoff peak flow and volume, resulting in increased carrying capacity of the minor systems.

Etobicoke Exfiltration System (EES) conveys the storm runoff via catch basins to two 200 mm PVC perforated pipes connected to manholes laid below the main storm sewer in a stone trench. The captured storm runoff would exfiltrate to the surrounding soil from the stone trench. (A.M. Candaras Associates Inc. 1997).

Many studies have been done recently to address the minor and major storm system deficiencies in Barrie by different consulting engineering firms such as AECOM and C.C Tatham & Associates Ltd and some alternative solutions are also proposed. Different types of potential LID BMPs are simulated in PC SWMM (DRAINAGE MASTER PLAN City of Barrie 2017). However, EES is not created as a default LID in PC SWMM software.

Eventually, EES is implemented by exfiltration storage model in SWMM 5.01.012, and the resulting model was applied for a case study in Barrie to monitor hydrological performance analysis.

1.2 Objective

The objective of this study is to evaluate the runoff control performance of EES with a focus on quantity control in Kidds Creek watershed area in Barrie for SCS 5-year-6-hours single design storms for three days. The exfiltration storage model of SWMM will be tested with recommendations for future applications.

1.3 Methods

A flow test from Candaras report,1997 (A.M. Candaras Associates Inc. 1997) were utilized to monitor the appropriateness of the exfiltration storage model. The Princess Margaret Boulevard/Princess Anne Boulevard was chosen to calibrate the exfiltration storage model.

The exfiltration storage model in this study includes orifices and a storage unit which represent the exfiltration loss.The exfiltration trench consists of the granular stone with 40% porosity. (James Li 2013). Since the exfiltration trench invert elevation is about 1 m above the groundwater table (James Li 2013), the soil is unsaturated at the beginning of exfiltration, and the exfiltration flow occurs in the vertical and horizontal direction due to head loss along the media length.

Consequently, the Green Ampt method is one of the suitable approaches to calculate the infiltration rate and cumulative infiltration into the surrounding native soil. However, the storage unit in SWMM is defined as an open pond such as lake or reservoirs which conflicts the underground EES trench design; As soon as the capacity of the storage unit in SWMM is exceeded, flooding would occur which represents overflow in the upstream manhole. Regarding the perforated pipes, the orifices with the discharge coefficient 0.65 were chosen. The sensitivity analysis was also conducted regarding the variation of the orifice outflows for different discharge coefficients. Another sensitivity analysis was also conducted regarding the seepage properties of the soil to address the suitable type of soil regarding EES performance.

Eventually, the exfiltration storage model is applied to evaluate the runoff control performance of EES in a case study in the City of Barrie which can be considered as a linear LID alternative solution to solve the minor system deficiencies.

2 Etobicoke Exfiltration System (EES)

2.1 Description of EES

Etobicoke Exfiltration System (EES) conveys the runoff via catch basins to two perforated pipes connected to manholes. Accordingly, the runoff exfiltrates to the surrounding soil via stone trench. (A.M. Candaras Associates Inc. 1997). The flow routing and the cross section of the EES are shown in Figures 1 and 2 respectively. As it is illustrated in Figure 2, the granular stone was placed from the bottom of the trench up to the inlet elevation of the main storm sewer. Accordingly, the granular stones are provided over and under the perforated pipes. The stone trench prepares a storage volume laid under the main storm sewer. The overflow to the main storm sewer occurs when the stone trench capacity is full.

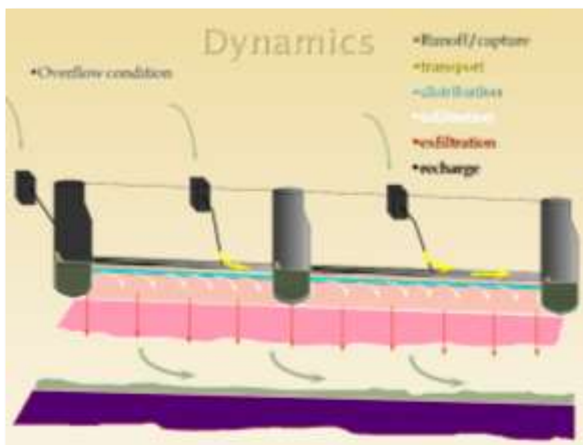


Figure 1. Flow dynamics of EES (James Li 2013)

The Etobicoke Exfiltration System (EES) in comparison with standard municipal storm sewer system has the following components. The EES layout is shown in Figure 3.

- Two perforated pipes under sewer pipe
- Cut-off walls (to force the stored water into the surrounding soil and to prevent the migration of water to downstream trench)
- Gross trap (to collect the spills in the avenues with high traffic volume or any area with oil spill such as old residential areas with oil furnace)

- Mechanical plug (which are installed in the downstream and upstream of perforated pipes (Li and Tran,2015)

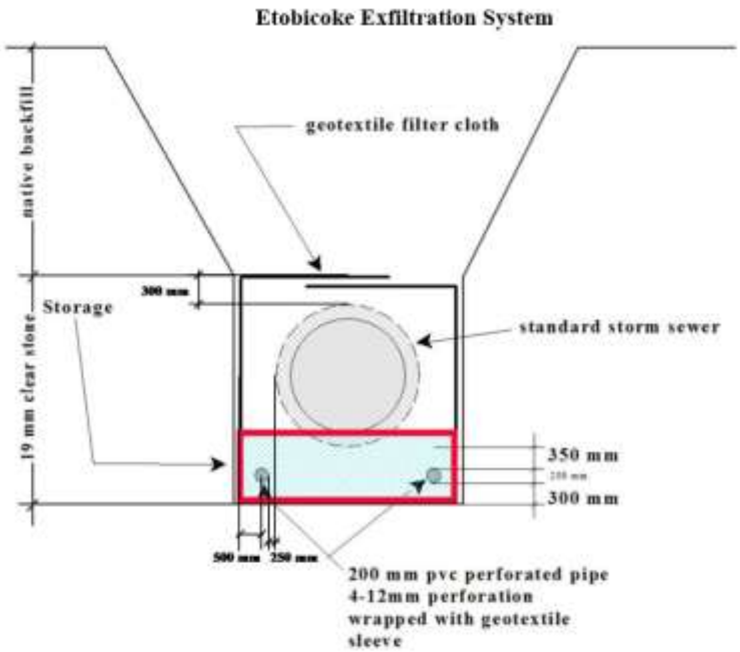


Figure 2. The Exfiltration System (A.M. Candaras Associates Inc. 1997)

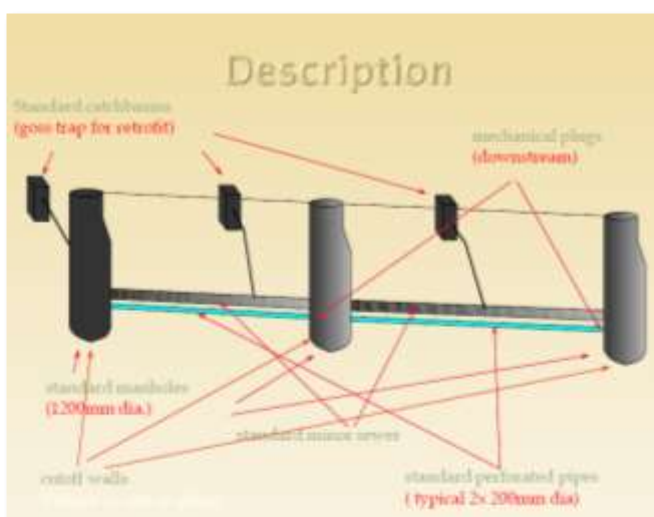


Figure 3. EES layout (James Li 2013)

2.2 Stone Trench Capacity Design

The storage capacity of the Exfiltration Trench includes void space of clear stone and the volume of perforated pipes which can be achieved in a manner similar to the reservoir routing method as follows:

Equation 1

$$I - Q = dS/dt$$

Where

I=inflow per unit time

Q=Outflow per unit

dS/dt=Change in storage within the system per unit time (A.M. Candaras Associates Inc. 1997)

Equation 2

$$Q = -K.A.i$$

Where

A=exfiltration area

K=hydraulic conductivity of the soil

Q=flow rate across the area A

i= σh/σl (Hydraulic Gradient)

Where

h=piezometric head

l=flow distance. (A.M. Candaras Associates Inc. 1997)

or

The infiltration rate (Q) would be calculated via the following procedure:

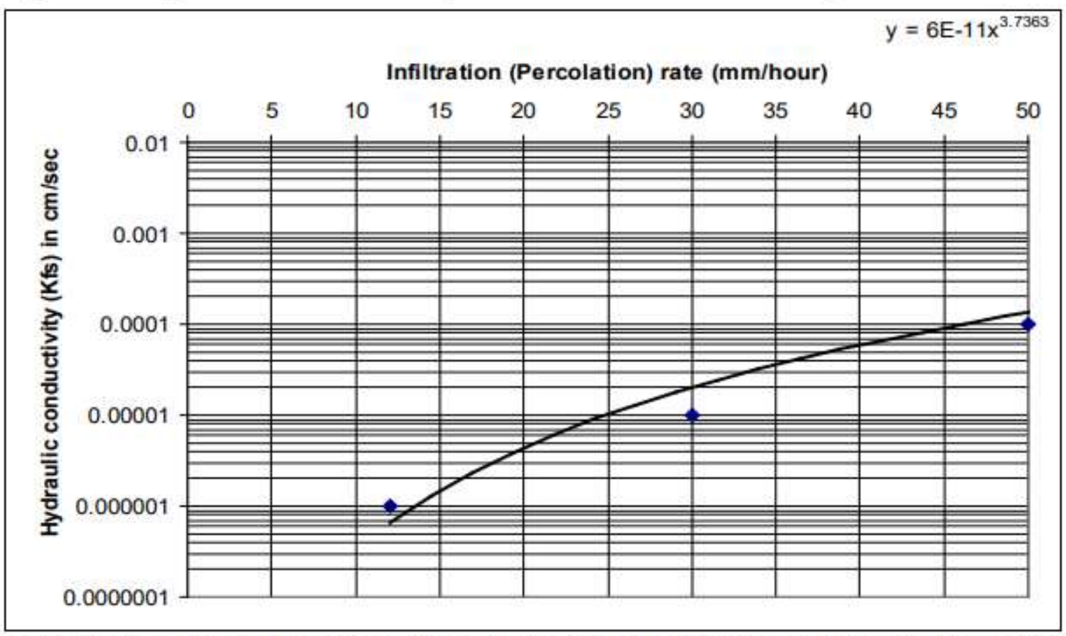
Table C1: Approximate relationships between hydraulic conductivity, percolation time and infiltration rate

Hydraulic Conductivity, K_{fs} (centimetres/second)	Percolation Time, T (minutes/centimetre)	Infiltration Rate, 1/T (millimetres/hour)
0.1	2	300
0.01	4	150
0.001	8	75
0.0001	12	50
0.00001	20	30
0.000001	50	12

Source: Ontario Ministry of Municipal Affairs and Housing (OMMAH). 1997. Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions. Toronto, Ontario.

Figure 4. Approximate relationship between hydraulic conductivity, percolation time. (TRCA 2011)

Figure C1: Approximate relationship between infiltration rate and hydraulic conductivity



Source: Ontario Ministry of Municipal Affairs and Housing (OMMAH). 1997. Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions. Toronto, Ontario.

Figure 5. Approximate relationship between hydraulic conductivity, percolation time. (TRCA 2011)

USDA Soil Texture Classification	SUCT Avg. Capillary Suction		HYDCON Saturated Hydraulic Conductivity		SMDMAX Initial Moisture Deficit for Soil (Vol. of Air / Vol. of Voids, expressed as a fraction)	
	(in)	(mm)	(in/hr)	(mm/hr)	Moist Soil Climates (Eastern US)	Dry Soil Climates (Western US)
Sand	1.95	49.5	9.27	235.6	.346	.404
Loamy Sand	2.41	61.3	2.35	59.8	.312	.382
Sandy Loam	4.33	110.1	0.86	21.8	.246	.358
Loam	3.50	88.9	0.52	13.2	.193	.346
Silt Loam	6.57	166.8	0.27	6.8	.171	.368
Sandy Clay Loam	8.60	218.5	0.12	3.0	.143	.250
Clay Loam	8.22	208.8	0.08	2.0	.146	.267
Silty Clay Loam	10.75	273.0	0.08	2.0	.105	.263
Sandy Clay	9.41	239.0	0.05	1.2	.091	.191
Silty Clay	11.50	292.2	0.04	1.0	.092	.229
Clay	12.45	316.3	0.02	0.6	.079	.203

Figure 6. Green and Ampt Method Parameters, (NVCA Stormwater Technical Guide), Table 10.4 (Glenn Switzer 2013)

Equation 3. Infiltration rate (DRAINAGE MASTER PLAN City of Barrie 2017)

$$Exfiltration\ rate\left(\frac{mm}{hr}\right) = 1.6667 * 10^{10} * {k_{fs}}^{1/3.7363}$$

Where k_{fs}= Saturated Hydraulic Conductivity (cm/s)

(DRAINAGE MASTER PLAN City of Barrie 2017)

Accordingly, the exfiltration rate(Q) should be adjusted by some safety factors depending on the type of the soil, (DRAINAGE MASTER PLAN City of Barrie 2017). The inflow rate(I) is calculated according to hydrograph generated by a design storm event. For example, a 15 mm AES 1-hour design storm was used for this study. The required storage of the exfiltration trench is calculated by Equation (1) every 5 minutes. Then, the maximum required storage volume would be calculated. Consequently, the required depth of the exfiltration trench would be calculated by dividing the volume by the surface area of the trench.

Moreover, the stored volume in the exfiltration trench is assumed to be drained within 48 hours after the rain is stopped.

3 The Princess Margaret Boulevard/ Princess Anne Boulevard

3.1 EES Simulation

In this study, EES was modeled as exfiltration storage via PC SWMM 5.1.012. To evaluate the exfiltration storage model appropriateness, a measured flow test in 1994 was conducted (A.M. Candaras Associates Inc. 1997) . This flow test was conducted on July 12th, 1994 via fire hose between manhole 2(MH2) and manhole 3(MH3) for 110 minutes located in the Princess Margarete Boulevard/ Princess Anne Crescent in the city of Etobicoke which is shown in Figure 7.

For a large storm event, the rate of exfiltration from the trench eventually approach a steady value while overflow occurs in the upstream manhole. Accordingly, the flow in MH3 represents the overflow.

Figure 7. Princess Margarete Boulevard/Princess Anne Crescent. (Google earth)

3.2 Exfiltration storage Model

The exfiltration storage model includes a storage unit (SU) and two orifices (orifice 1 & orifice 2) to present exfiltration loss. The layout of an exfiltration storage model is shown in Figure 8. As it is illustrated in Figure 8, manhole 2 (MH2) and manhole 3 (MH3) represents upstream and downstream manholes in Princess Margarete Boulevard respectively. Main storm sewer above the perforated pipes is specified by C1. The outfall (OF1) and conduit 2 (C2) were used to complete the model, and they would not monitor any runoff in this model. The surface runoff from the sub catchment was assigned to the upstream manhole. Orifices convey water with a discharge coefficient 0.65 to the storage unit. The volume of a storage unit was reduced by 60 percent due to the 40 % porosity of the 13mm granular stones. The void space storage volume was defined by storage curve comprised tabular & functional curves. The seepage properties of the storage unit were assumed as same as the corresponding subcatchment area seepage properties. Eventually, the equivalent situation in princess Margarette was simulated between manhole 2 and 3 in this model.

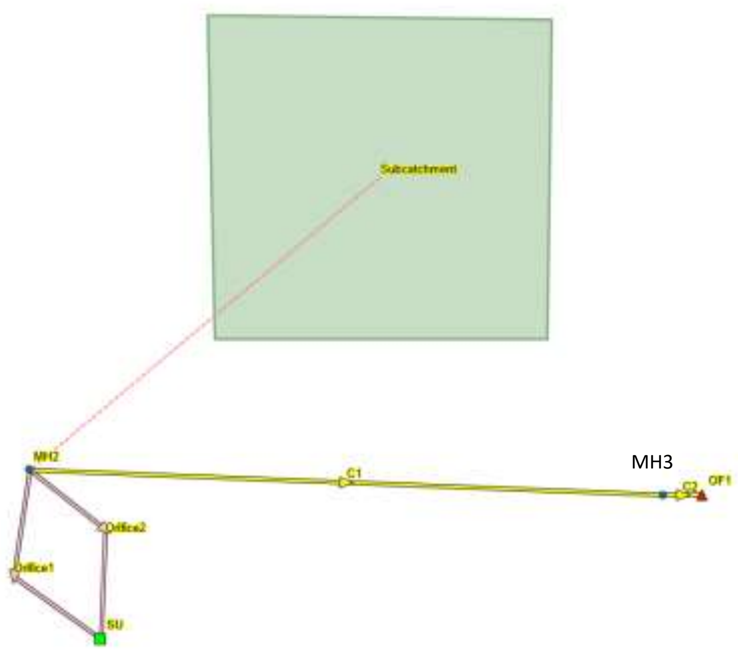


Figure 8. The exfiltration storage lay out model in SWMM 5.1.012 for Princess Margarete

3.3 The EES stone trench simulation via storage unit and Green-Ampt method

According to the Open SWMM, a storage unit can be represented by a loss code from SWMM code (International(CHI) 2017) viewer and be calculated according to the Green-Ampt method.

Since the surrounding soil of the EES is not saturated at the beginning of the rainfall event, the hydraulic conductivity is a function of the suction head and the soil moisture content. Consequently, the infiltration rate into the soil beneath the trench and the potential cumulated infiltration are similarly to those in the Green-Ampt method. Accordingly, the characteristics of the soil (e.g., initial moisture deficit, hydraulic conductivity, and suction head) are the variables of the Green-Ampt method which become the input data to PC SWMM. The infiltration rate and the cumulative infiltration are calculated via Eqs (4) and (5) respectively. It should be noted that when the capacity of the trench is full, the overflow will occur in the upstream manhole and the flow will be conveyed via main sewer system (i.e., the depth of water in manhole reaches 0.85 m from the manhole bottom). However, the storage unit in PC SWMM is represented as a pond, lake, impoundment, or chamber that provides water storage (A.Rossman 2016). When the runoff water reaches the maximum depth of the storage, it will flood or surcharge. As a result, the flooded amount of water from storage units should be added to final outfall from the catchments. However, PC SWMM will give the total exfiltration volume.

Equation 4.Green Ampt Infiltration Rate, (W.Mays 2010)

$$f = K(\frac{\psi \Delta\theta}{F(t)} + 1)$$

Equation 5.The Cumulative Infiltration, (W.Mays 2010)

$$F(t) = Kt + \psi \Delta\theta \ln(1 + \frac{F(t)}{\psi \Delta\theta})$$

Where

K= hydraulic conductivity

Ψ= Suction head

θ= Soil moisture content

3.3.1 The Storage Curve

PC SWMM calculates the volume of the storage unit using the storage curve specified by the user. The storage curve is the relationship between the depth of the storage unit and the surface area. *(A. Rossman 2017)*. There are two types of storage curves:

- Functional Curve
- Tabular Curve

3.3.1.1 Tabular Curve

The tabular curve can be used to define the relationship between water depth and water surface area of a stone trench in the exfiltration storage model. The relationship between the increasing surface area of the trench and the increasing depth in the sloped trench is illustrated in Figure 9. This trend is applicable where the upstream invert elevation is less than the stone trench depth. As it is illustrated in Figure 9, for water depth reaches the upstream invert elevation, the water area becomes constant. To calculate the effective storage volume of the trench, the porosity of the clear stones was assumed to be 0.4. Equation (6) shows the relationship between the water surface areas of the trench for different depths of water.

Equation 6

$$Surface\ area\ of\ the\ trench = 0.4 * Width * \frac{\min(\ depth\ of\ water, the\ invert\ junction\ elevation\ difference)}{slope}$$

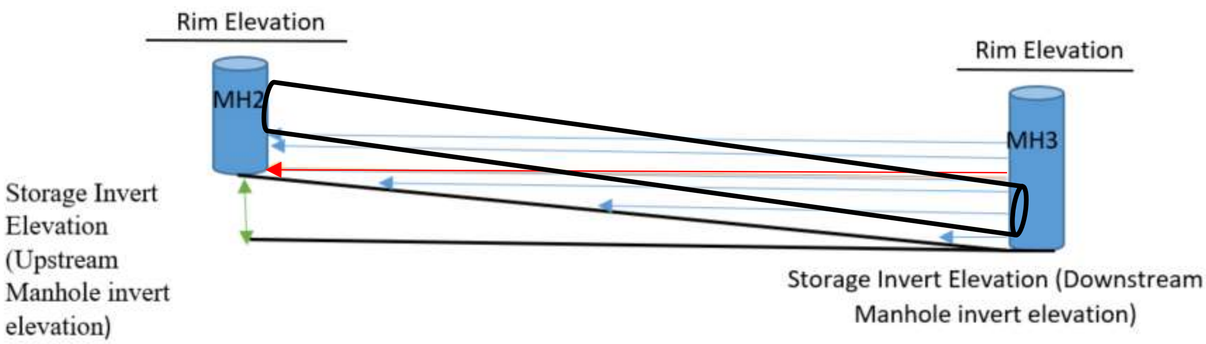


Figure 9. The trend of the increased surface area of the trench versus the depth

3.3.1.2 Functional Curve

The functional curve can also be used to demonstrate the relationship between the water surface area and the water depth regarding EES. Since water infiltrates into the surrounding void space volume along the length of the stone trench at the same time, the increasing surface area of the stone trench could be considered almost constant.

