Designing infiltration practices on low permeability soils

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Sustainable Technologies Evaluation Program

TRIECA 2013 Conference, Markham
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Sustainable Technologies Evaluation Program

- Multi-agency program led by TRCA
- Main program objectives:
    - ✓ Evaluate clean water and energy technologies;
    - ✓ Assess barriers to/opportunities for widespread implementation;
    - ✓ Develop knowledge transfer tools, guidelines and policy alternatives;
    - ✓ Education, advocacy, and technology transfer.
- Program web address: www.sustainabletechnologies.ca

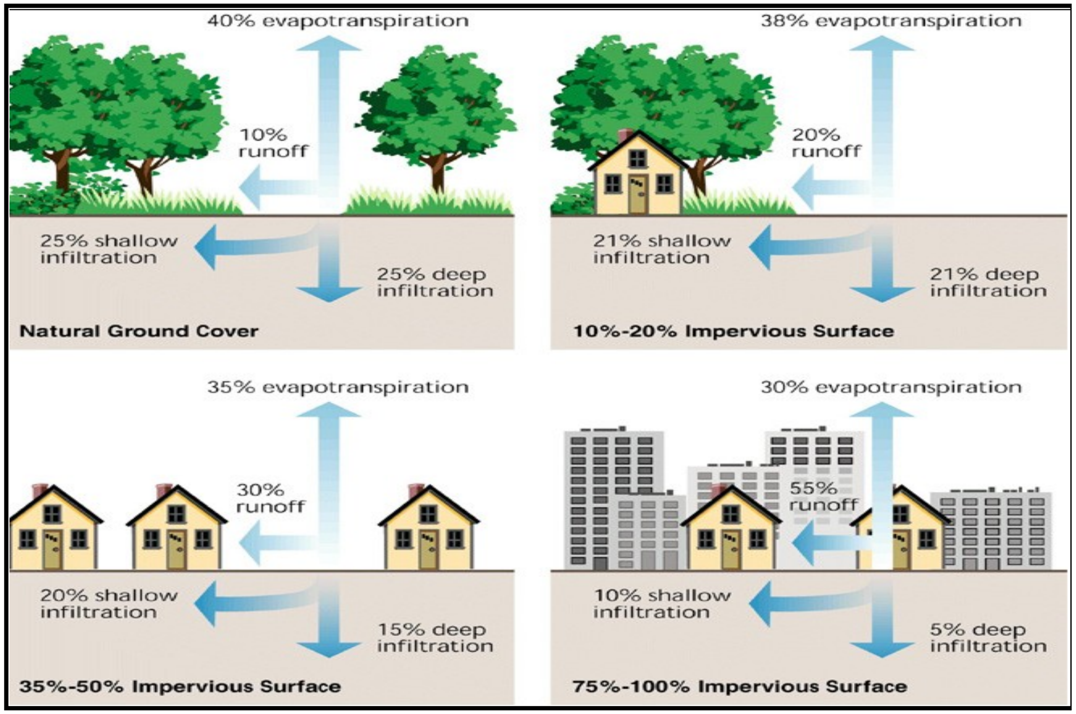
Effects of urbanization on hydrologic cycle

High infiltration and ET,

Low runoff

Low infiltration and ET,

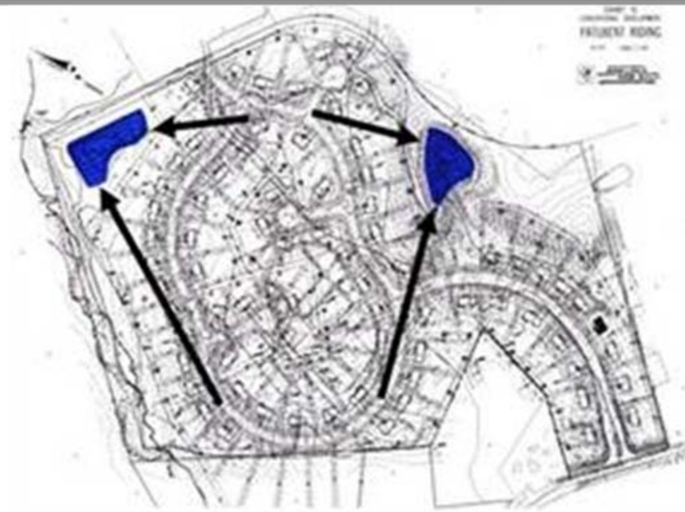
High runoff



Low Impact Development (LID) is a stormwater management approach that seeks to manage urban runoff and pollutants using distributed, small-scale controls.

The goal is to mimic a site's pre-development hydrology through:

- site designs that minimize impervious cover and preserve natural drainage features and patterns; and
- best practices that filter, harvest, evapotranspire, detain and infiltrate stormwater as close to its source as possible.



Conventional "end-of-pipe" approach

Low Impact Development approach

Soakaways, infiltration trenches and chambers

- Excavation lined with geotextile and filled with clear crushed granular or modular structures with open bottoms installed in a granular bedding;
- Conserves developable land;
- Recommended ratio of impervious drainage area to facility footprint area is 20:1 (CVC&TRCA, 2010).
- Typically limited to soils with infiltration rate of 15 mm/h or greater.

Source: Cultec

Site suitability for infiltration practices

Infiltration practices should <u>NOT</u> be applied…

- on contaminated soils;
- in areas of shallow depth (<1 m) to seasonally high water table or bedrock;
- in areas of karst topography;
- on steep or unstable slopes (15 to 20%);
- to treat construction site runoff;
- to treat combined sewer overflows;
- to treat road or parking area runoff within wellhead protection zones (2 year time of travel).

The Toronto And Region Source Protection Authority

Source:
Toronto & Region Conservation Authority © 2006.
Kassenaar, J.D.C. and Wexler, E.J., 2006.

DRINKING WATER SOURCE PROTECTION
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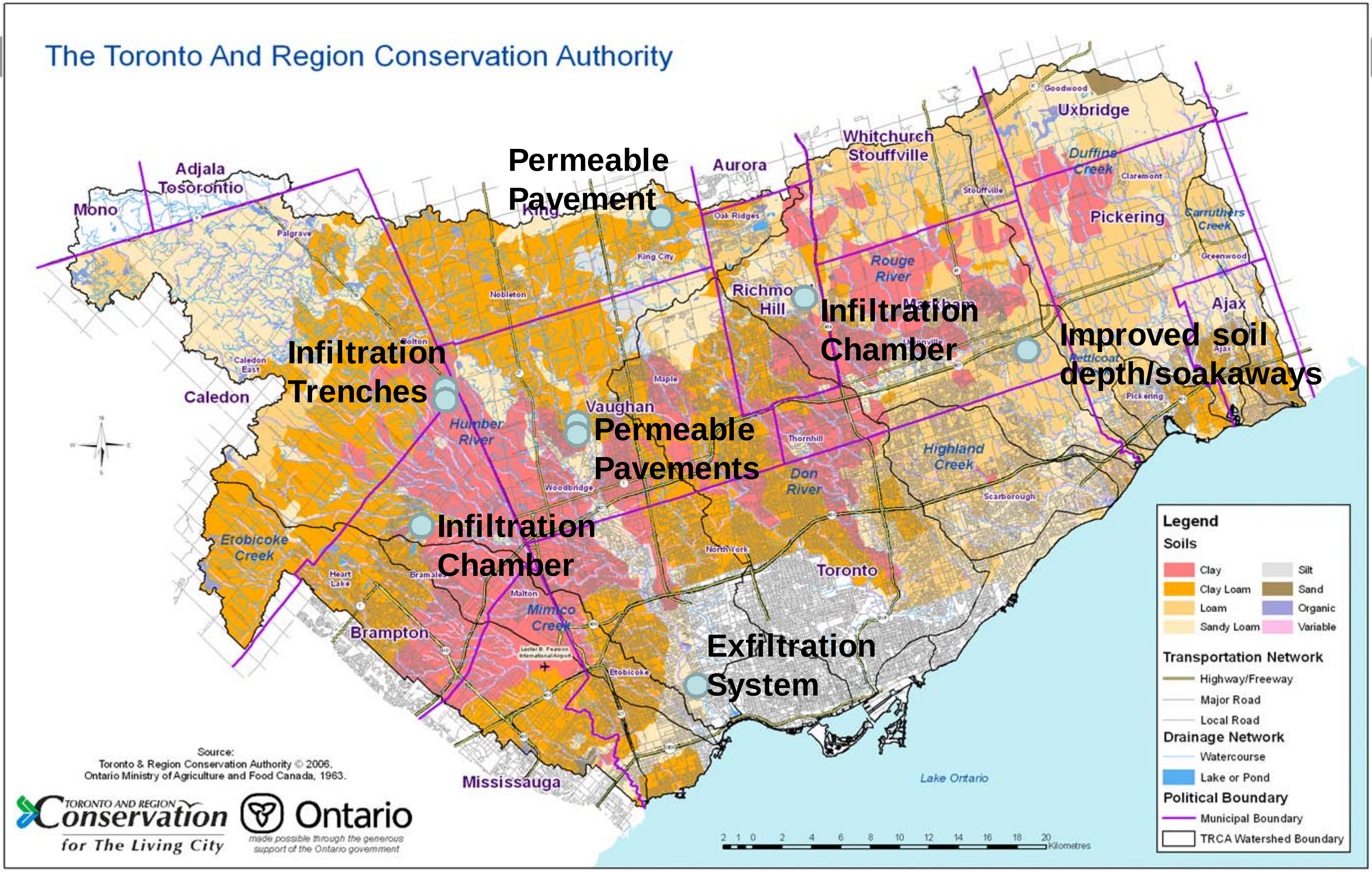
Guidelines on minimum soil infiltration rate

Reviewed manuals from 11 jurisdictions in Canada (4), Northeastern U.S. (6) and the UK (1)

Jurisdiction	Recommendations
Ontario (2003), Halifax (2006)	**15 mm/h** (60 mm/h for Infil. Basins)
British Columbia (2002)	**No restrictions**; underdrain recommended where infiltration is slow
Maine (2006)	**13 mm/h** (not > 61 mm/h)
Pennsylvania (2006)	**2.5 mm/h** (not > 254 mm/h)
Minnesota (2008)	**No restrictions**; underdrain recommended where < 25 mm/h
New York (2003); Maryland (2000)	**13 mm/h** (clay content < 20%; silt + clay content < 40%)
United Kingdom (2007)	**No restrictions**



The Toronto And Region Conservation Authority
Permeable Pavement
Infiltration Trenches
Permeable Pavements
Infiltration Chamber
Infiltration Chamber
Improved soil depth/soakaways
Exfiltration System
Mono
Adjala Tosorontio
Caledon
Aurora
Whitchurch Stouffville
Uxbridge
Pickering
Ajax
Richmond Hill
Markham
Vaughan
Humber River
Rouge River
Duffins Creek
Carruthers Creek
Highland Creek
Don River
Etobicoke Creek
Mimico Creek
Brampton
Mississauga
Toronto
Lake Ontario
Legend
Soils
Clay
Clay Loam
Loam
Sandy Loam
Silt
Sand
Organic
Variable
Transportation Network
Highway/Freeway
Major Road
Local Road
Drainage Network
Watercourse
Lake or Pond
Political Boundary
Municipal Boundary
TRCA Watershed Boundary
Kilometres
Source:
Toronto & Region Conservation Authority © 2006.
Ontario Ministry of Agriculture and Food Canada, 1963.
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Research questions

1. Can underground stormwater infiltration practices be an effective means of managing urban runoff volume on fine-textured, low permeability, glacial till soils like those commonly found in the Greater Toronto Area and southern Ontario?

