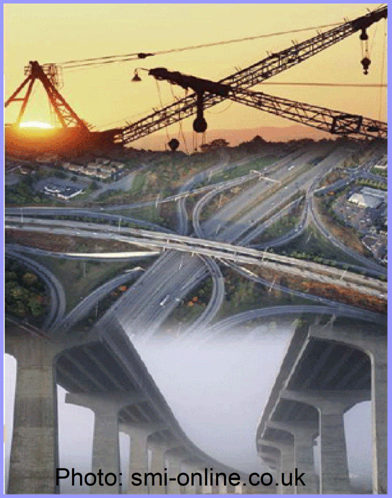


Building Resilience to Extreme Events in Regional Infrastructure Systems

Tim McDaniels
Professor, University of British Columbia

University of Chile August 2010

Big Picture

- Everyone is talking about resilience, for good reasons
- Most work is retrospective, theoretical, narrative, not applied or practical
- Our approach: characterize resilience and set priorities for mitigation action
- This presentation discusses resilience and mitigation priorities for an earthquake scenario in the Greater Vancouver, Canada

AIDRC

Acknowledgements

- The U.S. National Science Foundation (NSF)
- The Knowledge-building, Outreach and Awareness (KOA) program of Infrastructure Canada
- The Climate Decision Making Center at Carnegie Mellon University funded by NSF
- Team members at the University of British Columbia and University of Washington : Tim McDaniels, Stephanie Chang, Dorothy Reed, Jana Fox, Raj Dhariwal, Holly Longstaff, David Hawkins, Courtney Beaubien, & Gerard Chew

UBC

Introduction overview

- Resilience
  - Concepts and definitions
- Infrastructure Failure Interdependencies (IFIs)
- Our approach
  - Study methods
  - Key findings
  - Publications

Flood preparations along the Fraser River (June 2007, New Westminster, BC)

Collapse of Shi-wei Bridge, 1999 Chi-Chi Taiwan earthquake (Photograph by Ian G. Buckle, MCEER)

The concept of resilience

- A significant concept to many fields including psychology, materials science, economics, and environmental studies
- Many reasons to embrace the concept, but strikingly little practical efforts as to how to make decisions to apply it
- Related important concept: systemic risk (layers of systems, in which risks run across layers of governance)

- characteristics of resilience according to the resilience Alliance:

1. "The amount of change the system can undergo and still retain the same controls on function and structure"

Resilience defined

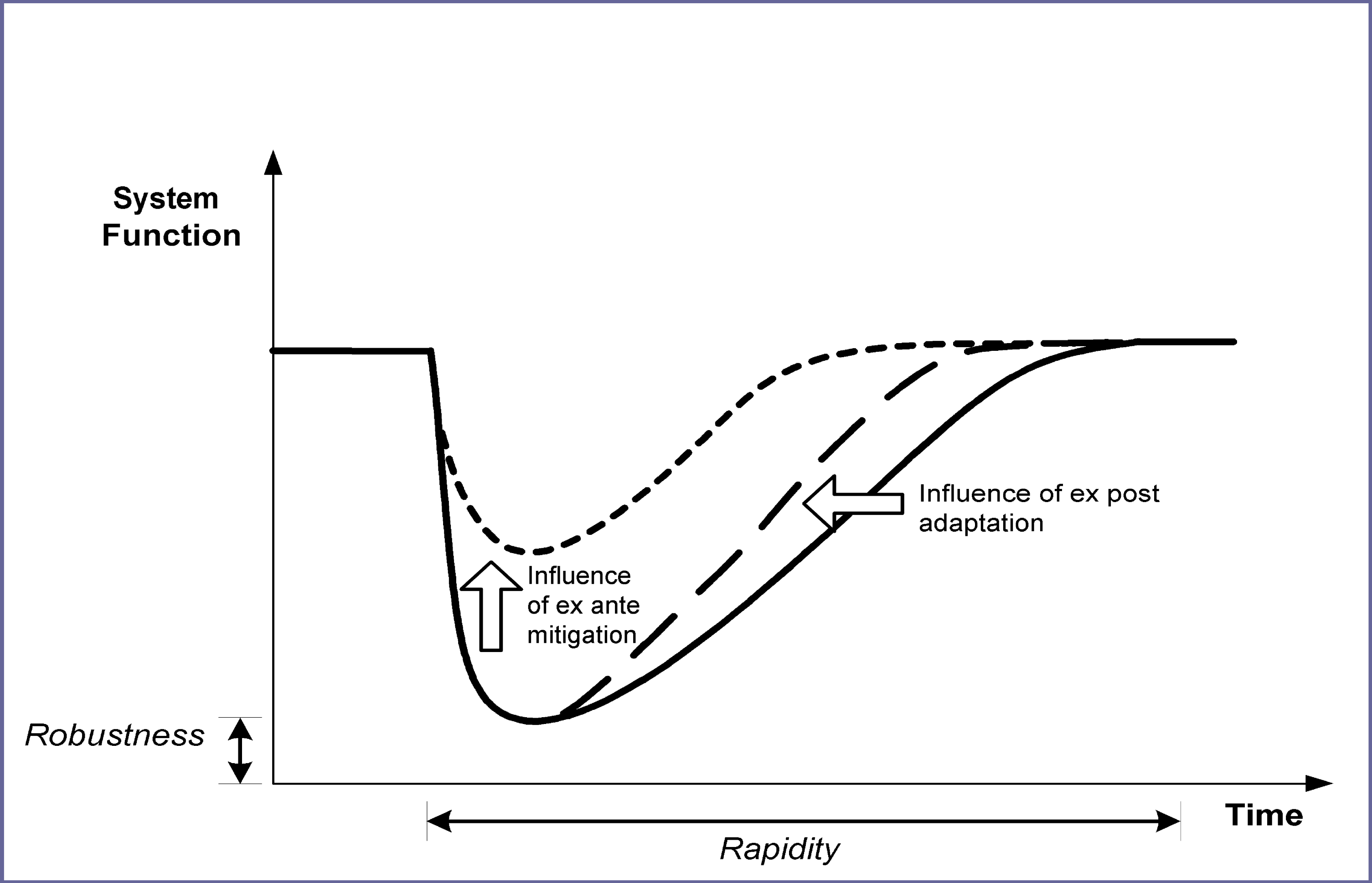
- While definitions of resilience differ, they concur that resilient complex systems (including ecological, engineering or even governance systems) are those that can absorb shocks while still maintaining function

Key properties of resilience

The MCEER framework for resilience identifies "robustness" and "rapidity" as two key properties of resilience.

