CSRN
RCRP
Canadian Seismic Research Network
Réseau canadien pour la recherche parasismique
Funded by NSERC / *Subventionné par le CRSNG*

Regional Seismic Damage Assessment and Interdependencies of Critical Infrastructures during Earthquakes

Prof. Carlos E. Ventura
University of British Columbia

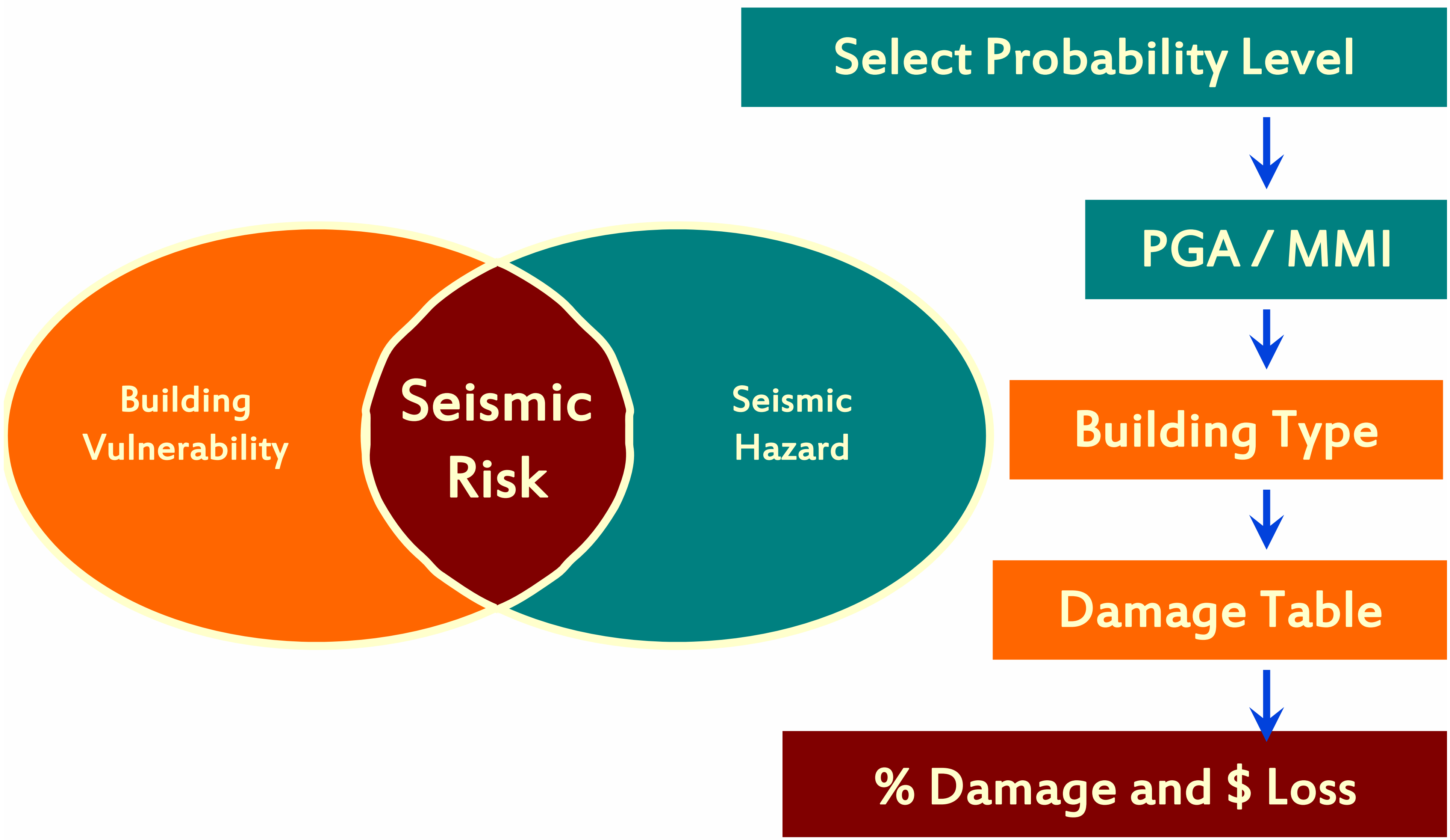
Workshop on Seismic Hazard and Microzonation
Toronto, 13 January 2012

Seismic Risk Studies in BC

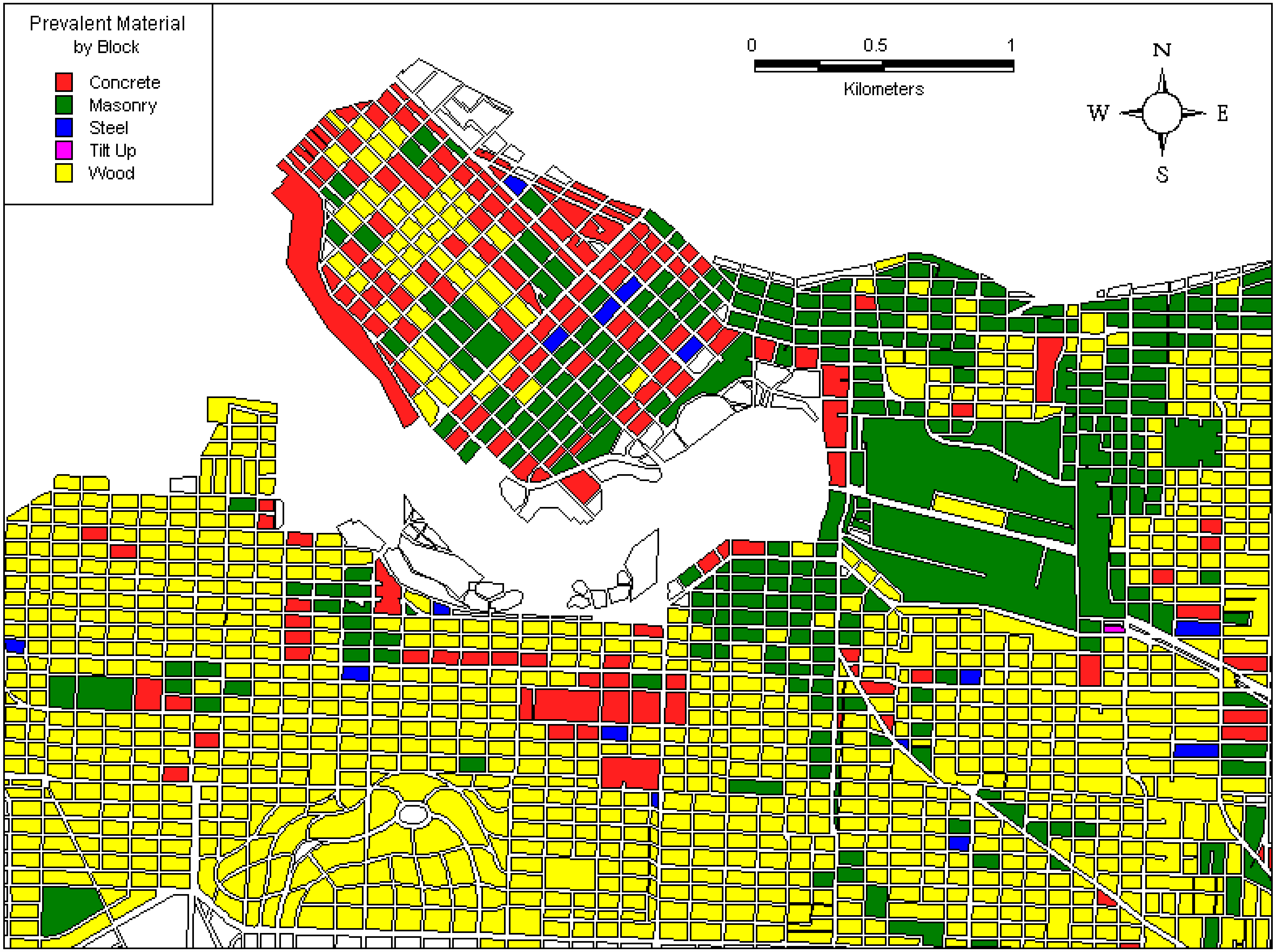
- Seismic risk in south-western BC
  - Deals with damage, monetary losses and casualties
- Critical Infrastructure Interdependencies
  - Development of technology and tools to better understand the interdependency between critical infrastructure during natural and man-made disasters
- Real-time monitoring of infrastructure in BC
  - Development of Internet-based technology for monitoring earthquakes and their effects in BC.

The methodology of each of these projects will be presented briefly.

Elements of Seismic Risk

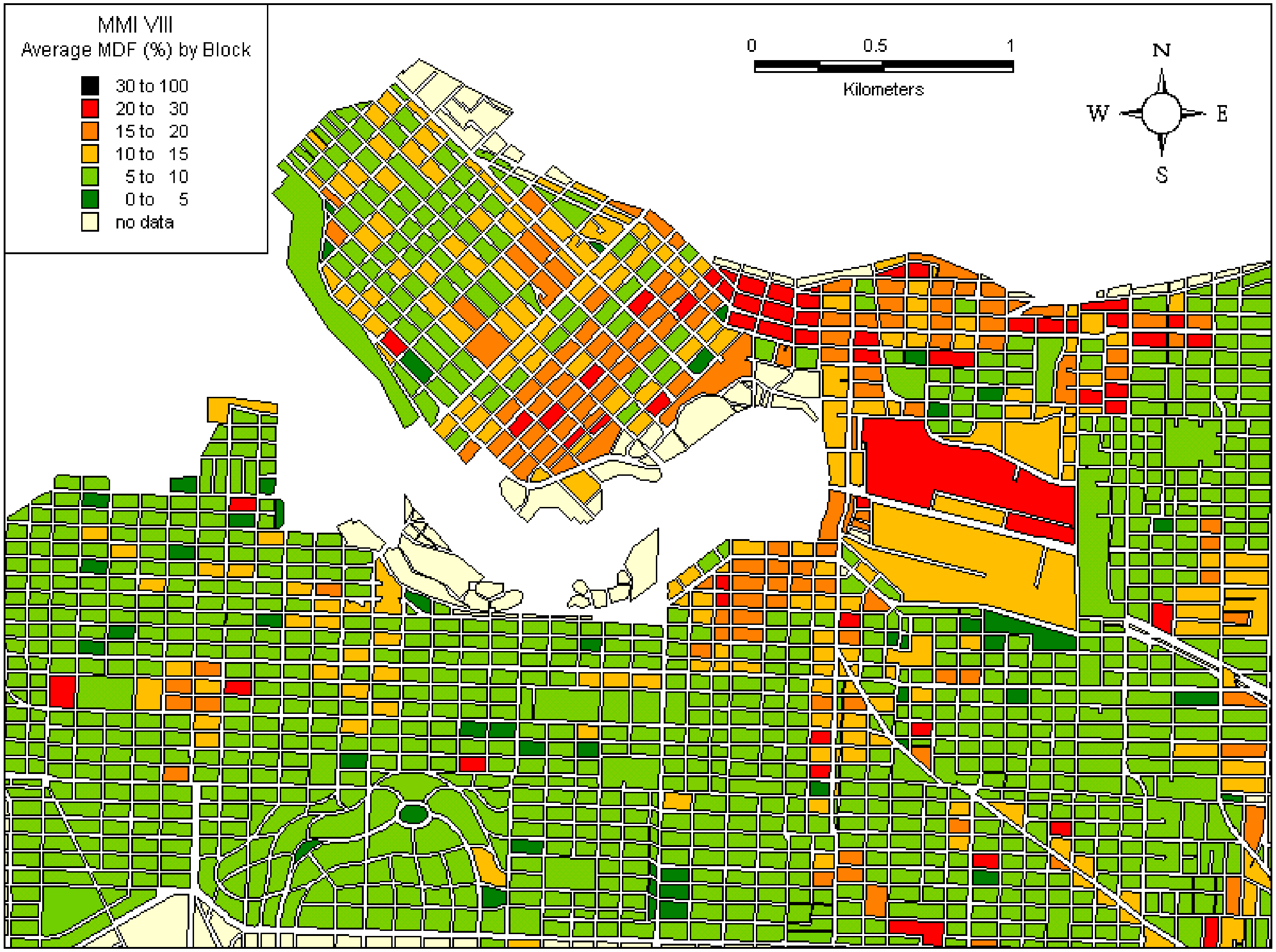


Prevalent Material Type by Block

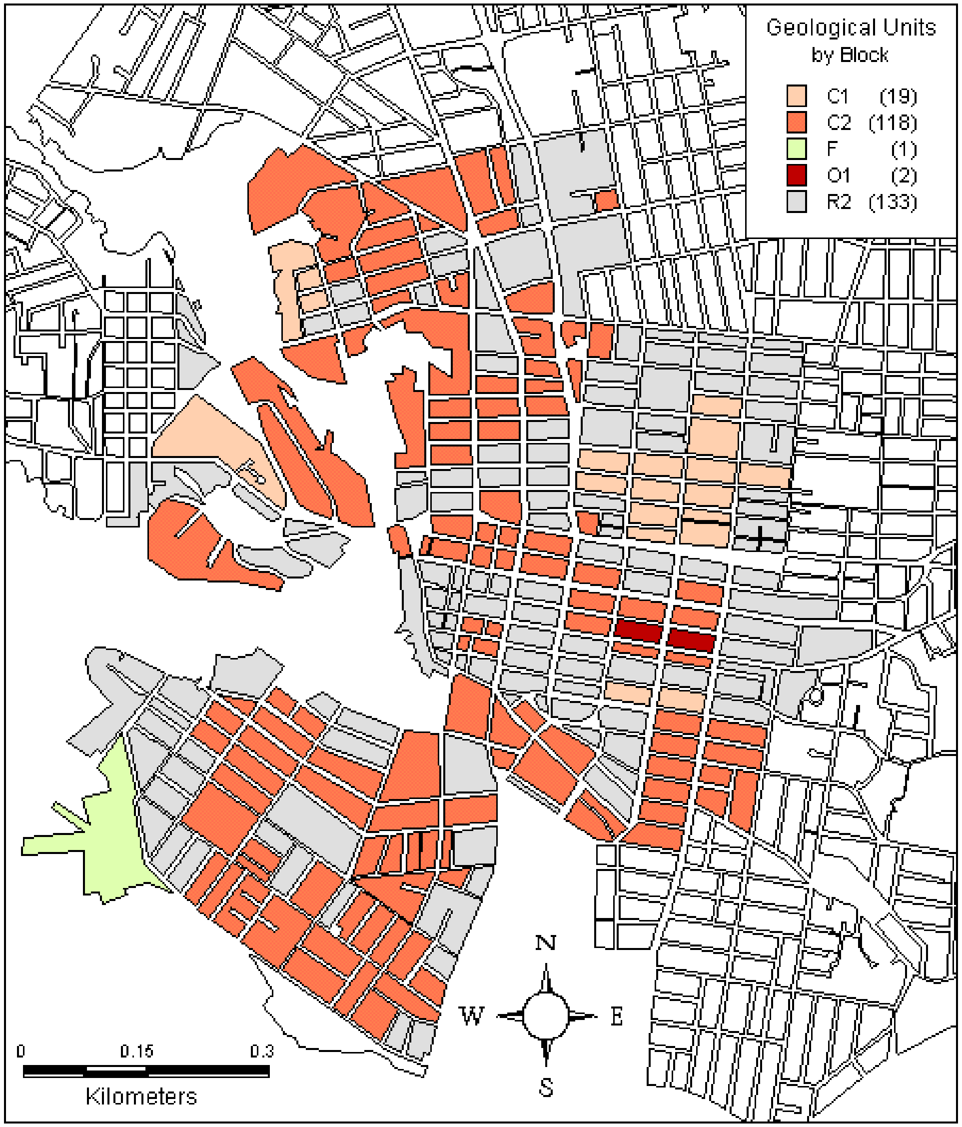


Structural Damage in Vancouver

Average MDF (%) by Block for MMI VIII



Geological Units in Victoria



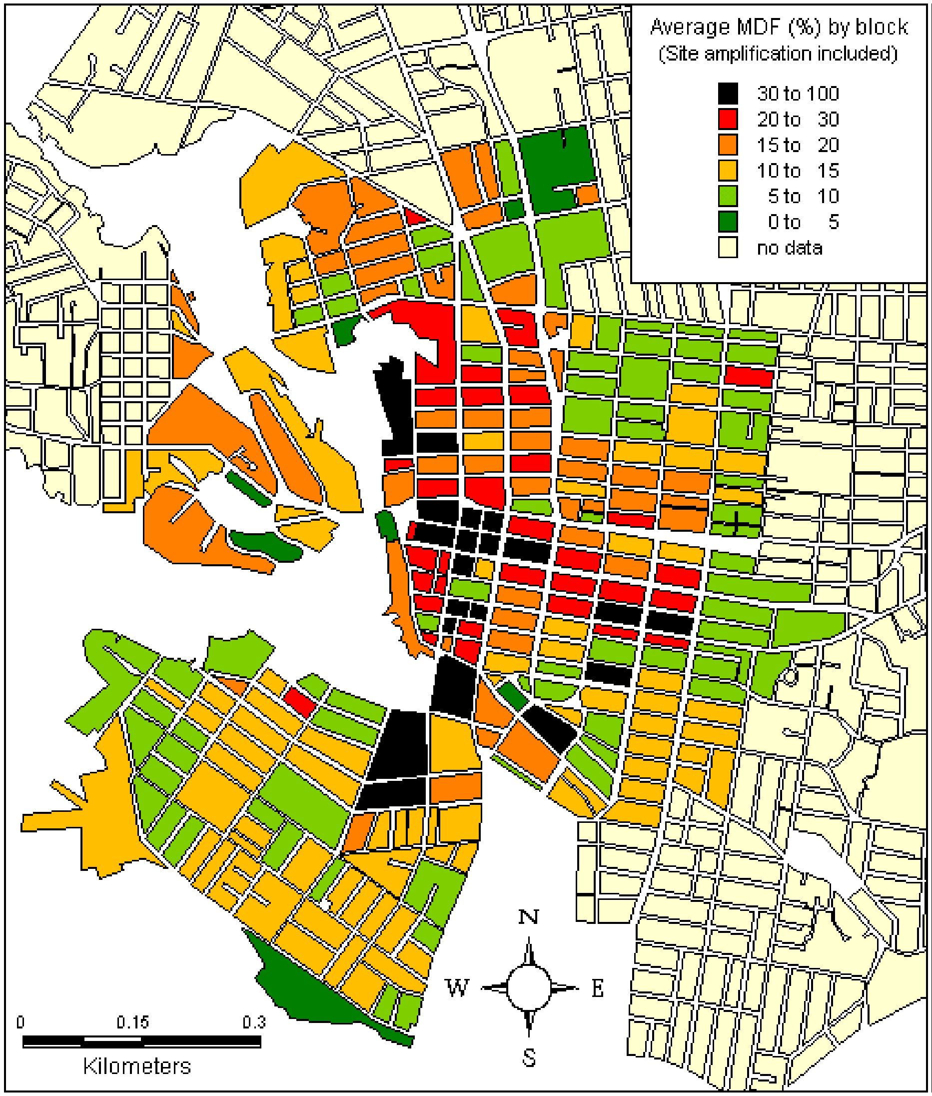
Main geological units and the corresponding amplification factors are:

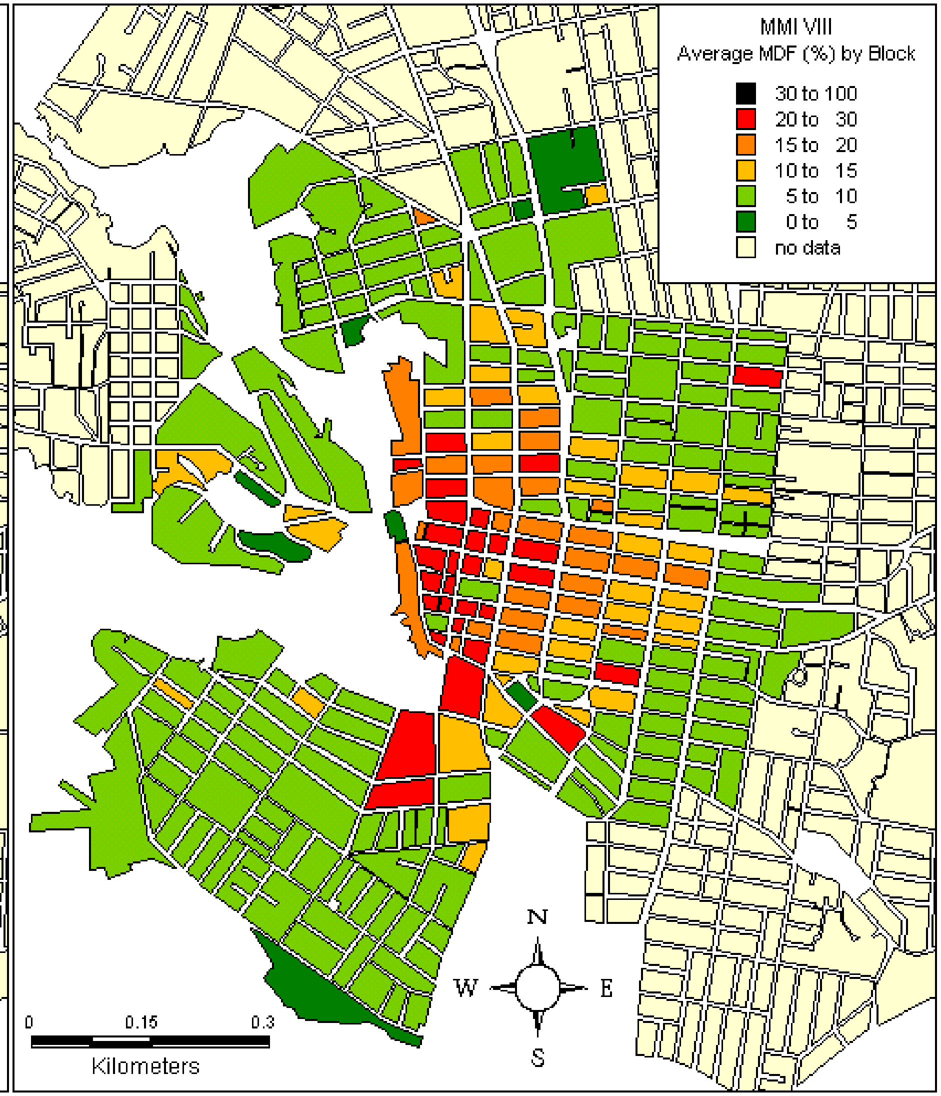
R2	1.0
C1	1.5
F	1.5
C2	2.0
O1	2.5

These amplification factors are for strong shaking and long-period ground motion.

