Lot-level approaches to control urban flood risk and mitigate basement flooding

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From: http://www.cbc.ca
Introduction

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Outline

1. Urban hydrology background
2. Basement flooding
3. Backwater valves
4. Future research direction
1. Urban hydrology background
Hydrologic cycle

\[ P = \text{precipitation} \quad E = \text{evaporation} \]
\[ R = \text{runoff (surface)} \quad F = \text{infiltration} \]
\[ T = \text{transpiration} \quad G = \text{ground water flow} \]

From: Bedient et al. (2012)
Anthropogenic effects:
Modifications to natural systems

Anthropogenic impacts:
• Water diversions
• Water impoundments
• Deforestation effects
• Agricultural runoff

From: http://www.nature.org
Anthropogenic and land development effects

From: Bedient et al. (2012)
Anthropogenic and climate change effects

From: https://www.epa.gov
Recent examples of Canadian floods

**Toronto 2013**

**Essex County 2016 (Windsor, Tecumseh)**
*From: [http://www.cbc.ca](http://www.cbc.ca)*

**Kashechewan 2015**
*From: [http://www.thestar.com](http://www.thestar.com)*

**Alberta 2013**
*From: [http://o.canada.com](http://o.canada.com)*
Socio-economic impacts of floods

Baseline flooding

Loss of land

Aquatic ecosystems

Damage to infrastructure

http://o.canada.com

http://www.iclr.org

http://i.huffpost.com

http://www.thestar.com
2. Basement flooding
• Flood events in Canada
  • Largest property damage of all natural disasters (Burn and Whitfield 2016)

• Basement flooding
  • Largest source of home insurance claims in Canada (IBC 2014a,b; Sandink 2015)
  • $1.8 billion in insured losses for water damage incurred every year (Eleuterio et al. 2013)
  • This trend is increasing
Extreme precipitation events are increasing in frequency and magnitude (Wang et al. 2014).

Urbanization and changes in land-use can increase the extent and damages due to flooding (König et al. 2002).

Greater economic wealth and populations concentrated in urban areas increases damages and vulnerability to flooding (Spekkers 2015).

Long-term sustainability of Canadian stormwater infrastructure is a growing concern (Upadhyaya et al. 2014).
## Economic impact of basement flooding

<table>
<thead>
<tr>
<th>Date</th>
<th>City</th>
<th>Return period of storm</th>
<th>Basement flooding</th>
<th>Insurable damages (in millions of $)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>May, 2000</td>
<td>Toronto, ON</td>
<td>25 to 50 years</td>
<td>&gt; 3000 basement floods</td>
<td>168</td>
</tr>
<tr>
<td>July, 2004</td>
<td>Edmonton, AB</td>
<td>200 years</td>
<td>&gt; 4000 basement floods</td>
<td>199</td>
</tr>
<tr>
<td>June, 2005</td>
<td>Calgary, AB</td>
<td>200 years</td>
<td>Unknown</td>
<td>351</td>
</tr>
<tr>
<td>August, 2005</td>
<td>Toronto, ON</td>
<td>&gt; 100 years</td>
<td>&gt; 12,000 flooded basements</td>
<td>732</td>
</tr>
<tr>
<td>June, 2013</td>
<td>Calgary, AB</td>
<td>100 years</td>
<td>Unknown</td>
<td>1863</td>
</tr>
<tr>
<td>July, 2013</td>
<td>Toronto, ON</td>
<td>&gt; 100 years</td>
<td>&gt; 5000 basement floods</td>
<td>1019</td>
</tr>
</tbody>
</table>

*Source for insurable damages: IBC, 2015

* adjusted to 2014 dollars
Three types of basement flooding

- Basement flooding occurs primarily due to inadequate sanitary and storm sewer systems or insufficient foundation and lot drainage systems (Kesik and Seymour 2003).

- Basement flooding can result from three mechanisms:
  - Overland Flooding
  - Infiltration Flooding
  - Sewer Surcharge
Many factors influence basement flooding vulnerability

- Governance factors:
  - Code interpretation and enforcement
  - By-law and by-law enforcement
  - Planning policies
  - Hydrology
  - Watershed characteristics

- Socio-political factors:
  - Construction practices
  - Economy
  - Public awareness and perception

- Municipal infrastructure:
  - Sewer infrastructure
  - Street storage
  - Stormwater management

- Lot-level infrastructure:
  - Foundation drainage
  - Lot drainage
  - Sewer backup prevention technologies
  - Sewer lateral
Factors affecting basement flooding vulnerability

Socio-political factors

Construction practices
Economy
Public awareness and perception

Affect the public and industry’s approach to the construction and adoption of flood mitigation technologies
Factors affecting basement flooding vulnerability