- *Robustness:* "the ability… to withstand a given level of stress… without suffering degradation or loss of function"
- *Rapidity: "*the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption." (MCEER, 2006, p.19)

Effects of decision-making on resilience



* From McDaniels, Chang et al, forthcoming in Global Environmental Change

Regional resilience

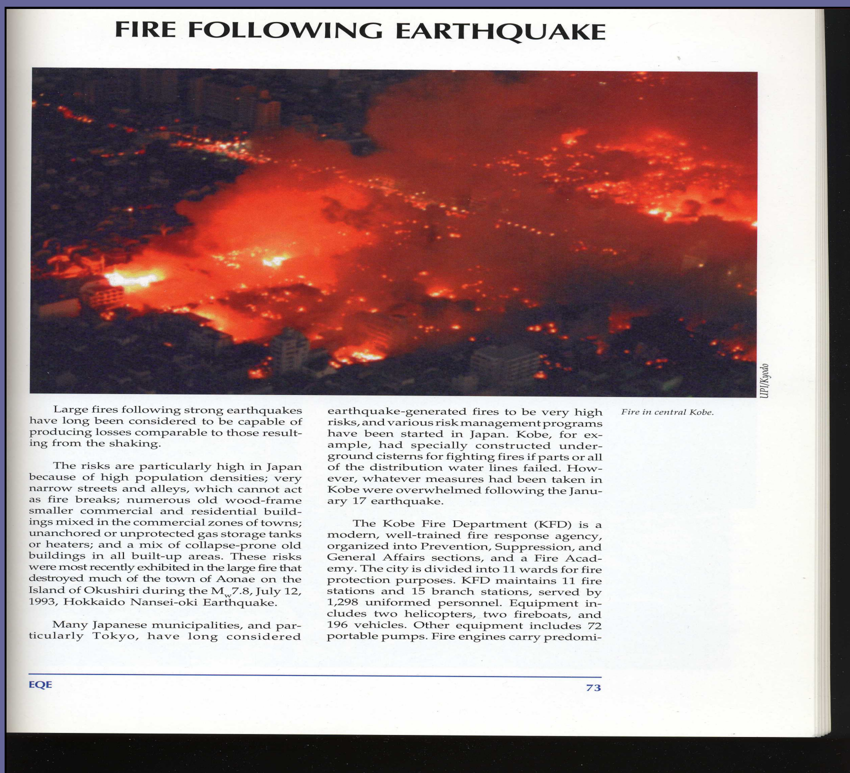
- Many researchers have called for research needed on understanding disaster resilience in the context of cities (Godschalk, 2003)
- Calls for concerted efforts aimed at making cities and interconnected urban regions more "disaster-resilient" (1999; UN ISDR, 2005; Berke and Campanella, 2006).

Fostering infrastructure resilience

- Cross-sectoral planning for infrastructure resilience faces at least three challenges: (1) incomplete incentives, (2) partial information, & (3) few opportunities for learning.
- Hence relying only on market incentives for firms to control risk is not enough. There is a high level of "systemic risk" that arises over and above firm risk
- Our approach addresses these challenges through structured data-gathering and information-sharing in a new approach to regional infrastructure planning

Infrastructure Failure Interdependencies

IFIs are failures in one infrastructure system that are due to failures in another infrastructure system.



FIRE FOLLOWING EARTHQUAKE

UPI/Kyodo

Fire in central Kobe.

Large fires following strong earthquakes have long been considered to be capable of producing losses comparable to those resulting from the shaking.

The risks are particularly high in Japan because of high population densities; very narrow streets and alleys, which cannot act as fire breaks; numerous old wood-frame smaller commercial and residential buildings mixed in the commercial zones of towns; unanchored or unprotected gas storage tanks or heaters; and a mix of collapse-prone old buildings in all built-up areas. These risks were most recently exhibited in the large fire that destroyed much of the town of Aonae on the Island of Okushiri during the M_w7.8, July 12, 1993, Hokkaido Nansei-oki Earthquake.

Many Japanese municipalities, and particularly Tokyo, have long considered earthquake-generated fires to be very high risks, and various risk management programs have been started in Japan. Kobe, for example, had specially constructed underground cisterns for fighting fires if parts or all of the distribution water lines failed. However, whatever measures had been taken in Kobe were overwhelmed following the January 17 earthquake.

The Kobe Fire Department (KFD) is a modern, well-trained fire response agency, organized into Prevention, Suppression, and General Affairs sections, and a Fire Academy. The city is divided into 11 wards for fire protection purposes. KFD maintains 11 fire stations and 15 branch stations, served by 1,298 uniformed personnel. Equipment includes two helicopters, two fireboats, and 196 vehicles. Other equipment includes 72 portable pumps. Fire engines carry predomi-

EQE 73

Urban fires in 1995 Kobe Earthquake

(Nojima and Kameda, 1996)

Power outage in Kobe led to:

- Malfunction of traffic signals
- Loss of satellite emergency communications
- Hospital shutdowns
- Loss of water filtration plants and pump stations
- Loss of water and elevators in high-rises
- Fire ignitions (gas leaks and electricity sparks)
- Lack of heating at shelters

Database of Interdependencies and Impacts

- Initiating event
- Interdependency
  - Impacted system
- Consequence
  - Severity
  - Type
  - Spatial extent
  - No. people
  - Duration
- 10 events, 785 unique records

EXAMPLE:

Power outage

Refrigerators and freezers stop working

Millions of perishable food items thrown out

Fresh food supply low in food banks, stores; spoiled food could cause illness

Overall approach

- Emphasis on IFIs as major source of societal impact
- Reliance on judgments of informed participants (infrastructure system owners and operators) to characterize vulnerability, informed by historical review of experience in similar extreme events
- Also use judgments to help set priorities for regionally oriented mitigation efforts to build resilience
- Overall: vulnerability and decision process to increase resilience and overcome governance gaps

AIDRC Approach

Hazard Scenario & Extreme Event Database

- Develop basic hazard scenario (focusing event)
- Summarize previous experience (actual events)

Expert Interviews

- Infrastructure disruption and recovery
- Infrastructure interdependencies
- Cross-sector expectations

Data Synthesis

- Detailed hazard scenario
- Service disruption diagrams
- Interdependencies diagrams