The functional curve has the general form:

Equation 7

$$A = c0 + c1Y^{c2}$$

Where C0, C1, and C2 are user supplied constants and Y is the water depth. The corresponding volume is achieved as follows:

Equation 8

$$V = c0Y + \left(\frac{C1}{C2+1}\right)Y^{c2+1}$$

(A. Rossman 2017)

3.4 Water Conveyance to the storage unit by orifices

The exfiltration rate of the perforated pipes was simulated via side orifices with the invert offset of 0.3 m from the bottom of the upstream manhole. The other property of the orifice such as discharge coefficient was assumed to be 0.65. However, the discharge coefficient of orifices (which is similar to the minor loss coefficient in the Energy equation and is a function of entrance constriction and exit expansion) was studied via a sensitivity analysis described in the following sections. Different streamlines and their corresponding discharge coefficients are shown in Figure

10. The relationship between a flow, the cross section of an orifice, and the discharge coefficient of an orifice is indicated in Equation (10)

Equation 9. The discharge through an orifice

$Q_0 = C_d . A_0 . \sqrt{2gh}$

Where

C_d= discharge coefficient

A_0 =cross-sectional area of the orifice

h =the difference between the headwater and tailwater elevations (A.Chin 2013)

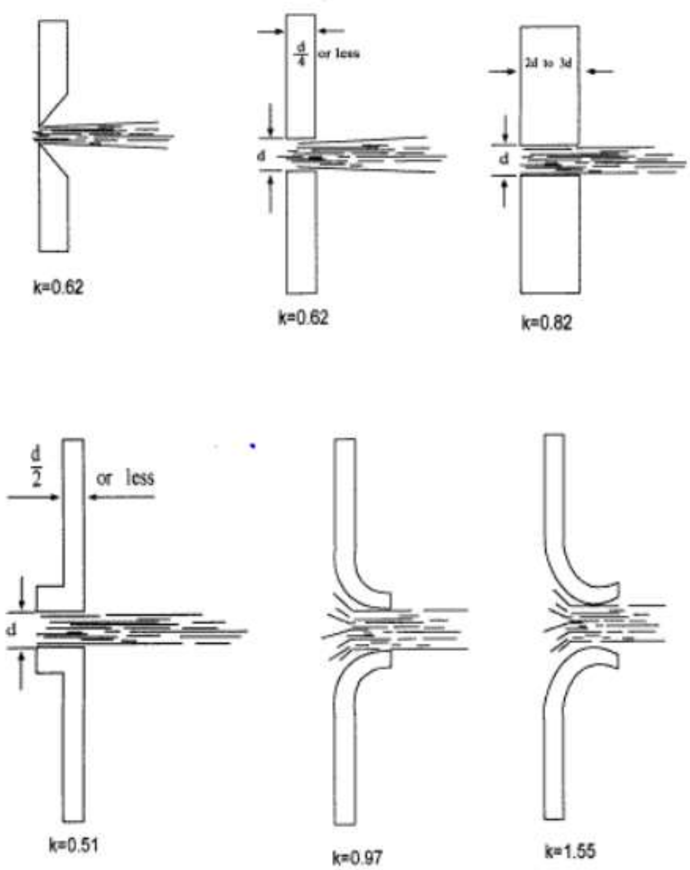


Figure 10. Different Streamlines of Orifices (Nally 2018)

3.5 The design specification regarding Princess Margarette Boulevard

The design specifications regarding the flow test of Princess Margarete Boulevard are as follows:

- The head difference between manhole 2 and 3 was 0.637 m (Sewer gradient 0.65% with 98 m length).
- The inlet offset elevation of the main storm sewer was 0.65 m according to a typical cross section of EES in princess Margarette, which is shown in Figure 11. As it is shown in Figure 11, the stone trench depth was assumed 0.3 m above the main conduit.
- The stone trench depth according to Candars report (1997) (A.M. Candaras Associates Inc. 1997) was estimated 1.287 m between MH2 and MH3.
- The tabular curve was used to define the relationship between the water depth and water surface area which is shown in Figure 12.
- The two orifices with diameter 0.2 m and invert offset 0.3 m were used in this system.
- The soil type of the studied location was reported sandy loam to loamy sand according to the borehole samples data (table 3.6, (A.M. Candaras Associates Inc. 1997)).
- The seepage properties of the loamy sand were collected from Green and Ampt Method Parameters, (NVCA Stormwater Technical Guide), Table 10.4 (Glenn Switzer 2013) as follows:
- Hydraulic Conductivity: 59.8 mm/hr.
- Suction Head:61.3 mm
- Initial Deficit: 0.312
- The invert elevation of the trench was considered as same as downstream manhole invert elevation (154.3 m).
- The stone trench width (2.264 m) was defined according to a typical cross-section of the EES.
- The equivalent radius of the stone trench is shown in Figure 13. As it is shown in Figure 13, the surface area increases steadily after reaching the upstream manhole elevation.

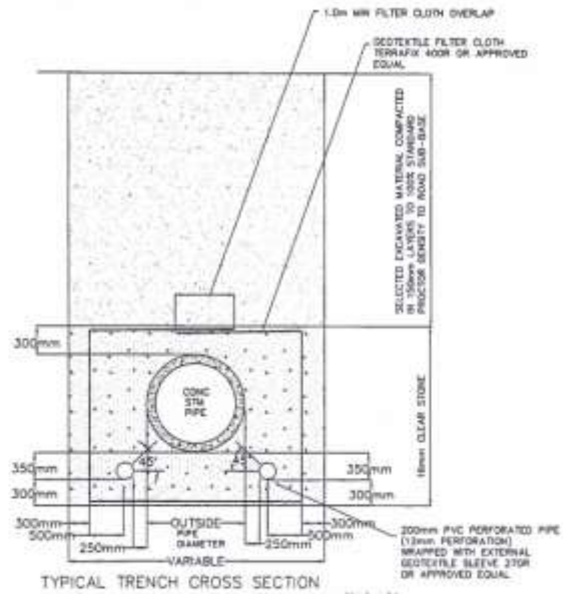


Figure 11. Typical cross section of EES in Etobicoke. (A.M. Candaras Associates Inc. 1997)

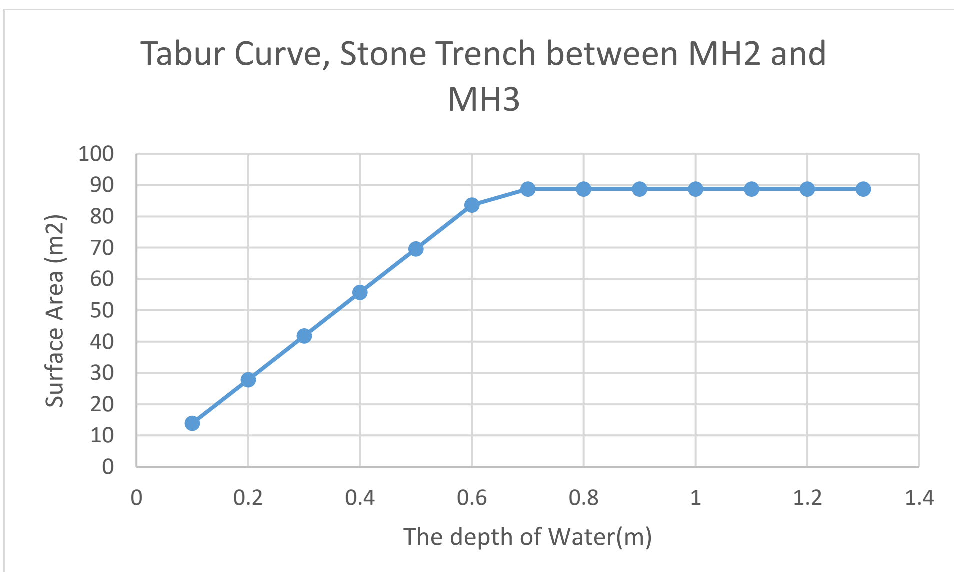


Figure 12. Storage Tabular Curve between MH2-MH3

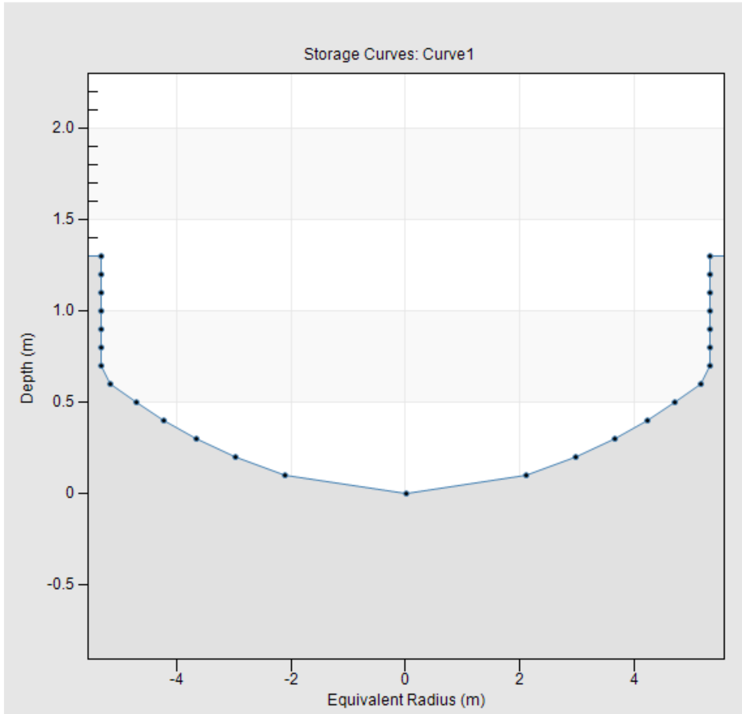


Figure 13. Storage unit cross section gained from PC SWMM

3.6 EES simulation using Tabular curve

A flow test was conducted in 1994 via fire hose between manhole 2 (MH2) and manhole 3 (MH3) for 110 minutes in princess Margarete Boulevard. According to the data collected from this flow test, total inflow to MH2 was reported 42 m3. The maximum water head in the stone trench was recorded 0.45 m from the base of the stone trench. The exfiltration loss volume, and the water stored volume was recorded 14 m3 and 27.28 m3 respectively. It was reported that no overflow was observed during the test and the monitored overflow was due to flow from an abandoned culvert connected to MH3 which is shown in Figure 16. *(A.M. Candaras Associates Inc. 1997)* .

All the recorded data from this test is shown in Figure 14. The total inflow to MH2 was simulated by Excel which is shown in Figure 15. The MH2 stone filter head which is shown in Figure 14 was defined as the water depth in the upstream side of the stone trench, and the MH3 stone filter head was defined as the water depth in the downstream side of the stone trench. (A.M. Candaras Associates Inc. 1997).

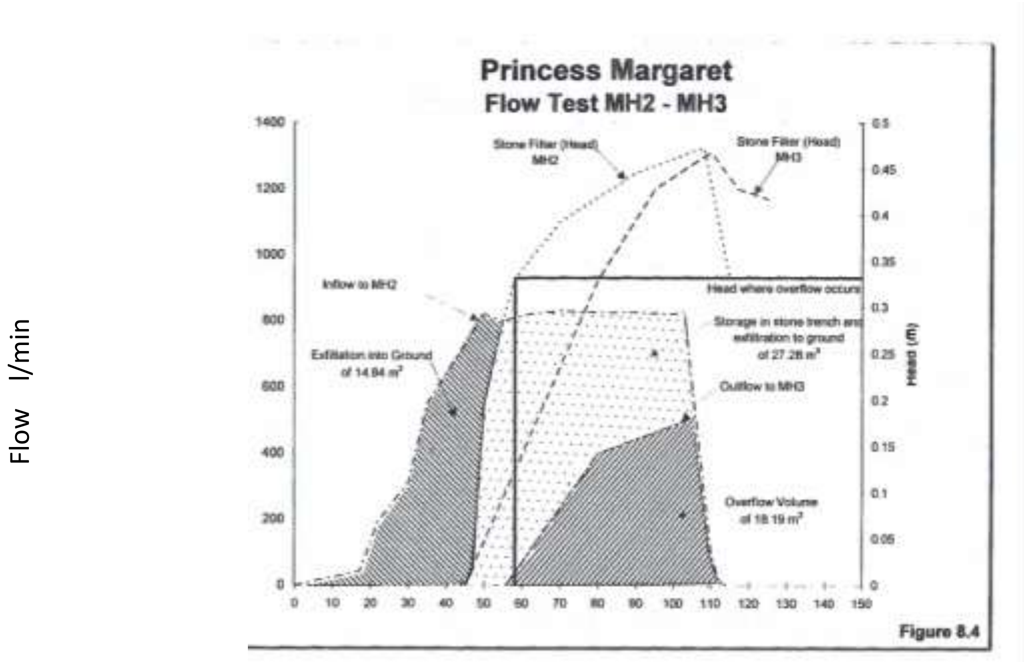


Figure 14. The Princess Margaret flow test MH2-MH3 (A.M. Candaras Associates Inc. 1997)

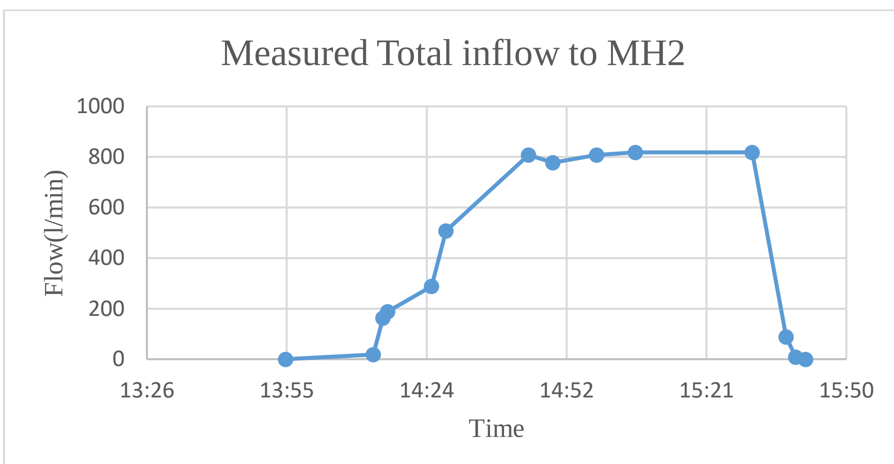


Figure 15. Measured Total inflow to MH2

Table 7.8: Princess Margaret Blvd. Exfiltration System Summary of Monitoring Results

Date	Storm Duration (hr)	Rainfall Depth (mm)	Peak Inflow (MH2) (l/s)	Total Inflow Volume (l)	Maximum Filter Head Upstream MH2 (mm)	Maximum Filter Head Downstream MH3 (mm)	Peak Outflow (MH3) (l/s)	Total Outflow Volume (l)	Comments
May 26 1994 (See Fig. 7.8)	22.5	28.3	9.7	73,668	Nil	65	0.3 (1)	4,486	Stone trench not full No overflow at MH2
May 31 1994 (See Fig. 7.9)	0.5	11.1	8.1	28,340	Nil	5	1.5 (1)	2,003	Stone trench not full No overflow at MH2
June 24 1994 (See Fig.7.10)	24.0	24.1	2.2	7,587	Nil	3	0.1 (1)	1,131	Stone trench not full No overflow at MH2
Oct. 5-6 1995 (See Fig. 7.11)	18.0	63	10.0	130,015	380	500	3.0 (1)	18,895	Stone trench full No overflow at MH2
July 12 1994 (See Fig. 8.2)		Flow Testing	13.3		430	430	8.3 (1)		Overflow occurs after 45 minutes of inflow at MH2, with the 13.3 l/s peak inflow occurring for a 10 minute period

(1) The observed flows at MH3 were due to an abandoned culvert that was connected to the sealed catchbasin downstream of MH2.

(2) The overflow in MH2 occurs prior to the theoretical static head of 650 being achieved. Overflows occured due to the inflow at MH2 exceeding the inlet capacity of the perforated pipes.

Figure 16. Princess Margarette Exfiltration System Summary

3.6.1 Peak flow and total Volume Analysis

According to the flow test in 1994, the total inflow volume, total exfiltration loss and the water stored volume were reported 42 m3, 14 m3 and 27.28 m3 respectively. After running the model for 110 minutes, the exfiltration loss and the water stored volume was reported 11 m3 and 31 m3 for loamy sand soil type which is shown in Figure 17. The maximum water depth in MH2 and the storage unit was founded 0.3672 m and 0.6983m respectively shown in Figure 18. The water head in MH2 and storage unit is also shown in Figure 19 which indicates that piezometric head (elevation head + pressure head) of water in MH2 is higher than the piezometric head in the storage unit.

```
**************************          Volume         Volume
Flow Routing Continuity           hectare-m      10^6 ltr
**************************        ---------      ---------
Dry Weather Inflow .......            0.000          0.000
Wet Weather Inflow .......            0.000          0.000
Groundwater Inflow .......            0.000          0.000
RDII Inflow ..............            0.000          0.000
External Inflow ..........            0.004          0.043
External Outflow .........            0.000          0.000
Flooding Loss ............            0.000          0.000
Evaporation Loss .........            0.000          0.000
Exfiltration Loss ........            0.001          0.011
Initial Stored Volume ....            0.000          0.000
Final Stored Volume ......            0.003          0.031
Continuity Error (%) .....            0.000
```

Figure 17. Flow Routing Continuity results

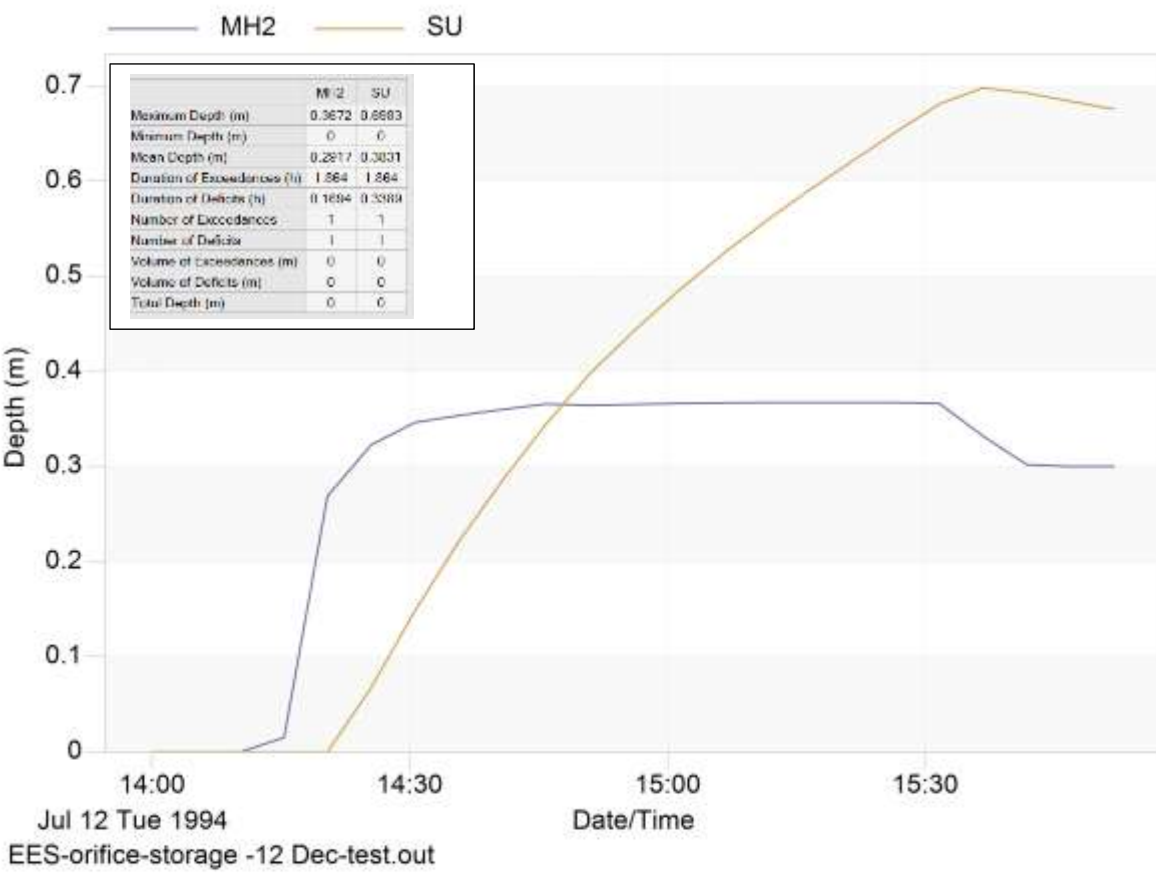


Figure 18. The water depth in manhole 2(MH2) and the storage unit (SU), using Tabular curve

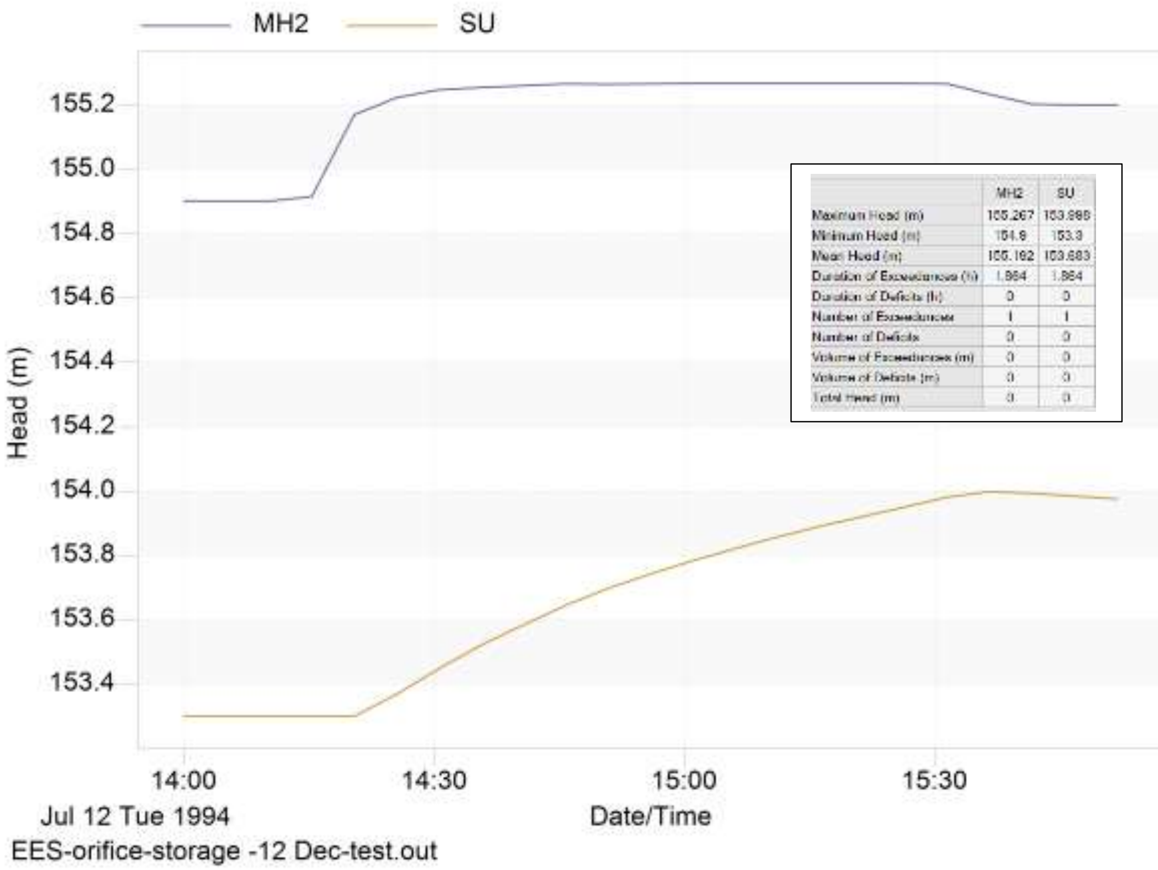


Figure 19. The piezometric head of Water in Manhole2 (MH2) and the storage Unit (SU), using Tabular curve

The water depth in the stone filter and storage unit achieved from the flow test, and the simulation result is compared in Figure20. Figure 20 indicates that the water depth will increase after 40 minutes in the stone trench regarding the flow test. However, the simulation result shows that after 25 minutes the water depth will increase. It means that exfiltration rate will drop sooner in the simulated model.