2. Should stormwater infiltration practices be designed differently when they are to be located on fine-textured, low permeability soil?

Existing design guidance

- OMOE (2003) and CVC & TRCA (2010) recommend basing design on 48 to 72 hour drainage time.
- Maximum depth of stone reservoir ($d_{r\ max}$, millimetres):

$$\mathbf{d_{r\ max} = i * t_s / V_r}$$

Where:

i = infiltration rate of native subsoil (mm/hour);

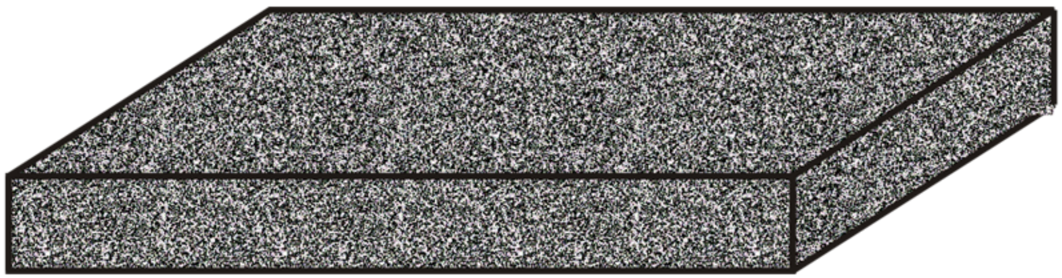
t_s = Time to drain (drainage time, typically 48 hours)

V_r = Void space ratio for aggregate used (35 to **40%**)

- For a **15 mm/h** soil = **1800 mm or 1.8 metres**.
- For a **3 mm/h** soil = **360 mm or 0.36 metres**.

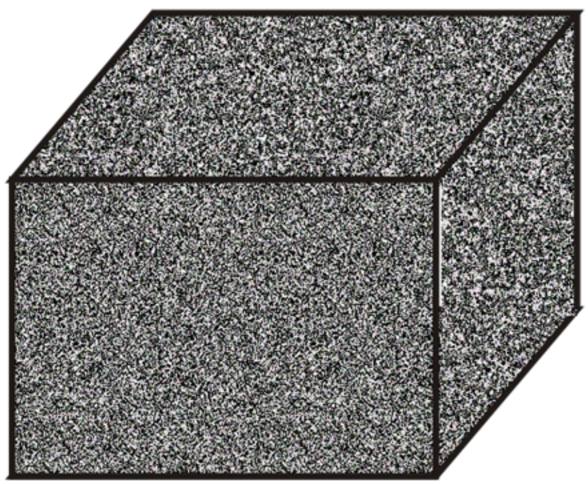
Soakaway/infiltration trench depth

Shallower trench = larger footprint area, higher bottom:side area ratio

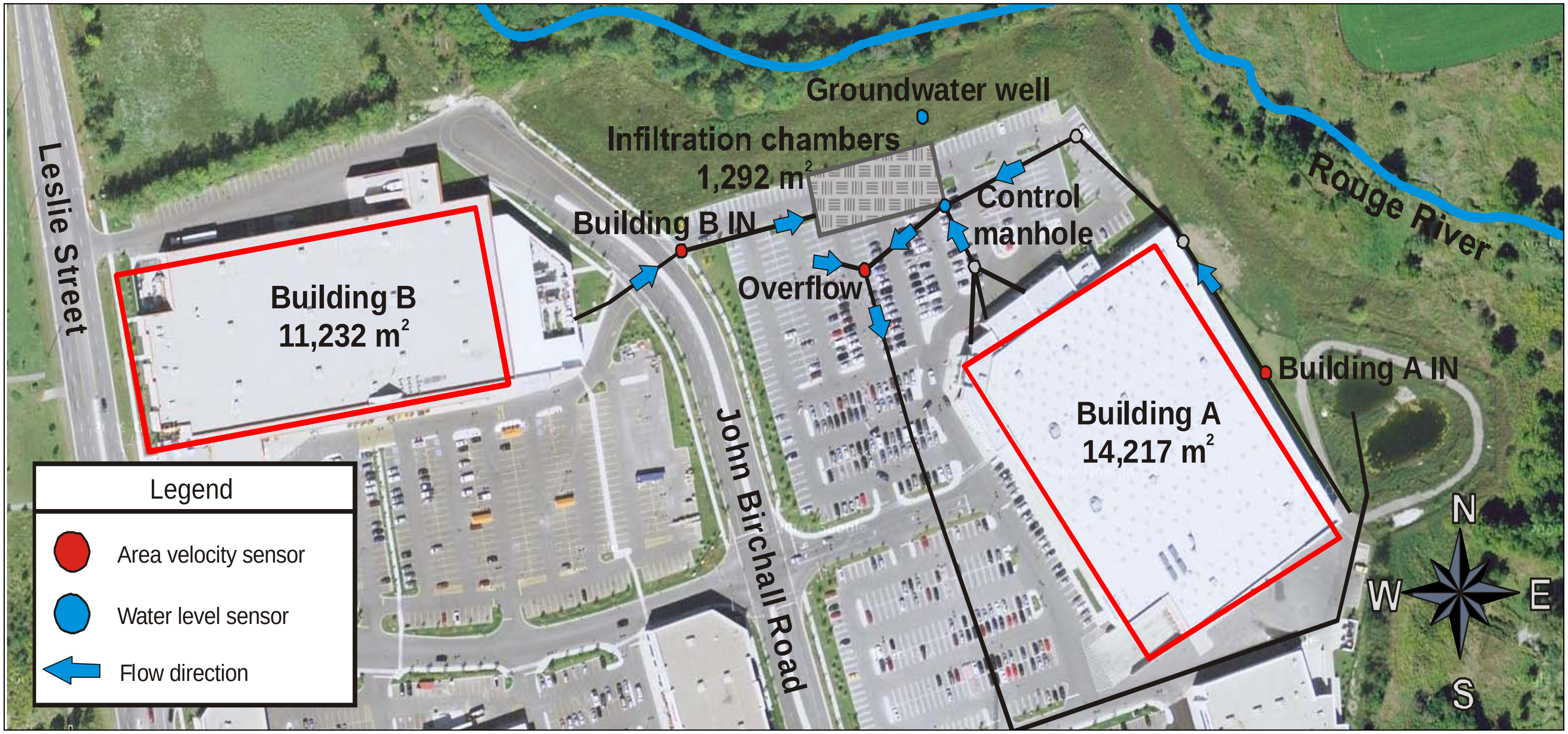


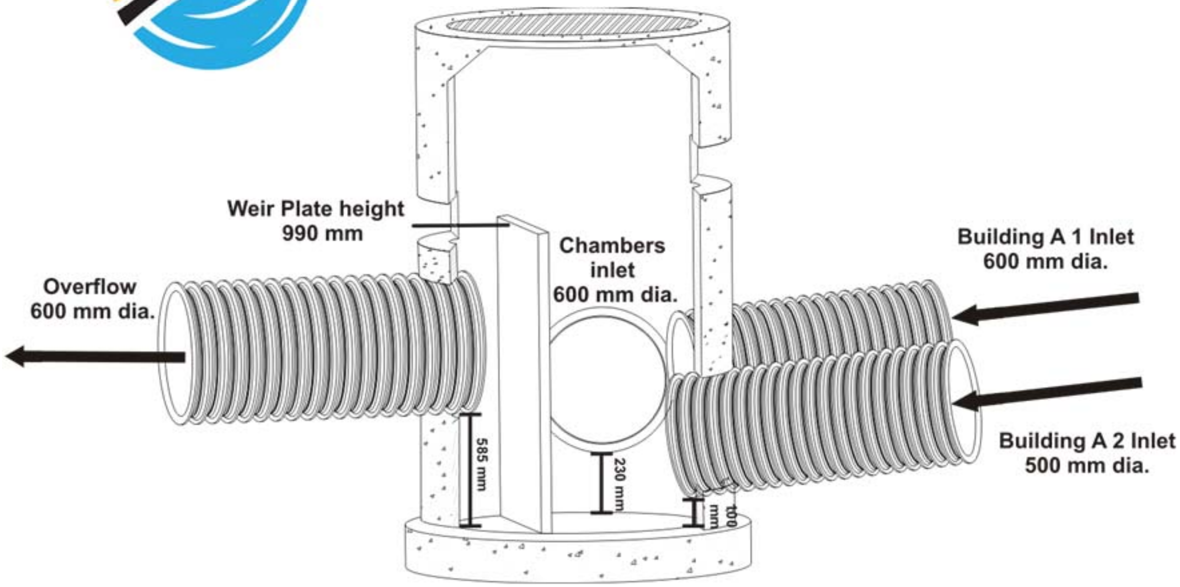
vs.