Information Sharing, Feedback & Revision

- Workshop
- Major regional concerns
- Summary reports

Approaches to CI Interdependencies

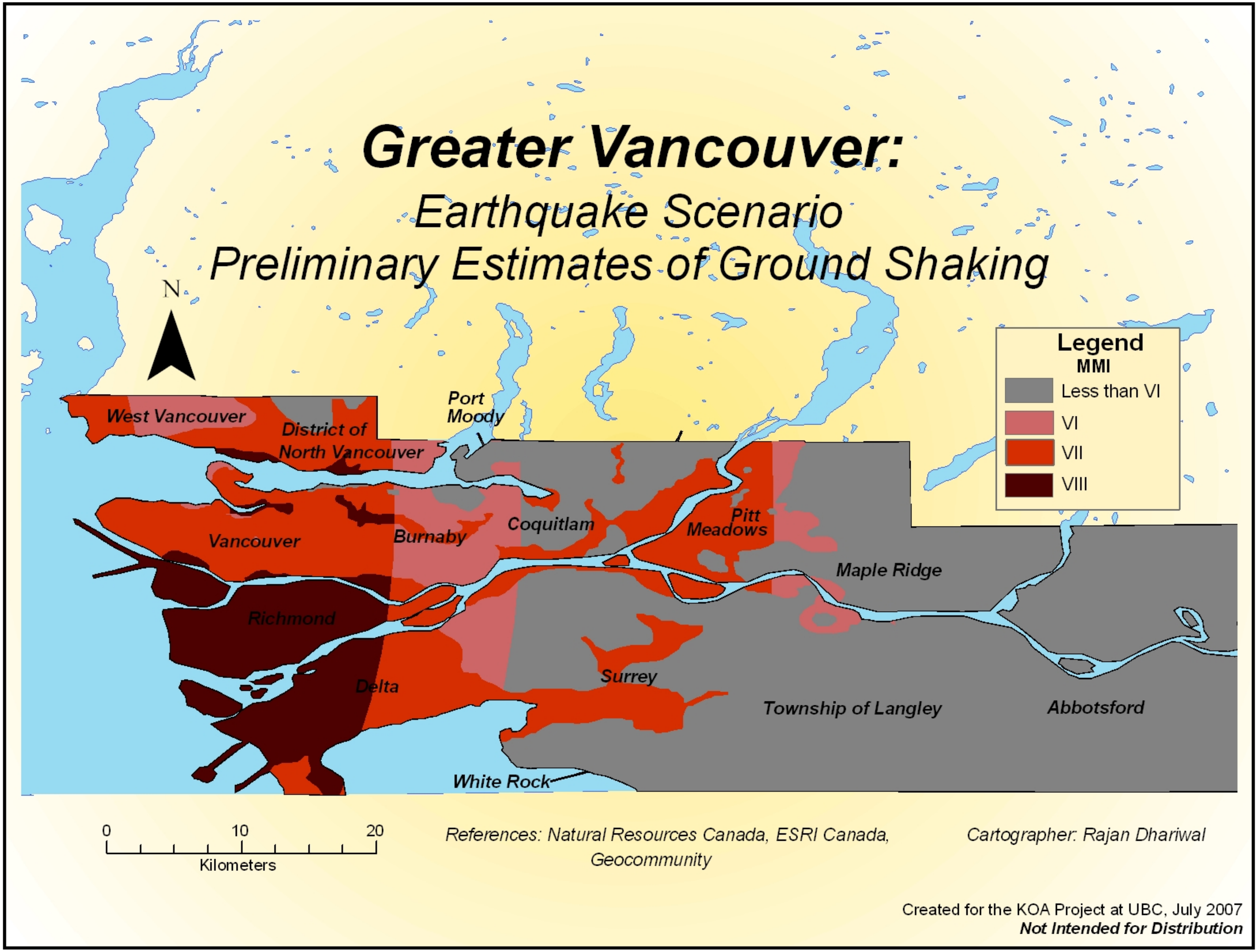
	OUR STUDY	JELC	JIIRP	Emerald Links
Data	Empirical obs., Experts	Experts	Engineering	Experts
Focus	Systems	Critical assets	Systems	Systems
Context	Single event (scenario)	All-hazard	Single event (simulation)	Single event (scenario)
Emphasis	Societal impacts	Societal impacts	Engineering	Emergency response
Outcome	Scenario; ranked strategies	Ranked assets	Simulation tool	Response exercise
Purpose	Mitigation & preparedness	Mitigation	Emergency response	Emergency response

Resilience Overview

1. Introduction:
2. Our Approach (hazard scenario and background info, expert interviews, workshop)
3. Data Synthesis: Service Disruption and Interdependencies
4. Workshop
5. Key Findings
6. Results and Conclusions

Approach

- Examine the potential for disruption to infrastructure services caused by vulnerabilities and interdependencies
  - Creation of a regionally specific scenario for a hypothetical hazard
  - Expert interviews
  - Data synthesized into diagrams
  - Diagrams facilitate discussion at workshop


Greater Vancouver:
Earthquake Scenario
Preliminary Estimates of Ground Shaking
N
Legend
MMI
Less than VI
VI
VII
VIII
West Vancouver
District of North Vancouver
Port Moody
Vancouver
Burnaby
Coquitlam
Pitt Meadows
Maple Ridge
Richmond
Delta
Surrey
Township of Langley
Abbotsford
White Rock
0
10
20
Kilometers
References: Natural Resources Canada, ESRI Canada, Geocommunity
Cartographer: Rajan Dhariwal
Created for the KOA Project at UBC, July 2007
Not Intended for Distribution

Infrastructures Interviewed

Utilities

- BC Hydro
- MetroVancouver (water & wastewater)
- Terasen Gas

Transportation

- Ministry of Transport
- Translink
- Airports (YVR and Abbotsford)
- Port of Vancouver