The maximum water depth for the flow test and simulation is recorded 0.45 m and 0.7m respectively which shows the compatibility of the trend of exfiltration rate.

The system should also be drained within 48 hours after the rain has been stopped. Subsequently, the system is monitored for 72 hours which is shown in Figure 21. The storage unit exfiltrates completely in less than 12 hours according to figure 21.

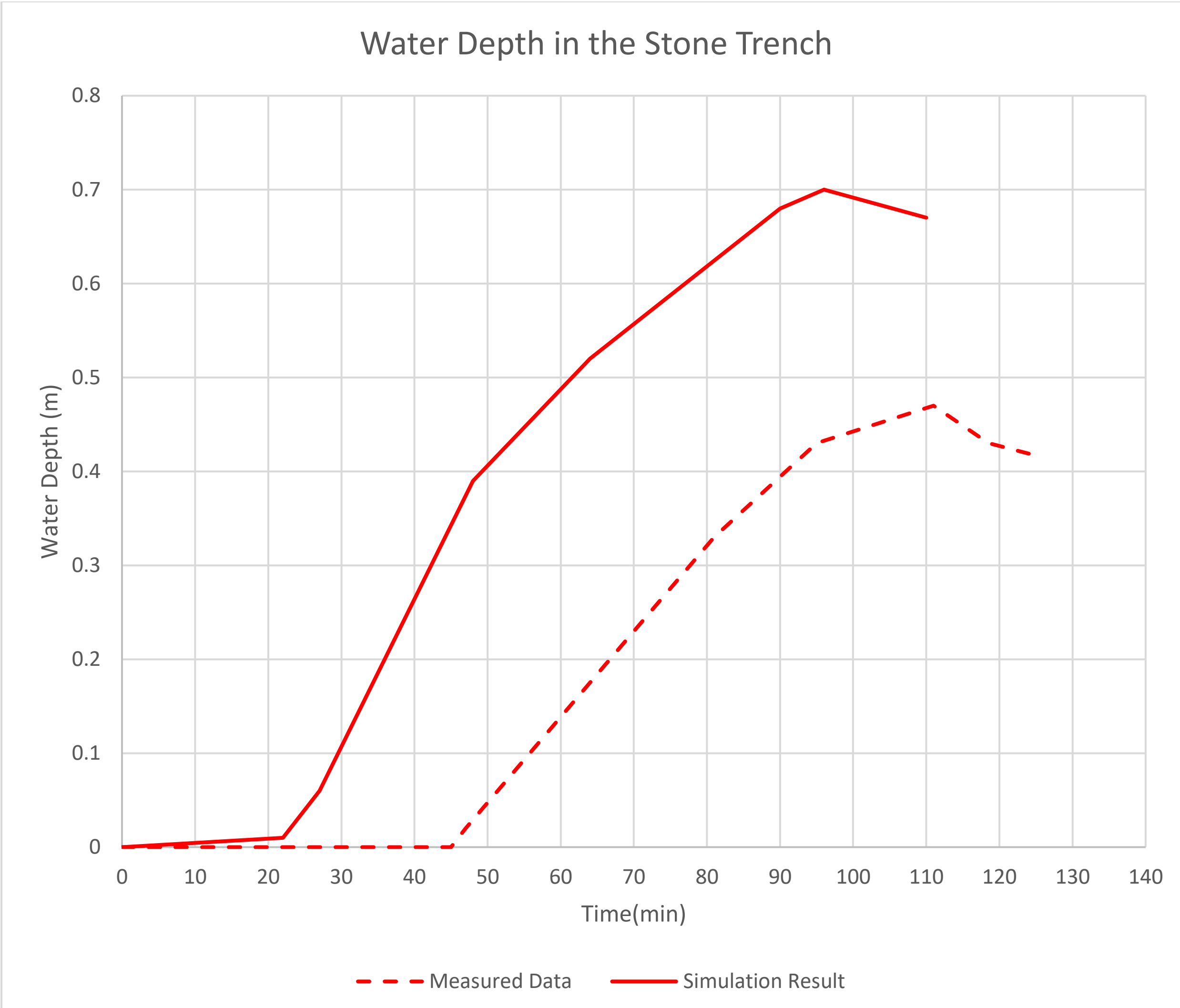


Figure 20. The measured Depth versus Simulation Result, using Tabular curve

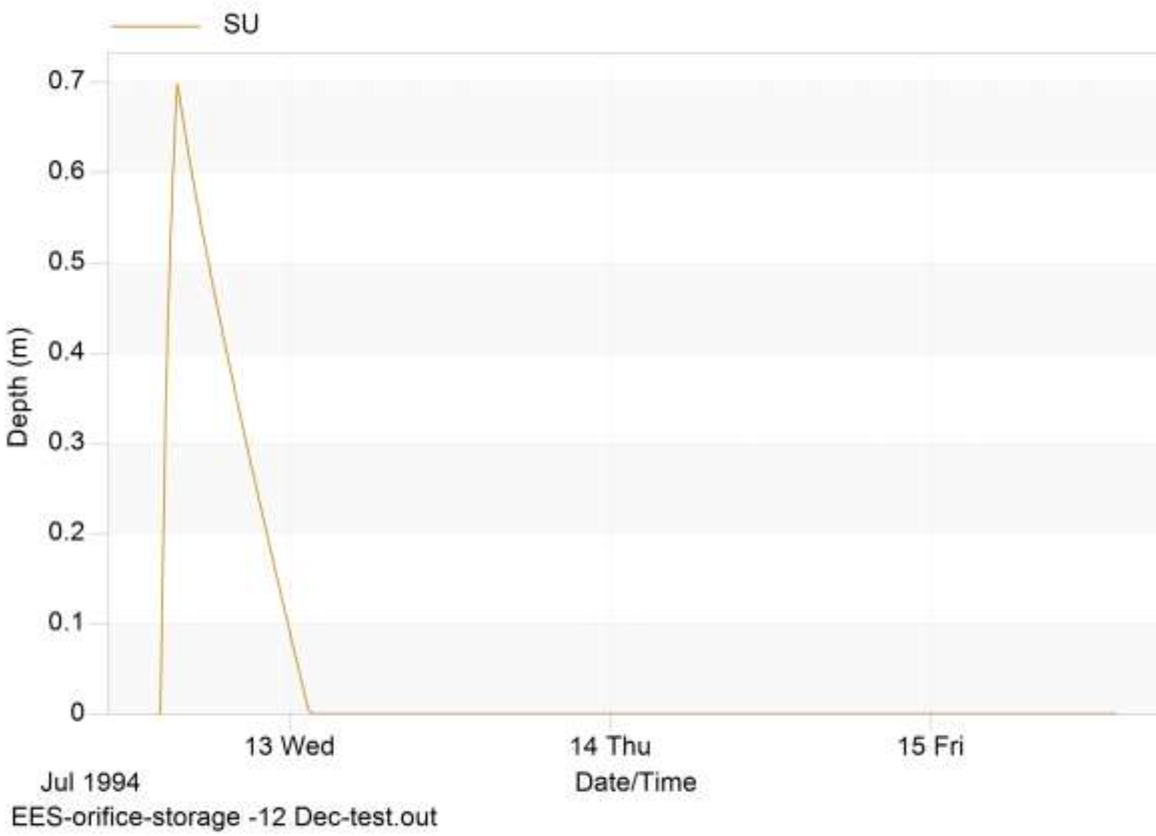


Figure 21. Exfiltration Summary of Storage Unit for 72 hours

3.6.2 Seepage Properties and Sensitivity analysis

As it was mentioned in Section 3.5, the type of the soil in Princess Margaret Boulevard was reported to be sandy loam to loamy sand below the trench. Accordingly, the storage unit seepage properties of loamy sand were used in the exfiltration storage model. A sensitivity analysis was also conducted for other types of soil as shown in Figure 22 and Table1. According to the sensitivity analysis, the seepage rate plays a critical role in determining the exfiltration in PC SWMM. For instance, the exfiltration loss becomes more prominent below a hydraulic conductivity of 60 mm/hr. (i.e., loamy sand).

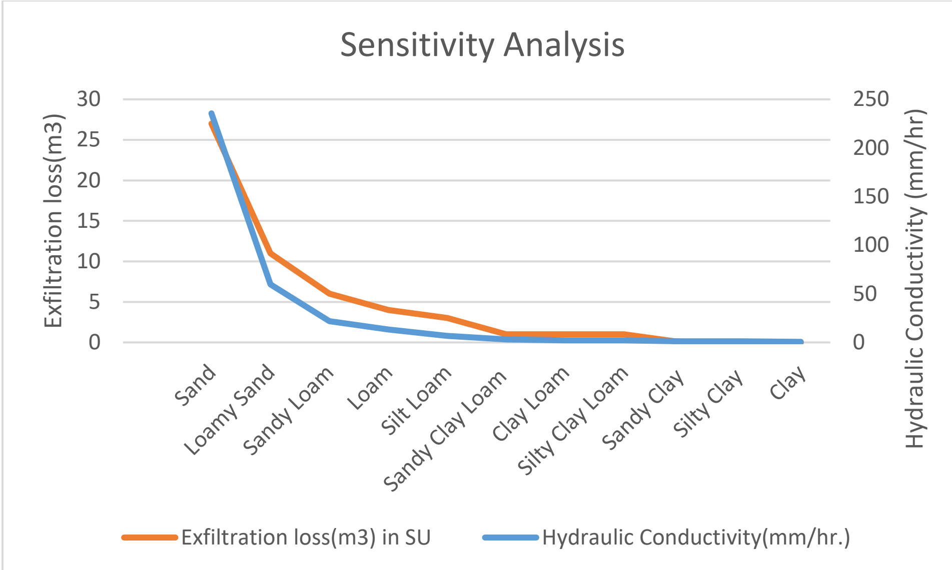


Figure 22. Sensitivity analysis regarding the seepage properties of the soil

Soil Type	Suction Head(mm)	Hydraulic Conductivity(mm/hr.)	Initial Deficit	Exfiltration loss(m3) in SU	Total inflow(m3) To MH2	Exfiltration Difference
Sand	49.5	235.6	0.346	27	42	0.015
Loamy Sand	61.3	59.8	0.312	11	42	0.000
Sandy Loam	110.1	21.8	0.246	6	42	-0.005
Loam	88.9	13.2	0.193	4	42	-0.006
Silt Loam	166.8	6.8	0.171	3	42	-0.007
Sandy Clay Loam	218.5	3	0.143	1	42	-0.009
Clay Loam	208.8	2	0.146	1	42	-0.009
Silty Clay Loam	273	2	0.105	1	42	-0.009
Sandy Clay	239	1.2	0.091	0	42	-0.010
Silty Clay	292.2	1	0.092	0	42	-0.010
Clay	316.3	0.6	0.079	0	42	-0.010

Table 1. Sensitivity analysis of seepage properties according to (Glenn Switzer 2013)

3.6.3 The orifice discharge coefficient sensitivity analysis

The orifice represents the perforated pipes in the exfiltration storage model with invert offset 0.3 m and discharge coefficient 0.65 in an exfiltration storage model. A sensitivity analysis was conducted for different orifice discharge coefficients between MH2- MH3 shown in Table 2. The sensitivity analysis shows that the discharge coefficient is not significant in determining the exfiltration loss by PC SWMM.

Orifice Exit Coefficient	Head (m)	Exfiltration Loss(m3)
0.51	154.716	11
0.62	154.716	11
0.65	154.716	11
0.82	154.716	11
0.97	154.716	11
1.55	154.716	11

Table 2. Orifice Discharge Coefficients Sensitivity Analysis

3.7 EES simulation using Functional curve

The exfiltration storage model was also monitored by the functional storage curve regarding the flow test in 1994. The tabular curve trend that was described earlier is not applicable when the stone trench depth is lower than the upstream invert elevation. For instance, if the stone trench designed up to the inlet offset of the main storm sewer, it will be less than the trench depth in many cases. This situation is shown in Figure 23. Case B in Figure 23 illustrates that the upstream invert elevation will be higher than the stone trench. Consequently, increasing water surface area will meet the stone trench depth prior to the upstream elevation and the described tabular curve trend is not be applicable.

Resultantly, a functional curve with a constant surface area was utilized to monitor the result. The invert elevation of the storage unit is assumed as same as upstream manhole invert elevation (154.9 m) in this model.

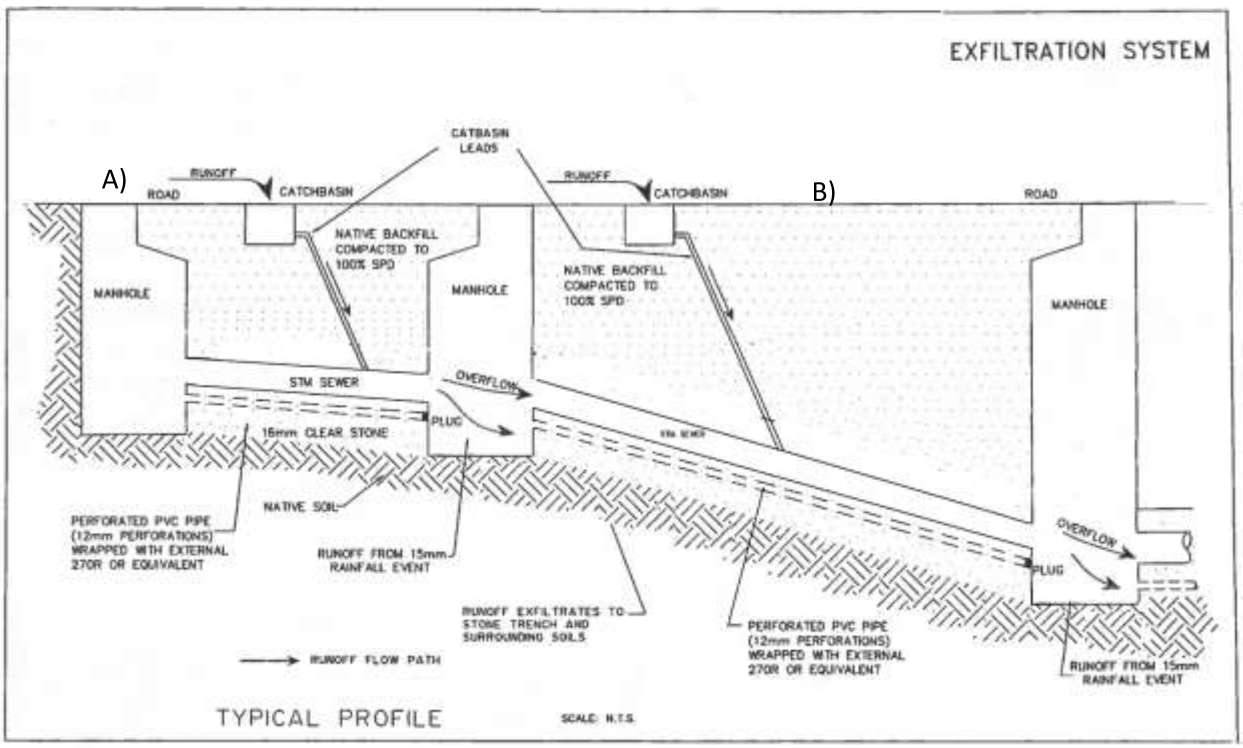


Figure 23. A typical profile of EES , A) the Sewer gradient is less than 2%, B) the sewer gradient is more than 2%

3.7.1 Design Specification

All the design specification was considered as same as the previous model except the following specifications:

- The storage curve was considered as a functional curve with a constant area 81.5 m2(40% porosity was applied), coefficient (C1) & exponent (C2) was considered zero
- The stone trench depth was considered as same as the inlet offset of the main sewer system 0.65 m.
- The invert elevation of the storage unit was considered as same as the upstream invert elevation.

3.7.2 Peak flow and total Volume Analysis

According to the flow test in 1994, the total inflow volume, total exfiltration loss, and the water stored volume were reported 42 m3, 14 m3 and 27.28 m3 respectively. After running the model for 110 minutes, the exfiltration loss and the water stored volume was reported 13m3 and 30 m3 for loamy sand soil type which is shown in Figure 24. The maximum water depth in MH2 and the storage unit was founded 0.33846m and 0.381m respectively. These numbers illustrate that the water movement in the stone trench and the upstream manhole is similar. The water depth in MH2 and the storage unit is shown in Figure 25. Figure 26 indicates the piezometric head (elevation head + pressure head) for upstream manhole and the storage unit.

