Are We Prepared?
Modelling Community Preparation and Response to Dam Failures and Tsunami

Presented by:
Bill Johnstone, Ph.D., P.Eng.
Spatial Vision Group, Inc.
North Vancouver, BC
<table>
<thead>
<tr>
<th>Event</th>
<th>Hazard Type</th>
<th>Year</th>
<th>Loss of Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halifax, NS</td>
<td>Explosion</td>
<td>1917</td>
<td>1,950+</td>
</tr>
<tr>
<td>St. Francis Dam, USA</td>
<td>Dam Failure</td>
<td>1920</td>
<td>450+</td>
</tr>
<tr>
<td>North Sea, Holland &amp; UK</td>
<td>Storm surge</td>
<td>1953</td>
<td>2,200</td>
</tr>
<tr>
<td>Malpasset Dam, France</td>
<td>Dam Failure</td>
<td>1959</td>
<td>450+</td>
</tr>
<tr>
<td>Bhopal, India</td>
<td>Chemical</td>
<td>1984</td>
<td>15,000</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>Tsunami</td>
<td>2004</td>
<td>283,000+</td>
</tr>
<tr>
<td>State of Victoria, Australia</td>
<td>Interface Fires</td>
<td>2009</td>
<td>141</td>
</tr>
<tr>
<td>Great Tohoku, Japan</td>
<td>Tsunami</td>
<td>2011</td>
<td>15,900+</td>
</tr>
<tr>
<td>Lac Mégantic, QC</td>
<td>Rail accident</td>
<td>2013</td>
<td>57</td>
</tr>
<tr>
<td>Haiyan, Philippines</td>
<td>Typhoon</td>
<td>2013</td>
<td>~6,166</td>
</tr>
<tr>
<td>Oso, Washington State</td>
<td>Mudslide</td>
<td>2014</td>
<td>41</td>
</tr>
<tr>
<td>Badakhshan, Afghanistan</td>
<td>Mudslide</td>
<td>2014</td>
<td>~500 to 2,000</td>
</tr>
</tbody>
</table>

Are We Prepared?
Worldwide Economic Losses for Disasters: Total & Insured (1950 to 2005) (Munich Re 2005)
Hazards in British Columbia, Risk and Emergency Planning Questions

Examples of Hazard Exposures in BC:

**Natural Hazards:**
- Earthquake
- Tsunami
- Landslide
- Urban-Wildland Interface Fire
- Extreme Rainfall / Flash Flood
- Volcanic Eruption and Lahar

**Technological Hazards:**
- Industrial Accident
- Dam Failure
- Dike Failure
- Spill / Release of materials

**Questions:**

1. Hazards:
   a) What can go wrong?
   b) Event probability?

2. Vulnerabilities / Consequences?
   a) People
   b) Economy
   c) Environment

3. Planning / Mitigation:
   a) What can be done?
   b) How do you know your plan will work?

Are We Prepared?
Modelling Hazards, Vulnerabilities, Consequences and Community Protection
Rapid-Onset, High-Intensity Hazards

Hazard Intensity

- Extreme
  - Bolide
  - Volcanic Eruption
  - Tunnel Fire
  - Earthquake

- High
  - Pandemic
  - Hurricane / Cyclone
  - Dam Failure
  - Volcanic Lahar
  - Levee Failure

- Low
  - River Flood
  - Interface Fire

Onset Speed

- Slow
- Rapid
- Extreme

Research Scope

No or minimal Life Safety Hazard

Are We Prepared?
The Disaster Cycle

MITIGATION / PREVENTION

Reconstruction

Restoration

Response / PREPARATION

Emergency

Pre-impact

After the Event

Before the Event

Recovery

Quiescence

Impact

Are We Prepared?
Thinking About the Problem: How Do We Know Our Plans Can Work?