Telecom

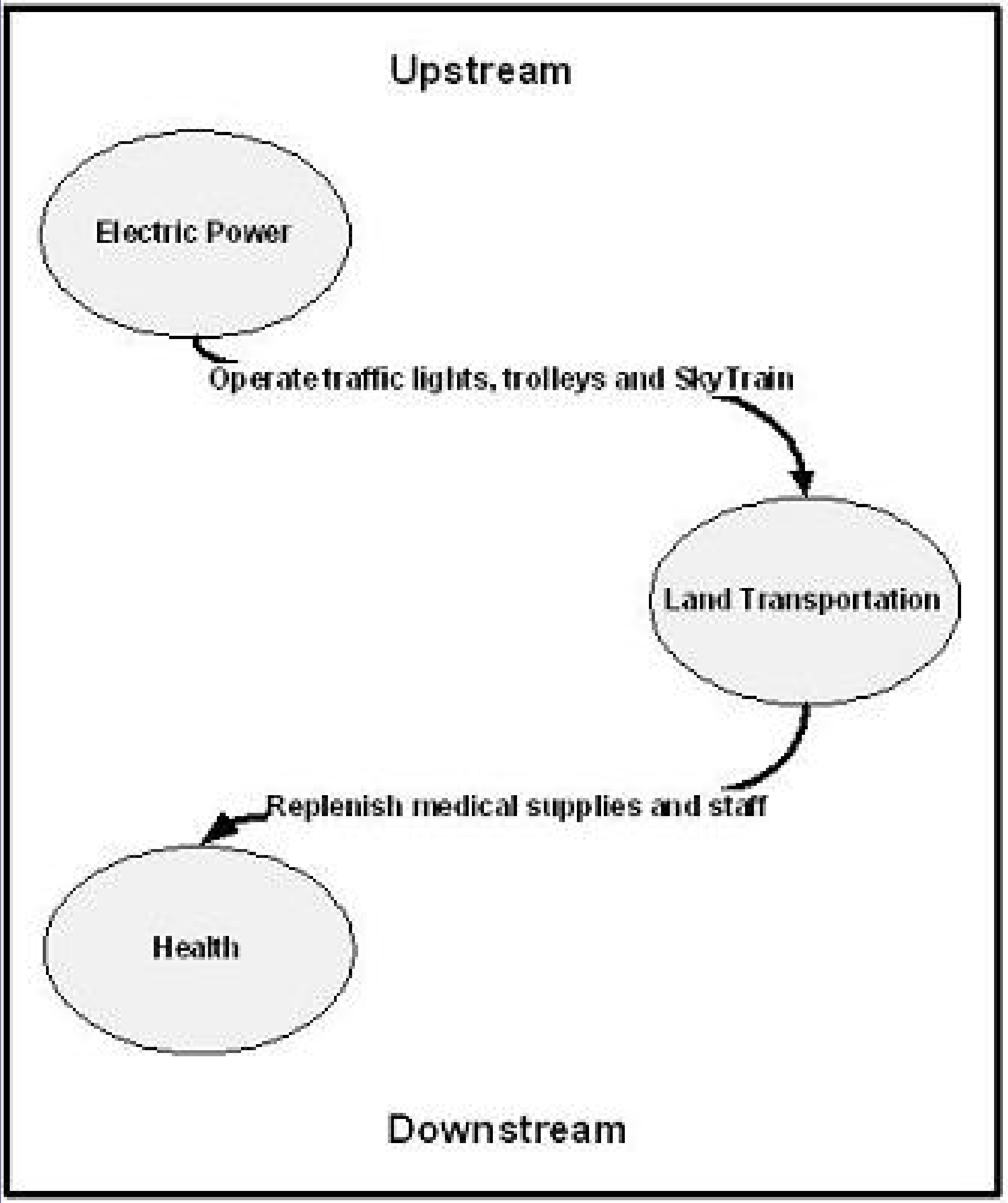
- Telus

Health

- Fraser Valley Health Authority
- BC Children's & Women's Hospital

Government

- BC PEP
- Coquitlam (municipality)
- JELC


Upstream
Electric Power
Operate traffic lights, trolleys and SkyTrain
Land Transportation
Replenish medical supplies and staff
Health
Downstream

Interview Content

- Verification of scenario
- Upstream interdependencies
  - Which infrastructures?
  - Expectations regarding their disruption in scenario?
- Own system disruptions
  - Immediately, at 72 hours, at 2 weeks?
- Downstream interdependencies
  - Expected consequences?
  - Cross-sector planning?
- Mitigation priorities
  - Own sector?
  - Other sectors?

