

Damaging Earthquakes and Their Implications for the Transfusion Medicine  
Function of the Health care System on Vancouver Island, British Columbia

by

Bruce Owen Sanderson  
BSc, University of Saskatchewan, 1982

A Thesis Submitted in Partial Fulfillment  
of the Requirements for the Degree of

MASTER OF ARTS

in the Department of Geography

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University of Victoria

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## **Supervisory Committee**

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### **Supervisory Committee**

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**Supervisor**

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## Abstract

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Greater Victoria, a conurbation of about 335,000 people located in southwestern British Columbia, Canada, is subject to significant seismic hazards. The major regional seismic factor is the offshore Juan de Fuca tectonic plate, subducting beneath North America along the 1,100 km-long Cascadia Subduction Zone (CSZ), a megathrust fault. This environment generates three types of potentially damaging earthquakes—shallow, subduction, and deep.

This research examines how the Transfusion Medicine (TM) component within transfusing facilities in Greater Victoria and the balance of Vancouver Island might function following these types of earthquakes. A shallow earthquake of magnitude (M)7 or greater that occurs near enough could heavily damage critical infrastructure in Greater Victoria. Decisions regarding the alternatives of (a) rapidly relocating a facility for storing and/or processing blood products within or near Greater Victoria or (b) transporting people injured in an earthquake to transfusing hospitals in or beyond Greater Victoria, or (c) both (a) and (b), may need to be made within the first few hours following a locally destructive earthquake. A subduction event (M8 to 9.2) in the CSZ could reduce or halt production of blood products in nearby Vancouver, diminish the supply of stored blood in southwestern coastal British Columbia, and sharply increase demand for blood products. Post-subduction-event conditions would likely result in a temporary shortage of blood products in at least two regional health authorities, and

would test the response of a few key related functions within smaller, more remote health care facilities. A subduction event also would impact ground transportation routes, airports, and wharves, making the transportation of blood products to and around Vancouver Island more difficult.

The researcher interviewed several professionals whose work supports the blood contingency emergency response by the Canadian Blood Services, the Vancouver Island Health Authority (VIHA), and the British Columbia Ministry of Health, to obtain information that could help maintain the TM function in post-quake circumstances. To prepare informants to answer questions regarding the health care implications of these earthquakes, the researcher generated--per earthquake type--order of magnitude estimates of the numbers of hospitalizations that would likely result in Greater Victoria or/and Vancouver Island. The study examines the inventorying and transportation of blood products, some communication, decision-making, and blood product distribution considerations—plus the hazard mitigation and vulnerability reduction aspects—that could be included in an earthquake-specific blood contingency plan for VIHA transfusing facilities. It also considers how VIHA could sustain the function of the TM Laboratory role within transfusing hospitals during post-earthquake circumstances in which some of their facilities for storing, monitoring, analyzing, or transfusing blood products are inoperable.

The risks of damaging earthquakes, and accompanying tsunamis affecting populated areas and health system assets in coastal British Columbia, are real. Implementing the recommendations of this study may help various players involved in the regional processing, distribution and allocation of blood products to: (a) define a more efficient response to earthquake impacts upon their operations, (b) reduce injury to people and damage to crucial equipment used in the health system, and ultimately, (c) save lives.

Key words: earthquake, tsunami, health system disaster response, blood supply, blood bank, transfusion medicine, emergency management, health care business continuity

## Table of Contents

Supervisory Committee .....	iii
Abstract .....	iv
Table of Contents .....	vi
List of Tables .....	ix
List of Figures .....	x
Acknowledgments .....	xi
Dedication .....	xii
Chapter 1: Introduction .....	1
1.1 The Purpose, Rationale, Scope, and Methods of the Investigation.....	1
1.2 The Design of the Study .....	11
1.3 Structure of the Thesis.....	13
Chapter Two: Literature Review .....	16
2.1 The concepts of hazard, risk, and vulnerability .....	16
2.2 Implications of Hazards, Risks, and Vulnerability for Health care Systems.....	22
2.2.1 The Development of System Responses to Emergencies and Disasters .....	24
2.2.2 Reducing Earthquake Impacts upon Victims and Health care Assets.....	26
2.2.3 Evaluating Progress in Developing, Implementing, and Improving Emergency Management Programs.....	33
2.2.4 Estimating the Post-quake Rate of Supply of Blood Products .....	36
2.2.5 Blood Supply System Response to Earthquakes .....	39
2.3 Chapter Summary .....	44
Chapter 3: Seismic Hazard, Example Quakes, and Plausible Scenarios.....	46
3.1 Seismic Hazard .....	46
3.1.1 The Seismogeologic Setting .....	47
3.1.2 The Probability of the Hazard Being Manifest as an Earthquake.....	49
3.2 Characterizing The Types a Earthquakes Likely to Affect Greater Victoria .....	51
3.2.1 Deep Earthquakes .....	51
3.2.2 Subduction (Megathrust) Earthquakes.....	51
3.2.3 Shallow (Crustal) Earthquakes .....	54
3.3 In Situ Factors That Affect the Consequences of the Earthquakes.....	55
3.4 Catalogued Earthquakes Relevant to Seismicity in Southwestern BC.....	57
3.4.1 Deep Earthquakes .....	58
3.4.2 Subduction (Megathrust) Earthquakes.....	59
3.4.2 Shallow (Crustal) Earthquakes .....	62
3.5 Scenarios for Such Earthquakes Affecting Greater Victoria.....	67
3.5.1 Scenario One: Deep Earthquake .....	68
3.5.2 Scenario Two: Subduction Earthquake .....	69
3.5.3 Scenario Three: Shallow Earthquake .....	76
3.6 Chapter Summary.....	77
Chapter 4: Research Methodology .....	78
4.1 Estimation Methodology: Injuries and Hospitalizations .....	78
4.1.1 Background .....	79
4.1.2 Deep Earthquakes .....	81
4.1.3 Subduction (Megathrust) Earthquakes.....	84

4.1.4 Shallow (Crustal) Earthquakes .....	87
4.3 Key informant interview methodology .....	94
4.3.1 Sampling and recruitment .....	96
4.4 Secondary data sources .....	98
4.5 Data analysis and interpretation .....	98
4.5 Chapter Summary .....	101
Chapter 5: Analysis of Results .....	102
5.1 VIHA Assets, Operations, and Options .....	103
5.1.1 Assessing Earthquake-driven Damage to Health Care Infrastructure .....	104
5.1.2 Business Continuity of Blood System Computerized Operational Assets .....	106
5.1.3 Coping with Likely Circumstances Following a <i>Shallow</i> Earthquake .....	108
5.1.4 Flexible Preparedness: Coping with Likely Local/Regional Impacts of Any Damaging Quake .....	111
5.1.5 Mitigation: Vulnerability Reduction Within the VIHA TM Supply Chain .....	115
5.1.6 Preparedness: Planning for Post-earthquake Decision Making .....	116
5.1.7 Response to a Subduction Earthquake: Transporting Blood and/or Blood Transfusion Patients to Hospitals Outside Greater Victoria .....	122
5.1.8 Preparedness: VIHA and TML Emergency Response Assets .....	126
5.2 Canadian Blood Services: Assets, Operations, and Options .....	130
5.2.1 CBS Operations on Vancouver Island .....	130
5.2.2 CBS Preparedness for Disaster Response in BC: CBS Inventories .....	130
5.2.3 CBS Emergency Management and Emergency Response Capability .....	132
5.2.4 CBS Business Continuity .....	133
5.3 Blood Contingency in BC Following a Cascadia Subduction Earthquake .....	137
5.4 Multiple-Agency Response to a Blood Contingency in British Columbia .....	138
5.4.1 CBS Procedure in a BC Blood Contingency .....	142
5.5 Summary of Risks, Capacities and Vulnerabilities for Key Agencies .....	143
5.6 Chapter Summary .....	145
Chapter 6: Summary, Evaluation, and Conclusions .....	147
6.1 The Purpose and Scope of the Investigation .....	147
6.2 Addressing the objectives of the study .....	147
6.2.1 Objective One .....	147
6.2.2 Objective Two .....	150
6.2.3 Objective Three .....	152
6.3 Contributions of the Research .....	153
6.4 Suggestions for further research .....	154
6.5 Conclusions .....	155
Bibliography .....	157
Appendix A: List of Abbreviations .....	186
Appendix B: Glossary of Terms .....	188
Appendix C: Components of Selected Risk Assessment Methodologies .....	189
Appendix D: Criteria for Effective Disaster Management .....	190
Appendix E: Levels VII to XII, Modified Mercalli Intensity Scale .....	191
Appendix F: Classification of Areas with Vulnerable Buildings .....	192
Appendix G: Phases of the BC Blood Contingency Plan .....	192
Appendix H: Rationale for Increasing the Documented Rates of Rural Risk, Injury, and Hospitalization, Regarding Fires Following Earthquakes .....	193

Appendix I: Potential Hospitalizations Due to Injuries Created by Fire Following an Earthquake--Subduction and Shallow Types .....	195
Appendix J: Abridged Estimates Package.....	196
Appendix K: Some Nearby Federal Resources That Could Assist VIHA in its Response to a Damaging Earthquake.....	206
Appendix L: Letter of Information and Consent Form .....	208
Appendix M: Interview Guide Questions .....	214
Appendix N: Telecommunication Resources Available via EMBC .....	227
Appendix O: British Columbia Ambulance Service - Key Services .....	227
Appendix P: Alternate Modes and Routes for Moving Blood Products into Greater Victoria .....	230
Appendix Q: Factors Likely to Affect the Post-subduction Quake Delivery of Blood Products and Retrieval of Casualties .....	234
Appendix R: Plausible Anticipated Dilemmas.....	237
Appendix S: Factors Affecting Post-Quake Decisions Regarding Ordering Blood Products from CBS Vancouver .....	238

## List of Tables

Table 1. By Discipline: Risk Concept, Form of Human Attention Applied to the Unknown, and Key Issues.....	17
Table 2. Factors that may affect how laypeople perceive uncertainty in environmental health risks.....	19
Table 3. The Donation and Distribution of Blood in the First Four Days Following the Bam Earthquake, Versus in a Normal Situation.....	40
Table 4. Blood components for 35 patients at Christchurch City Hospital, February, 2011 Earthquake .....	43
Table 5. 2007 Best Estimate Probabilities of an Earthquake Causing Shaking at MMI VII or Greater, and Potentially Damaging Buildings and Structures on Firm Soil in Victoria and/or Vancouver.....	49
Table 6. Various Cancers: Age-standardized Incidence and Mortality per 100,000/year in the VIHA Administrative Area, for 2009.....	50
Table 7. Details regarding the Nisqually Deep M6.8 Earthquake, 2001 .....	58
Table 8. Details regarding the M 6.5 Deep Earthquake of 1965.....	59
Table 9. Details regarding the March 11, 2011 M 9.0 Earthquake near Honshu, Japan .....	62
Table 10. Possible Consequences for Local Infrastructure, by Earthquake Type	69
Table 11. Serious injuries and hospitalizations from a scenario CSZ subduction earthquake.....	87
Table 12. Shallow earthquakes and scenarios examined to derive usable data ..	88
Table 13. Serious injuries and hospitalizations anticipated due to a shallow earthquake near Victoria .....	90
Table 14. Criteria used to design interview questions and to analyze the resulting data.....	95
Table 15. Criteria Defining Significance with Respect to a Health Organization's Response to the Consequences of an Earthquake.....	100
Table 16. Summary of Risks, Capacities and Vulnerabilities for Key Agencies...	144

## List of Figures

Figure 1 . The location of southern coastal British Columbia in western North America.....	4
Figure 2. Google Map image showing the locations of Victoria (on Vancouver Island) and Vancouver, in southern coastal British Columbia.....	5
Figure 3. The administrative area and subdivisions, Vancouver Island Health Authority.....	6
Figure 4. The structure of the BC emergency management organization.....	7
Figure 5. The BC Emergency Response Management System organizational structure..	8
Figure 6. The locations of facilities where blood products are taken or administered by VIHA staff.....	10
Figure 7. Emergency management objectives, Disaster Resilient Communities Program, Emergency Management BC.....	25
Figure 8. The AABB disaster-driven RBC order formula.....	36
Figure 9. Geological Survey of Canada 2005 Seismic Hazard Map.....	47
Figure 10. Plate tectonics and earthquake types in southern British Columbia. ..	48
Figure 11. Predicted structural damage distribution in downtown Victoria due to shaking at MMI (Modified Mercalli Intensity) level VIII.....	56
Figure 12. Aerial view of surface faulting revealed in the September, 2010 Darfield earthquake near Christchurch, New Zealand. ....	65
Figure 13. Tree line offset 4m by Darfield quake faulting, near Charing Cross, NZ.....	65
Figure 14. The setting of the 2010 Darfield earthquake in New Zealand.....	66
Figure 15. Prevalent building type by city block in downtown Victoria.....	68
Figure 16. Strathcona Dam, Upper Campbell Lake, Campbell River system, central Vancouver Island.....	74
Figure 17. Penstocks from the John Hart Dam to its powerhouse, near Campbell River.....	86
Figure 18. Google Earth image showing the locations of major hospitals in Greater Victoria.....	93
Figure 19. Google Earth image showing the locations of RJH (B), its existing helipad (F), and potential additional landing areas.....	110

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## **Dedication**

To my lovely wife, Jeannie, who, during this undertaking, has shown patience beyond comprehension.

# Chapter 1: Introduction

## 1.1 The Purpose, Rationale, Scope, and Methods of the Investigation

### *Purpose*

This research project is intended to help advance awareness and disaster management capability within the British Columbia health care system, regarding the likely consequences of three types of damaging earthquakes that could affect southwestern British Columbia – deep, subduction and shallow earthquakes. More specifically, the purpose is to identify ways to strengthen the Transfusion Medicine (TM) emergency response function within the Vancouver Island Health Authority (VIHA) such that the TM component will be better able to deal with the direct and indirect impacts that it would likely face as a result of any of these earthquake scenarios. The following objectives apply to the three different post-earthquake circumstances:

- **to provide realistic estimates of the numbers of local hospitalizations and types of injuries that would likely result if these different types of earthquakes were to affect Greater Victoria or/and Vancouver Island**
- **to briefly examine the inventory monitoring, communication, decision-making, transportation, and blood product distribution components—plus the hazard mitigation, vulnerability reduction, and capacity development aspects—that could be incorporated within an earthquake-specific blood contingency plan for VIHA blood handling facilities**
- **to plan for supplying new blood products, plus related materials and services to maintain the function of the TM Laboratories within transfusing facilities on Vancouver Island, during post-earthquake circumstances where some of the VIHA facilities for storing, monitoring, preparing, analyzing, or transfusing blood products are inoperable**

### *The Rationale for the Research*

This research project relates to earthquakes that could affect Greater Victoria, Vancouver Island, and southwestern coastal British Columbia, (BC) and addresses their possible consequences for the TM component of the Vancouver Island health care system. In the Spring of 2009, health professionals from VIHA and the BC Ministry of Health Services suggested that the researcher examine the subject of damaging earthquakes and their implications for the VIHA Transfusion Medicine function. Section 4.2 of this paper details further rationale for this pursuit. While this research is focused on the Transfusion Medicine function, it has wider implications for the health care system response to seismic events.

A chain of causality leads from a seismic hazard in a geographic area to the manifestation of the hazard as a disastrous event, with serious consequences for many people, and for some of the shelter, transportation and other economic resources they use. This discussion briefly develops that causality chain. Damage to buildings and to structures such as bridges and power transmission towers can lead directly or indirectly to human casualties. Some survivors of earthquakes will suffer injuries due to by being struck by heavy components of buildings or of other structures, or because of impact upon the interior or exterior of a motor vehicle that is no longer controlled by electrically-powered traffic lights, for example. Others may be cut by glass falling from high-rise buildings. Some injured in these ways will need blood replacement, likely creating increased demand for blood products. But increased demand for blood products may be just one of the consequences that the VIHA Transfusion Medicine function could face as a result of a damaging earthquake. A shallow quake near and in Victoria may damage physical plant, some of the VIHA TM staff, members of their families, or their homes. A shallow quake near Vancouver, or a *subduction* earthquake may also damage blood collection and processing assets of the Canadian Blood Services (CBS) at their Vancouver Center. The post-subduction-quake circumstances could lead to a blood shortage contingency within southwestern BC, since a subduction quake would likely generate many casualties in Greater Vancouver. This research therefore examines some of the implications that a blood supply contingency might have for VIHA and its Vancouver Island operations.

### *Geographic Scope - The Study Area*

The study area for this project involves two scales, local and regional. Damage from a shallow quake near or in Greater Victoria may be limited to an area of only about 1,000 km<sup>2</sup>. However, a CSZ subduction earthquake will likely damage southern coastal BC, Washington, and Oregon. The blood system response to a subduction event could involve neighbouring provinces, depending in part upon which is quicker: for the CBS to ship blood from outside BC, or to process blood from donors in Greater Vancouver and/or the BC interior. For planning the post-subduction-quake transportation of blood products and casualties, the study area encompasses several other communities on, and adjacent to, Vancouver Island, and extends eastward to include Greater Vancouver and parts of interior BC.

This is a geographic undertaking, due to relationships amongst numerous and geographically-dispersed casualties and agencies likely to be affected by the different types of earthquakes. People injured in remote parts of northern Vancouver Island (VI), may need to be med-evaced to receive blood in Campbell River, or possibly in Victoria. In addition, an offshore subduction quake could render inoperable some of the hospital facilities on Vancouver Island and health system assets such as the CBS blood processing facilities in the Lower Mainland. A high volume and rate of *tele*communication will be required to coordinate the post-quake disaster response and business continuity efforts of the VIHA TM function.

Figure 1 illustrates the location of southern coastal British Columbia within western North America. In the event of a subduction earthquake, VIHA and the agencies that help meet its post-quake transportation needs may need more aircraft to traverse the mountainous Vancouver Island terrain evident in Figure 2, in order to re-supply remote VIHA facilities with blood products, or to transport seriously injured victims to higher level health care facilities.



Figure 1 . The location of southern coastal British Columbia in western North America. In the orange region, subduction earthquake impacts may affect the Vancouver Island Health Authority, and at least three other BC regional health authorities (Google Maps, 2012).

Greater Victoria, the provincial capital, is the major focus, in terms of the post-quake fate of, and load upon, key VIHA TM assets, plus for decision-making regarding the response to health consequences, hospitalizations, and infrastructure damage due to quakes within southwestern BC. Greater Victoria includes the city of Victoria, plus the surrounding thirteen easternmost municipalities on the southern tip of Vancouver Island. Figure 3 illustrates the entire VIHA administrative area.

#### *Temporal Scope*

The investigation considers the disaster management capabilities of the VIHA TM function and of CBS Vancouver, from present planning, mitigation and preparedness practices, through their anticipated post-quake response and early recovery phases.

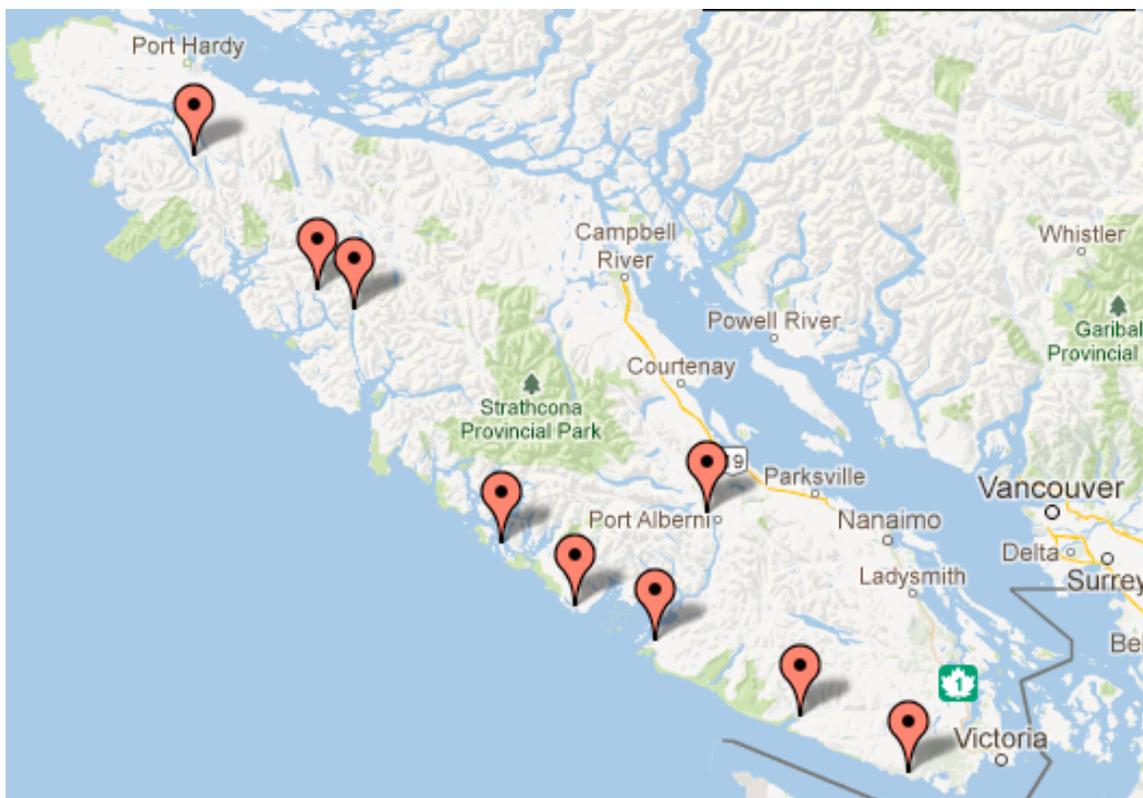


Figure 2. Scale: 1cm = 26km. Google Map image showing the locations of Victoria (on Vancouver Island) and Vancouver, in southern coastal British Columbia. In order from the northwest on Vancouver Island, the red markers indicate the communities of Port Alice, Zeballos, Tahsis, Tofino, Ucluelet, Bamfield, Port Alberni (inland), Port Renfrew, and western Sooke, which are vulnerable to tsunamis. Port Alberni and Zeballos were damaged by the tsunami that resulted from the 1964 subduction quake in Alaska. The bold grey line marks the Canada-U.S. border. (Aardvark Maps, 2013; Google Maps, 2013).

### *Institutional Scope*

Various public agencies, including municipal governments and many provincial government ministries, respond in concert to disasters in British Columbia. Should the scale of a disaster response demand resources beyond what the Province can provide, BC could obtain resources from the Canadian federal government, including certain medical assets, and assistance from the armed forces. The federal government, consulting with BC, may request international assistance, depending upon the disaster. In October, 2012, British Columbia and the Canadian Red Cross Society (CRCS) formally partnered in plans to deploy CRCS disaster management personnel and equipment more quickly and effectively in response to a major natural disaster in BC (British Columbia Newsroom (BCN), 2012).



Figure 3. The administrative area and subdivisions, Vancouver Island Health Authority. VIHA (2005, n.p.).

Hence, Emergency Management British Columbia (EMBC), two BC provincial government ministries, and the CRCS will collaborate on planning, training and joint exercises to enhance mutual disaster response capacity (BCN, 2012). The plan helps ensure the continued availability of international or national Red Cross Emergency Response Units (ERUs) to assist in a major disaster in BC (BCN, 2012). ERUs are standardized modules of trained personnel and equipment, deployable within 24 to 48 hours, and self-sufficient for one month (BCN). From a VIHA TM perspective, the potential availability of certain complementary services—IT and Telecommunications, the treatment and distribution of potable water, plus several types of health care functions, including injury treatment and surgery (BCN)—is encouraging.

*The Provincial Emergency Program /Emergency Management BC (EMBC)*

The Provincial Emergency Program (now Emergency Management BC) is the provincial agency mandated to develop, manage, and facilitate mitigation, preparedness, response, and recovery regarding disasters in BC. It coordinates information flow and activities within the provincial emergency management structure, illustrated in Figure 4 (EMBC, 2008a). Various provincial government agencies exercise interlocking disaster response plans within the umbrella of EMBC. EMBC delivers the Local Authority Emergency Program, which helps local authorities establish emergency management structure, conduct hazard, risk and vulnerability analyses (HRVAs), develop emergency response plans, carry out public preparedness and emergency response education, and train staff (EMBC, 2008a). The Public Safety Lifeline Volunteer Program involves EMBC Air Operations, Search and Rescue, and Emergency Radio Communications (EMBC, 2008a). EMBC employs the BC Emergency Response Management System (BCERMS) to advance disaster response in BC (EMBC, 2011).

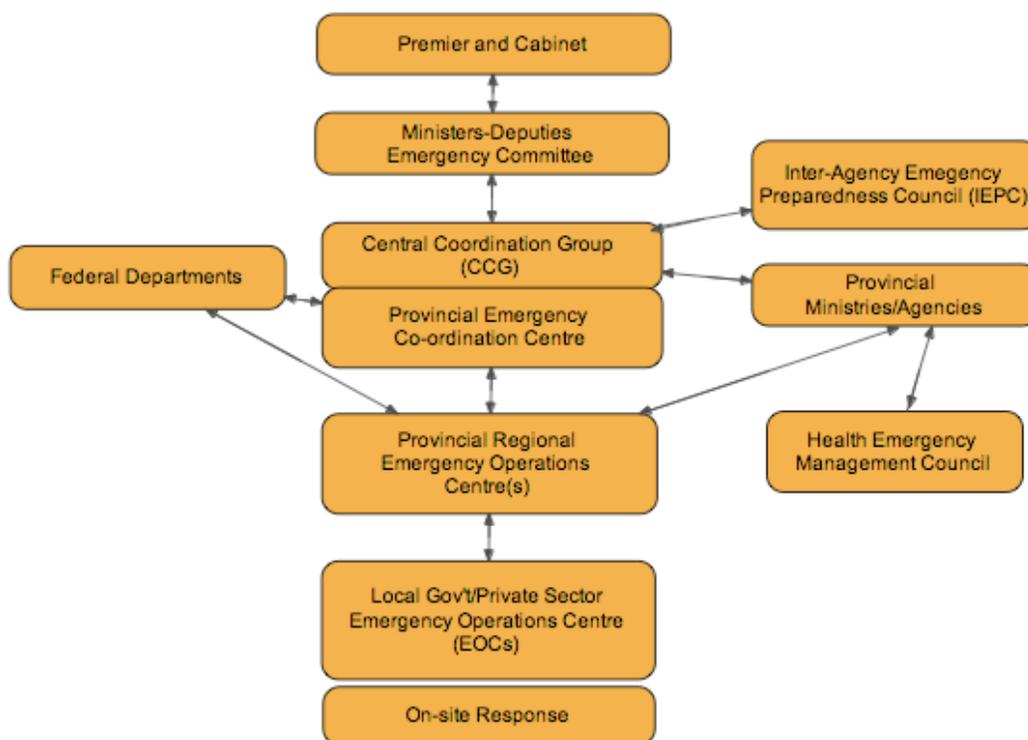


Figure 4. The structure of the BC emergency management organization. After EMBC (2008a).

*The British Columbia Emergency Response Management System (BCERMS)*

BCERMS is a province-wide management system that coordinates and integrates multi-level emergency response, business continuity, and recovery by BC agencies and businesses, regarding emergency incidents and disasters within British Columbia (EMBC, 2011). It focuses on the Incident Command System (ICS) as the framework to guide the development and execution of emergency plans, to support a standardized emergency response (EMBC, 2011). BCERMS is linked to and assists emergency response agencies, plans, and functions—at the municipal government/local authority/government agency level on the one hand—and requests and coordinates aid from the federal level (Public Safety Canada) on behalf of such provincial entities (EMBC, 2008a). It also engages the private sector in BC, (e.g. businesses, industry educational functions, and suppliers of health care services and equipment) in analyses of hazards, risks, and vulnerabilities, in developing plans for emergency response, business continuity, and recovery, and in linking those plans to local, provincial, and federal plans and programs (EMBC, 2008a). Figure 5 depicts the BCERMS response organizational structure.

