More flood than meets the eye:  
The role of groundwater in the June 2013 Alberta floods

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ICLR Webinar
Outline

1. Surface water and groundwater
2. Floods
3. June 2013 flood
4. Study area: Calgary
5. Study methodology and results
6. Conclusions
7. Moving forward
Surface water & Groundwater
Surface water

• Water that collects on the surface of the ground
  • River, lake, wetlands

• Overland or riverine flooding
  • Occurs when river breaches banks

Groundwater

• “Underground” water stored in pores and void space in rock and sediment

http://geologylearn.blogspot.com/2015/03/sandstone.html
Groundwater: RCAA

- **Alluvial**: river-deposited
- **Aquifer**: high hydraulic conductivity (permeability)
- **River-connected**: exchange between river and groundwater in the alluvial aquifer
Groundwater: RCAA

- River-connected Alluvial Aquifers
  - Water exchange between GW in AA and river (SW)
  - Sub-parallel GW flow to river movement

*Figure 4:* Time series of groundwater elevation in piezometers #27 (masl) and estimated relative Bow River stage at Canmore between 2002 and 2012.

Modified from Kendall, 2017
Measuring groundwater

- Confined aquifer
- Unconfined aquifer
- Aquitard

https://water.usgs.gov/edu/earthgwwells.html


http://www.walterbeantrail.ca/groundwater.htm
Confined and Unconfined Aquifers

- Groundwater is measured as a hydraulic head, \( h \)
- \( h = z + \psi \)
  - Function of elevation and pressure head
- Groundwater moves from high head \( \rightarrow \) low head

Freeze and Cherry, 1979
Unconfined aquifers and elevation

- Aquifers are said to be **discharging** when they **lose** water
- Aquifers are said to be **recharging** when they **gain** water
Groundwater storage

- Ground is stored in pore space
- Storage refers to how much water can be kept in an aquifer
  
Storage, storativity, specific storage

- GW flooding occurs when:
  - Aquifer recharge with low storage
  - Decrease in pumping
  - Propagation of river into aquifer

![Water-table drawdown and recovery after pumping](https://kyocp.files.wordpress.com/2012/08/untitled5.png)
Bow River RCAA in Calgary

Legend

- Bow River Alluvial Area
- City Sampling Locations

Cantafio, 2012
Floods
Floods 101: magnitude and frequency

Flow (Q)

rare

often

Frequency
Floods 101: magnitude and frequency
Floods 101: magnitude and frequency

\[ T = \frac{N}{m} \]

where \( T \) = Recurrence interval
\( N \) = # of years of record
\( m \) = magnitude (rank in series)
Flood Hazard Area: The flood hazard area is typically divided into floodway and flood fringe zones and may also include areas of overland flow.

Floodway: The portion of the flood hazard area where flows are deepest, fastest and most destructive. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. New development is discouraged in the floodway.

Flood Fringe: The portion of the flood hazard area outside of the floodway. Water in the flood fringe is generally shallower and flows more slowly than in the floodway. New development in the flood fringe may be permitted in some communities and should be flood proofed.

Overland Flow: Areas of overland flow are part of the flood hazard area outside of the floodway, and are typically considered special areas of the flood fringe.
Groundwater Flood Hazard Area: Region where basement flooding by groundwater inundation is likely to occur.
Accepted flooding mechanisms
Accepted flooding mechanisms

- Flood Hazard Area
- Flood Fringe
- Floodway
- Normal River Level
- Flood Proofed Building

**NOT!**
“Groundwater flooding is poorly understood, often confused with surface water flooding, and has not been widely recognized as a problem, either in the UK or internationally.” - Hughes et al., 2011

Flood risk from groundwater: Examples from a Chalk catchment in southern England, JFRM 4(3):143-155
June 2013 Flood
Canada & Alberta

- Canmore
- Calgary
- High River
- Bragg Creek
- High River
Canmore
Bragg Creek
High River
### Calgary

![Map of Calgary and its rivers](image)

<table>
<thead>
<tr>
<th>River</th>
<th>Mean seasonal flow (m³/s)</th>
<th>2013 peak flow (m³/s)</th>
<th>Factor increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bow</td>
<td>300</td>
<td>2,400</td>
<td>8x</td>
</tr>
<tr>
<td>Elbow</td>
<td>103</td>
<td>1,240</td>
<td>12x</td>
</tr>
</tbody>
</table>
Calgary: Bow River
Calgary: Downtown
Calgary Stampede
Calgary Zoo

The City of Calgary Faced $2.2 Billion in Development Costs due to the downtown area flooding in 2013. The flood resulted in:
- $1.8 Billion in lost City employee productivity
- $1.4 Billion lost City services to Calgarians