Governance factors

- Code interpretation and enforcement
- By-law and by-law enforcement
- Building and plumbing code requirements
- Planning policies

Affect decisions, requirements and legal aspects related to the installation of flood mitigation approaches and technologies
Factors affecting basement flooding vulnerability

Environmental factors

- Watershed characteristics
- Hydrology
- Climate change and urbanization

Responsible for the magnitude and frequency of the hydrometeorological events that produce flooding
Factors affecting basement flooding vulnerability

- Sewer infrastructure
- Street storage
- Stormwater management

Systems or approaches that can be applied at the municipal level to manage stormwater and wastewater
Factors affecting basement flooding vulnerability

- Lot drainage
- Sewer lateral
- Sewer backup prevention technologies

Lot-level infrastructure

Technologies or approaches that can be applied to individual homes to reduce the risk of basement flooding
Lot-level approaches to reduce flood risk

Sewer lateral
- Lateral condition (age and deterioration)
- Slope
- Material

Sewer backup prevention technologies
- Sewage ejector system
- Backwater valve

Lot-level infrastructure

Foundation drainage
- Sump pump
- Weeping tile system
- Foundation waterproofing

Lot drainage
- Lot grading
- Splash pads

Infiltration techniques
- Downspout disconnection
Infiltration flooding

- Risk reduced by ensuring perimeter of the building is well-drained (e.g., weeping tile systems) and protecting the foundation wall against moisture (Swinton and Kesik 2008)

- Flood damages can be reduced through foundation drainage, waterproofing and flood proofing systems (Sheaffer et al. 1967)

- Failure potential due to clogging of the weeping tile system, sump pump failure and improper backfilling practice exist
Overland flooding

- Typically occurs where overland flow routes and municipal drainage system are overwhelmed
  - Water enters basements through windows, below-ground openings and foundation cracks

- Lack of pervious surfaces and insufficient lot drainage contribute to the increased risk of overland flooding

- Low impact development (LID) measures, large-scale SWM measures, and increased street storage capacity can reduce the risk of overland flooding

Mitigating strategies

Overland flooding
Low impact development (LID) measures

Impervious surfaces
- Decreased groundwater seepage
- Increased volume and speed of surface runoff

Pervious surfaces
- Increased groundwater seepage
- Decreased volume and speed of surface runoff

Impervious ‘hard’ surfaces (roofs, roads, large areas of pavement, and asphalt parking lots) increase the volume and speed of stormwater runoff. This swift surge of water erodes streambeds, reduces groundwater infiltration, and delivers many pollutants and sediment to downstream waters.

Pervious ‘soft’ surfaces (green roofs, rain gardens, grass paver parking lots, and infiltration trenches) decrease volume and speed of stormwater runoff. The slowed water seeps into the ground, recharges the water table, and filters out many pollutants and sediment before they arrive in downstream waters.

From: http://managingstormwater.blogspot.ca/
Lot-level approaches to reduce flood risk

- Sewer backup prevention technologies
  - Sewage ejector system
  - Backwater valve
Sewer backup

- Arises from overloaded storm or sanitary sewer systems and excessive I/I (inflow and infiltration) contributions

- Sewer backup prevention technologies help stop sewage from backing-up into the home during surcharge events
  - Backwater valves
  - Sewage ejector systems

- Installation and maintenance issues
3. Backwater valve research
Backwater valves

- One lot-side technology to reduce risk of sewer backup is the installation of backwater valves on sewer laterals in individual homes.

- Backwater valves have been in the market for 25 years and are gaining more widespread use in recent years (e.g., ~500,000 Mainline valves installed in Canada since 1998).

- Several backwater valve designs exist in the marketplace today (i.e., Mainline Backflow Products).

Source: http://backwatervalve.com
**Backwater valves**

**Normal operation:**
- **From Home**
- **Built-in drainage slope**
- **To Sewer**
- **Flap in standard position under normal conditions**
- **Clear Top allows for easy inspection**

**During surcharge events:**
- **Flap Floats up to block back flow**
- **Back Flow from Sewer**

**Source:** [http://backwatervalve.com](http://backwatervalve.com)
Backwater valves

- Either installed on individual branch connections in the home or on the main sanitary sewer connection
- Can operate in normally-open or normally-closed positions
- Valves can be physical gates that open and close or be an inflatable technology

Bladder, sensor operated (Aqua-Protec)
ML-FR4 (limited opportunity to appropriately grade valve)
Mainline Open-Port (where grading can be achieved)
Backwater valves

- Gated valves can be hinged from the top or the bottom of the device
- Also suitable for sewer laterals a large distance below basement floor
- May require homeowner maintenance
- Can be installed inside or outside home
## Backwater valves models