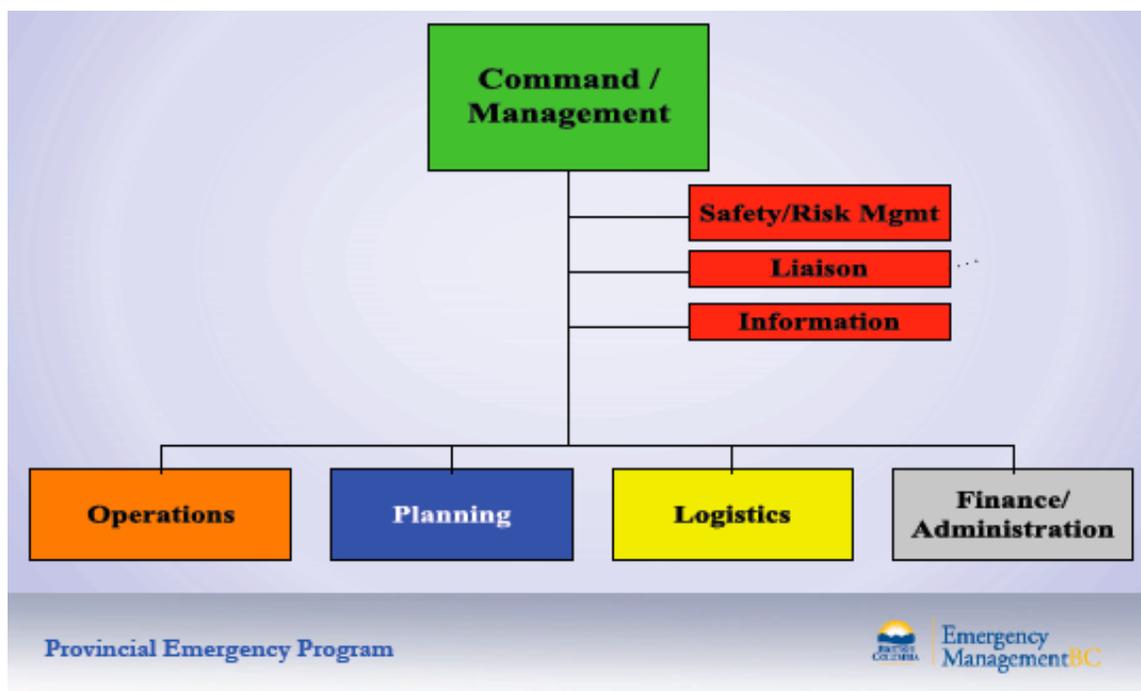


Figure 5. The BC Emergency Response Management System organizational structure. EMBC (2008a).

### *Emergency Management in the Provincial Health Sector*

For this research, the key components of the BC Ministry of Health administration are the Emergency Management Branch, Health Authorities—including the Provincial Health Services Authority (PHSA)—and the Health Emergency Management Council (HEMC).

Within its Population Health & Wellness Division, the British Columbia Ministry of Health has an Emergency Management Branch, (EMB) located in Victoria. The Emergency Management Unit helps coordinate a comprehensive emergency management program within the provincial health sector (BC Ministry of Health (MoH), 2008). The EMB provides leadership and facilitates activities via the BC Health Emergency Management Council (HEMC), illustrated in Figure 4 and comprised of the BC Health Authorities, the BC Ambulance Service, Providence Health Care, and the EMB (BC MoH, 2008). The HEMC establishes and supports priority projects and program planning, plus develops program-consistent policies and standards, to help ensure an operationally integrated response to events in BC that may require an enhanced response from the health system, or may impact the continuity of health services (BC MoH, 2008). Within HEMC, the provincial health system has prepared and exercised disaster response plans. These interlock within individual (especially large) hospitals, and key administrative and operational segments nest within five Regional Health Authorities (RHAs)—Northern, Interior, Vancouver Island, Vancouver Coastal, and Fraser (BC MoH, 2008). These, plus the Provincial Health Services Authority (PHSA), comprise the group of health authorities. The PHSA, *inter alia*, addresses emergency management and business continuity within the Ministry of Health, assisting its agencies and corporate services to develop strategies and practices to ensure that departments, programs and agencies have plans in place to sustain critical services during and after an emergency (BC Ministry of Health Services, Provincial Health Services Authority (PHSA), 2009).

### *Pertinent Functions of the Vancouver Island Health Authority (VIHA)*

The Vancouver Island Health Authority (VIHA) is the Regional Health Authority that includes Vancouver Island, its archipelago, and a nearby segment of the BC mainland

coast (see Figure 3). The locations of facilities where blood products are taken or administered are identified in Figure 6. The VIHA Emergency Management and Business Continuity function focuses on emergency management/business continuity, assists with and reviews disaster response plans, and has a geographic information system to assist with these. The Emergency Management function webpage advises that “the best action for the citizens of BC to take at this time is to be prepared for an earthquake or tsunami” (VIHA, 2010). In Emergency Management and other functions, VIHA “operationalizes a “plan regionally - deliver locally” philosophy” (VIHA, 2011, n.p.).



1cm = 28km

Figure 6. The locations of facilities where blood products are taken or administered by VIHA staff. PA = Port Alberni, while AB = Alert Bay. The names Courtenay-Comox, Parksville-Qualicum, and Nanaimo-Gabriola each represent two communities that are in close proximity to each other. Google Earth (2012) image.

Since VIHA would mount a disaster response as part of the BC Emergency Response Management System, EMBC would liaise closely with VIHA and any of its key facilities. When a site (e.g., a health facility such as a major regional hospital) level of response requires off-site support, EMBC may activate an Emergency Operations Center (EOC) or Department Operations Center (DOC) within that site (BC Ministry of Public Safety and Solicitor General/Inter-Agency Emergency Preparedness Council, 2000).

Transfusion Medicine is a VIHA-wide function, part of the Department of Laboratory Medicine, Pathology and Medical Genetics (LMPMG), led by its Medical Director, Hematopathology. This department employs Technologists and Assistants who work in VIHA Medical Laboratories, in a hub and feeder network delivering services in Transfusion Medicine, Hematology, Chemistry, Microbiology and Anatomic Pathology (VIHA, n.d.). The LMPMG island-wide integrated Laboratory Information System (LIS) allows seamless access to quality information regardless of where a patient is, or the location of a service provider (VIHA, n.d.). The department is currently standardizing processes and procedures to fully implement a quality system, including equipment platforms (VIHA, n.d., a). LMPMG has its own disaster response plan, entitled "VIHA Transfusion Medicine Internal Disaster Response Procedure". This thesis may assist in strengthening this plan, if and where necessary, and could inform the related activities of VIHA hospitals and the Canadian Blood Services.

## **1.2 The Design of the Study**

The three research objectives align with the major concepts--*risk, capacity, and vulnerability*--that frame and focus this study. Understanding these concepts and how they relate to real world hazard scenarios has important implications for human security and health. All three concepts are explored in greater detail and context in the Chapter 2 literature review, but in this introduction, the following definitions are provided.

Risk is a property of an uncertain situation, in this case a seismic event, for which the possible outcome relates to undesired consequences, to an event or process (scenario) causing the consequences, and to an estimated likelihood that the consequences will occur (Meacham, 2004). Capacity is the ability of an entity or a system, in this case a

health care system, to mount and co-ordinate a response to and recovery from the impacts of an unwanted outcome, thereby diminishing post-event vulnerability to those impacts. Capacity involves resources such as equipment, operations, staff, and training, and is linked to the skill, wisdom and leadership to use these resources effectively (EMBC, 2011b). Vulnerabilities are the residual liabilities that remain when the capacity of an entity or a system is insufficient to adequately address *all* of the major undesired consequences flowing from a risk that has resulted in an adverse event (Zakour and Gillespie, 2013)

The broad intent of Objective 1, addressed mainly in Chapters 3 and 4, was to gauge for three plausible seismic event scenarios the risk and magnitude of infrastructure damage and human injury that may result if each of these types of earthquakes occurs in the Greater Victoria region. To characterize the possible scenarios, comparable global examples of the three types of earthquakes were examined (Chapter 3).

The reasoning here was threefold:

- to ground the description of the hazard and associated risk in terms of available evidence and knowledge;
- to prepare plausible scenarios in which critical infrastructure and health care facilities may be damaged, and blood product supply, distribution, and administration limited; and
- to develop order of magnitude estimates of the numbers of hospitalizations that may also result from these scenarios, since those numbers would drive the response process of ordering blood products.

In characterizing the types of earthquakes and associated consequences that could affect Greater Victoria and in developing the estimates, some *general* aspects of local capacity (major health care assets and disaster response coordination expertise) and vulnerabilities (elements of infrastructure and populations) were identified.

To further address Objective 1, the first section of Chapter 4 presents estimates of the injuries and hospitalizations that might result due to each of the three types of earthquakes. The estimates followed from comparisons based mainly on (1) the average population densities and numbers of serious injuries or known hospitalizations in areas

that have been intensely affected by (an) earthquake(s) of a given type, (2) the intensity and duration of shaking and the degree of destruction within the areas intensely affected, and (3) how far such settled areas are from the corresponding earthquake epicenters. The estimates also incorporated assessments of the likely impacts of earthquake-triggered events such as landslides and tsunamis.

The estimates and the brief descriptions of the anticipated outcomes for each earthquake scenario provided key health care sector informants with sufficient information to inform their answers to interview questions regarding how their component of the health care system might respond to those types of events.

Objectives 2 and 3, covered chiefly in Chapter 5, speak to the capacity and vulnerability of the health care system players involved in supplying, distributing, and administering blood products and services in southwestern BC, and more specifically, on Vancouver Island. Content analysis of key informant responses and relevant reports was the principal analytic method for this second component of the methodology. The analysis involved the integration of the primary data gathered via semi-structured interviews with the 12 health professional key informants and information from several documents regarding health care system preparedness. This integration produced a synthetic analysis of the capacity and vulnerability of VIHA and other lead agencies responsible for post-quake response, including the emergency supply, distribution and administration of blood products. Validation of the study findings included review and feedback by the VIHA Medical Director of Hematopathology.

Chapter 6 provides an overall summary of the results of the analysis and evaluates how well the three objectives have been met.

### **1.3 Structure of the Thesis**

The structure of this thesis is as follows:

To assist the reader, Appendix A contains a List of Abbreviations, while Appendix B consists of a short Glossary of Terms. Chapter 2 commences with a review of the health care response system in the broader context of the geographic and allied literature

regarding health care, hazards, and the management of risks and disasters. A summary of the state of regional health care planning regarding disasters rounds out the unit. Chapter 3 elaborates the nature of the seismic hazard in the southern half of coastal British Columbia, then develops the three different earthquake scenarios, first considering earthquake catalogue case examples relevant to Greater Victoria and Vancouver Island. The cases and scenarios characterize the earthquakes as to the amount of energy released, depth of hypocenter, location of epicenter, intensity of shaking, and how the wave energy might be modified by local conditions such as deep clay deposits, or areas of unconsolidated fill, for example. These characterization factors and the case example information are also employed in Chapter Four to estimate hospitalizations in Greater Victoria as a direct or indirect result of the range of shaking and movement locally, and in a few other Vancouver Island locations.

Chapter 4 describes the methodologies used for differing purposes within the research. It details the techniques used for estimating injuries and hospitalizations likely to result from the three different types of earthquakes, plus the design of the interview guide and consultation process employed to obtain *feedback* from health care professionals regarding the implications of the damage, injuries, and hospitalizations anticipated to result from those earthquakes. It also reviews the process of analyzing and interpreting the themes that emerged from that feedback, and explains how this process is used in Chapter 5.

The fifth Chapter combines and integrates relevant material from related literature sources with the results of executing the consultation process. It interprets the results, chiefly with respect to the various interrelated agencies, services, and infrastructure components that support the VIHA TM function in Greater Victoria and across Vancouver Island. In addition, it links the informants' input to material on health care response to risk, capacities and vulnerability, to the discussion of the regional earthquake hazards, as mentioned in earlier Chapters, and provides findings and recommendations that Chapter 6 reviews and summarizes in a broader, more generalized context.

Chapter 6 contains the key findings and recommendations of the research. It reiterates the research objectives and describes how the research has addressed and answered them, plus identifies and evaluates the limitations of the study, such as its institutional

span, the sources and measures of uncertainty regarding the hazard itself, and within the methodologies used. The research is also discussed in terms of its value to emergency management planning, and to the academic literature regarding health geography and disaster management. This final chapter also suggests logical avenues for further research, and closes with the major conclusions of the study.

## Chapter Two: Literature Review

This study is part of a larger body of research regarding the understanding and management of environmental hazards, and of associated risk and vulnerabilities. The literature reviewed in this chapter also positions that research within the context of geographic scholarship. Various works demonstrate that, via multiple processes, the *geography* of hazards, risk, and vulnerabilities may determine who is drastically affected when adverse events do occur, and who is not. The discourse traces some of the evolution of thought regarding hazards, and notes divergence within the community studying hazards and risk, based upon a researcher's approach to analyzing and managing risk and hazards. The implications of hazards, risks, and vulnerabilities for current health care systems, and health system response to multiple-casualty disasters, round out the topics covered. The response of health care systems to rapid onset, multiple-casualty disasters constitutes the broader focus of this study.

### 2.1 The concepts of hazard, risk, and vulnerability

Meacham (2004, p. 204) defines *risk* as incorporating hazard, thusly:

the possibility of an unwanted outcome in an uncertain situation, where the possibility of the unwanted outcome is a function of three factors: loss or harm to something that is valued (consequence), the event or hazard that may occasion the loss or harm (scenario), and a judgment about the likelihood that the loss or harm will occur (probability).

To clarify, Meacham (2004) specifies that "loss or harm" entails social, cultural, physical, technical, and psychological dimensions, and qualifies "hazard or event" as a phenomenon or act with the potential to lead to loss or harm. Further, he provides that loss or harm encompasses, for example, loss of life, injury, disease, reduced quality of life, damage to the environment and property, and the inability—for an individual or for a business—to continue conducting economic activity (Meacham, 2004). This is a useful definition, but the concept of risk has other facets. Risk is a complex and multi-faceted

concept. It is dynamic in that it is now incorporated into various subdisciplines, with an array of definitions and uses (Althaus, 2005; Covello and Merkhofer, 1993).

**Table 1. By Discipline: Risk Concept, Form of Human Attention Applied to the Unknown, and Key Issues**

Discipline	Risk Concept	Attention Applied	Possible key issue or question
Anthropology	cultural phenomenon	culture	treating risk technically diffuses sovereignty
Economics	decision process, avoid loss or secure wealth	information accuracy, rules for decision-making	stress or profit motive may lead to decisions classified as inaccurate, irrational, or immoral
History	risk as a story	narrative	do undiscovered unknowns exist?
Law	fallible conduct, judicable phenomenon	definite rules	remote, dispersed, and ecologically complex effects; scientific uncertainty, fallible verdicts
Linguistics	concept	terminology and meaning	noun/verb with converse meanings, malleable concept varies temporally by region and society
Logic and Mathematics	calculable phenomenon	assumptions, logic, estimates, calculations	inconstant variability of hazards, hazard threshold, effect delay
Philosophy	problematic phenomenon	assumptions, wisdom	can moral systems deal with the implications of various risks?
Psychology	cognitive and behavioural phenomenon	cognition	infinite variability among individuals, requires unifying perceptual and behavioural framework
Science and Medicine	objective reality	principles, assumptions. hypotheses, estimates, calculations	risk perceptions differ (lay public vs. science and governments), complex technological hazards, inertia of growth, and globalization confound science; may lead to anxiety and/or intentional ignorance
Sociology	social phenomenon	social constructs, frameworks	globalization, technological hazards lessen control, or diminish certainty; result: ignorance and/or anxiety

The origin of the word “risk”, like its meaning, is in dispute (Cutter, 1993). Althaus (2005) lists various authors’ suggestions, including that the term risk arose amongst early mariners, perhaps coming to English from the Spanish “sailing into uncharted waters, or near rocks”—or from Portuguese, where one root of the term means “to dare”. Althaus (2005) considered risk from the perspective of several academic disciplines. Some of her observations, along with some questions and issues, (more uncertainty) appear in Table 1. As for the function of risk in society, Bernstein (1996) argues that devising the concept of risk and the attempts to assess it have been catalysts that enabled humanity to progress beyond the limits of fate, to face the positive *and* negative implications of our now greater number of choices. Thompson (1986) as cited in Althaus (2005, p. 568) propounds that philosophically, risk can be differentiated via definitions arising from different risk literatures:

1. Subjective risk: the mental state of an individual who experiences uncertainty or doubt or worry as to the outcome of a given event or process.
2. Objective risk:...occurs when actual losses differ from expected losses.
3. Real risk: ...probability and negative consequence...in the real world.
4. Observed risk: ...measurement...obtained by constructing a model of the real world.
5. Perceived risk: the rough estimate of real risk made by an untrained member of the general public.

The *context* of the risk situation being considered often governs how risk is interpreted and measured (Meacham, 2004). In everyday meaning and usage, risk has duality—negative (endangering) connotations, and/or the positive promise of a venture rewarded. Modernity has increasingly given it a negative tone, as modernity has witnessed the accelerating creation of technological risk (Beck, 2006; Lupton, 1999).

Cutter (1993) summarized concepts of hazard advanced by Kates and Kaspersen (1983) and Whyte and Burton (1980). To them, hazard

incorporates the probability of the event happening...the impact or magnitude of the event on society and the environment, as well as the socio-political contexts within which these take place. Hazards are the threats to people and the things they value, whereas risks are measures of the threats of the hazards (Cutter, 1993, p. 2).

*Hazard perception* research initiated sustained and interdisciplinary inquiry, increasing our understanding of risk *perception*. Perrow (1984) analyzed and also classified various types of hazards. Damaging earthquakes exemplify his low probability/high consequence hazard category (Perrow, 1984). Kates (1971) in Cutter (1993) presented a hazard-adjustment model useful for explaining individuals' and policy makers' choices of adjustments to natural hazards. It identified "the range of theoretical adjustments...actual adjustments...and...why one coping strategy was selected over another...in response to natural hazards" (Cutter, 1993, p. 14). Hazard-perception research initially provided indications of how people felt about localized hazards, but extrapolating findings obtained from relatively few people was not acceptable, and assuming that people would "choose...action that was good enough but not optimal" did not anticipate "the constraints on the range of choice...in social, political or economic systems" (Cutter, 1993, p. 17).

Risk-perception analysis centered on controlled psychological experiments on "...how information is processed (heuristics and biases) and how attitudes adjust based on conflicting information and differences between thought and action (cognitive dissonance)" (Cutter, 1993, p. 16). Individuals who heuristically process complex information may overly simplify actual risk (Covello and Merkhofer, 1983), and over-confidence in risk estimates may make people complacent. Powell, Dunwoody, Griffin, and Neuwirth (2007) considered how laypeople perceive uncertainties about environmental health risks. Table 2 summarizes their general results. How risk is perceived has pervasive social implications.

**Table 2. Factors that may affect how laypeople perceive uncertainty in environmental health risks**

<b>Factor</b>	<b>Apparent relationship to perceived uncertainty</b>
Uncertainty itself	Reflects individual-level emotions and cognitions, but may also be shaped by a variety of social and contextual factors
Emotions (worry and anger)	Are strongly associated with perceived uncertainty; perceived lack of knowledge and perceived likelihood of becoming ill are weakly associated with it.
Demographic variables, information exposures, and risk judgment variables	Affect perceived uncertainty indirectly, primarily through perceived knowledge and emotions.

The growing number and complexity of technological hazards and associated risk perceptions mean that health care systems must prepare for many technological risk scenarios and related human behaviours that may have a wide range of consequences. As Cutter (1993, p. 13) states, "our individual and collective perceptions of risk not only influence our acceptance or tolerance of a technology or activity, but they ultimately affect public policies and the basic functioning of societies." A recent and relevant case in point is the 2011 subduction earthquake and tsunami that devastated the north-eastern coast of Honshu, Japan which involved a combination of profound natural and technological (nuclear radiation exposure) risks. The perceived ineptitude of the Japanese government response to, and uncertainty regarding the implications of, this exposure surpassed the trust and tolerance levels of many Japanese people (see pp. 253-4 in Nakamura, 2012). Although the full extent and implications of the radiation exposure have not yet been assessed, the "dis-ease" of mistrust of officials from the nuclear utility and overseeing government represents an initial health effect within a segment of the Japanese population (Nakamura, 2012; see also pp. 523-4 in Schillmeier, 2011).

The growth of geographic scholarship regarding hazards, risks, and vulnerabilities results from sources within and outside of the overall discipline, reflecting, as Turner (2002) maintains, the openness of geography to outside ideas, and its willingness to increase its ways of knowing. The work of Gilbert F. White regarding adjustment exemplifies this. Natural hazards research, led by G.F. White, Kates and Burton, initially involved hazard mapping (Hewitt, 1980). Case studies, focused on human settlement in hazardous areas, provided opportunity for researchers to detect patterns in the types of adjustments humans made in response to the hazards (Cutter, 1993; Hewitt, 1980). In the 1970s, critiques by Torry (1979) and Waddell (1977) promoting a political ecology view of hazards, held that this traditional view of natural hazards was simplistic, and that cultural, economic, political and social forces govern people's perceptions of and adjustments to hazards, thereby defining the areal distribution and frequency of hazards. Hewitt (1983), Watts (1983) and Wisner, O'Keefe and Westlake (1977) added credence to political ecology, alleging that people were made more vulnerable to hazards via economic and political shackles on their responses.

Geography may determine who bears the consequences of a hazard or hazardous event, and why (Cutter, 1993).

The “hazards in context” school stems from the human-ecological path that arose within geography, but via behavioural and empirical analysis, incorporates the political and social contexts within which the hazards occur (Mitchell, Devine, and Jagger, 1999). Palm (1990), and Palm and Hodgson (1992) constructed a sophisticated model within this genre, analyzing the California housing market in relation to earthquake risk. Their framework includes geographical scale considerations, plus finer analysis of and spatial connections between the levels of economic, political and social entities and forces that allow or limit the comprehension of hazards.

Geographic scale may dictate the complexity (context and processes) of a technological hazard, the extent of impacts of a hazardous event (e.g. a subduction earthquake), and the effort required to respond to its consequences or to reduce the level of danger latent in a hazard (Cutter, 1993). Notable long-period ground motions occurred in Tokyo, Nagoya, and Osaka, Japan, respectively *375 km, 600 Km, and 730 km* from the epicenter of the 2011 Tohoku earthquake (Google Earth, 2012; Takewaki, 2011). In planning and preparing to respond effectively to such consequences, and in helping to educate their publics about reducing risk, health care systems face a daunting challenge.

The social amplification of risk, hazards considered in context, and social theory share a common element—*vulnerability* (Cutter, 1993). According to Cutter (1993), this frequently-used term has been compromised in the literature by uncertainty in both geographic scale and as to whom it applies. She states that Hewitt and Burton (1971) prepared the ground for this concept in a “hazardousness of place model”, essentially assessing vulnerability of place, and credits Timmerman (1981) for proposing that the quality and degree of the adverse reaction of a system to a hazardous event expresses the *vulnerability* of the system (Cutter, 1993). Vulnerability has also been termed “the potential for loss” (Mitchell, Devine, and Jagger, 1989; Bogard, 1989), but Cuny (1983), for one, linked the hazardousness of place with the concept of *reducing* vulnerability via changes to infrastructure construction codes, and through adaptation by economic systems and socio-political forces. Individual, social, and biophysical

vulnerabilities intertwine to produce the overall vulnerability of a *place* (Cutter, Boruff, and Shirley, 2003). Definitions aside, the issue is how the pace, scale, intensity, and complexity of human activities are increasing vulnerabilities around the globe, and secondly, whether key steps to decelerate the generation of such vulnerabilities will become economically and politically palatable soon enough.

When individuals do not know enough—or fail to reflect seriously—about how a damaging earthquake could affect them, they remain more vulnerable than if they act, both to reduce potential damage from a quake and to prepare an effective response in reaction to, and for recovery from, its consequences. And if individuals remain more vulnerable than *they* need be, their health system is more vulnerable to overload and functional collapse than *it* need be.

## **2.2 Implications of Hazards, Risks, and Vulnerability for Health care Systems**

To this point, we have reviewed literature regarding environmental hazards, risk, and vulnerability, mainly from the perspectives of hazards and risk research. These phenomena and their interpretations have numerous implications for medical geography and health care systems. What follows is a discussion of implications for the health care system, flowing from some of the factors and contributions identified in the related literature. This section reviews recent trends and issues pertaining to the development of scholarship and practical knowledge regarding environmental hazards, risk, and vulnerability, as they relate to health care. It closes with a brief summary of various factors identified in the literature as having significant implications for the health care system response to seismic events.

For this project, our health system is broadly defined, based on the Mission statement of the British Columbia Ministry of Health, as a public effort “to guide and enhance the province’s health services to ensure British Columbians are supported in their efforts to maintain and improve their health” (Government of British Columbia, n.d.).

The statement by Cutter (1993, p. 13) that “our individual and collective perceptions of risk not only influence our acceptance or tolerance of a technology or activity, but they

ultimately affect public policies and the basic functioning of societies” is laden with implications for our health care system, and for health geography. Complex new technological hazards, associated risk-perceptions, increases in vulnerability, and the rising, sometimes risk-averse expectations of various publics, mean that health care systems have had to prepare for numerous scenarios arising from a wide array of potential consequences—some of them obvious, and some not. In turn, this broad response capability implies the need for robust systems with built-in flexibility in staffing, for analysis, and in uses of equipment and supplies. Budgetary constraints may mean that potentially risky arrangements, such as *just-in-time inventory*, are sometimes put in place.

The spread of knowledge and debate about public safety and the collective negotiation of what societies accept as reasonable degrees of risk reduction have in part flowed from geographers’ research. The assessment, monitoring and surveillance of hazards and risks that Whyte and Burton (1980) promoted informs action plans that involve preparedness measures already taken, and that imply a clear chain of direction and command, specific staffing needs, plus the timely flow of concise information and necessary supplies, in the execution of a response appropriate to the circumstances. Given that, health care planners must have a role in shaping what to publics are acceptable levels of (a) preparedness against drastic consequences of hazards, and (b) tolerable risk.

As time passes and pressure between seismic plates on the west coast of North America mounts, the probability of a damaging subduction earthquake in this area increases. People’s perceptions of the risk and consequences of a significant earthquake occurring affect the extent to which they will act before the event to reduce potential personal consequences, and to prepare for a relatively short but more difficult and hazardous recovery period. The British Columbia (BC) Ministry of Health (MoH) is taking proactive steps to prepare for this eventuality. By knowing how people perceive this risk, the MoH can prepare effective communication plans and educational materials—that help deliver an integrated, government-wide message—to stimulate appropriate public preparations before, and actions after, a damaging earthquake. But

with respect to an earthquake, for example, the general public must play the *major role* in reducing risks to health from such an event.

### **2.2.1 The Development of System Responses to Emergencies and Disasters**

The current western systems of response to hazards with high magnitude health consequences originated mainly in military models refined during the past 200 years, and have evolved significantly. Responses initially focused upon casualty retrieval that may ultimately proceed to a hospital(s) (Bissell, Pinet, Nelson, Levy, 2004; Dara et al., 2005). Napoleon's army invented triage, since refined in more recent wars and via health system analysis (Dara et al., 2005). Speed of response and triage have proven critical in preventing loss of life following many earthquakes (Ricci et al., 1994). After the 1881 Vienna Ring Theatre Fire, local trained personnel became known as the Emergency Management System (EMS) (Dara et al., 2005). A U.S. National Academy of Sciences 1966 paper "Accidental Death and Disability: The Neglected Disease of Modern Society" initiated the modern American era of EMS (Pozner, Zane, Nelson, and Levine, 2004). The U.S. federal government organized a system to improve EMS and develop an emergency medical technician training curriculum (Pozner et al., 2004). In 1970, to better fight California wild fires, planners spawned the Incident Command System (ICS), a major step toward the standardization, hierarchical structure, and role definition needed in civilian responses to disasters (Dara et al., 2005). Disaster medicine now overlaps public health functions, and after a catastrophic event, limits injuries and deaths, and prevents health complications. A destructive earthquake would likely be one of the more challenging types of responses for disaster medicine to marshal.

#### *The Emergency Management Cycle*

The four pillars of emergency management are: Mitigation/Prevention, Preparedness, Response, and Recovery (EMBC, 2011b). In order to develop an effective disaster and emergency response plan, organizations typically undertake a hazard, risk and vulnerability analysis (HRVA), to develop an awareness of the threats that the entity is likely to face, and its existing vulnerabilities to those threats. In an online description of its Disaster Resilient Communities Program, the Provincial Emergency Program

schematically laid out (in Figure 7) the program objectives and tools (EMBC, n.d.) As part of this program development package, EMBC has prepared a step-by-step hazard, risk and vulnerability analysis (HRVA) tool kit, plus a computer program application designed to ultimately help a community conduct a community emergency program review (CEPR) (EMBC, 2004). Various levels of health care organizations can employ these and other resources to conduct environmental scans, analyses, and reviews that will help develop and improve their respective and collective emergency management programs.