The water depth in stone filter and storage unit for flow test and the SWMM simulation are compared in Figure27. As Figure 27 shows, the water depth will increase after 40 minutes in the stone trench regarding the flow test. However, the simulation result shows that the water depth will increase after 25 minutes. It means the stone trench will meet its capacity sooner than the flow test. It means that exfiltration rate will drop sooner in the simulated model.

```
**************************        Volume        Volume
Flow Routing Continuity         hectare-m      10^6 ltr
**************************       ---------     ---------
Dry Weather Inflow .......           0.000         0.000
Wet Weather Inflow .......           0.000         0.000
Groundwater Inflow .......           0.000         0.000
RDII Inflow ..............           0.000         0.000
External Inflow ..........           0.004         0.043
External Outflow .........           0.000         0.000
Flooding Loss ............           0.000         0.000
Evaporation Loss .........           0.000         0.000
Exfiltration Loss ........           0.001         0.013
Initial Stored Volume ....           0.000         0.000
Final Stored Volume ......           0.003         0.030
Continuity Error (%) .....           1.070
```

Figure 24. Flow Routing Continuity results, using Functional Curve

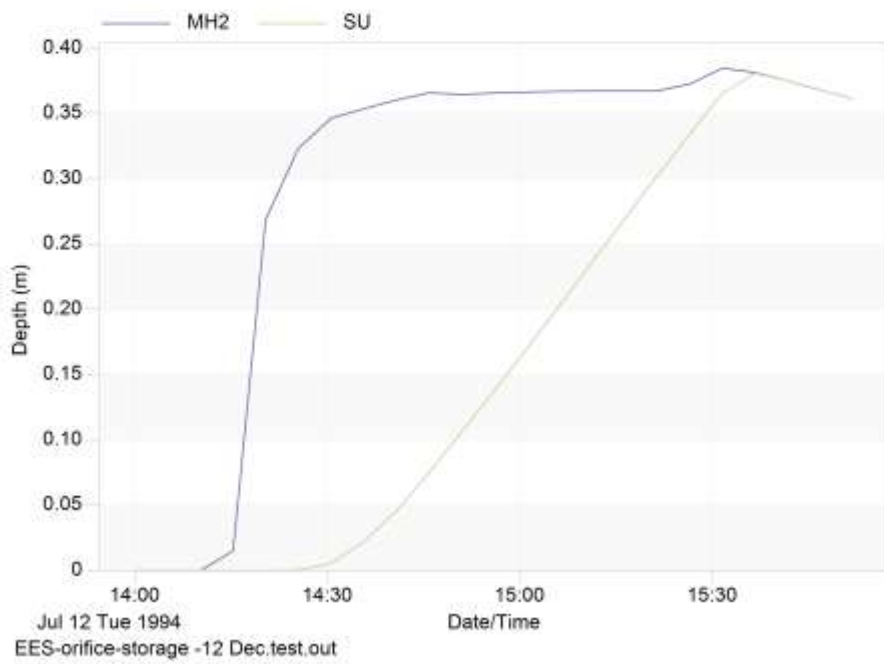


Figure 25. The water depth in manhole 2(MH2) and the storage unit (SU), using Functional Curve

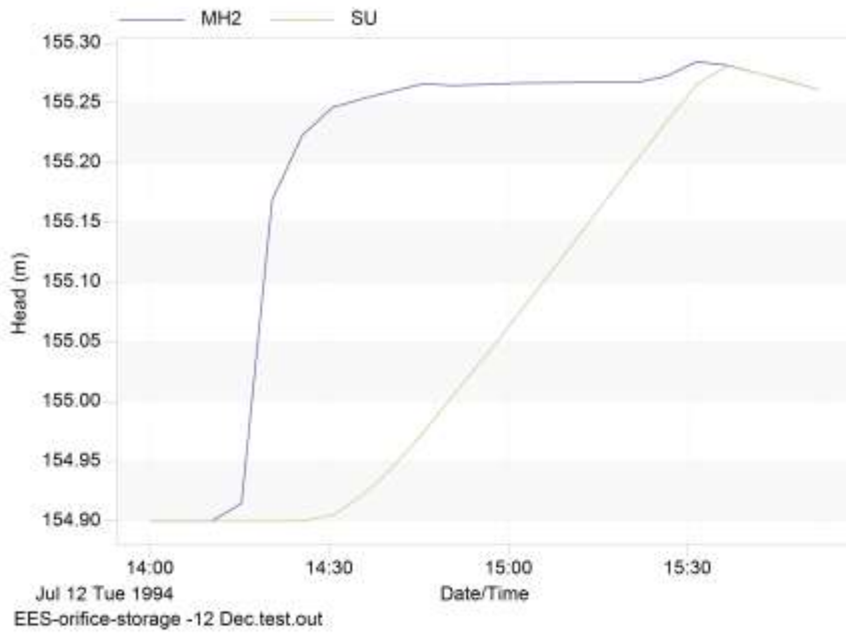


Figure 26. The Piezometric head of Water in Manhole2 (MH2) and the storage Unit (SU), using Functional Curve

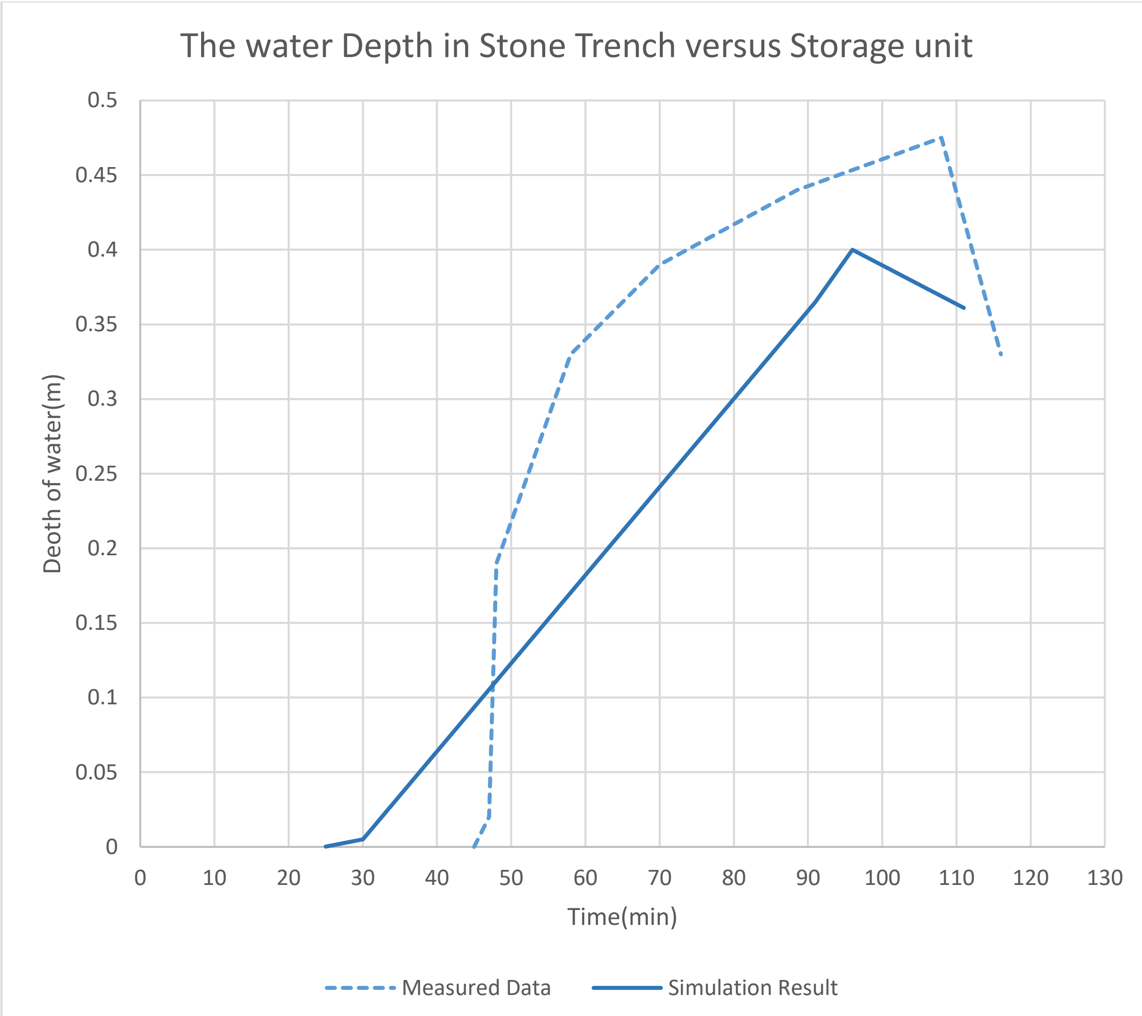


Figure 27. Measured Depth versus Simulation Result, using Functional curve

Eventually, the exfiltration loss and the water head were studied for two scenarios for the flow test in princess Margarete:

- 1-The stone trench depth was considered above the main storm sewer simulated by the exfiltration storage and the corresponding tabular curve
- 2-The stone trench depth was considered up to the inlet offset of the main sewer system simulated by the exfiltration storage model and corresponding functional curve

Comparing the SWMM results and the flow test data, it is founded that the exfiltration storage is compatible with EES. The comparison of water depth in storage units and the stone filter for the simulation and flow test is shown in Figure 28.

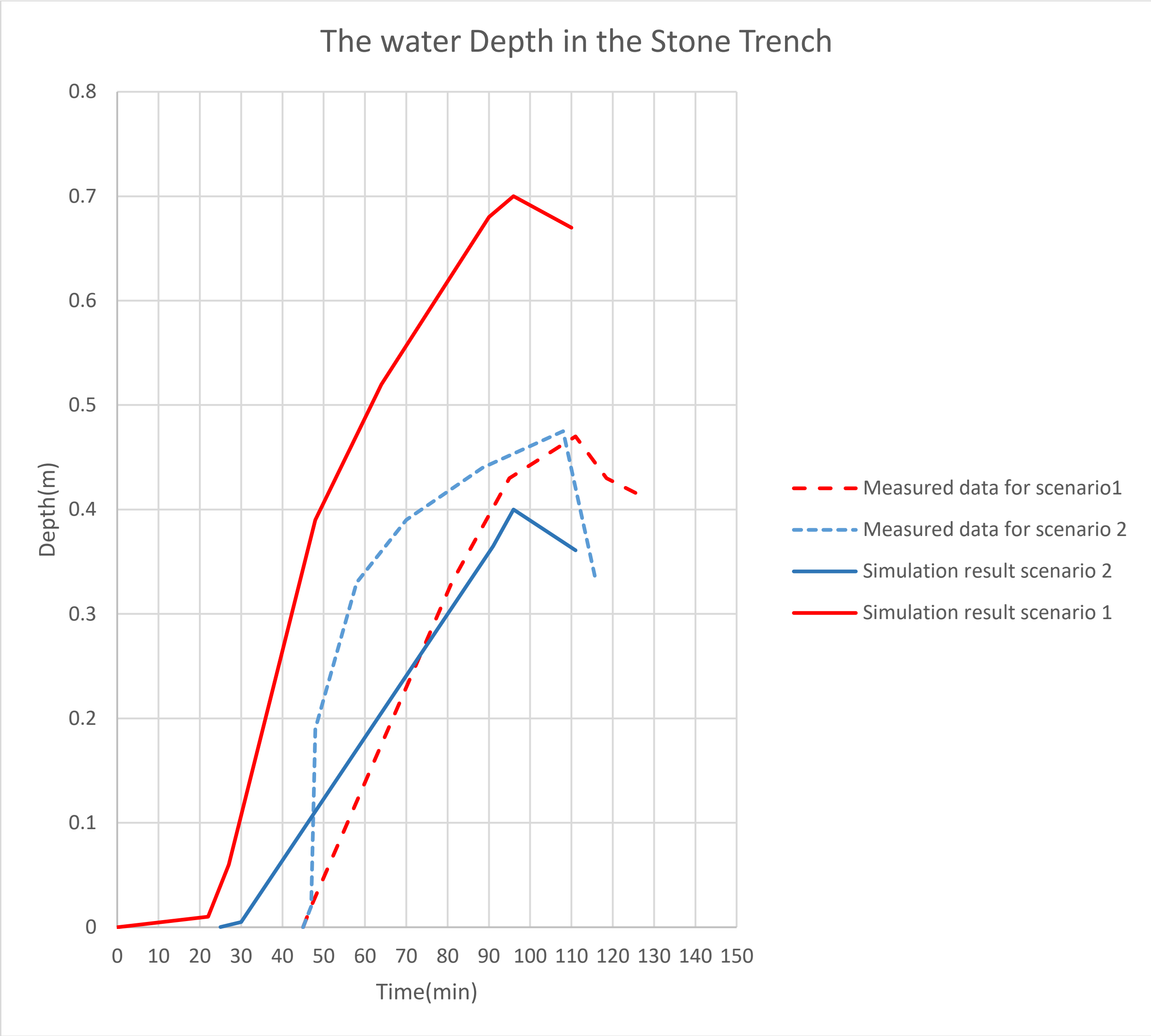


Figure 28. Measured Depth versus Simulation Result

4 Case Study

4.1 Site Description

To address the storm sewers system deficiencies, the City of Barrie retained C.C Tatham & Associates Ltd. (CCTA) to study Barrie watershed areas. Consequently, Barrie was divided into three main watershed areas:

- Barrie Creeks Drainage Study Area;
- NVCA Watershed Drainage Study Area
- Lovers Creek, Hewitt's Creek and Sandy Cover Drainage Study Area.

It should be noted that Sophia Creek watershed and Mulcaster drainage area were excluded from the study by the city of Barrie. Accordingly, the major and minor deficiencies of the stormwater system were detected all over the city, and alternative solutions were proposed. In this study, Kidds Creek watershed area from Barrie Creek drainage study area was nominated to evaluate the EES regarding potential for quantity control. The location of Barrie watershed areas and subwatershed areas are shown in Figure 29. (DRAINAGE MASTER PLAN City of Barrie 2017)

4.2 Barrie major and minor system deficiencies

Flooding of both major and minor stormwater system was detected from recent studies. This flooding is due to lack of channel and culvert capacities. Accordingly, the minor and major system deficiency was addressed by the city of Barrie, and alternative solutions including centralized LIDs, linear LID's, and major and minor improvements are proposed. (DRAINAGE MASTER PLAN City of Barrie 2017). EES was considered as a LID solution to solve the minor system deficiencies. Subsequently, the EES were evaluated for Kidds creek watershed area using exfiltration storage model.

4.3 EES Locations Considerations

The highly favorable EES locations throughout Barrie was determined by the city of Toronto considering the following properties for an area using SUSTAIN:

- All local public roads that are not in the intake protection zone (In this study all the polygon layers of the roads have been created from polyline layers via Arc GIS10.)
- Wellhead zone A-B is excluded

- The groundwater > 8 ft is considered
- Storm sewer installed before 1998 are considered
- Pavement installed before 1993 are considered
- Soil group A and B has been selected

Accordingly, the highly favorable places of EES throughout Kidds Creek watershed area are shown in Figure 30.

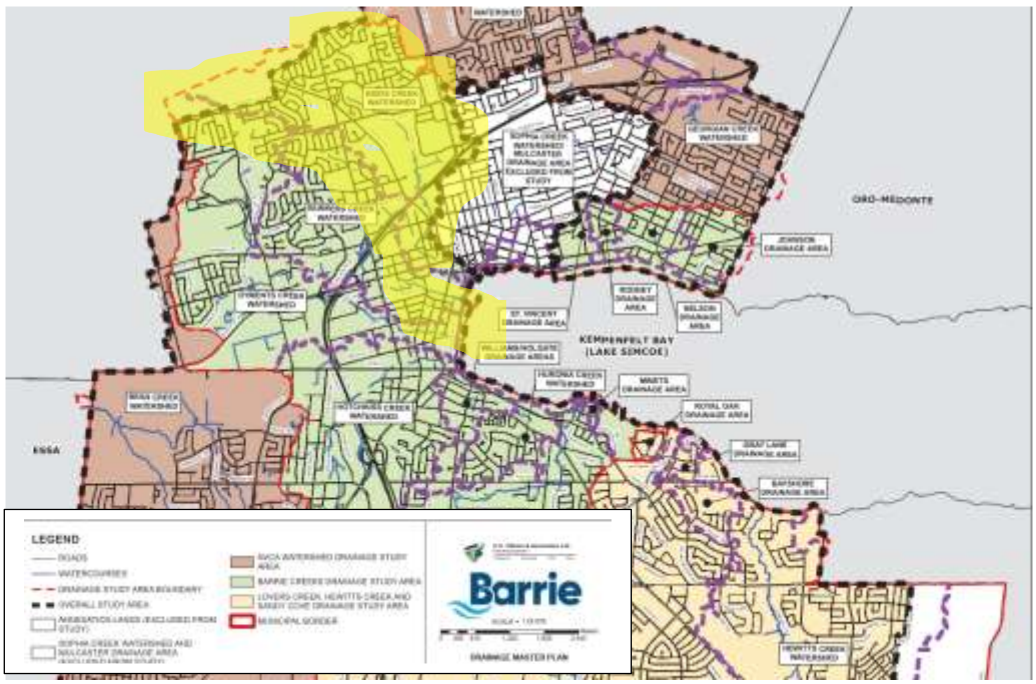


Figure 29. Watershed areas in Barrie (DRAINAGE MASTER PLAN City of Barrie 2017)

Figure 30. EES locations throughout Kidds Creek watershed area shown in brown routes

4.4 Design Specification for Kidds Creek Watershed Area

The EES design specifications throughout Kidds Creek are considered as follows:

- Storage seepage properties (Suction Head, hydraulic conductivity, initial deficit) are considered as same as the corresponding sub-catchments. The seepage properties of the storage units are attached in Appendix A.
- The inlet offset of the sewer conduits is designed 0.85 m across manhole invert elevation.
- The maximum required depth for a storage unit up to the main storm sewer is achieved (0.9 m) for all the watershed areas throughout Barrie according to (DRAINAGE MASTER PLAN City of Barrie 2017)
- To meet the EES required design criteria 0.85 m is added to the inlet offsets of existing conduits in highly favorable location regarding EES design.
- The inlet offset of the existing sewer pipes was set 0 by the city of Barrie. According to Design Criteria for water sewers and water mains (Toronto 2009) minimum drop required

in a manhole is 0.03 m. As a result, only the qualified paths should be selected to meet Design Criteria for water sewers and water mains (Toronto 2009).

- The Depth and width of the storage units are considered for two scenarios:

Equation 10

1-$Depth\ of\ the\ trench = Pipe\ Outer\ Diameter + 0.85m + 0.3m$ (if the storage unit capacity is assumed 0.3 m above the main storm sewer), which meets the design criteria of the city of Barrie (Depth of trench = maximum 0.9 m) (DRAINAGE MASTER PLAN City of Barrie 2017)

2-$Depth\ of\ the\ trench =$

$$0.9\ m\ if\ the\ storage\ unit\ capacity\ is\ assumed\ equal\ to\ inlet\ offset\ of\ the\ main\ storm\ sewer$$

Equation 11

$The\ Width\ of\ the\ trench = Pipe\ OD + 1.7\ m$(according to a typical cross section of EES)

- The Major system was created by the city of Barrie in the model, and it conveyed water for large events.
- The design storm, SCS 5-year,6-Hours (with a 15% increase due to future condition) was proposed by the City of Barrie
- The volume reduction and peak flow reduction were achieved for EES by comparing the results with the conventional method
- Extra overflow to upstream manholes presented as flooding in storage units. Since the storage unit is an open ponded area (A.Rossman 2016) not a pressurized storage unit.
- The peak flow could not be compared by utilizing the PC SWMM graphs since the flooded volume of the storage units was not detected in the charts. Consequently, the results were modified via Excel.
- Water should be drained entirely during 48 hours after the rain stopped, so infiltration summary was conducted for 3 days.

- Storage units were organized according to the invert elevation from the highest to lowest for every rout designated in different colors.
- Tabular Curve design for 38 storage units was attached in Appendix A. The trend of the tabular curves are considered according to section 3.3.1.

4.5 Barrie watershed/ Drainage Areas

4.5.1 Kidd's Creek

Kidds creek watershed area includes 581 sub-catchments with 463 ha area and 47 % imperviousness and two outfalls located in west side of Simcoe lake. This watershed area is Shown in Figure 30. Consequently, 70 exfiltration storage units were designed for this watershed area. However, 38 storage units in a sequence were chosen to monitor the peak flow and volume reduction before entering an existing water course. These storage units are shown in Figure 31. The components of the exfiltration storage model such as orifices were not possible to show in Figure 31 due to the zoom view. The storage unit routes are presented by different colors which are shown in Figure 32, and their corresponding attributes are shown in Table 3 & 4.

The storage units were monitored for two scenarios:

1-Scenario1

- Storage unit depth= outer diameter +0.85m (the inlet offset of main storm sewer) +0.3 m above the main storm sewer
- Storage curve =Tabular curve (the tabular curve detail is attached in Appendix A)
- Stone trench elevation= Downstream manhole invert elevation

2-Scenario2

- Storage unit depth = 0.9 m
- Storage curve =Functional curve with a constant area=0.4(void ratio of the granular stone) *width of the trench * length of the trench,
- Stone trench elevation= upstream manhole invert elevation

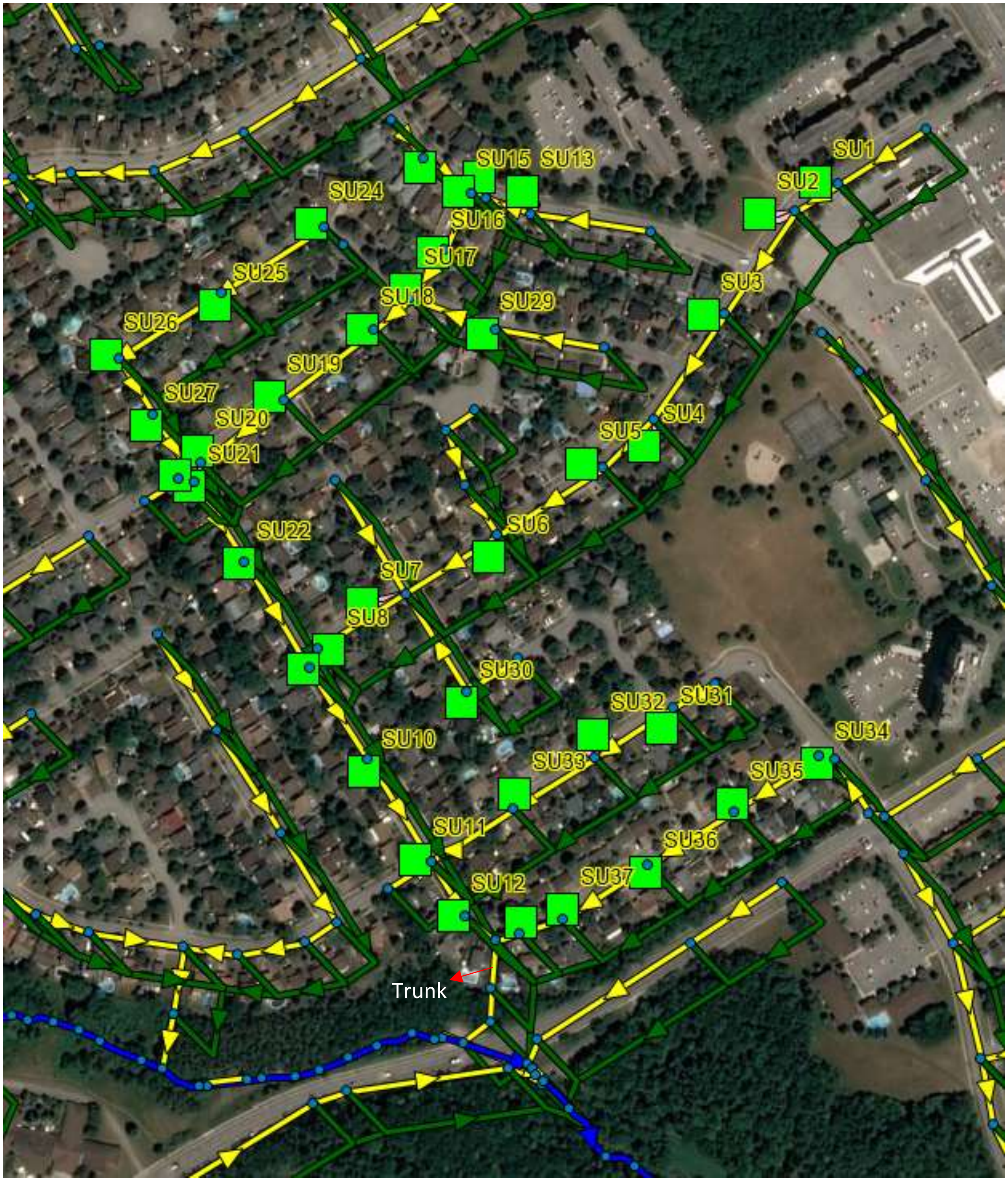


Figure 31. EES model, Kidds Creek watershed area

Figure 32. EES model, Kidds Creek watershed area including storage units routes

4.5.2 Scenario1

4.5.2.1 Rout1 (SU1-SU12)

This route comprises storage unit 1 to storage unit 12 which is shown in yellow color in Figure 32. The profile of this route is shown in Figure 33. The attribute table of the storage units is shown in Table 3. The storage units 4,5,6,7 meet their capacity after running the model.