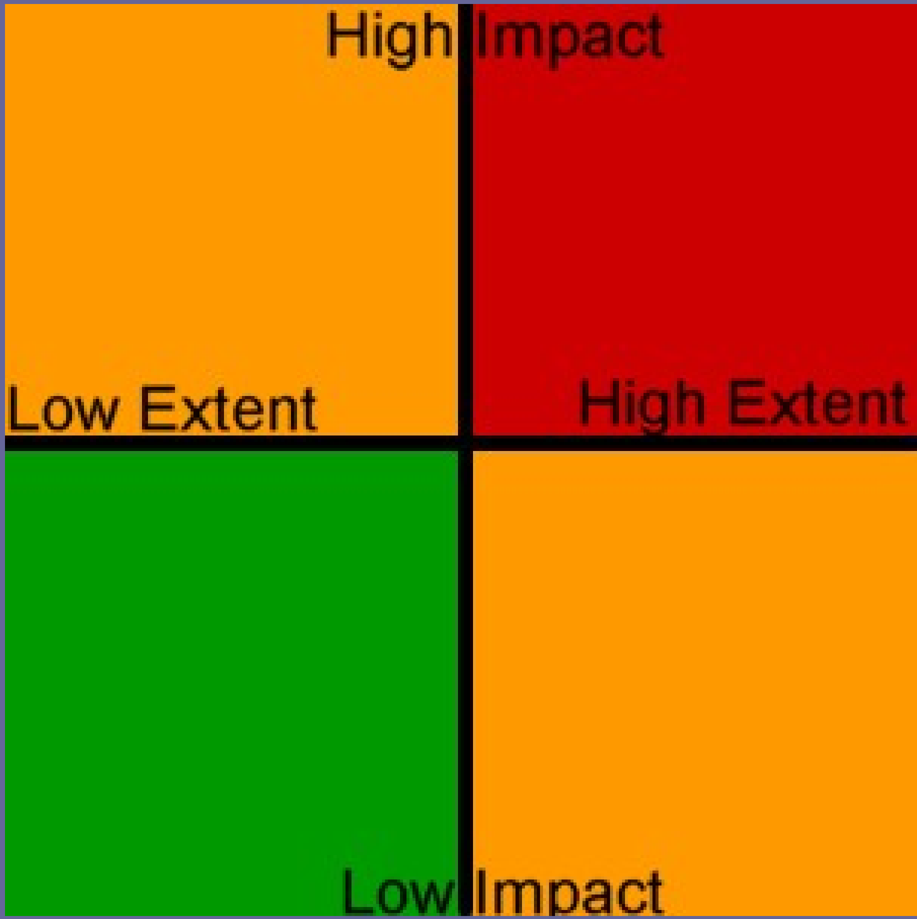
Service Disruption Level

No Loss

Slight Disruption

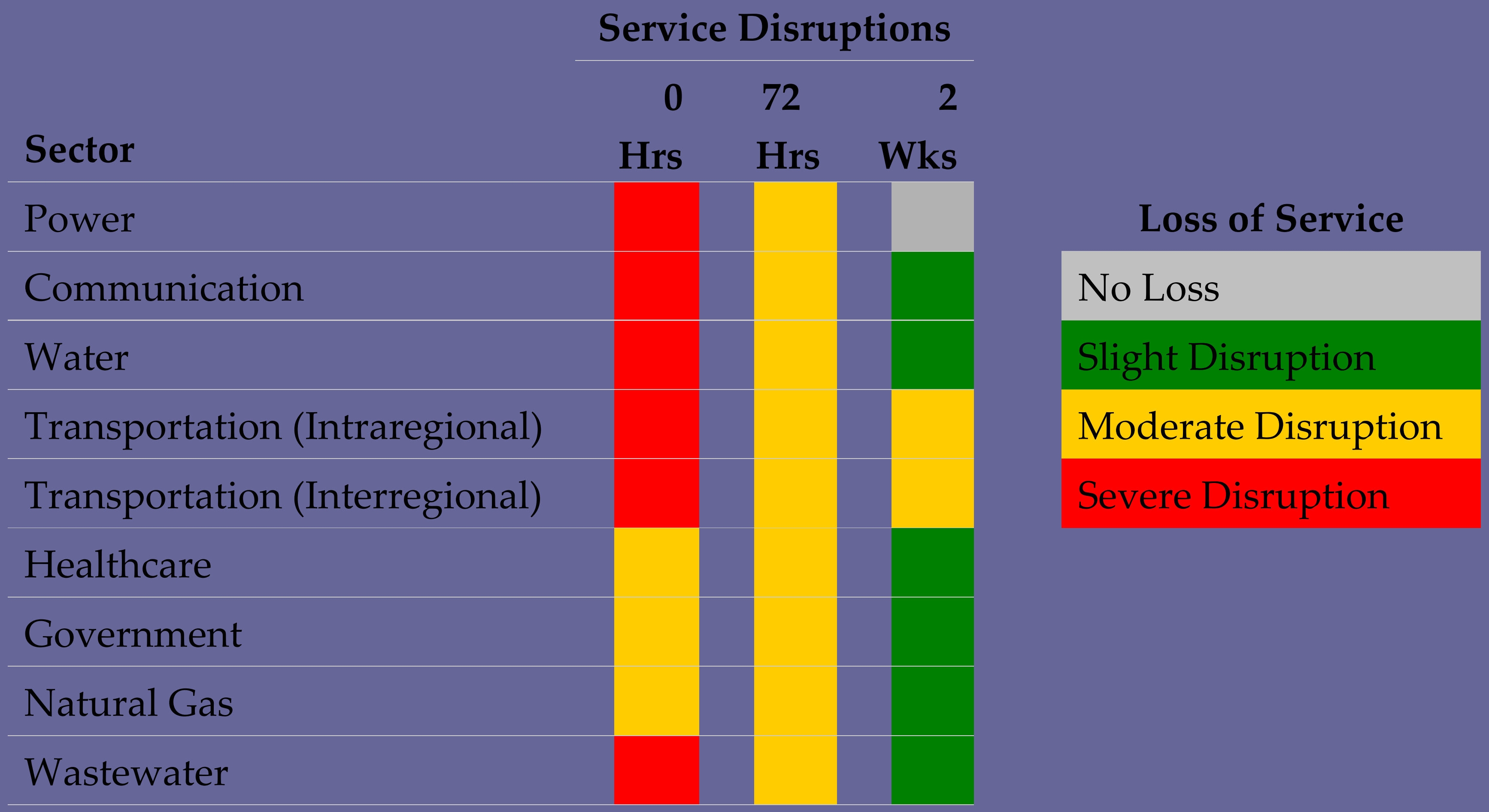
Moderate Disruption

Severe Disruption



Service Disruption Scale

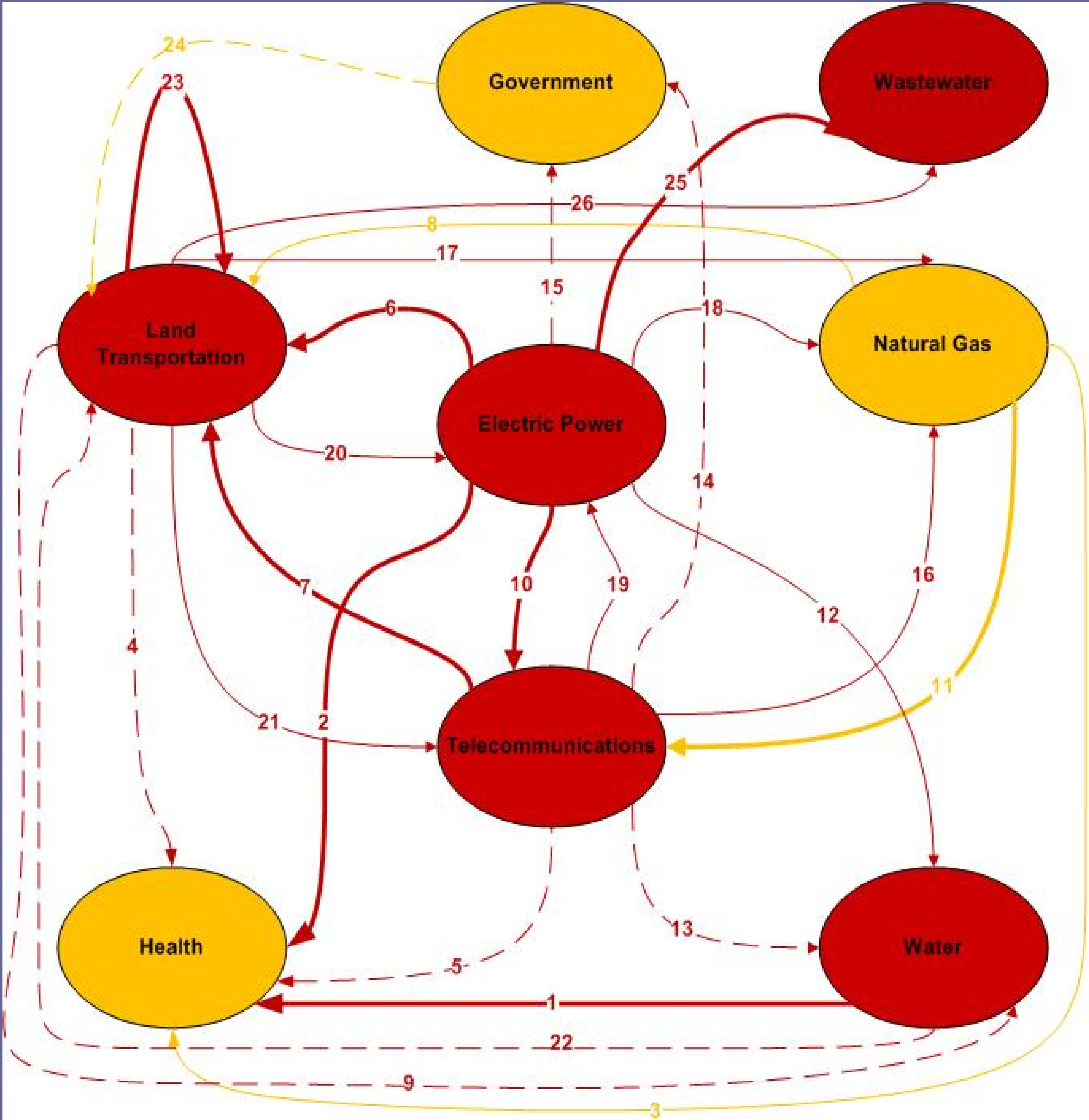
Preliminary Estimates of Service Disruption Levels

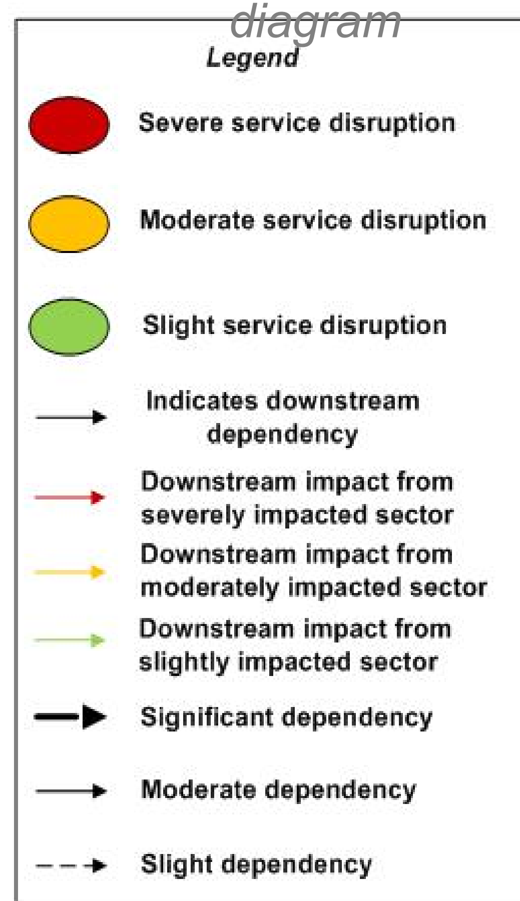


Greater Vancouver's Infrastructure Interdependencies

Service Disruption (Immediate Aftermath)

Initial working diagram





Workshop

- Review of data and key findings
  - Using the scenario and diagrams
- Discussion
  - Allowed participants to consider, revise, and augment the findings
- Workbooks
  - Provided opportunity for diagram revisions