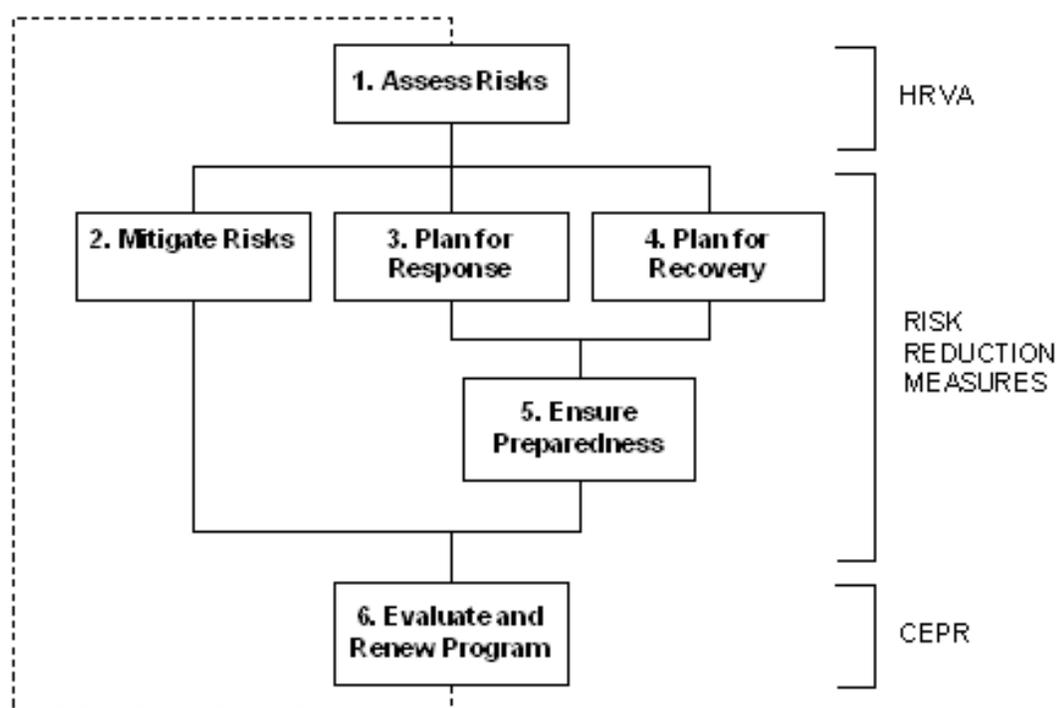


Figure 7. Emergency management objectives, Disaster Resilient Communities Program, Emergency Management BC. HRVA stands for hazard, risk and vulnerability analysis. EMBC (n.d.).

The first step in analyzing hazard, impact, risk and vulnerability (HIRV) regarding health system assets in a particular locality is to identify its potential hazards. The second step is to complete a risk analysis to answer the question “What is most likely to happen here?” (MoH, 2005). A health system vulnerability analysis also evaluates the capacity of a health jurisdiction to provide emergency health services in post-disaster conditions, in terms of what facilities, functions, and operational support are assumed to be available

(MoH, 2005). Arnold (2005) identified and analyzed components of selected risk assessment methodologies, and some of his excellent work is reflected in Appendix C. Health care jurisdictions generate *community* profiles that assess how health care assets in a community and its population in general might fare in the face of various types of disasters (MoH, 2005). A risk-based approach addresses the import of initially assessing vulnerability to all hazards, in order to optimize a balanced integration of functions that reduce vulnerabilities and risks (Government of Canada, 2008).

The following section discusses the emergency management cycle with respect to the threat that damaging earthquakes pose to health care systems.

### **2.2.2 Reducing Earthquake Impacts upon Victims and Health care Assets**

According to Mileti, Nathe, Gori, Greene, and Lemersal (2004), and Tekeli-Yesil (2006), local mitigation and preparedness activities are the most important tools for coping with disasters. With respect to incentives for *individuals* to invest in earthquake consequence mitigation, Bolt (1991) proposed that earthquake insurance, if regulated properly and consistently, could help reduce risk via market incentives for risk/vulnerability mitigation incorporated in graduated insurance premiums. Local citizens who can deliver disaster first aid and effective psychological support within the initial 24 hour post-quake period would be valuable assets in an emergency response (Tekeli-Yesil, 2006). Therefore, health care systems already conduct education that (1) generates awareness of typical health outcomes flowing from earthquakes, (2) addresses mitigation measures, and (3) prepares the public to respond to and recover from the short-term physical and long-term mental outcomes of earthquakes.

But mitigation efforts would likely be much more effective if they were well-advertised, collective and coordinated. Johnston, Becker, and Paton (2012, p. 263) are convinced that "community participation allows an outlet for people to articulate and solve problems, empowers them to take action, and as a result assists in reducing anxiety...and helps build resilience to cope with future events." The public and the private sectors can and should be a part of health system HRVAs, and of a broader health system planning and policy-building process regarding the short-term and long-term response to earthquakes (Gaillard and Mercer, 2013).

Basolo et al. (2009, p. 358) conclude that policies regarding the communication designed to drive mitigation of potential earthquake damage should encourage clear linkages between potential consequences and each preparedness action, and go on to state that:

this communication...strategy would require a concerted, coordinated effort by all levels of government, the private sector, and other organizations. For example, information pamphlets distributed in communities and government Web sites communicating risk and preparedness information should be complemented by school- and workplace-based information programs.

Recently in California, an earthquake scenario entitled "the Great California Shakeout" involved an estimated 5.4 million people in awareness-building about earthquakes (Earthquake Country Alliance, 2009). This broad effort, influenced by researchers like Denis Mileti, expanded and focused social networks in urban settings to accelerate and expand local pre-quake mitigation and preparedness efforts to reduce the incidence of earthquake-related minor injuries in households and business premises within regional jurisdictions. The BC health care system has wisely embraced participation in subsequent Shakeout exercises, and the VIHA Emergency Management website allows the public to follow *its* progress on Twitter.

#### *Reducing Vulnerability to the Impacts of Earthquakes and tsunamis*

As Goenjian et al. (2000, p. 911), who interviewed 78 non-treatment-seeking survivors of the 1998 Spitak earthquake in Armenia, reveal:

After exposure to...an earthquake...adults are at high risk of developing severe and chronic posttraumatic stress reactions that are associated with chronic anxiety and depressive reactions. Clinical evaluation and therapeutic intervention should include specific attention to these reactions...to prevent their chronicity.

Chou, Huang, Lee, Tsai, Chen, et al. (2004) studied the mortality associated with the September 21, 1999, 7.3 M earthquake that occurred in Taiwan, during the middle of that night. People with mental illnesses, those with moderate physical disabilities, and victims hospitalized pre-quake were the most vulnerable (Chou et al., 2004). Nearly half of street people typically have some form of mental illness (Kermode, Crofts, Miller, Speed, and Streeton, 1998; Patterson, Somers, McIntosh, Shiell, and Frankish, 2008).

Many in this group, and among the elderly, who are subject to depression and anxiety may be doubly vulnerable, since they may be more prone to suffer from post-traumatic stress disorder shortly after a damaging earthquake (Chubb and Bisson, 1996). As part of a long term process, health jurisdictions may want to seriously consider ways to help strengthen and focus inclusive and productive networks based upon neighbourhoods, workplaces, or shared interests, in order to achieve better mitigation *before*, trauma support immediately after, and *sustained* psychosocial intervention *years after*—a devastating earthquake affects their constituent communities.

Community-based, *integrated mitigation and response* activities can reduce human vulnerability to the vagaries of natural disasters (Kelm, 2008). Johnston et al. (2012, pp. 264-265) provide an indication of the effect that integrated planning for mitigation and response may have:

In the early stages of the 1995 Ruapehu eruptions in New Zealand, the lack of prior arrangements was seen as a significant issue (Paton et al., 1998a, b, 1999; Johnston et al., 2000)....In contrast, the benefits of prior planning for multidisciplinary and multi-agency warning response were seen during the 18 March 2007 Ruapehu lahar...This was achieved through clearly documented, shared and agreed planning; cooperation and communication at regular planning meetings and...exercises; and education through the meetings, exercises, documentation and media coverage. A key element was a concerted and sustained team approach across a wide range of agencies. This was aided by political, media and public interest in averting a disaster, and the relative ease of forecasting the timing of occurrence of the event..."

### *Emergency Preparedness*

Disaster response exercises may empower hospital staff to assume more responsibility, provide them an opportunity to solve some of the problems that may arise during an actual emergency incident or disaster, and help them create a confident culture and climate of preparedness (Vu, 2012). Organizations such as Disastermed.ca now provide real-time simulations of emergency response situations for medical and emergency response trainees who have, in the process, been designated as in-class response teams (Franc-Law, Dong, and Nichols, 2009). Organization, communication, coordination, and cooperation are vitally important in disaster preparedness and response programs. Organization is fundamental, while cooperation, coordination, and communication form

the cornerstones of such programs. Without them, preparedness and response programs cannot succeed effectively (Tekeli-Yeşil, 2006).

With respect to a damaging earthquake event(s) affecting Greater Victoria, Jaswal (2012) explored the levels of preparedness and the degree of integration of response planning for two local tertiary care hospitals. Inter alia, her results highlight the need for greater engagement and integration of earthquake response planning [among] health system stakeholders—especially, at the community level, NGOs and the British Columbia Ambulance Service (BCAS)—and all levels of government (Jaswal, 2012). Such findings are plausible, because as she quotes one health authority Emergency Manager, “there are so many things happening on a day-to-day basis that there is barely enough time to deal with regular everyday crises, never mind what might or might not happen. So it’s a challenge getting people’s attention to talk about earthquake preparedness” (Jaswal, p. 133). Regarding health care *in the midst of a disaster*, Thompson (2011, p. 122), in stating that “the nature of health care—where operations not only must continue in a crisis, but typically accelerate, under adverse conditions”, implies that health care human resources would be severely stretched.

### *The Response Process*

As regional health authorities, their hospitals, and various functional subunits within hospitals (1) establish linkages with local first responders, municipal governments, other provincial agencies, local and regional businesses, and emergency social services, and (2) further train their own employees in disaster response, they clarify the disaster response role of these players, and induce “interaction between essential personnel and available community resources that could [for instance] enhance hospital surge capacity” (Braun et al., 2006, p. 799).

Disaster response occurs locally, at the site(s) where people, or things that they value, have been damaged. To align, prepare, marshal, and coordinate the requisite disaster response resources to address the aftermath of a severe earthquake, for example, *integrated* multi-agency emergency management expertise, planning, organization and execution are vital (Coles and Buckle, 2004; Johnston et al., 2012; Mileti, 1999; Thompson, 2011).

Bruneau et al. (2003, p. 737) identified four properties that can be applied to all systems, including the disaster response of a health care system:

- robustness (the ability of elements, systems, or other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function)
- resourcefulness (capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis)
- redundancy (the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable [of] satisfying functional requirements in the event of disruption, degradation, or loss of functionality)
- and, rapidity (the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption).

These properties are desirable in the VIHA and CBS emergency response capability, and were used in designing the original research interview guide, and to help evaluate the utility of information and suggestions that were put forward based on interpretation of the results of that interrogation.

Another key to an optimal health system disaster response is interoperability—the ability to link activities across hospital jurisdictions to achieve coordination and increase surge capacity. Hick, Koenig, Barbisch, and Bey (2008) offer a conceptual model to assist hospital incident command personnel to efficiently assess evolving incidents, prioritize initial incident actions, rapidly mobilize appropriate resources, and adequately address key components of surge capacity. The tool is structured to ensure that: an incident management structure is implemented, the logistical requirements for staff, stuff, space, and special (event-specific) conditions are considered, and basic patient care and patient movement functions will be well-managed (Hick et al., 2008).

A planned response to a disaster bears the promise of the best available information, analytical methodology, decision-making capacity and teamwork practices, but is only as strong as the weakest link(s) in its planning and execution. After sudden-impact disasters, urgency, and disruption of an area's infrastructure may call for non-probability sampling techniques such as modified cluster-sampling, to perform a rapid needs assessment survey of the affected population, and to identify any potential secondary

risks to health (PAHO, 1981; Noji, 2005). Quarantelli (1997) developed an extensive and useful set of criteria for the effective management of disasters, which appears in Appendix D.

A disaster situation often pits many agents from varying backgrounds against a demand to perform too many different functions simultaneously under unpredictable, dynamic, and radically altered conditions that offer unique and vitally important combinations of choices and actions (Kapucu, Bryer, Garayev, and Arslan (2010). Kowalski-Trakofler, Vaught, Burnish, and Jansky (2010) identified several factors that may affect decision-making in disaster circumstances:

#### *Cognitive*

- Information – The value or credibility associated with information received depends upon the source, the associated degree of certainty and accuracy, and the nature of the information flow. Whether it is clear, concise, from several different sources, or is duplicated are additional considerations.
- Communication – The source is considered as the most important evaluation factor.
- Knowledge gained directly apparently has a higher value versus that gained indirectly. Whether the knowledge gained is adequate is a separate question.

#### *Autonomic*

- Training – Good training leads to the ability to make good decisions. In those well-trained, awareness of environmental conditions, of chains of causality, and of how to use instinct, reduce the number of decisions to be made. Whether one plays one's role calmly and with confidence also influences the quality of those decisions.

#### *Physiological/Psychological*

- Stress – Stress may distort perception, and thus can lead to poor quality decisions.
- Fatigue – When people are fatigued, their decision-making processes often deteriorate.
- Adrenalin – With too much adrenalin in their systems, people can be less observant, which may lead to decisions that are quick, but poor.
- Fear – Fear may be due to perceived risk or uncertainty, and may paralyze a person's decision-making capability.

With respect to stress and fatigue, during the first day or two of a blood product supply contingency and/or a multiple-casualty, emergency increased blood-demand situation driven by an earthquake, Transfusion Medicine staff would likely need to scale up operations, perhaps despite some of their workplace and tools having been damaged. Yet the right mix of staff may be in short supply due to damage to their homes, to being victims themselves, or to a family member being injured. If fewer staff are working longer hours, they face higher risk of screening errors due to stress and exhaustion (Kuruppu, 2010).

#### *Health System Response to Rapid-onset, Multiple-casualty Disasters*

Those assessing the consequences of a hazardous event must make a significant distinction - not all disasters are public health emergencies, but as Burkle, Jr. and Greenough (2008, p. e3) advise, "the timely and accurate recognition of the public health impact [of a disaster] is critical for proper...preparedness, planning, and response". Burkle, Jr. and Greenough (2008) define public health emergencies as those situations:

that adversely impact the public health system and/or its protective infrastructure (i.e., water, sanitation, shelter, food, fuel, and health), resulting in both direct and indirect consequences to the health of a population, and occur when this protective threshold is absent, destroyed, [or] overwhelmed...( p. e3).

Community-wide recovery commences with the provision of emergency social services, after casualties have been assisted. Once hazards—such as collapsed bridges, other collapse-prone structures, spills of toxic or very flammable materials—within damaged infrastructure have been removed, the repair of crucial transportation infrastructure can permit vehicular traffic on a scale required for cleanup and reconstruction. In health care systems, recovery includes restoring numerous services (such as full amperage electric power, most computerized systems, natural gas heating, and full pressure water from mains) which may ensure that health care entities of various operational scales can function at or near pre-event levels. Brown (2008) advocates that, as part of the recovery process, communities—and, logically, health care organizations—should take

measures to reduce future exposure to the consequences of a similar event. Johnston et al. (2012, p. 253) point out that:

international research on recovery highlights the importance of not only strong local government capacity, but also of a cohesive system of public, private and volunteer groups integrated into the community (Mileti, 1999; Rubin, 2000, 2009; Norman and Coles, 2002; Dynes, 2003; Coles and Buckle, 2004; Gordon, 2004; Smith and Wenger, 2006; Hayashi, 2007; Johnson, 2009; Siembieda, 2010).

### **2.2.3 Evaluating Progress in Developing, Implementing, and Improving Emergency Management Programs**

Emergency management entities usually conduct an annual evaluation of their comprehensive programs, and then prepare an annual report to the executive level of the organization (EMBC, n.d.). The report should review progress on the Strategic Plan implementation schedule, addressing objectives, action plans, training activities, and actual response situations, if applicable (EMBC, n.d.). The following sample questions were extracted and modified from the EMBC Community Emergency Program Review template (EMBC, n.d.):

1. Has the emergency program:
  - a) successfully implemented action plans and reduced risk to the public and to the organization, so that it can justifiably advertise in a newsletter, on a website, or via other means, its success in achieving an effective emergency program?
  - b) entered into mutual aid arrangements with health care organizations or facilities in neighboring communities, and local emergency response organizations, for emergency resources or assistance of any kind?
2. Have provisions been made for installing power, lighting and communications equipment in all EOCs, and for inspecting and testing this critical EOC equipment on a regular basis?
3. Does the approved recovery plan include a procedure to establish priorities for restoring essential services?

In many countries, health system emergency responses to disastrous events are coordinated on multiple levels depending upon the magnitude of the event. As mentioned in the introduction, individual hospitals, *and* regional health authorities, *and* senior political jurisdictions, such as provinces, may be involved. From the top down, British Columbian examples include:

a) The 2008 version of the EMBC earthquake-specific British Columbia Earthquake Plan (EMBC, 2008) involved input from at least four Canadian federal agencies, four provincial ones, two regional governments, and the California Governor's Office of Emergency Services.

b) The BC Ministry of Health all-hazard Emergency Management Plan (BC Ministry of Health, 2005a). The British Columbia Earthquake Response Plan (2008) offers some direction for implementing this Ministry of Health plan in post-earthquake circumstances (EMBC, 2008).

c) the VIHA Disaster Plan – The Victoria General Hospital Site – March, 2006 (VIHA, 2006), which contains and explains various abbreviations, such as:

AEOC – Area Emergency Operations Center. An Emergency Operations Center established and operated at the area level in order to coordinate the response and support of all VIHA SEOCs within its jurisdiction and to liaison with the HAEOC.

SEOC – Site Emergency Operations Center. A pre-designated location at a site to coordinate the site response and support in an emergency.

DETR – Disaster Emergency Response Team. The DETR is a support team that provides technical emergency management advice and support to the Incident Commander of the EOC.

HEICS – Health Emergency Incident Command System. The Health Emergency Incident Command System is based upon the same standards and organizational structure as the Incident Command System (ICS) as used in HABCERMS and is operationally compatible with that structure. HEICS is used at the SEOC command level within a facility (VIHA, 2006, pp. 10-11).

This plan also contains a Business Continuity Plan, as *its* Appendix B. Business Continuity

Management involves making advance preparations needed to identify the impact of potential business interruptions, formulate resilience and business continuity using recovery plans, and administer a training, exercise, and maintenance process (VIHA, n.d. a).

d) The VIHA Transfusion Medicine Internal Disaster Laboratory Response Procedure. This plan applies to the Transfusion Medicine aspect of the VIHA-wide Department of Laboratory Medicine, Pathology and Medical Genetics (LMPMG). It specifies the actions and procedures that personnel within the TM laboratories would follow in disaster circumstances. In a blood shortage contingency, this plan would mesh with a VIHA TM Blood Contingency Plan (VIHA, 2010b).

e) the British Columbia Blood Contingency Plan (BCBCP) (BCTMAG/PHSA/BCPBCO,2009). The BCBCP, examined in more detail in Chapter 5, is intended to ensure that during a blood shortage, as many patients as need them would have access to safe blood transfusions, and to equitable allocation of blood, based on need.

Some researchers applying locational analysis to blood services have defined and addressed criteria such as minimizing outdate and shortage targets for blood in each administrative region, a regional level of supply and distribution strategy, the access to, and availability of, fresh blood, and the age of blood in a blood product inventory (Şahin, Süral, and Meral, 2007). For the Yale-New Haven Hospital Transfusion Service and Blood Bank, Erickson et al. (2008) developed a detailed disaster plan, coupled with a comprehensive emergency blood management strategy and plan, which includes maintaining a tactical, limited supply of frozen group O red blood cells (RBCs). The frozen blood supply serves as a short-term, 3 to 4 day bridging supply, which could help a hospital cope with a temporarily increased demand for blood components or an interruption in blood supply (Erickson et. al., 2008). Since thawing is the rate-determining step in extending the duration of the blood supply, it must be initiated early in the contingency (Erickson et. al.). Unfortunately, this particular emergency blood management plan would likely break down when faced with some of the anticipated outcomes of a damaging earthquake—mass casualties simultaneously requiring immediate access to liquid blood, or loss of electricity, or significant damage to areas of the hospital blood bank (Erickson et. al.).

The VIHA Transfusion Medicine Internal Disaster Response Procedure employs the Şahin, Süral, and Meral (2007) criteria and includes directives for thawing frozen group O RBCs (Erickson et. al., 2008). In Chapter 5, the input from VIHA TM staff reflects their knowledge of this procedure and their practice of minimizing outdate and shortage targets, for example.

## 2.2.4 Estimating the Post-quake Rate of Supply of Blood Products

Estimating the blood product demand arising from a sudden onset, multiple-casualty disaster so far appears to be an imperfect practice. The American Association of Blood Banks (AABB) (2008, p. 40), for example, has offered a generally-accepted formula for estimating how many units of RBCs a blood transfusion service should order to top up its "disaster response" inventory of that product, based on the anticipated number of disaster-driven hospitalizations (see Figure 8). The author developed the hospitalization estimates in this research in order that they be used in this formula.

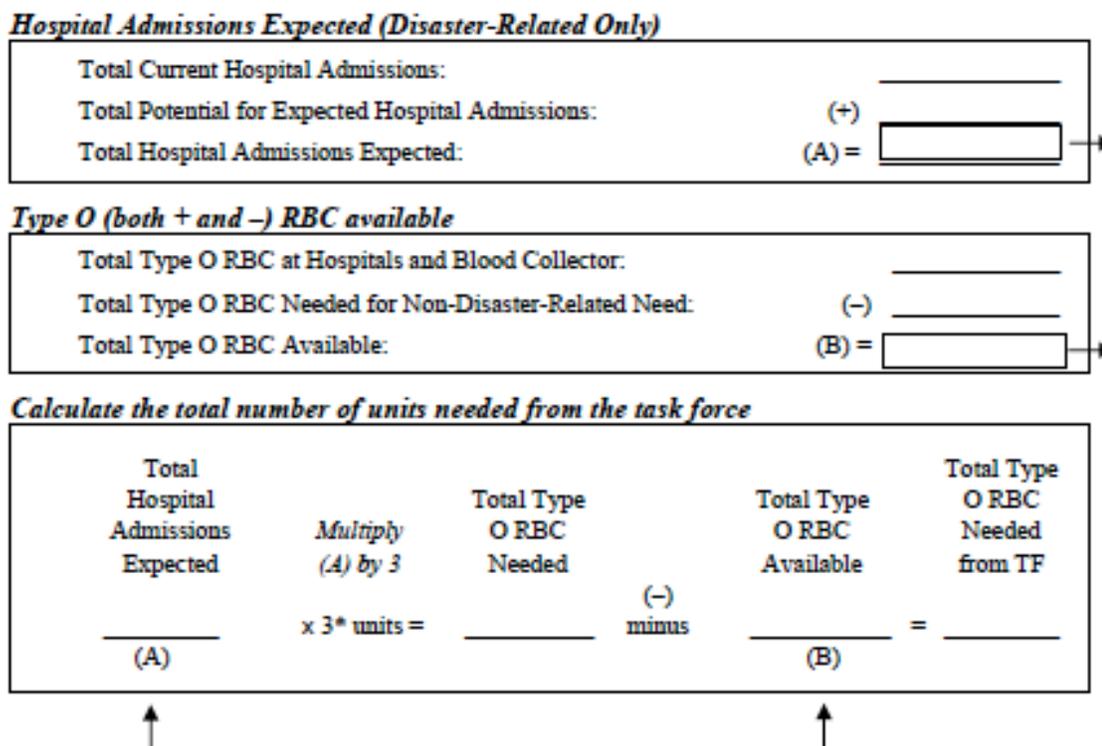


Figure 8. The AABB disaster-driven RBC order formula. Source: AABB (2008, p. 40).

Estimating hospitalizations in turn involves examining what fraction of disaster-driven serious injuries result in hospitalizations. Iranian blood agency experts involved in the Bam (2003) and Zarand (2005) earthquakes in Iran estimated that 5–10% of those seriously injured (SI) were transfused (Tabatabaee et al., 2010). Based mostly on these two earthquakes, Tabatabaee et al. (2010) considered two different hospital admission rates, 0.25 and 0.35 of the number of SI, and blood transfusion rates of 0.05, 0.07, and 0.10 of the SI, in their scenarios for *shallow* earthquakes that would generate shaking of MMI VII to IX *near Tehran*. Shortly after the 2010 *shallow* M=7.0 January 12, 2010 earthquake in Haiti, the U.S. hospital ship USNS Comfort supplied an average of 11 units of blood daily for transfusions and replenishment of blood products. In approximately 5% of the surgeries performed, patients required blood transfusions (Jackson/USNS Comfort Public Affairs, 2010). By Feb. 15, 2010, the staff of the Comfort's blood bank had supplied more than 300 blood units for transfusions and replenishment (Jackson/USNS Comfort Public Affairs, 2010).

Strong and sustained ground movement would seriously damage buildings with glass facades in downtown Victoria, and falling glass likely would create numerous cut injuries, some of which may require replacement of lost blood. Abdominal injuries, such as pelvic fractures, rupture of a hollow viscus, or of the bladder, often involve intra-abdominal haemorrhage, and require immediate surgery. They stem from blunt abdominal trauma (e.g., direct hit, or acceleration-deceleration forces) often due to impacts from (a) falling materials, (b) shaking of hard, rigid materials, or (c) tsunami-borne debris (Gautschi, Cadosch, Rajan, and Zellweger, 2008). In addition, those who have been trapped under debris and had to have limbs amputated, or who have penetration wounds (also likely from falling glass), or septicaemia (Vain, Mazlumian, Swarner, and Cha, 1980) are likely to require blood soon after their rescue (Gautschi et al., 2008; Loyolaems, 2009). Many injured people rescued after being trapped for more than 48 hours may arrive at hospital *at the same time*, needing transfusions to restore lost blood. Especially in a severe, localized shallow earthquake, trauma injuries could be significant in Greater Victoria, since many of the older masonry buildings downtown would likely come down.

Glasgow, Allard, Doughty, Spreadborough, and Watkins (2012) conducted a retrospective review of the British National Blood Service (NBS) response to the London

Bombings of July, 2005. They found that the major implication for blood services in general is that victims suffering major haemorrhage now will likely generate an increased demand for platelets, plasma, and cryoprecipitate (Glasgow et al., 2012). Even today, a large fraction of trauma-related deaths are due to uncontrolled haemorrhage (Davenport and Khan, 2011; Glasgow et al., 2012; Moran and Clamp, 2011; Stanworth, 2012). (Glasgow et al., 2012, p. 250) suggest that "the least severely injured 'priority three' casualties should be assumed not to require any blood components. However, further work is required to look at the [blood] demand for severe and moderately injured patients such as priority one and two casualties." Davenport and Khan (2011) identified a current ratio, near 3 : 2, of red cells to fresh frozen plasma, with additional platelet and cryoprecipitate as required, that is currently applied to deal with massive haemorrhage in most UK blood centers. Stanworth (2012) advocates that blood transfusion services in Canada design and implement practical, locally-developed plans that can deal with multiple-casualty haemorrhage injury situations, and that stress and utilize the significance of education, communication, and the scrutiny of cases. With respect to several BC RHAs,, such a plan would be a logical component of a needed RHA-level mass casualty plan to which Jaswal (2012) refers. In addition, as more treatment results are accurately documented, researchers may identify the average proportion of survivors injured, by both disaster type and the bodily locations of traumatic hemorrhaging, and use that analysis to contribute to even more powerful plans that address blood demand planning for disasters.