SU	Trench Depth	Trench Invert Elevation	Trench Rim elevation	Length (m)	slope	Storm sewer diameter(m)	Trench Width(m)	Junction difference elevation
SU1	1.938	291.559	293.497	36.802	0.008043	0.6	2.488	0.296
SU2	1.938	290.749	292.687	90.418	0.008958	0.6	2.488	0.81
SU3	1.938	289.197	291.135	91.746	0.016916	0.6	2.488	1.552
SU4	1.938	287.122	289.06	50.507	0.041083	0.6	2.488	2.075
SU5	1.538	283.464	285.002	90.826	0.040275	0.3	2.088	3.658
SU6	1.938	280.782	282.72	79.056	0.033925	0.6	2.488	2.682
SU7	1.938	278.465	280.403	74.96	0.03091	0.6	2.488	2.317
SU8	1.938	277.929	279.867	15.329	0.034966	0.6	2.488	0.536
SU9	2.201	276.935	279.136	78.414	0.012676	0.825	2.751	0.994
SU10	2.201	275.554	277.755	86.562	0.015954	0.825	2.751	1.381
SU11	2.288	275.021	277.309	46.362	0.011496	0.9	2.838	0.533
SU12	2.288	273.71	275.998	28.262	0.046387	0.9	2.838	1.311
SU13	1.714	287.579	289.293	34.828	0.026243	0.45	2.264	0.914
SU14	1.714	285.89	287.604	11.429	0.147782	0.45	2.264	1.689
SU15	1.813	285.122	286.935	45.607	0.01684	0.525	2.363	0.768
SU16	1.813	284.43	286.243	42.131	0.016425	0.525	2.363	0.692
SU17	1.813	283.455	285.268	35.558	0.02742	0.525	2.363	0.975
SU18	1.813	281.321	283.134	82.578	0.025842	0.525	2.363	2.134
SU19	1.938	280.498	282.436	74.89	0.010989	0.6	2.488	0.823
SU20	1.938	280.236	282.174	14.982	0.017488	0.6	2.488	0.262
SU21	2.114	279.642	281.756	67.568	0.008791	0.75	2.664	0.594
SU22	2.114	277.929	280.043	90.1	0.019012	0.75	2.664	1.713
SU23	1.538	285.89	287.428	41.865	0.008671	0.3	2.088	0.363
SU24	1.538	281.699	283.237	87.574	0.020851	0.3	2.088	1.826
SU25	1.619	281.105	282.724	88.79	0.00669	0.375	2.169	0.594
SU26	1.714	280.843	282.557	47.516	0.005514	0.45	2.264	0.262
SU27	1.714	280.236	281.95	57.867	0.01049	0.45	2.264	0.607
SU28	1.538	280.236	281.774	11.628	0.01677	0.3	2.088	0.195
SU29	1.538	284.43	285.968	65.903	0.033671	0.3	2.088	2.219
SU30	1.619	281.361	282.98	83.323	0.006949	0.375	2.169	0.579
SU31	1.538	280.84	282.378	66.481	0.025722	0.3	2.088	1.71
SU32	1.538	278.45	279.988	69.972	0.034157	0.3	2.088	2.39
SU33	1.619	275.554	277.173	70.138	0.04129	0.375	2.169	2.896
SU34	2.201	278.532	280.733	73.139	0.018759	0.825	2.751	1.372
SU35	2.201	277.185	279.386	73.536	0.018318	0.825	2.751	1.347
SU36	2.201	276.316	278.517	73.133	0.011882	0.825	2.751	0.869
SU37	2.201	275.856	278.057	32.585	0.014117	0.825	2.751	0.46
SU38	2.201	273.71	275.911	19.108	0.112309	0.825	2.751	2.146

Table 3. The attribute table of the storage units, regarding Scenario1

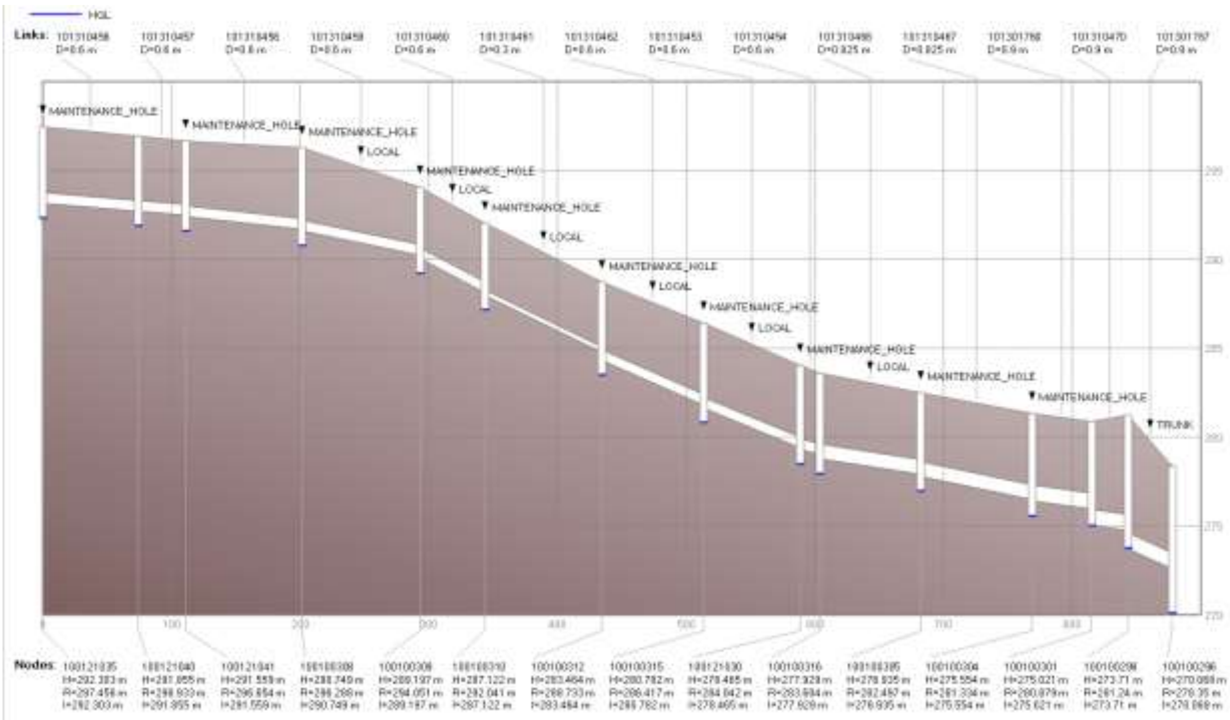


Figure 33. Route 1, profile, the first manhole is excluded regarding EES design

4.5.2.2 Rout2 (SU 13-22)

This route comprises storage unit 13 to storage unit 22 which is shown in pink color in Figure 32. The profile of this route is shown in Figure 34. The attribute table of the storage units is shown in Table 3. The storage units 13,17 met their capacity.

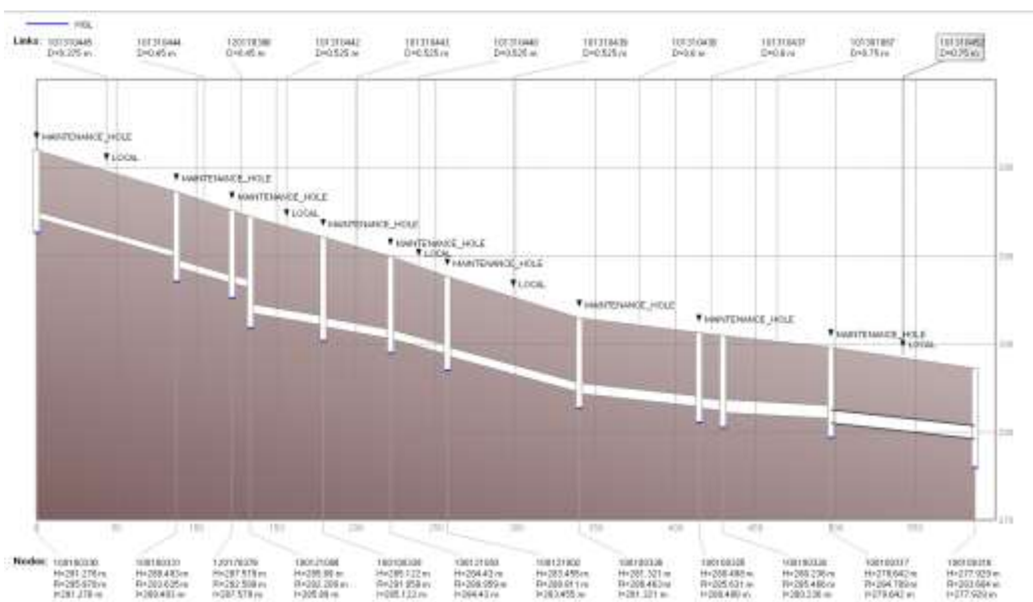


Figure 34. Route 2, profile, the first manhole is excluded regarding EES design

4.5.2.3 Rout3(SU23)

This route comprises storage unit 23 which is shown in blue color in Figure 32. The profile of this route is shown in Figure 35. The attribute table of the storage units are shown in Table3.

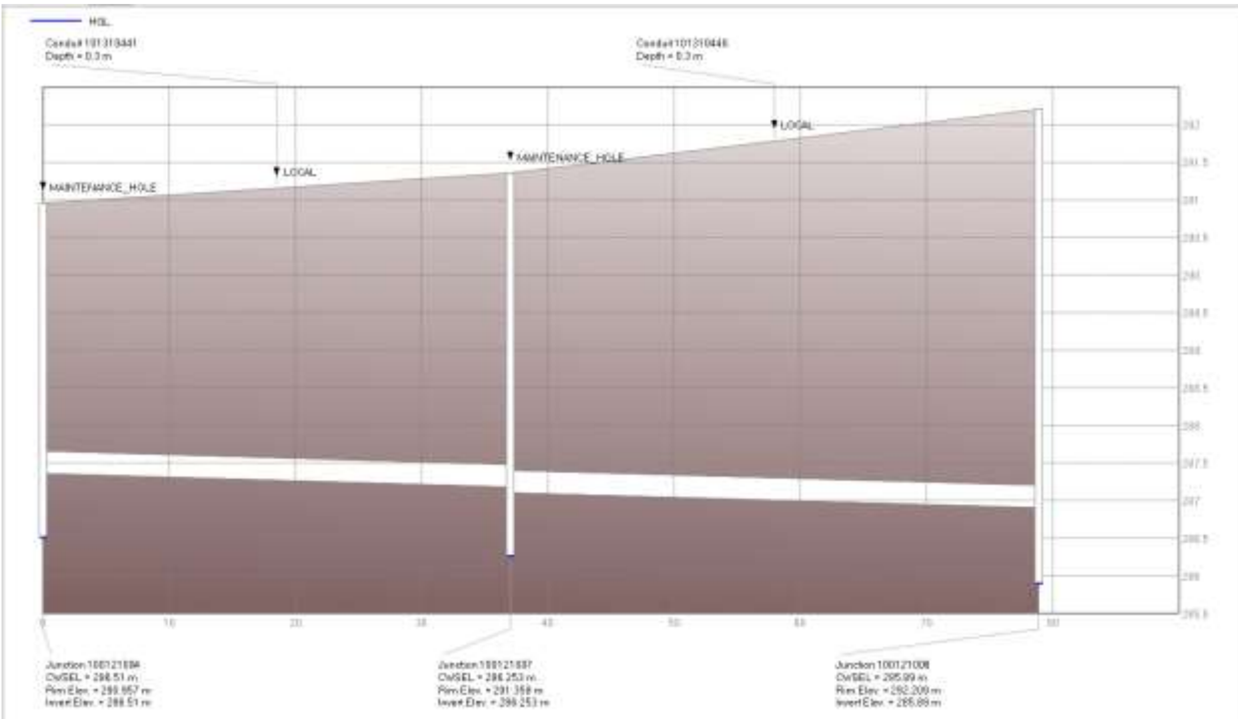


Figure 35. Route 3, profile, the first manhole is excluded regarding EES design

4.5.2.4 Route4(SU 24-27)

This route comprises storage unit 24 to storage unit 27 which is shown in green color in Figure 32. The profile of this route is shown in Figure 36. The attribute table of the storage units is shown in Table3. The storage unit 24 met its capacity.

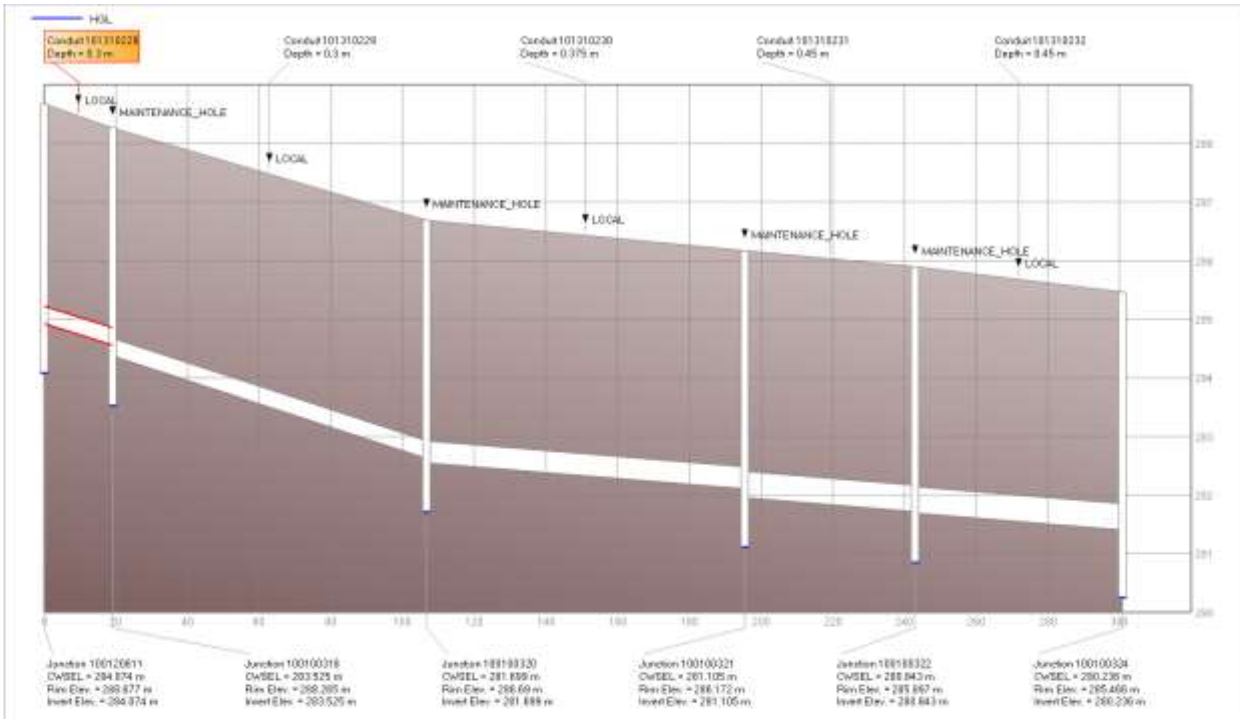


Figure 36. Route 4 profile, the first manhole is excluded regarding EES design

4.5.2.5 Route5 (SU28)

This route comprises storage unit 28 which is shown in orange color in Figure 32. The profile of this route is shown in Figure 37. The attribute table of the storage units are shown in Table 3.

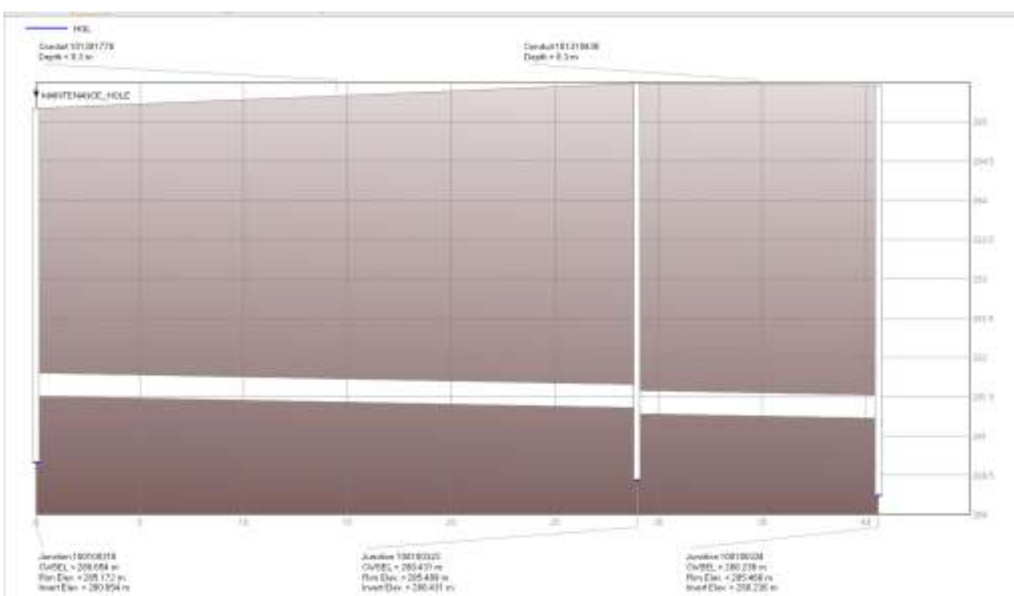


Figure 37. Route 5, profile, the first manhole is excluded regarding EES design

4.5.2.6 Route6 (SU29)

This route comprises storage unit 29 which is shown in light blue in Figure 32. The profile of this route is shown in Figure 38. The attribute table of the storage units is shown in Table 3. The storage unit 29 met its capacity.

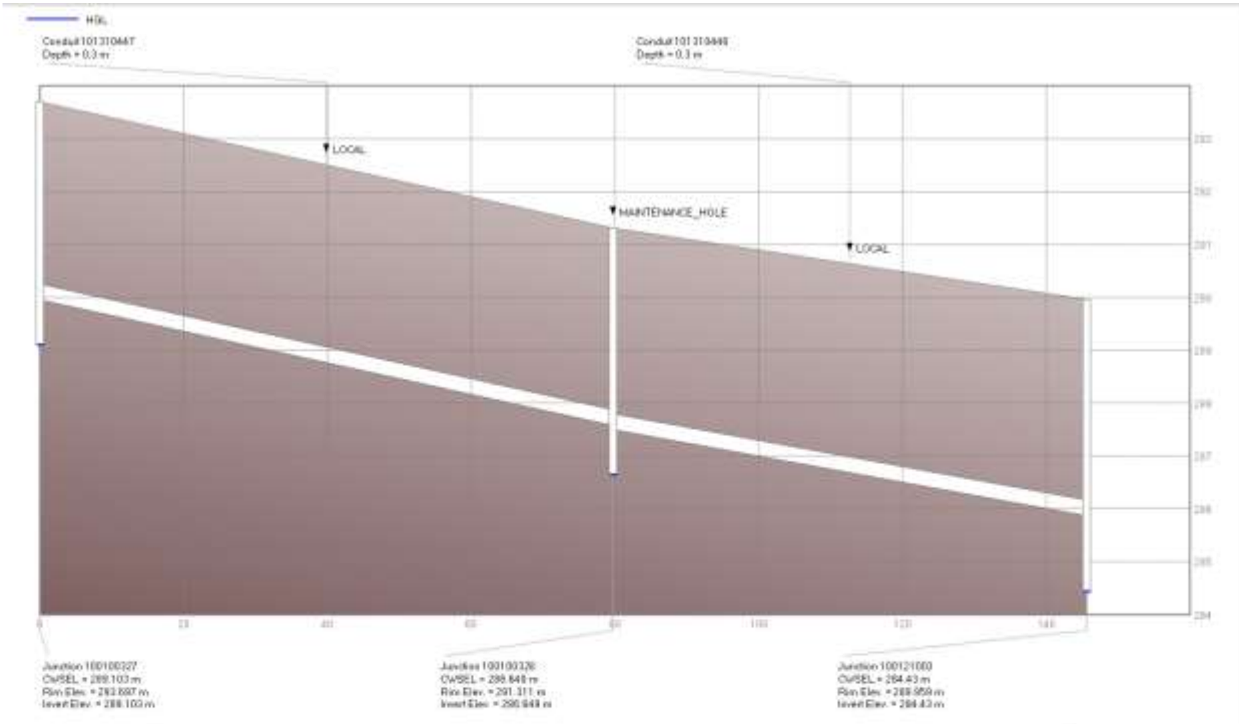


Figure 38. Route 6, profile, the first manhole is excluded regarding EES design

4.5.2.7 Route7 (SU30)

This route comprises storage unit 30 which is shown in grey color in Figure 32. The profile of this route is shown in Figure 39. The attribute table of the storage units is shown in Table 3.