Structural Damage in Victoria

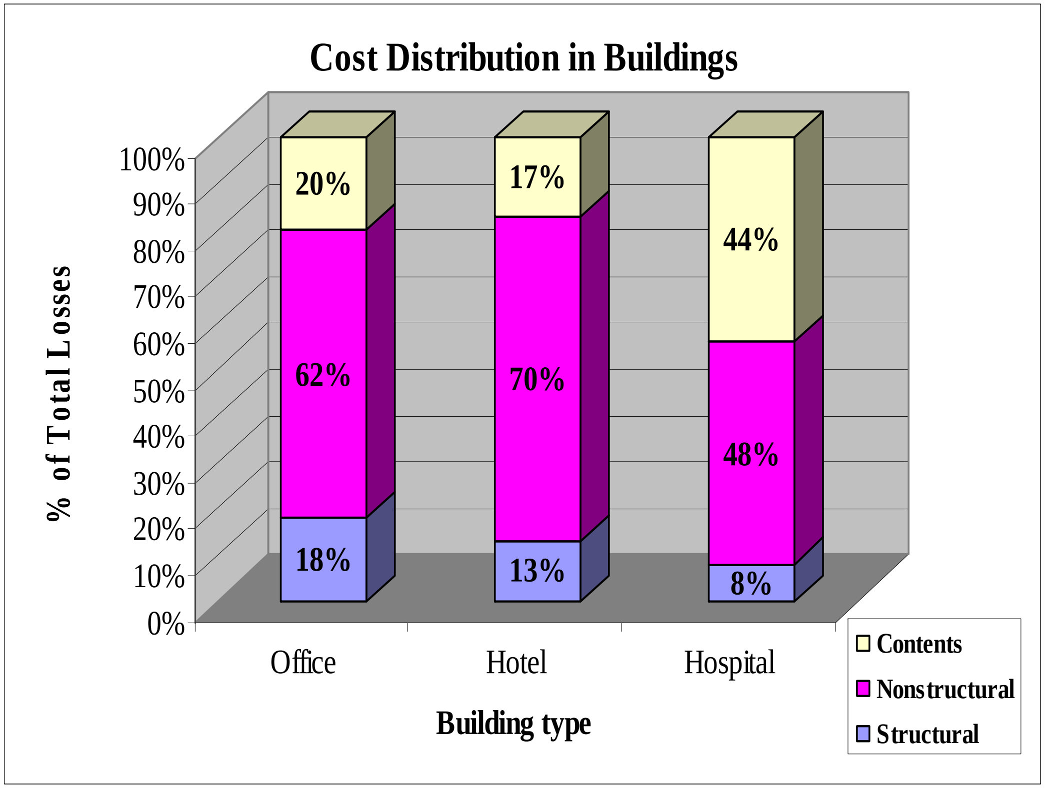
with and without Site Amplification





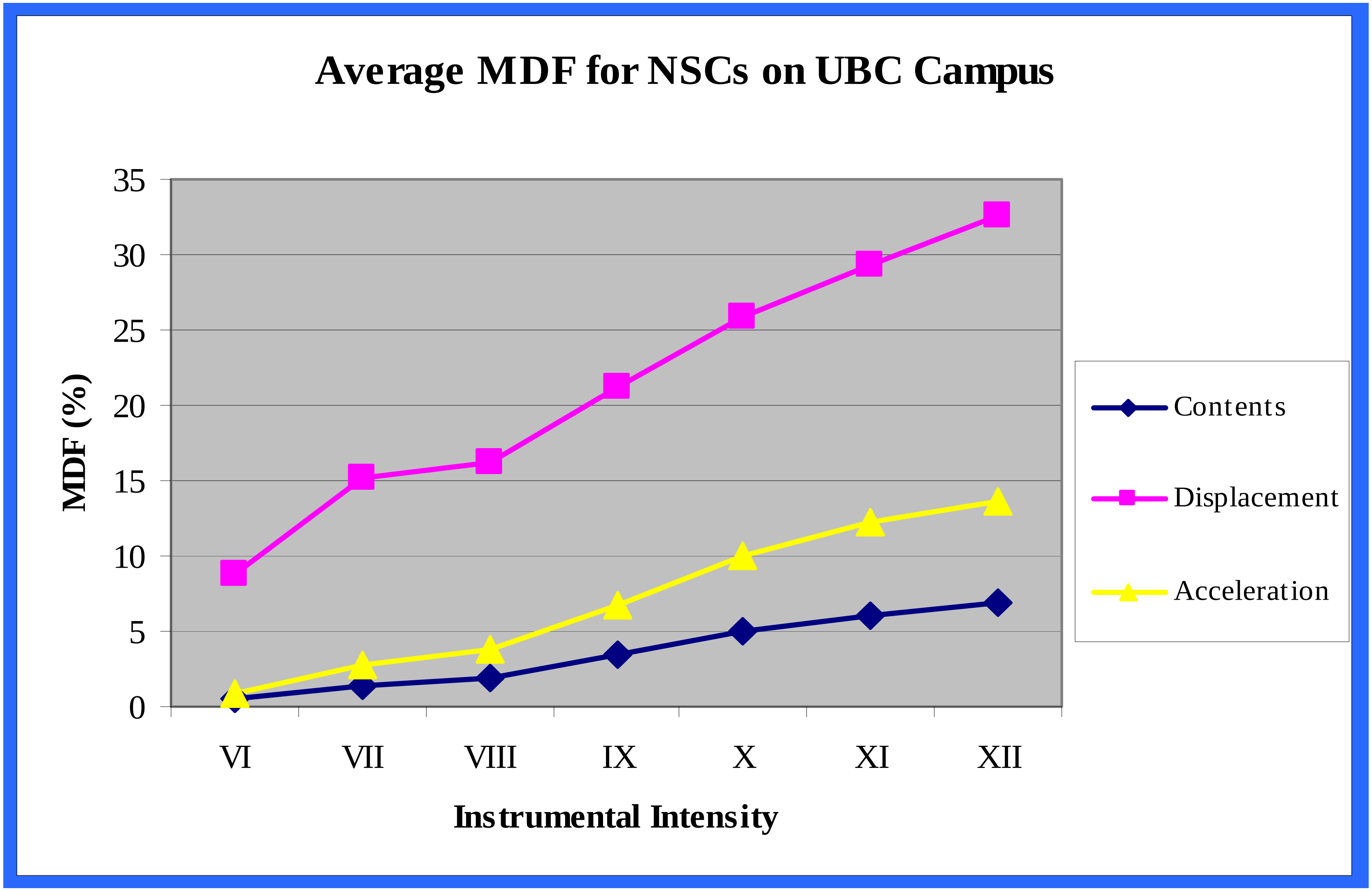
Monetary Losses

- Economic losses estimated based on building use, replacement value and damage
- FEMA Facility Dependent monetary loss estimation



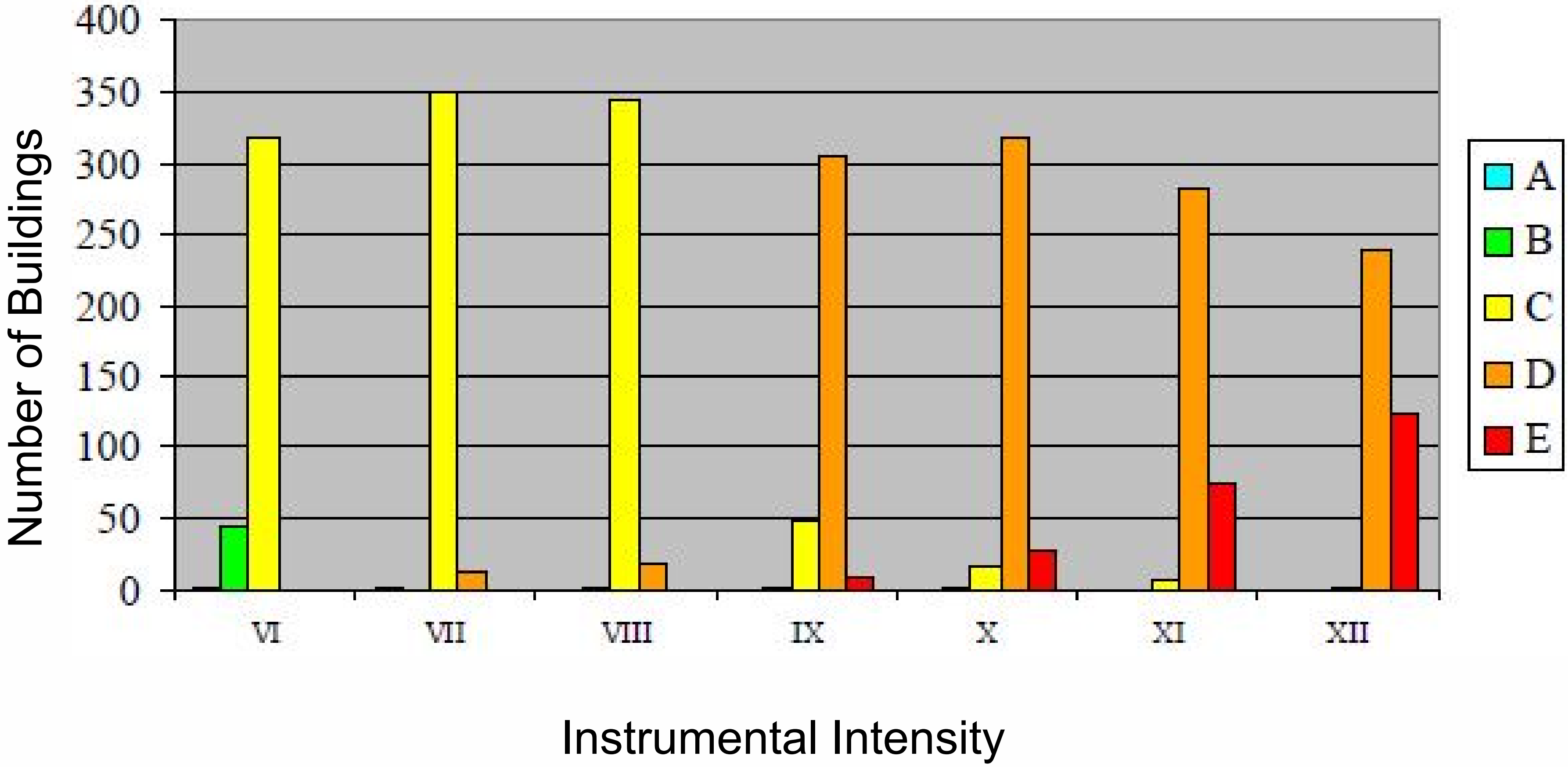
After Prof. E. Miranda

Non-structural Damage



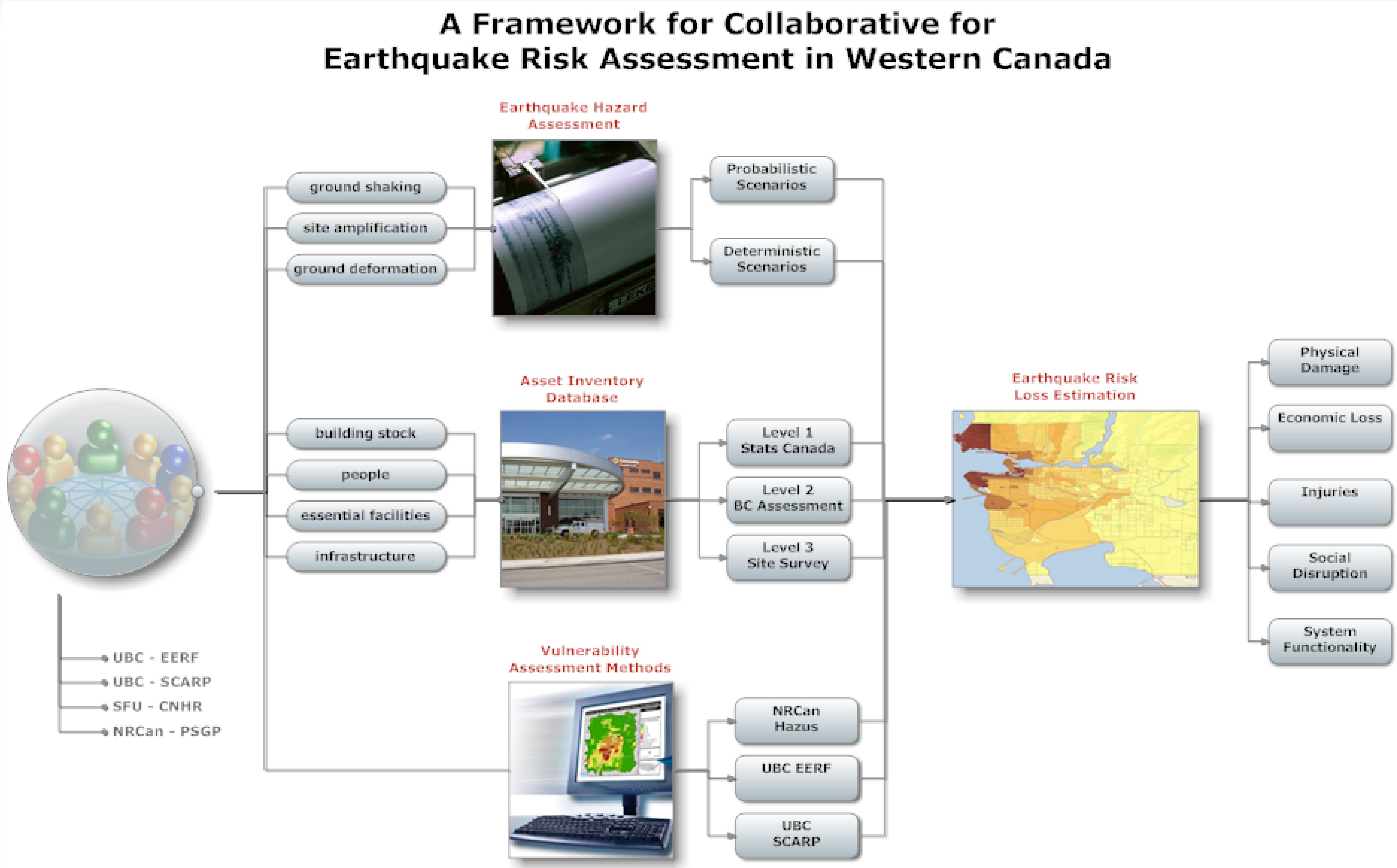
Building Functionality

UBC Campus



Collaborative work in BC to adapt HAZUS Methodology to CANADA

Recent collaborative work in BC

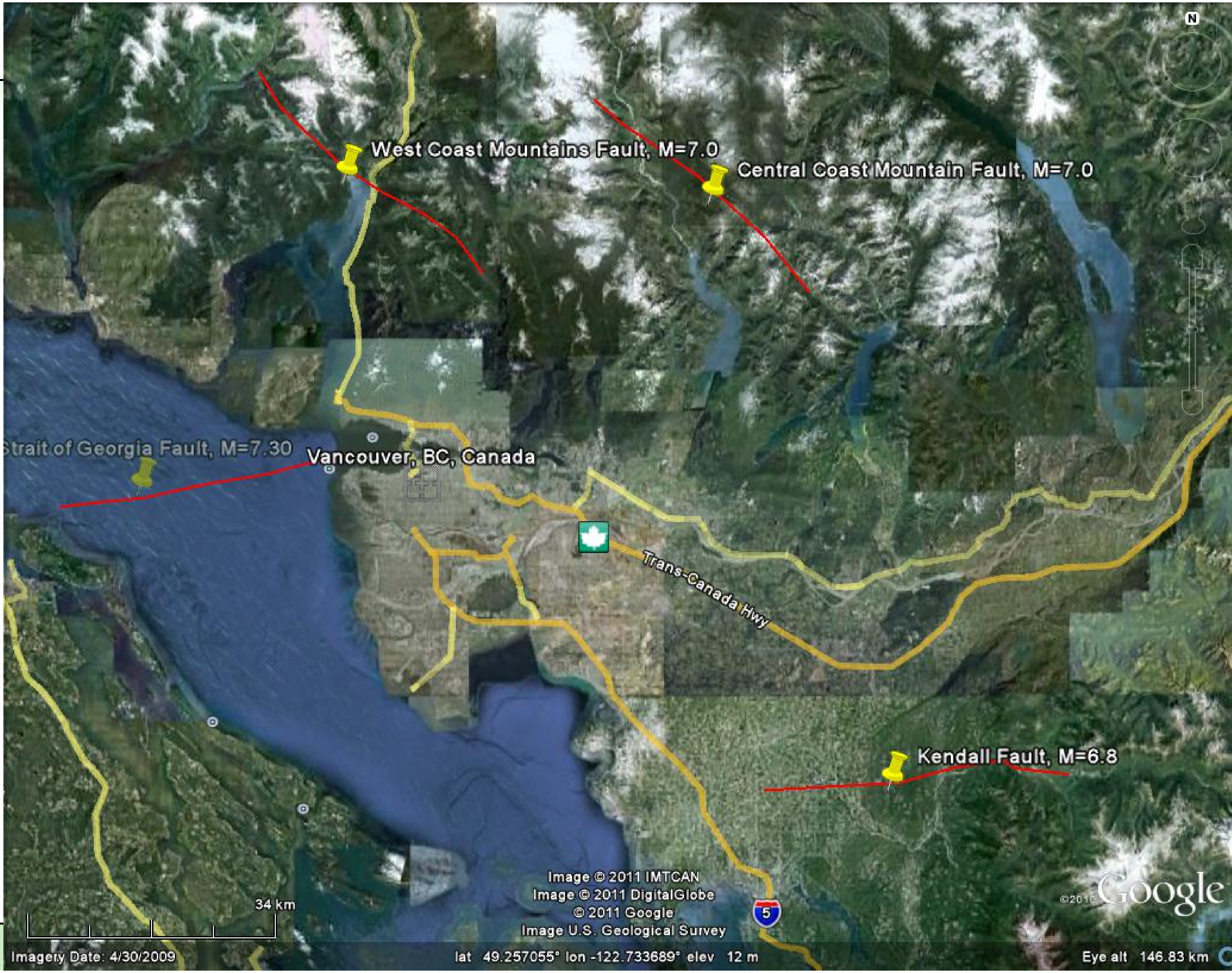


Example of Earthquake Damage Scenarios Developed by NRCan as part of this Collaborative Work

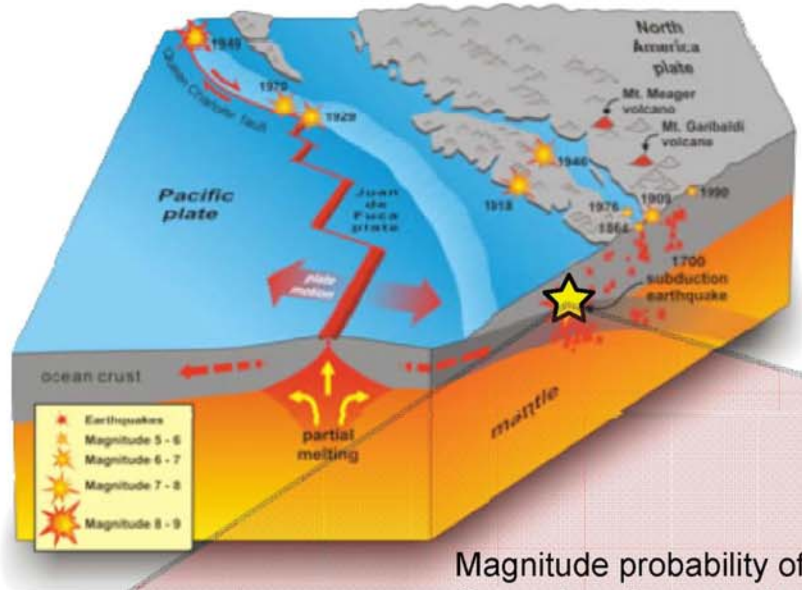
The following slides were kindly provided by Dr. M. Journeay of NRCan

Disclaimer:

The results presented here are of very preliminary nature and should only be used to better understand the concepts described in this presentation and to get a general idea of the comparative impact of various types of earthquakes that may affect the BC region

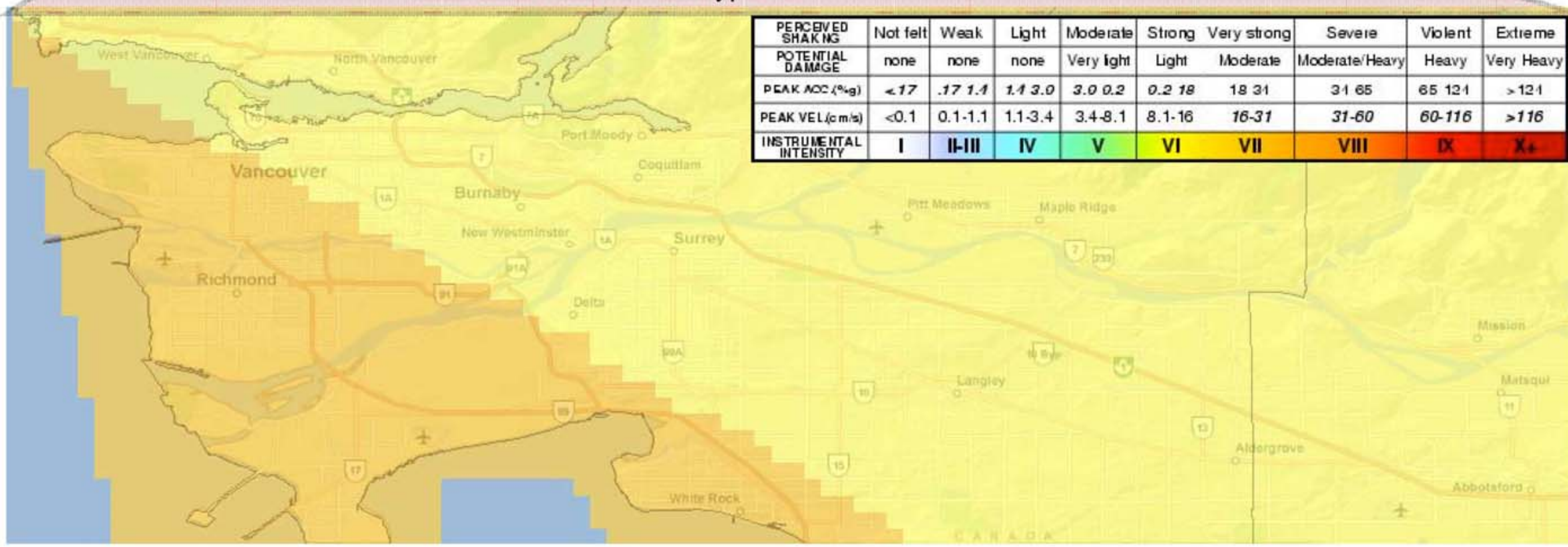

West Coast Mountains Fault, M=7.0
Central Coast Mountain Fault, M=7.0
Strait of Georgia Fault, M=7.30
Vancouver, BC, Canada
Trans-Canada Hwy
Kendall Fault, M=6.8
Image © 2011 IMTCAN
Image © 2011 DigitalGlobe
© 2011 Google
Image U.S. Geological Survey
34 km
Imagery Date: 4/30/2009
lat 49.257055° lon -122.733689° elev 12 m
Eye alt 146.83 km
Google

