Evidence-Based Policy, Programs and Design Standards in Municipal Engineering to Adapt to Extreme Weather and Climate Change

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Outline

• **Data-driven, Evidence-based Risk Management:**
  - Policy, Programs, Priorities for Remediation
  - Design Practices & Resiliency for New Development

• **Responding to Non-technical Reports & Media**

• **Quantifying Risk Factors and Design Practice Adaptation**
  - Hydrology – intensification, return period safety factors
  - Meteorology – critical hyetographs selection, past IDF trends & climate change projections (safety factors & stress tests)

• **Stress Tests for System Resiliency Future IDF**
  - PCSWMM minor and major system hydrologic/hydraulic assessment
  - InfoWorks sanitary surcharge / basement back-up assessment

• **Adaptation Measures (municipal & private)**
History of Flooding & Known Design Limitations Drive Policy, Programs and Priorities for Risk Reduction
West Thornhill – August 19, 2005 (> 100 year)
Where Priorities for Risk Mitigation?

Potentially Limited Design Standards Pre-1980’s:
- no overland flow routes
- high sanitary I&I
- floodplain encroachment
What Are Program Level of Service Targets?

- Class EA Initiated
  - 5+ Year Private Channel

- Future Class EA
  - 100 Year Storm Sewer System
  - Upgrades With Capital Works (Roads)

- Class EA Complete
- 100 Year Storm Sewer System
- Construction Ongoing

- Future Class EA
  - 100 Year Storm Sewer System
  - Special Policy Area for River Flooding

Hazel storm (non–IDF) may govern

West Thornhill
Don Mills Channel
Unionville
Markham Village
Various 2005 Flooding Types in Pre-1980 Areas

- Storm Flooding
- Sanitary Flooding
- Unknown
- Riverine
Pre – 1960 Standards

- Uncontrolled Inflows
- Partially Separated High I&I
- Enclosed / Encroached

Post -1980 Standards

- 100 Year Dual Drainage
- Fully Separated Low I&I
- Preserved

Post 1980 design standards limit flood risks (storm, sanitary, & riverine)
Post-1980’s Design Standards Are Effective

Flood Count and Density by Construction Era
(normalized by number of buildings)

Pre 80’s: 1% Flooded

Post 80: 0.1% Flooded

New areas are resilient so focus on priority old areas
Quantitative methods are required to identify specific local risks and remediation.
Responding to Non-Technical Reports & Media
Media & Government Data Gaps

- Operational issues mis-characterized as a climate change-induced event.
- Reported “unprecedented” conditions contradict past data & reports.

July 8, 2013
Stranded GO Train
Don River

Less than
5 Year Flow

May 28, 2013
Greater Flood Weeks Before
Operational Risk Overlooked

… or Data?

Address existing
operational
risks first!

Insurance Industry Data Gaps

Confused arbitrary prediction with real observed trend data

Telling the Weather Story - Gordon McBean - Empire Club presentation - YouTube
Comparing Data Facts With “Alternative Facts”

Environment Can. Intensity Decrease (statistically significant over 6 - 24 hrs, 2x as common as increases in S. Ontario)

Data-driven analysis needed for design

IBC “Weather Story” Intensity Increase

IBC “Weather Story” Intensity Increase

Environment Can. Intensity Decrease

Environment Can. Intensity Increase
Economic Growth Ignored in Damage-Cost Data

**Catastrophic losses are up but ...**

* Losses normalized by net written premiums peaked in ‘98

New standards have reduced risk profile & losses

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**Catastrophic Losses in Canada (in CAD billion)**

- Loss + Loss Adjustment Expenses in 2014 dollars
- Estimated Trend Line

<table>
<thead>
<tr>
<th>Year</th>
<th>Catastrophic Losses</th>
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<tr>
<td>1983</td>
<td>0.05</td>
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<td>1985</td>
<td>0.15</td>
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<td>1993</td>
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<td>2013</td>
<td>1.55</td>
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<tr>
<td>2014</td>
<td>1.60</td>
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**Loss / NWP**


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**Talking points may ignore data**