Community Protection System (CPS)
Services: e.g., Mitigate, Adapt, Prevent, Prepare, Monitor, Abate, Control, Evacuate, Shelter, Recover

Hazard (HAZ)
hazard plume progresses in space and time

Vulnerabilities (VUL)
Population at Risk (PAR)
Critical Infrastructure (CI)
Social Infrastructure (SI)
Economy
Environment

Key
- Control, Communications & Services
- Hazard
- Consequences

Consequences
- Loss of Life, Injuries
- Economic & Infrastructure Loss
- Environmental Loss

Are We Prepared?
Integrated Approach to Reducing Impacts

Community Protection System

<table>
<thead>
<tr>
<th>Monitoring / Notification</th>
<th>Abatement / Control (Hazard)</th>
<th>Evacuation/Sheltering (Vulnerability)</th>
</tr>
</thead>
</table>

Protection Chain

Response Chain

Hazard Sources (e.g.)
- Seismic Event
- Structural Failure
- Cascading Failure
- Human Agency
- Extreme Flood

Hazard Chain
- Progressive progression in space and time

Are We Prepared?
Using GIS and System Models to Inform Stakeholders

Study Design

Hazard Model

Vulnerability Model: Community at Risk

Loss Scenarios

Protection Scenarios

Risk Communication

Are We Prepared?
Example 1: Dam Safety
Malpasset Dam Failure (1959)
Malpasset Dam Failure (December 1959)

Malpasset Dam (Before & After)

Loss of Life ≈ 450 to 550 people

Are We Prepared?
Life Safety Modelling Principles

- $N_{POP}$ = Total Population
- $N_{PARU}$ = Population at Risk
- $N_{LOL}$ = # Loss of Life
- $N_{OK}$ = # Survive
- $F_{LOL}$ = Mortality Rate
- $F_{OK}$ = Survival Rate

Are We Prepared?
Using GIS for Forensic Analysis of the Malpasset Dam Failure

1. Gathering
- GIS Datasets
- Airphotos
- Testimony (video, radio)
- Personal Communications
- Photos (hand-held, oblique airphoto)
- Reports of Official Inquiries
- Site Visit, Field Data Gathering

2. Compilation / Inferencing
- Consequences (Evidence) Database
  - Hazard Model
  - GIS Features (Roads, Buildings, Earth Surface, Neighbourhoods, etc.)
  - Database Records (Building destruction events, fatality events, etc.)

3. Application
- Model Development and Validation
- Calibration Parameters for:
  - Hazard <-> Human Interactions
  - Hazard <-> Building Interactions
  - Hazard <-> CI/SI Interactions
  - Hazard <-> Vehicle Interactions

Are We Prepared?
Estimating Outcomes: Examples of Flood ↔ Object Interactions

Are We Prepared?
Estimating Loss / Survival Outcomes Using Reliability-Based Methods

\[ G = R - S = \text{Capacity} - \text{Demand} \]

Fail if \( G \leq 0 \)

- **R**: Safe Haven Capacity
- **S**: Flood Demand

Hazard (t), e.g., depth
Performance Criterion
Time
Instantaneous Loss

Hazard (t), e.g., integral of momentum
Performance Criterion
Time
Cumulative Loss

Are We Prepared?
Dam Safety Simulation: Estimate Event Mortality as a Function of Detection and Mobilization Times

Are We Prepared?
Influence of Delays on Loss of Life for the Malpasset Dam Failure

Scenario 1:
No Evac, No Warning: "Shelter-in-Place"

Losses greater than "No Evacuation" scenario

Losses less than "No Evacuation" scenario

Scenario 2A
Scenario 2B
Scenario 2C

Increasing delay in response time (minutes)

Are We Prepared?
Example 2: Tsunami Preparedness for Vancouver Island
Geographic Setting: Cascadia Subduction Zone and Study Areas

Are We Prepared?
Numerical Tsunami Hazard Model

- Develop a wave run-up model that can be used to predict the onshore extent of a hypothetical tsunami on coastal communities.
Simulation Outputs

WARNING -- unvalidated proof of concept. t = 10

Are We Prepared?
Tsunami Animation for Tofino

Are We Prepared?
Selected Impact Zones for Tofino

- Tofino Harbour
- Peninsula Area

Are We Prepared?
Vulnerability x Hazard = Consequences

Tsunami Hazard

Risk

Vulnerability

People

Buildings

Structural Vulnerability

Buildings by Hazard (Draft)

- 1-High
- 2-Medium
- 3-Low
- 4-Green

Roads & Trails

Hazard Boundary (Draft)

Hazard Rating (Draft)

- 1-High
- 2-Medium
- 3-Low
- 4-Green Zone

Mostly Commercial and Accommodation

Mostly Residential and Commercial

0 62.5 125 250 Meters

Are We Prepared?