Hazard Threat - Earthquake Ground Shaking



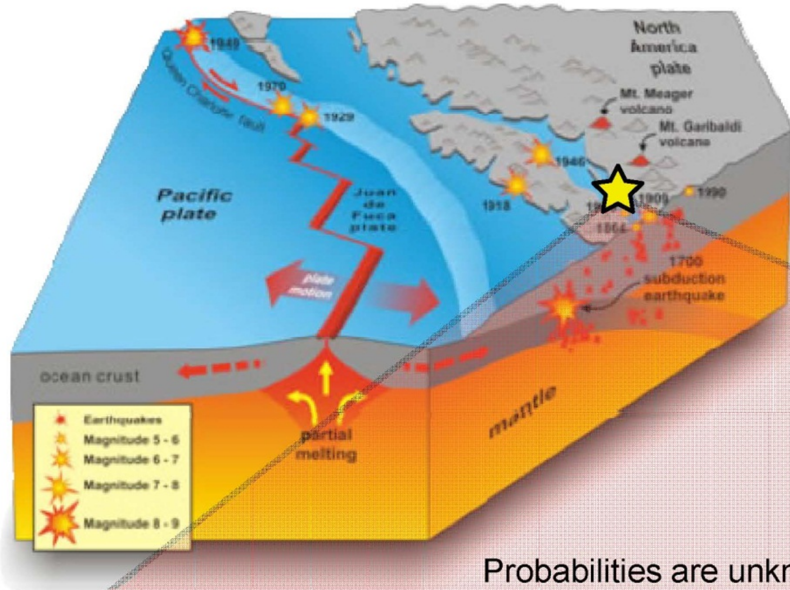
Cascadia Subduction Zone Event

Magnitude probability of occurrence: 10% in 50 years.
Ground motions used, probability of exceedance: 1.6% ~ 2% in 50 years.
Reference NEHRP soil type "C"



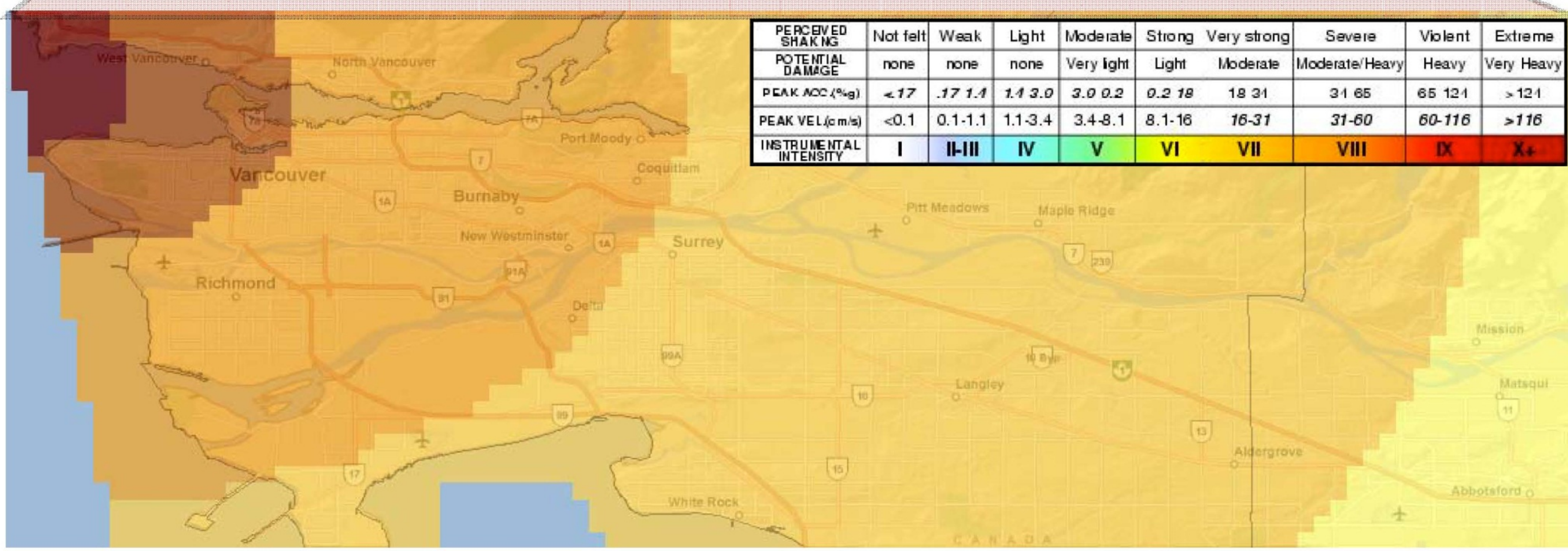
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17 1.4	1.4 3.0	3.0 0.2	0.2 18	18 31	31 65	65 124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Hazard Threat - Earthquake Ground Shaking



Georgia Strait Fault Zone Event

Probabilities are unknown for this scenario.
Reference NEHRP soil type "C"



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
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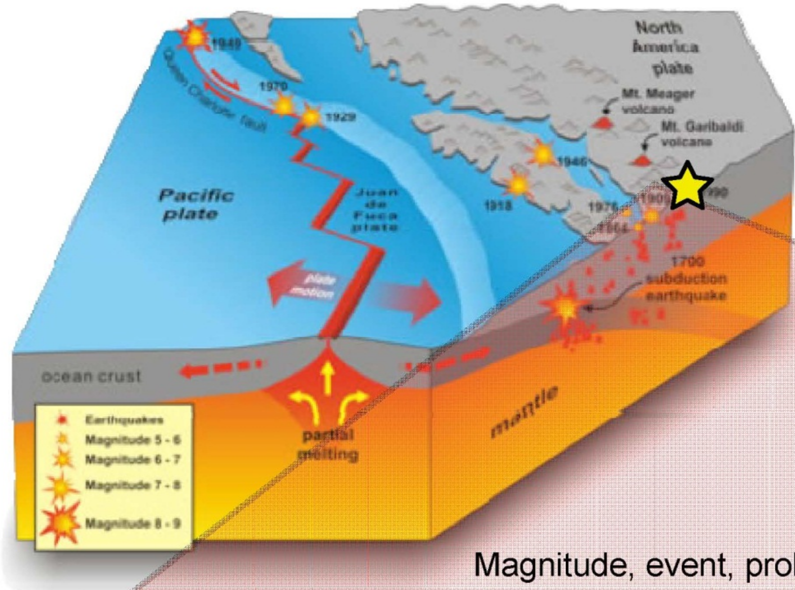
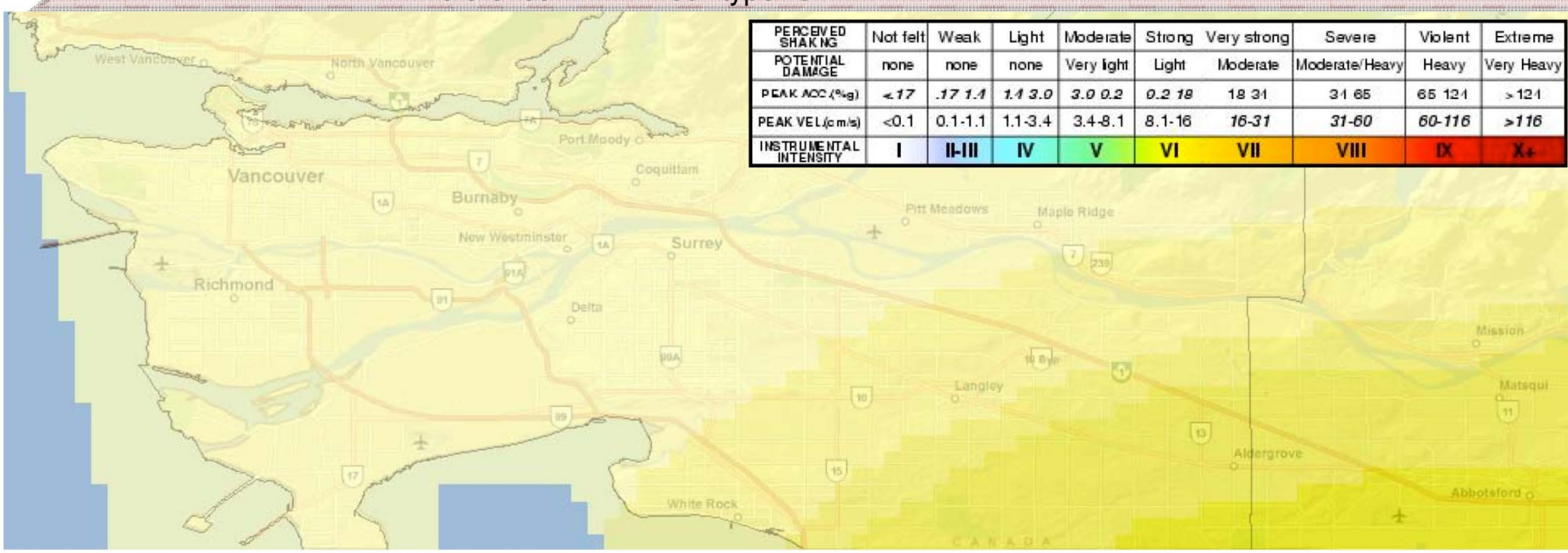
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Hazard Threat - Earthquake Ground Shaking



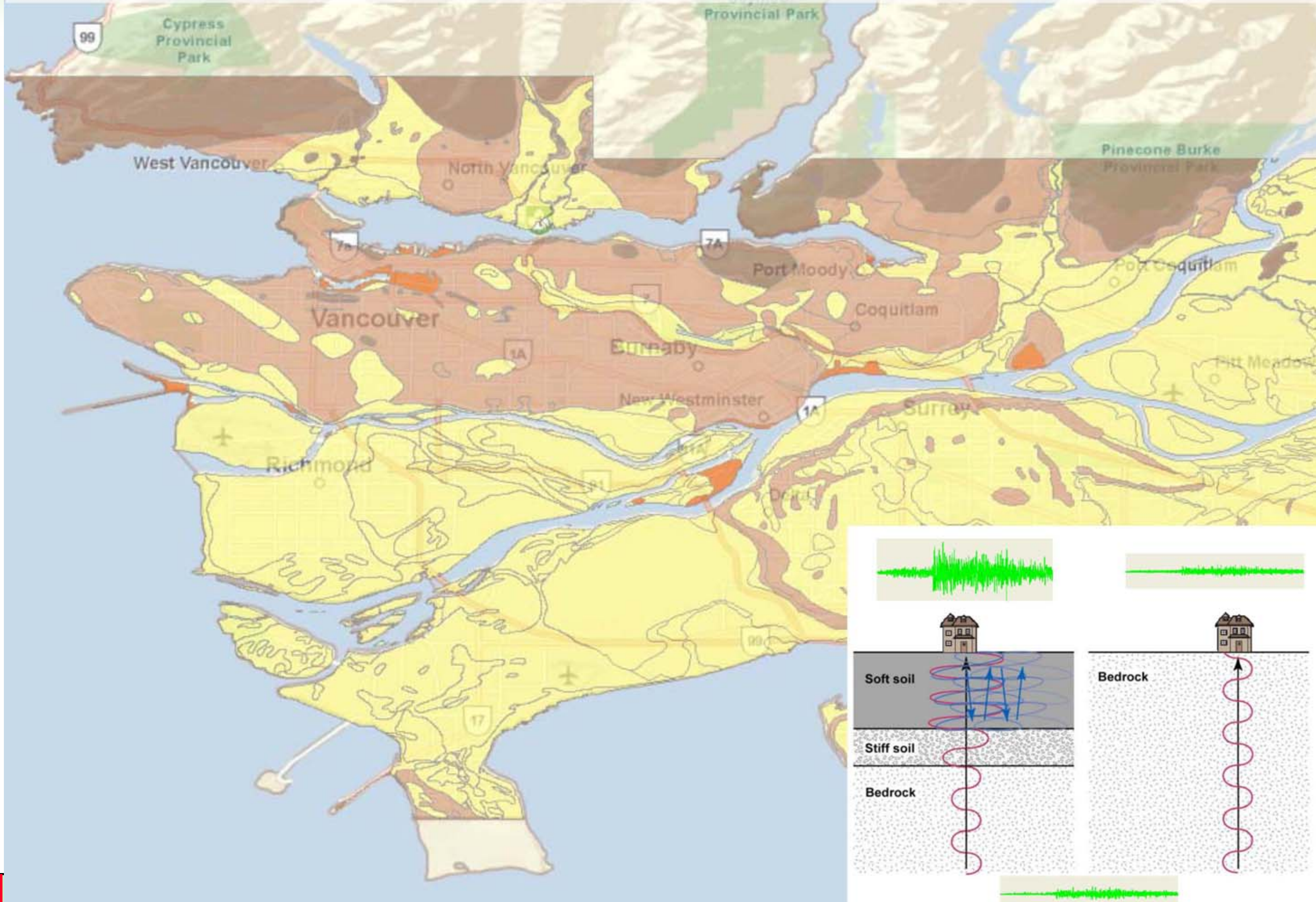
Kendall Fault Zone Event

Magnitude, event, probability of occurrence: 3% in 50 years.
Ground motions used, probability of exceedance: 0.5% in 50 years.
Reference NEHRP soil type “C”

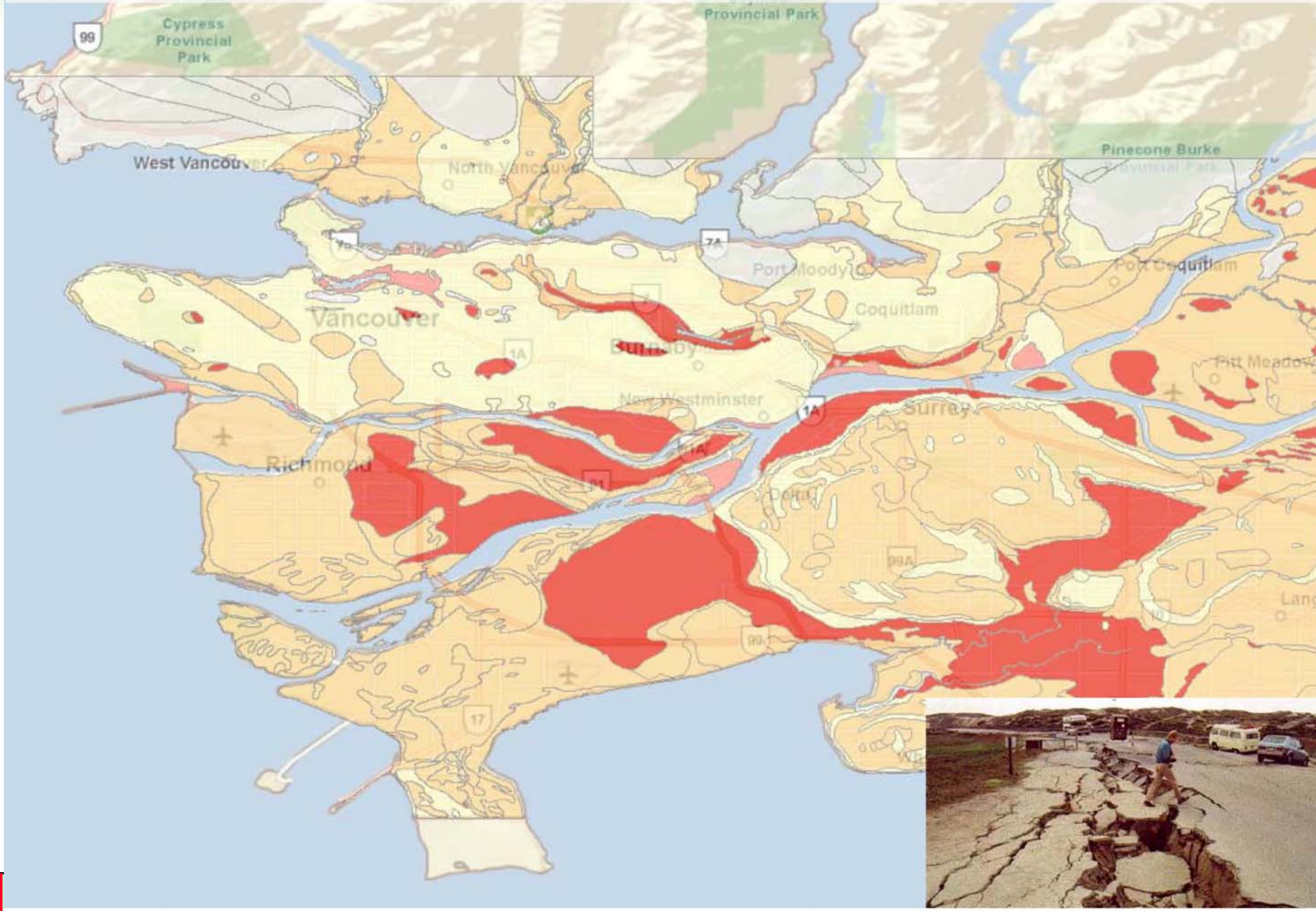


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17 1.4	1.4 3.0	3.0 0.2	0.2 18	18 34	34 65	65 124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Hazard Threat - Site Amplification of Seismic Energy

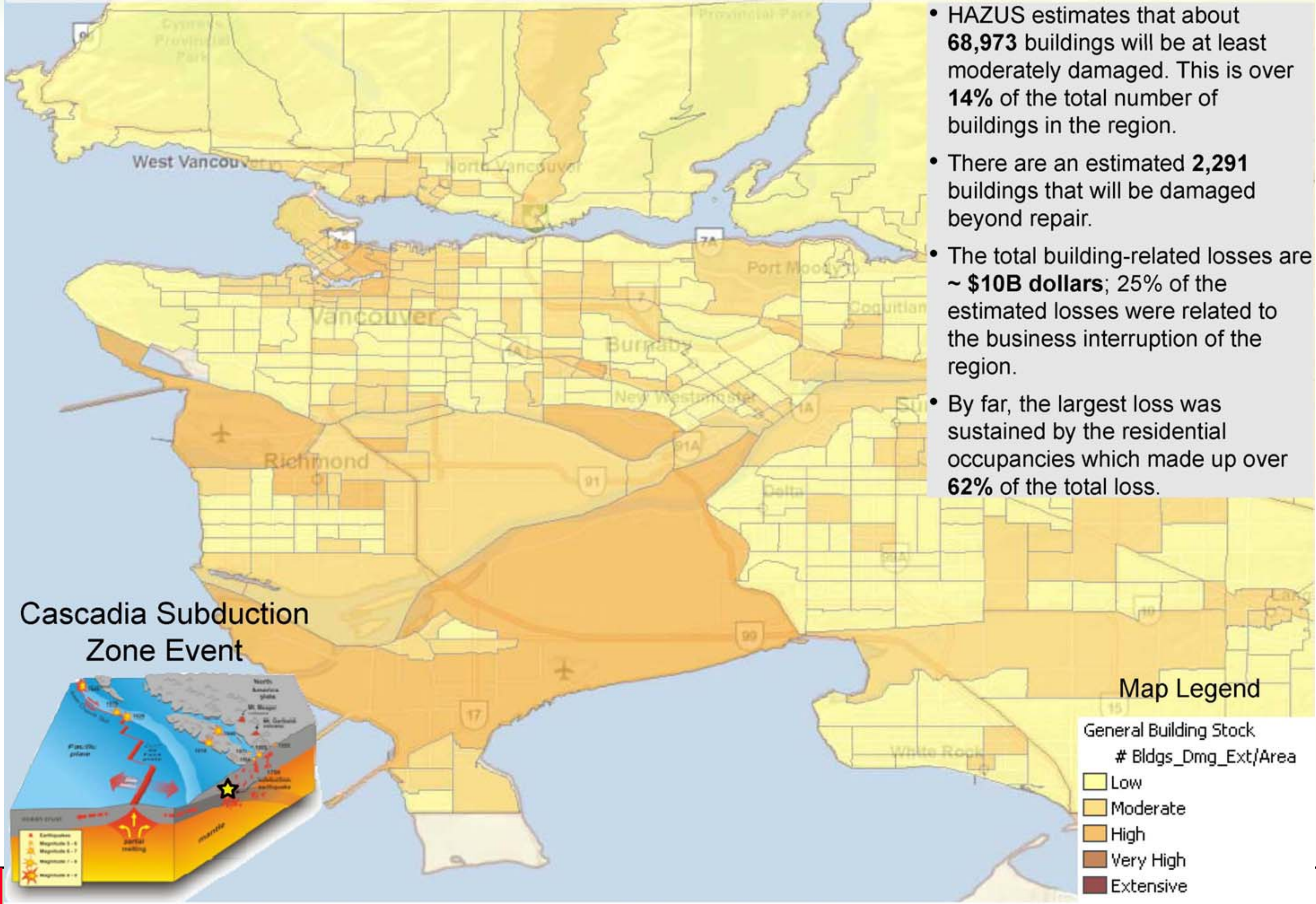


Hazard Threat - Liquefaction Susceptibility



Physical Damage & Loss - Building Stock

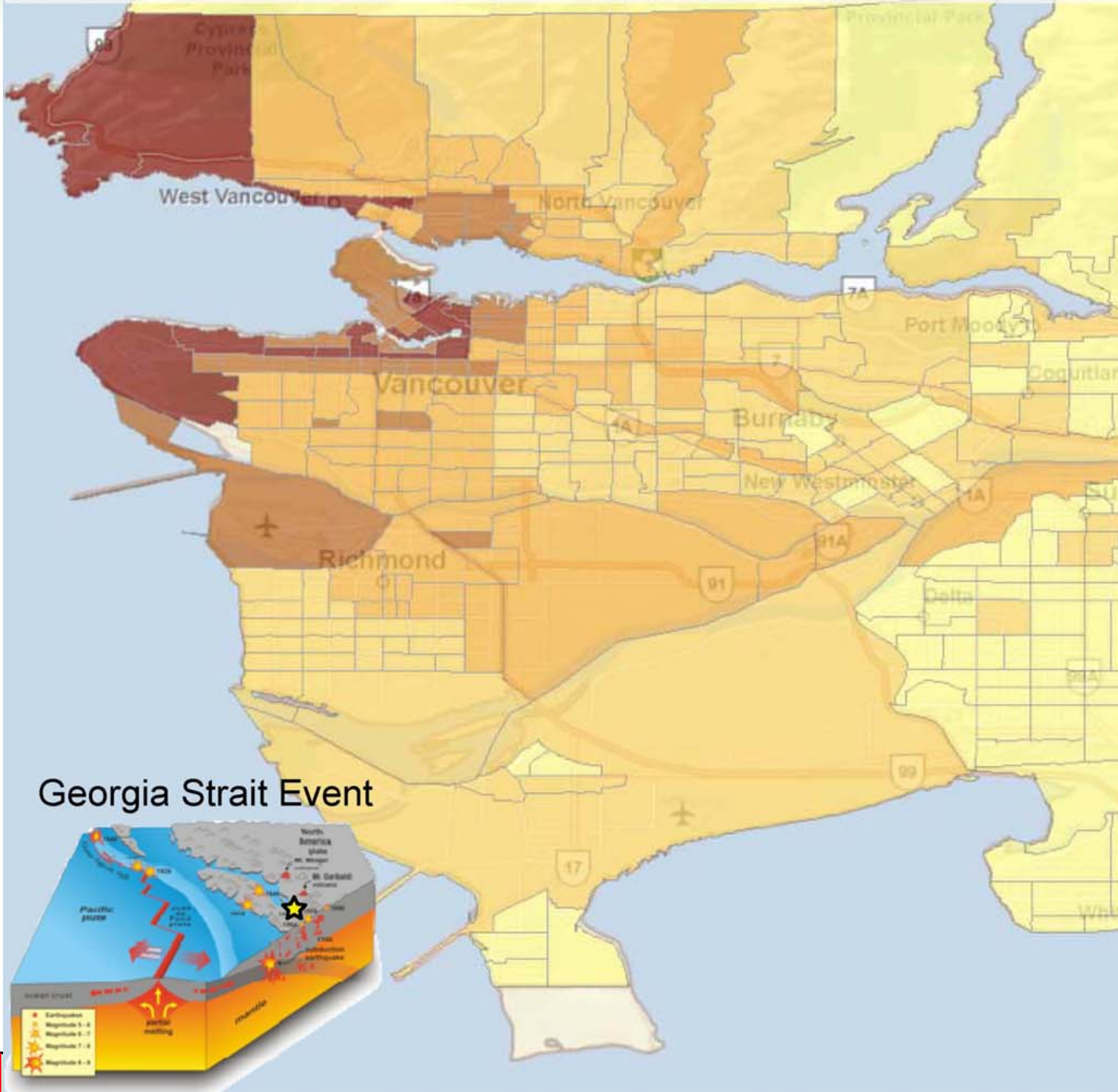
- HAZUS estimates that about **68,973** buildings will be at least moderately damaged. This is over **14%** of the total number of buildings in the region.
- There are an estimated **2,291** buildings that will be damaged beyond repair.
- The total building-related losses are **~ $10B dollars**; 25% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over **62%** of the total loss.