Blood transfusions are often employed to reduce hypovolaemic shock in trauma victims (Pascoe and Lynch, 2007), but may also be required to help treat people infected with a dangerous strain of E. Coli contracted via compromised water treatment facilities, or via seepage of sewage into a cracked or broken municipal water main (Sands and Klinkenberg, 2012; NZherald.co.nz, 2010). In addition, those who are seriously burned in fires caused by an earthquake and who exhibit a demonstrated physiologic need for blood products may benefit from blood transfusions (Palmieri et al., 2006). Most earthquake victims retrieved within 24 hours have a survival rate of 85–95% (Gautschi et al., 2008). The peak segment of the response phase will be intense, but short in duration. Depletion of stocks of fresh frozen plasma, cryoprecipitate, and platelets could endanger those with crushed muscle tissue, because crushed muscle can lead to

disseminated intravascular coagulation, a significant predictor of mortality (Bartels and VanRooyen, 2012).

Earthquakes and aftershocks may trigger spikes in the numbers of:

- premature births and normal deliveries, some involving caesarean sections (Drackley, Newbold, Paez, and Heddle, 2012), prenatal transfusions, and congenital disorders such as clotting protein deficiencies and haemolytic anaemia (Government of India, 2008)
- miscarriages, some due to parental peripheral-blood karyotype abnormalities (Quenby, 2010)
- blood requirements associated with myocardial infarctions due to coronary artery disease (Cosgrove et al., 1985)
- hip and knee replacement surgeries and other injuries to the aged, some who have pre-existing normocytic anaemia, or other types of anaemia (Kumar et al., 2011)
- immune thrombocytopenia, coagulation defects, and burn patient transfusion issues (Government of India, 2008)
- transfusion reactions including haemolytic, febrile, allergic, and non-immune reactions as well as transfusion-associated immunomodulation (Government of India, 2008), and
- strokes: in the 3 months immediately following the 1995 Kobe earthquake, the frequency of deaths due to strokes increased dramatically in older people (Bartels and VanRooyen, 2012).

#### **2.2.5 Blood Supply System Response to Earthquakes**

The following segments represent some of the scant literature available regarding how various blood supply and transfusion agencies have responded to earthquakes, or to other comparable multiple-casualty disasters or emergencies.

Abolghasemi, Radfar, Tabatabaee, Hosseini-Divkolayee, and Burkle (2008) reported on the blood system impacts of a M 6.5 earthquake that struck on December 26, 2003 near

Bam, in Kerman Province, Iran, causing more than 29,000 deaths, and 23,000 injuries. Although the Iranian Blood Transfusion Organization (IBTO) mounted valiant efforts to manage this crisis, it lacked a formal, detailed disaster response plan (Abolghasemi et al., 2008). In addition, damage to health care facilities and major disruptions in telecommunication stymied coordination amongst IBTO blood collection centers, and damage to ground transportation infrastructure delayed the shipment of blood units into the area (Abolghasemi et al., 2008). Thus, air transportation to the Bam airport became the main access route for blood products (Abolghasemi et al.). Despite these obstacles, the IBTO collected and distributed the blood products identified in the middle row of Table 3 (Abolghasemi et al., p. 392). The volume of blood units required was available without any emergency donation campaign, which supports the view that “regular donation and sufficiency of the blood inventory is more important than emergent donation to save lives in times of crisis and in normal times” (Abolghasemi et al., p. 394).

**Table 3. The Donation and Distribution of Blood in the First Four Days Following the Bam Earthquake, Versus in a Normal Situation**

Situation	Daily Average No. of Blood Units Donated in the Country	Daily Average No. of Blood Units Distributed in the Country	Daily Average No. Blood Units Distributed in Kerman Province
the first four days	27,246 (6.9-fold increase)	7,519 (1.3-fold increase)	458 (3.7-fold increase)
normal	3,458	3,250	98

After Abolghasemi et al. (2008, p. 392).

During the crisis, the IBTO convened—from among representatives involved in disaster preparedness and response, communications, blood transportation, security and safety, and supply and personnel management—an *ad hoc* Disaster Response Committee with immediate responsibilities for:

- a) Developing a revised disaster national strategy based on current information and victim status of the disaster
- b) Facilitating coordination among the IBTO, its affiliated centers with other disaster organizations and agencies

- c) Appointing a Committee representative to be liaison with other emergency response organizations
- d) Ensuring continuous contact with the transfusion team quickly established in Bam, the provincial center of Kerman, and the major coordinating center in Tehran, and
- e) Incorporating lessons learned from this disaster in the development of a permanent IBTO disaster preparedness and response plan (Abolghasemi et al., p. 392).

The 2008 version of the IBTO disaster preparedness and response plan calls for the IBTO to “convene a disaster task force immediately as the main coordinator of all disaster preparedness and response activities” (Abolghasemi et al., 2008, p. 392). To ensure effective communication amongst hospitals, blood collection centers, and the task force during a disaster, the IBTO has identified one staff member per blood collection center/affiliated hospital(s) as the contact person (Abolghasemi et al.). In a blood contingency, these contacts would help assess whether the local inventory can supply the blood products required, and then communicate their findings to the task force (Abolghasemi et al.). If outside assistance is warranted, the task force will activate blood centers in “assisting” Iranian provinces (Abolghasemi et al.). Currently in all Iranian provinces, blood transfusion center staff receive disaster-specific education and training (Abolghasemi et al., 2008).

Following the 2005 M7.6 earthquake in Kashmir, northern Pakistan, Mujeeb and Jaffery (2007) observed that it quickly created a demand for Rh-negative blood, antisera, blood transfusion sets, desktop centrifuge machines, glassware, and blood bank refrigerators. Zaheer (2012) identified several impediments to an effective response to such a disaster. Some of the impediment situations listed below (Zaheer, 2012) have affected the health care response in other regions, (hence the other references) and could affect the VIHA TM response to a damaging earthquake:

- damage to physical health care infrastructure (Abolghasemi et al., 2008; Flanagan, 2011); power failures (Abolghasemi et al., 2008; Flanagan, 2011);
- lack of (1) blood storage equipment and (2) information on available blood stocks;
- lack of coordination and duplication of efforts, (Mujeeb and Jaffery, 2007; Tabatabaee et al., 2010; Zaheer, 2012);

- the blood transfusion workforce and/or their families and homes are casualties (Abolghasemi et al., 2008; Bridgewater et al., 2006; Flanagan, 2011);
- breakdown in logistic and/or communications support (Abolghasemi et al., 2008);
- inaccurate assessment of the magnitude of the disaster;
- inability to accurately estimate the transfusion requirements;
- low priority for transfusion therapy within emergency health care; and
- no forum for experience-sharing among stakeholders involved in blood transfusion disaster management.

The Christchurch Blood Center (CBC), located approximately 1.5 km from the hospital, suffered only minor structural damage, but closed for 3 weeks following the February, 2011 local earthquake, mainly because (1) the automated apheresis, processing and testing equipment had moved significantly during the quake and required external engineers to re-validate its operation, and (2) blood center staff needed time to arrange alternative child care, since schools were closed (Flanagan, 2011). At the Christchurch city hospital, the only major public hospital and emergency center in the city, a damaged emergency generator provided a perilous and inadequate supply of electricity to the automated technologies and cooling system in the New Zealand Blood Service (NZBS) blood bank located in one of the two hospital blocks (Flanagan, 2011).

As part of the coordinated response to this earthquake, first responders directed the 'walking wounded' to emergency triage centers for initial care; only the more severely injured were sent to the Christchurch city hospital (Flanagan, 2011). Just 164 of 431 patients seen by the hospital emergency department in the 36 hours immediately post-quake were seriously injured (Flanagan, 2011). Early in the response, staff accessed a 'Group O' bank, and over the next 12 hours, dispensed O Rh (D) positive red cells to male casualties, and O Rh (D) negative to the female ones (Flanagan, 2011).

As prescribed in the New Zealand health sector emergency plan, many critically ill patients from Christchurch were moved to Auckland and other major hospitals across the country within hours of the event (Flanagan, 2011). Some 35 patients did receive blood components in Christchurch hospital in the 36 hours following the earthquake

(Flanagan, 2011), and Table 4 provides information on their blood component usage.

**Table 4. Blood components for 35 patients at Christchurch City Hospital, February, 2011 Earthquake**

Blood Product	Red Cells	Fresh Frozen Plasma	Platelets
Average issued	2.83	0.74	0.31
Average transfused	2.66	0.69	0.31

After Flanagan (2011).

Platelet supplies were adequate but production was stepped up to offset lost production in Christchurch, and an expected increase in demand there (Flanagan, 2011). In Auckland, NZBS management increased apheresis platelet collection, and expedited supplies of it into Christchurch via road transport (Flanagan, 2011). On the day of the earthquake, Christchurch airport was closed and the military controlled the airspace over the city, to support the civil defence response to the emergency (Flanagan, 2011). NZBS contacted the military control center to arrange for emergency transfer of components if required (Flanagan, 2011).

From experience following the February, 2011 Christchurch earthquake, Flanagan (2011) suggests that pre-existing emergency plans must be flexible in order to respond to rapidly changing situations, based upon access to timely and accurate information.

Tadokoro (2011) reports that the 2011 subduction earthquake and tsunami in Japan damaged blood processing equipment in the three Honshu prefectures most affected—Iwate, Miyagi, and Fukushima, limiting blood centers to merely supplying blood. However, the blood demand in the region dipped, since medical services were disrupted, and few survived the tsunami (Nollet, Ohto, Yasuda, and Hasegawa, 2013; Tadokoro, 2011). Telecommunication media did not function for several days post-quake, so Miyagi Blood Center distribution staff delivered blood to functioning regional hospitals *without awaiting orders for blood* (Tadokoro, 2011). Using supplies from other areas, the Tokyo Blood Center successfully delivered all necessary blood supplies, including platelets, to the affected centers (Tadokoro). By mid-April, 2011, the blood services in these three prefectures had resumed full operations (Tadokoro).

Latent in these examples, the overriding challenge in dealing with disasters lies in how effectively we plan, because planning influences health outcomes and the economic

burdens that such events ultimately place on society (Martel, 2009). A well-prepared community is one in which responsibility for pre-quake mitigation and post-quake response and recovery is shared by households, local government, and other agencies involved in local emergency management teamwork. Social networking promises to be a very useful function in the evolution of a community to a higher level of preparedness. Health jurisdictions must therefore invest further in planning and training, in exercising their respective emergency plans, and in helping to marshal enhanced public involvement in planning, preparation, response and recovery with respect to sudden-onset disasters.

### **2.3 Chapter Summary**

This literature review has positioned the management of environmental and technical hazards, risk, and vulnerability in the context of western geographic scholarship, and has drawn upon insights from widely-separated but relevant seismic events. Drastic losses or harm from hazardous events have generated a long history of human concern and inquiry, leading to measures to mitigate direct and indirect causes, and to reduce loss and harm. The review explored the key concepts of hazard, risk, and vulnerability—initially at a multidisciplinary, broad societal level—noting how institutional, socio-economic, and cultural context may modify such concepts and how they are analyzed.

The complexity of new, unevenly distributed technological hazards, increases in vulnerability, exposure and effect, plus the rising, sometimes risk-averse expectations of various publics, mean that health care systems have had to prepare for numerous scenarios arising from a huge array of potential consequences. This broad response capability suggests a need for robust systems with flexibility in analysis, staffing, and in uses of equipment, supplies and space. Budgetary constraints may mean that relatively risky arrangements, such as just-in-time inventory, are put in place.

The current systems of response to rapid-onset hazardous events that have high magnitude health care consequences originated mainly in military models refined during the past 200 years. Speed of response and triage have proven critical in preventing loss of life following earthquakes, for example (Ricci et al., 1994). The military, civil

authorities, plus the medical/health discipline have since developed a response capability that has grown increasingly broader, and more layered, efficient, and standardized.

Health system emergency responses to hazardous events are now often coordinated on multiple levels, depending upon the magnitude of the event. One key to an optimal cross-jurisdiction response is interoperability—the ability to coordinate activities amongst hospitals to increase surge capacity, for example. A planned response to a disaster depends on the best information obtained via rapid needs assessment survey of the affected population (Reilly, 2011), the analytical methodology, decision-making capacity and teamwork available, and is only as strong as the weakest link in its planning and execution.

Earthquakes involve multiple, simultaneous casualties, which imply that triage and hospital surge response must be rapid, resourceful, and well-practiced. Injuries due to earthquakes may require treatment with blood products. Examples include cuts or penetration injuries from falling glass, and abdominal injuries—pelvic fractures, rupture of a hollow viscus, or of the bladder—often involving intra-abdominal haemorrhage, and urgently requiring surgery. Limb amputations, treatment of victims who have pre-existing serious forms of anaemia or haemophilia, plus cases with crushed muscle tissue or septicaemia all may require blood transfusions. As shown by the examples cited in this chapter, various factors affect the success of blood system response to the health care impacts of earthquakes.

As pressure between seismic plates on the west coast of North America mounts, the probability of a damaging subduction earthquake in this area increases. The BC Ministry of Health (MoH) is preparing proactively for this eventuality. With the knowledge of how people perceive this type of risk and the likely consequences of such an event, the MoH can develop effective communication plans and educational materials to address public perceptions, mitigation measures and preparations before, and actions after, it. If individuals remain more vulnerable to large-scale, rapid-onset hazards than *they* need be, their health system is more vulnerable to overload and functional collapse than *it* need be.

## Chapter 3: Seismic Hazard, Example Quakes, and Plausible Scenarios

This chapter examines the nature of the seismic hazard in the southern half of coastal British Columbia, and identifies key characteristics and consequences of comparable catalogued earthquakes that have occurred elsewhere. Three different plausible earthquake scenarios – for deep, subduction and shallow quakes - are developed around parameters such as the amount of energy released, depth of hypocenter, distance to epicenter, intensity of shaking in various zones, and how the wave energy might be modified by local conditions such as areas of deep clay, or unconsolidated fill. Best estimates of resulting damage to people and cultural features, developed in Chapter 4, are based upon these characterization factors, and upon the case examples.

### 3.1 Seismic Hazard

The seismic hazard that applies to a target geographic area is a combination of the potential for initiating strong ground movement (SGM) that is latent in the nearest seismic source area(s), and the vulnerabilities to that SGM that are associated with human settlement in the target area. Source area potential to generate SGM in a distant target relates to factors such as:

- a) how large the source area is, and therefore, how much energy the source area likely will release (magnitude, or *M*) when previously locked fault faces suddenly slip,
- b) the distance between a source and the target area,
- c) how the intervening geology transmits seismic energy (attenuation), and
- d) whether seismic energy received at the target location is amplified in terms of ground motion, by near-surface local geologic factors, such as deep clays. The *intensity* of SGM is gauged on the Modified Mercalli Intensity scale (MMI), based on human observations of the shaking and its effects (NRCan, n.d.; Wood and Neumann, 1931). Appendix E elaborates the MMI scale above MMI VI. Shoaf, Nguyen, Sareen, and Bourque (1998) found that injuries occur at MMI VII or greater, with injury rate increases *generally* paralleling increases in MMI.

### 3.1.1 The Seismogeologic Setting

Coastal British Columbia is situated along the Pacific Ring of Fire, in which frequent earthquakes and volcanic eruptions occur. The southern half of this coast is one of the most hazardous areas in Canada for earthquakes, as illustrated in Figure 9. The major regional seismic factor is the offshore Juan de Fuca (JdF) tectonic plate subducting along the 1100 km-long Cascadia Subduction Zone (CSZ), a megathrust fault. At about **5 cm** per year, the JdF plate is being pushed and pulled beneath the North America plate—under the southern three-quarters of Vancouver Island, and the Lower Mainland of British Columbia (Natural Resources Canada (NrCan), 2008a), as illustrated in Figure 10. The Coastal BC/CSZ region is complicated and predisposed to earthquakes as it also has zones where plates are converging, diverging, and transforming (sliding past each other) (Bird, Kagan, and Jackson, 2002; Sibson, 1983). This environment generates three potentially damaging types of earthquakes—deep, or intraslab quakes, subduction quakes, and shallow ones—discussed separately in upcoming sections.

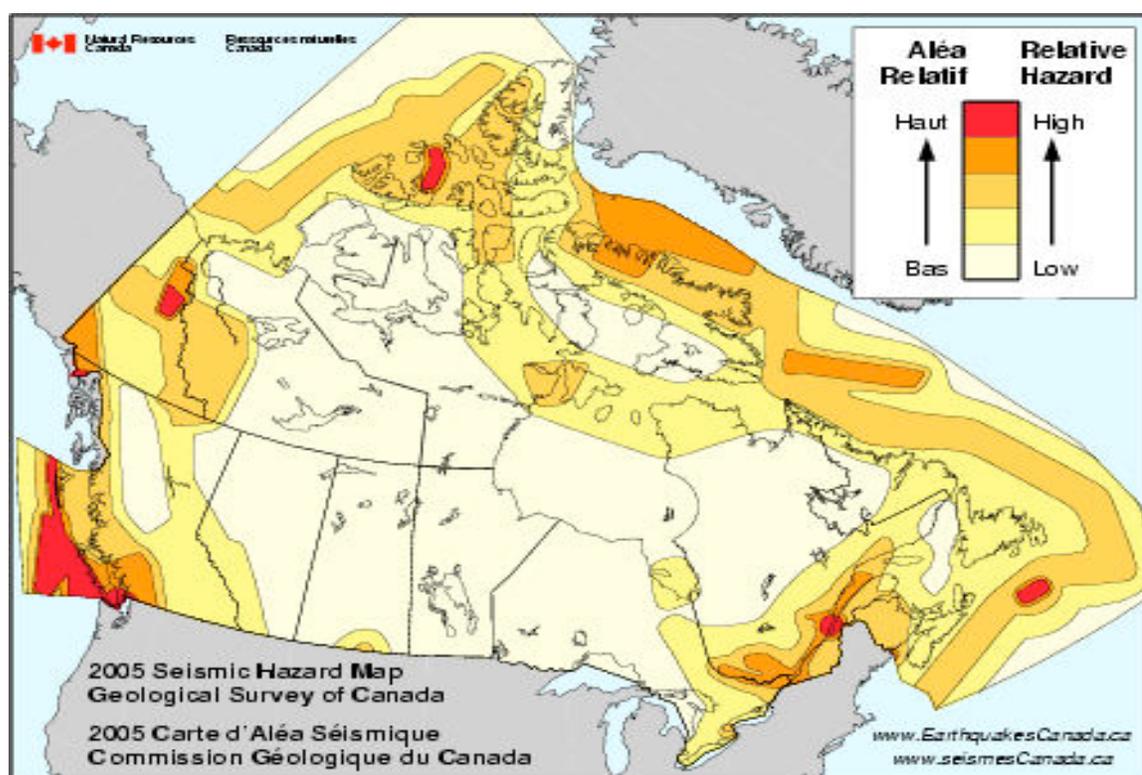
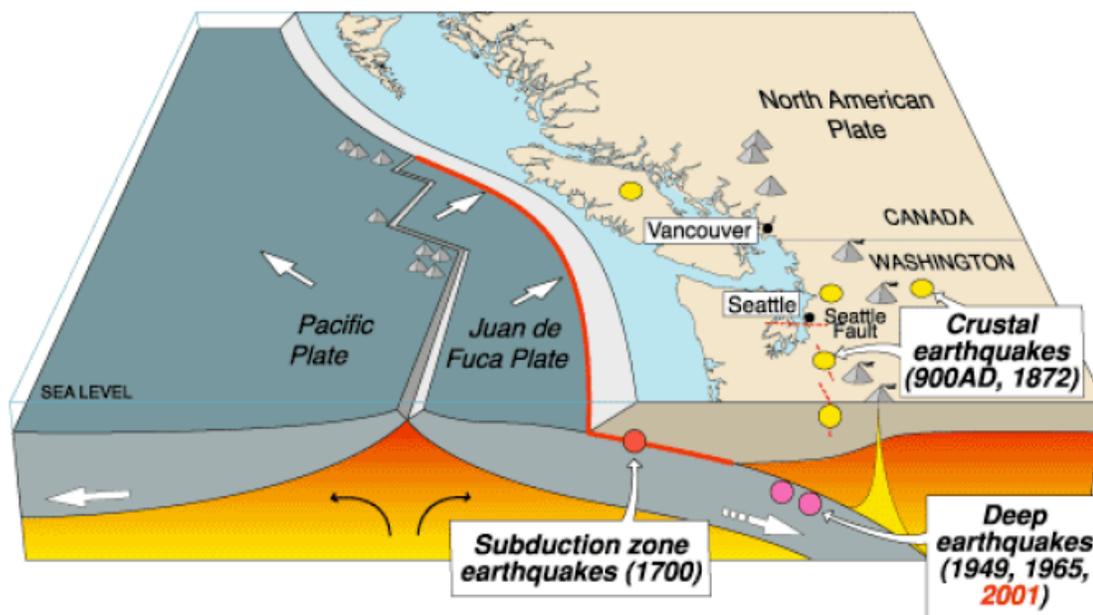


Figure 9. Geological Survey of Canada 2005 Seismic Hazard Map. Greater Victoria is located on the island in the extreme southwestern corner of the non-grey land mass.

Based on the interpretation of laminated sediment sequences in Saanich Inlet, Blais-Stevens, Rogers, and Clague (2011) suggest that an average return period for strong shaking in the Victoria area would be about 220 years. Onur (2001) and others have noted that many of the smaller seismic events in southwestern British Columbia occur in the *crust* of the North America continental plate, and are mainly strike-slip and thrust events in which the dominant north-northwest orientation of the principal stress suggests compression in that direction. These *shallow* or crustal earthquakes are diffuse, and do not appear to be aligned with active faults (Onur, 2001). Most occur at about 20km depth, and have fewer aftershocks than shallower quakes of around 10km depth; their likely maximum magnitude and distribution are therefore difficult to assess (Onur, 2001).



Source	Affected area	Max. Size	Recurrence
● Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
● Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
● Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Figure 10. Plate tectonics and earthquake types in southern British Columbia. In plan view, the thin red boundary demarcates the part of the Cascadia Subduction Zone nearest the surface of the Earth. Source: Washington State Emergency Management Division (WSEMD) (2004a, Tab 7.1.3 – Page 4).

### 3.1.2 The Probability of the Hazard Being Manifest as an Earthquake

The historical average occurrence rate of earthquakes of a given magnitude and type in a source area provides the basis for estimating the probability of their recurrence there. Given a constant annual rate of occurrence, one can assess a recurrence probability (USGS, 2009). Onur and Seemann (2004) estimated the likelihood that seismic activity may damage *some* buildings in Vancouver and/or Victoria sometime within the next 100 years. Table 5 displays these probabilities.

**Table 5. 2007 Best Estimate Probabilities of an Earthquake Causing Shaking at MMI VII or Greater, and Potentially Damaging Buildings and Structures on Firm Soil in Victoria and/or Vancouver**

Area	Type of Earthquake	10 years	50 years	100 years
Victoria	Local unknown crustal or subcrustal fault	4.5	21	37
	Offshore subduction megathrust	7.5	11	17
	Combined probability	12.1	30.1	47.6
Vancouver	Local unknown crustal or subcrustal fault	2.5	12	32
	Offshore subduction megathrust	7.5	11	17

After Onur and Seemann (2004) and Seemann (2012).

#### Perspective: Earthquakes Compared to Other Regional Hazards to Human Health

Seeman, Onur, and Cloutier-Fisher (2011) calculated *aggregate* shaking likelihood (combined probabilities from all three types of earthquakes) to derive a 30% (one in 3.33) probability that during *the next 50 years* at least parts of Greater Victoria would be shaken at MMI VII or more. At MMI VII, some of the older local buildings with brick facades are likely to suffer visible damage, while others likely would not be visibly affected. If the actual level of shaking were to exceed MMI VIII, many buildings in Greater Victoria would very likely incur significant structural damage (Wood and Neumann, 1931).

By using 18 documented large submarine debris flows as indicators of local earthquakes that occurred in Saanich Inlet over the past 4000 years, Blais-Stevens, Rogers, and

Clague (2011, p. 10) derived a "return period of about 200 yr (mean 220 and standard deviation 187) for strong earthquake shaking" there. They graphically estimated the *annual probability* of exceeding shaking at MMI VII in Saanich Inlet to be around .0017, or about one in 588 (Blais-Stevens, Rogers, and Clague, 2011, p. 10). For comparison of risk, Table 6 includes the 2009 age-standardized Incidence and mortality per 100,000 for various cancers in the *VIHA* administrative area (BC Cancer Agency, 2009; 2011).

**Table 6. Various Cancers: Age-standardized Incidence and Mortality per 100,000/year in the VIHA Administrative Area, for 2009**

Cancer type	Age-standardized Incidence per 100,000/year	Chance of contraction in 2009	Age-standardized Mortality per 100,000/year		Chance of dying from the condition in 2009	
Breast Cancer	96.78	one in 1,033	F 18.4		F 1 in 5,435	M
Lung	47.95	one in 2,085	F 33.9	M 42.3	1 in 2,950	1 in 2,364
Skin	19.19	one in 5,211	2.0	2.6	1 in 50,000	1 in 38,461
Leukemia (Acute Granulocytic)	9.5	one in 10,526	1.6	2.4	1 in 62,500	1 in 41,667
Brain Cancer	7.22	one in 13,850	2.9	5.5	1 in 34,483	1 in 18,182
Esophagus	5.4	one in 18,518	2.0	6.6	1 in 50,000	1 in 15,152

The chance of a person contracting and dying from one of these cancers *in the same year* is not included or explicitly implied in Table 6. Coburn, Spence, and Pomonis (1994) calculated the probability of a person *dying in any one year* due to a variety of causes, including an earthquake in California, and the likelihood of that specific event was one in 2,000,000. How an average Californian compares to a British Columbian counterpart in terms of vulnerability to an earthquake is unknown. In addition, the secondary hazards that a strong earthquake could trigger would likely increase the health risks of such earthquake events (Kappes, Keiler, von Everfeldt, and Glade, 2012).

This brief and inexact analysis, based solely on the parameter of risk, indicates that the threat of exceeding a significant level of shaking in Victoria ranks higher, for example, than that of a person in the same general region contracting any one of the cancers reviewed above.

## 3.2 Characterizing The Types a Earthquakes Likely to Affect Greater Victoria

### 3.2.1 Deep Earthquakes

*Deep* earthquakes in the Pacific Northwest are usually under M7.5, and occur at about 50km depth (Cascadia Regional Earthquake Workshop, (CREW) 2008). The fault fractures occur 25 to 100 km deep, often near faults reactivated by near-trench plate bending (Ranero et al., 2005; Walsh, Gerstel, Pringle, and Palmer/Washington Geology and Earth Resources, 2009). The epicenter depth allows the seismic wave energy to spread over a much larger area than in a shallow quake (CREW, 2005), so it attenuates more rapidly with distance than seismic waves from crustal earthquakes (Atkinson, 2004; Halchuk and Adams, 2004). Subcrustal or deep events *in the JdF plate* are constrained to approximately M7 because the brittle portion of the subducting plate is less than 10km thick, and fault ruptures of significant cross-sectional area are typically less than 100km long (Onur, 2001). The 2001 Nisqually, Washington M6.8 shock was a recent, nearby intraslab earthquake. Although it was centered 150 km to the southeast, deposits of a soft, grey, glaciomarine clay in Victoria amplified *target* peak horizontal ground accelerations *and* MMI, which varied between not felt on bedrock, to slight damage (MMI VI) on this clay in Greater Victoria (Molnar, Cassidy, & Dosso, 2004). Seemann, Onur, and Cloutier-Fisher (2011) calculated for Victoria the time-independent probabilities of MMI VII level shaking from *crustal and subcrustal* earthquakes to be 4.5% in 10 years, 11% in 25 years, 21% in 50, and 37% in 100.

Few medium- and high-rise buildings were severely damaged in Olympia, near the epicenter of the 2001 Nisqually quake. To deal with the consequences of a damaging deep quake, slightly increased surge capacity may be required at one or more Greater Victoria hospitals, but the Greater Victoria health system likely would cope with the impacts, perhaps with help from Island-wide resources (CREW, 2008).

