Assessment of climate change induced flood risk to buildings
City of London case study

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ICLR and the University of Western Ontario
Background

- City of London supported project: *Assessment of infrastructure vulnerability to climate change*
- Interdisciplinary team:
  - Slobodan P. Simonovic, Professor (UWO, ICLR)
  - Donald H. Burn, Professor (UW)
  - Dan Sandink, Manager (ICLR)
  - Hyung-Il Eum, PostDoctoral Fellow (UWO)
  - Angela Peck, MESc candidate (UWO)
  - Lisa Bowering, MESc candidate (UWO)
  - Dragan Sredojevic, MESc (UWO).
Key Messages

• Urban environments and infrastructure are vulnerable to climate change
• Adaptation cost can be very high
• Adaptation = Risk management
• Comprehensive risk assessment methodology is required to gather and examine available data in order to develop an understanding of the relevant climate effects and their interactions with municipal infrastructure
• Time to act is now
Presentation Outline

• Methodology for the assessment of climate change induced flood risk
  – Climate modeling
  – Hydrologic modeling
  – Hydraulic modeling
  – Risk assessment
• Case study – London, ON
• Conclusions
Methodology
Risk Assessment

Hazard Analysis

Climate Modelling
Output: precipitation for four climate scenarios

Hydrologic Modelling
Output: streamflows

Hydraulic Modelling
Output: water surface profiles for climate scenarios

Risk Assessment

Risk Index Calculation
Output: climate change flood risk indices for all infrastructure

Infrastructure Ranking
Output: risk maps showing the locations of high risk areas; prioritized areas of high risk
Methodology

• Hazard Analysis
Risk Assessment

Hazard Analysis

Climate Modelling
Output: precipitation for four climate scenarios

Hydrologic Modelling
Output: streamflows

Hydraulic Modelling
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Risk Assessment

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Output: climate change flood risk indices for all infrastructure

Infrastructure Ranking
Output: risk maps showing the locations of high risk areas; prioritized areas of high risk
Climate Scenarios

- Lower bound climate scenario
  - The lowest extent of change
  - Historical data, GCM and weather generator

- Upper bound climate scenario
  - The highest extent of change
  - Historical data, GCM and weather generator
Choice of GCM

![Graph of Pmean (2050s) showing precipitation (mm) over time with different GCM models.]
Weather Generator
Risk Assessment

Hazard Analysis

- Climate Modelling
  Output: precipitation for four climate scenarios

- Hydrologic Modelling
  Output: streamflows

- Hydraulic Modelling
  Output: water surface profiles for climate scenarios

Risk Assessment

- Risk Index Calculation
  Output: climate change flood risk indices for all infrastructure

- Infrastructure Ranking
  Output: risk maps showing the locations of high risk areas; prioritized areas of high risk
Hydrologic Modelling

- Modification of HEC-HMS
- Nesting of sub-basins
  - Medway (5 sub-basins)
  - Stoney (6 sub-basins)
  - Pottersburg (4 sub-basins)
  - Dingman (16 sub-basins)
Hydrologic Modelling

• Two hydrologic scenarios
  – 100 year return period
  – 250 year return period
Risk Assessment

Hazard Analysis

- Climate Modelling
  Output: precipitation for four climate scenarios

- Hydrologic Modelling
  Output: streamflows

- Hydraulic Modelling
  Output: water surface profiles for climate scenarios

Risk Assessment

- Risk Index Calculation
  Output: climate change flood risk indices for all infrastructure

- Infrastructure Ranking
  Output: risk maps showing the locations of high risk areas; prioritized areas of high risk
Hydraulic Modelling

- HEC-RAS and HEC-GeoRAS
- Input: Streamflows from hydrologic model
- Output: floodplains to represent flood extent and depth for use in risk analysis
Hydraulic Modelling
Methodology

• Risk Assessment
Risk Assessment Methodology

Probability of Hazard $\times \sum [\text{Monetary Value} \times \text{Consequence}]$
Data Collection

Buildings
  – City
  – Commercial, industrial, institutional, residential
  – More than 120,000

Stage-Damage Curves
  – Ministry of Natural Resources
  – Research

Economic Data
  – Municipal Property Assessment Corporation
  – City
Spatial Data
## Infrastructure Flood Impact

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Potential Flood Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>Structure, contents, evacuation</td>
</tr>
<tr>
<td>Critical Facilities</td>
<td>Structure, equipment/contents, delay in service, evacuation</td>
</tr>
</tbody>
</table>
Risk Index Calculation

Probability of Hazard $\times \Sigma [\text{Monetary Value} \times \text{Consequence}]$
Risk Index Calculation