Cascadia Subduction Zone Event

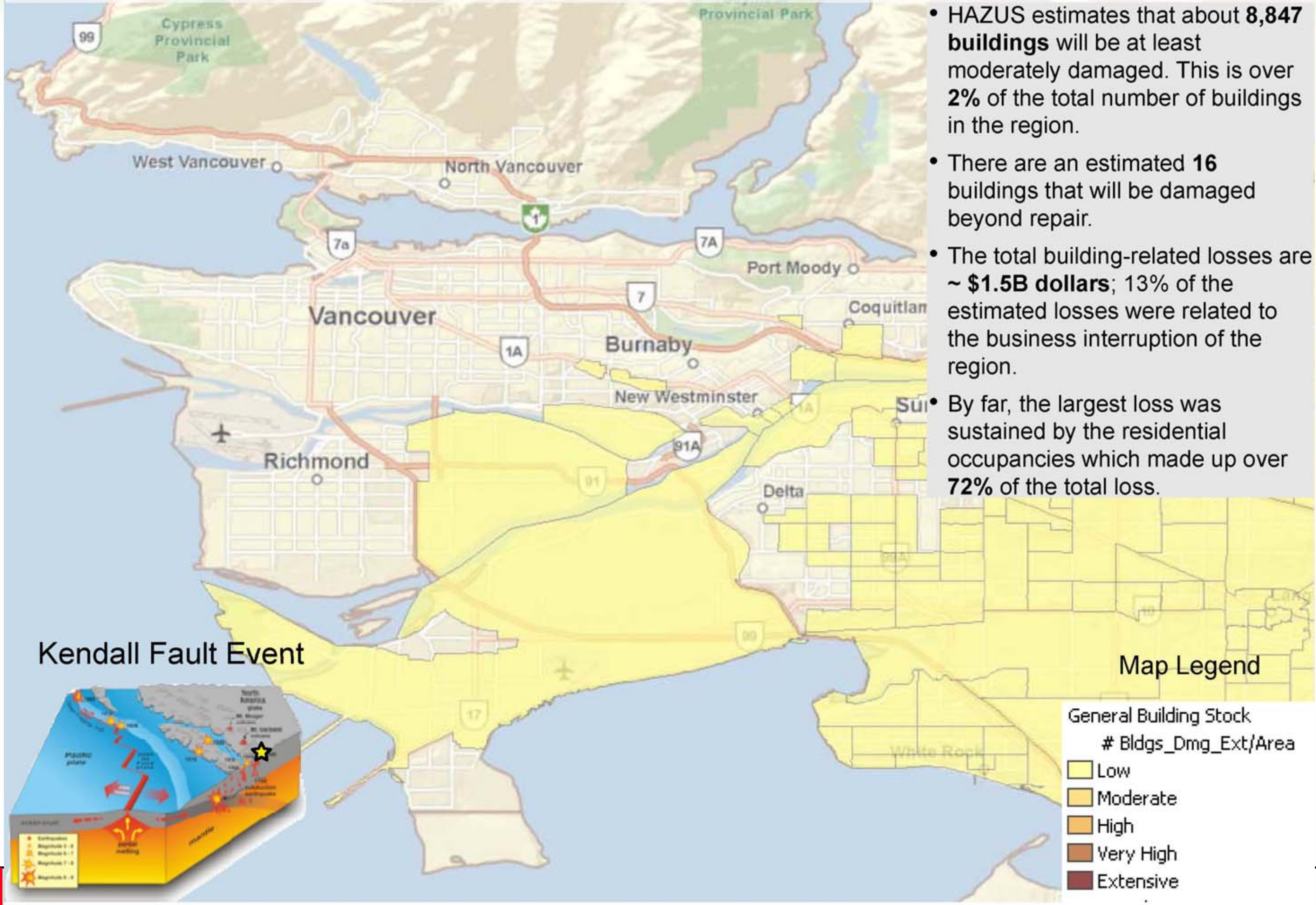
Physical Damage & Loss - Building Stock

- HAZUS estimates that about **129,034** buildings will be at least moderately damaged. This is over **27%** of the total number of buildings in the region.
- There are an estimated **8,093** buildings that will be damaged beyond repair.
- The total building-related losses are **~ $21B dollars**; 21% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over **68%** of the total loss



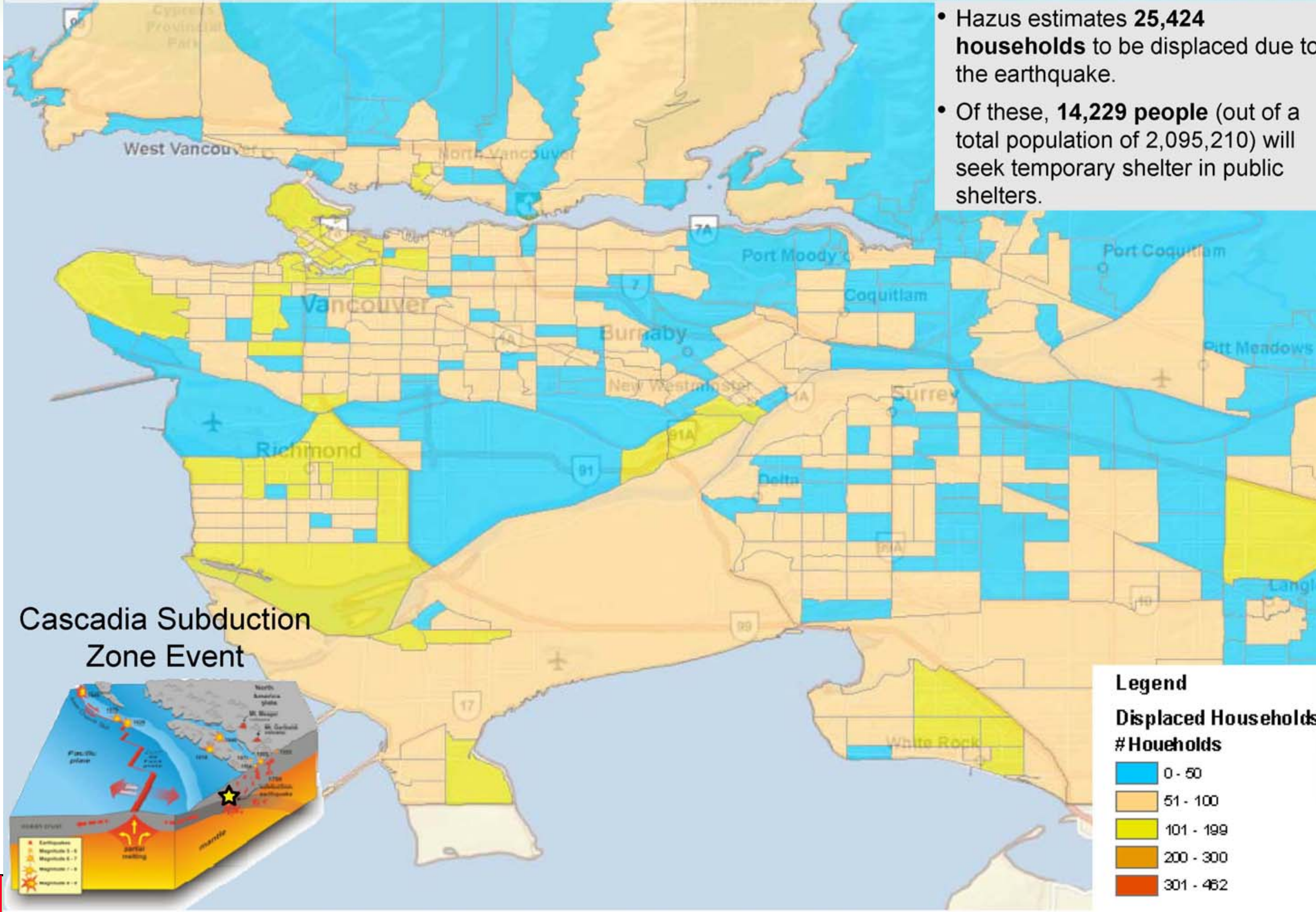
Physical Damage & Loss - Building Stock

- HAZUS estimates that about **8,847 buildings** will be at least moderately damaged. This is over **2%** of the total number of buildings in the region.
- There are an estimated **16** buildings that will be damaged beyond repair.
- The total building-related losses are **~ $1.5B dollars**; 13% of the estimated losses were related to the business interruption of the region.
- By far, the largest loss was sustained by the residential occupancies which made up over **72%** of the total loss.



Physical Damage – Social Disruption

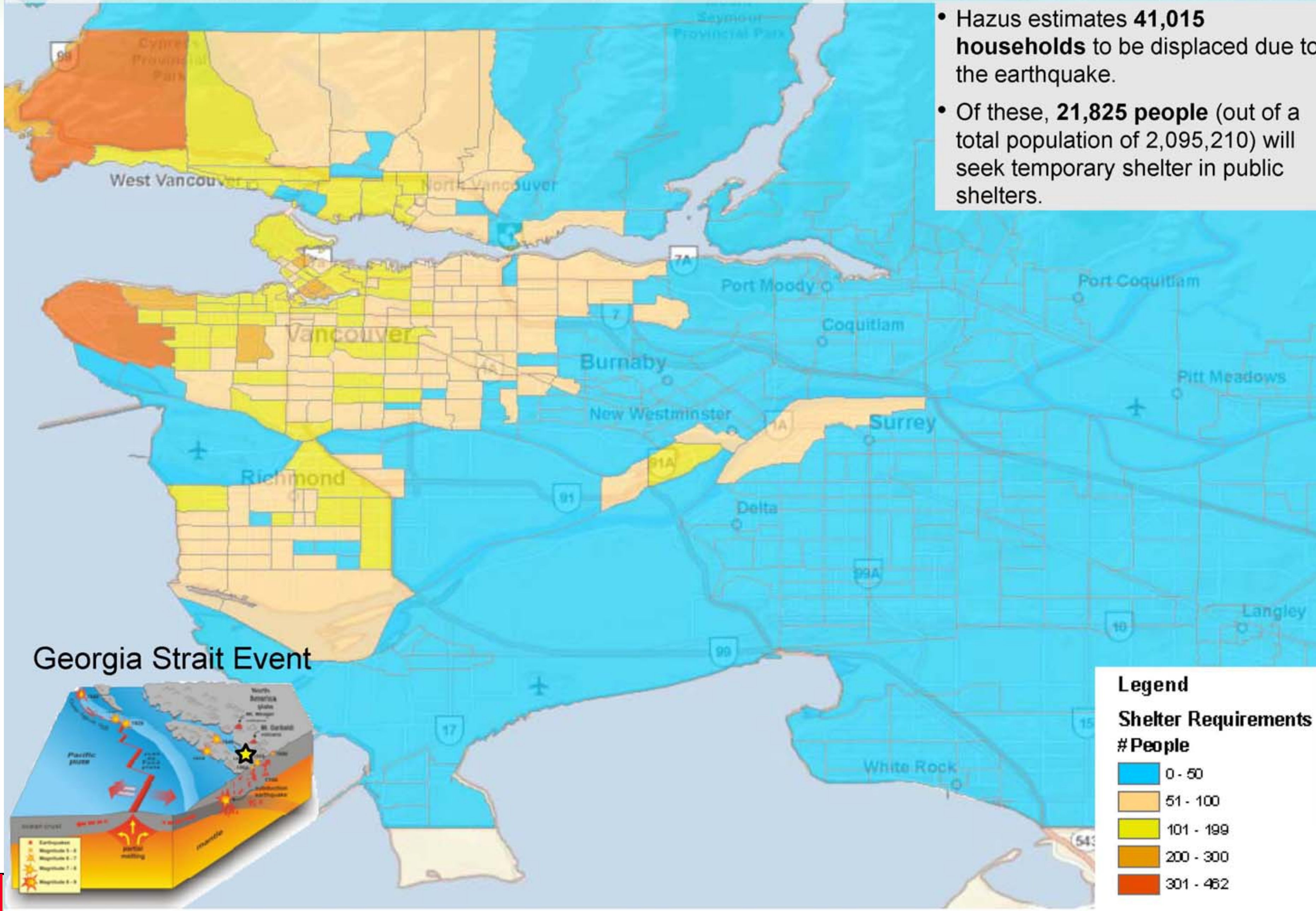
- Hazus estimates **25,424 households** to be displaced due to the earthquake.
- Of these, **14,229 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.



Cascadia Subduction Zone Event

Physical Damage – Social Disruption

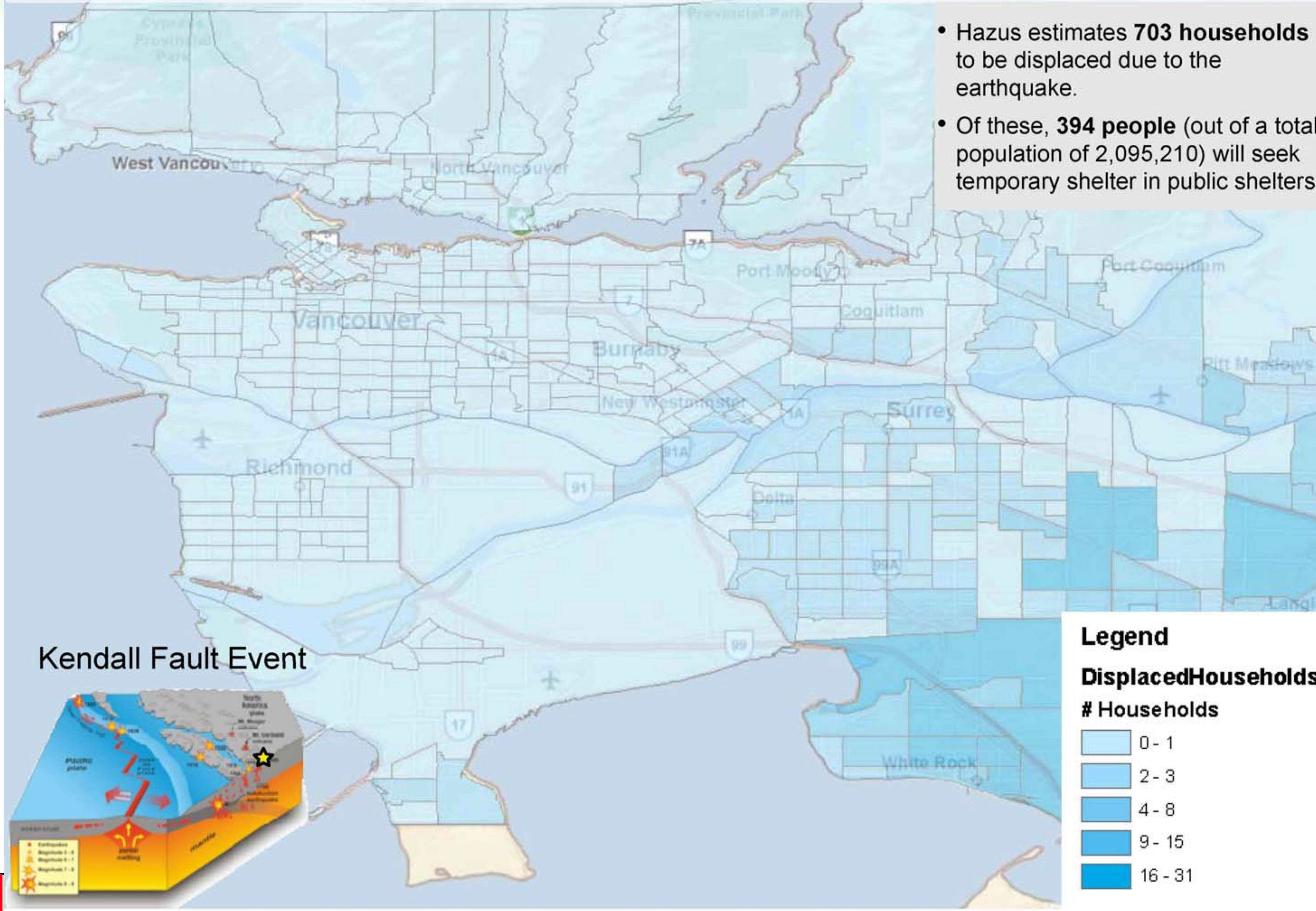
- Hazus estimates **41,015 households** to be displaced due to the earthquake.
- Of these, **21,825 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.



Georgia Strait Event

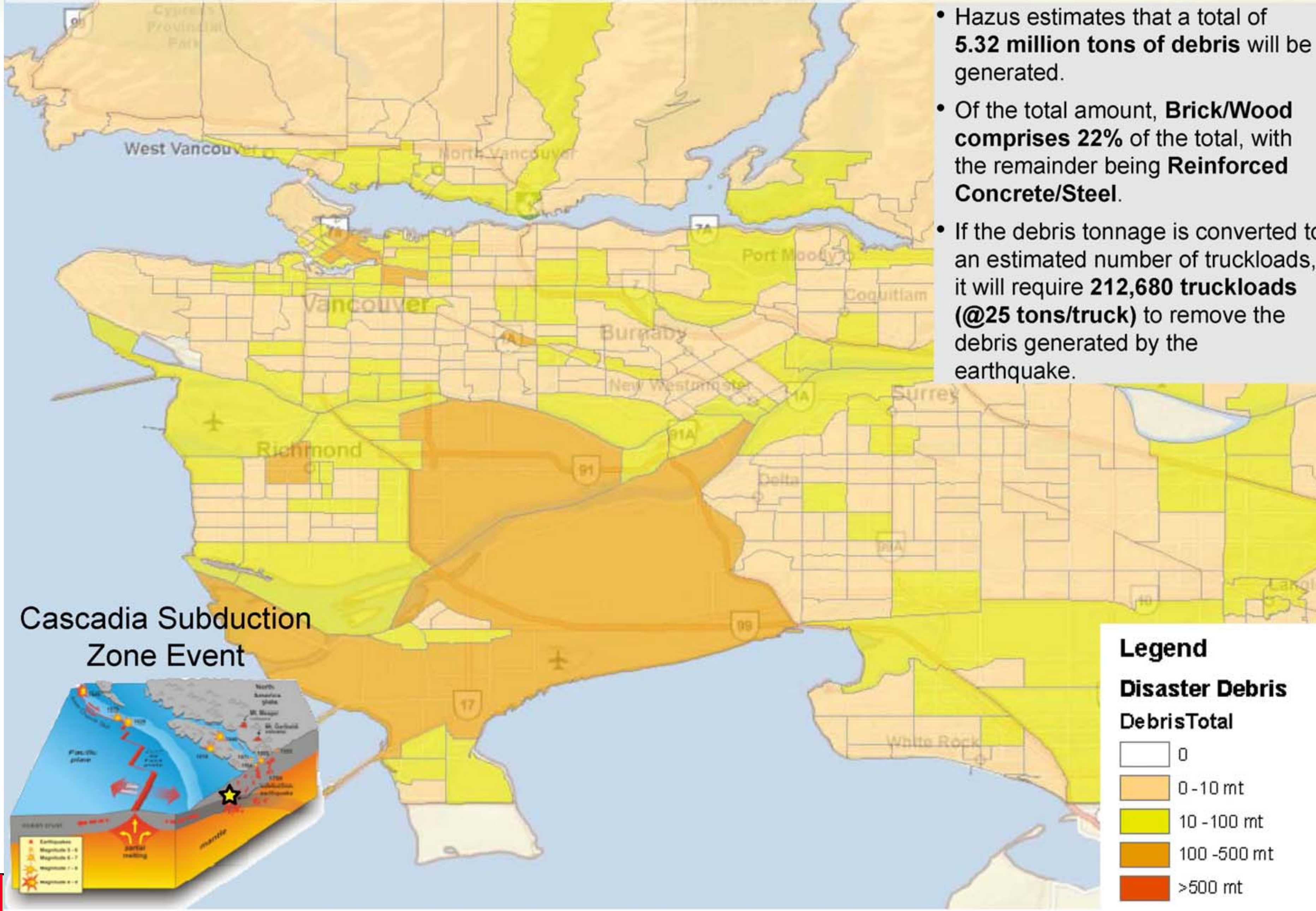
Social Disruption – Social Disruption

- Hazus estimates **703 households** to be displaced due to the earthquake.
- Of these, **394 people** (out of a total population of 2,095,210) will seek temporary shelter in public shelters.