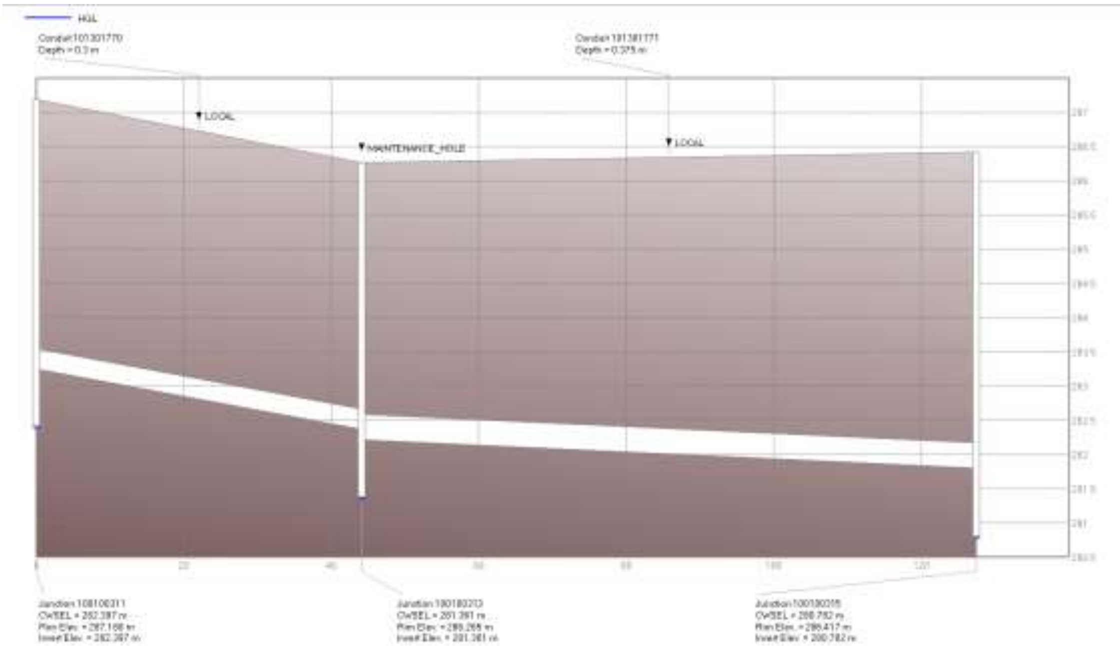


Figure 39. Route 7, profile, the first manhole is excluded regarding EES design

4.5.2.8 Route 8 (SU31-33)

This route comprises storage unit 31 to storage unit 33 which is shown in red color in Figure 32. The profile of this route is shown in Figure 40. The attribute table of the storage units is shown in Table 3. Storage unit 33 met the capacity.

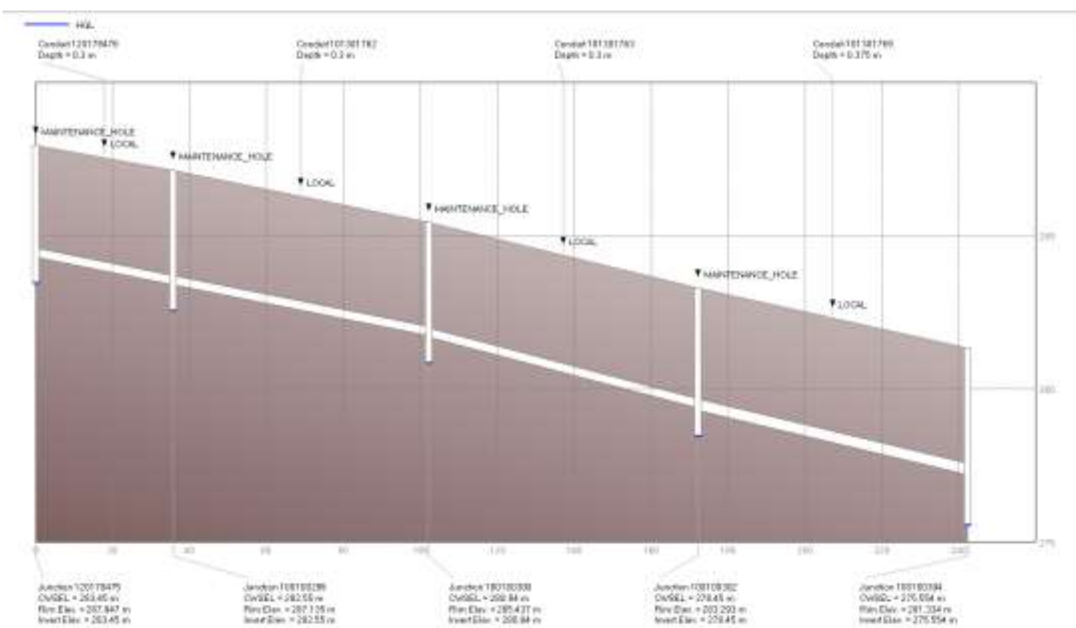


Figure 40. Route 8, profile, the first manhole is excluded regarding EES design

4.5.2.9 Route 9 (SU34-SU38)

This route comprises storage unit 34 to storage unit 38 which is shown in dark blue color in Figure 32. The profile of this route is shown in Figure 41. The attribute table of the storage units is shown in Table 3. The storage units 34,35,38 meet their capacity. The flooding summary is attached in Appendix A.

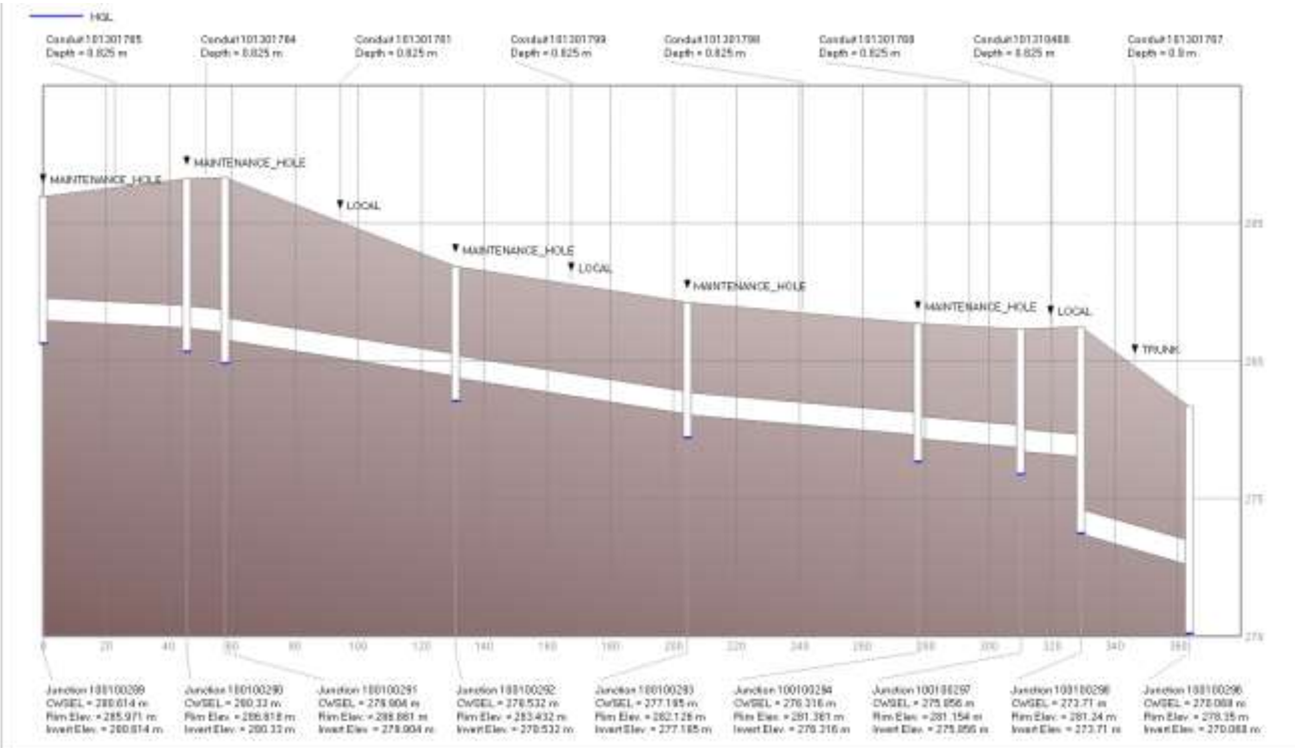


Figure 41. Route 9, profile, the first manhole is excluded regarding EES design

4.5.2.10 Infiltration Summary

The exfiltration summary was monitored for SU1-SU38 shown in Figure 42 which indicates that all of the storage units exfiltrated for 48 hours.

4.5.2.11 Discussion

The attributes of the storage units which met their capacity were monitored. This monitoring revealed that this issue could be explained in different ways. However, they had at least one of the following attributes:

- The maximum surface area was less than 80 m2
- There was a substantial total inflow volume into the upstream manhole greater than 80 m3

Moreover, the minor system deficiency might affect this issue. For example, corresponding storm sewer to the storage unit 5 had the deficiency.

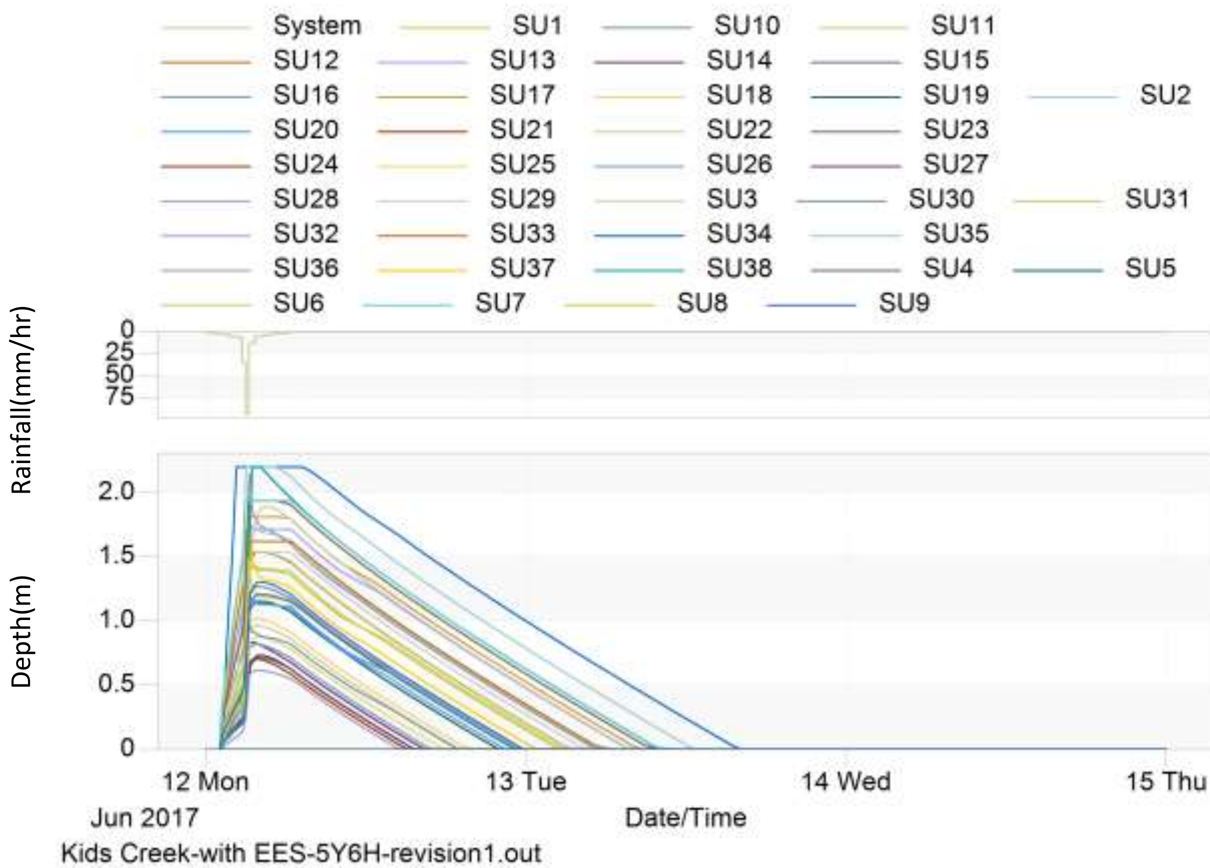


Figure 42. Exfiltration Summary for SU1-SU38, Kidds Creek watershed area for 72 hours

4.5.3 Scenario2

4.5.3.1 Route1 (SU1-SU12)

This route comprises storage unit 1 to storage unit 12 which is shown in yellow color in Figure 32. The profile of this route is shown in Figure 33. The attributes of the storage units are shown in Table 4. The storage units 1,7,8,9 and 11 meet their capacity.

SU	Trench Depth	Trench Invert Elevation	Trench Rim elevation	Length (m)	slope	Storm sewer diameter(m)	Trench Width(m)	Constant surface area
SU1	0.9	291.855	293.497	36.802	0.008043	0.6	2.488	36.6253504
SU2	0.9	291.559	292.687	90.418	0.008958	0.6	2.488	89.9839936
SU3	0.9	290.749	291.135	91.746	0.016916	0.6	2.488	91.3056192
SU4	0.9	289.197	289.06	50.507	0.041083	0.6	2.488	50.2645664
SU5	0.9	287.122	285.002	90.826	0.040275	0.3	2.088	75.8578752
SU6	0.9	283.464	282.72	79.056	0.033925	0.6	2.488	78.6765312
SU7	0.9	280.782	280.403	74.96	0.03091	0.6	2.488	74.600192
SU8	0.9	278.465	279.867	15.329	0.034966	0.6	2.488	15.2554208
SU9	0.9	277.929	279.136	78.414	0.012676	0.825	2.751	86.2867656
SU10	0.9	276.935	277.755	86.562	0.015954	0.825	2.751	95.2528248
SU11	0.9	275.554	277.309	46.362	0.011496	0.9	2.838	52.6301424
SU12	0.9	275.021	275.998	28.262	0.046387	0.9	2.838	32.0830224
SU13	0.9	288.493	289.293	34.828	0.026243	0.45	2.264	31.5402368
SU14	0.9	287.579	287.604	11.429	0.147782	0.45	2.264	10.3501024
SU15	0.9	285.89	286.935	45.607	0.01684	0.525	2.363	43.1077364
SU16	0.9	285.122	286.243	42.131	0.016425	0.525	2.363	39.8222212
SU17	0.9	284.43	285.268	35.558	0.02742	0.525	2.363	33.6094216
SU18	0.9	283.455	283.134	82.578	0.025842	0.525	2.363	78.0527256
SU19	0.9	281.321	282.436	74.89	0.010989	0.6	2.488	74.530528
SU20	0.9	280.498	282.174	14.982	0.017488	0.6	2.488	14.9100864
SU21	0.9	280.236	281.756	67.568	0.008791	0.75	2.664	72.0004608
SU22	0.9	279.642	280.043	90.1	0.019012	0.75	2.664	96.01056
SU23	0.9	286.253	287.428	41.865	0.008671	0.3	2.088	34.965648
SU24	0.9	283.525	283.237	87.574	0.020851	0.3	2.088	73.1418048
SU25	0.9	281.699	282.724	88.79	0.00669	0.375	2.169	77.034204
SU26	0.9	281.105	282.557	47.516	0.005514	0.45	2.264	43.0304896
SU27	0.9	280.843	281.95	57.867	0.01049	0.45	2.264	52.4043552
SU28	0.9	281.105	281.774	11.628	0.01677	0.3	2.088	9.7117056
SU29	0.9	286.649	285.968	65.903	0.033671	0.3	2.088	55.0421856
SU30	0.9	281.361	282.98	83.323	0.006949	0.375	2.169	72.2910348
SU31	0.9	282.55	282.378	66.481	0.025722	0.3	2.088	55.5249312
SU32	0.9	280.84	279.988	69.972	0.034157	0.3	2.088	58.4406144
SU33	0.9	278.45	277.173	70.138	0.04129	0.375	2.169	60.8517288
SU34	0.9	279.904	280.733	73.139	0.018759	0.825	2.751	80.4821556
SU35	0.9	278.532	279.386	73.536	0.018318	0.825	2.751	80.9190144
SU36	0.9	277.185	278.517	73.133	0.011882	0.825	2.751	80.4755532
SU37	0.9	276.316	278.057	32.585	0.014117	0.825	2.751	35.856534
SU38	0.9	275.856	275.911	19.108	0.112309	0.825	2.751	21.0264432

Table 4. The attribute table of the storage units, regarding Scenario2

4.5.3.2 Route 2 (SU 13-22)

This route comprises storage unit 13 to storage unit 22 which is shown in pink color in Figure 32. The profile of this route is shown in Figure 34. The attributes of the storage units are shown in Table 4. The storage units 14, 15, 16, 17 meet their capacity.

4.5.3.3 Route 3 (SU23)

This route comprises storage unit 23 which is shown in blue color in Figure 32. The profile of this route is shown in Figure 35. The attributes of the storage units are shown in Table 4.

4.5.3.4 Route 4 (SU 24-27)

This route comprises storage unit 24 to storage unit 27 which is shown in green color in Figure 32. The profile of this rout is shown in Figure 36. The attribute table of the storage units is shown in Table 4.

4.5.3.5 Route 5 (SU28)

This route comprises storage unit 28 which is shown in orange color in Figure 32. The profile of this route is shown in Figure 37. The attribute table of the storage units is shown in Table 4.

4.5.3.6 Route 6 (SU29)

This route comprises storage unit 29 which is shown in light blue in Figure 32. The profile of this route is shown in Figure 38. The attribute table of the storage units is shown in Table 4.

4.5.3.7 Route 7 (SU30)

This route comprises storage unit 30 which is shown in grey color in Figure 32. The profile of this route is shown in Figure 39. The attributes of the storage units are shown in Table 4.

4.5.3.8 Route 8 (SU31-33)

This route comprises storage unit 31 to storage unit 33 which is shown in red color in Figure 32. The profile of this route is shown in Figure 40. The attributes of the storage units are shown in Table 4.

4.5.3.9 Route 9 (SU34-SU38)

This route comprises storage unit 34 to storage unit 38 which is shown in dark blue color in Figure 32. The profile of this route is shown in Figure 41. The attribute table of the storage units is shown in Table 4. The storage units 34,37,38 meet their capacity

The flooding summary is attached in appendix A.

4.5.3.10 Infiltration Summary

According to the figure 43, water exfiltrated during 48 hours for the SU1-SU38.

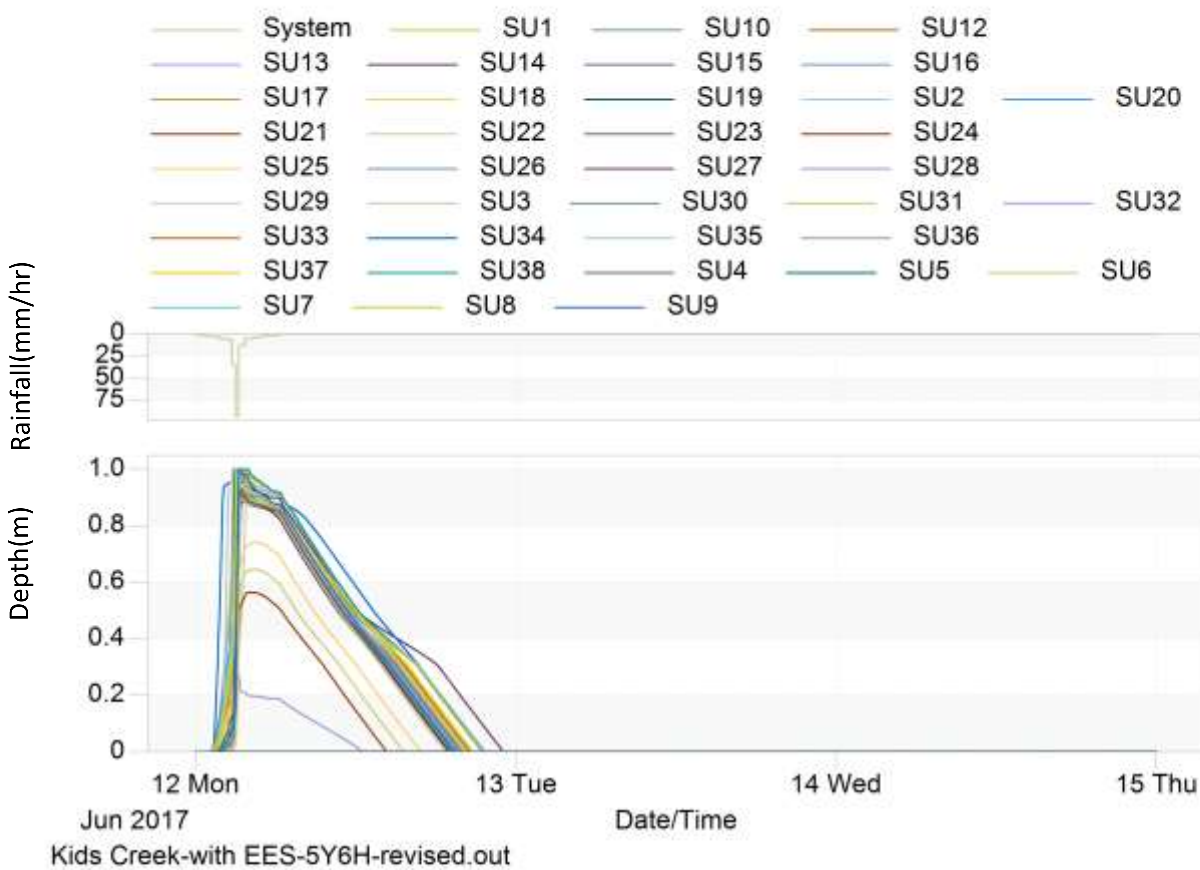


Figure 43. Exfiltration Summary for SU1-SU38, Kidds Creek watershed area for 72 hours

4.5.3.11 Discussion

Similar to scenario1, attributes of the storage units which met their capacity were verified. This monitoring revealed that this issue could be explained in different ways. However, they had at least one of the following attributes:

- The maximum surface area was less than 80 m2

- There was a substantial total inflow volume into the upstream manhole greater than 80 m3

Moreover, the minor system deficiency might affect this issue. For example, corresponding storm sewer to the storage unit 5 had the deficiency.