Revised Estimates of Service Disruption Levels

	Service Disruptions		
Sector	**0 Hrs**	**72 Hrs**	**2 Wks**
Power	Severe Disruption	Moderate Disruption	Slight Disruption
Communication	Severe Disruption	Moderate Disruption	Moderate Disruption
Water	Severe Disruption	Moderate Disruption	Moderate Disruption
Transportation (Intraregional)	Severe Disruption	Moderate Disruption	Moderate Disruption
Transportation (Interregional)	Severe Disruption	Moderate Disruption	Moderate Disruption
Healthcare	Severe Disruption	Moderate Disruption	Moderate Disruption
Government	Moderate Disruption	Moderate Disruption	Slight Disruption
Natural Gas	Moderate Disruption	Moderate Disruption	Slight Disruption
Wastewater	Severe Disruption	Moderate Disruption	Moderate Disruption

Loss of Service

Grey	No Loss
Green	Slight Disruption
Yellow	Moderate Disruption
Red	Severe Disruption

Key Findings

- Variation amongst sectors for types of information sources, and for the amount of cross-sectoral discussions
  - 31% drew information from both experience-based sources and regional cross-sectoral discussion
- Service level diagrams were changed, with sectors typically increasing the level of disruption
  - Greater disruption, over longer time period
- Trend towards increase in service over time, with no sectors completely recovered (no service loss) after two weeks
- Interdependency diagrams reveal core/peripheral sector distinction
  - Electric power is most connected, followed by land transportation and telecommunication
  - Water?

Results

- Upstream service loss expected to increase in the days and weeks after disaster
  - Backup resources depleted
- Each sector is highly interconnected with all of the others
  - Directly upstream sectors dependent on other sectors
  - High complexity
- Resolved discrepancies in expectations between sectors
  - E.g., Transportation/Healthcare's expectation on roads
- Developed or strengthened cross-sectoral contacts
- Increased practitioners' understanding of infrastructure interdependencies and their potential outcomes in disasters

Mitigation Section Outline

- Introduction: Concepts for priority-setting
- Screening from vulnerability assessment
- Selecting decision contexts
- Priority setting decision process
- Example: fuel supply
- Results
  - Sectoral analysis
  - Appraisal of method, relative to challenges

Concepts for mitigation priorities

- Broad question: given vulnerabilities to earthquake scenario, what steps should be encouraged to mitigate regional vulnerability, particularly in light of IFIs?
- Requires attention to who, what, where, how questions
- Recall governance structure: private and public ownership of infrastructure
- Recall challenges: partial incentives, incomplete information, need for communication

Information needed (Ideal)

- For every sector, what are specific vulnerabilities that could be reduced?
- What are the societal and private costs of these specific activities, scaled in some way to make them comparable?
- What are the societal and private benefits of these specific activities, scaled to make them comparable?

- These information requirements are not feasible

Practical implementation

- The task is somewhat like “risk ranking”
- What are the key priorities to help build resilience
- Screening level comparisons (no detailed studies)
- Need to select the context appropriately
  - Avoid prescriptions for avoiding impacts within privately owned systems
  - Avoid contexts in which the public role and rationale for public funding are not obvious

Devising Strategic Alternatives

- Three areas of focus selected
  - Fuel Supply
  - Water Supply
  - Road Mobility
- Two mitigation principles adopted
  - Redundancy (diversify the vulnerable component, or the means of recovering it)
  - Hardening (make the component and its functional dependencies less vulnerable)

Example: Fuel Supply

- Supply/Re-Supply
  - bringing fuel into the affected region
- Access
  - distributing to stations within the region, and ensuring user access to these same stations
- Facility Functionality
  - maintaining integrity of the stations (building, pumps, and the payment/fuel release mechanism)
- User Entitlement
  - determining who should be entitled access to a potentially scarce resource

Example: Fuel Supply

- Element in Question: Access
  - Interregional Distribution & Intraregional User
- *Redundancy?*
  - **Build new** fuelling stations
- *Hardening?*
  - **Designate existing** fuelling stations
- *Other Considerations?*
  - Situate on **DRRs** or according to other **locational factors** or access routes(e.g. residential access, proximity to CI)

Example: Fuel Supply

Strategy [redacted]							
[redacted]							
Regulate fuel supply and distribution by establishing prioritization agreements	Provincial government, fuel providers, CI sectors	24	>10	H	L	Helps maintain baseline fuel supply for CI sectors, and establishes expectations about fuel availability and needs	
[redacted]							
a) Designate and seismically upgrade **existing** fuelling stations	Governments and commercial operators	12	>3	L	M	Helps maintain fuel supply and transportation, specifically on the emergency roadway system, and for entitled DRR users	
b) Build **new** seismically reinforced fuelling stations	Governments and commercial operators	36	>3	H	H		
[redacted]							
a) Designate and seismically upgrade **existing** fuelling stations	Governments, commercial operators, CI sectors	24	>10	M	M	Helps maintain fuel supply and transportation, specifically for those selected according to locational factors	
b) Build **new** seismically reinforced fuelling stations	Governments, commercial operators, CI sectors	36	>10	H	H		
Other Strategies							

Cost: Low - $1-5 million. Medium - $5-10 million. High - >$10 million.

Findings: Methodological Analysis

- Strengths of method:
  - Worked well within time constraints
  - Shared focus and consistency
- Weaknesses of method:
  - Supply side focus (redundancy/hardening)
  - Low on detail and implementation

Findings: Content Analysis

Strategy	Ranking
1) **Regulate** supply & distribution (prioritization agreements)	H=11 M=1 L=0
2a) **DRRs**: Upgrade **existing** stations	H=3 M=6 L=3
2b) **DRRs**: Build **new** designated stations	H=0 M=5 L=7
3a) **Other locations**: Upgrade **existing** stations	H=1 M=3 L=8
3b) **Other locations**: Build **new** designated stations	H=0 M=3 L=9
4) Demand management and public education	H=12 M=0 L=0

Findings: Sectoral Analysis

- Strongest consensus for regulation and low cost strategies
- Consistency between emergency government agencies
- Rankings reflect sectoral interests and requirements in some cases

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Recent publications

- S.E. Chang, T.L. McDaniels, J. Mikawoz, and K. Peterson. 2006. "Infrastructure failure interactions in extreme events: the 1998 Ice Storm," Natural Hazards, Vol. 41, No. 2, pp. 337- 358.
- S.E. Chang, T.L. McDaniels, H. Longstaff, and S. Wilmot. "Fostering Disaster Resilience through Addressing Infrastructure Interdependencies," Plan Canada, Vol. 46, No. 4, pp. 33-36.
- C.E. Brown, S.E. Chang, and T.L. McDaniels. "Utility Provider Liability for Electrical Failure: Implications for Interdependent Critical Infrastructure," The Electricity Journal, Vol. 19, No. 5, pp. 69-81.
- S.E. Chang, T.L. McDaniels, D. Reed, and K. Peterson. "Mitigation of extreme event risks: electric power and infrastructure failure interactions," ch. 5 in Richardson, H., P. Gordon, and James E. Moore II, eds., The Economic Impacts of Terrorist Attacks. Northampton, MA: Edward Elgar Publishing, pp. 70-90.
- McDaniels, Timothy, Chang, Stephanie, Cole, Darren, Mikawoz, Joey and Longstaff, Holly. Forthcoming. "Fostering resilience to extreme events within infrastructure systems: characterizing decision contexts for mitigation and adaptation". Global Environmental Change.
- Chang, Stephanie, McDaniels, Timothy, Longstaff, Holly, Dhariwal, Rajan, Fox, Jana, Beaubian, Courtney, Hawkins, David. Submitted. "Fostering Regional Resilience to Infrastructure Failure Interdependencies in Disasters: Characterizing Vulnerability of Systems." Journal of the American Planning Association.