### 3.2.2 Subduction (Megathrust) Earthquakes

These quakes usually last 1 to 4 minutes, with shaking less intense than in a shallow quake, but over a much greater area (Onur and Seemann, 2004). A M8.2 to 9.0 event

in the Cascadia Subduction Zone (CSZ) is possible (CREW, 2005; Youngs, Chiou, Silva, and Humphrey, 1997). At the highest magnitudes, the intensity of shaking at a given moment does not increase significantly, but the duration and geographic range of the strong shaking does (American Red Cross Multi-Disciplinary Team, (ARCMDT), 2011). The CSZ subduction quake recurrence interval has apparently been as short as about 200 years, and up to 1,100 years; the most recent great earthquake struck the Pacific Northwest in 1700 A.D. (Walsh, Gerstel, Pringle, and Palmer, 2009). Analysis of contemporary crustal deformation on Vancouver Island indicates that strain is building for another subduction event (Adams, Rogers, Halchuk, McCormack, and Cassidy, 2002; Dragert, Hyndman, Rogers, and Wang, 1994; NRCAN, 2008b). Onur and Seemann (2004), as shown in Table 5, calculated the probabilities of a subduction quake causing damage to buildings and structures on firm soil in Victoria to be 11% in 50 years, and 17% in 100 years. The probability of a subduction quake occurring increases over time, until such a quake occurs.

Moderate shaking damage to buildings and structures would generate casualties, as would landslides and tsunami, expected *inland and along* the coastal Pacific Northwest, respectively, within about 400 km from the epicenter (CREW, 2005). Initially, help will be needed from *outside the region*; help from Greater Vancouver likely will not be available during the first few days, at least (CREW, 2005). Many seriously injured on Vancouver Island may initially be brought to Greater Victoria, with the more sophisticated level of health care available there.

In a subduction earthquake, the longer period of shaking at varying frequencies, plus local ground acceleration and displacement in various directions could possibly, but not likely, crack man-made concrete gravity dams (Government of New Zealand, ca. 2009; Sawicki, Kulczykowski, and Chybicki, 2007), or lead to structural failure of earth fill dams (Arslan and Siyahi, 2008; Chen, 2009). The long duration of shaking may damage some of the high-rise buildings in Victoria and Vancouver, and could possibly cause some to collapse, which would likely cause many casualties. *Damaging aftershocks* usually follow subduction quakes, generating additional damage to structures already weakened, and exacerbating rescue operations. After the 1964 Alaska quake, the *aftershock zone* was

250 km by 800 km; on day one, eleven aftershocks were of  $M > 6.0$ , with nine of this magnitude in the next three weeks (Alaska Earthquake Information Center, 2002).

### *Tsunamis*

For populations in nearby vulnerable coastal locations, large tsunamis are usually deadlier than the subduction quakes that generate them. The most effective way to survive a tsunami is to evacuate directly to higher ground (Koshimura et al., 2006). The tsunami casualty rate for a certain tsunami height varies significantly within each event and depends in part upon the physical characteristics of a location (Koshimura et al., 2006). According to Koshimura et al., (2006), tsunami casualties occur when the local tsunami height exceeds 2 m and the hydrodynamic force of the tsunami inundation flow exceeds the resistance force or stability of a would-be evacuee. However, Sugimoto, Murakami, Kozuki, Nishikawa, and Shimada (2003) maintain that injuries can result after inundation height surpasses only 50 cm, or flow velocity is greater than 2.0 m/s, as buoyancy makes keeping one's balance difficult when water moving fast enough merely exceeds knee height.

Secondary considerations influencing the human consequences of tsunamis include timing—the time of day, and time of year, (extreme tides, or not) the temperature of the floodwater and of the ambient air (Graham, 1999), barriers such as bridges and fences that influence flow, or temporarily catch, and may later become, debris (Aboelata, Bowles, and McClelland, 2003), and whether the flood waters carry significant debris such as splintered trees, logs, houses, or vehicles, which can impale or crush people (Penning-Rowsell, Floyd, Surendran, and Ramsbottom, 2005). In Chile in 1960, Alaska in 1964, Indonesia in 2004, and Japan in 2011, *tsunamis caused far more casualties* than the earthquakes that generated them.

### *Types of injuries sustained during tsunami events*

Regarding the types of injuries, Zoraster (2005) noted that survivors of the 2004 Sumatran tsunami needed surgical services for wounds, infection control, and acute care, while according to Deebaj, Castren, and Gunnar (2011), soft tissue and orthopedic injuries contaminated with sand and mud predominated, many with severe infection

(Charuluxananan, Vorapaluk, Tuchinda, Bunburaphong, and Kyokong, 2006). Among 107 Sumatra–Andaman Islands tsunami victims at Phang-Nga Provincial Hospital, Thailand, most patients had multiple injuries, particularly on their extremities. Other complications included multiple organ injury, pulmonary aspiration, sepsis, and hypovolaemia (Charuluxananan, et al., 2006). When they slam together people, debris, and stationary objects, tsunamis can inflict head injuries, fractures, and cuts (Loyola Emergency Medical Services System, 2011). Physicians at Takua pa General Hospital on the west coast of peninsular Thailand “treated 2,285 patients with trauma, with 11% of those cases categorized as serious and 17% considered intermediate” (Healy, 2011). In addition, debris pushed by tons of force may crush the flesh surrounding tsunami victims' wounds, cutting off blood supply, and ultimately leading to amputation (Healy, 2011; Carballo, Daita and Hernandez, 2005).

### **3.2.3 Shallow (Crustal) Earthquakes**

Shallow crustal earthquakes (less than 30 km deep) are hazardous because the energy released is nearer to, and *more intense at, the surface* (NRCan, 2008c). The 1995 M7.2 Kobe, Japan quake and the M7.6 1999 “Ji-Ji” quake in Taiwan, discussed in a later segment, are pertinent examples where the shaking was intense. Close proximity to a shallow earthquake will expose a structure to a greater proportion of higher frequency ground motions compared to the frequencies emitted by deep earthquakes or subduction earthquakes (Garry Rogers, personal communication, January 30, 2013). Localized quake-driven tsunamis can occur, and numerous serious fires are very likely (Jones et al./USGS, 2008; Scawthorn, 2008). *Damaging aftershocks* often follow shallow quakes, as well. In the five days immediately after the Taiwan *shallow* quake, thousands of aftershocks—several of  $M > 6.0$  (Chan et al., 2003), and three of  $M > 6.8$ —occurred (Altenburger, 2004).

Assuming an epicenter just south of Victoria, the impacts of a fifteen-second quake that generates MMI of VIII or more may *overwhelm* the Greater Victoria health care system for at least a week. Help will be required from the Lower Mainland and Vancouver Island.

### 3.3 In Situ Factors That Affect the Consequences of the Earthquakes

Local geology influences how seismic energy is transmitted to buildings and structures, landforms largely control *slope stability*, and soil texture and moisture content are significant factors regarding *liquefaction*. How does the damage to buildings and structures translate in terms of injuries and deaths? The morbidity and mortality consequences of earthquakes largely depend upon how the buildings that house people have been designed and constructed (seismic codes and their implementation), the time of day/where people are when the shock(s) occur(s), and population density in the locations where damage to cultural infrastructure occurs.

The surface geology beneath Greater Victoria is dominated by thin soils that overlie crystalline volcanic and metamorphic rock, with several deeper pockets of soft clay (Molnar, Cassidy, and Dosso, 2004). Victoria itself has a population of about 77,400, contains the downtown area, and is the most densely populated jurisdiction on Vancouver Island (BC Stats, 2009; City of Victoria, 2009a).

Buildings with weight-bearing walls of unreinforced masonry (URM) are the most prone to earthquake damage (CREW, 2008). Approximately 30% of downtown Victoria's buildings are medium-rise, with URM bearing walls (Onur, Ventura, and Finn, 2005). In the first strong and locally damaging quake, many URM buildings in Victoria will likely collapse at least partially. Figure 11 illustrates where the most serious damage to buildings in downtown Victoria is likely to occur (Onur, Ventura, and Finn, 2005).

The 2006 population density in the city of Victoria was 3,966 people/km<sup>2</sup>, and the median age was 41.9 years (StatsCan, 2006). Shoaf, Nguyen, Sareen, and Bourque (1998) presented strong evidence that earthquake casualties vary with the population density, the intensity of shaking, local soil conditions, the built environment, the timing of impact, and the location and behaviour of potential victims. Peek-Asa et al. (1998) examined information about the deaths and injuries from the 1994 Northridge earthquake in California. They found a strong positive correlation between earthquake-related injury rates and increasing age, and that most of the fatalities were from building collapse, while many who were hospitalized had fallen or had been hit by objects, or burned, or injured in or by a motor vehicle.

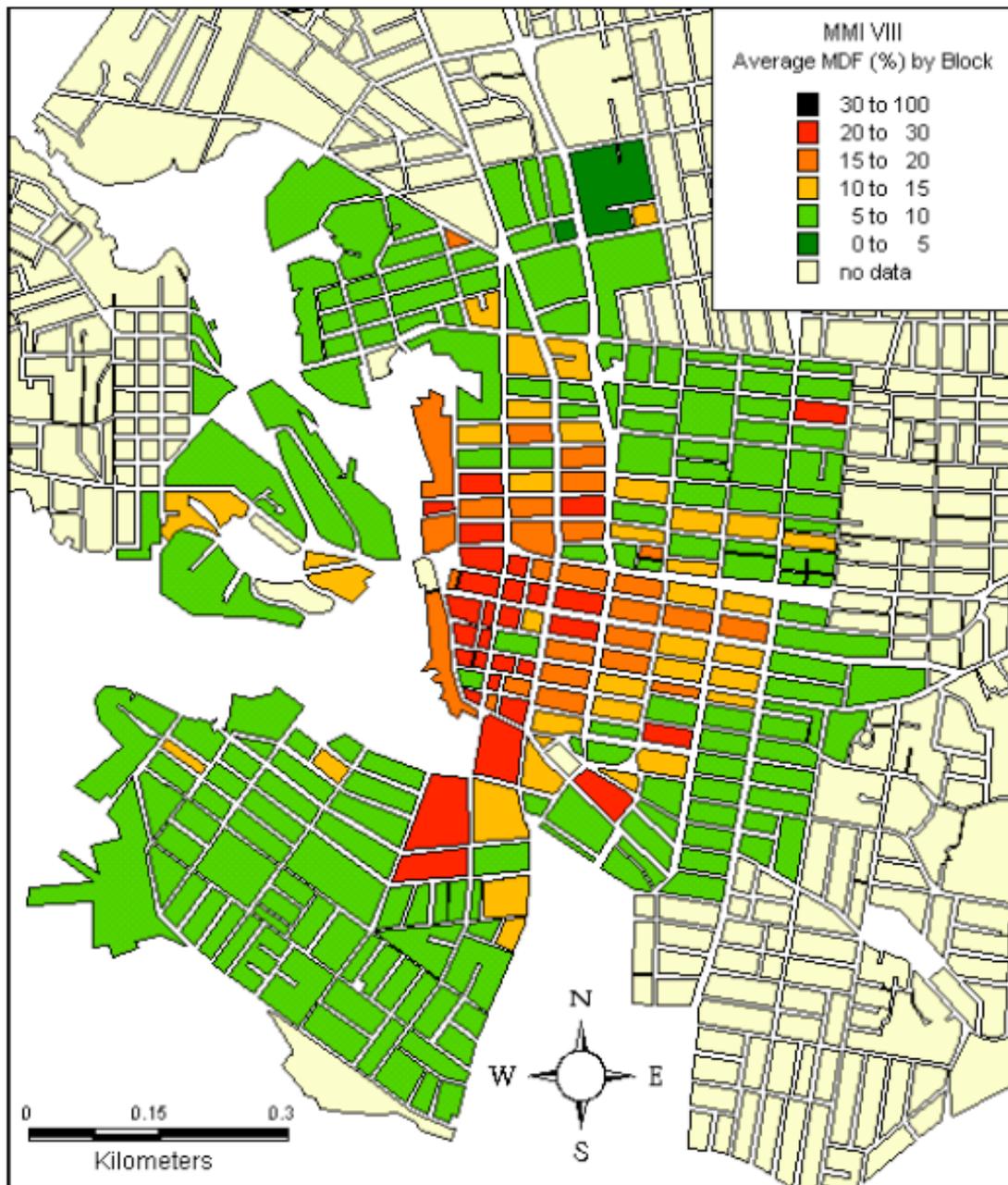


Figure 11. Predicted structural damage distribution in downtown Victoria due to shaking at MMI (Modified Mercalli Intensity) level VIII. The colored units indicate, in per block percentage, the mean damage factor, MDF, or the ratio of dollar loss to replacement cost. Source: (Onur, 2001, p. 75).

In these cases, chest and head injuries were common among fatalities, and extremity injuries prevailed among those hospitalized (Peek-Asa et al., 1998). Peek-Asa Ramirez, Seligson, and Shoaf (2003, p. 62), in considering seismic, structural, and individual factors associated with earthquake-related injury in an Armenian quake, found that

“individuals over age 65 had 2.9 times the risk of injury as younger people...Location in multiple unit residential and commercial structures each led to increased injury risk compared with single unit residential structures...” Although the death-to-injury ratio typically may be as high as 1:3, most earthquake survivors will have minor cuts and bruises, fewer will sustain simple fractures, and even fewer will have serious multiple fractures or internal injuries requiring intensive treatment (PAHO, 1981). The first patients to arrive at hospitals after a quake are usually the walking wounded, who generally have minor injuries. In hospitalizing some of them, hospital staff would tie up beds or equipment needed for the more serious casualties who arrive later (Hamilton, 2005).

Not all of the injuries sustained as a result of earthquakes are physical. The multiple, sequential impacts of quakes that trigger other events produce greater psychological distress in survivors (Shultz et al., 2011), many of whom will need to try and construct a new normality (Yasui, 2012). Thus, the most numerous and chronic human impacts of a damaging earthquake will likely be psychological injuries (PAHO, 1981).

Movements of segments of faults or merely strong ground movement may crack man-made dams, causing flash floods downstream. Cascading effects may affect various socioeconomic systems, especially if electrical services are knocked out for a significant duration. Some impacts, such as landslides in remote areas inland, may not be detected for months. A tsunami associated with a subduction earthquake off the west coast of Vancouver Island would have dramatic effects along most of that coast, some of the northern BC coast, the coasts of Washington, Oregon, and California, and westward. Some of the earthquake examples discussed below illustrate such impacts.

### **3.4 Catalogued Earthquakes Relevant to Seismicity in Southwestern BC**

All of the earthquakes reviewed in this section, plus a few others, have been further analyzed in Chapter 4 as part of the methodology for estimating injuries and hospitalizations that likely would result from a similar type and magnitude of quake that damages Greater Victoria significantly.

### 3.4.1 Deep Earthquakes

#### *The 2001 Deep Earthquake Near Nisqually, Washington*

Due to the amplification of seismic energy in softer river valley sediments, the most intense ground shaking in this event (see Table 7) flanked heavily populated Interstate 5 (WSEMD, 2007). More than 400 injuries--the great majority of them minor ones--resulted, placing limited demands on the health system, typical of deep earthquakes in the Puget Sound area (CREW, 2008).

#### ***The M 6.5 Deep Earthquake of 1965***

A large area of MMI intensity VII shaking, and pockets of VIII shaking in Seattle characterized this quake (WSEMD, 2007). Seattle Public Schools were closed already for spring holidays, which prevented loss of life in those locations. However, 30 regional schools were damaged and closed temporarily, with 10 shut permanently (Seattle Public Schools, 2000). Fifty percent of chimneys in town were knocked down or severely damaged, and several houses slid into Puget Sound (Seattle Public Schools, 2000). In Olympia, walls cracked in nearly all large buildings, and water and gas mains broke (WSEMD, 2007). All area hospitals stayed open, but non-structural damage affected some; a Seattle hospital had to replace 85 seismic joints, at a cost of \$3million in 1965 dollars (CREW, 2008). Table 8 provides further details about the consequences. The most severe damage likely occurred in areas subject to shaking at MMI VIII.

**Table 7. Details regarding the Nisqually Deep M6.8 Earthquake, 2001**

Earthquake /community population data	Population density	# deaths	# injuries	# hospital admissions
<p><i>Nisqually earthquake, deep, M6.8 2001</i></p> <p>Duration: 15 to 20 seconds (WMDEMD, 2009).</p> <p>Epicenter: 17.6 km NE of Olympia 23.7 km WSW of Tacoma 57.5 km SSW of Seattle (WMDEMD, 2009). Felt: over 350,000 km<sup>2</sup> (Molnar, Cassidy, and Dosso, 2004).</p> <p>Impact: damaged ¼ of the dwellings in the Puget Sound region (EERI/WMDEMD, 2005). Seattle population (City of Seattle, 2010).</p>	<p>Seattle 2592.6/km<sup>2</sup> in 2000</p> <p>Olympia 1025.91/km<sup>2</sup> in 2000</p> <p>Tacoma 1495/km<sup>2</sup> in 2000</p>	<p>1 (PNSN, 2010).</p>	<p>Nearly 700, 12 serious (TRPC, 2009; WMDEMD, 2009).</p> <p>320 (EERI and WMDEMD, 2005).</p>	<p>4 known, 2 at Olympia (EQE, 2001; PNSN, 2010).</p> <p>Possible total of 12</p>

**Table 8. Details regarding the M 6.5 Deep Earthquake of 1965**

Earthquake /community population data	Population density	# deaths	# injuries	# hospital admissions
<i>Seattle fault earthquake 1965, M 6.5</i> Depth: 64.4 km. (WSEMD, 2007). Duration: About 45 seconds (Emergency Preparedness Northwest, 2010). Epicenter: 19.4 km north of Tacoma Seattle population (Washington State, Office of Financial Management, 2002).	2,439.4/km <sup>2</sup> in 1970  2,501.5 <i>(averaged)</i>  2,563.7/km <sup>2</sup> in 1960	7 (Thurston Regional Planning Council, 2009)	30-60 (30 + dozens) (Von Hake and Cloud/ U.S. Department of Commerce, 1976)	Over 30 treated at Seattle hospitals (Lange, 2000; Von Hake et al., 1976).

*Puget Sound (Olympia) Area, Washington, 1949 04 13, M 7.1, MMI VIII*

Strong shaking lasted twenty seconds (WMDEMD, 2009) in this 54 km-deep quake that had an epicenter 13 km NNE of Olympia, Washington (TRPC, 2009). As a result, several structures were condemned, including two schools and a church at Centralia, south of Olympia, and a junior high school in Auburn, northeast of Tacoma (USGS, 2009a). A total of 303 were injured, with 64 of them likely hospitalized, and 10 confirmed as hospitalized, in Centralia (CREW, 2005; Murphy and Ulrich, 1951). The shaking damaged 40% of Chehalis; a *landslide* generated a *tsunami* in Tacoma Narrows (EERI/WMDEMD, 2005).

The health outcomes of these nearby events suggest that Greater Victoria health care resources would be adequate to cope following a deep earthquake of M7.0 that has a hypocenter within 50 km. Although the earthquake examples above resulted in hospitalizations, the process of estimating hospitalizations in all three *earthquake scenarios* wherein Greater Victoria is damaged, is laid out Chapter 4.

### 3.4.2 Subduction (Megathrust) Earthquakes

*The M 9.2 1964 Subduction Earthquake, Prince William Sound, Alaska*

The fortuitous late afternoon Good Friday timing of this earthquake meant that stores, offices, and schools were closed, and most people in Anchorage were awake and wearing shoes (Wilson, 1964). However, much of the most densely populated area of

that city was the most vulnerable--located on *slide-prone deltaic deposits* (Municipality of Anchorage, 2006). The shaking lasted 3 to 5 minutes; most failed structures initially remained intact, then gave out with repeated flexing (Municipality of Anchorage, n.d.; USGS, 2011). Wood frame structures on firm ground fared relatively well, but the shaking damaged some 75 homes in Anchorage, due to soil failure (USGS, 2011). Onur and Seemann (2004, n.p.) note that this earthquake generated "*MMI levels of VIII-IX up to 200 km from its epicenter*". The aftershock zone was about 250 km wide by nearly 800 km long. On day one there were 11 aftershocks of magnitude greater than 6.0, with nine more in the next 3 weeks (AEIC, 2002). Over an area of approximately 518,000 km<sup>2</sup> along the source fault, large vertical displacements generated a major tectonic tsunami, which struck the western coasts of southeast Alaska, BC, and the contiguous continental U.S. (University of Southern California tsunami Research Group (USCTRG), 2005). The ensuing waves killed 119 and caused approximately \$300 to \$400 million in damage to Alaska; just 12 died due strictly to the earthquake (USCTRG, 2005).

*The M 8.0 Subduction Earthquake of August, 2007, Near Chincha Alta, Peru*

The area most severely affected was sparsely populated desert with few large cities. Taucer, Alarcon, and So (2009) surveyed 115 survivors near or in Chincha Alta and Pisco. The shaking in that area lasted approximately 2.6 minutes, including 20–30 seconds of relatively uniform, lower amplitude shaking, when most people evacuated their homes (Taucer et al., 2009). Nearly all deaths and injuries throughout the country were due to building collapse; more than 58,000 traditional adobe houses either collapsed or nearly collapsed (Taucer et al.). Buildings constructed according to modern earthquake-resistant design standards were visibly undamaged (Taucer et al.).

*The February, 2010 M 8.8 Subduction Earthquake near Maule, Chile*

Large segments of the offshore Nazca plate suddenly slipped 13 m eastward beneath the South American plate on February 27, 2010 (Cassidy, Boroschek, Ventura, and Huffman, 2010). As the fault rupture spread outward from its middle, the shaking lasted only about two minutes, less than if it had begun at one end of the megathrust fault (American Red Cross Multi-Disciplinary Team, (ARCMDT), 2011). In Concepcion,

crews restored cell phone service within two hours of the shock. However, this was not the case with local water, sewer, and transportation services (ARCMDT, 2011).

Three 2.3m waves hit Constitucion, causing half of the deaths there (Wade and Badal/Reuters, 2010; ReliefWeb, 2010a). The maximum (29m) wave inundated a 40-block area (Fritz et al., 2011; USAID, 2010a), seriously damaging 2,989 homes (INE, 2010). In the area affected by the quake and tsunami, 581 people died, and "half of the deaths were due to the tsunami and most others occurred via collapse of adobe/brick style houses" (ARCMDT, 2011, p. 32). The Red Cross unofficially estimates that the quake caused approximately 60,000 (mostly minor) injuries (ARCMDT, 2011). At many coastal locations, the recorded shaking levels exceeded values estimated for the building code, especially at periods longer than 1 second (Cassidy et al., 2010). Yet, Chile's strong, well-enforced building code evidently saved many lives, since large buildings built according to code performed extremely well (ARCMDT).

According to the American Red Cross Multi-Disciplinary Team, despite devastation of the regional Chilean health care infrastructure and civic facilities, the health care response to the earthquake was effective, due, in part, to the following factors:

1. A resourceful medical community that responded without centralized control early in the response phase and under austere conditions;
2. Quickly restoring utilities and transportation infrastructure that supported health care, and rapidly mobilizing national and international resources (ARCMDT, 2011).

*The March 11, 2011 M9.0 Quake, off the Pacific Coast of Honshu, Japan*

The reverse fault apparently moved down-dip more than 40 m, over an area approximately 300 km along its strike, by 150 km wide, triggering a huge tsunami (USGS, 2011a). Table 9 contains further details about the quake and tsunami.

**Table 9. Details regarding the March 11, 2011 M 9.0 Earthquake near Honshu, Japan**

Earthquake/community data	Number of deaths	Number of injuries	Number of hospital admissions
Depth: 30 km Duration: nearly 3 minutes (IRIS/UoP, 2011; USGS, 2011a) Epicenter: near the east coast of Honshu, Japan, (USGS, 2011a) Maximum ground acceleration: 2.93 <i>g</i> at Tsukidate, 120 km from the epicenter (USGS, 2011a). Recorded seismic intensity: 7 on the Japan Meteorological Agency (JMA) scale (Google Earth, 2012; JMA, 2012) in Kurihara, Miyagi Prefecture, 127 km from the epicenter. This intensity equates to MMI Intensity ranges <i>11 and 12</i> (Kono et al., 1996).	At least 15,703, with 4,647 missing (USGS, 2011a)	At least 5,314 (USGS, 2011a) (Zare Afrouz, 2012)	Still unknown
Maximum tsunami run-up: 37.88 m at Miyako, Japan (USGS, 2011a)			
Impacts: several fires occurred in Chiba and Miyagi, and a dam failure destroyed many homes in Fukushima prefecture, 142 km from the epicenter (Google Earth, 2012; USGS, 2011a). The earthquake and tsunami damaged at least 332,395 buildings, 2,126 roads, 56 bridges, and 26 railways along the east coast, and created a nuclear disaster (USGS, 2011a).			

### *Summary Regarding Subduction Earthquakes*

Vulnerability—of people and cultural infrastructure—and their proximity to the sources of devastating tsunamis have been recombined recently, demonstrating the extreme *extent* of the subduction earthquake hazard. Yet, for all the energy that subduction *quakes* typically release, relatively few deaths have resulted *directly* from them.

### **3.4.2 Shallow (Crustal) Earthquakes**

#### *The M7.2 Earthquake, Kobe, Japan, January 17, 1995*

In intermittent areas of land about 15 km long and .75 km wide paralleling the shoreline, the 15 seconds of shaking was most intense (Munich Re, n.d.; Sakai, 1997). Kono, Hattori, and Higashiura (1996) note that the shallow (14 km) hypocenter (Ukai, 1997) contributed to one of the strongest ground motions in seismographic history, intensity 7 on the Japan Meteorological Agency (JMA) scale. This level equates to 11 to

12 on the MMI Scale (Kono et al., 1996).

By far, most of the 55,000 wooden buildings that collapsed were traditional structures, designed and maintained poorly, with heavy tiled roofs—in downtown Kobe, Ashiya, Nishinomiya, and Nagata (Tobriner, 1998). The quake also damaged more than 2,500 high-rise condominiums in the Osaka-Kobe area (West and Morris, 2003). Even reinforced concrete buildings, such as banks and hospitals built according to the pre-1981 construction code, suffered damage (Sakai, 1997). The most deadly of 294 fires raged in the densely-populated Nagata ward, where water was not available from hydrants (Ukai, 1997). Shoaf, Nguyen, Sareen, and Bourque (1998) note that more than half of those who died were over 60 years old, and typically lived on the ground floor of older Japanese-style wooden houses or tenements disproportionately damaged in the earthquake. The quake completely disrupted local telecommunication and transportation systems, preventing a prompt health system response (Tanaka, 1996). In Kobe City, 92% of the hospitals and 763 of the 1,363 clinics were damaged (Ogawa, Tsuji, Shiono, et al., 2000).

*The M7.6 Taiwan "Chi-Chi" Earthquake, September 20, 1999*

In this event, buildings 20-storeys or taller were not severely damaged, but traditional one-storey buildings in rural areas were destroyed (Chan et al., 2006). Soft first storeys in many 3–4-storey buildings, and many mid-rise 12–15-storey apartment buildings, collapsed (Chen, et al., 2003). The death rate was proportional to the percentage of completely collapsed houses; the main causes of death were asphyxiation and intracranial injuries (Chan et al., 2006). Tsai, Lung, and Wang (2004) identified a 3.6-fold increase in admissions for acute myocardial infarction following the quake, versus admissions during the same six-week period in the previous year, a significant difference. Liang et al. (2001) found that demand for health services peaked 12 hours after the earthquake, and remained elevated for 3 days.

*The Loma Prieta Section, San Andreas Fault, California, October 17, 1989*

The Oakland/Berkeley East Bay Hills Fire caused by the quake killed 25 people and injured 150 (Coile, 1997). Collapse of the Cypress Viaduct created the balance of serious casualties in San Francisco (Durkin, Thiel, Jr., Schneider, and de Vriend, 1991).

This earthquake had relatively little impact on those hospitals affected (Pointer et al., 1992). Durkin, Thiel, Jr., and Schneider/USGS (1994) estimated that only 7% of those injured in Santa Cruz County from this quake *required* hospital admission.

*The M 6.7 Northridge, California, Earthquake of January 17, 1994*

This quake cracked connections that held together steel moment frame medium- and high-rise buildings (Jones et al./USGS, 2008). Ten hospitals lost functionality due to structural and/or non-structural damage. Fifty percent of building damage from this quake was non-structural, with unrestrained materials falling over or shaking loose (Jones et al./USGS, 2008). According to McArthur, Peek-Asa, and Kraus (2000), only 138 were hospitalized. At some hospitals, the numbers of admissions for injuries were five times greater than in the days previous, but injury admission rates normalized within two days of the quake.