<table>
<thead>
<tr>
<th>Model</th>
<th>Manufacturer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fullport</td>
<td>Mainline</td>
<td>• Normally-open allowing for ventilation of gasses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Flap hinge located at the base of valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Clear lid allows for visual inspection of valve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Self-cleaning with built-in slopes</td>
</tr>
<tr>
<td>2. Straight fit</td>
<td>Mainline</td>
<td>• Normally-closed, for in-line installations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Features a flapper that guides cleaning and surveying equipment through the valve</td>
</tr>
<tr>
<td>3. Adapt-a-valve</td>
<td>Mainline</td>
<td>• Normally-closed or normally-open designs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Versatile model that can be adapted to serve several functions (i.e., laterals located deep under basement floor, pressure testing, etc.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Self-cleaning step through design</td>
</tr>
</tbody>
</table>
### Backwater valves models

<table>
<thead>
<tr>
<th>Model</th>
<th>Manufacturer</th>
<th>Description</th>
</tr>
</thead>
</table>
| 4. **Fullport Retrofit** | Mainline             | • Normally-open allowing for ventilation of gasses  
• Gate hinge is located at top of valve for protection from debris accumulation  
• Valve works well at low slopes |
| 5. **Aqua-Protec**       | Inflotrolix           | • Installed and housed in the main drainage cleanout allowing for ventilation of gasses  
• Inflatable balloon with built-in sensors that detect backflow events and trigger balloon to inflate and seal off sewer lateral  
• No retrofitting or demolition work required |
| 6. **Blokker**           | Secureleak Inc.       | • Normally-open allowing for ventilation of gasses  
• Does not have a significant slope through the body permitting easier retrofit installations |
Since the technology is relatively new, several key questions regarding the function and durability of backwater valves have yet to be addressed.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Debris accumulation in valve</td>
<td>• Affects performance over time</td>
</tr>
<tr>
<td></td>
<td>• May affect movement of the valve, formation of the seal, or condition of floats</td>
</tr>
<tr>
<td>2. Suitability of specific backwater valve for situation</td>
<td>• New homes versus retrofit scenarios</td>
</tr>
<tr>
<td></td>
<td>• Particular individual home plumbing and sewer lateral configuration</td>
</tr>
<tr>
<td>3. Installation, retrofit</td>
<td>• Loose, cross-threaded clean-out caps</td>
</tr>
<tr>
<td></td>
<td>• Appropriate grading (e.g., &gt;2%)</td>
</tr>
<tr>
<td>4. Variety of technologies</td>
<td>• Open-port, ML-FR4, adapt-a-valve, etc.</td>
</tr>
<tr>
<td></td>
<td>• Bladder systems, etc.</td>
</tr>
</tbody>
</table>
Addressing these questions will allow for the:

1. Determination of the lifespan of particular backwater valve models
2. Identification of causes of valve failure
3. Assessment of optimal maintenance periods for values
4. Determination of optimal valve models for particular situations
Backwater valves to reduce the risk of basement flooding due to sewer surcharge

• **Debris accumulation** known to affect valve performance over time

• The adjacent pictures show an **unmaintained** Mainline Fullport backwater valve (installed January 2011)

No maintenance had been performed on this valve since installation (January 2011) [pictures taken November 2016]
Backwater valve failure

- Poor valve grading

- Field experience – approx. 25% of values not likely functional (valves ‘stuck’ as a result of oil and grease, grit, dental floss, etc.), flappers had to be pried off the body of valve with a screwdriver

- Most valves, once installed, have never been maintained

Source: photo courtesy Protective Plumbing Canada Inc.
Most valve failures are due to debris build up.

This inhibits the valve from forming a proper seal during a surcharge event.

Periodic maintenance can assist in ensuring valve performance.

### Recent basement flooding events in Canadian cities

<table>
<thead>
<tr>
<th>City</th>
<th>Cause of valve failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamilton</td>
<td>Mechanical failures Low-lying location</td>
</tr>
<tr>
<td>Cambridge</td>
<td>Not reported</td>
</tr>
<tr>
<td>Thunder Bay</td>
<td>Debris build-up Mechanical failures Low-lying location</td>
</tr>
<tr>
<td>London</td>
<td>Debris build-up</td>
</tr>
<tr>
<td>Estevan</td>
<td>Not reported</td>
</tr>
<tr>
<td>Essex</td>
<td>Not reported</td>
</tr>
<tr>
<td>Tecumseh</td>
<td>Debris build-up</td>
</tr>
<tr>
<td>Waterloo</td>
<td>Not reported</td>
</tr>
<tr>
<td>Calgary</td>
<td>Debris build-up</td>
</tr>
<tr>
<td>Edmonton</td>
<td>Mechanical failures</td>
</tr>
</tbody>
</table>
Backwater valves laboratory and computational research

1. Characterization of backwater valve failure
2. Performance evaluation of backwater valves under varying conditions
3. Flow visualization to create computational model

Source: https://sowc.ca

Wastewater laboratory platform in Guelph

Laboratory model to test backwater valve performance
Backwater valve research

Preliminary results

• Dye tests to visualize the flow pattern in the laboratory model are used to validate a computational fluid dynamics (CFD) model.