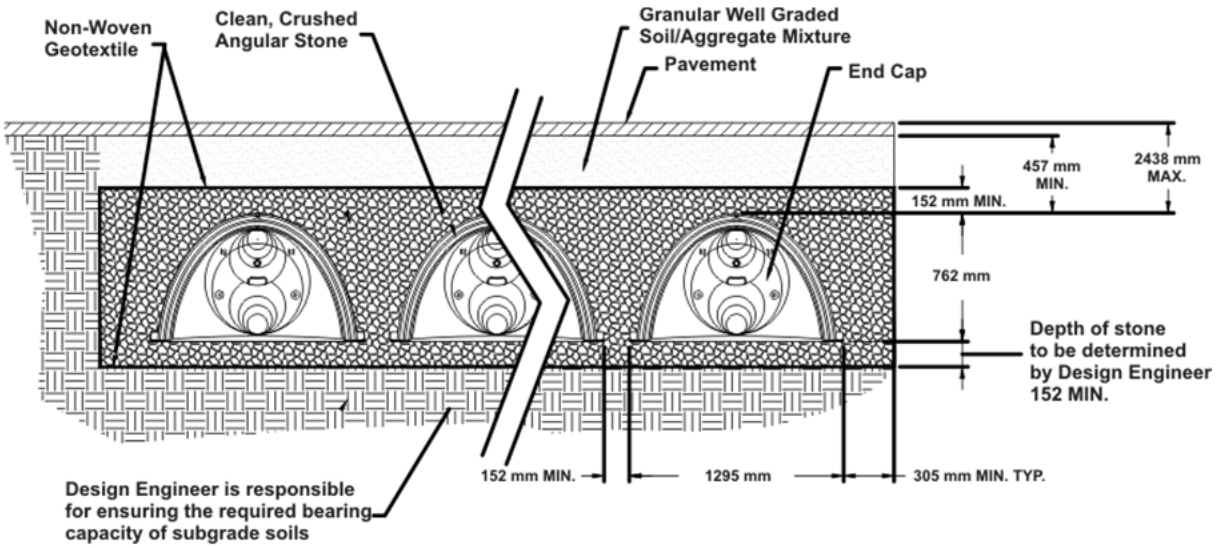
Deeper trench = smaller footprint area, lower bottom:side area ratio



Infiltration Chambers – Elgin Mills Crossing Richmond Hill, Ontario




Weir Plate height
990 mm
Chambers
inlet
600 mm dia.
Building A 1 Inlet
600 mm dia.
Overflow
600 mm dia.
Building A 2 Inlet
500 mm dia.
585 mm
230 mm
100 mm


Non-Woven
Geotextile
Clean, Crushed
Angular Stone
Granular Well Graded
Soil/Aggregate Mixture
Pavement
End Cap
457 mm
MIN.
2438 mm
MAX.
152 mm MIN.
762 mm
Depth of stone
to be determined
by Design Engineer
152 MIN.
152 mm MIN.
1295 mm
305 mm MIN. TYP.
Design Engineer is responsible
for ensuring the required bearing
capacity of subgrade soils

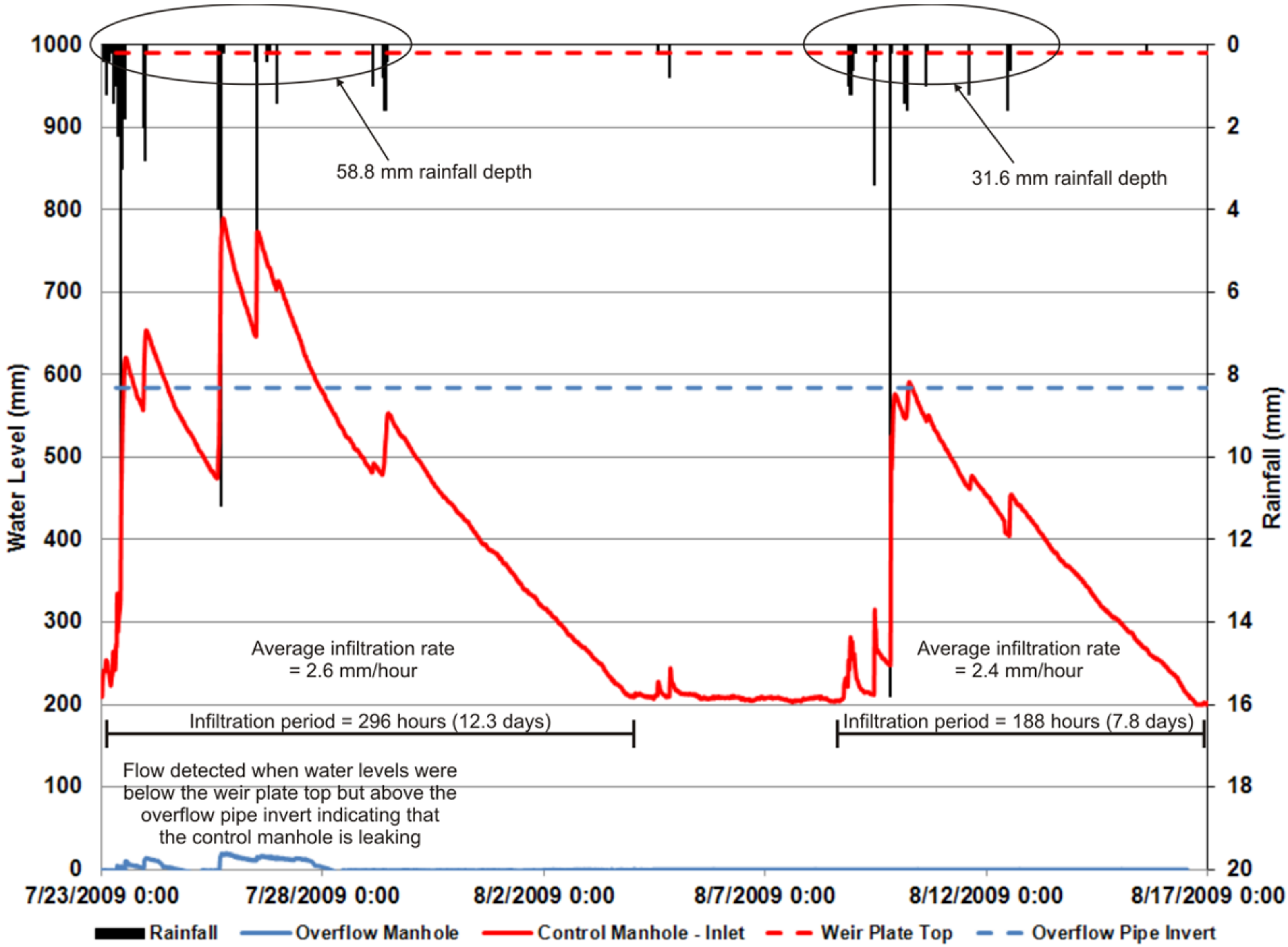
Infiltration Chambers – Elgin Mills Crossing

- Storage volume for **41 mm** event (includes sewers)
- Ratio of drainage area-to-facility area is **20:1**
- **Sandy silt till** underlain by higher conductivity fine sand

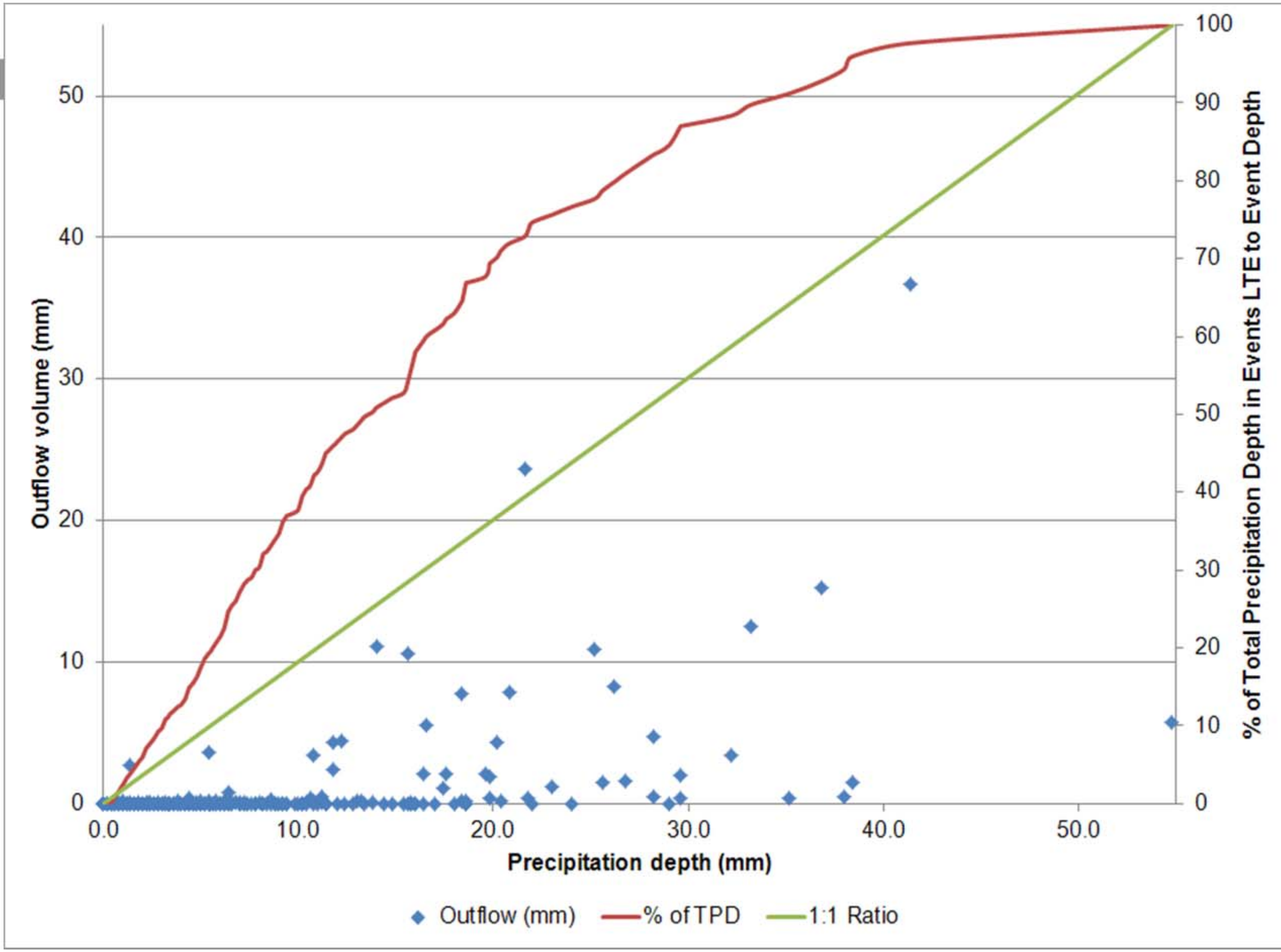

Source: StormTech


Source: StormTech

- Observed infiltration rate (full drainage period): **3.0 – 3.5 mm/h**
- Requires **9 days** to fully drain
- Approx. **90% runoff volume reduction**