Quantity Reduction

4.5.4 Volume Reduction

The volume reduction for Kidds Creek watershed area was achieved from the flow routing summary report for 3 following conditions:

1-Without EES

2-With EES regarding scenario1

3- With EES regarding scenario2

The flow routing summary is shown in Figure 44-46. The volume reduction was reported 3303 m3 and 2955 m3 for scenario1, and scenario2 respectively. The exfiltration loss for scenario2 is less than scenario 1 since the storage unit capacity was considered smaller.

```
**************************        Volume         Volume
Flow Routing Continuity        hectare-m      10^6 ltr
**************************     ---------      ---------
Dry Weather Inflow .......         0.000          0.000
Wet Weather Inflow .......         6.865         68.652
Groundwater Inflow .......         0.000          0.000
RDII Inflow ..............         0.000          0.000
External Inflow ..........         0.001          0.008
External Outflow .........         5.234         52.336
Flooding Loss ............         0.000          0.000
Evaporation Loss .........         0.000          0.000
Exfiltration Loss ........         0.000          0.000
Initial Stored Volume ....         0.001          0.010
Final Stored Volume ......         1.541         15.409
Continuity Error (%) .....         1.348
```

Figure 44. Flow Routing Summary, without EES

```
**************************        Volume         Volume
Flow Routing Continuity         hectare-m      10^6 ltr
**************************       ---------      ---------
Dry Weather Inflow .......          0.000          0.000
Wet Weather Inflow .......          6.865         68.653
Groundwater Inflow .......          0.000          0.000
RDII Inflow ..............          0.000          0.000
External Inflow ..........          0.001          0.008
External Outflow .........          4.585         45.846
Flooding Loss ............          0.167          1.675
Evaporation Loss .........          0.000          0.000
Exfiltration Loss ........          0.330          3.303
Initial Stored Volume ....          0.003          0.031
Final Stored Volume ......          1.780         17.802
Continuity Error (%) .....          0.096
```

Figure 45. Flow Routing Continuity Summary, with EES regarding Scenario 1

```
**************************        Volume         Volume
Flow Routing Continuity         hectare-m      10^6 ltr
**************************       ---------      ---------
Dry Weather Inflow .......          0.000          0.000
Wet Weather Inflow .......          6.865         68.653
Groundwater Inflow .......          0.000          0.000
RDII Inflow ..............          0.000          0.000
External Inflow ..........          0.001          0.008
External Outflow .........          4.695         46.953
Flooding Loss ............          0.093          0.926
Evaporation Loss .........          0.000          0.000
Exfiltration Loss ........          0.295          2.955
Initial Stored Volume ....          0.003          0.031
Final Stored Volume ......          1.780         17.802
Continuity Error (%) .....          0.082
```

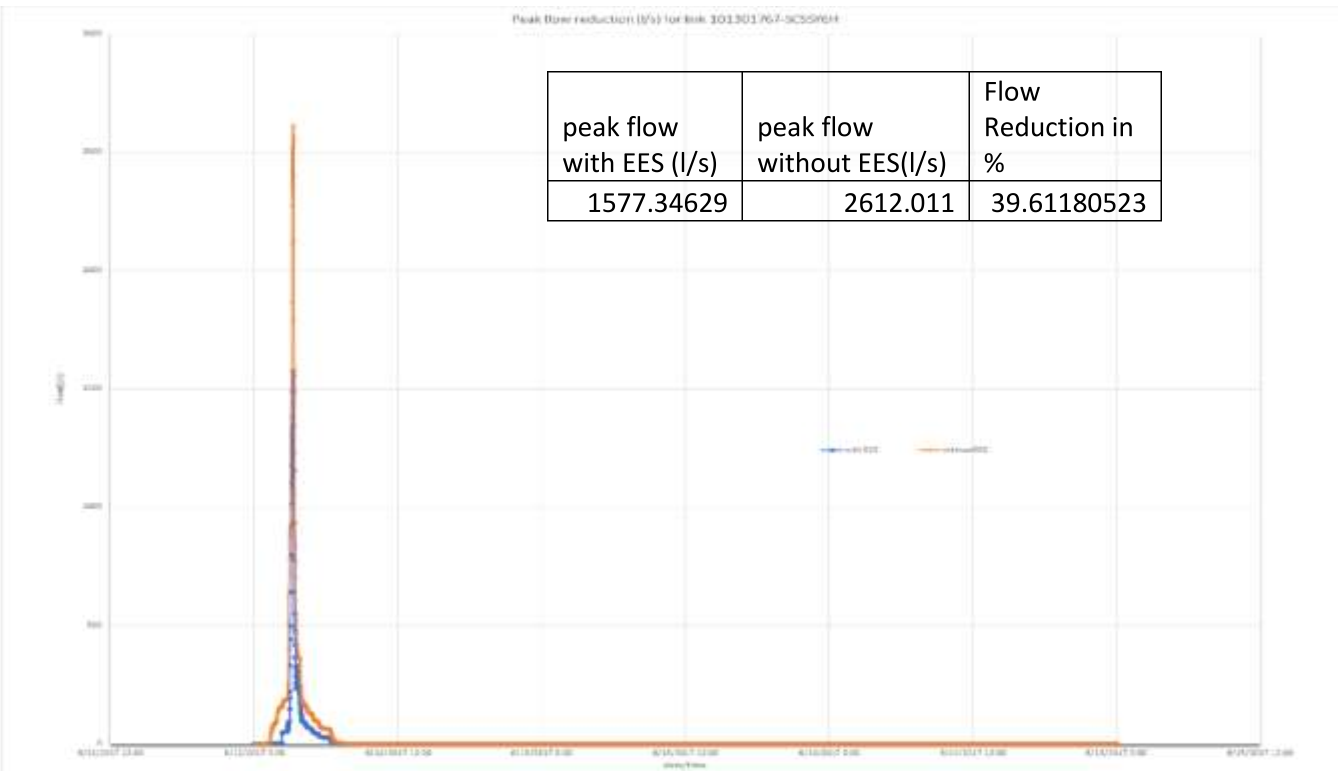
Figure 46. Flow Routing Continuity Summary, with EES regarding Scenario 2

4.5.5 Flow Reduction

4.5.5.1 Scenario1

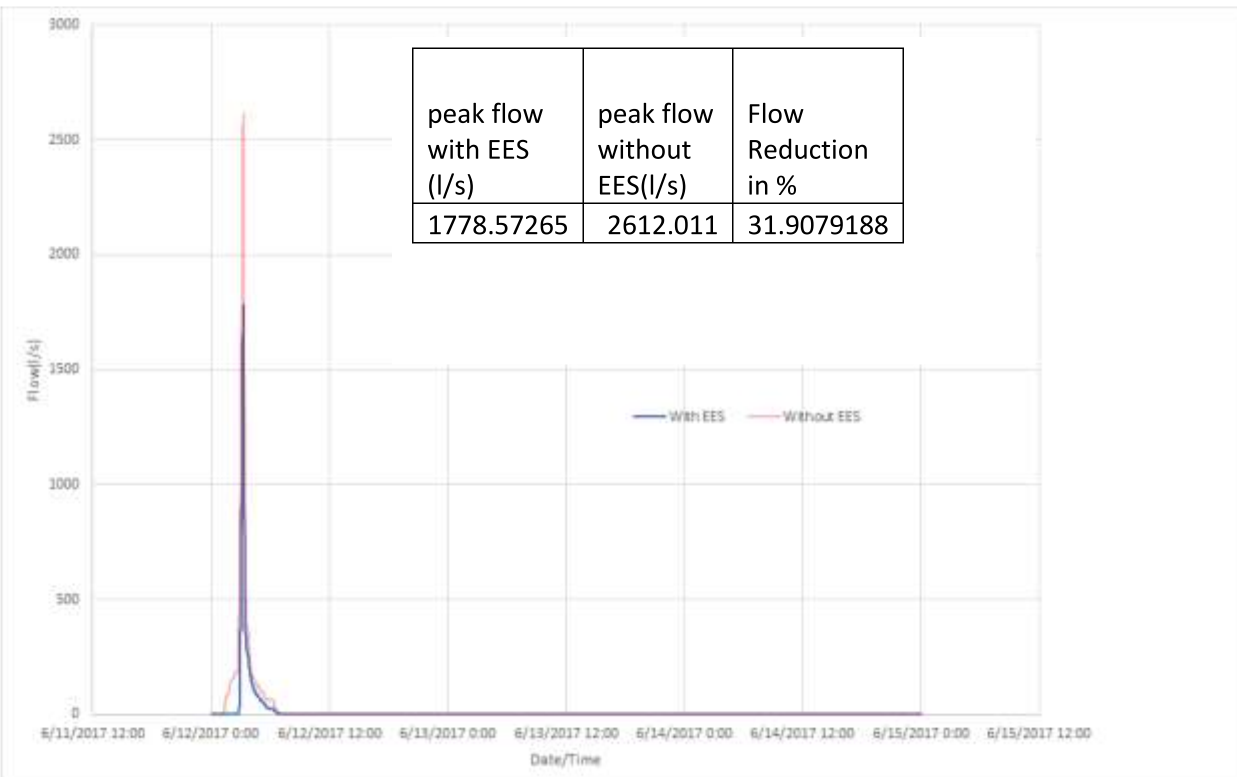
The flow reduction analysis in an exfiltration storage model is not reliable since as soon as exfiltration rate dropped in a storage unit, the water will overflow to the surrounding instead of overflowing to main conduit. Accordingly, the SWMM graphs for monitoring peak flow reduction should be modified by Excel. The flow reduction was analyzed in the last trunk (101301767) prior to an existing watercourse for both scenarios. This trunk is shown in Figure 31.

The modified simulation results are shown in Figure 47 and 48 for both scenarios. According to these results, 40 % and 32 % peak flow reduction is monitored for scenario 1 & 2 respectively.



peak flow with EES (l/s)	peak flow without EES(l/s)	Flow Reduction in %
1577.34629	2612.011	39.61180523

Figure 47. Flow reduction analysis for SCS,5-year-6-hour, with EES, scenario1,



peak flow with EES (l/s)	peak flow without EES(l/s)	Flow Reduction in %
1778.57265	2612.011	31.9079188

Figure 48. Flow reduction analysis for SCS,5-year-6-hour, with EES and without EES, scenario2

4.6 Modified Model:

As it was mentioned earlier in Section 3.7.2, if the same value is considered for the storage unit invert elevation and the upstream manhole (the same head elevation), the water movements in the upstream manhole and the storage unit will be similar. This will let the system to drain water when its depth reaches the main conduit inlet elevation. Resultantly flooding will not occur.

Consequently, scenario 2 was monitored one more time by considering the storage unit depth 0.3 m above main conduit.

The monitored results are as follows:

- The exfiltration loss 2958 m3 which is shown in flow routing summary in Figure 49.
- The flow reduction is 40 percent. The flow reduction is shown in Figure 50.
- Exfiltration Summary is shown in Figure 51 which confirms that the water drained in less than 48 hours.

```
**************************        Volume         Volume
Flow Routing Continuity         hectare-m      10^6 ltr
**************************      ---------      ---------
Dry Weather Inflow .......          0.000          0.000
Wet Weather Inflow .......          6.865         68.653
Groundwater Inflow .......          0.000          0.000
RDII Inflow ..............          0.000          0.000
External Inflow ..........          0.001          0.008
External Outflow .........          4.786         47.865
Flooding Loss ............          0.000          0.000
Evaporation Loss .........          0.000          0.000
Exfiltration Loss ........          0.296          2.958
Initial Stored Volume ....          0.003          0.031
Final Stored Volume ......          1.780         17.803
Continuity Error (%) .....          0.096
```

Figure 49. Flow routing summary for modified model

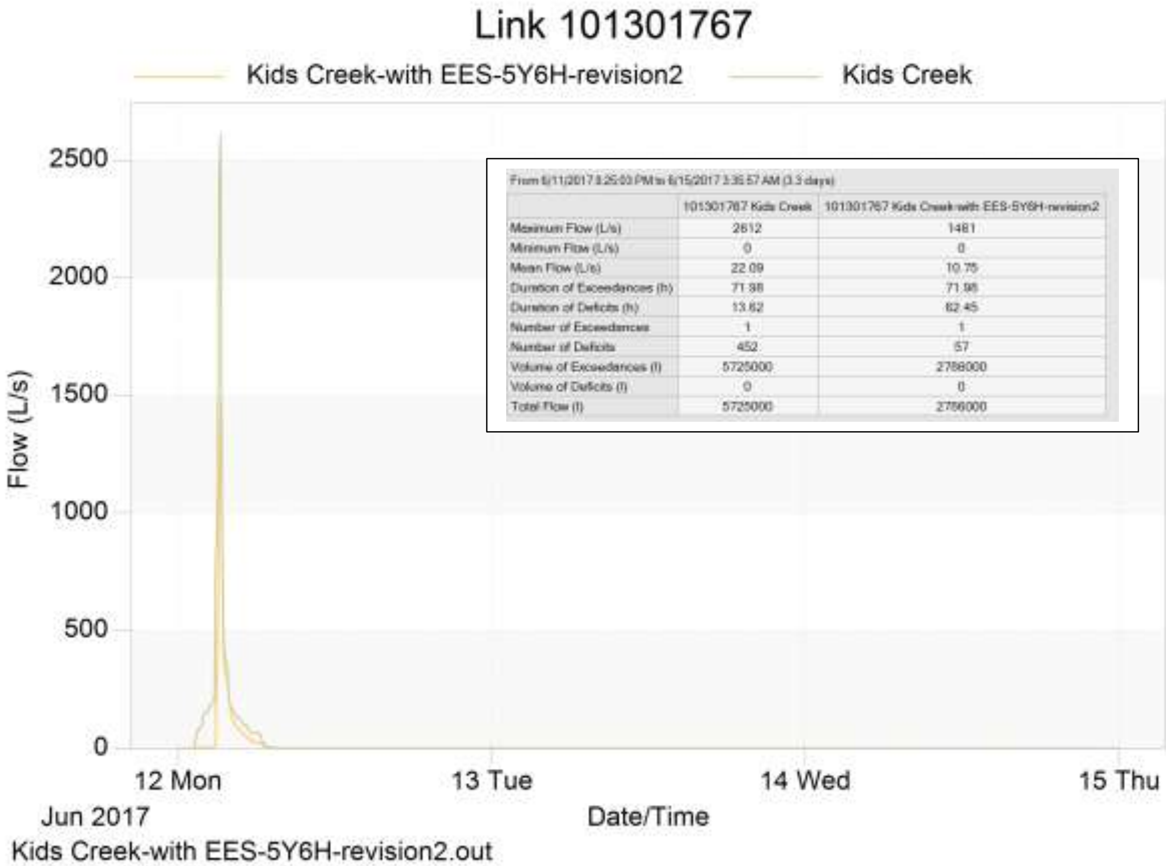


Figure 50. Flow reduction analysis for SCS,5-year-6-hour, with EES and without EES, modified model

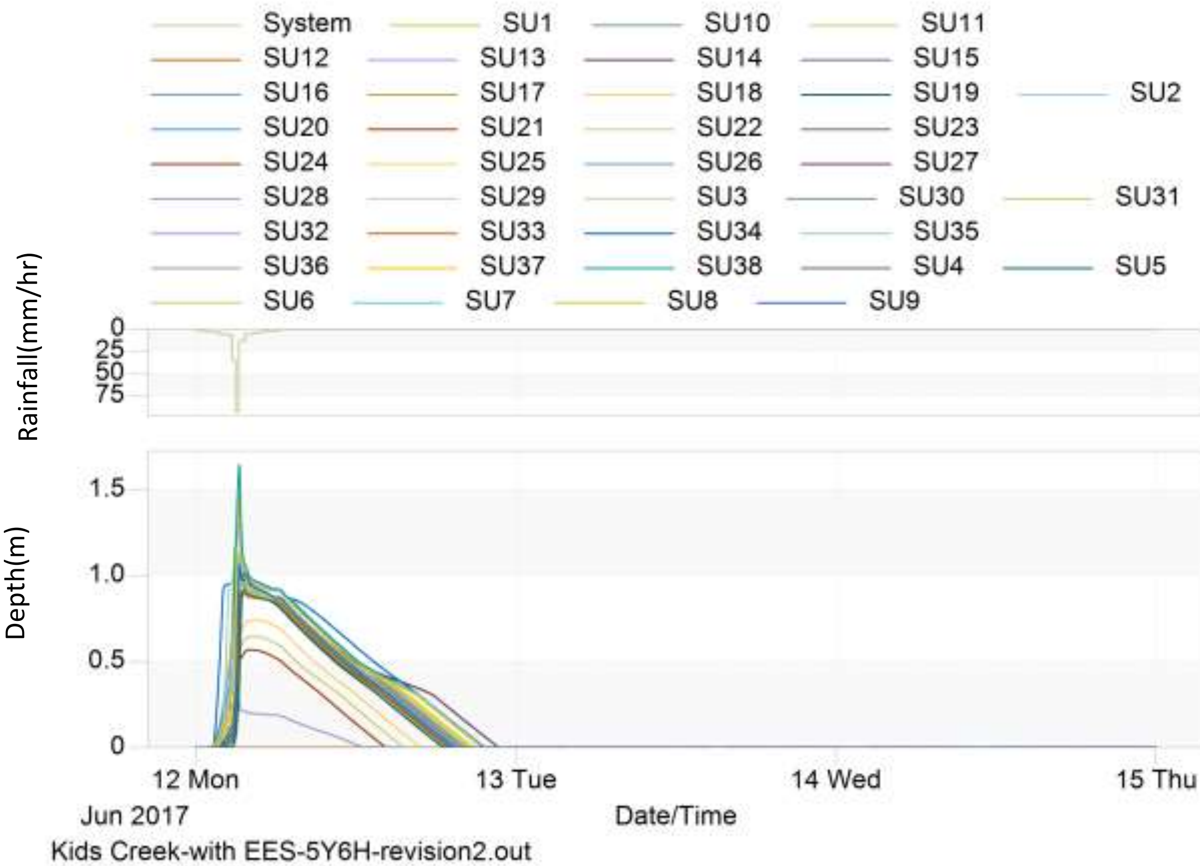


Figure 51. Exfiltration Summary for modified model

5 Conclusion

Regarding this study, the exfiltration storage model was compatible with EES according to Princess Margaret flow test. The exfiltration loss in the exfiltration storage model was well matched with EES regarding Green Ampt infiltration method.

Moreover, in this study, the exfiltration storage model was evaluated for a design storm SCS 5-year,6-Hour regarding Kidds Creek watershed area in Barrie. Resultantly, some issue was monitored regarding the case study as follows:

- Flooding occurred instead of overflowing to the upstream manhole when the capacity of the storage unit was met
- The flow graphs should be modified by Excel

Eventually, to fix this issue the model was modified to make the storage unit water head similar to the EES. Thus, the invert elevation of the storage unit was considered as same as upstream manhole. As a result, the flooding issue was solved and the exfiltration loss and peak flow reduction for 38 storage units were reported 2958 m3 and 40 % for 72 hours respectively.

Recommendations:

- A new measured data might be used to evaluate the reliability the system
- The pressurized situation in the exfiltration storage model such as artesian condition might also be studied
- Applying the functional curve with a constant surface area and constant stone trench depth compared to tabular curve might be easier and faster regarding exfiltration storage model

Appendix A

Note:

- The inlet and outlet offset of conduits are for existing conditions, and 0.85 m is added in PC SWMM model regarding the design of EES.
- Every EES route is shown in different color. In each rout(color), the storage units are ordered regarding the invert elevation from the highest invert elevation to the smallest one.