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Analyzing Infrastructures for Disaster-Resilient Communities

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- IFI Research Approach
- Recent Research
- Downtown Survey
- Database
  - Search Database
  - Database Instructions
  - Database Terms
- News & Events
- Links
- Glossary
- Contact

Collapse of Shi-wei Bridge, 1999 Chi-Chi Taiwan earthquake (Photograph by Ian G. Buckle, MCEER)

Database

Description of Event
Any

Impacted System
Any

Specific System
Any

Type of Impact
Any

Spatial Extent of Impact
Any

Number of People
Any

Severity
Any

Duration
Any

Unique Impact?
Any

Ranked Quadrant
Any

Search Database

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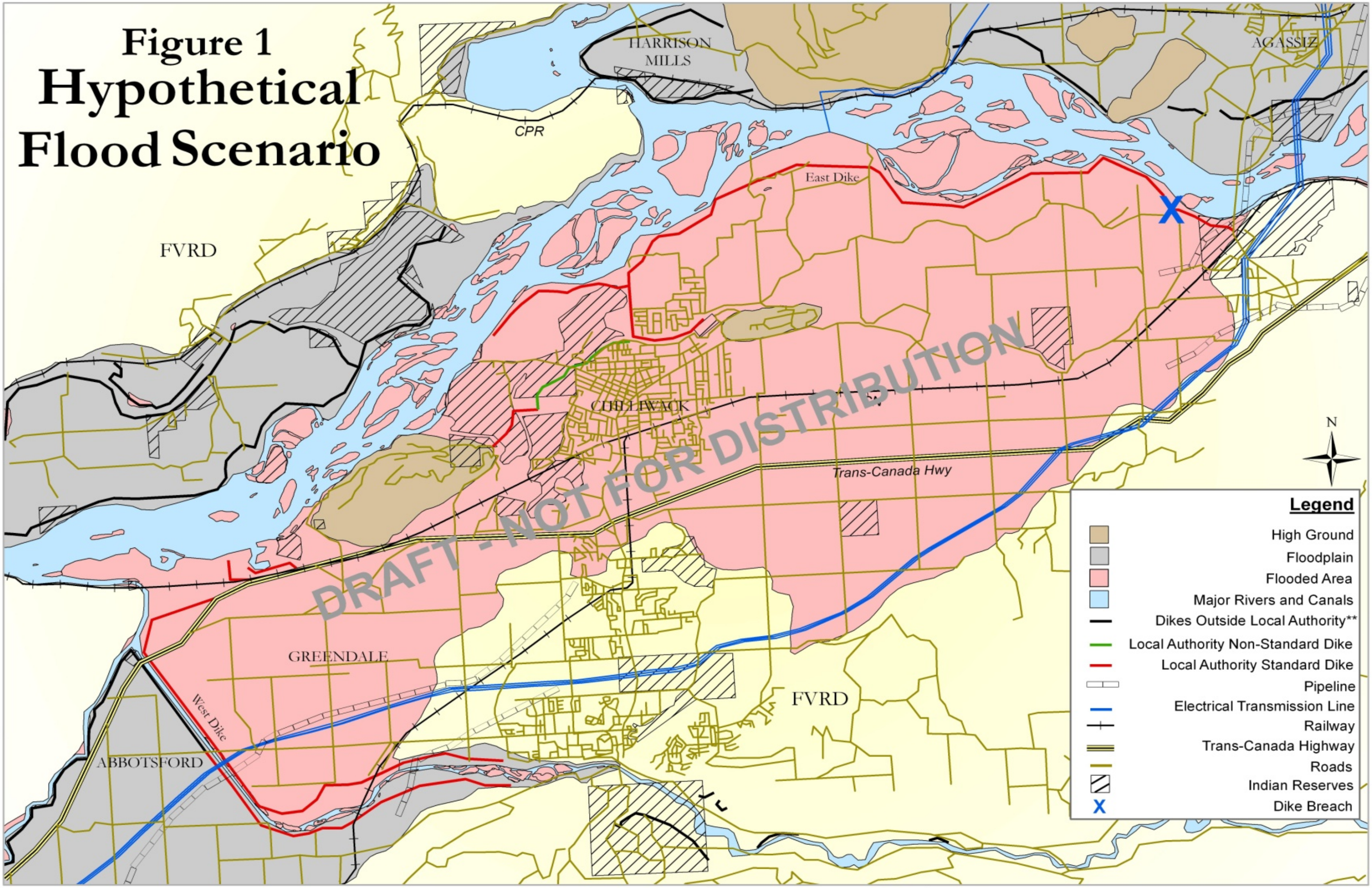
Questions or comments?

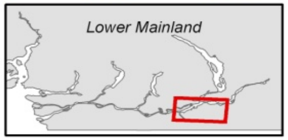
Figure 1 Hypothetical Flood Scenario

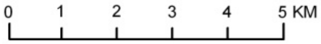


Cartographer: Rajan Dhariwal

Data Source: Ministry of Environment

Disclaimer: The floodplain boundaries & dike information shown are not warranted by the Ministry of Environment as to their accuracy or sufficiency. Flooding may occur outside of the floodplain areas shown.





***City of Chilliwack serves as the local diking authority*

Flood study participants

Interviews

- Health service regions
- Water and waste water
- Power
- Natural gas
- Transportation