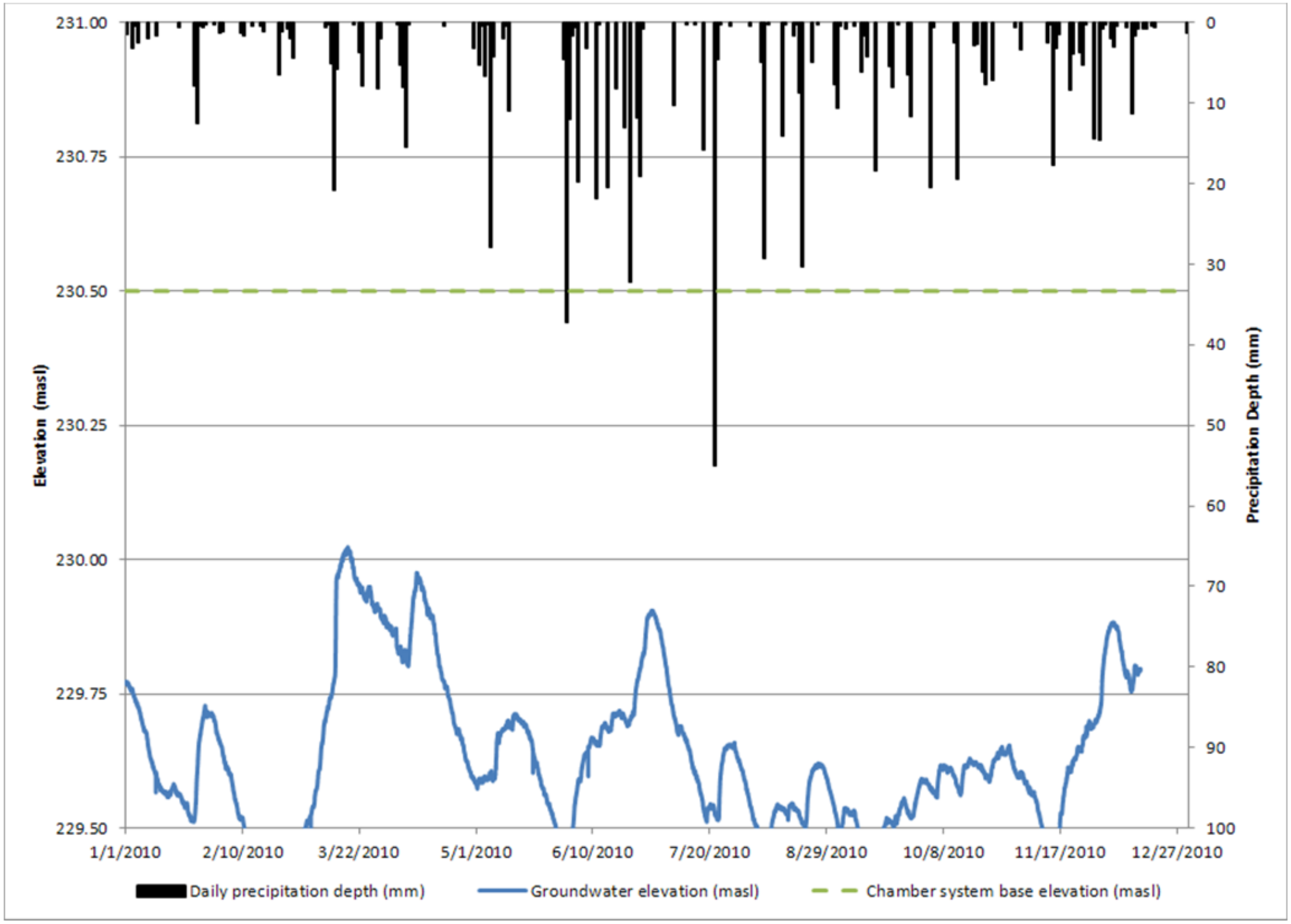
1000
900
800
700
600
500
400
300
200
100
0
Water Level (mm)
0
2
4
6
8
10
12
14
16
18
20
Rainfall (mm)
58.8 mm rainfall depth
31.6 mm rainfall depth
Average infiltration rate
= 2.6 mm/hour
Average infiltration rate
= 2.4 mm/hour
Infiltration period = 296 hours (12.3 days)
Infiltration period = 188 hours (7.8 days)
Flow detected when water levels were below the weir plate top but above the overflow pipe invert indicating that the control manhole is leaking
7/23/2009 0:00
7/28/2009 0:00
8/2/2009 0:00
8/7/2009 0:00
8/12/2009 0:00
8/17/2009 0:00
Rainfall
Overflow Manhole
Control Manhole - Inlet
Weir Plate Top
Overflow Pipe Invert


Outflow volume (mm)
% of Total Precipitation Depth in Events LTE to Event Depth
Precipitation depth (mm)
0
10
20
30
40
50
0.0
10.0
20.0
30.0
40.0
50.0
0
10
20
30
40
50
60
70
80
90
100
Outflow (mm)
% of TPD
1:1 Ratio

Elgin Mills Crossing - Inflow, Outflow and Infiltrated Volume Summary

Parameter	Monitoring Period			
	Sept. 13, 2008 to July 14, 2010	**July 15, 2010 to July 31, 2011**	**Sept. 13, 2008 to July 31, 2011**	**Jan. 1, 2009 to Dec. 31, 2009**
Total Precipitation Depth (mm)	1,421.3	903.4	2,324.7	800.7
Total Inflow Volume (m^3)	32,958.3	21,261.9	54,220.2	17,953.2
Total Outflow Volume (m^3)	4,598.6	896.9	5,495.5	3,012.1
Total Infiltrated Volume (m^3)	28,359.7	20,365	48,724.7	14,941.1
Runoff Reduction Ratio	0.86	0.96	0.90	0.83

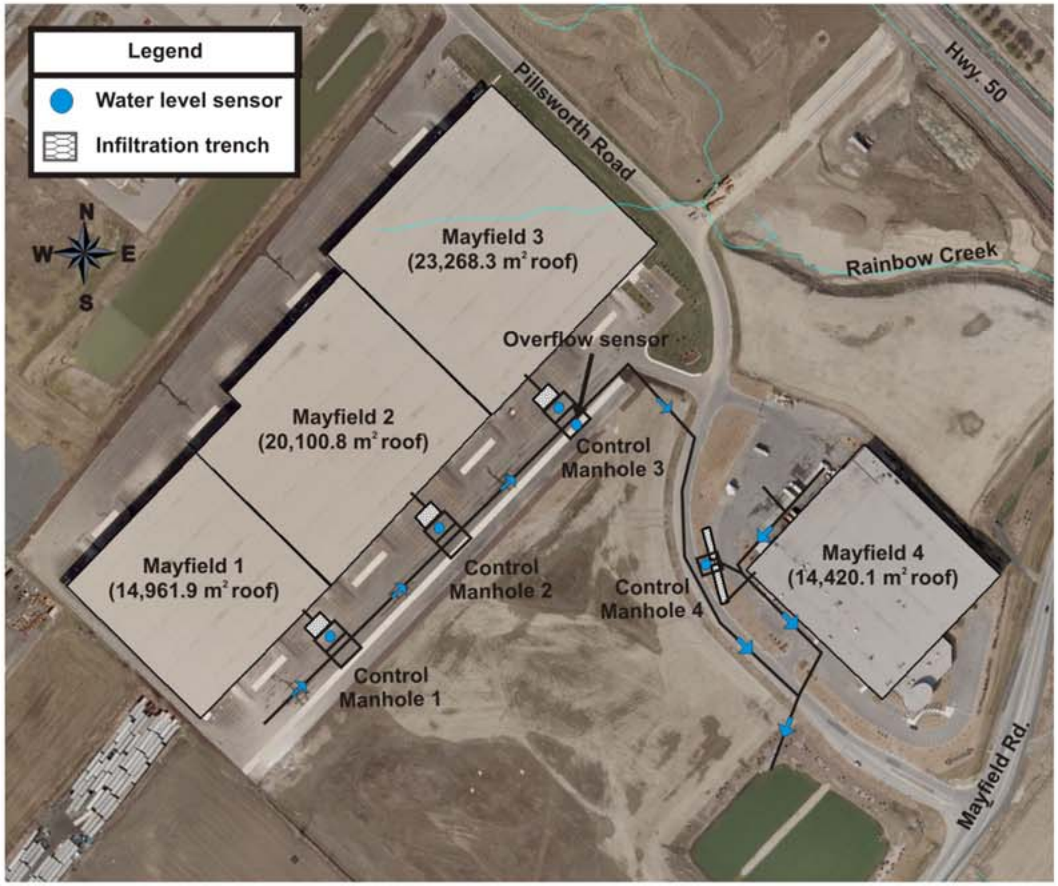
Elgin Mills Crossing - Groundwater Levels



Elgin Mills Crossing Infiltration Chambers - Conclusions

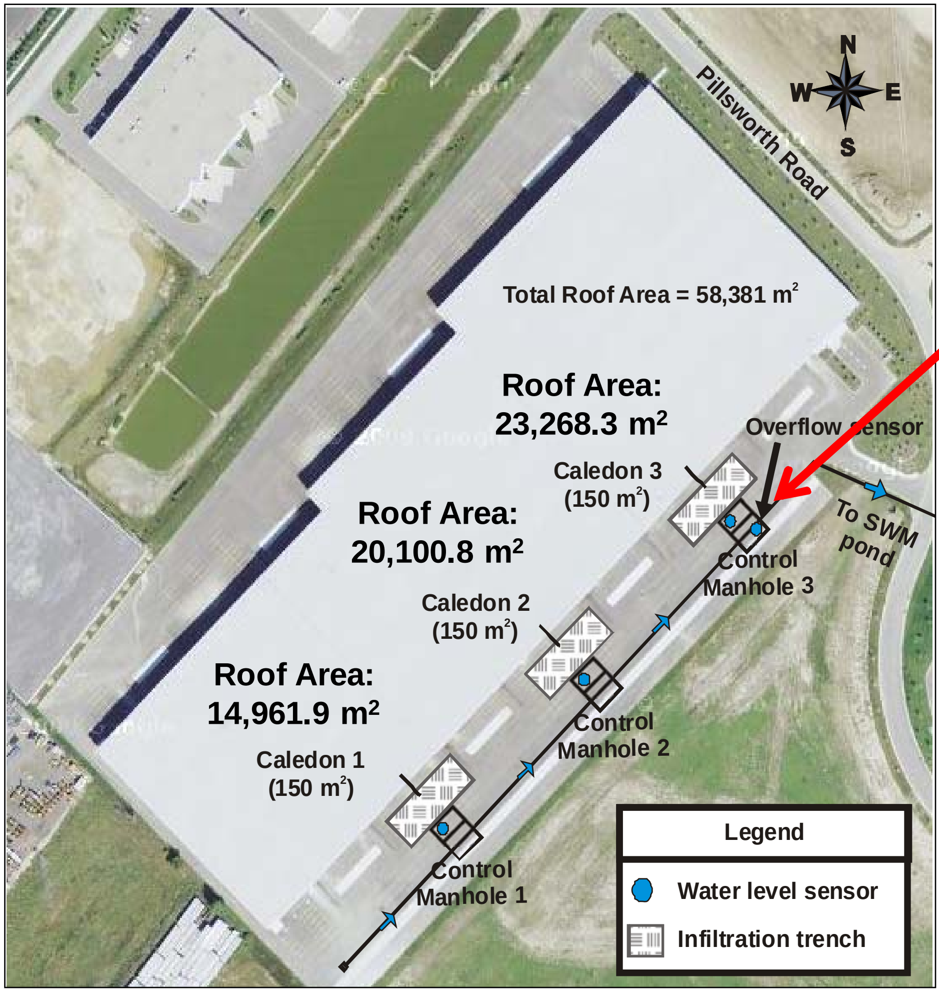
- Minor leakage in control manhole causing more frequent outflow than expected;
- Slower than expected drainage time (~9 days) – likely installed in sandy silt till, not silty fine sand lens;
- Potential for water table elevation to interact with the base of the practice;
- **Meeting or exceeding pre-dev. infiltration volume target through infiltration of roof runoff alone;**
- Favorable performance is due to the water storage capacity (41 mm event over the combined roof areas).