**link:** Net Written Premiums to 2015

**link:** NWP 1990-1991

**link:** http://www.cityfloodmap.com/2016/12/book-review-rightful-place-of-science.html
Quantifying Risk Factors and Design Practice Adaptation

Markham Imperviousness Trends

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>1952</td>
<td>32%</td>
</tr>
<tr>
<td>1971</td>
<td>45%</td>
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<tr>
<td>1981</td>
<td>56%</td>
</tr>
<tr>
<td>2002</td>
<td>70%</td>
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Rational Method Peak “Instant” Flow

\[ Q = k \cdot C \cdot i \cdot A \]

- **C** values required updates based on densities
- **i** values did not require updates for current IDF
- **Q** may require “stress test” for some future IDF
- **Return Period Factor** for extreme storms increases resiliency / conservatism for extreme events
Rational Peak Safety Factor

\[ Q_{\text{Peak Flow}} = C \cdot \alpha \cdot i \cdot A \]

Add Return Period Factor (+ 25% for 100 year)

Increase Residential C from 0.5 to 0.7

Keep higher, older Toronto IDF rate of 275 vs 219
Local IDF at Buttonville

Return period factor, higher C, and old higher rain intensity
adds 120% to old standards and local IDF approach (new resilient systems).

New:

\[ Q_{100 \text{ resid.}} = 1.25 \times 0.70 \times 275 \times 1.0 = 240.6 \text{ L/s} \]

Old:

\[ Q_{100 \text{ resid.}} = 1.0 \times 0.50 \times 219 \times 1.0 = 109.6 \text{ L/s} \]
IDF Trends – Lower in Southern Ontario (Safety Factor)

- As annual maximum values trend lower, extreme IDF intensities decrease as well.

- Toronto City “Bloor Street” trends are lower for all durations and for all return periods.

- Design standard IDF is conservative.

<table>
<thead>
<tr>
<th>Return Period (Years)</th>
<th>5 Minute Rainfall Intensity (mm/hr)</th>
<th>Change in Rainfall Intensity</th>
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<tr>
<td>2</td>
<td>113.9</td>
<td>110.8</td>
</tr>
<tr>
<td>5</td>
<td>159.4</td>
<td>154.4</td>
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<tr>
<td>10</td>
<td>189.6</td>
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<td>25</td>
<td>227.7</td>
<td>219.8</td>
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<td>50</td>
<td>256</td>
<td>246.8</td>
</tr>
<tr>
<td>100</td>
<td>284</td>
<td>273.7</td>
</tr>
</tbody>
</table>

| Overall:              | -5.0%                                      |                              |

Source:
Environment Canada Engineering Climate Dataset
Up to 2007 per Dataset v2.3, to 2003 per Dataset v1, to 1990 per hardcopy records
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5 Minute 100-Year Intensity Past Trends / Safety Factors

- Observed

Bloor Street (Toronto)
- Markham IDF is based on old Toronto IDF
- GTA IDF values now dropped below std.
- Markham Design Standard
- R² = 0.8844

Pearson Airport (Mississauga)
- Local IDF values lower than standard & declining
- R² = 0.9958

Buttonville Airport (Markham)
- Today’s Safety Factors: 2 to 26%
Design IDF May be Above or Below Future IDF Depending on the Scenario Before Return Period Factor Applied

- Design IDF values are above local IDF values.
- Design IDF above UofW RCP 4.5 & below UofR A1B values.
- Factored design IDF values can exceed future IDF for shortest durations (adds resiliency).
Simulation Flow Time Series

\[ Q(t) : \text{Land Use / Soil} \leftarrow \text{transformation} \ \text{Hyetograph} \]

Hydrograph : Catchment Parameters \leftarrow Rain Pattern

Wet Weather : Groundwater & Inflow Response \leftarrow Rain Pattern / Vol.
Flow (‘black box’)

- **Runoff parameters** based on soil & development
- **Rain pattern** may be conservative or unconservative & require review, and/or updates for current IDF
- **Q(t)** may require “stress test” for future IDF especially where hyetograph is unconservative or where safety factors for resiliency are not incorporated in the infrastructure system
Some Hyetographs Have ‘Risk Gap’ For Flashy Urban Areas

- IDF data show some watershed storms do not reach the short duration design intensities.
- Markham 3hr AES* storm is conservative (above IDF values).