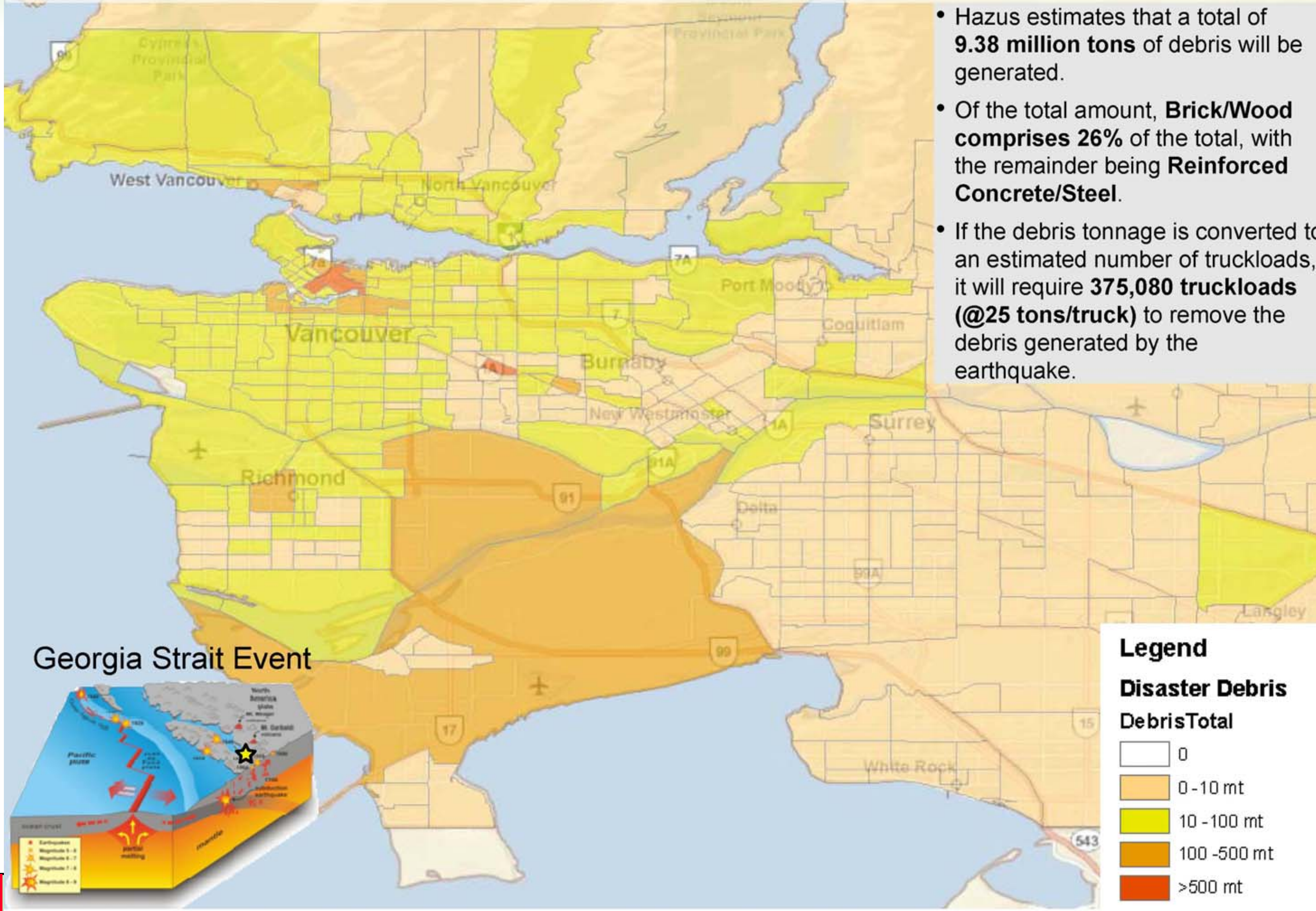
Induced Damage - Debris Generation

- Hazus estimates that a total of **5.32 million tons of debris** will be generated.
- Of the total amount, **Brick/Wood comprises 22%** of the total, with the remainder being **Reinforced Concrete/Steel**.
- If the debris tonnage is converted to an estimated number of truckloads, it will require **212,680 truckloads (@25 tons/truck)** to remove the debris generated by the earthquake.



Induced Damage - Debris Generation

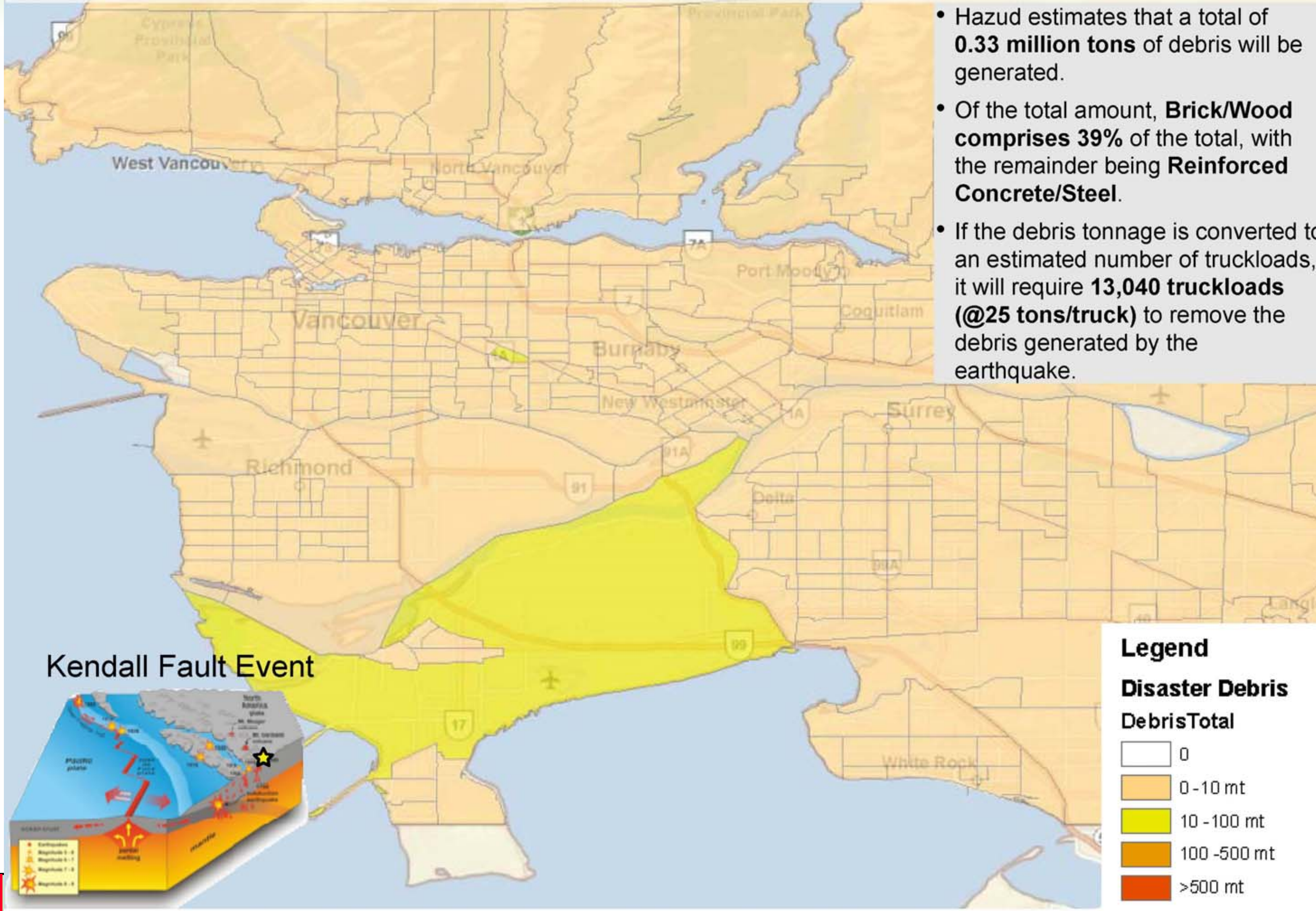
- Hazus estimates that a total of **9.38 million tons** of debris will be generated.
- Of the total amount, **Brick/Wood comprises 26%** of the total, with the remainder being **Reinforced Concrete/Steel**.
- If the debris tonnage is converted to an estimated number of truckloads, it will require **375,080 truckloads (@25 tons/truck)** to remove the debris generated by the earthquake.



Georgia Strait Event

Induced Damage - Debris Generation

- Hazud estimates that a total of **0.33 million tons** of debris will be generated.
- Of the total amount, **Brick/Wood comprises 39%** of the total, with the remainder being **Reinforced Concrete/Steel**.
- If the debris tonnage is converted to an estimated number of truckloads, it will require **13,040 truckloads (@25 tons/truck)** to remove the debris generated by the earthquake.

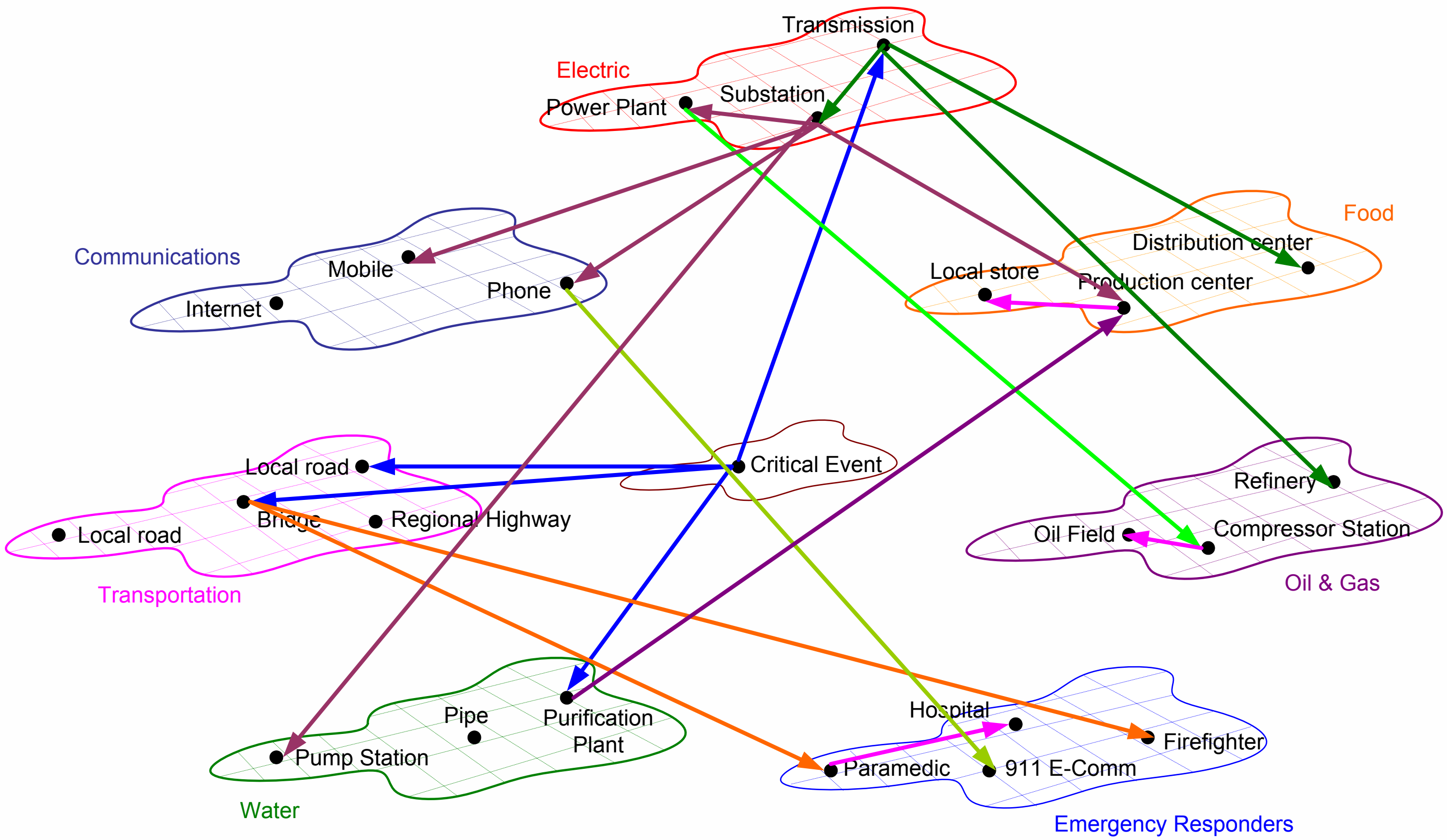


Kendall Fault Event

UNDERSTANDING INTERDEPENDENCIES AMONG CRITICAL INFRASTRUCTURES

System of Systems - interdependencies

- Many critical infrastructure Networks rely on one another in order to function
- In the event of a disaster, Critical Infrastructures can sustain significant damage which could render them inoperable
- Important to identify infrastructure interdependencies in order to mitigate the effects of a disaster



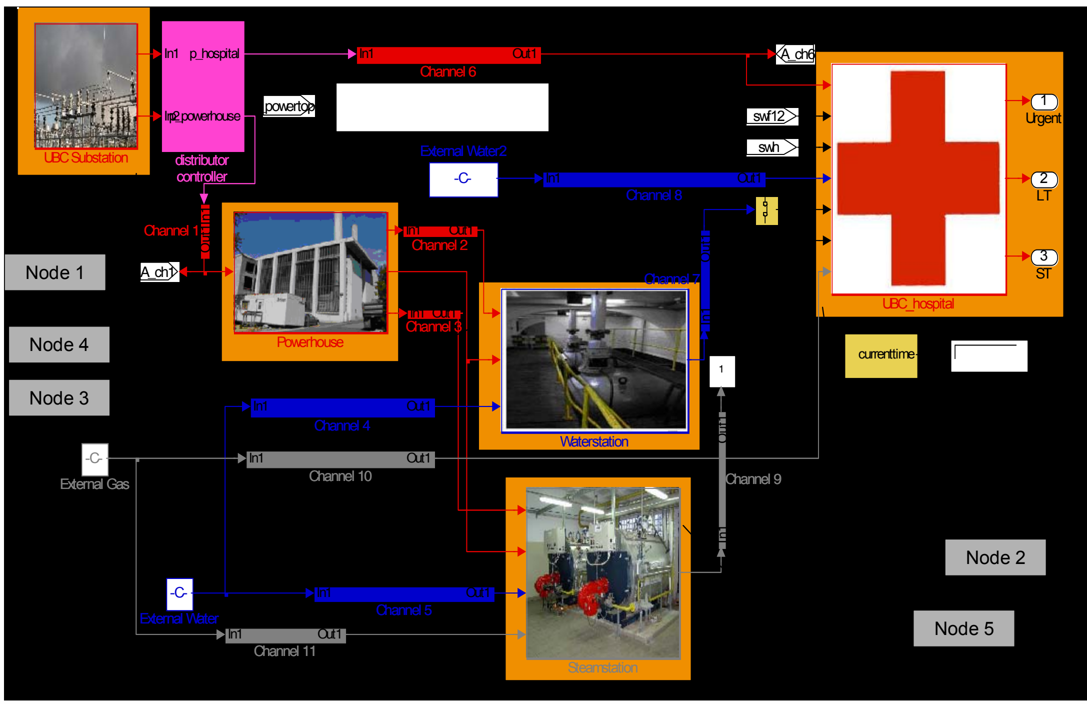
How do we do it?

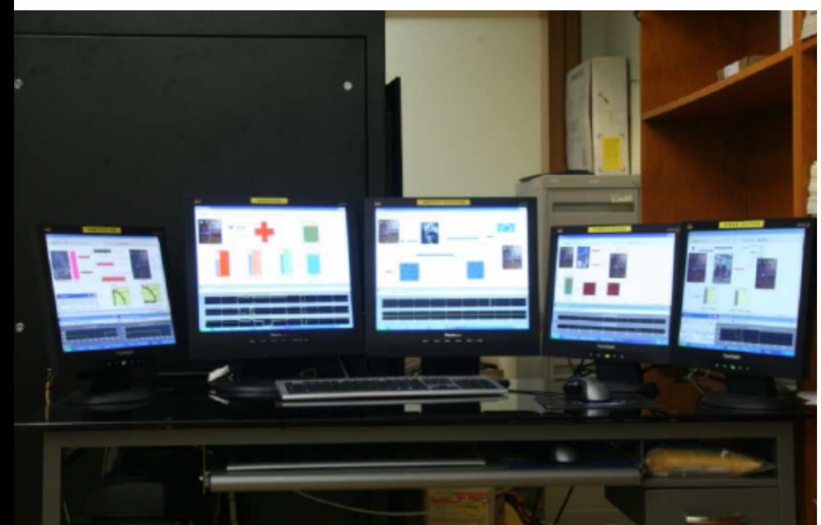
- First, there are interdependencies within and in between infrastructures networks
- Second, we need to recognize that interdependencies are time dependent and have very complex relationships
- Third, we have to recognize that this is a difficult problem to solve because it is highly nonlinear and time dependent

- The problem can be made more manageable by linearizing the interdependencies in segments of time, using Seismic Risk Assessment techniques for individual infrastructures and implementing a rational approach to combine the information available to determine the effect of these interdependencies

I2Sim

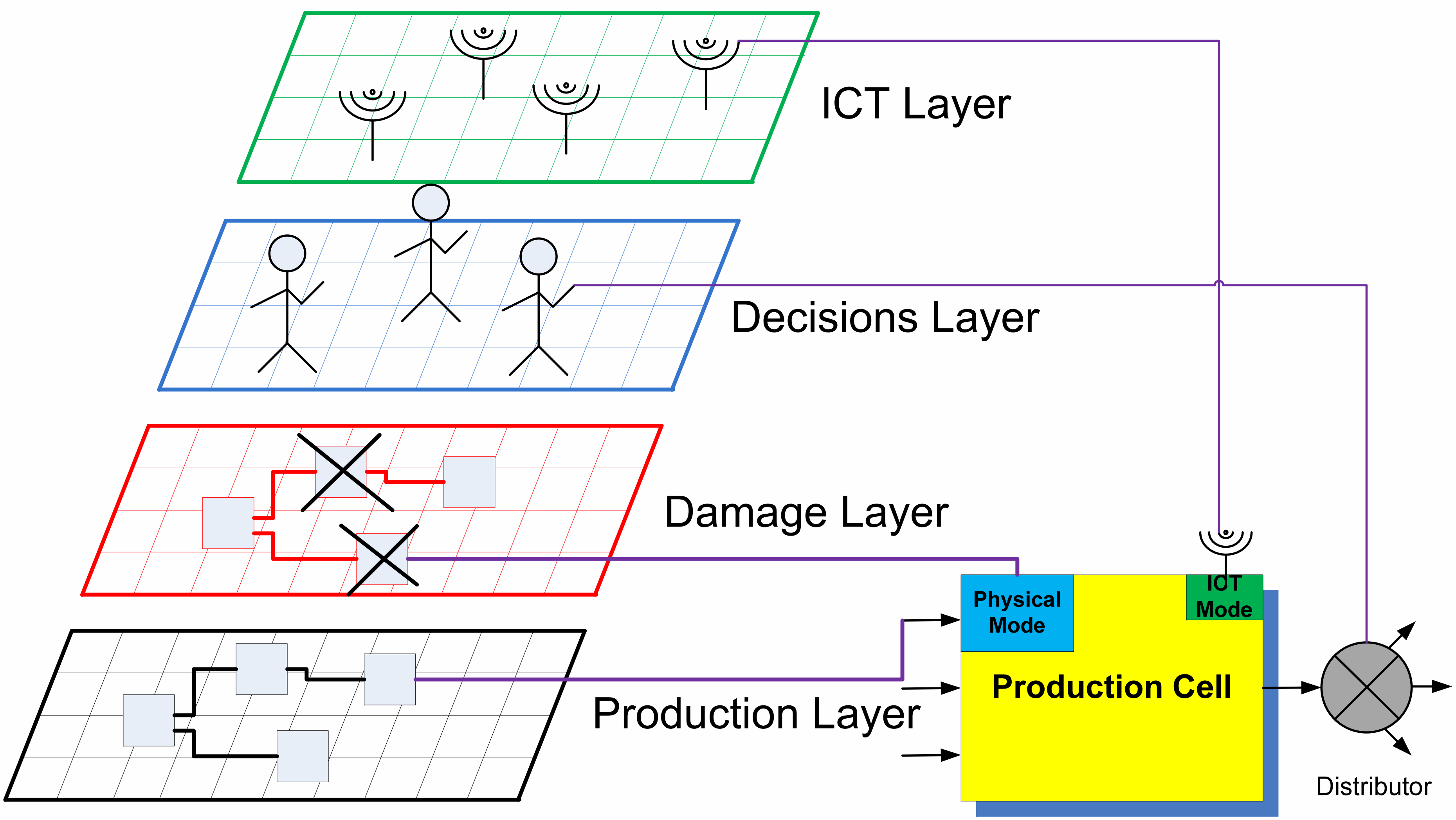
- I2Sim is a tool that we have developed to determine the consequences of the failure of one or more of the infrastructures