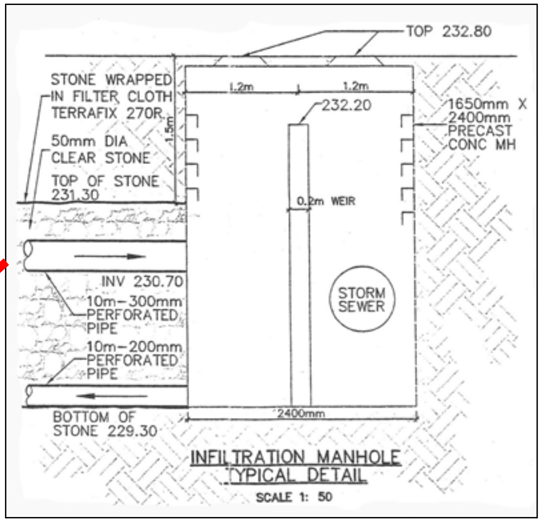
Infiltration Trenches – Mayfield Industrial Park Bolton, Ontario



- Four underground trenches receiving **roof runoff** from two commercial buildings;
- **Clayey silt glacial till** over bedrock with some discontinuous sand and gravel layers;
- Approx. infiltration rate of clayey silt till = **12 mm/h.**
- Site drains to **Rainbow Creek**, warm water trib. to Humber River.

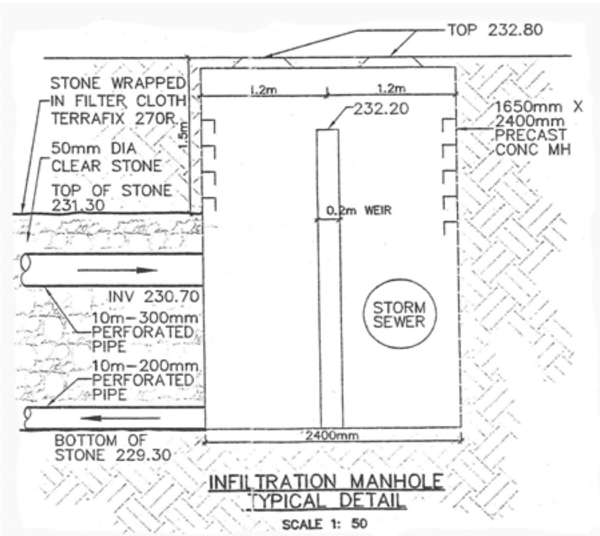
Mayfield Trenches 1, 2 & 3

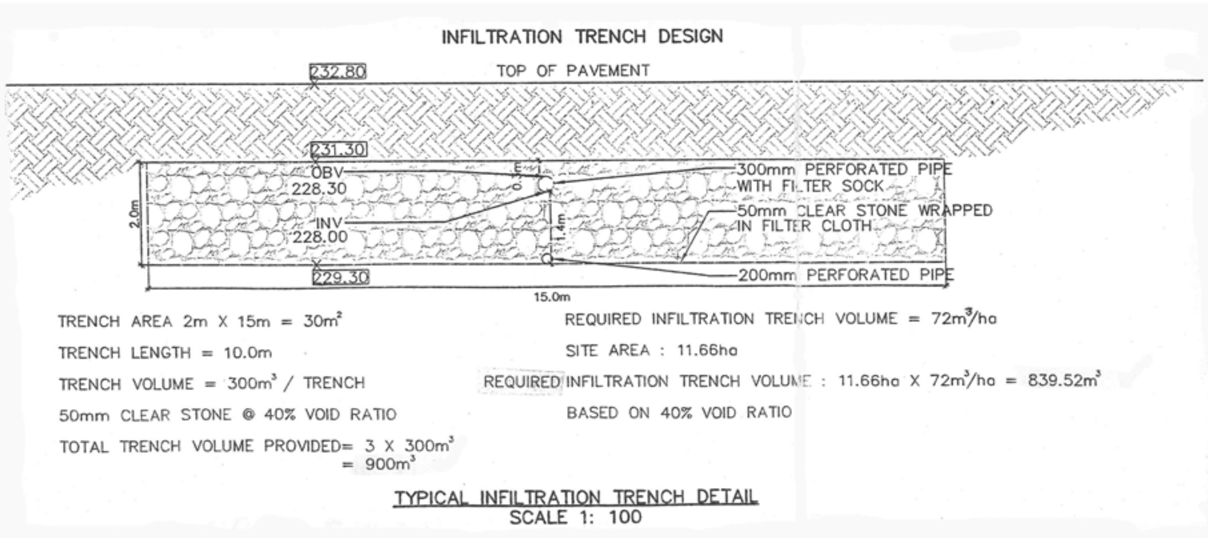




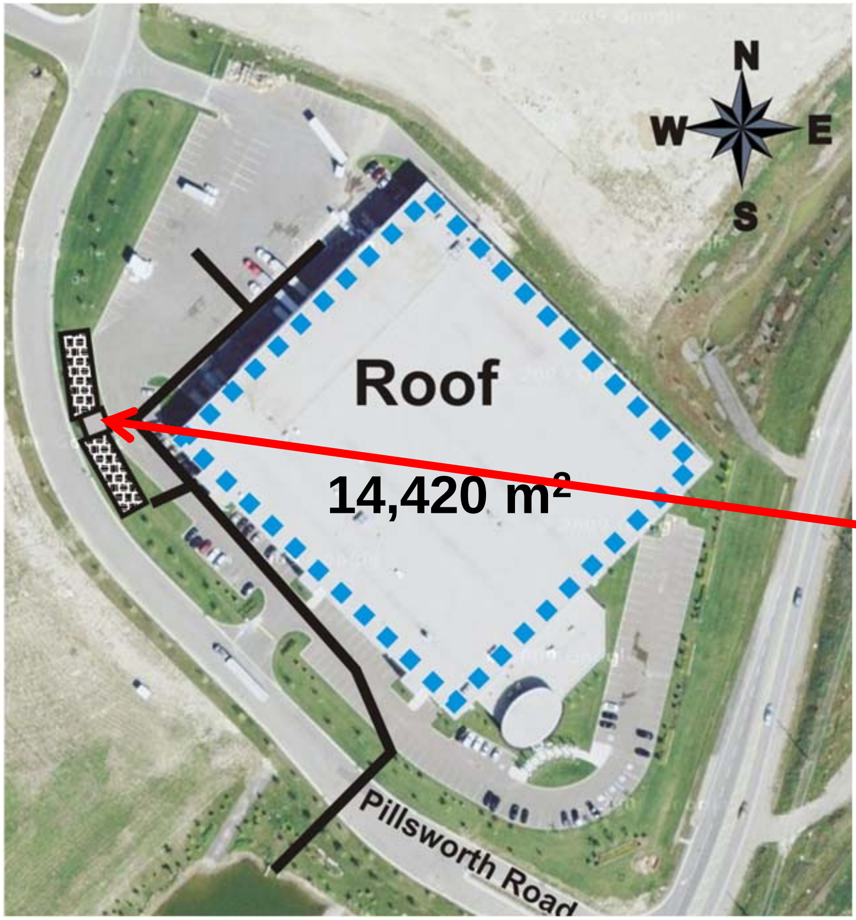
- Trench sizing = water storage cap. of **28.8 m³/ha. lot area** (trench volume of 72 m³/ha. lot area).
- Annual infiltration volume target (11.86 ha. lot) = **23,490 m³**
- Ratio of roof area to trench footprint area ranges from **155:1 to 100:1**
- Water storage cap. = **9.4 mm, 7 mm and 6 mm events** for Trenches 1, 2 and 3 respectively.