**Probability** - The likelihood that a particular flood event will occur in a given year

1:100yr 1:100yr 1:250yr 1:250yr
Risk Index Calculation

**Probability of Hazard x Σ[Monetary Value x Consequence]**
Risk Index Calculation

Flood Consequence Multipliers

Loss of Function (IM₁)

Loss of Equipment (IM₂)

Loss of Structure (IM₃)
Risk Index Calculation

Identify inundated buildings
Risk Index Calculation

Stage-Damage Curves

Single-storey with basement

(after Waters Edge, 2007)
Risk Index Calculation

Deterministic (quantitative) and fuzzy (qualitative) damage measures are combined to describe loss of structure ($IM_3$)

$$IM_3(CM) = \begin{cases} 1, & CM = 0 \\ \min \left(1, LS \times \frac{1}{CM}\right), & CM > 0 \end{cases}$$
Risk Index Calculation

Probability of Hazard x Σ[Monetary Value x Consequence]
Risk Index Calculation

Monetary Value

The dollar value associated to a particular building as a result of flooding

\[ D_1 \quad D_2 \quad D_3 \]
Risk Index Calculation

Probability of Hazard \times \Sigma \text{[Monetary Value x Consequence]}
Risk Index Calculation

\[ R_{ke} = P \times \sum_{i=1}^{3} (D_{ike} \times IM_{ike}) \]

- \( R_{ke} \) = risk index
- \( P \) = probability
- \( D \) = monetary value
- \( IM \) = impact multiplier

\( k \) = building type
\( e \) = building element
\( i \) = impact category
Results

Probability of Hazard $\times \sum [\text{Monetary Value} \times \text{Consequence}]$
Results

• Table and map for each of the 4 climate scenarios + 1 for the current state:
  100 CC_LB    250 CC_LB    250 UTRCA
  100 CC UB    250 CC UB

• Areas of high risk within each scenario individually
## Results

### Infrastructure affected

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Area (km²)</th>
<th>Buildings</th>
<th>Critical Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 CC_LB</td>
<td>22.95</td>
<td>1110</td>
<td>3</td>
</tr>
<tr>
<td>100 CC_UB</td>
<td>25.79</td>
<td>2535</td>
<td>6</td>
</tr>
<tr>
<td>250 CC_LB</td>
<td>25.95</td>
<td>2517</td>
<td>6</td>
</tr>
<tr>
<td>250 CC_UB</td>
<td>27.87</td>
<td>2706</td>
<td>6</td>
</tr>
<tr>
<td>250 UTRCA</td>
<td>24.56</td>
<td>1762</td>
<td>3</td>
</tr>
</tbody>
</table>
100 CC_LB Scenario

<table>
<thead>
<tr>
<th>Cell</th>
<th>DA</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3</td>
<td>0326</td>
<td>0.17</td>
</tr>
<tr>
<td>C3/C4</td>
<td>0550</td>
<td>0.28</td>
</tr>
<tr>
<td>B3/B4</td>
<td>0677</td>
<td>0.49</td>
</tr>
</tbody>
</table>

May 26, 2011  ICLR-Basement Flooding
Results

100 CC_LB scenario

Case 2 - 100 CC_LB Scenario
Buildings

DA 0035
2\textsuperscript{nd} highest risk
Broughdale dyke

DA 0092
Highest risk
Pottersburg Creek culvert

DA 0890
3\textsuperscript{rd} highest risk
The Coves

May 26, 2011
ICLR-Basement Flooding
Results

100 CC_UB scenario
Results
250 CC_LB scenario
Results

250 CC_UB scenario

Case 2 - 250 CC_UB Scenario
Buildings
Comparison Analyses

Five analyses:

(1) Climate change impact
   250 UTRCA vs. 250 CC_UB

(2) CC uncertainty - comparison of 100 year climate events
   100 CC_LB vs. 100 CC_UB

(3) CC uncertainty - comparison of 250 year climate events
   250 CC_LB vs. 250 CC_UB

(4) Regulatory flood - comparison of lower bound scenarios
   100 CC_LB vs. 250 CC_LB

(5) Regulatory flood - comparison of upper bound scenarios
   100 CC_UB vs. 250 CC_UB
Comparison Analyses
Areas of interest include:

- **Cells B5/C4**: Along Pottersburg Creek, north of Trafalgar to the airport
- **Cell C3**: Forks of Thames River
- **Cells E3/E4 & D4/D5**: Dingman Creek
Comparison Analyses
Comparison Analyses
Comparison Analyses
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Resources

www.slobodansimonovic.com

Research -> FIDS -> Projects