Flow visualisation of Mainline Fullport valve with gate open 15 degrees

Flow visualisation of Mainline Fullport valve with gate open 10 degrees

Laboratory model used to calibrate CFD model
Backwater valve research

Preliminary results

- CFD model will allow for long-term evaluation of backwater valve performance and failure

CFD backwater valve model results illustrating velocity distribution in the valve with gate failure (i.e., stuck in an open position)
4. Future research direction
GOAL OF RESEARCH
To evaluate the performance of various technologies and approaches to reduce the risk of occurrences of basement flooding and develop a more comprehensive understanding of the risk of basement flooding in Canadian cities.

OVERLAND FLOODING

INfiltration

SEWER SURCHARGE
Initial focus

To be pursued over 2017-2021 with a NSERC Collaborative Research & Development 4-year grant.
GOAL OF RESEARCH:
To evaluate the performance of various technologies and approaches to reduce the risk of occurrences of basement flooding and develop a more comprehensive understanding of the risk of basement flooding in Canadian cities

• To accomplish this goal the following specific objectives will be pursued:

1. Investigate the performance of backwater valves to reduce the risk of basement flooding due to sewer surcharge

2. Evaluate the effect of alternative low impact development measures on improved urban drainage and sewer network response to extreme events

From: https://www.tatukgis.com
Future research direction

a) Backwater valves to reduce the risk of basement flooding due to sewer surcharge

• Characterization of backwater valve failure

• Performance evaluation of backwater valves under varying conditions

Applying laboratory and computational methods

Source: https://sowc.ca
• Characterization of backwater valve performance under different closure conditions
  • Laboratory tests
  • Flow visualization
  • Reasons for valve failure

• Computational fluid dynamics (CFD) modeling to extend range of scenarios and investigated long-term effects
  • Impact of partial blockages for debris build-up conditions

Source: https://sowc.ca
### Examples of backwater flow scenarios

<table>
<thead>
<tr>
<th>Flow</th>
<th>Valve condition</th>
<th>Lateral slope</th>
<th>Lateral condition</th>
<th>Wastewater material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal flow</td>
<td>Normal (well-maintained)</td>
<td>Recommended grade (2%)</td>
<td>Ideal condition of lateral pipe</td>
<td>Normal domestic grey and black water</td>
</tr>
<tr>
<td>Sloshing effect</td>
<td>Un-maintained (i.e., presence of biofilm)</td>
<td>Steep grade (&gt;2%)</td>
<td>Root blockages</td>
<td>Presence of brine from water softener</td>
</tr>
<tr>
<td>Hydraulic high pressure jet flow (i.e., sewer flushing)</td>
<td>Improperly maintained (i.e., improperly screwed on clean-out)</td>
<td></td>
<td></td>
<td>Presence of non-disposable materials (i.e., baby wipes, Q-tips, etc.)</td>
</tr>
<tr>
<td></td>
<td>Dried out (after prolonged period of non-use)</td>
<td>Reverse grade</td>
<td></td>
<td>Presence of excessive cooking materials (i.e., cooking oils)</td>
</tr>
</tbody>
</table>

CFD modeling allows for testing of many different scenarios.
Future research direction

Schematic of backwater valve apparatus

Constructed backwater valve laboratory apparatus
Future research direction

- Interchangeable backwater valve on the “sewer lateral”
- Option to vary the lateral slope
- Reversible valve to simulate surcharge event

Head tanks to mix grey and black water recipes
b) Effect of low impact development on improved urban drainage and sewer network response

- Urban drainage and sewer network response to extreme events
- Effect of LID measures on reducing loading on sewer infrastructure

Source: http://www.nerc.ac.uk
Significance and benefit to Canada

- **Results from this research will:**
  1. Provide guidance to improve *guidelines* for installation of backwater valves and *O&M strategies*
  2. Provide *insurance industry* with technical recommendations to develop appropriate policy
  3. Provide *homeowners* with greater information to implement lot-level measures to reduce risk of water damage due to basement flooding during surcharge events
  4. Develop a *risk assessment tool* to assist municipalities in developing mitigation strategies for locations sensitive to basement flooding
References


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