Mayfield Infiltration Trenches 1, 2 & 3

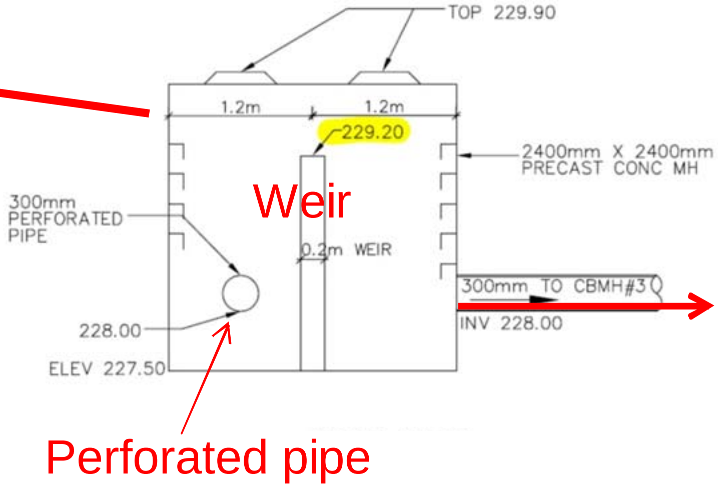


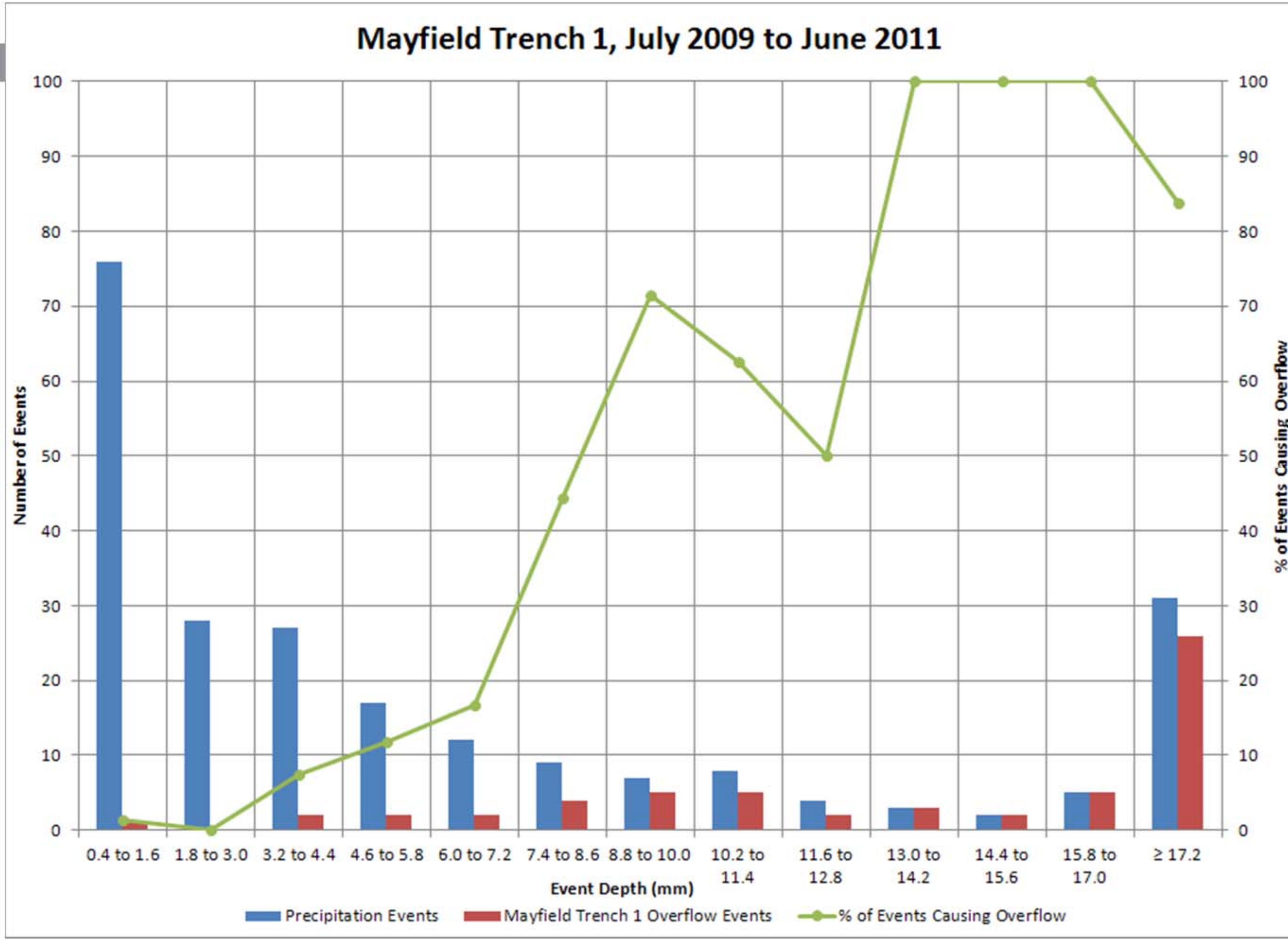


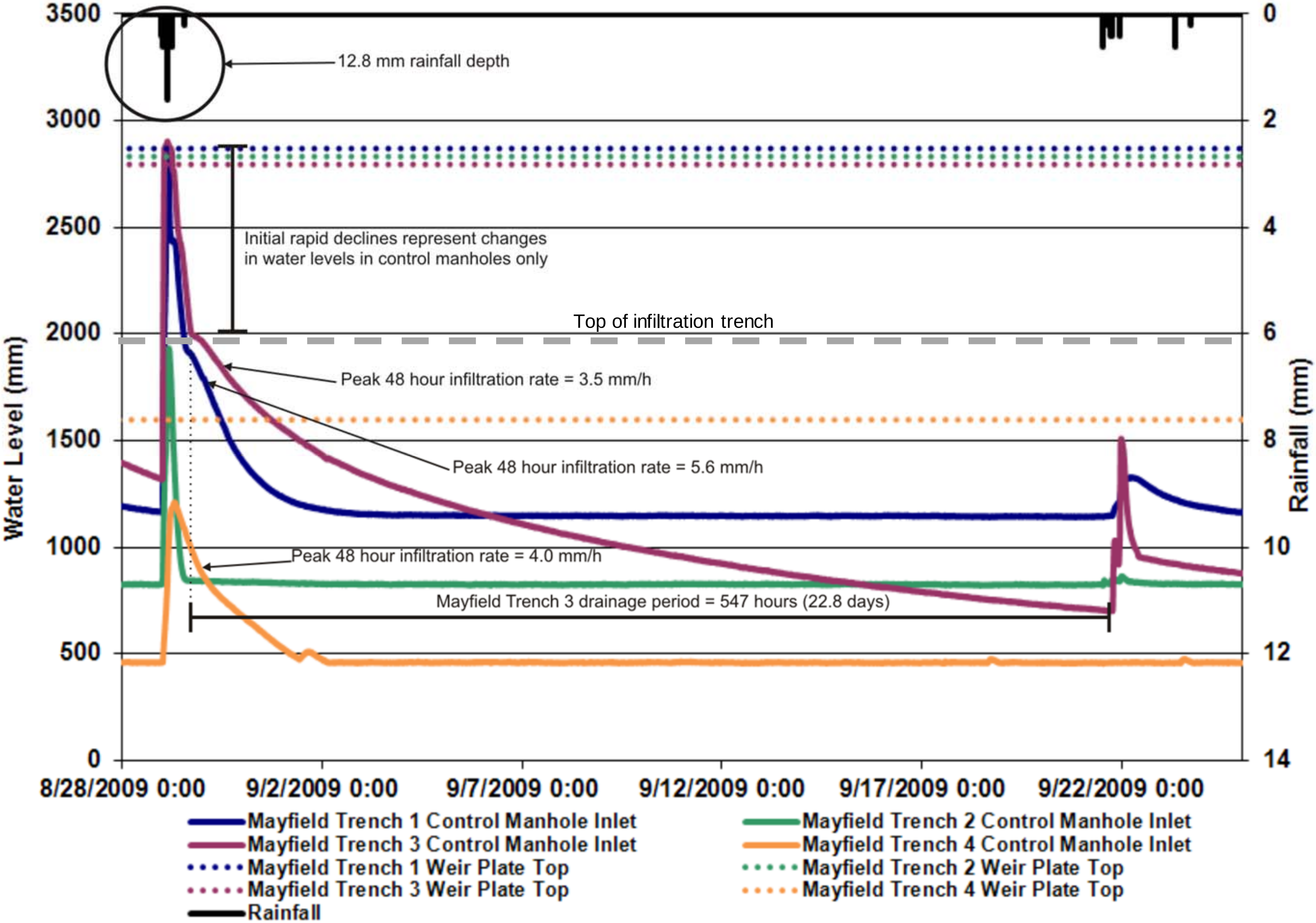
Mayfield Infiltration Trench #4



- Annual infiltration volume target (3.21 ha. lot) = **6,456 m³**
- Ratio of roof area to trench footprint area: **64:1**
- Water storage capacity of 184 m³ (**14.2 mm event**)




Mayfield Trench 1, July 2009 to June 2011
Number of Events
% of Events Causing Overflow
0
10
20
30
40
50
60
70
80
90
100
0.4 to 1.6
1.8 to 3.0
3.2 to 4.4
4.6 to 5.8
6.0 to 7.2
7.4 to 8.6
8.8 to 10.0
10.2 to 11.4
11.6 to 12.8
13.0 to 14.2
14.4 to 15.6
15.8 to 17.0
≥ 17.2
Event Depth (mm)
Precipitation Events
Mayfield Trench 1 Overflow Events
% of Events Causing Overflow

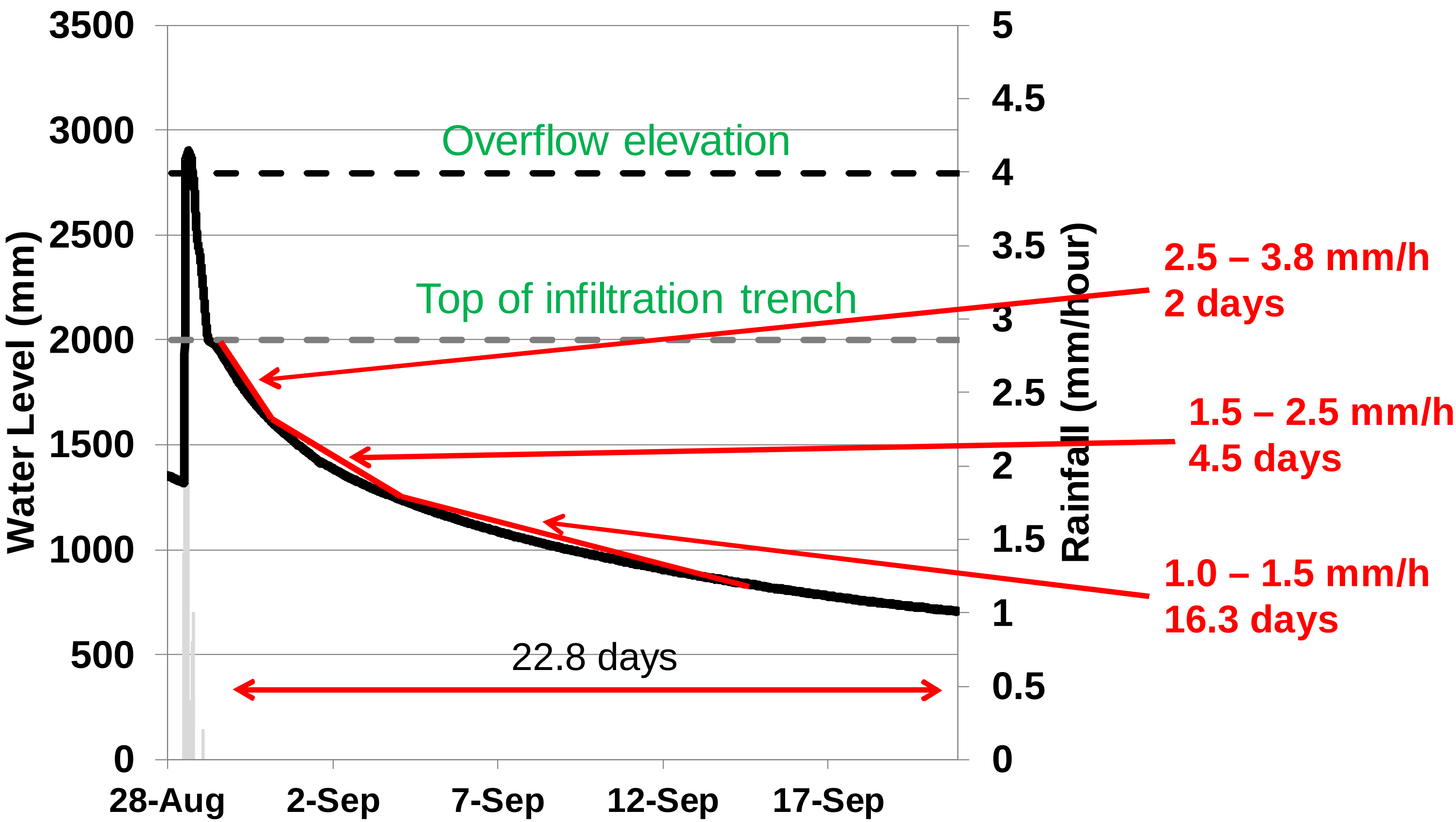

12.8 mm rainfall depth
Initial rapid declines represent changes in water levels in control manholes only
Top of infiltration trench
Peak 48 hour infiltration rate = 3.5 mm/h
Peak 48 hour infiltration rate = 5.6 mm/h
Peak 48 hour infiltration rate = 4.0 mm/h
Mayfield Trench 3 drainage period = 547 hours (22.8 days)
Water Level (mm)
Rainfall (mm)
3500
3000
2500
2000
1500
1000
500
0
2
4
6
8
10
12
14
8/28/2009 0:00
9/2/2009 0:00
9/7/2009 0:00
9/12/2009 0:00
9/17/2009 0:00
9/22/2009 0:00
Mayfield Trench 1 Control Manhole Inlet
Mayfield Trench 2 Control Manhole Inlet
Mayfield Trench 3 Control Manhole Inlet
Mayfield Trench 4 Control Manhole Inlet
Mayfield Trench 1 Weir Plate Top
Mayfield Trench 2 Weir Plate Top
Mayfield Trench 3 Weir Plate Top
Mayfield Trench 4 Weir Plate Top
Rainfall