*Earthquakes near or in Christchurch, New Zealand, in 2010 and 2011*

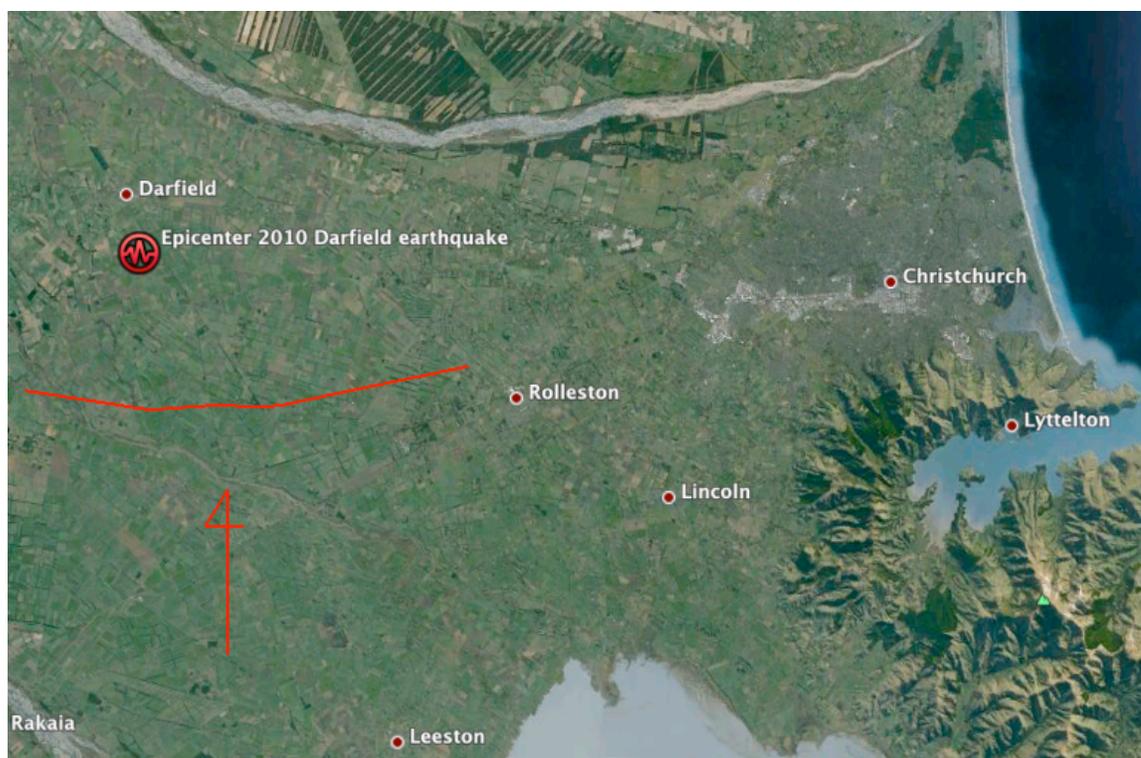
An M7.0 earthquake struck on September 4, 2010, near Darfield, 45 km west of Christchurch, (USGS, 2012a) on a fault (see Figures 12, 13 and 14) previously hidden under gravels covering the Canterbury Plains (GeoNet, 2012). The 5km-deep Darfield quake seriously injured two people (USGS, 2012a), and severely damaged many buildings, particularly in Christchurch (GeoNet, 2012). The shaking (MMI IX maximum) triggered landslides, and caused liquefaction damage at Christchurch (USGS, 2012a).



Figure 12. Aerial view of surface faulting revealed in the September, 2010 Darfield earthquake near Christchurch, New Zealand. The fault was previously undetected. Photo: R. Jongens/GNS (2012).



Figure 13. Tree line offset 4m by Darfield quake faulting, near Charing Cross, NZ. Photo: Faultrock.



\_\_\_\_\_ 10 km  
 Figure 14. The setting of the 2010 Darfield earthquake in New Zealand. The red shaking circle signifies the epicenter, the red arrow points north, while the red horizontal line trace indicates the location of the fault that runs through Figures 12 and 13 (Google Earth, 2013; USGS 2011b).

#### *M 6.3, Christchurch, February 22 2011, 12:51 pm*

This quake, located within 10 km of the city and with a focal point only 5 km below the ground surface, occurred around 1:00 p.m., and resulted in about 100,000 buildings destroyed or damaged, 1,500 injuries, and 181 deaths (GeoNet, 2012; USGS, 2012b). Due to the shallowness of the hypocenter and its proximity to Christchurch, the shaking intensity in Christchurch far surpassed that of the September 2010 M7.1 earthquake, or any of its other aftershocks (GeoNet, 2012). Three instruments within Christchurch recorded ground acceleration at 220% g, 188% g and 107% g, respectively (GeoNet, 2012). Between the February 22, 2011 aftershock and January 7, 2012, Christchurch residents experienced 30 significant aftershocks, ranging from M4.8 to M6.4, and felt as MMI VI to IX (Wikipedia, 2012).

### *Summary*

Damage to health care facilities, plus to communications and transportation systems complicated and slowed the health system response in Kobe; in the Northridge quake, *non-structural* damage to health facilities and other buildings was significant. In the Loma Prieta quake, deep clay deposits amplified ground motions over a broad area; in Greater Victoria, similar amplification effects would likely be more isolated. In a damaging shallow quake, firefighters in Greater Victoria will likely encounter, as in Kobe, a lack of hydrant water supply to fight fires in some areas. A local emergency management official anticipates that such a quake would cause more fires in Greater Victoria than local departments initially can deal with (Brock Hensen, personal communication, November 23, 2011).

## **3.5 Scenarios for Such Earthquakes Affecting Greater Victoria**

### *Some Assumptions Regarding the Scenario Earthquakes that Affect Greater Victoria*

The set of assumptions selected for each scenario is intended to help medical planners plan for the worst type of event. As illustrated by Figure 15, downtown Victoria still has numerous URM buildings vulnerable to collapse in a quake (FEMA, 2003), because no earthquakes strong enough to bring them down have occurred. Especially if a shallow, more intense quake occurs there before one of the other types, the injuries from that event will likely be numerous, with a relatively high proportion of them involving trauma, due to victims being crushed in building collapse. This has potential implications for retrieval of casualties in that scenario, and is discussed in Chapter 5.

*a) Timing:* A July weekday noon hour, with locals and tourists in downtown Victoria streets, and in restaurants—some of which are located in soft storeys of medium-rise unreinforced masonry (URM) buildings. Many elderly people are at home for lunch; a significant number of them are in older URM buildings, such as those illustrated in Figure 15. Traffic downtown is relatively heavy, with people arriving at or leaving eating establishments. Many others are at beaches on the west coast of Vancouver Island.

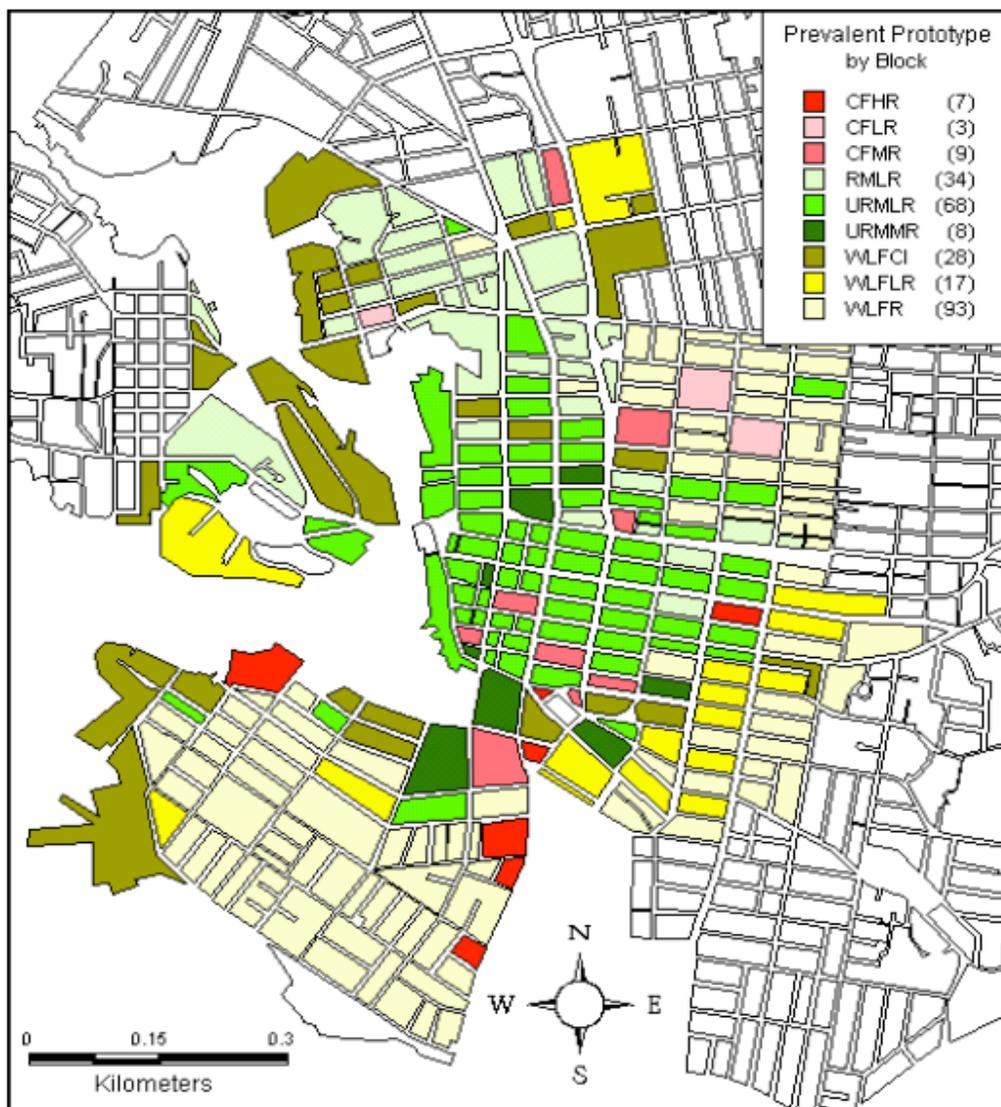


Figure 15. Prevalent building type by city block in downtown Victoria. Units colored bright green or dark green and generally centrally located, indicate that either low-rise or medium-rise buildings, both types with bearing walls of unreinforced masonry, predominate in those blocks. Source: (Onur, 2001, p. 73). Appendix F elaborates the legend of Figure 15.

### 3.5.1 Scenario One: Deep Earthquake

Further assumptions for this scenario include a M of 7.1, shaking at up to MMI VIII lasting 15 to 20 seconds, with one BC Ferry in port one, and the Victoria Clipper in the Inner Harbour, as potential extra health care resources. The hypocenter is offshore, 50 km deep, about 5km north of the Swartz Bay Ferry Terminal (Adams and

Halchuk 2003; Molnar, Cassidy, Dosso, and Olsen, 2010). The shaking is felt as MMI VI to VII across southern Vancouver Island. In terms of fire following, 13 fires are projected, but these result in no hospitalizations. Table 10 illustrates the different degrees of impact that the respective earthquakes could exert upon some of the regional infrastructure assets.

**Table 10. Possible Consequences for Local Infrastructure, by Earthquake Type**

Infrastructure item\earthquake	Deep	Shallow	Subduction
BC Ferries' Swartz Bay terminal	closed for the first 2 hours post-quake	unusable for 40 days post-quake	unusable for 6 days post-quake
(1) Victoria International Airport: (2) Inner Harbour Seaplane Bases (3) Helijet base near Ogden Point	(1) closed for first 2 hours post-quake	(1) closed for first 10 hours post-quake, (2) closed for 5 hours	(1) closed for first 8 hours post-quake, (2) closed for 5 hours
<i>Telecommunication capabilities:</i>			
Cellular telephone service	out for first 1.5 hours post-quake	unavailable for the first 3 days	unavailable for the first 3 days
EMBC, VIHA TM, CBS Vancouver Center, EBMCs, BCAS, local police and fire departments	limited problems telecommunicating	first 3 hours post-quake: problems telecommunicating	problems telecommunicating in first 3 days post-quake:
<i>Other critical infrastructure</i>			
lines carrying natural gas, water, sewer, and electricity	damaged in several areas, leading to 20 car accident/electric shock injuries	heavily damaged in several areas, leading to 60 car accident/electric shock injuries	heavily damaged in several areas, leading to 55 car accident/ shock injuries

### 3.5.2 Scenario Two: Subduction Earthquake

Onur & Seemann (2004, n.p.) expect the likely location of a megathrust earthquake to be over 100 km from major cities in BC, with longer shaking (1 to 5 minutes) likely.

Assume substantial damage to:

- the CBS Vancouver Center Facility, such that it cannot resume full production for ten days,

- 30% of facilities in Greater Vancouver for testing, transfusing, and storing blood products, such that some of the blood product inventory in and near Greater Vancouver is lost or unusable, and the initial rate of performing transfusions is reduced by 25%;
- road transportation infrastructure in Greater Vancouver that could otherwise be used to move blood products from the CBS via marine ferries to *VIHA transfusing facilities* on Vancouver Island.

Also assume significant damage to:

- many high-rise buildings in Greater Vancouver and Greater Victoria, which causes casualties, creating an even greater demand for blood products;
- 30% of transfusing facilities in Greater Victoria and up Island, such that 25% of the current VIHA blood product inventory is lost, or unusable;
- road transportation infrastructure in and beyond Greater Victoria, that would otherwise be used to move blood products from the CBS to *VIHA transfusing facilities* in Victoria and Nanaimo, or between other Vancouver Island hospitals;
- other critical infrastructure in both Greater Vancouver and Greater Victoria, causing power outages, and numerous fires over widely separated areas.

Assume that all regular external couriers used by CBS BC&Yukon (Air Canada cargo, Dynamex, and DHL) have shut down. However, CBS BC&Yukon *can* send samples to Calgary for testing. The earthquake impacts mean that BC is now into the Red phase of a blood shortage contingency for all blood groups of red blood cells. For details about this and other phases of the BC Blood Contingency Plan, see Appendix G.

Table 10 details some of the anticipated impacts on transportation assets and other aspects of critical infrastructure. Throughout downtown Victoria, debris, including glass, falling from buildings seriously injures several people. In a semicircle with a radius of about 400 km from the epicenter, critical facilities such as hospitals, water treatment plants, and power substations are damaged. As a result, water from mains and electric power is not available for some days or weeks, and natural gas is unavailable for months (CREW, 2005). Critical services (fire department, police, and ambulance) are overwhelmed, initially. Across southwestern BC, thousands of buildings, including many

high-rises, are destroyed, generating thousands of injuries, and numerous fatalities. Aftershocks of up to M7 create additional damage while rescue work is underway.

### *Fires*

Given the duration and intensity of the shaking, metallic objects pounding together may cause sparking, and damage to overhead power lines may leave lines arcing to ground. These sources can ignite fuels such as natural gas, spilled heating oil, certain painting supplies, or grass, causing fires in Greater Victoria. Damaged gas cylinders, ruptured oxygen lines, and spilled chemicals in hospitals can also cause or fuel fires (World Health Organization (WHO), Europe, 2005). Firefighters may be unable to respond quickly, due to casualties among them, or to damage to the local water supply and transportation systems. Such circumstances could contribute to *nearly simultaneous* urban wildfires. A significant amount of property will be lost due to having a collection of firefighting resources acquired to cope with less demanding circumstances (Sugimoto, 2001).

### *Mass movement on terrain slopes*

#### Landslides

The May, 2008 Ms 8.0 earthquake in Wenchuan county, China, triggered more than 20,000 landslides (Nie, Wang, and Wang, 2010). Such landslides also created more than 30 *natural* dams, seriously threatening the lives and property of downstream inhabitants (Nie et al., 2010). The low structural integrity and degree of consolidation of soils apparently contributed to some of these slides (Nie et al., 2010). Several thousand landslides and rockfalls also occurred during the 1999 Chi-Chi earthquake in Taiwan, and in the 1990 Manjil earthquake in Iran (Wieland, 2010).

In mountainous areas of British Columbia, steep slopes, shallow soils, incised streams, and intense rainfalls are common, and when taken collectively, are conducive to landslides (Chatwin, 2005). Factors such as the ground motions produced by an earthquake, the presence of steep mountain slopes, deposits of fine-grained sediments on slopes, liquefaction, inclined bedrock geology, and bedrock degradation due to repeated glaciation and isostatic rebound, altering drainage or slope integrity for road construction, and climatic conditions, all influence the frequency and scale of mass movements in this setting (NRCan, 2009). Since 1855, 15% of the known catastrophic

landslides in the Canadian Cordillera region have occurred on Vancouver Island (BC MEMPR, 1991). Of 26 large mass movements on Vancouver Island, eight have occurred within 11 km of lakes in the Campbell River system, and three of these events likely have been triggered by recent earthquakes (VanDine and Evans, 1992).

In 1958, a Mw 8.3 earthquake nearby triggered a major landslide ( $30.69 \times 10^6 \text{ m}^3$ ) into Lituya Bay, southeast Alaska (Yoo, Fritz, and Mohammed, 2009). The resulting giant wave scoured the opposite wall above the inlet, to an elevation of 524 m (Munro, Murty, and Clague, 2003). At the same time, a large gravity wave raced seaward at nearly 58 m/s, razing trees up to 208 m asl (Yoo et al., 2009). The (1) recently-glaciated steep slopes no longer buttressed by glaciers, (2) active fault zone with highly-fractured rocks, (3) frequent freeze and thaw cycles, (4) heavy rains, and (5) deep water in the inlet, combined to enable this event (Yoo et al., 2009).

Closer to the study area, the 1946 central Vancouver Island M7.2 earthquake triggered a rock avalanche from the north face of Mount Colonel Foster into Landslide Lake, located in the Campbell River drainage about 51 km southwest of Campbell River and 34 km from the epicenter (Mathews, 1979). The ensuing wave ravaged the river valley downstream for a distance of 10 km (Mathews, 1979). Vancouver Island centers such as Port Alberni, Port Alice, Tahsis, Woss, Youbou, and Zeballos--all located beside narrow bodies of water--are vulnerable to events similar to Lituya Bay, which a local shallow quake or a CSZ subduction quake could trigger.

#### *Dam Failure Due to Earthquakes or to Quake-triggered Events*

The incidence of an earthquake directly or indirectly causing the failure of a man-made dam is very low. The 17.5 m-high by 133 m-long Fujinuma dam in the Fukushima Prefecture failed as a result of the March, 2011 subduction earthquake in Japan, but its 62 year-old foundation and fill materials appear to have been suspect (Ono, Kazama, Kawagoe, Yokoo, and Gunawardhana, 2011). However, McCann, Jr., Ostenna, and Addo (2009, n.p.) state that subduction in the CSZ may "generate large ( $M \sim 9$ ) megathrust earthquakes . . . below Vancouver Island and the location of a number of BC Hydro's facilities." A *long* duration of ground shaking, typical in a subduction earthquake, could create significant damage to a dam (Arslan and Siyahi, 2008; Chen, 2009).

In 1991, dam failures involving 100 or more fatalities in the U.S. apparently had an overall annual probability of 1 to 17 (British Columbia Ministry of Energy, Mines and Petroleum Resources (BC MEMPR), 1992). This value may reflect a high proportion of *aging*, poorly-designed dams in the U.S. In contrast, singular *modern* [researcher's emphasis] earth-fill dam structures have annual failure rates of "between 1:1,500 and 1:25,000" (BC MEMPR, 1992, p. 61). For example, although the 40 m-high earth-fill Yuvacik dam was only 10 km from the epicenter of the 1999 Ms7.4 Kocaeli earthquake in Turkey, this *brand new* dam did not fail (Ulusay, Aydan, and Hamada, 2001).

The Water Stewardship Division, BC Ministry of Environment has identified on Vancouver Island five dams, which, if they failed, would present a very significant hazard to people downstream (BC Ministry of Environment, 2010). Three of these dams regulate most of the flow of the Campbell River system, while waters from Elsie Lake Dam drain to Port Alberni, and those from the Sooke River Dam reach the Pacific at Sooke, near Victoria.

Although BC Hydro does have a rigorous dam safety program,

most of the B.C. Hydro dams were built when knowledge of floods and earthquakes was far less advanced... Less data were available and the criteria used for dam design were less exacting. The major deficiencies identified in B.C. Hydro's dams are generally related to their inadequacy in meeting current flood and seismic criteria...the dams in the Campbell River area...had original designs that assumed Zero or relatively low seismic loading...(BC Hydro/Nielsen, 1990).

Major BC Hydro reservoirs in the Campbell River drainage basin include the 52 km-long Buttle/Upper Campbell Lake (Strathcona Dam), Lower Campbell Lake (Ladore Dam), and John Hart Lake, in order of descending elevation and lake size (see Figure 16). All of these structures have been closely monitored and have had recent and significant seismic-related improvements (BC Hydro 1986; 1989; 2003; 2006; 2010; 2011).



Figure 16. Strathcona Dam, Upper Campbell Lake, Campbell River system, central Vancouver Island. The dam is 53 m high, with a roadway along its crest. Source: BC Hydro (2012).

*Release of materials that are toxic, flammable, or noxious*

Releases of several types of hazardous materials into the air, ground, or water in or near Greater Victoria and other communities may occur as a result of a subduction earthquake. At facilities such as marinas, tsunami waves may damage lines or containers that contain boat fuels, and at associated facilities for boat repair and maintenance, cause spills of various chemicals. Many boat maintenance products contain chemical solvents such as acetone, benzene, toluene, styrene, alcohol, and mineral spirits

(Moore/Western Mariner, 2008). Example facilities are located near Swartz Bay, Oak Bay, Cadboro Bay, Head Street in Esquimalt, and in Sooke.

If spilled in hospital laboratories, *reagents* such as sodium azide (Wikipedia, 2011a) a useful biocide, and tissue fixatives (Manitoba Federation of Labour Occupational Health Center, 1995) may endanger hospital employees. Liquid oxygen, stored in hospitals, is about four times heavier than air, and when spilled, will spread across the floor and boil into a gaseous form, relatively concentrated immediately above the floor (FEMA, 1999). Oxygen-enriched atmospheres enable easier ignition of combustibles, and increase the intensity of fires (FEMA, 1999). Ruptured natural gas lines may represent the most likely release threat.

### *Tsunami*

A subduction earthquake near shore may generate a damaging tsunami that could impact southern coastal B.C. very soon after the quake (Kohl, O'Rourke, Schmidman, Dopkin, and Birnbaum, 2005; EMBC, 2004a). Travel time would be short for a tsunami initiated in the CSZ, with very little warning for the west coast of Vancouver Island (WCVI). When people there feel very strong shaking, they should run *immediately* via the shortest safe route to an elevation of more than 15 metres above sea level (EERI, 2011; EMBC, 2012).

Tsunami waves grow in height as they enter shallowing water and surmount the upland (Fisheries and Oceans Canada, 2008). When a trough arrives first, shoreline conditions resemble an extremely low tide, and tidal conditions can affect wave height (Koshimura, Katada, Mofjeld, & Kawata, 2006; EMBC, 2004a). As the largest of the waves is usually the third or fourth and may arrive hours after the first, no one should soon return to the shore, as debris from earlier waves could become projectiles in or upon later waves (EMBC, 2004a). Fisheries and Oceans (2009) mathematically modeled a tsunami driven by a CSZ subduction quake. The model projects, in Victoria harbours, wave heights of 3m to travel the entire waterways. Following a CSZ subduction earthquake, people in Victoria should seek high ground, 4 metres or more above sea level (City of Victoria, n.d.).

### 3.5.3 Scenario Three: Shallow Earthquake

The worst-case scenario in terms of Greater Victoria casualties due to earthquake would be a shallow event of M7.2 or greater, with an epicenter within 20 to 30km, since the energy level would be intense at ground level.

Assume that this event has a M of 7.3, with a duration of 30 to 40 seconds, and a hypocenter located 13 km deep, 3.2 km south of the provincial Legislature Building in Victoria. MMI is felt VII to IX throughout Greater Victoria. This range of intensity extends 35 km west, as far east as Oak Bay (11 km), and to southern Salt Spring Island. For comparison, in the 1999 Taiwan shallow quake, the 15km-wide linear zone of highest intensity shaking was 60km long on one side, and 40km on the other. In this area, well-designed structures deformed, building frames shifted, and underground pipes ruptured (Liao, Hwang, Chang, Hong, Lee, Huang, et al., 2003).

Numerous fires occur, fuelled by natural gas line ruptures. The local firefighters will be overwhelmed for a couple of days, but firefighters from communities such as Duncan and Ladysmith could soon help crews control the blazes. The earthquake generates a local tsunami. Because the wave would arrive almost immediately, very little warning could be provided (City of Victoria, n.d.), but the impact of this event may not be severe. Based on a scenario M=7.2 quake over an area of 19 km by 60 km on the Seattle Fault, Koshimura, Mofjeld, and Moore (2001) modeled wave heights at just 2 to 4 m in narrow inlets, and only up to 2m in less-confined areas.

Debris falling from buildings injures several people. Lines carrying electricity, sewer, water, and natural gas are severely damaged in several low-lying areas of Greater Victoria, causing more than 60 serious injuries related to automobile accidents and electric shocks. Glass falling from downtown high-rises strikes and seriously cuts many people. There is one BC Ferry in port, which could temporarily house some people with minor injuries and no homes to return to. The damage to buildings and to people—in downtown Victoria, at least—is concentrated in an area identified in Figure 15 (Onur, 2001).

### **3.6 Chapter Summary**

This chapter has addressed the nature of the seismic hazard in the southern half of coastal British Columbia, and examined key characteristics and consequences of comparable catalogued earthquakes that have occurred elsewhere. Some of the parameters and outcomes from these observed events provided elements for the three different and plausible earthquake scenarios. Various parameters were considered, including the amount of energy released, location and depth of hypocenter, the intensity of shaking in various zones, and how the wave energy might be modified by local conditions such as deep clay deposits, or areas of unconsolidated fill.

The parameters, catalogue examples, and scenario information were also employed in Chapter 4 to estimate hospitalizations in Victoria as a direct or indirect result of the range of damage—locally and, in the case of a subduction quake—to other Vancouver Island and Lower Mainland locations.

## Chapter 4: Research Methodology

Chapter 4 describes the methodologies used for different purposes within the research. It describes the techniques used for estimating injuries and hospitalizations likely to result from the three different types of earthquakes. It also discusses the design of interview questions and the consultation process employed to obtain *feedback* from health care professionals regarding the implications of the damage, injuries, and hospitalizations anticipated to result from those earthquakes.

In analyzing the primary data that resulted from the interview process and in a review of secondary data sources, described in sections 4.4 (Secondary data sources) and 4.5 (Data analysis and interpretation), the author utilized content analysis as the principal analytic method. In Chapter 5, he then integrated the primary and secondary data to achieve a synthetic analysis of the capacity and vulnerability amongst the key agencies responsible for post-quake response including the emergency supply, distribution and administration of blood products. Validation of the study findings included review and feedback by the VIHA Medical Director of Hematopathology.

### 4.1 Estimation Methodology: Injuries and Hospitalizations

The order of magnitude estimates of injuries and hospitalizations likely to result from three types of earthquakes that could affect Greater Victoria were prepared in order to inform key informants before their interviews. The estimates package provided key informants with information and perspective on the regional seismic hazard and some of its implications for the VIHA Transfusion Medicine function. The researcher subsequently interviewed these informants, to obtain feedback that could be included in order to strengthen the VIHA Transfusion Medicine Internal Disaster Response Procedure, specifically with respect to earthquakes.

Earthquakes can cause damage, deaths and injuries directly and indirectly, as discussed in Chapter 3. Since these direct and indirect effects differ from each other, for example, in terms of their preconditions, physical chain of events, complexity, scale, location, frequency, intensity, and probability, researchers have developed various methodologies for estimating the numbers, types, and gravity of injuries that

the respective processes generate. The research examines impacts of shallow, subduction, and deep earthquakes, in terms of various appropriate elements.