Table 5. Tabular Curve, Case Study

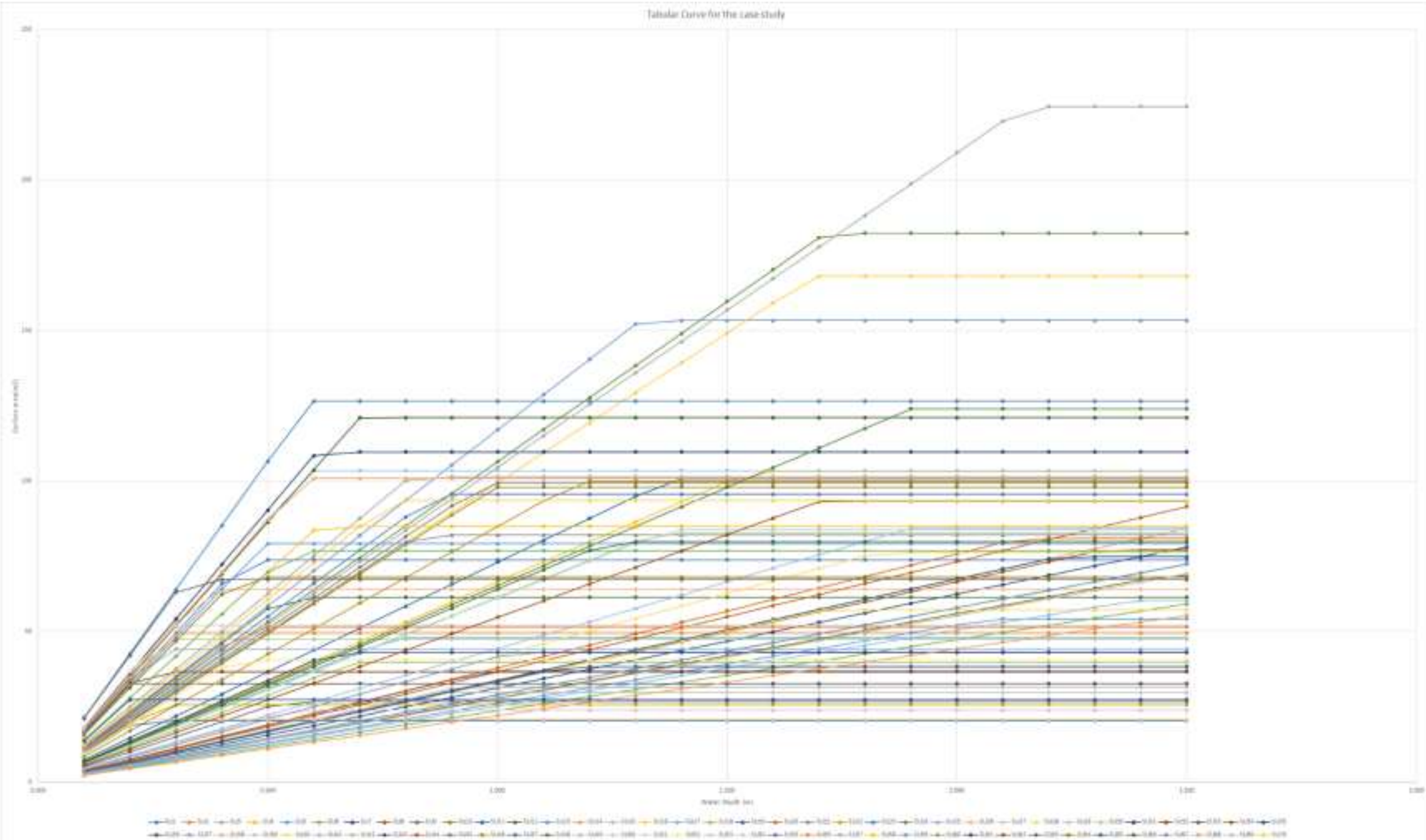


Figure 52. Tabular Curve, Case Study

SU	Trench Depth	Trench Invert Elevation	Trench Rim elevation	Inlet Junction	Outlet Junction	Junction difference	Path	Conduit Name	Inlet Node	Outlet Node	Tag	Length (m)	Roughness	Inlet Elev. (m)	Outlet Elev. (m)	Cross-Section	Geom1 (m)	Slope	Pipe Thickness (m)	Trench Width
SU1	1.938	291.559	293.497	100121040	100121041	0.296	SU1	101310457	100121040	100121041	LOCAL	37	0.013	291.855	291.636	CIRCULAR	0.6	0.00595	0.094	2.488
SU2	1.938	290.749	292.687	100121041	100100308	0.810	SU2	101310458	100121041	100100308	LOCAL	90	0.013	291.559	290.840	CIRCULAR	0.6	0.00795	0.094	2.488
SU3	1.938	289.197	291.135	100100308	100100309	1.552	SU3	101310459	100100308	100100309	LOCAL	92	0.013	290.749	289.377	CIRCULAR	0.6	0.01496	0.094	2.488
SU4	1.938	287.122	289.060	100100309	100100310	2.075	SU4	101310460	100100309	100100310	LOCAL	51	0.013	289.197	287.274	CIRCULAR	0.6	0.0381	0.094	2.488
SU5	1.538	283.464	285.002	100100310	100100312	3.658	SU5	101310461	100100310	100100312	LOCAL	91	0.013	287.122	283.921	CIRCULAR	0.3	0.03527	0.044	2.088
SU6	1.938	280.782	282.720	100100312	100100315	2.682	SU6	101310462	100100312	100100315	LOCAL	79	0.013	283.464	280.946	CIRCULAR	0.6	0.03187	0.094	2.488
SU7	1.938	278.465	280.403	100100315	100121030	2.317	SU7	101310453	100100315	100121030	LOCAL	75	0.013	280.782	278.541	CIRCULAR	0.6	0.02991	0.094	2.488
SU8	1.938	277.929	279.867	100121030	100100316	0.536	SU8	101310454	100121030	100100316	LOCAL	15	0.013	278.465	278.160	CIRCULAR	0.6	0.0199	0.094	2.488
SU9	2.201	276.935	279.136	100100316	100100305	0.994	SU9	101310468	100100316	100100305	LOCAL	78	0.013	277.929	277.054	CIRCULAR	0.825	0.01116	0.113	2.751
SU10	2.201	275.554	277.755	100100305	100100304	1.381	SU10	101310467	100100305	100100304	LOCAL	87	0.013	276.935	275.631	CIRCULAR	0.825	0.01507	0.113	2.751
SU11	2.288	275.021	277.309	100100304	100100301	0.533	SU11	101301760	100100304	100100301	LOCAL	46	0.013	275.554	275.097	CIRCULAR	0.9	0.00986	0.119	2.838
SU12	2.288	273.710	275.998	100100301	100100298	1.311	SU12	101310470	100100301	100100298	LOCAL	28	0.013	275.021	274.747	CIRCULAR	0.9	0.0097	0.119	2.838
SU13	1.714	287.579	289.293	100100331	120178379	0.914	SU13	101310444	100100331	120178379	LOCAL	35	0.013	288.493	287.579	CIRCULAR	0.45	0.02625	0.057	2.264
SU14	1.714	285.89	287.604	120178379	100121008	1.689	SU14	120178380	120178379	100121008	LOCAL	11	0.013	287.683	287.579	CIRCULAR	0.45	0.0091	0.057	2.264
SU15	1.813	285.122	286.935	100121008	100100329	0.768	SU15	101310442	100121008	100100329	LOCAL	46	0.013	285.890	285.198	CIRCULAR	0.525	0.01517	0.069	2.363
SU16	1.813	284.43	286.243	100100329	100121003	0.692	SU16	101310443	100100329	100121003	LOCAL	42	0.013	285.122	284.430	CIRCULAR	0.525	0.01643	0.069	2.363
SU17	1.813	283.455	285.268	100121003	100121002	0.975	SU17	101310440	100121003	100121002	LOCAL	36	0.013	284.430	283.540	CIRCULAR	0.525	0.02504	0.069	2.363
SU18	1.813	281.321	283.134	100121002	100100326	2.134	SU18	101310439	100121002	100100326	LOCAL	83	0.013	283.455	281.397	CIRCULAR	0.525	0.02493	0.069	2.363
SU19	1.938	280.498	282.436	100100326	100100325	0.823	SU19	101310438	100100326	100100325	LOCAL	75	0.013	281.321	280.574	CIRCULAR	0.6	0.00998	0.094	2.488
SU20	1.938	280.236	282.174	100100325	100100324	0.262	SU20	101310437	100100325	100100324	LOCAL	15	0.013	280.498	280.346	CIRCULAR	0.6	0.01015	0.094	2.488
SU21	2.114	279.642	281.756	100100324	100100317	0.594	SU21	101301867	100100324	100100317	LOCAL	68	0.013	280.236	279.898	CIRCULAR	0.75	0.005	0.107	2.664
SU22	2.114	277.929	280.043	100100317	100100316	1.713	SU22	101310452	100100317	100100316	LOCAL	90	0.013	279.642	278.740	CIRCULAR	0.75	0.01001	0.107	2.664
SU23	1.538	285.89	287.428	100121007	100121008	0.363	SU23	101310446	100121007	100121008	LOCAL	42	0.013	286.253	286.055	CIRCULAR	0.3	0.00473	0.044	2.088
SU24	1.538	281.699	283.237	100100319	100100320	1.826	SU24	101310229	100100319	100100320	LOCAL	88	0.013	283.525	281.775	CIRCULAR	0.3	0.01999	0.044	2.088
SU25	1.619	281.105	282.724	100100320	100100321	0.594	SU25	101310230	100100320	100100321	LOCAL	89	0.013	281.699	281.257	CIRCULAR	0.375	0.00498	0.047	2.169
SU26	1.714	280.843	282.557	100100321	100100322	0.262	SU26	101310231	100100321	100100322	LOCAL	48	0.013	281.105	280.867	CIRCULAR	0.45	0.00501	0.057	2.264
SU27	1.714	280.236	281.950	100100322	100100324	0.607	SU27	101310232	100100322	100100324	LOCAL	58	0.013	280.843	280.553	CIRCULAR	0.45	0.00501	0.057	2.264
SU28	1.538	280.236	281.774	100100323	100100324	0.195	SU28	101310436	100100323	100100324	LOCAL	12	0.013	280.431	280.373	CIRCULAR	0.3	0.00499	0.044	2.088
SU29	1.538	284.43	285.968	100100328	100121003	2.219	SU29	101310448	100100328	100121003	LOCAL	66	0.013	286.649	285.018	CIRCULAR	0.3	0.02476	0.044	2.088
SU30	1.619	281.361	282.980	100100313	100100315	0.579	SU30	101301771	100100313	100100315	LOCAL	83	0.013	281.361	280.946	CIRCULAR	0.375	0.00498	0.047	2.169
SU31	1.538	280.84	282.378	100100299	100100300	1.710	SU31	101301762	100100299	100100300	LOCAL	66	0.013	282.550	280.888	CIRCULAR	0.3	0.02501	0.044	2.088
SU32	1.538	278.45	279.988	100100300	100100302	2.390	SU32	101301763	100100300	100100302	LOCAL	70	0.013	280.840	278.526	CIRCULAR	0.3	0.03309	0.044	2.088
SU33	1.619	275.554	277.173	100100302	100100304	2.896	SU33	101301769	100100302	100100304	LOCAL	70	0.013	278.450	276.347	CIRCULAR	0.375	0.03	0.047	2.169
SU34	2.201	278.532	280.733	100100291	100100292	1.372	SU34	101301761	100100291	100100292	LOCAL	73	0.013	279.904	278.587	CIRCULAR	0.825	0.01801	0.113	2.751
SU35	2.201	277.185	279.386	100100292	100100293	1.347	SU35	101301799	100100292	100100293	LOCAL	74	0.013	278.532	277.216	CIRCULAR	0.825	0.0179	0.113	2.751
SU36	2.201	276.316	278.517	100100293	100100294	0.869	SU36	101301798	100100293	100100294	LOCAL	73	0.013	277.185	276.454	CIRCULAR	0.825	0.01	0.113	2.751
SU37	2.201	275.856	278.057	100100294	100100297	0.460	SU37	101301768	100100294	100100297	LOCAL	33	0.013	276.316	275.996	CIRCULAR	0.825	0.00982	0.113	2.751
SU38	2.201	273.71	275.911	100100297	100100298	2.146	SU38	101310469	100100297	100100298	LOCAL	19	0.013	275.856	275.655	CIRCULAR	0.825	0.01052	0.113	2.751

Table 6. The attribute table of storage units, and main storm sewers

Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm	Zero Imperv (%)	Dstore Perv (mm)
S-100100290	602884.991	4917622.346	WDT	SCS5y6H	100100290	2.207	81.744	269.989	2.87	25.568	0.013	0.15	2	0	5
S-100100291	602838.129	4917572.642	WDT	SCS5y6H	100100291	0.332	26.88	123.512	7.358	20.909	0.013	0.15	2	0	5
S-100100292	602816.855	4917520.262	WDT	SCS5y6H	100100292	0.486	99.834	48.681	7.631	50.73	0.013	0.15	2	0	5
S-100100293	602754.589	4917491.756	WDT	SCS5y6H	100100293	0.775	134.668	57.549	8.91	40.869	0.013	0.15	2	0	5
S-100100294	602695.94	4917424.182	WDT	SCS5y6H	100100294	0.297	75.837	39.163	8.365	63.191	0.013	0.15	2	0	5
S-100100296	602616.595	4917365.458	WDT	SCS5y6H	100100296	0.077	43.629	17.649	13.261	26.415	0.013	0.15	2	0	5
S-100100297	602662.074	4917441.864	WDT	SCS5y6H	100100297	0.558	87.776	63.571	7.022	26.917	0.013	0.15	2	0	5
S-100100298	602615.389	4917396.42	WDT	SCS5y6H	100100298	0.157	95.088	16.511	6.988	62.875	0.013	0.15	2	0	5
S-100100299	602757.009	4917570.585	WDT	SCS5y6H	100100299	0.162	74.924	21.622	8.24	48.292	0.013	0.15	2	0	5
S-100100300	602717.348	4917580.182	WDT	SCS5y6H	100100300	0.712	129.335	55.051	7.005	46.092	0.013	0.15	2	0	5
S-100100301	602591.788	4917421.047	WDT	SCS5y6H	100100301	0.166	66.201	25.075	5.373	62.304	0.013	0.15	2	0	5
S-100100302	602660.386	4917503.406	WDT	SCS5y6H	100100302	0.329	91.331	36.023	6.92	55.217	0.013	0.15	2	0	5
S-100100304	602592.505	4917504.014	WDT	SCS5y6H	100100304	1.526	288.649	52.867	8.255	37.677	0.013	0.15	2	0	5
S-100100305	602518.138	4917557.532	WDT	SCS5y6H	100100305	0.568	118.754	47.83	7.627	48.869	0.013	0.15	2	0	5
S-100100306	602580.446	4917779.581	WDT	SCS5y6H	100100306	0.37	78.141	47.35	6.121	52.794	0.013	0.15	2	0	5
S-100100307	602603.812	4917737.699	WDT	SCS5y6H	100100307	0.231	81.703	28.273	9.534	24.128	0.013	0.15	2	0	5
S-100100308	602801.328	4917881.84	WDT	SCS5y6H	100100308	0.363	77.026	47.127	6.756	45.081	0.013	0.15	2	0	5
S-100100309	602756.45	4917800.723	WDT	SCS5y6H	100100309	0.391	85.834	45.553	6.992	56.436	0.013	0.15	2	0	5
S-100100310	602709.724	4917748.447	WDT	SCS5y6H	100100310	0.29	111.917	25.912	8.776	53.7	0.013	0.15	2	0	5
S-100100311	602680.82	4917650.592	WDT	SCS5y6H	100100311	0.515	44.277	116.313	8.404	30.869	0.013	0.15	2	0	5
S-100100312	602649.103	4917711.676	WDT	SCS5y6H	100100312	0.672	137.395	48.91	8.622	49.2	0.013	0.15	2	0	5
S-100100313	602634.056	4917581.609	WDT	SCS5y6H	100100313	0.377	105.774	35.642	6.904	61.291	0.013	0.15	2	0	5
S-100100314	602502.001	4917753.889	WDT	SCS5y6H	100100314	0.51	43.667	116.793	7.805	43.532	0.013	0.15	2	0	5
S-100100315_1	602536.8	4917698.361	WDT	SCS5y6H	100100315	0.77	120.656	63.818	8.424	39.817	0.013	0.15	2	0	5
S-100100315_2	602595.022	4917630.308	WDT	SCS5y6H	100100315	0.861	167.987	51.254	7.201	42.178	0.013	0.15	2	0	5
S-100100316	602466.546	4917635.027	WDT	SCS5y6H	100100316	0.637	122.585	51.964	6.555	43.707	0.013	0.15	2	0	5
S-100100317	602429.784	4917693.799	WDT	SCS5y6H	100100317	0.509	115.674	44.003	5.525	44.352	0.013	0.15	2	0	5
S-100100319	602513.406	4917921.559	WDT	SCS5y6H	100100319	0.298	53.356	55.851	8.542	39.688	0.013	0.15	2	0	5
S-100100320	602457.227	4917884.121	WDT	SCS5y6H	100100320	0.845	174.756	48.353	7.067	37.292	0.013	0.15	2	0	5
S-100100321	602376.465	4917828.866	WDT	SCS5y6H	100100321	0.553	115.93	47.701	6.179	51.33	0.013	0.15	2	0	5
S-100100322	602354.561	4917779.543	WDT	SCS5y6H	100100322	0.24	100.963	23.771	6.415	56.259	0.013	0.15	2	0	5
S-100100323	602371.39	4917708.892	WDT	SCS5y6H	100100323	0.087	52.53	16.562	5.732	45.122	0.013	0.15	2	0	5
S-100100324	602388.426	4917761.478	WDT	SCS5y6H	100100324	0.36	100.43	35.846	5.407	39.724	0.013	0.15	2	0	5
S-100100325	602430.15	4917766.304	WDT	SCS5y6H	100100325	0.403	85.345	47.22	6.071	41.225	0.013	0.15	2	0	5
S-100100326	602489.856	4917808.969	WDT	SCS5y6H	100100326	0.479	98.944	48.411	7.631	51.457	0.013	0.15	2	0	5
S-100100327	602724.346	4917832.586	WDT	SCS5y6H	100100327	0.401	55.352	72.445	7.622	42.967	0.013	0.15	2	0	5
S-100100328	602661.57	4917839.006	WDT	SCS5y6H	100100328	0.642	121.171	52.983	7.832	47.184	0.013	0.15	2	0	5
S-100100329	602586.036	4917897.049	WDT	SCS5y6H	100100329	0.126	52.731	23.895	9.154	48.657	0.013	0.15	2	0	5
S-100100330	602758.302	4917892.15	WDT	SCS5y6H	100100330	0.319	79.107	40.325	7.492	50.252	0.013	0.15	2	0	5
S-100100331	602682.29	4917901.673	WDT	SCS5y6H	100100331	0.405	90.45	44.776	7.396	57.296	0.013	0.15	2	0	5
S-100100359	602498.55	4917441.416	WDT	SCS5y6H	100100359	0.676	123.261	54.843	6.383	42.516	0.013	0.15	2	0	5
S-100100698	602644.039	4917779.811	WDT	SCS5y6H	100100698	0.345	53.503	64.482	9.868	33.434	0.013	0.15	2	0	5
S-100120611	602539.483	4917890.447	WDT	SCS5y6H	100120611	0.36	46.482	77.449	8.056	44.205	0.013	0.15	2	0	5
S-100121002	602540.513	4917828.76	WDT	SCS5y6H	100121002	0.135	67.054	20.133	6.899	51.084	0.013	0.15	2	0	5
S-100121003	602590.196	4917853.882	WDT	SCS5y6H	100121003	0.51	124.314	41.025	7.142	49.712	0.013	0.15	2	0	5
S-100121007	602543.105	4917964.809	WDT	SCS5y6H	100121007	0.162	46.429	34.892	2.13	68.338	0.013	0.15	2	0	5
S-100121008	602596.305	4917954.178	WDT	SCS5y6H	100121008	0.436	66.03	66.031	2.99	42.937	0.013	0.15	2	0	5
S-100121030	602514.1	4917617.514	WDT	SCS5y6H	100121030	0.254	61.393	41.373	7.711	47	0.013	0.15	2	0	5
S-100121040	602904.282	4917939.317	WDT	SCS5y6H	100121040	1.028	96.028	107.052	1.14	72.205	0.013	0.15	2	0	5
S-100121041	602839.265	4917933.017	WDT	SCS5y6H	100121041	0.155	63.7	24.333	5.23	48.621	0.013	0.15	2	0	5
S-120178379	602626.061	4917916.95	WDT	SCS5y6H	120178379	0.163	84.763	19.23	5.909	46.013	0.013	0.15	2	0	5
S-120178475	602779.93	4917693.387	WDT	SCS5y6H	120178475	1.745	88.263	197.705	5.493	5.829	0.013	0.15	2	0	5
S-J900KD_2	602596.088	4917336.815	WDT	SCS5y6H	J900KD	0.217	63.985	33.914	24.278	10.075	0.013	0.15	2	0	5

Table 7. Subcatchment attribute table

Node	Hours Flooded	Maximum Rate LPS	days	hr:min	Total Flood Volume10^6	ltr
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SU13	2.76	58.85	0	3:15	0.097	0
SU17	1.58	35.5	0	3:15	0.02	0
SU24	0.11	1.64	0	3:47	0	0
SU29	3.22	60.27	0	3:15	0.073	0
SU31	0.86	2.08	0	3:45	0.003	0
SU32	3.31	56.14	0	3:10	0.079	0
SU33	1.58	29.71	0	3:15	0.014	0
SU34	4.65	116.99	0	3:15	0.688	0
SU35	2.06	109.49	0	3:15	0.25	0
SU38	0.5	112.65	0	3:30	0.06	0
SU4	2.05	39.18	0	3:15	0.021	0
SU5	1.57	22.06	0	3:15	0.01	0
SU6	3.29	99.51	0	3:12	0.135	0
SU7	3.38	127.27	0	3:15	0.224	0

Table 8. Flooding Summary, Case Study, Scenario 1

Node	Hours Flooded	Maximum Rate LPS	days	hr:min	Total Flood Volume10^6

SU1	0.32	44.76	0	3:15	0.034
SU11	0.31	34.57	0	3:16	0.016
SU14	0.22	16.23	0	3:15	0.011
SU15	0.1	7	0	3:10	0.002
SU16	0.04	8.38	0	3:15	0.001
SU17	0.13	35.2	0	3:15	0.013
SU34	0.82	93.3	0	3:15	0.148
SU35	0.89	90.11	0	3:15	0.138
SU36	1.01	100.6	0	3:15	0.171
SU37	1	100.21	0	3:15	0.159
SU38	1.06	110.74	0	3:15	0.173
SU7	0.19	31.82	0	3:15	0.016
SU8	0.29	49.69	0	3:15	0.038

Table 9. Flooding Summary, Case study, Scenario 2

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