Peak 48 hour infiltration rates

Trench	Mean 48 h i_p (mm/h)	Min 48 h i_p (mm/h)	Max 48 h i_p (mm/h)	Number of observations
Mayfield 1	5.1	3.6	6.4	51
Mayfield 2	n/a	n/a	n/a	n/a
Mayfield 3	3.1	2.5	3.8	52
Mayfield 4	3.8	3.3	4.1	40

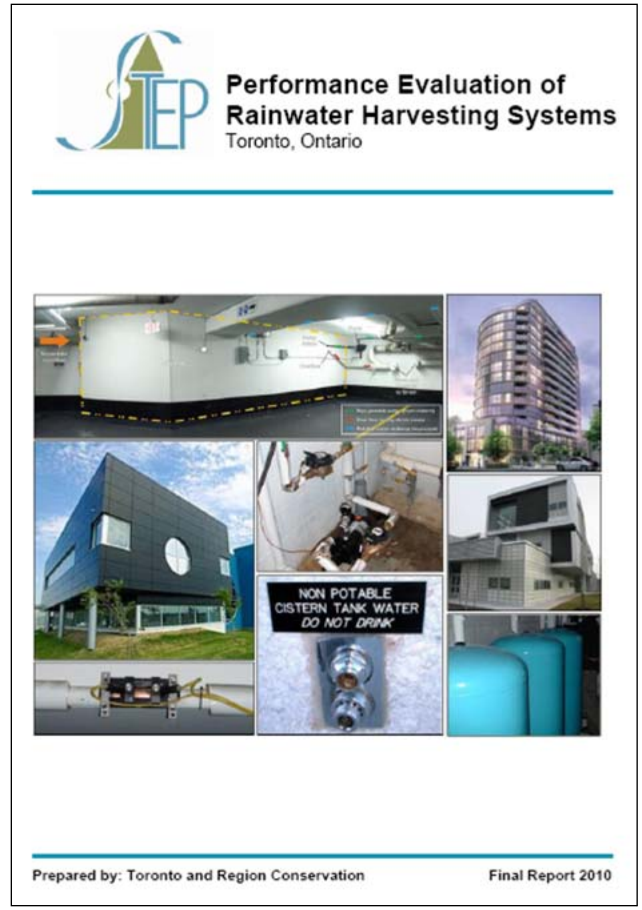
Peak 48 hour infiltration rates (48 h i_p) are those observed over the 48 hour period following a storm event, beginning when the trench is full of water.

Mayfield Infiltration Trench #3



Roof runoff/trench drainage model

- Roof runoff model assumes 100% inflow for events >9 mm; 70% for 9 to 6.1 mm; 60% for 6 to 4.1 mm; 40% for 4 to 2.1 mm; 30% for 2 mm or less.
- Trench drainage based on a Mayfield Trench 3 drainage event (Aug. 29 – Sept. 19, 2009);
- “Normal” precipitation input data simulated using historical daily totals from months closest to 30 year climate normal values.



Mayfield Infiltration Trench #3

Scenario #	Trench footprint area (m^2)	Ratio of roof area to trench footprint (m^2)	Volume infiltrated* (m^3)	Percent of total* roof runoff (%)
1	150	155:1	2,914	16
2	235	99:1	4,168	23
3	465	50:1	7,103	40
4	1165	20:1	13,314	75
5	665	35:1	9,238.34	52
6	680	34:1	9,381	53

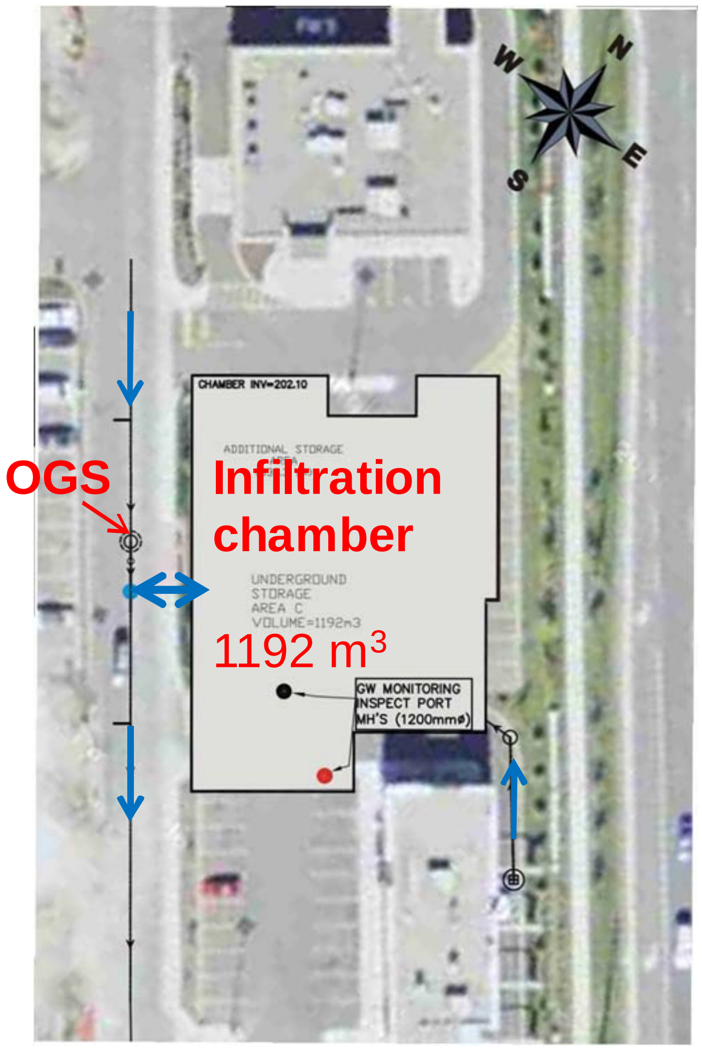
Keeping the trench 2 m deep, the footprint needed to meet the infiltration target for Mayfield Trench 3 (**9,367.91 m^3/yr.**) is 680 m^2 (~4.5 x 150) or a water storage capacity of 116.4 m^3/ha. lot area.

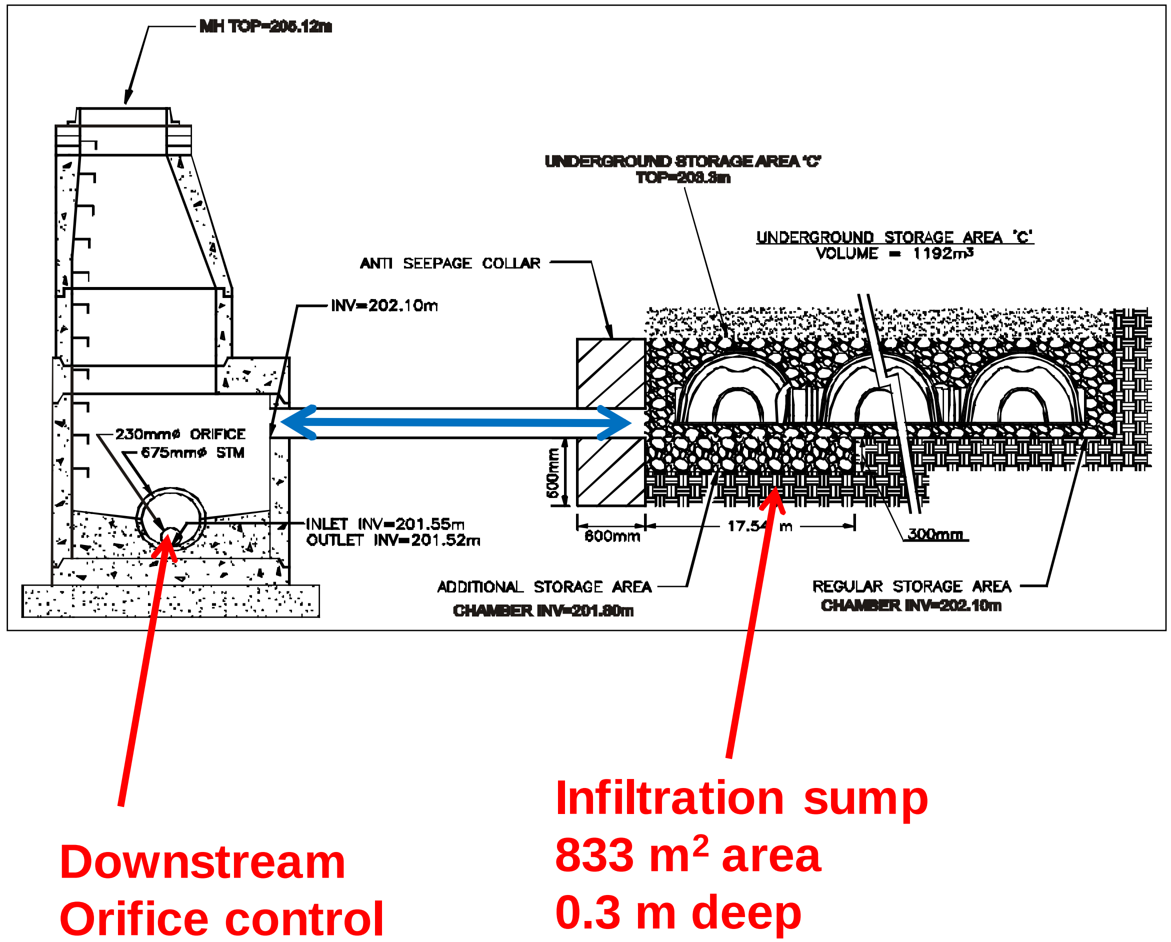
* Predicted by a roof runoff/trench drainage model using a simulated "climate normal" year of daily precipitation data.

Mayfield Industrial Park Infiltration Trench System - Conclusions

- Trenches are draining more slowly and overflow more frequently than expected;
- Trench infiltration rates are very similar, do not exhibit significant seasonal variation and decrease exponentially with depth (head);
- Minimum trench water storage capacity needed to meet the annual infiltration volume target is 116.4 m^3/ha. lot area (90% impervious cover) = 23 mm event over the 5.84 ha. roof.