The Calgary Zoo suffered $50 Million in damages from the flood.
Elbow River
Elbow River

www.newinfills.ca/wp-content/uploads/2013/06/Calgary-Floods.jpg
Study Area: Hydrograph

Recorded Flows on Elbow River (Below Glenmore Dam)

City of Calgary, Water Resources
Hydrograph showing precipitation (mm) and Elbow River stage (m) measured upstream of study area below Glenmore Reservoir.
Study Area: Elbow River
Study area: DEM of Study Area
Cross-section of Bow River

Modified from Kendall, 2017
Our Study
Study area: Elbow River

Outline of the city of Calgary (left) and study area (right). Stippled patterning shows alluvial aquifer, gray area delimits 100-year flood zone, and dotted areas show alluvial aquifer above 100-year flood zone,
Methodology

• Survey instrument
• Door-knocking: in-person interviews and online surveys
• Airphoto analysis

• Survey analyses were compiled
• Data analyzed based on geospatial analysis of flooded area
## Survey Results

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of Respondents</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asked to Participate</td>
<td>~680</td>
<td></td>
</tr>
<tr>
<td>Direct Refusals</td>
<td>~3</td>
<td></td>
</tr>
<tr>
<td>Respondents</td>
<td>189</td>
<td>100</td>
</tr>
<tr>
<td>Not Flooded</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>GW Flooding Only</td>
<td>23</td>
<td>12</td>
</tr>
<tr>
<td>GW and Overland Flooding</td>
<td>159</td>
<td>84</td>
</tr>
</tbody>
</table>
Bar graph showing (a) initial route of floodwater entry as reported by residents. Routes are divided by those representing direct groundwater infiltration (black), infiltration via connections to wastewater system (grey), and overland flooding (white). Graph (b) describes floodwater characteristics within the homes.
Initial route of floodwater entry. Basement, or groundwater, flooding was determined by entry through sump pump, floor drain, toilet, sinks, cracks in the wall/foundation.
Plot showing mean values and confidence intervals for basement floor elevations in dry homes and homes flooded by basement or basement and overland water. Basement floor elevation was calculated by subtracting the basement depth below grade from the DEM-derived ground elevation. Lines indicate 95% confidence interval.
Role of Basement Elevation

Cost of damage and flood water height from the homes that were only basement flooded versus the basement floor elevation. Reported \( R^2 \) values are for relationships.
First-pass GW Modelling

https://upload.wikimedia.org/wikipedia/commons/thumb/8/80/MODFLOW_3D_grid.png/300px-MODFLOW_3D_grid.png
First-pass GW Modelling

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First-pass GW Modelling
First-pass GW Modelling
First-pass GW Modelling

Baseflow conditions
First-pass GW Modelling

Baseflow conditions

Peak GW flooding conditions
GW Modelling Results
Sewage infrastructure

ICLR, Basement Flooding
Sewage Infrastructure in GW flooding

- Carries GW flooding to areas beyond typical overland and groundwater flooding zones
- Acts as conduits, exacerbating the problem to areas beyond
- GW flooding masked as sewage backup because of leaky infrastructure
Study conclusions

- GW flooding can cause significant damage in the absence of SW flooding
- Basement floor elevation is relevant to the degree and severity of flood damage
- Sewage infrastructure can carry floodwaters beyond areas of SW and GW flooding
- Groundwater modelling shows that river propagation into the aquifer could have caused the observed groundwater flooding in homes
Moving forward
Cost and Insurance

• One of every two dollars paid by home insurers are for damages caused by water
  • This represents $500 million per year
Solution to GW flooding?

• Limit basement depths based on GW flooding levels
Cost-effective monitoring system

- Groundwater monitoring wells
- Piezometers
- ~ $5000
Cost-effective monitoring system

• Groundwater monitoring wells
• Piezometers
• ~ $5000

+ empty basements

+ no utilities in basement
Solution to GW flooding?
Monitoring GW: Canmore

• Installed GW monitoring wells in RCAA
• Measure aquifer response to river stage
• Better understand GW levels in the context of river stage and flood recurrence intervals
• Industry can insure based on basement floor elevation
Flood Forecasting & Warning Measures

• “... involves education of the public”

• “Economic benefit of a warning system is limited by river [aquifer] response”

• “Emergency evacuation, flood fighting such as sandbagging and emergency relief services.”
Proposed Mitigation for Calgary

- Flood diversion tunnel
- McLean Creek Dam
- Springbank Dry Dam
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  • Jasper Candel (WU)

• Elbow River Residents
Read all about it!

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Original Article

Groundwater flooding in a river-connected alluvial aquifer

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