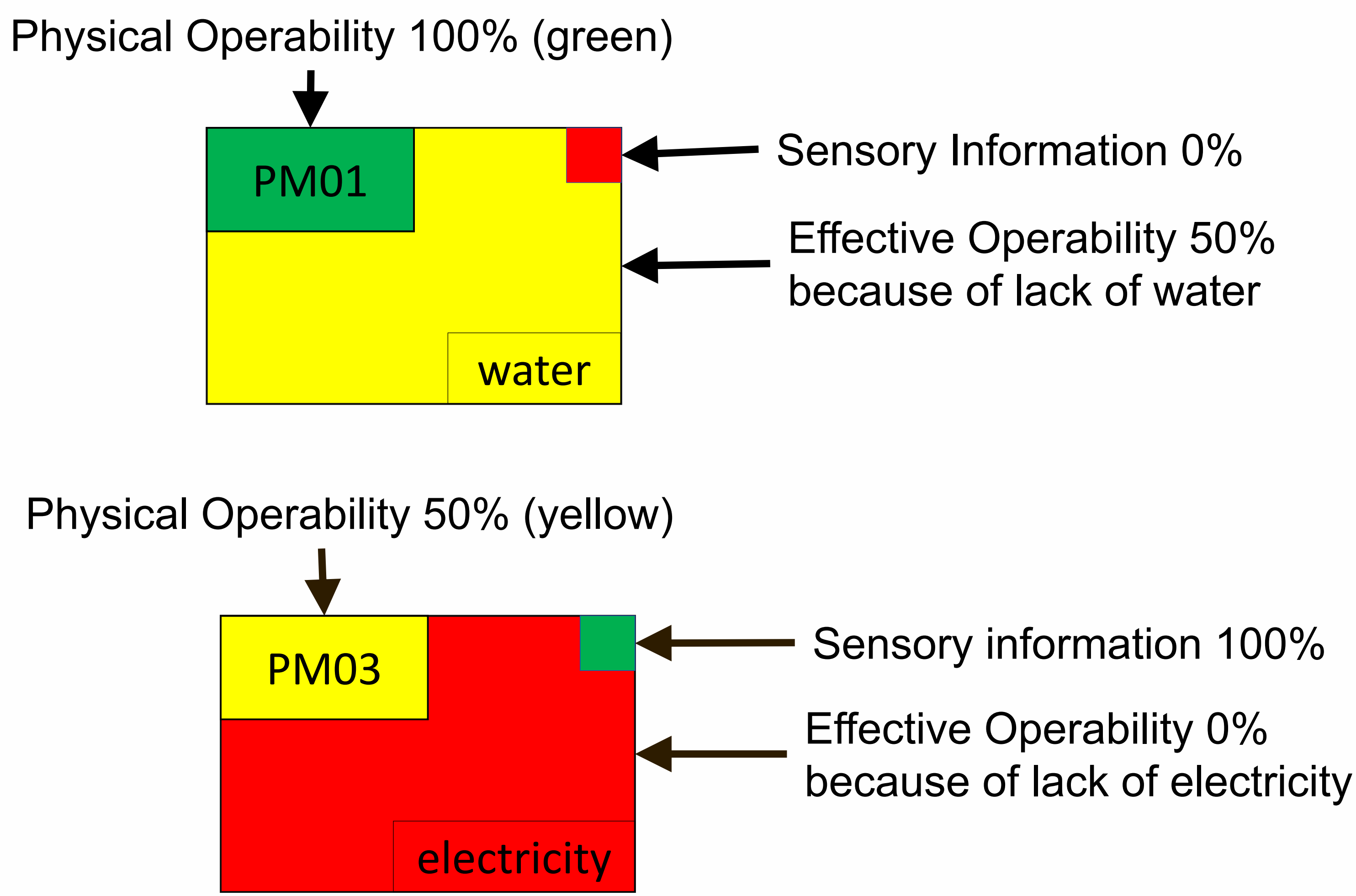


www.i2sim. ca

Superimposed Layers

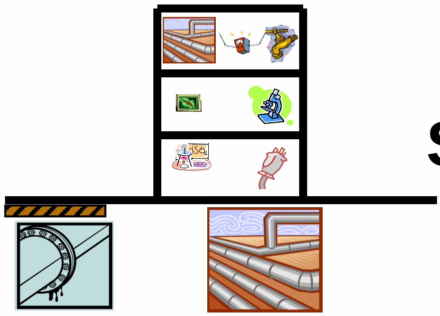


Cell's State

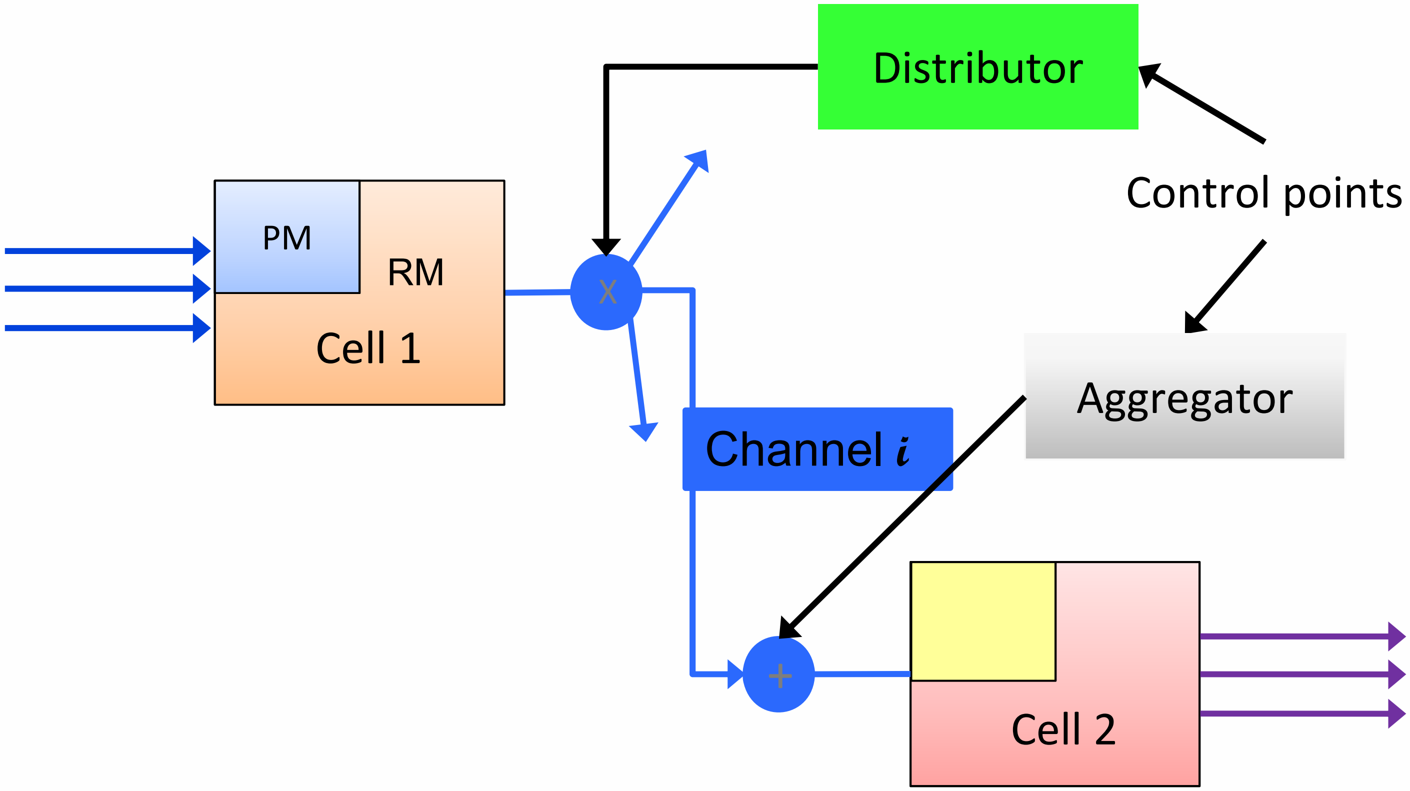


Physical Operability 100% (green)
PM01
water
Sensory Information 0%
Effective Operability 50%
because of lack of water
Physical Operability 50% (yellow)
PM03
electricity
Sensory information 100%
Effective Operability 0%
because of lack of electricity

i2Sim Model



Structure + NSCs + Lifelines



Interdependencies

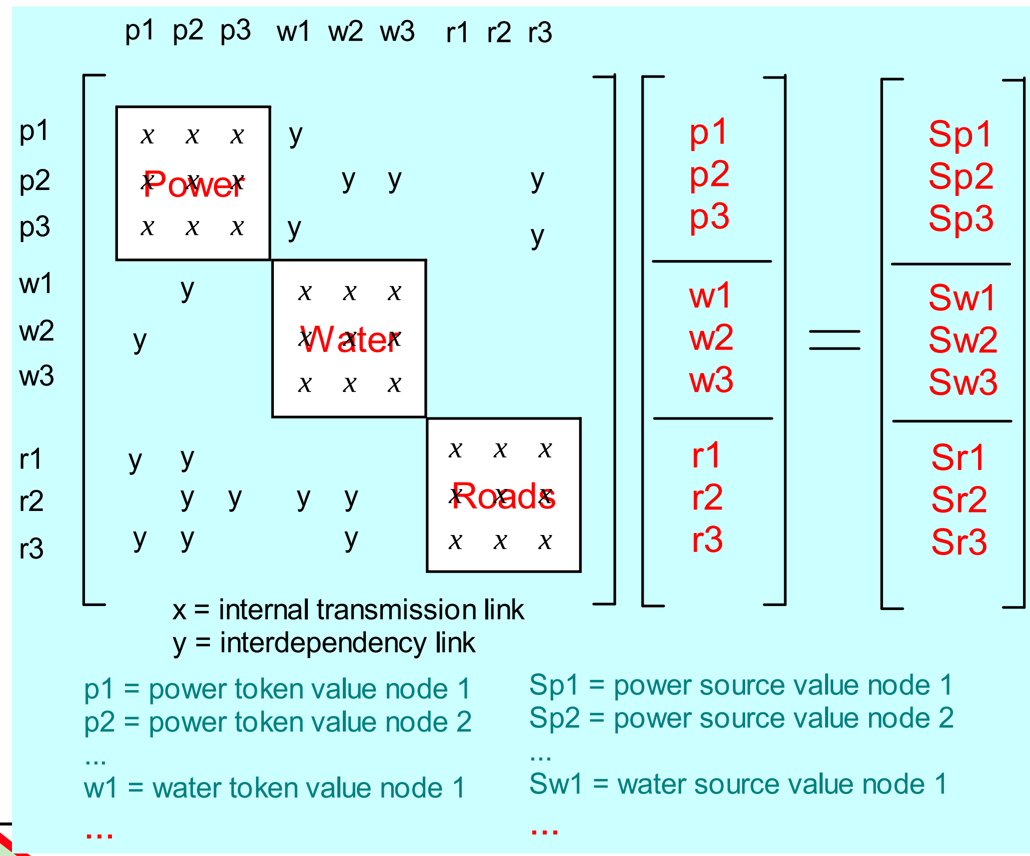
Can be represented by the following equation:

$$[\mathbf{T}][\mathbf{x}] = [\mathbf{w}]$$

[T]: Transportation matrix

[X]: Received Goods

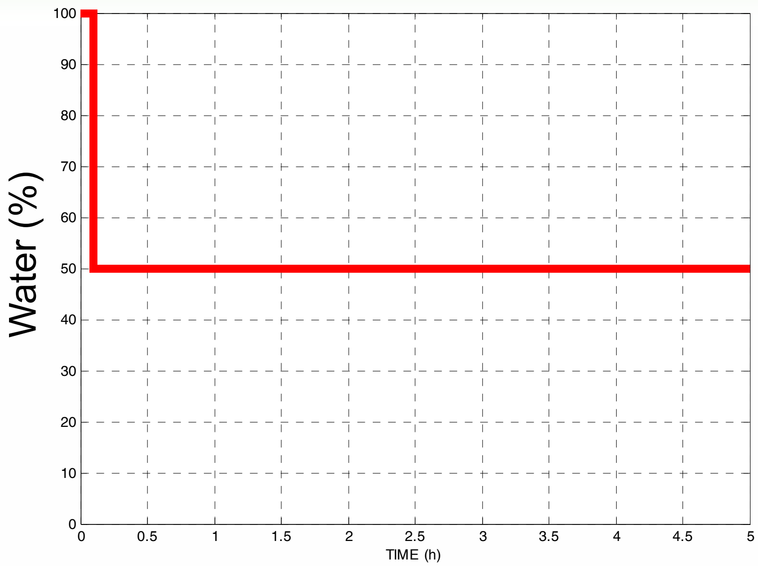
[W]: Sent Goods

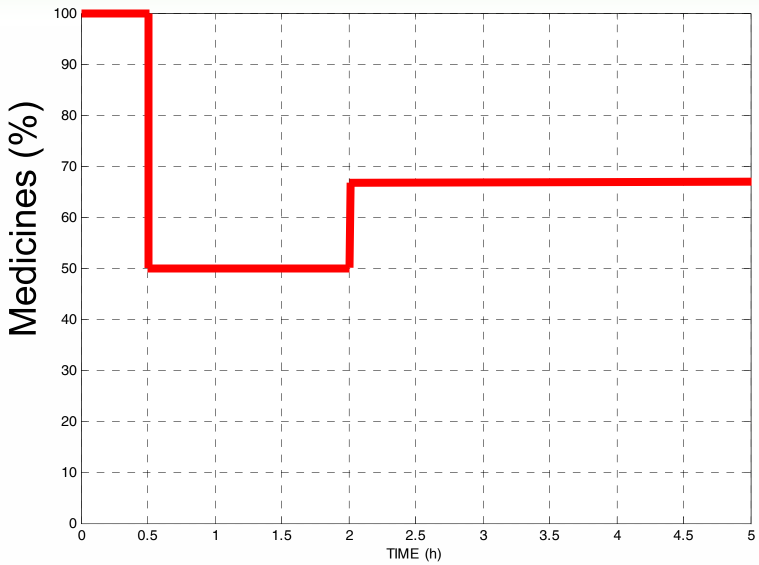


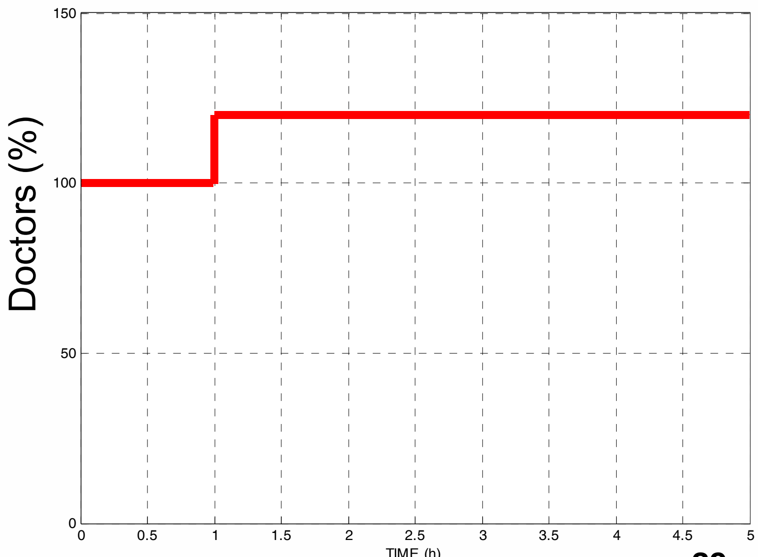
Real-Time Responsiveness

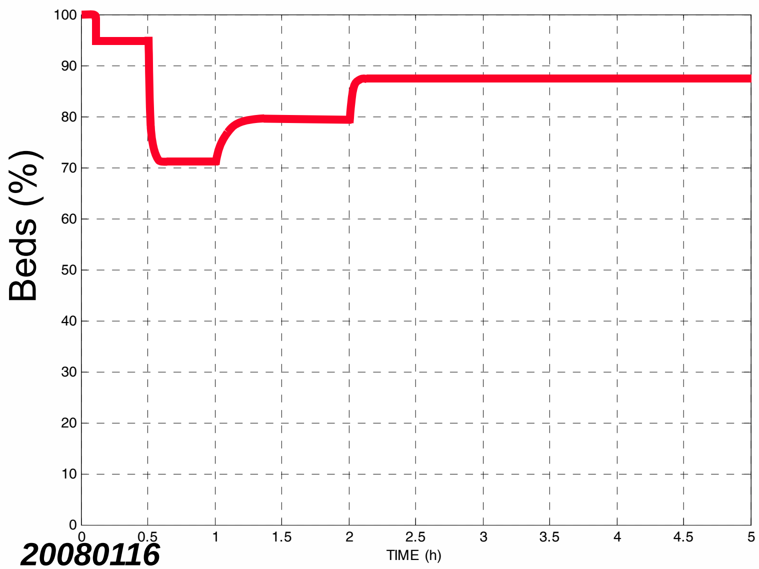
- Closed solution much faster than open iterative solutions (e.g., agent-based modelling) by two or three orders of magnitude
- As an example, a system of 3,000 cells with 15 inputs/outputs per cell (45,000 state variables) for a 10 hr scenario with Δt = 5 minutes can be anylized in a few seconds of computer time
- Interactive scenario playing is basically instantaneous

Cells Outputs

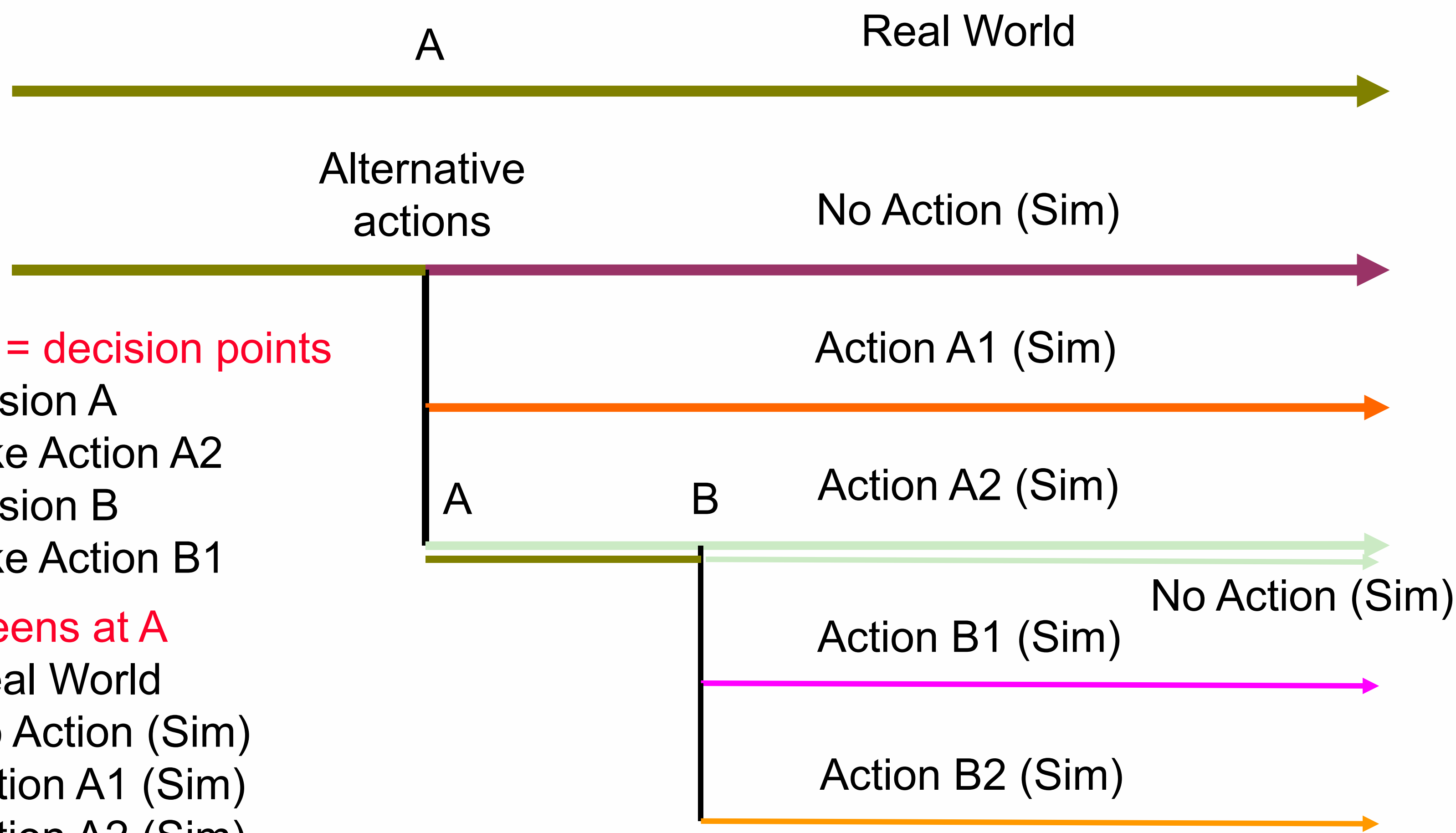








Decision Making Scenario



A, B = decision points

Decision A

- Take Action A2

Decision B

- Take Action B1

Screens at A

- Real World
- No Action (Sim)
- Action A1 (Sim)
- Action A2 (Sim)

UBC Campus Case Study

UBC Campus Case

Why modeling UBC campus?