Infiltration Chambers – Bramport, Brampton





Infiltration Chambers – Bramport, Brampton

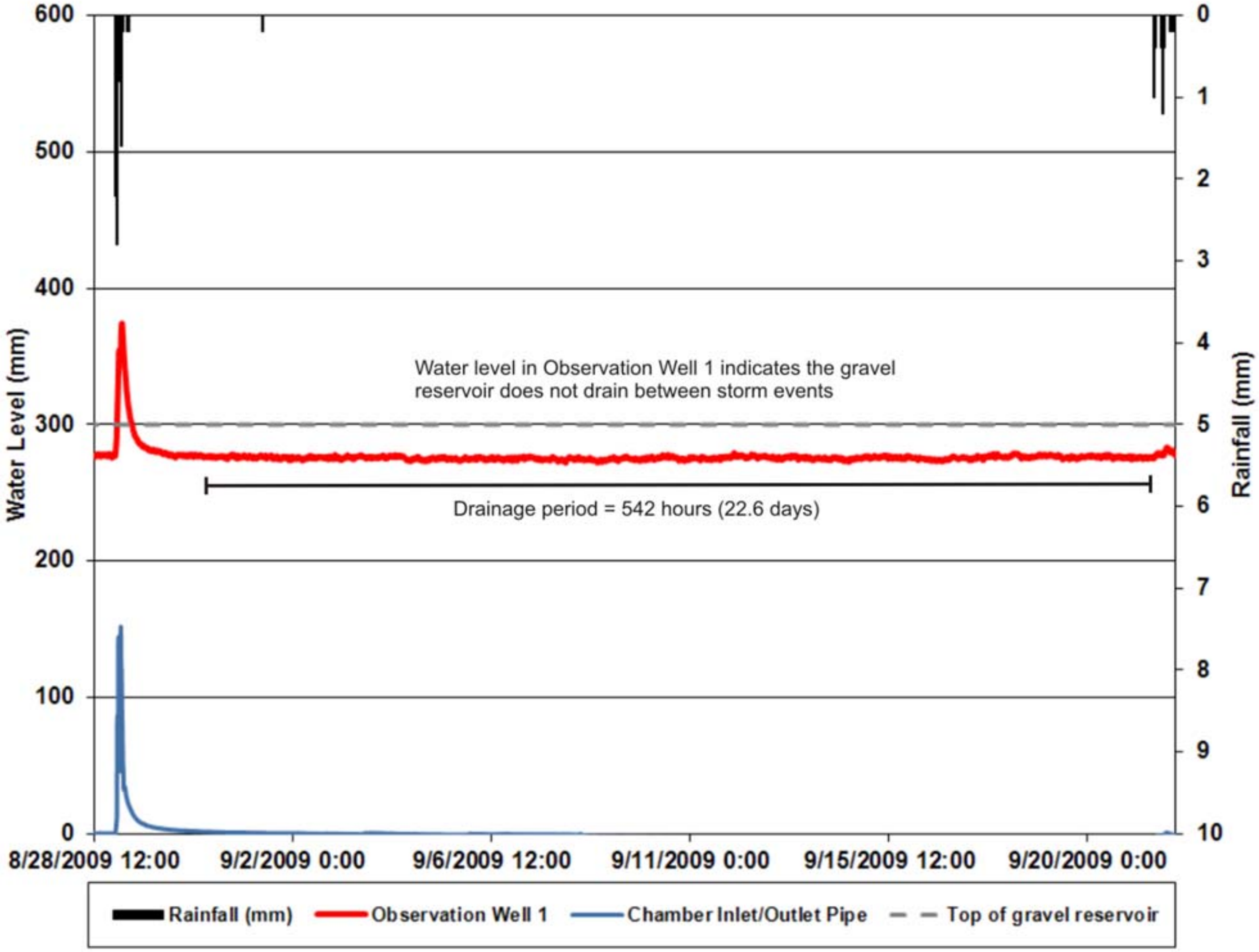
- Road and roof runoff with OGS pre-treatment
- Designed for detention/peak flow control
- Storage volume for **36 mm** event
- Drainage area to gravel bed footprint area ratio: **22:1**


Source: Cultec


Source: Cultec

- Shallow 0.3 m sump
- **Sandy silty clay till**
- **Little or no infiltration observed**
- **Possibility of perched water table**

Infiltration Chamber, Bramport, Brampton



Performance on fine-textured soils: Local studies

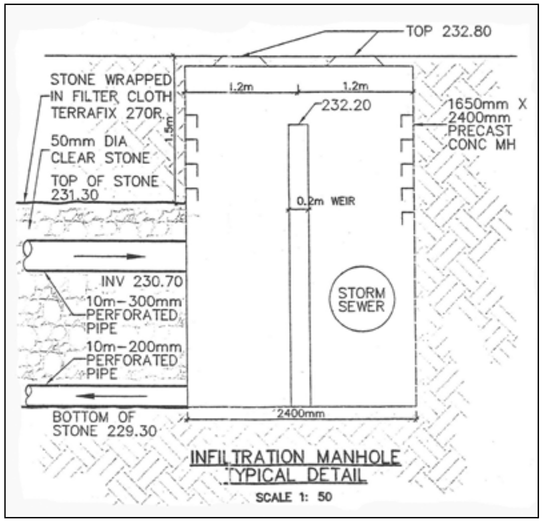
Study	Practice	Location	Soil Type	Runoff reduction	Underdrain
U of Guelph & TRCA, 2011	Permeable Pavements	Kortright Parking Lot	Silty Clay Till	**43%**	Yes
TRCA, 2008	Permeable Pavement	Seneca College Parking Lot	Silty Clay Till	**99%**	No
SWAMP, 2002	Perforated Pipe	Toronto Resid. Road	Clay to Clay Silt Till	**47 to 86%**	No
TRCA, 2013	Infiltration Chamber	Richmond Hill Roof Runoff	Sandy Silt Till	**90%**	No
TRCA, 2011	Detention Chamber	Brampton Parking Lot	Sandy Silty Clay Till	**negligible**	No
TRCA, 2011	Bioretention	Kortright Parking Lot	Silty Clay Till	**Approx. 90%** (interim result)	Yes

Key findings of the study

1. Underground stormwater infiltration practices can be an effective means of managing urban runoff on fine-textured soils where:
   - ✓ Design is based on good knowledge of native subsoil permeability;
   - ✓ Underlying stratigraphy and groundwater flow pattern is conducive (i.e. presence of an aquifer to recharge or interflow path to a receiving waterbody).
2. In big box commercial lots on glacial till soils it is possible to maintain pre-development infiltration volume through infiltration of roof runoff alone.

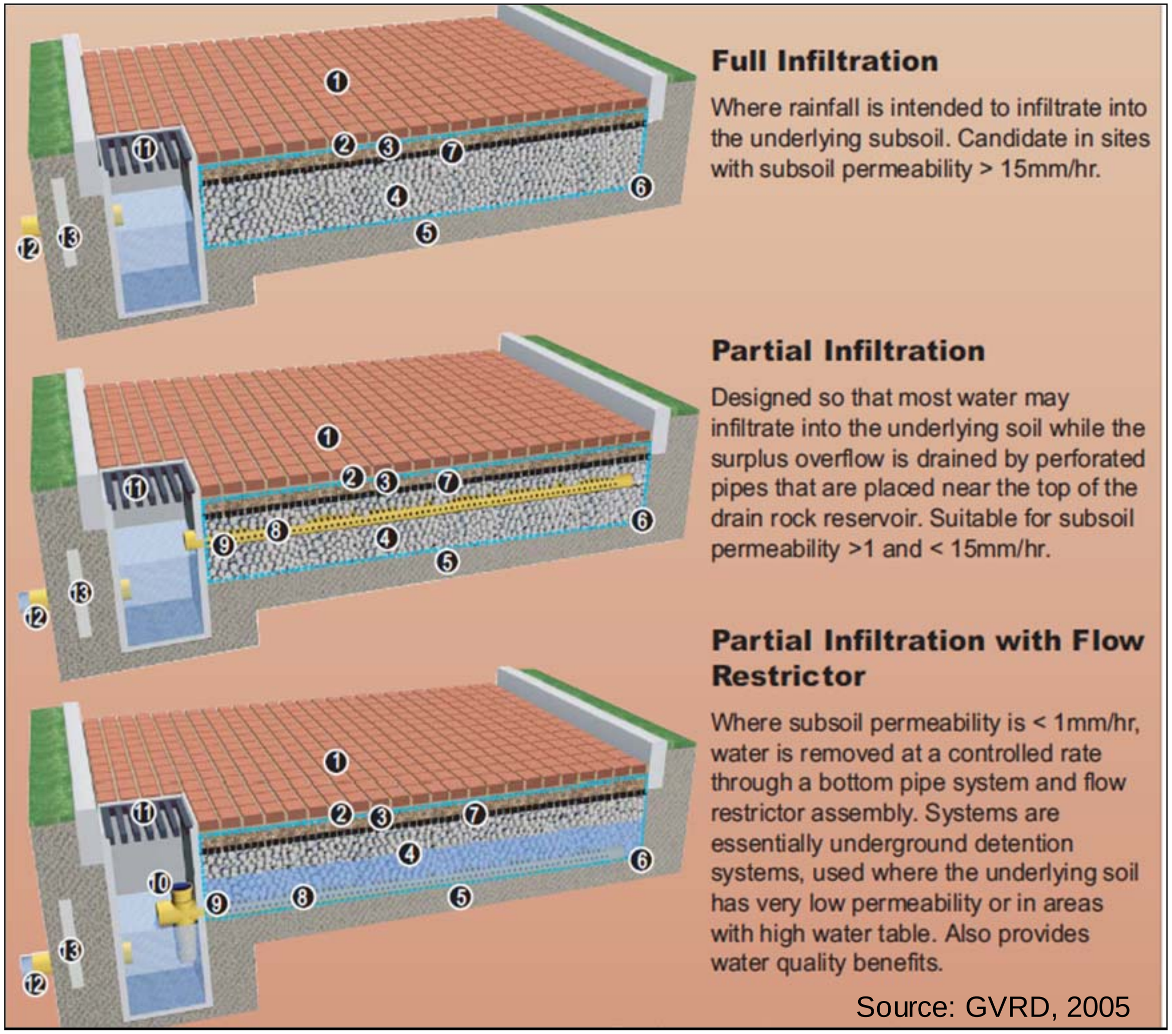
Design guidance: General

- Improvements to control manhole design, material specifications, construction and inspection practices to prevent leakage;
- Include pre-treatment devices u/s of trenches/ chambers (e.g. Goss trap and sump, OGS) to reduce accum. of sediment/clogging.



Design guidance: Soil infiltration rate

- Conduct pre-construction soil percolation rate measurements and geotechnical investigations;
- Where soil percolation rate is <15 mm/h an underdrain is required;
- Design for drainage of ponded water in 24 hrs and event based treatment target (e.g. 5 mm) within 48 hrs.



Design guidance: Fine textured soils

- Design to maintain hydraulic head in water storage reservoirs for longer than 48 to 72 hours to help maximize drainage rate and annual infiltration volume;
- Drawn upon water stored in gravel reservoirs like a rainwater cistern for non-potable uses (e.g. landscape irrigation, vehicle/outdoor washing);
- Design manholes to prevent mosquitoes from entering;
- Include a means of draining the system by gravity to improve ease of maintenance (e.g. outlet pipe through the weir wall with flow restrictor valve).

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Thank You

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Email: dyoung@trca.on.ca

STEP website:

www.sustainabletechnologies.ca

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