“100-year” can have less than 2-year intensity – urban application needs review.
Stress Tests for System Resiliency
Future IDF
Storm & Sanitary Sewer Systems
Short Duration Rain Intensity Adaptation Requirements

Test systems for scenarios above standards (future IDF +20 to 30 % < 2 hrs)

Markham Design Standard

R² = 0.8844

Pearson Airport (Mississauga)

Buttonville Airport (Markham)

Low risk with existing standards = no adaptation required. Design resilient for future IDF (8 to 17 %)

Future Safety Factors

Stress Test

Bloor Street (Toronto)

U of W RCP 4.5

CCDP Markham Grid A1B 50%

U of W RCP 4.5

Hyetographs Intensities Above & Below Future IDF (< 2hrs) (systems have safety factors or require stress test)

- Markham 3hr AES design storm intensities above above UofW RCP 4.5, below UofR A1B values.
- Other study design storm intensities may underestimate short duration intensities.

![Graph showing rainfall intensities and safety factors](image-url)

- Stress Test for U of R A1B 50%
- Safety Factor for U of W RCP 8.5
- Acceptable for Small Urban Areas?
Future IDF ‘Stress Test’ – Minor & Major Storm System (PCSWMM)

- Evaluate worst case +20% U. of R. A1B 50% 2065-2095 avg. shift over 2Hrs.
- Markham 3-hr AES (base intensities > local IDF values by 29% over 2 hrs).
- Assume existing hydrology parameters.
- Inlet capture devices in 50%+ of CBs limit minor system flow impacts.
- Unsteady, gradually varied flow model (PCSWMM).
- Storm system HGL exceeds freeboard of 0.5 m to reach lowest basement elevation.
Future IDF ‘Stress Test’ – Sanitary Sewer System (InfoWorks)

- Evaluate worst case +30% U. of R. A1B 50% 2065-2095 avg. shift over 2Hrs.
- **Chicago** (per Master Plan base intensities > local IDF values by 22% over 2 hrs).
- Use calibrated/monitored values.
- Apply existing calibrated parameters for inflow and infiltration response.
- Dynamic / gradually varied flow model (InfoWorks).
- Sanitary system HGL less than 2.0 m below grade (near basement elevations).

Baseline Performance

- 7.4% surcharged pipes.
- 1.8% MH’s less than 2.0 m of freeboard with sanitary basement back-up risk.

Future Performance

- 12.1% surcharged pipes.
- 3.5% MH’s less than 2.0 m of freeboard with back-up risk +1.7% IDF impact.

- Damages / Risk – Assess Need for Adaptation
- Hydraulic Performance / Freeboard
- I&I Transformation (Extraneous Flow)
- Dry Weather Sanitary Flow
- Hyetograph Pattern
- IDF Data
Conclusions

• **System vulnerability varies with design standards:**
  - Current standards have significantly decreased extreme weather risk (riverine, storm, and sanitary systems).
  - Historical land use practices with limited design standards drive specific, local remediation priorities.
  - Riverine flood risks not readily addressed (Special Policy)

• **Design practice adaptation adds resiliency**
  - Hydrology – higher runoff coefficients and return period factors
  - Meteorology – conservative hyetographs selection for urban areas

• **Stress tests demonstrate system resiliency for those future IDF scenarios above design standard intensities**
  - Negligible minor and major system impacts where common ICDs are in place (limit minor systems capture, use major freeboard)
  - Sanitary surcharge / basement back-up assessment shows negligible change in surcharge in system with future IDF
Conclusions

• Adaptation Measures (municipal & private)

  • Cost effective / timely:
    – Sanitary downspout disconnection
    – Sanitary manhole sealing
    – Storm ICDs
    – Commercial flood-proofing, Special Policies
    – Minor system upgrades

  • Costly / partially effective or ineffective
    – Floodplain system upgrades
    – Catchment-wide green infrastructure (cost constraint)
    – On-site runoff over-control (timing constraint)
Thank You

Questions ?