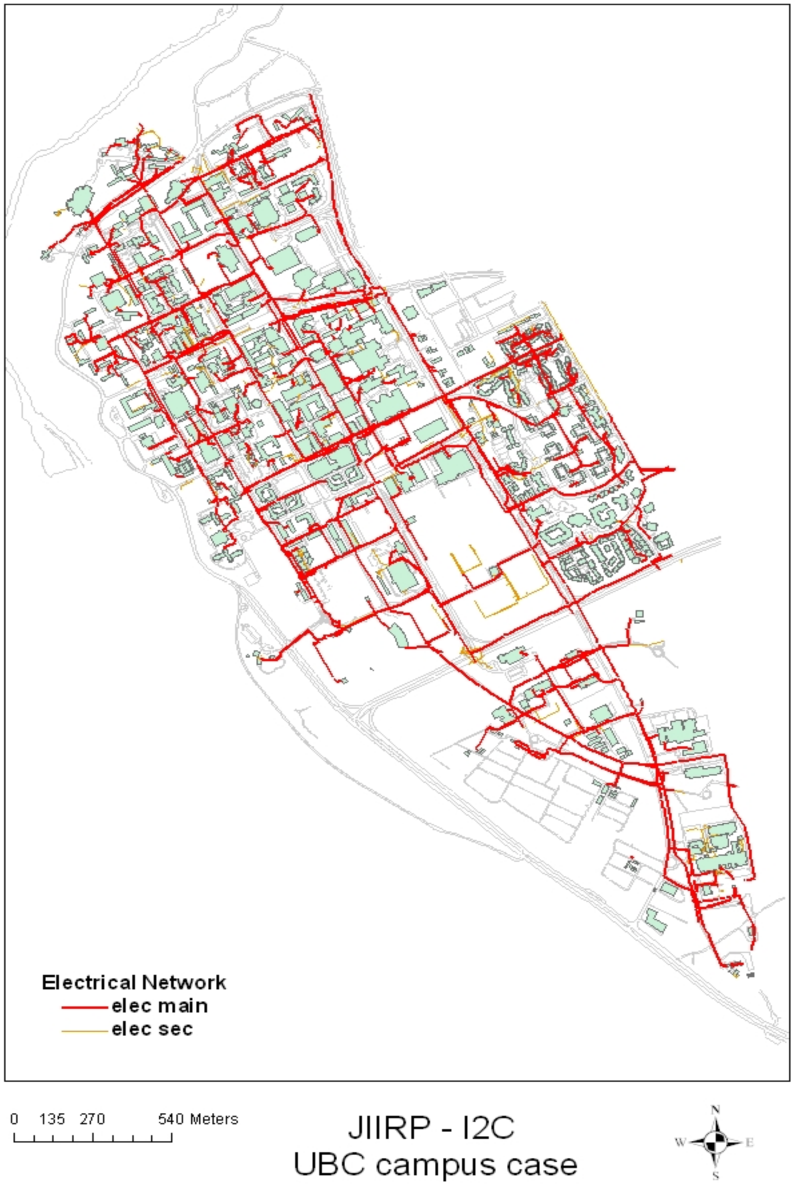
- The UBC campus shares many attributes of a small city
  - 47000 daily transitory occupants
  - 10000 full time residents
  - own utilities providers
- Information

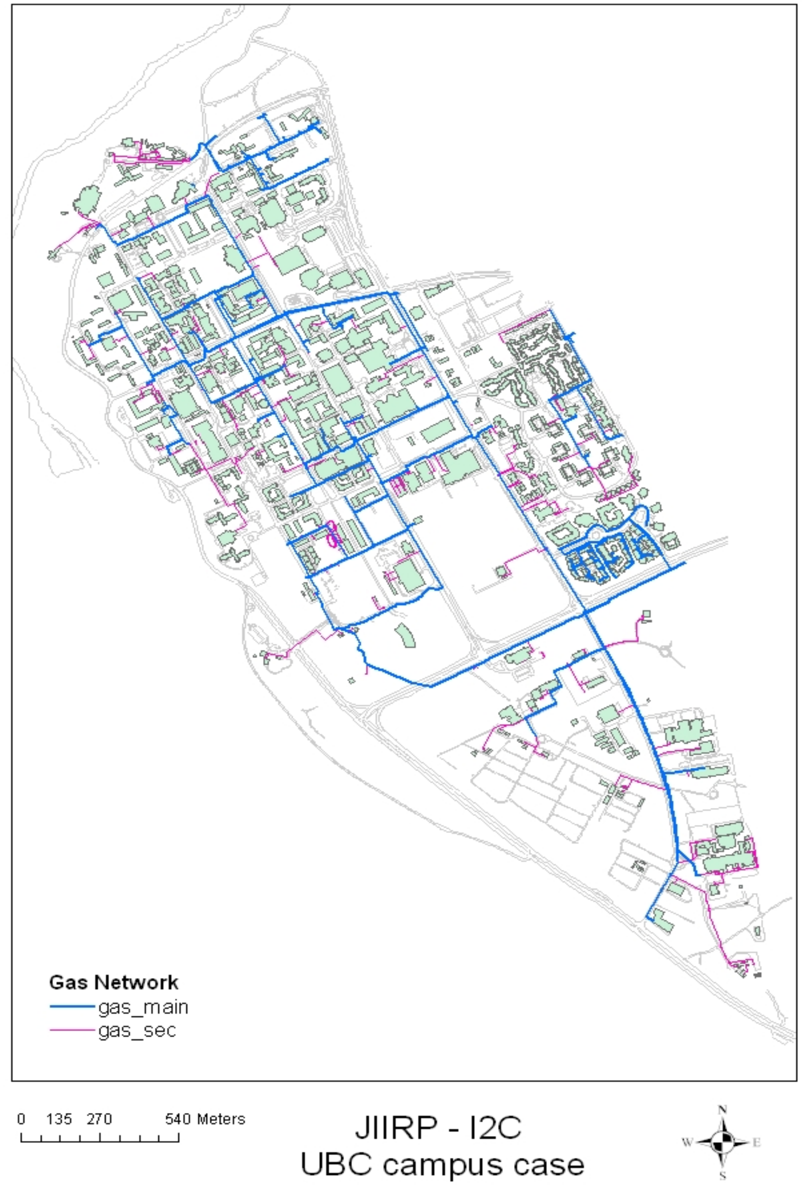
After an earthquake, you will have losses in the services (electricity, water, etc.)

<u>What will be the overall functionality of UBC?</u>

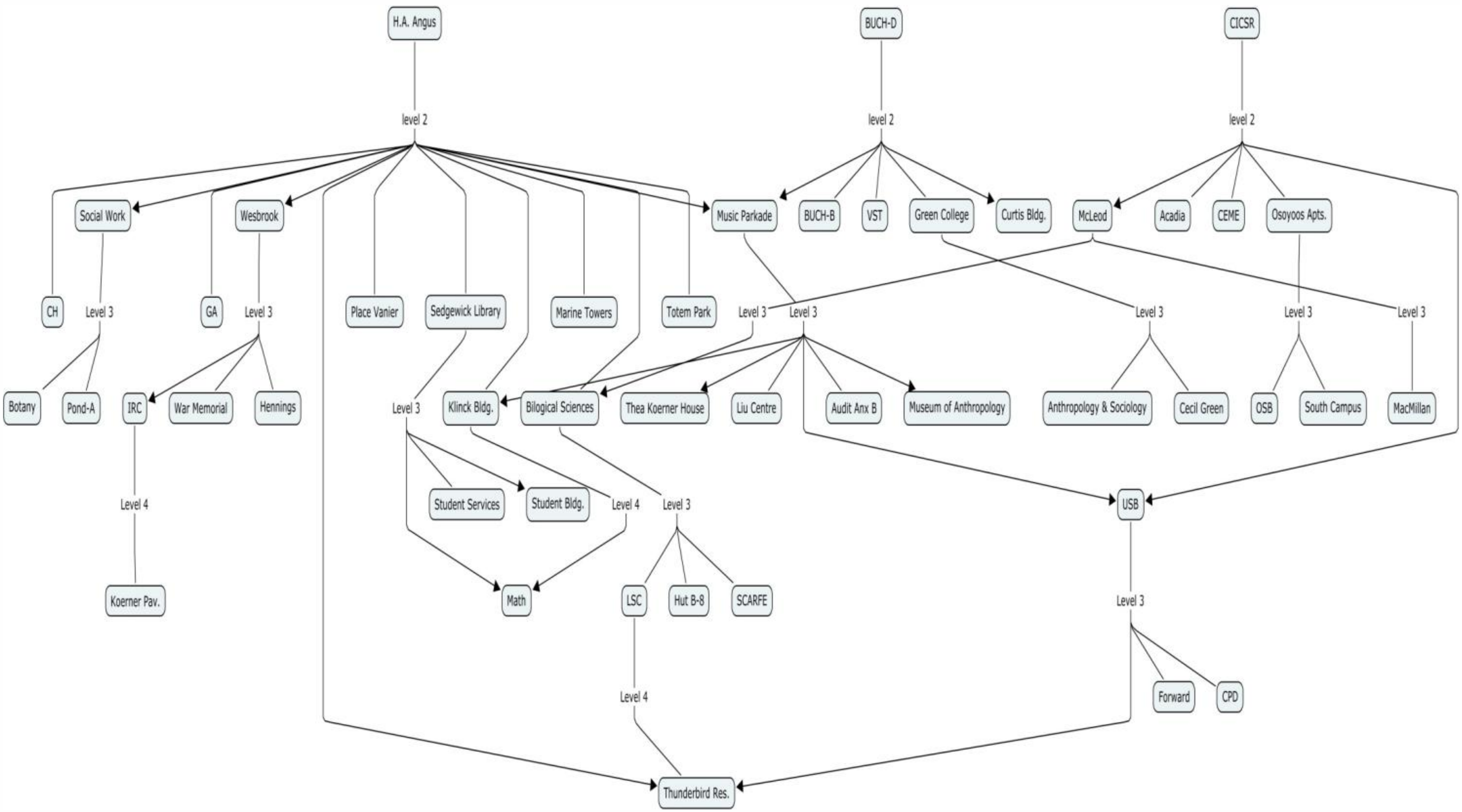
<u>Where to put the available resources?</u>

Campus Networks: GIS





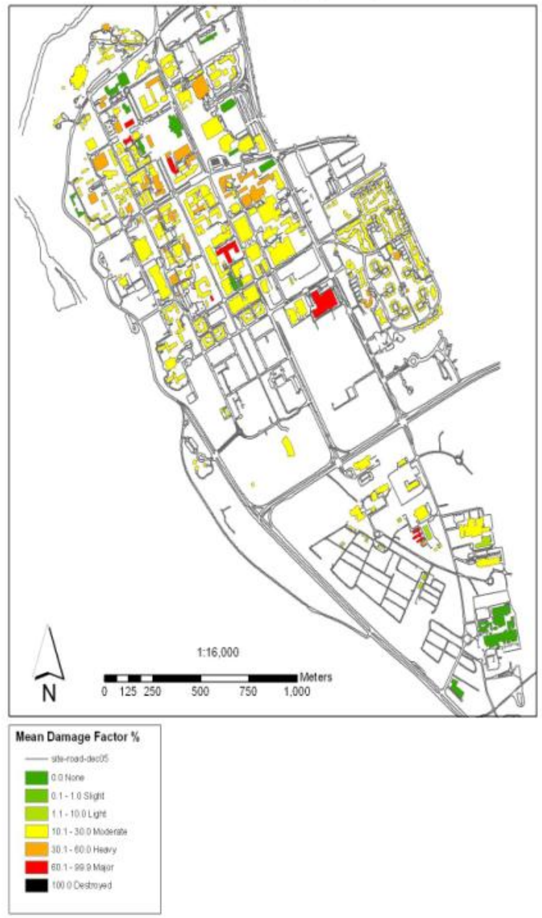
Campus Fiber Network



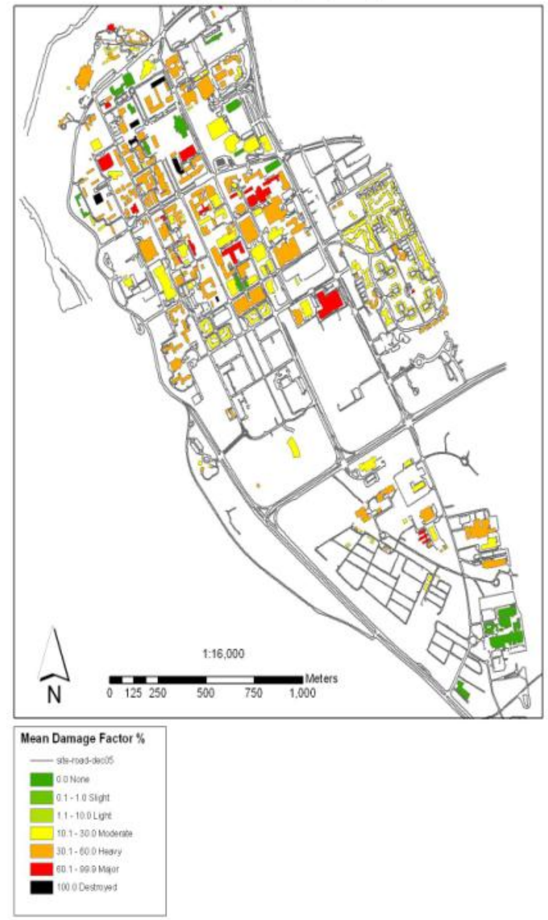
Earthquake Damage Assessment

BC31 Mean Damage Factors with Modifiers
Intensity VIII - UBC Campus

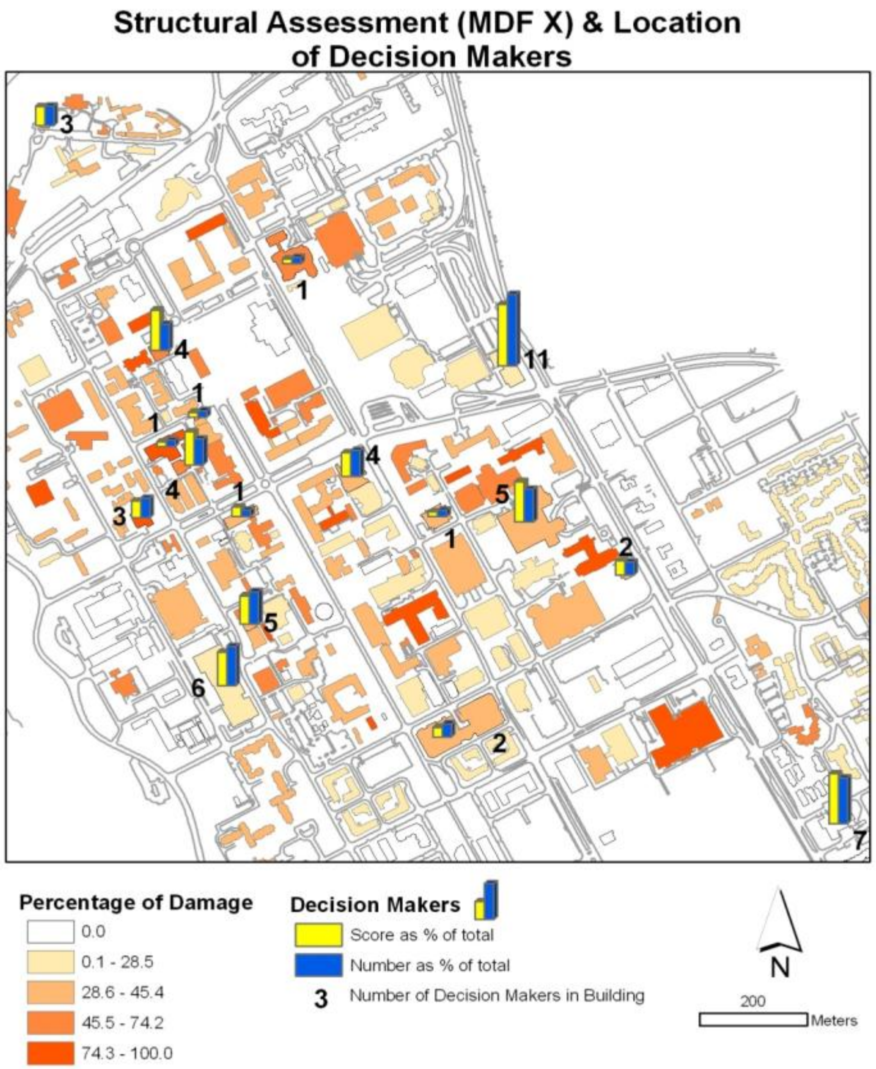
BC31 Mean Damage Factors with Modifiers
Intensity IX - UBC Campus

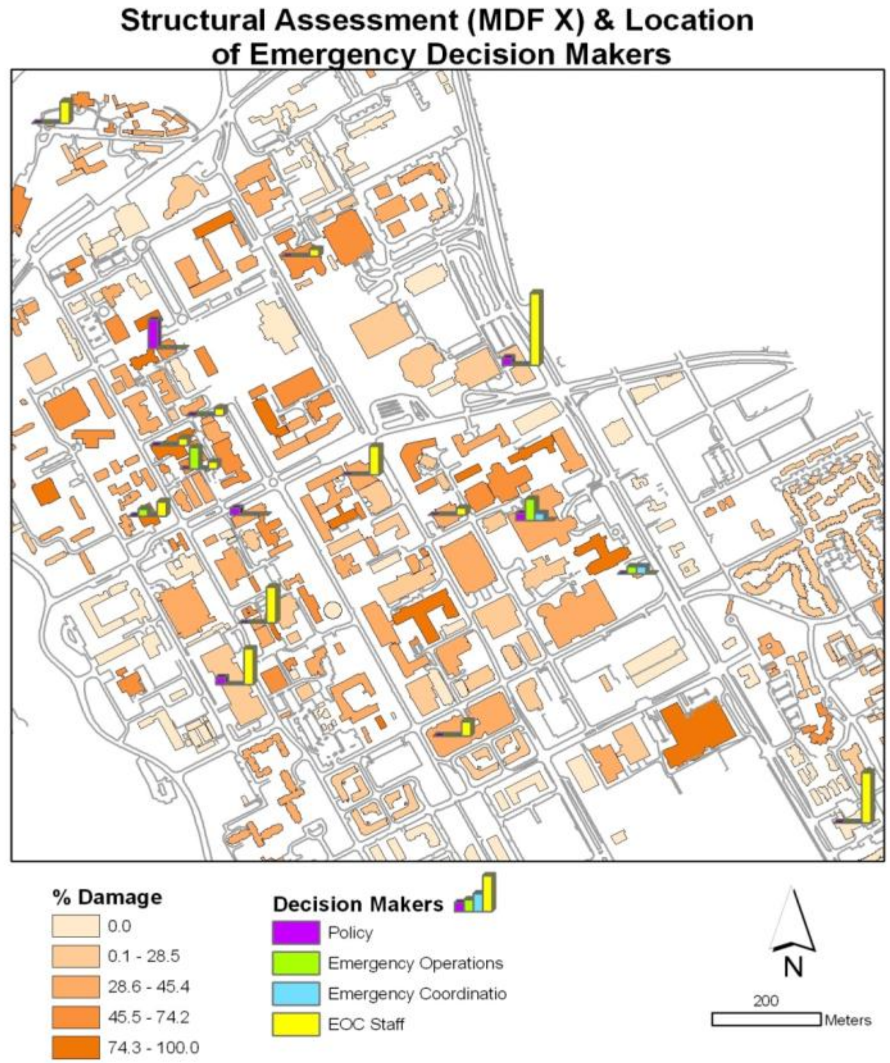


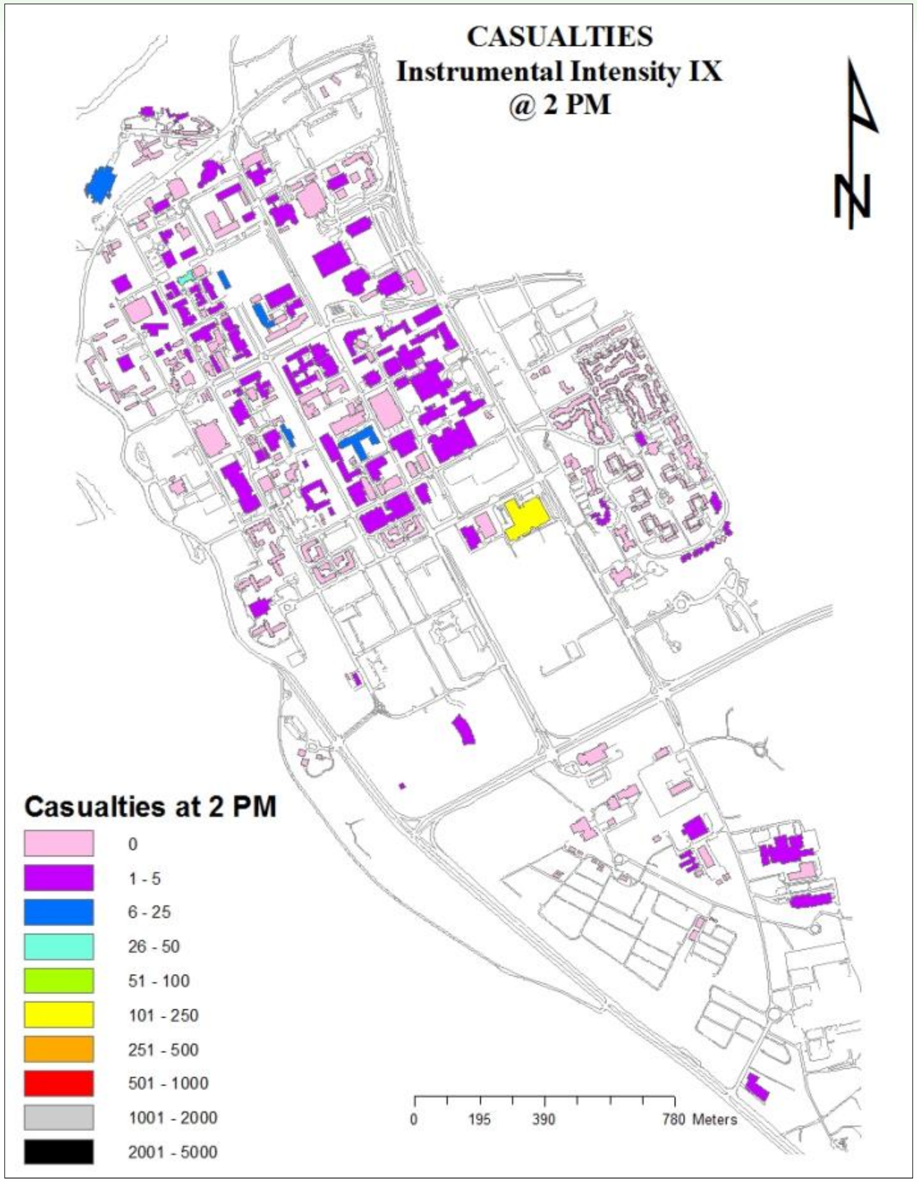
BC31 Mean Damage Factors with Modifiers
Intensity X - UBC Campus