#### 4.1.1 Background

Several authors and groups have addressed the problem of estimating earthquake casualties, but relatively little work outside of the US Federal Emergency Management Agency and the USGS appears to have been conducted to determine *hospitalizations* resulting from earthquakes. Regarding casualties, Ohta, Goto, & Ohashi (1983) modeled the number of earthquake *victims* as a function of the number of completely destroyed houses. However, Wagner, Jones, and Smith (1994) lamented a lack of data that were comprehensive, well-defined, and usable to isolate risk factors for injury, as collection of accurate data in the aftermath of earthquakes has often been difficult, or a lower priority. Osaki and Minowa (2001) carried out descriptive and case-control studies in one ward of Greater Kobe, Japan, to isolate age and the degree of damage to dwellings as chief factors associated with earthquake deaths in the 1995 Hanshin-Awaji earthquake. Shoaf, Nguyen, Sareen, and Bourque (1998) presented strong evidence that earthquake casualties vary with the population density, the intensity of shaking, local soil conditions, the built environment, the timing of impact, and the location and behaviour of potential victims. Similarly, Peek-Asa, Ramirez, Seligson, and Shoaf (2003) proposed a population based case-control study to illustrate how individual choices, building characteristics, and seismic features contributed to physical injury during the 1994 earthquake in Northridge, California. Ramirez and Peek-Asa (2005) highlighted findings from various population-based epidemiologic studies on earthquake-related traumatic injuries. Epidemiologic modeling is useful for estimating casualties resulting from earthquakes, because it can incorporate the risk in demographic data with that in building and seismic data.

Jaiswal, Wald, Earle, Porter, and Hearne (2009) determined for western North America a *fatality rate* of 0.03/1000 people exposed at Modified Mercalli Intensity (MMI) level IX. Naghii (2005) noted that as a result of the 1968 earthquake south of Khorasan, Iran, only 3.3% of 11,254 people injured required in-patient care. The Federal Emergency Management Agency (2003, p. 13-8) provides, relative to a particular quake death rate, one of the few indications of the number of *hospitalizations*

generated by recent earthquakes in the western United States, stating that

[g]eneral data trends such as, 10 to 20 times as many non-hospitalized injuries as hospitalized injuries occurred in the Northridge earthquake (Durkin, 1995) and the hospitalization rate (hospitalizations that did not result in death) for LA county of 1.56 per 100,000 was four times the fatality rate of 0.37 per 100,000 (Peek-Asa et al., 1998), were gathered from available data to provide guidance as to reasonable casualty rates. For several recent events, including the Northridge, Loma Prieta and Nisqually earthquakes, the casualties estimated by...[these rates]...are a reasonable representation of the actual numbers observed.

The key factors considered in order to estimate the numbers of hospitalizations in Greater Victoria due to damage from the respective earthquake types are (1) the average population densities and numbers of serious injuries or known hospitalizations in areas that have been intensely affected by (an) earthquake(s) of a given type, (2) the intensity and duration of shaking and the degree of destruction within the areas intensely affected, and (3) how far such settled areas are from the corresponding earthquake epicenters. Shoaf, Nguyen, Sareen, and Bourque (1998) identified several key parameters that affect the number of casualties resulting from an earthquake, and some of these (e.g. alluvial soils, building construction, and seismic wave frequencies and directions) interact in very complex ways. Thus, the estimation methodology is a basic, almost heuristic approach when compared to computerized GIS/database systems such as HAZUS, that manipulate massive amounts of data to rapidly project casualties just after a damaging earthquake (FEMA, 2003).

Translating, for each type of quake scenario, the cumulatively averaged numbers of recorded hospitalizations or *serious* injuries from actual *source* unit areas—into the numbers likely hospitalized in a *target* unit area with similar averaged population density values, distance from quake epicenter, shaking intensity, plus intensity of destruction—has involved attempts to determine the relationships between data at different levels of population density and aggregation. Such relationships are shaped by numerous variables, including the “packing” of the aggregation, the building construction types, surficial geology, and human behaviour, within the respective spaces (Gotway and Young, 2002). The derived estimates of hospitalizations are of the appropriate *order of magnitude* given specified earthquake magnitudes, distances to

epicenters, and likely intensities of shaking, but involve considerable uncertainty, as discussed in Chapter 6.

The researcher calculated spatially-averaged population density ratios that allowed proportional allocation of the observed source unit serious injuries and/or hospitalizations to the target scenario unit, in a spatial unit matching methodology. For illustration purposes, example tables containing data regarding *shallow* earthquake parameters that may have influenced injuries—and others with data on population density and injuries that *have* occurred—complement the discussions of rationale for the calculations made to derive the various estimates.

Step one involved defining the criteria from shallow earthquakes that have occurred elsewhere and that logically could apply to a scenario shallow quake in the Greater Victoria *target* setting. Since the intensity of shaking, expressed in terms of the Modified Mercalli Intensity (MMI) scale, the duration of shaking, and peak ground acceleration, (PGA) reflect the ultimate *expression* of incoming seismic energy once it reaches a *target site*, these factors were ranked higher than the *magnitude* of a given tremor and the distance between its epicenter/hypocenter and the particular target site it affected. The design and type of construction used in buildings of various purposes, and the averaged population density in communities shaken also ranked highly.

#### **4.1.2 Deep Earthquakes**

Three relatively recent quakes that occurred in western Washington state provided some rationale for estimating the injuries and hospitalizations that would result from a M7.1 deep earthquake that would structurally damage buildings in Greater Victoria. These are the M6.8 2001 Deep Earthquake near Nisqually, the M6.5 Seattle Fault Earthquake of 1965 and the Puget Sound (Olympia) Area, M7.1 quake in April, 1949. The Nisqually quake injured nearly 700, 12 seriously, (TRPC, 2009; WMDEMD, 2009), and hospitalized four, while the 1965 Seattle quake injured 30 to 60, with 30 hospitalized (Lange, 2000; Von Hake et al., 1976). The 1949 Olympia quake injured 303, with 64 likely serious and requiring hospitalization (CREW, 2005); in Centralia 10 were hospitalized (Murphy and Ulrich, 1951).

Again, the researcher compared population densities, reports of where certain levels of MMI were apparent, the duration of shaking, magnitudes, and distances to epicenters of

earthquakes, in order to make judgments about estimating injuries and hospitalizations resulting from a scenario deep earthquake that damages Greater Victoria. The Nisqually data (overall admitted prorated for population density equal to the *city* of Victoria) had an 80 percent weighting in this consideration. The Seattle 1965 prorated values had the least certainty associated with them, so were not used in the calculations.

For Nisqually 2001:  $.8 \times 30 = 24$

For Olympia 1949:  $.2 \times 74 = \underline{15}$

Final adjusted total: 41 (additional two due to injury from landslides)

Although this adjusted total may seem high with respect to the data from the Puget Sound quakes, the unreinforced masonry buildings in Victoria have not been tested by a damaging earthquake. This fact, plus the likelihood that a significant fraction of older multi-unit residential URM buildings in downtown Victoria are occupied by people of age 65 or older (*North Park Neighbourhood Association, ca. 2011; Statistics Canada, 2012; Victoria Women in Need Community Cooperative, 2013*), increases the probability of injuries that may become more serious over a short time.

#### *Injuries and hospitalizations likely to result indirectly from deep earthquakes*

##### Earthquake-induced fire

Fire is regarded as a likely indirect result of an earthquake (Nishino, Tanaka, and Hokugo, 2012; Tanaka, 2012). In fact, "the losses from fires following earthquake (FFE) have sometimes been greater than the direct losses caused by the earthquake itself " (Zhao, 2010, p. 83). The 2001 Nisqually quake triggered 8 fires in the Olympia *area* (McDonough, 2002, p. 109). In the 1949 Olympia deep quake, the gas distribution system broke at nearly 100 points, mainly due to failures of unconsolidated ground (WSEMD, 2004). Scawthorn (2008, p.10) developed a rule of thumb for fire-following ignitions:

for a population shaken at MMI VIII, there will be approximately one fire following earthquake requiring fire department assistance, for each 10.5 million sq. ft. of floor area – that is, for approximately 7,000 single family dwellings, or a residential population of about 25,000.

In addition, Jones et al./USGS (2008, p. 205) state that

approximately 3% of residential fires in the United States result in an injury or death. In rural areas, the risk of injury or death is 2.7 times higher...primarily due to fire department response times greater than 5 minutes. For each injury-causing fire, 51% result in mortality, 29% in...injuries requiring specialized care..., and 39% in injuries treated in and released from an emergency department.

However, this Jones et al./USGS (2008) *residential* fire statistic does not accurately represent the anomaly of post-earthquake conditions, and therefore, these rates would likely increase in a post-quake situation. Appendix H elaborates the reasoning for increasing the rates of injury to 5%, of hospitalization (specialized care) to 35%, and of rural risk to 3 times, while Appendix I shows the calculations for fire following the subduction and shallow quakes.

Assume that in this deep event, Greater Victoria is shaken at MMI VIII. In part of Greater Victoria, the population density is only 101-499 persons per square km; this area comprises approximately 83% of the Victoria Census Metropolitan Area (Capital Regional District (CRD), 2008). The population in this zone totals about 75,000 (74,891 by census) (Statistics Canada, n.d.; 2009) and the private dwelling count is 30,887 (Statistics Canada, 2010).

Using the Scawthorn (2008) indicator, 30,887 dwellings (assumed to be single family) *in this low density area*/7000 = 4.412 fires likely in the *rural* region

$4.412 \times .05 \times 3.0 = .662$  associated risk of injury  $\times .35 = .232$  hospitalizations

$369,775 - 75,000 = 294,775$  remaining *urban* population/25000 = 11.791 (11) fires requiring fire department assistance;

$11 \times .05 = .55$  associated risk of injury  $\times .35 = .193$  hospitalizations

$.232 + .193 = .425$ , which is  $< 1$  hospitalization

Since Scawthorn, Eidinger, and Schiff (2005) found that fire-following ignition rates per million square feet for industrial and commercial occupancies are much lower than for the residential types, and since the Scawthorn (2008) guideline includes those occupancies as well, it appears reasonable to conclude that hospitalizations due to fires in Greater Victoria following a *deep* earthquake event are unlikely.

### *Landslides, the state of dams, and local tsunami possibilities*

Assume that two landslides within southern Vancouver Island hospitalize 2 people as a result of mass movement on terrain slopes. In the 2001 Nisqually deep earthquake, Washington dams fared well. Of 290 inspected, five dams incurred earthquake-related damage, chiefly due to weak foundations and poor construction (WSEMD, 2004). No dam failures or tsunami waves are predicted due to a deep earthquake that damages buildings and structures in Greater Victoria.

### *Summary Regarding Deep Earthquakes*

A total of 41 people are assumed to be hospitalized following a *deep* earthquake that structurally damages buildings and structures in Greater Victoria.

#### **4.1.3 Subduction (Megathrust) Earthquakes**

With this type of earthquake, events that take place in relatively remote locations within the VIHA administrative area may also affect the numbers and time spread of hospitalizations in a secondary or tertiary health care facility, such as in Victoria. In the Fukushima Prefecture following the 2011 Tohoku earthquake in Japan, disaster response at 8 hospitals designated for disaster response began March 11, 2011, and continued for at least 11, and up to 24 days (Nollet et al., 2013).

The procedures for estimating subduction earthquake hospitalizations *due to shaking in Greater Victoria* were identical to those for deriving the hospitalizations resulting from a shallow localized earthquake. The balance of discussion in this section focuses on how this type of earthquake could generate additional hospitalizations indirectly.

### *Injuries from tsunami Waves and Wave-swept Debris*

Cherniawsky et al. (2007) predicts that a CSZ earthquake will generate tsunami waves about 5–8 m high on the outer coast of Vancouver Island, and current velocities up to 17 m/s. The greatest hazard is a tsunami generated nearby—for which the earthquake itself will be the warning. Therefore, people on the west coast of Vancouver Island need to know to where they should evacuate (USGS, 2010a).

The researcher used Google Earth to estimate the tsunami inundation zone, based on

shoreline slopes and channel configurations, and to count apparent dwellings and typically staffed workplaces sited at elevations of up to 7 m in major inlets and outer shoreline along the west coast of Vancouver Island. This scan provided a geographic zone that would likely contain human casualties generated by an anticipated tsunami event. In this tsunami scenario, it is assumed that:

- the average wave height is in the 5-8m range,
- 3 people usually occupy each dwelling or workplace, and that
- 70% of people who live or work in the 7m asl zone are not in the inundation zone when the waves arrive, due to chance and/or to evacuation.

Via the Google Earth scan, approximately 1,200 buildings estimated to be at or below 7m asl, and that also appeared to be dwellings or workplaces, were observed on the west coast of Vancouver Island, between Port Alice and Becher Bay.

$1,200 \times 3 = 3,600$  people  $\times .086 = 310$  people with serious injuries, and of these, only 14% (43) require hospital admission (Doocy, Robinson, Moodie, and Burnham, 2009). Further assume that 65% (28) of these are admitted to Greater Victoria hospitals, including 10 in Royal Jubilee.

#### *Injuries from mass movement on terrain slopes*

Marano, Wald, & Allen (2010) analyzed 18,807 earthquakes that occurred since 1968, and determined that in terms of the non-shaking *deaths* (excluding the Sumatra–Andaman Islands tsunami), landslides are responsible for 71.1%, followed by tsunamis at 11.5%. In the Greater Victoria area, the incidence of death or injury from landslides likely will be a lesser fraction, in part because relatively few buildings are on or near precarious slopes (City of Victoria, 2006). However, injuries from earthquake-triggered landslides are more probable in communities such as Port McNeil, which has a history of slides (Town of Port McNeill, 2007), Tahsis, or Zeballos, which are flanked by rockfall slope hazards on mountains over 1500m high. People cannot outrun most types of catastrophic mass movement. The 1999 Nomash River landslide near Tahsis attained a maximum speed estimated at 400 m/s (Hung and Evans, 2004).

Since several logging operations, communities, and highways are adjacent significant slopes on Vancouver Island, at least 3 people with serious injuries due to earthquake-triggered landslides likely will be hospitalized in Victoria.

*An earthquake triggers a landslide into an inlet or a lake*

This possibility associated with a subduction earthquake involves several settings on Vancouver Island, namely at Coal Harbour, Port Alice, Tahsis, Zeballos, Cumberland, Port Alberni, Youbou, Cowichan Lake, Horne Lake, Port Renfrew, and the Gold River Pulp Mill site. Assume that 2 people are hospitalized in Greater Victoria due to a large wave, or debris carried by such a wave, slamming them against firm surfaces.

*Regarding the possibility of a dam failure due to a subduction earthquake in the CSZ*

To assess the likelihood of dam failure caused either directly or indirectly by a subduction earthquake, the researcher relied to a significant extent upon BC Hydro reports regarding 4 of the 5 high-consequence dams on Vancouver Island. The three dams on the Campbell River system ranked highest in terms of potential human consequence. However, BC Hydro will soon significantly reduce this vulnerability, as by 2019, its contractors will bore a 2.1-kilometre tunnel to replace the three 65-year-old, seismically-vulnerable wooden-stave and steel pipelines (see Figure 17) between the John Hart Dam and its generating station (BC Hydro, 2012a; Google Earth, 2012). No hospitalizations are anticipated due to dam failure, as no failure is anticipated.



Figure 17. Penstocks from the John Hart Dam to its powerhouse, near Campbell River. SilentOwl photo.

**Table 11. Serious injuries and hospitalizations from a scenario CSZ subduction earthquake**

Event	Number seriously injured	Number hospitalized
Subduction earthquake	276	276
Dam failure floods	0	0
tsunami	310	43 (28 to Victoria)
Earthquake-triggered landslide	3	3
Landslide into an inlet, a lake, or a dam reservoir causes large wave(s) to directly injure people	2	2
Totals	591	324

From Table 11, it is evident that an anticipated tsunami, and not the subduction earthquake, could produce the greatest number of injuries, although a relatively small fraction of injuries generated via tsunami would result in hospitalizations.

#### 4.1.4 Shallow (Crustal) Earthquakes

Table 12 illustrates the selection of earthquakes along with some of their parameters, considered in order to develop a plausible shallow earthquake scenario for Greater Victoria.

Ultimately, the data regarding past earthquakes and proposed scenarios were compared via categories such as:

- Setting of actual quake or scenario quake versus Greater Victoria setting
- Area in km<sup>2</sup> subjected to intense shaking
- Population density in number of persons/km<sup>2</sup>
- Victoria or Greater Victoria setting area/Area in km<sup>2</sup> subjected to intense shaking
- severe or trauma injuries/population density/km<sup>2</sup>
- prorated serious injuries/population density/km<sup>2</sup>
- prorated serious injuries/100,000 people exposed
- Numbers admitted due to fire following the earthquake/population density/km<sup>2</sup>
- Numbers admitted due to fire following the earthquake/100,000 exposed
- Overall total number admitted/100,000 exposed
- Overall total number admitted prorated for an area equal to Victoria or Greater Victoria.

**Table 12. Shallow earthquakes and scenarios examined to derive usable data**

<b>Name and Magnitude of Earthquake</b>	<b>Location</b>	<b>Depth and Other Notable Features</b>
Kobe, Japan, 1995 M=7.2	Greater Kobe Epicenter: 11km from zone of heavy damage, 24 km from Kobe (1)	depth: 14 km, duration: 15 seconds MMI: 11-12 (2) basin effects: confirmed
"Chi-Chi", Taiwan, 1999 M=7.6	Nantou Province, Central Taiwan, Epicenter at 23° 46' 12" N, 120° 58' 48" E; (3)	depth: 1–7 km duration: MMI: VIII-IX (4) basin effects: suspected (5)
Loma Prieta, California, 1989 M=7.1 (6)	Loma Prieta Section, northern San Andreas Fault. Epicenter 15 km east of Santa Cruz	depth: 17.5 km duration: 7 to 15 seconds. MMI: VIII in Santa Cruz and Watsonville; damaged properties 100 km from epicenter, as deep clays amplified ground motion (7)
Northridge, California, 1994 M=6.7 (8)	Epicenter at 34° 12' 32.4"N, 118° 32' 27.6" W, 32 km WNW of Los Angeles (9)	depth: 16.6 km duration: 7 to 15 seconds (10); MMI: VII-X (11)
Southern California (Shakeout) <i>Scenario</i> M 7.8	on the San Andreas fault in southern California	depth: 13-16 km duration: 100 seconds (12)
Olympia Area-Seattle Fault <i>Scenario 1</i> (Thurston County) M=6.7	Seattle Fault zone (13)	depth: 5-15 km (14) duration: MMI:
Puget Sound, Washington <i>Scenario</i> M7.0 – 7.5		depth: Up to 25 km duration: MMI: VII – IX (16)
Christchurch, N.Z., 2011 M 6.1 (17)	Epicenter at 43° 34' 58.8"S, 172° 40' 48" E, 6.7 km SSE of Christchurch Cathedral	depth: 5.9 km duration: MMI: VII – IX. Destroyed or damaged more than 100,000 buildings. Left 181 dead and 1,500 injured; 164/594 admitted had serious injuries (19)

For the numbered references, please see this same Table in Appendix J.

The Victoria setting was compared on two levels to actual earthquake locations. Since Onur, Ventura, and Finn (2005) had already identified vulnerable buildings in downtown Victoria *city*, the city of Victoria was a useful unit for comparisons to urbanized settlements. The larger unit included the balance of Greater Victoria, which also had equivalencies in some communities damaged by earthquakes.

In some instances, the researcher used Google Earth images in estimating population density. The researcher first conducted Internet searches to find accurate measurements of the area and population included in a given administrative unit when a damaging earthquake occurred. In some instances regarding the subduction earthquakes in Peru and Chile, such *area* information was not available. For these situations, the researcher located images of some of the communities in which

earthquake casualties had occurred, and on Google Earth, used the ruler line/path tool to estimate the approximate area of such communities.

To calculate the number of expected hospitalizations within the city of Victoria that would likely result from a damaging shallow quake, the researcher selected a limited amount of the data available regarding pertinent earthquakes. The data on hospitalizations following the 1995 Kobe earthquake were selected because (1) there was good evidence that they were geographically tied to their specific ward areas, (2) their densities and overall areal extents were more similar to those of the City of Victoria (CoV) than were the data for other areas, and (3) because they are empirical, versus the *hypothetical* data synthesized for earthquake *scenarios* set on the west coast of North America. These Japanese injury and hospitalization values, prorated for area and population density, were then used to produce upper and lower bounds of the range of hospitalizations likely to result from a shallow earthquake in the city of Victoria. The averaged value became the final estimate for the number of hospitalizations. Estimates of the uncertainty associated with these values are discussed in Chapter 6. The author matched, averaged, and then ultimately combined values comparable to CoV and GV-C in terms of density, to produce a community-wide averaged number of hospitalizations due to a given scenario earthquake.

*Injuries and hospitalizations likely to result indirectly from a shallow earthquake*

The water and sewer infrastructure in the city of Victoria is aged, and vulnerable especially to damaging earthquakes (City of Victoria, 2012; Gordon, 2011; Smart Risk Control Inc., 2007). This vulnerability implies that post-quake within the city of Victoria (1) the water supply for firefighting purposes may not be dependable, and (2) sewage contamination in segments of the water system could occur. Ground motions of MMI VIII or more will damage buildings, impact utility systems, and create a potential for gas-fueled fire ignitions or explosions (State of California Seismic Safety Commission (SoCSSC), 2002). In the 1994 Northridge shallow earthquake, numerous fires started when houses shifted off their foundations, thereby breaking natural gas lines, or when unsecured gas-fired water heaters fell over (EMBC, 2008). The calculations regarding fires following the shallow scenario quake are contained in Appendix I, and did not suggest hospitalization due to these phenomena. Table 13 totals the serious injuries and

hospitalizations anticipated from a M 7.3 shallow earthquake that has an epicenter within 5km of Greater Victoria.

**Table 13. Serious injuries and hospitalizations anticipated due to a shallow earthquake near Victoria**

Event	Number seriously injured	Number hospitalized
Shallow earthquake	403	403
Dam failure floods	0	0
tsunami	21	3
Earthquake-triggered landslide	0	0
Release of materials that are toxic, flammable, or noxious	2	1
Fire	0	0

The overall hospitalization totals for the major types of earthquakes are: 41 in a deep quake, 403 in a shallow earthquake, and 324 from a subduction event. The number of hospitalizations derived differs slightly from the number contained in the Estimates Package. Since producing the Estimates Package, the researcher gathered more information about the potential for fires and firefighting in Greater Victoria, and about the rates of injury and hospitalization that would likely apply to people caught in a tsunami. Although the demand for blood will largely be derived by the estimates, it also would reflect factors listed under "Possible additional sources of demand for blood products" on pages 53 and 54.

This segment of the methodology Chapter has produced order-of-magnitude estimates of the serious injuries and ensuing hospitalizations that could occur as a result of any of the three types of earthquakes that could affect Greater Victoria. The balance of the Chapter examines two main topics: firstly, the rationale for focusing on the health system assets in Greater Victoria, and secondly, the design of interview questions and the execution of the consultation process employed to obtain *feedback* from health care professionals regarding the regional health care implications of the damage, injuries, and hospitalizations anticipated to result from those earthquakes.

#### **4.2 Greater Victoria: Vulnerable population, key health care assets, and disaster response coordination capacity**

The vulnerable population of people aged 75 + in the Greater Victoria Local Health Area (see Figure 18) is expected to increase to almost 35,600 by 2030 (Vancouver Island

Health Authority, Planning and Community Engagement (VIHA PCE), 2011b). In a shallow event or a subduction quake, Greater Victoria could become an area in need of blood products.



1 cm = 1.14 km

Figure 18. Image showing the areal extent of the Greater Victoria Local Health Area, located below and to the right of the longer red line. Sources: Google Earth, (2012) and VIHA PCE (2011b).

Greater Victoria is the capital of British Columbia, and a key distribution and administrative center for Vancouver Island. A considerable array of assets important to

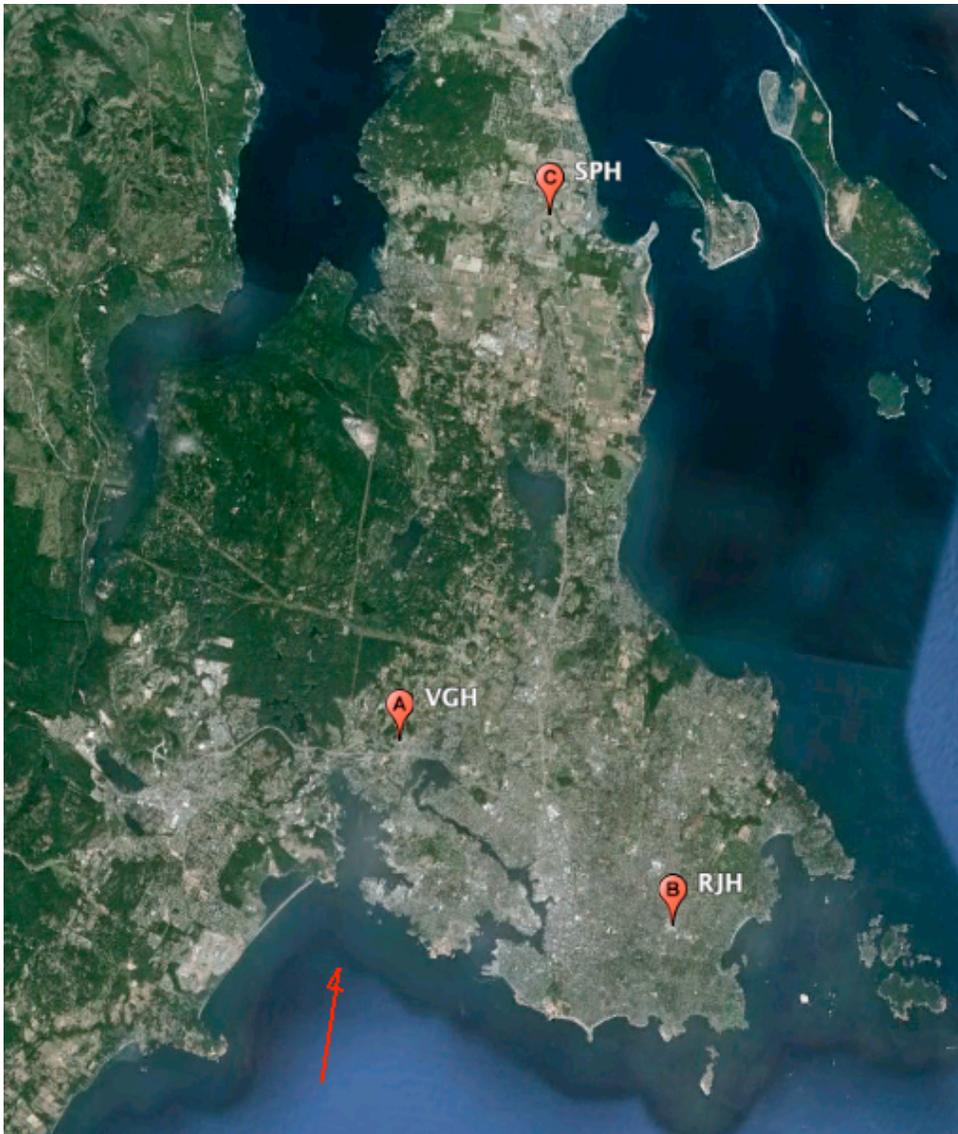
disaster response is located in Greater Victoria, including the emergency planners, social services, police, fire departments and communications specialists of the thirteen municipalities that comprise the area. In addition, the BCAS Victoria Dispatch Operations Center serves Vancouver Island, while the BCAS Provincial Air Ambulance Coordination Center (PAACC) in Victoria coordinates and arranges air and ground Critical Care Transport and non-critical air transports around BC (BCAS, 2011). After a subduction earthquake, the PAACC would hopefully be capable of coordinating Critical Care Transport within the Lower Mainland, as well as on Vancouver Island.

The Joint Rescue Coordination Center (JRCC) and Canadian Coast Guard operations in Greater Victoria may prove vital if a tsunami damages structures and people on the west coast of Vancouver Island. The JRCC coordinates Search And Rescue (SAR) aircraft in the Victoria Search and Rescue Region, (all of BC and much more) (Fisheries and Oceans Canada/Canadian Coast Guard (F&OC/CCG), 2012; National Defence Canada, 2012). Appendix K lists more details regarding federal resources that are either located in the Greater Victoria area, or available for emergency response upon provincial government request.

Under normal circumstances, the assets aforementioned or referred to have significance for a considerable portion of the population in southwestern BC, in terms of emergency health care, and transportation safety. In a post-quake situation, they would be even more valuable. In addition, VIHA's headquarters, its highest level of expertise, greatest number of staff, and most sophisticated equipment are in Greater Victoria. Three main hospitals, with their locations shown in Figure 19, serve the Greater Victoria Local Health Area (and beyond): the Royal Jubilee Hospital (RJH), the Victoria General Hospital (VGH), and the Saanich Peninsula Hospital, (SPH). Blood transfusion services offered at these facilities could be vital in post-earthquake circumstances.