Spatial Vision Group

esri Canada
Estimated Population at Risk & Losses

<table>
<thead>
<tr>
<th>Times of Year and Day</th>
<th>Community (all)</th>
<th>Coastline</th>
<th>Inlet</th>
<th>Harbour</th>
<th>Estimated Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time of Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>Day</td>
<td>2,609</td>
<td>233</td>
<td>776</td>
<td>408</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>2,224</td>
<td>335</td>
<td>677</td>
<td>233</td>
</tr>
<tr>
<td>Summer</td>
<td>Day</td>
<td>5,265</td>
<td>508</td>
<td>1,792</td>
<td>1,149</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>3,323</td>
<td>469</td>
<td>908</td>
<td>838</td>
</tr>
<tr>
<td></td>
<td>Locals</td>
<td>2043</td>
<td>305</td>
<td>638</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Tourists</td>
<td>1280</td>
<td>164</td>
<td>270</td>
<td>688</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>69</td>
<td>268</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>49</td>
<td>142</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>220</td>
<td>681</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>123:</td>
<td>253:</td>
<td>223:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>35</td>
<td>133</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>88</td>
<td>120</td>
<td>200</td>
<td></td>
</tr>
</tbody>
</table>

- Land use and time of year greatly affect how many are at risk
- Losses could be 19 to 33% of the people at risk (~1/5 to 1/3)
- High exposure and loss rates for tourists
Population Protective Actions

“Evacuate”

Traffic Management / Evacuation Routes

“Shelter in Place”

Vertical Evacuation Platforms

Are We Prepared?
Expanded Safe Havens:
Ucluelet, BC (Johnstone 2007, Johnstone & Lence 2009)
Assessing Evacuation Plans: Cascadia Subduction Zone Earthquake

Evacuation Time Window

Most Effective Alternative

Least Effective Alternative

% Safe

0%

100%

0 15 30 45

Time (minutes)

Single Haven/Vehicle

Single Haven/Pedestrian

Multi-Havens/Vehicle

Multi Havens/Pedestrian

Are We Prepared?
Results: Tsunami

- The communities now have a characterization of:
  - The tsunami hazard
  - The community vulnerabilities
  - Possible consequences
  - The estimated effectiveness of different response strategies
Discussion
The Potential for Global Processes to Produce More Extreme Rainfall Events

Can the spillways on our small & medium-sized dams in BC handle the more extreme rainfall events?

Spillway Capacity of Dams in the Okanagan: Testalinden Dam Failure

Dam, Pathway & Impact Zone (Google Earth)

Debris Deposit at Fan Apex?
200,000 m³

Photo from BC Gov’t

Downstream Impact Zone

Are We Prepared?
Slave Lake Interface Fire (May 2011)

Major challenge: Fire Behaviour Modelling

Are We Prepared?
Post-Event Use of GIS: Typhoon Haiyan

Copernicus Maps & Site Photos on NY Times Website 3 days after event

Emergency Management Service Funded by European Commission Operational April 2012

Are We Prepared?
Discussion

• We have used GIS as a key tool to:
  • Support the development of hazard and vulnerability models
  • Estimate losses of people, buildings, infrastructure
  • Assess mitigation/response alternatives

• Today, the destructive potential of these hazards should be much less of a surprise to stakeholders / decision-makers.
  • Why?:
    > We have better baseline GIS datasets
    > We have better measurement/monitoring tools, sensor webs
    > We have better predictive/numerical models
    > We can use tools like GIS, the web, animations, visualizations to develop better plans, to educate the population
Questions?

THANK YOU
bill.johnstone <at> spatialvisiongroup.com
604-985-1741