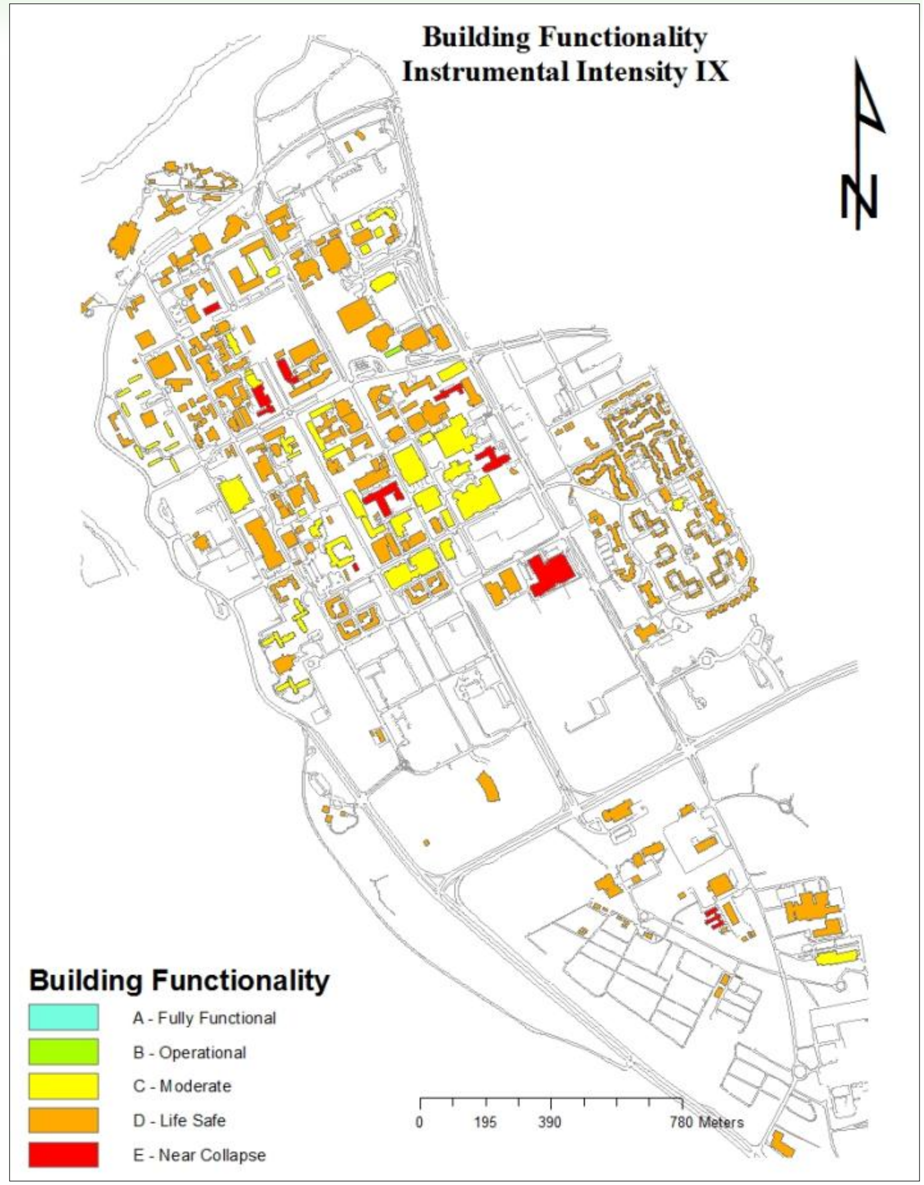


GIS: Decision Makers Risk Mapping



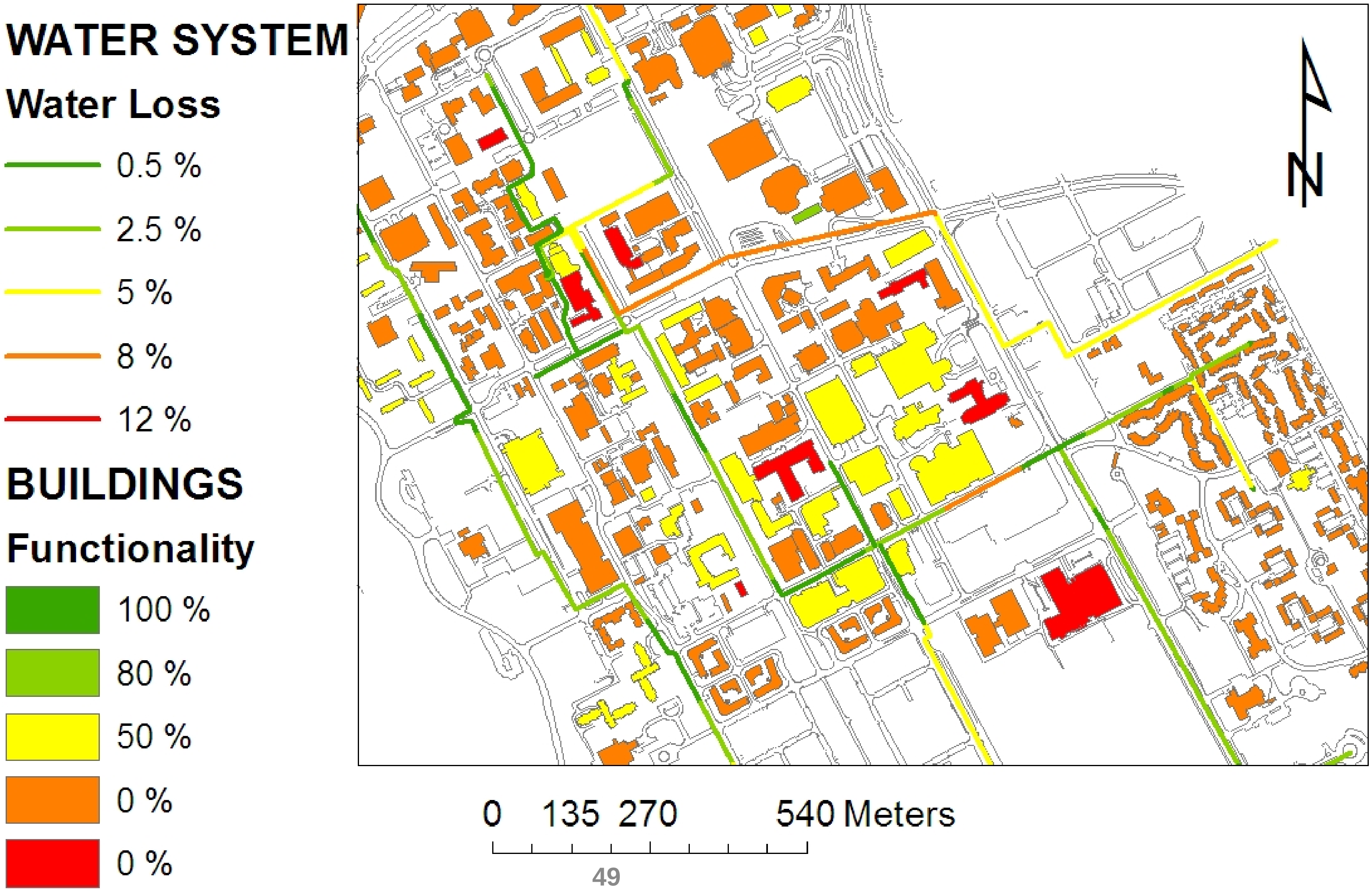



CASUALTIES
Instrumental Intensity IX
@ 2 PM
N
Casualties at 2 PM
0
1 - 5
6 - 25
26 - 50
51 - 100
101 - 250
251 - 500
501 - 1000
1001 - 2000
2001 - 5000
0
195
390
780 Meters

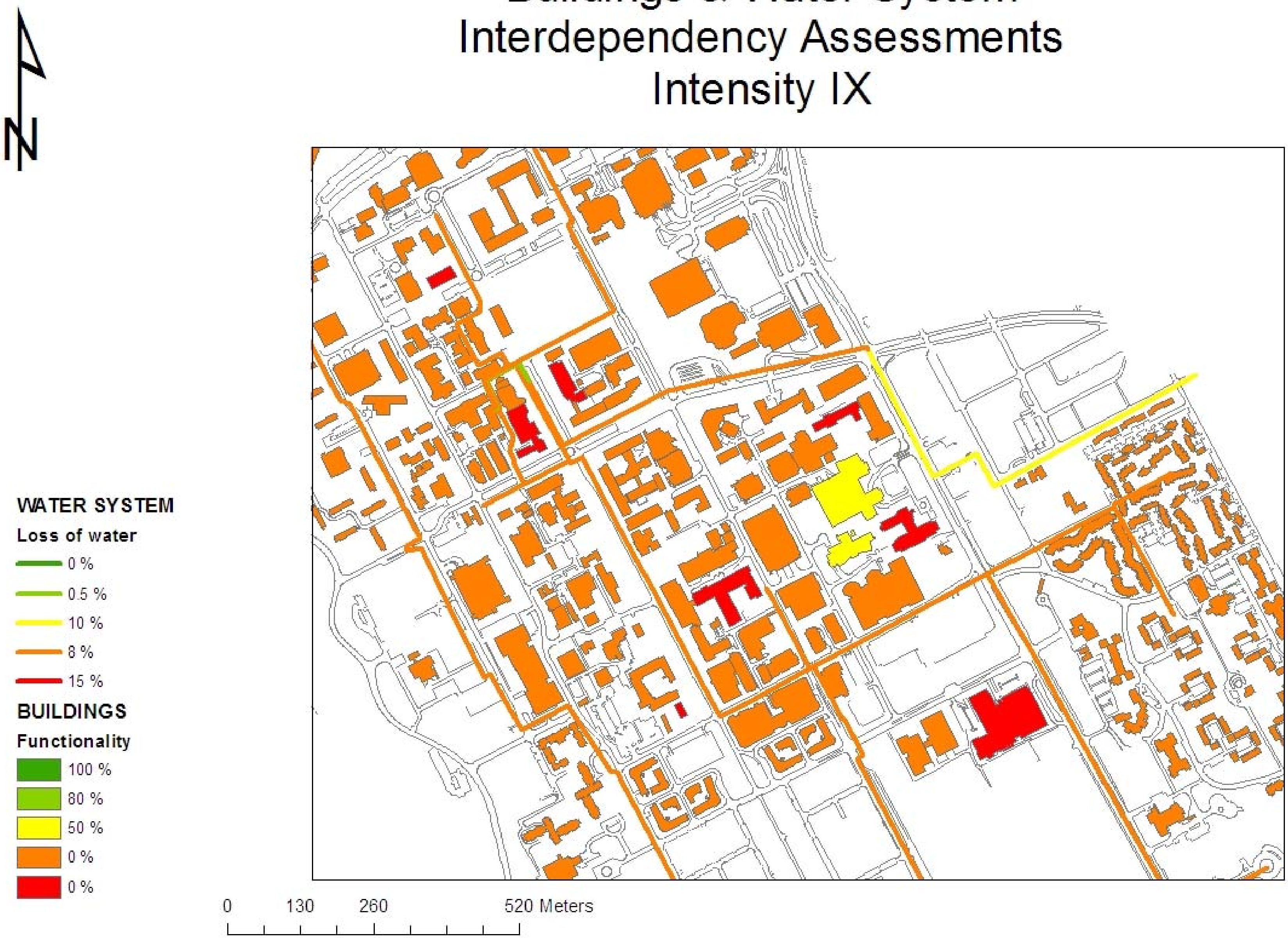

Building Functionality
Instrumental Intensity IX
N
Building Functionality
A - Fully Functional
B - Operational
C - Moderate
D - Life Safe
E - Near Collapse
0
195
390
780 Meters

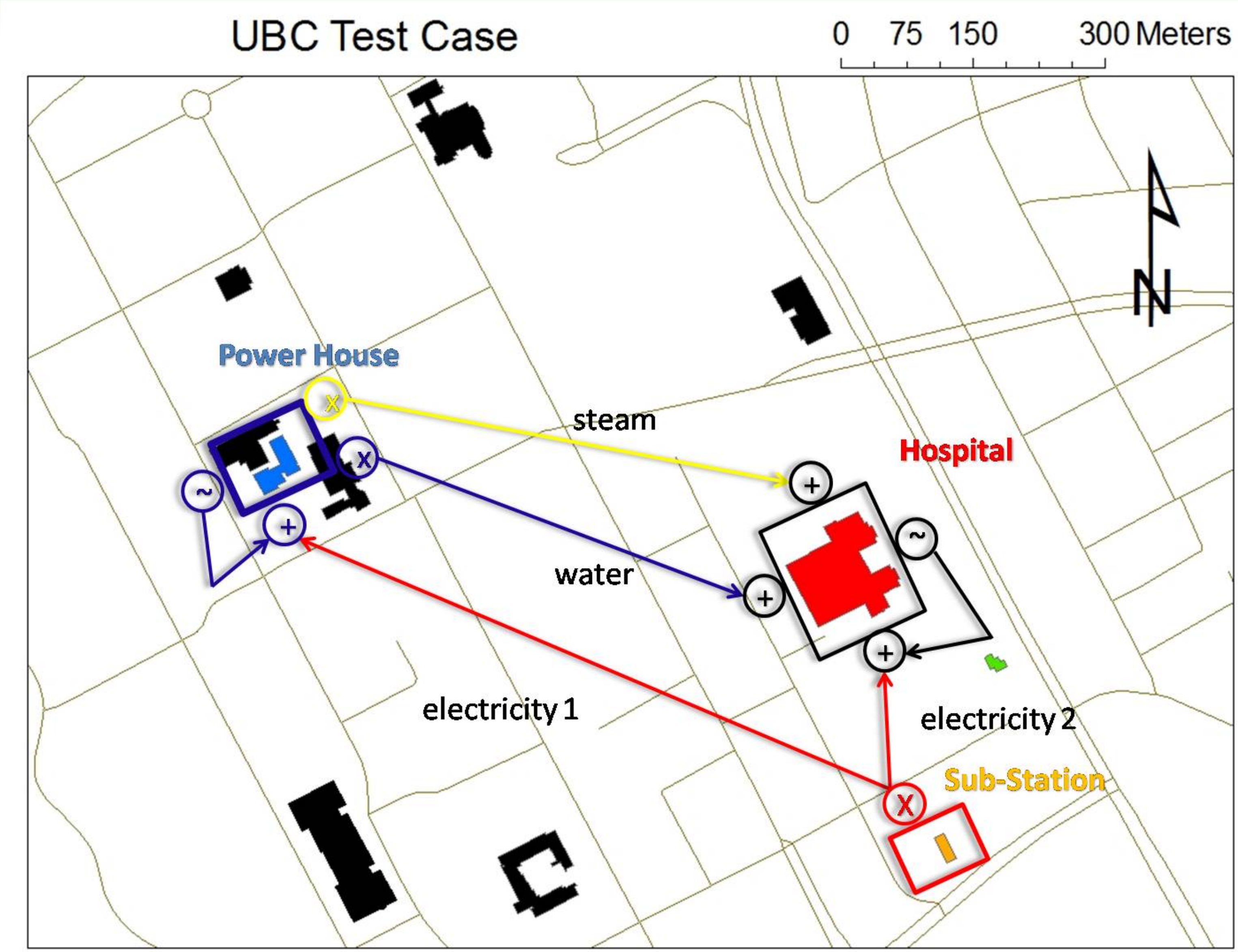
Water system

Buildings & Water System
Overlayed Damage Assessments
Intensity IX

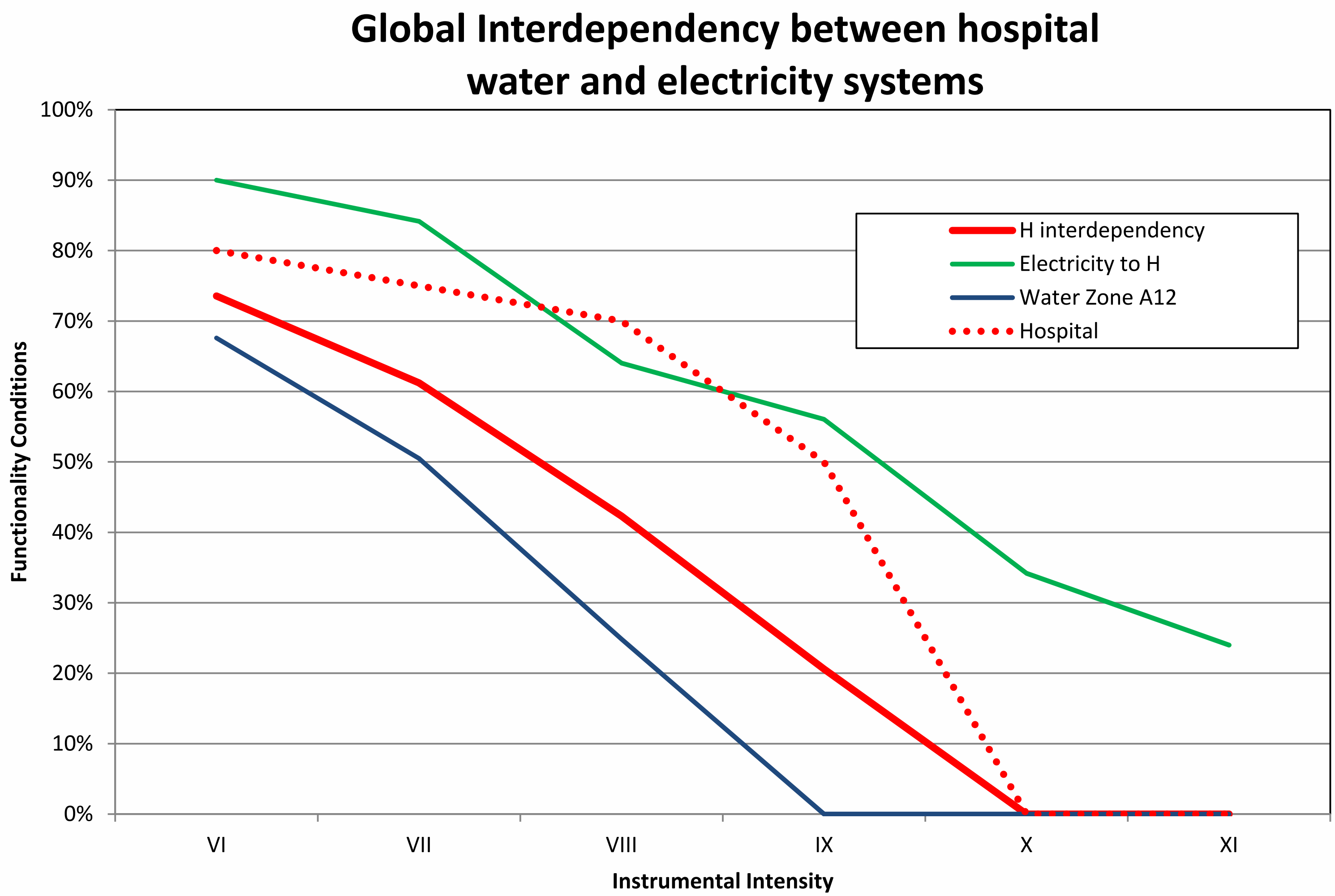


Buildings & Water System Interdependency Assessments Intensity IX

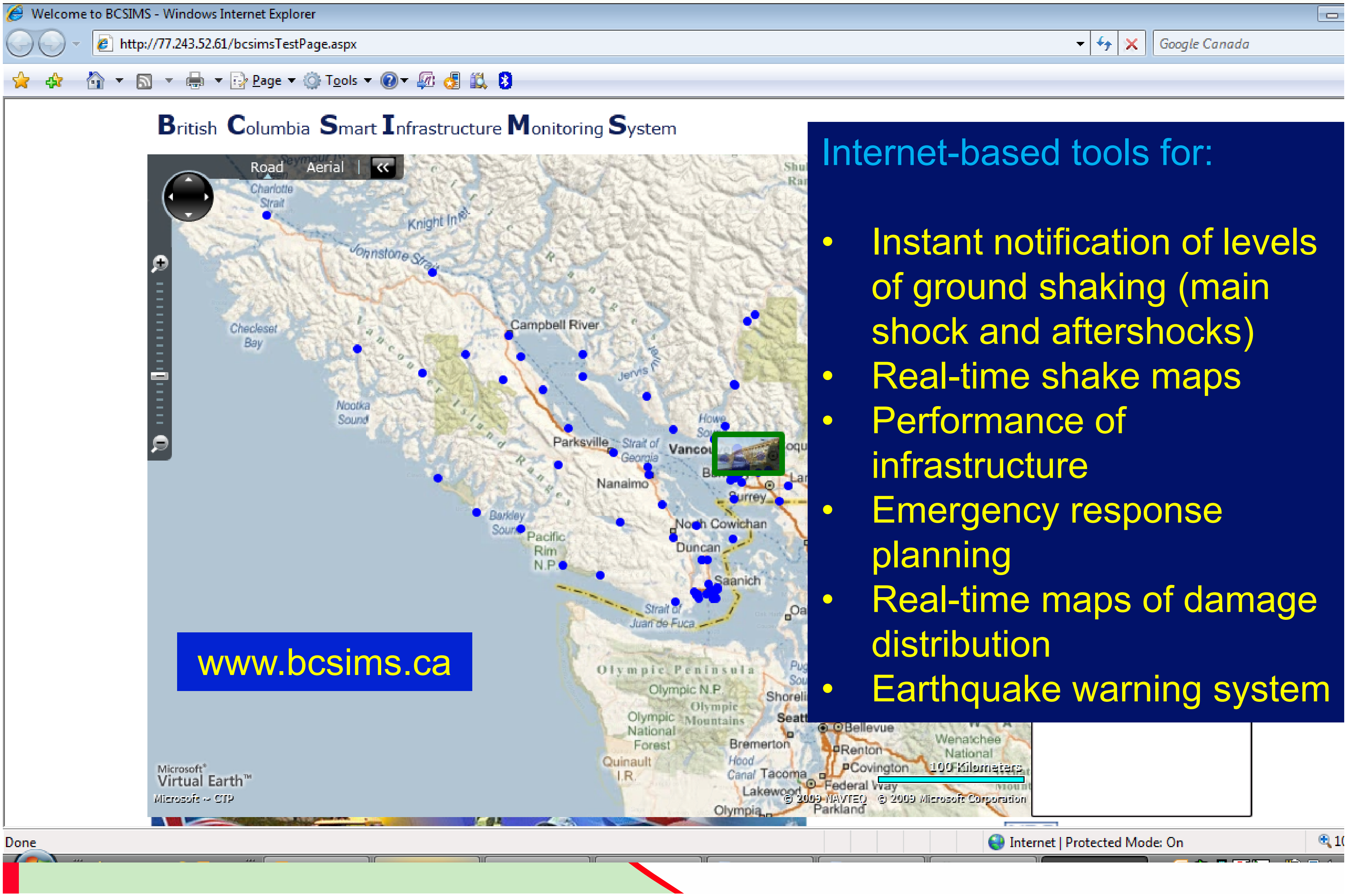



UBC Test Case
0 75 150 300 Meters
N
Power House
X
X
~
+
steam
water
Hospital
+
+
~
+
electricity 1
electricity 2
X
Sub-Station

Global Interdependency of the Hospital



Collaborative effort between BCMOT-UBC-GSC (and BCMOE)



Internet-based tools for:

- Instant notification of levels of ground shaking (main shock and aftershocks)
- Real-time shake maps
- Performance of infrastructure
- Emergency response planning
- Real-time maps of damage distribution
- Earthquake warning system

Remarks

- When interdependencies are taken into account, they can help develop more realistic risk reduction programs and emergency response plans.
- Methodologies being developed are useful for the identification of regions of high seismic risk and the interdependencies among critical infrastructures
- Real-time information tools, such as the BCSIMS project, and simulators, such as I2SIM, are powerful tools that allow the investigation of risk levels and interdependencies among Critical Infrastructure, so that consequences can be minimized.
- Improving response to infrastructure failures is a necessary condition for disaster resilience
- **First priority during disaster situations is, and should be, human survival**