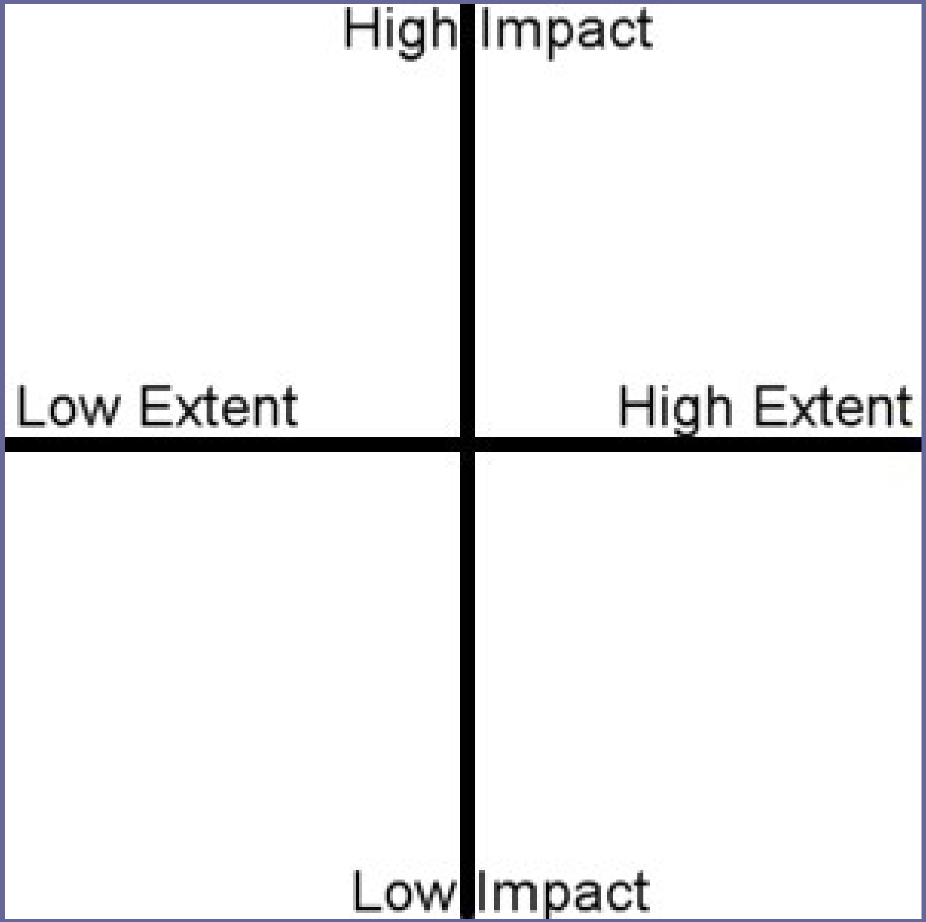
Workshop

- Health regions
- Transportation
- Power
- Local/Regional Government
- Government emergency managers
- Natural Gas
- NGOs

Service Disruption Scale

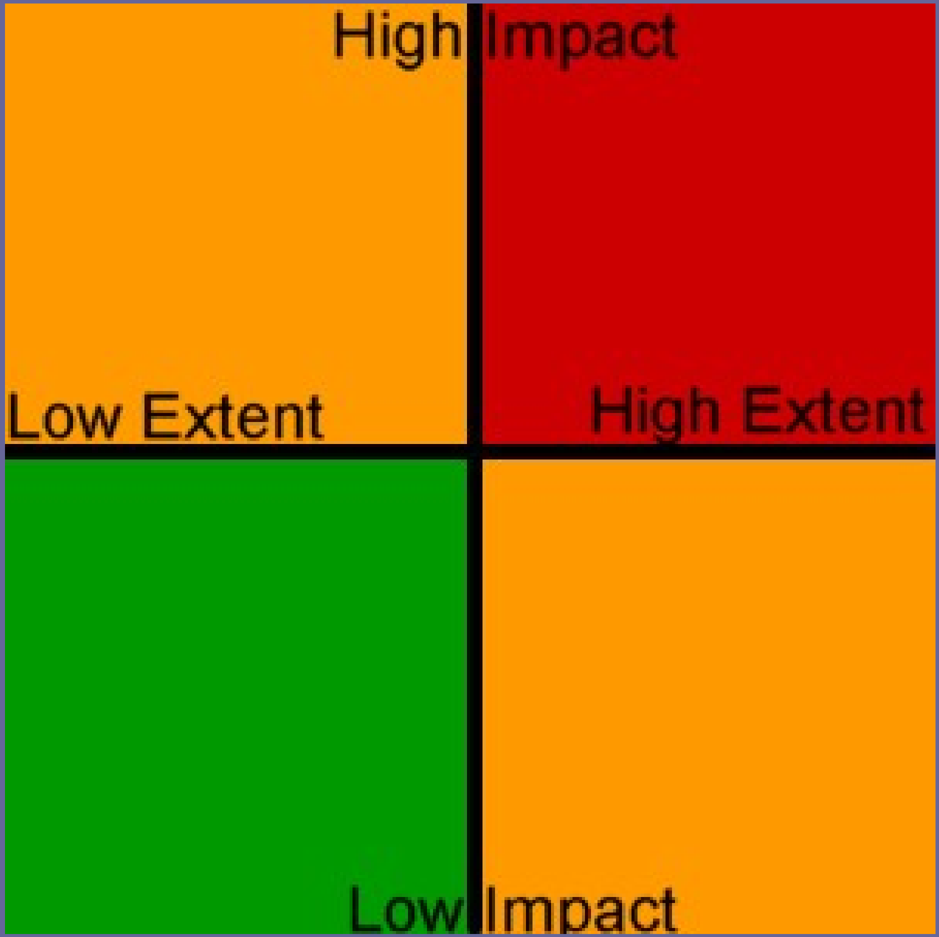
- **Extent** = spatial area of disruption

- **Impact** = magnitude of consequence



Service Disruption Scale

Service Disruption Level
No Loss
Slight Disruption
Moderate Disruption
Severe Disruption



Preliminary Service Disruption Estimates (Metro Vancouver)

Service Disruption Level
No loss
Slight Disruption
Moderate Disruption
Severe Disruption
Uncertain

Sector	**Time After Event**				
	0 hours		72 hours		2 weeks
Power	[No loss]		[No loss]		[No loss]
Transportation	[No loss]		[Moderate Disruption]		[No loss]
Water	[Slight Disruption]		[Slight Disruption]		[No loss]
Wastewater	[Moderate Disruption]		[Moderate Disruption]		[No loss]
Natural Gas	[No loss]		[No loss]		[No loss]
Healthcare	[Moderate Disruption]		[Moderate Disruption]		[Moderate Disruption]
Solid Waste	[Slight Disruption]		[Slight Disruption]		[No loss]

Inconsistencies in Expectations (Metro Vancouver)

Service Disruptio n Level
No loss
Slight Disruption
Moderate Disruption
Severe Disruption
Uncertain

	Sector Expectations of Disruptions (0 hours)		
Sector	To Power	To Water	To Transportation
Power			
Transportation			
Water			
Wastewater			
Natural Gas			
Fraser Health			
Vancouver Coastal			
PHSA			

Inconsistencies in Expectations – II (Metro Vancouver)

Service Disruption Level
No loss
Slight Disruption
Moderate Disruption
Severe Disruption
Uncertain

	Sector Expectations of Disruptions (0 hours)		
Sector	To Wastewater	To Natural Gas	To Healthcare
Power			
Transportation			
Water			
Wastewater			
Natural Gas			
Fraser Health			
Vancouver Coastal			
PHSA			

Selected Findings (in general)

In interviews

- Tendency toward overestimation of possible service disruption relative to the expectations of the service provider

In workshops

- Revisions informed by group discussion
- Value of using minor event to determine thresholds or tipping points for systems
- Usefulness of eliciting failure judgments to determine uncertainties

Selected Findings (specific)

Feedback

- 80% of participants suggested modifications to the figures
- Suggested revisions revealed less predicted service disruption overall but more uncertainty concerning particular assumptions (e.g., transportation)

Value of event

- All participants agree the event was "time well spent"
- All participants reported that the workshop was either "somewhat" or "very useful" in the exit survey