In 2011, the Victoria International Airport, a key Vancouver Island regional facility, served 1,499,792 passengers, making it one of Canada' busiest terminals in terms of passengers (Wikipedia, 2012a). The Victoria Inner Harbour aerodrome is, by road, approximately 4.13 km from Royal Jubilee Hospital, and 8.6 km from Victoria General, and could be a link in rapid air-to-ground transportation support following a damaging earthquake (Google Earth, 2012).

Some senior professionals involved in the emergency management function of various provincial and municipal agencies are located within this metropolitan area. While others on Vancouver Island or from mainland BC may be able to assume their roles, the earthquake response in Greater Victoria and on Vancouver Island would be less rapid and effective if some of them are injured. If any of them are killed in a quake, some of the precious response capacity for future disasters is lost, as well.



1cm = 2km

Figure 18. Google Earth image showing the locations of major hospitals in Greater Victoria.

A = Victoria General Hospital, B = Royal Jubilee Hospital, and C = Saanich Peninsula Hospital. The yellow arrow in the lower left corner indicates approximate north. Google Earth (2012).

### 4.3 Key informant interview methodology

For the purposes of confirming and/or improving the mitigation, preparedness, emergency response, and recovery of the VIHA TM function with respect to the three types of damaging earthquake events, three key objectives were:

- to identify if and how the TM function is vulnerable to the three types of seismic events,
- to affirm or determine how to reduce the risks of injuries to staff and patients, and the risks of having valuable equipment and/or facilities rendered inoperable due to *non-structural* damage to the TML area of (a) Greater Victoria transfusing hospital(s), and
- to consider potential impacts on operations, including critical business interdependencies, and associated resource requirements of the VIHA TM function and the Canadian Blood Services' Vancouver Center operations.

In order to gather information to address these objectives, the key investigator designed interview questions to be put to VIHA health care professionals involved with the taking, processing, and administration of blood products.

#### *Designing the interview questions*

The interview questions flowed from preliminary conversations with the VIHA Medical Director, Hematopathology, with the then VIHA Director, Emergency Management, plus those with some staff members at the MoH EMU, and at the local CBS blood collection center. The literature regarding the response--by multiple agencies (Bruneau et al., 2003; Johnston et al., 2012; Kowalski-Trakofler et al., 2010; Noji, 2005; Ricci et al., 2004), by hospitals and the general health care system (Burkle, Jr. and Greenough, 2008; Naghii, 2005; Shultz et al., 2011), and where possible, by blood bank or transfusion services (AABB, 2008a, 2008b; Kuruppu, 2010; Mujeeb and Jaffery, 2007)--to multiple casualty, sudden onset disasters and/or earthquake in particular, also helped define priorities in terms of lines of inquiry. Table 14 lists several of the considerations used in both the *design* of the interview questions and in partial evaluation of the responses to them.

**Table 14. Criteria used to design interview questions and to analyze the resulting data**

Category of Questions	Possible ways this could impact health system response
Improvement and specialization, disaster response	<p>lessen the time used to transport blood products or casualties?  enable earlier or more reliable telecommunications amongst key parties?  help justify development of a response plan that is more <i>earthquake-specific</i>?  enable a health care entity in southwestern BC to mount a more complete and reliable disaster response to a sudden onset multiple casualty incident?  help such an entity pre-define its strengths and weaknesses in preparing for a post-quake situation?  help such an entity define its strengths and weaknesses <i>in</i> a post-quake situation?</p> <p>improve the amount and quality of staff training for disaster response?  provide more options to expand the flexibility of the response?</p>
Blood product allocation during an earthquake-driven blood contingency in southwestern BC	<p>help ensure that blood products are allocated safely, in time, efficiently and effectively?</p>
Operations continuity	<p>help Facilities Maintenance and Operations better prepare for post-quake consequences?  improve the emergency preparedness of suppliers and contractors?  complicate, or simplify, TM and closely-related operational procedure or process?  affect significantly other key operational components or departments in a transfusing hospital(s)?</p>
Internal political considerations	<p>imply the purchase of additional and very costly equipment/large budget?  maximize the within-authority political support for proposing, creating, and implementing an <i>earthquake-specific</i> disaster response plan?</p>
Evaluating dynamics of group procedures, processes, and function	<p>complicate, or simplify--group procedure, process or function?  negatively affect the dynamic of a group trying to manage post-disaster consequences?</p>
Issue analysis	<p>Is this issue:  long-term and complex, requiring considerable research and specialized relevant experience to assess properly?</p> <p>unnecessarily chronic?</p>
Appropriateness of proposed solution	<p>Is this suggestion new, necessary, or sensible, or practical, or important?</p>

This research involved examining both (a) the *elasticity* of the blood supply (the ability of the blood supplier, Canadian Blood Services, to possibly expand production and/or compensate for sudden contraction of blood supply), and (b) the *fluidity* of the supply (the ability of the CBS blood supply center to move products to areas experiencing either disproportionate reduction in supply or extraordinarily high demand) (Jones, 2003). Especially in a damaging shallow earthquake, there could be a significant reduction in

supply, plus an immediate, significant increase in demand—for blood products at Greater Victoria transfusing hospitals. In addition, decisions regarding the alternatives of (a) rapidly relocating a facility for the storage and/or transfusion of blood products within Greater Victoria, (b) transporting people injured in an earthquake directly to transfusing hospitals in and/or (c) outside of Greater Victoria, may need to be made within the first few hours following a destructive earthquake. By implementing the consultation portion of the methodology, the researcher obtained information to help shape recommendations that health professionals involved could implement, regarding post-quake circumstances.

#### **4.3.1 Sampling and recruitment**

##### *Recruiting key informants*

Initial contact was with a representative of the Emergency Management Unit, Ministry of Health, who identified contacts within the Provincial Health Service Authority (PHSA) and VIHA. The PHSA contact suggested further contacts within VIHA, and with the Canadian Blood Services, BC & Yukon. Within VIHA, the initial contact was the then Director, Emergency Management, who introduced the researcher to the Medical Director, Hematopathology (MDH). The MDH identified well-qualified members of his staff who would be logical, capable, and articulate key informants.

The researcher initially requested, per agency, that a person(s) who did not supervise potential key informants (PKIs) assist with recruitment, and approach suitable PKIs in that agency about participating in the research project. In one instance, ultimately, it was a supervisor who acted as the go-between. These intermediaries then provided each interested PKI with a copy of the Letter of Information and Consent Form (Appendix L). In one case, the researcher formally interviewed a supervisor that he had previously interviewed more informally.

After considering this information, each PKI decided whether s/he would give free and informed consent to participate in the research as a respondent. Once consent was granted, the researcher forwarded an information package (Appendix J), which contained (a) estimates of the injuries and hospitalizations, and (b) other health care-related impacts, that three different types of earthquakes might generate. He also provided each respondent a copy of the interview guide questions (Appendix M). Twelve

of 17 potential respondents who were initially contacted to participate in the study participated, for a success rate of 70%. Most of those who did not participate cited competing priorities as their reasons for not participating.

### *The Consultation Process*

The researcher consulted professionals focused on health emergency management, blood transfusion operations, hospital blood bank management, blood-related laboratory functions, and on the supply of blood products and other related services. He allowed each respondent to choose the time and location of his or her 1-to-2 hour interview. With the respondents' consent, he recorded the interview with a tapeless digital audio recorder, and via typing field notes into a laptop computer file. Taking field notes also spawned clarification questions and answers. For a few respondents, time constraints or mid-interview telephone calls may have influenced responses to some of the questions.

The principal investigator interviewed the twelve key informants between March 8, 2011 and April 7, 2011 (Ministry of Health contacts at the MoH building on Pandora Avenue, VIHA representatives in Royal Jubilee Hospital and at the Gorge Road facility, and CBS contacts at the CBS Vancouver Center). The list of those interviewed is as follows:

- Manager of Operations, Emergency Management Unit, Ministry of Health
- VIHA Corporate Director, Emergency Management and Business Continuity (EMBC)
- VIHA Medical Director, Hematopathology, Department of Laboratory Medicine, Pathology and Medical Genetics
- VIHA Regional Technical Co-ordinator, Transfusion Medicine Laboratories
- VIHA Technical Specialist for Transfusion Medicine Laboratories
- VIHA Manager, Laboratories Licensure & Standards
- VIHA Senior Lab Technician, RJH
- a second VIHA Lab Technician, RJH
- VIHA Assistant Chief Engineer, RJH
- Manager, Field Logistics, CBS BC & Yukon
- Site Manager, Product & Hospital Service, CBS BC & Yukon
- Hospital Liaison Specialist, CBS BC & Yukon

#### **4.4 Secondary data sources**

A collection of secondary data sources, used in combination with the interview feedback, extended the range and completeness of the information base required for the study, and helped triangulate the results. Information from the American Association of Blood Banks (AABB) (2008a, 2008b) disaster operations handbooks, for example, supported interview data given regarding blood bank services most likely to be required post-event, and regarding several other data topics. Other documents, from the Canadian Standards Association (2008), the Pan American Health Organization (PAHO) (1981, 2010), the World Health Organization (WHO), Europe (2005), and PAHO/WHO (2003), also provided considerable background information on health care risk reduction planning, emergency management, and disaster response. Peer-reviewed journal articles, books, reports, grey literature, online slide presentations, and the websites of the British Columbia Provincial Blood Coordinating Office (PBCO) (2009), the National Advisory Committee on Blood & Blood Products (2009), and the Canadian Blood Services (2012) enhanced the perspective regarding these planning, management, and response topics by providing general principles, real world examples, and in-depth levels of detail.

#### **4.5 Data analysis and interpretation**

Shortly after most interviews, the researcher transcribed the recordings and notes verbatim per interview, to ensure accuracy. For the data analysis, the researcher developed a qualitative database in Microsoft Word. The data were then organized into the following themes regarding the relationships among, and capability/readiness of, the VIHA Transfusion Medicine function, the CBS, and multiple other agencies, with respect to the following issues:

(1) Mitigation, (2) Assets, Operations, and Options, (3) Preparedness, (4) Response, (5) Recovery and (6) Planning.

Within this framework, the author identified *key* themes and patterns based upon their response recurrence rates, significance, and scope. The VIHA Medical Director, Hematopathology, provided validation feedback via commenting on the accuracy and significance of the draft recommendations. As a result, some recommendations were

added, and others corrected. In this analysis process, the author utilized the criteria contained in Table 15 to determine and rank attributes such as significance and scope.

This analysis process (a) stimulated further questions and elaborative research, (b) identified challenges and limitations regarding organizational preparedness for an earthquake and a blood supply contingency, and (c) offered insight into the practices of experts in transfusion medicine, the BC blood system, and health care emergency response.

**Table 15. Criteria Defining Significance with Respect to a Health Organization's Response to the Consequences of an Earthquake**

<b>Criterion</b>	<b>Rationale</b>
<b>(1)</b> The immediacy or criticality of care required by a newly-arrived patient	preserve human life and health
<b>(2)</b> The singular criticality, and number of interdependent linkages, of health (a) care system component(s) impacted by an event (Arnold, 2005).	a matrix of health care capacities is likely to be required to respond to a disaster
<b>(3)</b> Is a damaged component of the health care system a rate-determining step in the processing or administering of blood?	capacity in terms of rate may be critical following an MCI disaster
<b>(4)</b> Could the event limit or prevent the appropriate delegation and execution of tasks (division and mobilization of labour) within an entity's response effort?	division and mobilization of skilled labour enacts the matrix of health care capacities
<b>(5)</b> Any factor that prevents the incident commander and/or response managers of an entity from receiving or quickly and adequately processing incoming information that is necessary for building and maintaining accurate situational awareness post-event	lack of attention to details pre-event, lack of reliability, redundancy of equipment, or unanticipated circumstances may thwart efforts
<b>(6)</b> Any factor that prevents the pre- and post-event assessment of the geographic scale, intensity, or immediacy of potential (tsunami, severe aftershocks) or actual harm to human health inherent in the threat of an earthquake hazard, or  extreme error in recognizing or assessing the potentials of these attributes latent in the threat of such a hazard	gauging anticipated or actual consequences of a disaster affects the speed and effectiveness of the response plan and effort
<b>(7)</b> Any resources that geographically extend, or enlarge, diversify, or accelerate--the capacity of an entity's disaster response system	time and the ability to span space are crucial, post event
<b>(8)</b> Post-event factors an hour or more in duration that disrupt the continuity of health care functions needed to adequately treat in-patients and disaster victims	a matrix of health care capacities is likely to be required to respond to a disaster
<b>(9)</b> The basic, essential functions likely to be required of the TM/TML function during the first week following a damaging earthquake	the TM/TML function is an important component of the matrix of health care capacities

Although the sample size was relatively small, the reliability and validity of the analysis are supported by the recruitment of appropriate informants, the use of an interview schedule derived from related previous studies (AABB, 2008a, 2008b; Erickson et al., 2008; Flanagan, 2011; Glasgow et al., 2012; Kowalski-Trakofler et al., 2010, and others), and the use of source triangulation techniques (Baxter and Eyles, 1997) combining the interview data and information garnered from secondary sources.

The theme framework facilitated comparing the interview data to primary and secondary literature in order to secure transferability of findings. As an example, strong levels of 'fittingness' (Lincoln and Guba, 1985) exist between some of the (anticipated) blood bank emergency response procedures mentioned by key informants, protocols detailed in the VIHA (2010b) blood contingency plan, and actions taken by the New Zealand Blood Service in response to the February, 2011 Christchurch earthquake (Flanagan, 2011). The interviews elicited clear and consistent responses from appropriate health care professionals. The use of audio recordings of the interviews, and comparisons of insights gleaned from respondents in related roles increased the validity and reliability of the key themes, in accordance with qualitative research criteria (Baxter and Eyles, 1997).

#### **4.5 Chapter Summary**

Chapter Four has described the methodologies used for a) estimating injuries and hospitalizations likely to result from the three different types of earthquakes, and for (b) designing and executing the consultation process employed to obtain *feedback* from health care professionals regarding the implications of the earthquake-driven damage, injuries, and hospitalizations. It also outlined the thinking and procedure for interpreting the primary data that were solicited. To render the final document more complete and readily understood, the author incorporated ideas and reference material--such as segments of the BC Blood Contingency Plan--from contextual sources into Chapter 5, which highlights the results and the findings derived from the interviews.

## Chapter 5: Analysis of Results

As presented in Chapters 3 and 4, the seismic hazard and associated risks in southwestern BC are real and their potential consequences are serious, so the BC health care system must maximize its preparedness and response capacity, and minimize its vulnerabilities. Therefore, attention in this chapter turns to assessing the preparedness of the relevant health care facilities and response agencies to deal with the TM-related anticipated consequences of shallow and subduction earthquakes in southwestern BC, based upon the *combination* of data derived from key informant interviews and the analysis of secondary data drawn from primary reports. The analysis of the resultant data, and the findings and recommendations based upon that analysis focus upon assessing and reducing vulnerabilities and risk, and upon identifying capabilities and shortfalls—associated with the major players that would be involved in, *inter alia*, a blood product contingency that might follow either of these events. Since the impacts of a *deep* earthquake likely will be less drastic than those of the other types, shallow and subduction quakes warranted more attention.

This fifth chapter integrates (a) the results of the consultation process with (b) relevant background material. Related sources include the BC Blood Contingency Plan, various levels of Emergency Blood Management Committees (EBMCs), the BCAS, resources that Emergency Management BC could bring into play, some business entities, plus research papers and presentations regarding disaster response and business continuity. In this multiplayer emergency management network context, “a unified approach to communication among facilities and transportation of blood and blood components during a contingency” is *essential* (BCTMAG, CBS, and PBCO, 2009, p. 8). Several segments of the discussion and many of the considerations, findings, and recommendations address practicalities in gathering and communicating information, in decision-making, and in transporting people and/or blood products, in post-earthquake situations.

As mentioned in Chapter 4, the data were grouped into the following categories for analysis regarding the reduction of risk and/or vulnerability and the preparation for business continuity, with respect to the VIHA TM function and supporting operations: (1)

Assets, Operations, and Options with respect to (2) Mitigation, (3) Preparedness, (4) Response, (5) Recovery and (6) Planning. In this chapter, those groupings, or combinations of them, guide the layout and interpretation of the data.

The analysis begins by considering some of the ways in which VIHA and its TM function may be able to reduce their vulnerability to various consequences of a damaging earthquake. A short segment focuses upon business continuity measures that could be applicable chiefly in a shallow earthquake scenario, and is followed by discussion regarding resources, decisions and actions potentially applicable in post-quake circumstances in general. The Canadian Blood Services is treated similarly, under section 5.2—Canadian Blood Services: Assets, Operations, and Options. Section 5.3 examines some of the implications of a blood contingency in BC following a Cascadia subduction earthquake, while section 5.4 anticipates the multiple-agency response to a blood contingency in British Columbia. Section 5.5 lists the essential, cross-cutting risks, capabilities, and vulnerabilities implicit in the preceding sections of the Chapter. Section 5.6 is a summary of the discussion, findings and recommendations put forward in this chapter. Findings and recommendations that are related to (a) the information gathered from informants, and to (b) relevant facts or principles gleaned from research papers or presentations, are inserted at logical points after elaborating such information. Key findings and recommendations are carried forward into Chapter 6.

## **5.1 VIHA Assets, Operations, and Options**

### *Front End Mitigation*

Prior to considering the detailed findings from the interviews and secondary source data pertaining to earthquake response, it is important to note initially the need to sustain current efforts aimed at pre-event mitigation. To lessen *human* vulnerability to earthquakes via mitigation, the MoH and VIHA could continue advocating municipal measures regarding reducing the seismic vulnerability of structures and systems, while conducting public education to enhance individuals' earthquake safety reactions and preparedness, to help *reduce* the number of casualties generated. Provincial and municipal entities should continue supporting laymen who take and maintain levels of first aid training to assist in the delivery of emergency health care. VIHA could conduct

passive education regarding seismic vulnerabilities and earthquake preparedness via having brochures in reading materials and posters on the walls of waiting areas and other rooms in its facilities. Educational brochures regarding self-preservation and family disaster response plans could incorporate brief self-test forms that patients and visitors can complete, detach, and keep in their wallets, for example. Such efforts to diminish the number and severity of earthquake casualties could help lighten the post-quake load on the health care institutions that may themselves be victims of the same quake(s).

*VIHA TM Function: Vulnerability Reduction via Comprehensive Business Continuity Planning*

At least one staff member of the MoH EMU, plus Lazar, Cagliuso, and Gebbie, (2009), Lewis and Wang (2004), and Ushizawa et al. (2012) have indicated that for a health care entity, integrated business continuity is a key priority for a post-earthquake situation, since nearby health care resources would be vital for treating injuries sustained in a damaging earthquake. VIHA Emergency Operations Centers, the CBS, BC Ambulance Service, the Ministry of Health Emergency Management Unit, VIHA Facilities Maintenance and Operations (FMO) crews, suppliers and services, plus other health sector, provincial government, and local partners will be needed to support and help coordinate both the disaster response and the continuity of VIHA Transfusion Services. Managing that co-ordination will be one of several crucial steps in the larger task of maintaining health care business continuity. That task will likely involve addressing the restoration of key components and functions within at least one major hospital in Greater Victoria.

### **5.1.1 Assessing Earthquake-driven Damage to Health Care Infrastructure**

Health care facilities are complex—functionally, technologically, and administratively (Lewis and Wang, 2004; WHO (Europe), 2005). Factors that make health facilities vulnerable to seismic damage include: very high density of operational and functional components; complexity, continuous occupancy, infrastructure connections, heavy objects, hazardous materials, and the need for sterile conditions, minimal noise, critical supplies, and security services (Lewis and Wang, 2004; WHO (Europe), 2005). Lewis

and Wang (2004, n.p.) point out that modern high-tech hospitals have a brittle, vulnerable existence, due to

the high densities of sophisticated equipment, heavily dependent on computer controls and telecommunications, ... susceptible to complete failure, often triggering evacuation of the building. A large hospital also has hundreds of kilometers of pipes containing water, fuel, medical gases, medical waste, and other substances. The rupture of these pipes within the structure can cause fire, flooding, contamination and the loss of life-sustaining systems.

Although VIHA Facilities Maintenance and Operations (FMO) crews, their contractors and suppliers, have some of the expertise required to adequately assess seismic damage to assets such as Building Automation Systems, VIHA would need to secure more comprehensive expertise externally.

**Finding 1:** Through the interview process, reviewing the EMBC Earthquake Plan (2008), the British Columbia emergency response management system interim overview (British Columbia Ministry of Public Safety and Solicitor General/Inter-Agency Emergency Preparedness Council, 2000), and conducting Internet research of the VIHA website, the author determined that these sources at least, do *not explicitly state* that EMBC or VIHA employs its own structural engineers who could properly assess damage to hospitals and other health care structures following a destructive earthquake.

**Recommendation 1:**

1) The Province, on behalf of the MoH and other provincial departments and agencies, should establish or contract with a committed, well-prepared *team* of "assessment" engineers, with a set minimum number of staff on call continuously. Their initial role post-quake would be to assess the structural and operational viability of Vancouver Island hospitals and other critical health system infrastructure *simultaneously*, and as soon as possible, following a damaging earthquake *and* any significant aftershocks. A few of them should reside in northern Vancouver Island, or a central regional community that has multiple commercial helicopter services. This assessment capacity is crucial to organizing further aspects of the VIHA and TM disaster response and business

continuity, and is therefore a major recommendation.

Regarding a computer-controlled health care environment, via its provincial health sector information management/information technology strategy (MoH, 2011), the Ministry of Health has envisioned and partially implemented computerized information systems that offer advances in areas such as clinical decision support, medical imaging and testing, and information and education services. However, if VIHA staff, for example, become too dependent on this electronic medium, and an earthquake disrupts electricity in hospitals for a significant time, aspects of the Vancouver Island health care system may be more vulnerable.

### **5.1.2 Business Continuity of Blood System Computerized Operational Assets**

#### *The Cerner-based Clinical Information System*

The 'Cerner' Clinical Information System is an integrated computerized system that assists the operation and management of Transfusion Medicine laboratories (Cerner, 2011; BC Ministry of Health, Health Authorities Division, 2008). As a *VIHA-wide* clinical information system, it creates a unique client identifier, plus delivers standardized information regarding laboratories, and diagnostic radiology images. The TM function stores red blood cell (RBC) inventory data on the Cerner system. The program also allows swift, accurate ordering and documentation, numbering, processing of numerous blood specimens, and phlebotomy management, helping to save time and reduce operational errors (Cerner, 2011; BC MoH, Health Authorities Division, 2008a).

One member of the VIHA TM contingent indicated that there would be no access to real time RBC inventory data if the Cerner system was inoperable, but that technicians could implement the "down time procedure". Most VIHA labs still complete *manual* Comprehensive (Blood) Inventory Forms twice per week, which prepares technicians to take inventory efficiently in down time situations. Another team member noted that lab technicians could enter a manual count of RBCs into a laptop computer and possibly share this information via e-mail. Stand-alone computers on back-up power in the RJH and VGH TM labs, she elaborated, contain data only on regular client blood group, or whether clients require antibodies and/or regular transfusions.

According to contacts within the MoH and VIHA, Health Shared Services BC (see Glossary) and the VIHA Information Management/Information Technology (IM/IT) team

have proactively consulted on how to restore computerized health care technology such as Cerner within a province-wide systems approach. VIHA IM/IT disaster recovery *training* for rapidly troubleshooting and restoring the cybersystems that support Cerner and other programs, and VIHA FMO staff *vigilance* in preventing, post-quake, excessive amounts of dust being drawn into—and overheating—any in-hospital servers and/or computers, would reduce general cybersystem vulnerability.

*Computer-controlled equipment in the TM Laboratory*

The researcher toured the TM Laboratory at Royal Jubilee Hospital, and observed a computer-automated blood sample processing system in operation. This system appears vulnerable to damage and disruption, especially from severe shaking. Similar equipment operates in TM laboratories of other VIHA major transfusing hospitals.

**Finding 2:** VIHA TM technicians agreed that if the Cerner System is operable, it can increase safety levels in the handling and processing of blood products (Cerner, 2011). If it is inoperable, frequent down-time training applies control, certainty, and flexibility for reducing vulnerability regarding verifying patient blood information and tracking blood product inventory if the Cerner system cannot function. Restoring the computer-automated blood sample processing system could save certain TML staff considerable time, and may help them regain a near-normal capacity for blood transfusions, post-quake.

**Recommendations 2 to 7:** The rationale for recommendations 2 to 4 is that given a post-quake surge situation, health care staff, more than ever, would need computerized resources that save time and help prevent errors.

2) The Province should rank the restoration of the VIHA TM/Clinical Information cybersystem as a high priority in its overall post-quake restoration process

3) As a long-term objective, VIHA should establish and maintain an Information Management/Information Technology Services team that could *simultaneously assess* computer systems *at all of its usable hospitals* as soon as possible after such a quake.

4) VIHA should develop a decision support system (Power, 2007) or decision tree in order to assist the restoration team in rationalizing and accelerating the restoration process in the instance of varied damage to cybersystems at different hospitals

(Ranajee, 2012). For example, restore the Transfusion Medicine Cerner Laboratory Information cybersystem first at whichever Greater Victoria transfusing hospital is the least damaged. This support system document should be storable on a laptop, and available in print. Greater Victoria has the greatest concentration of population, and likely the widest array of diagnostic and treatment equipment and specialists on Vancouver Island, so it is logical to first restore whatever range of *these* assets can be restored.

The ultimate *simultaneous* assessment, decision support system, and concentration on the facilities that can be made safe and usable the soonest during or after hospital repair constitute a *key recommendation*.

5) If the Cerner system is still operating following a destructive quake, VIHA TM staff should immediately print out the current red blood cell inventory and any other essential records, as aftershocks may cause a power outage. If the Cerner system is down, the VIHA EBMC should identify one person per shift to update the entire VIHA blood inventory system as (a) new orders arrive, (b) aftershock damage diminishes supply, and (c) various requests for blood products (transfusions) are approved.

6) As per TM team member suggestion, following (5) above, staff should enter into a TM lab laptop (a) a manual count of blood products on hand, for transmission to the CBS, and (b) the patient index used for down time.

7) Ensure that at least one of the *backup* power systems at each major transfusing hospital can run air conditioning, and have numerous air conditioning system filters ready to clean particulates from the air, for the welfare of staff and patients, and to cool and keep the computer system servers clean (PAHO, 2010).

The aforementioned discussion and recommendations have addressed the potential post-quake loss of key computerized operational assets that support the VIHA TM function. Two upcoming sections examine some of the other impacts and coping mechanisms associated with (a) shallow earthquakes and (b) earthquakes in general.

### **5.1.3 Coping with Likely Circumstances Following a *Shallow* Earthquake**

As mentioned in section 3.5, a shallow event, especially, could generate TM Priority 1 and 2 casualties, in numbers reflecting the order-of-magnitude estimate provided herein.

Some injured survivors, unless they were haemophiliacs, or extremely anaemic, would need transfusions less urgently, and could be treated in Duncan and Nanaimo, to lessen the surge demand in Greater Victoria created by those injured gravely and bleeding rapidly. Under contract with various BC Health Authorities, several private ground ambulance operators transfer stable patients who do not require treatment by a paramedic during transport (BCAS, 2011a). Given enough qualified health care workers, within the first two days post-quake these vehicles could possibly transport patients and blood products to as far away as Nanaimo.

Collectively, numerous survivors who are haemorrhaging would likely spike the Greater Victoria demand for blood products. Local health care providers could likely handle a quake-driven blood shortage (contingency) merely within and very near Greater Victoria by obtaining blood products from other Vancouver Island transfusing hospitals, the CBS, and nearby BC Regional Health Authorities (RHAs). Transportation facilities for travel between the mainland and most points on Vancouver Island would still be intact, although the use of some telecommunications and transportation infrastructure in and near Greater Victoria may be limited for at least a few days. If ground transportation infrastructure in Greater Victoria is damaged such that access routes to the major hospitals are cut off, helicopters may be the logical alternative to move casualties to hospitals where they can receive sustained intensive care. The BCAS may not have enough air ambulances available at the same time to retrieve casualties that should be removed from downtown Victoria to hospital. Lack of sufficient helicopter transport for patients was identified as an issue in the evacuation and transport of patients following the 1995 Kobe earthquake (Kusuda, Fujimura, and Takeuchi, 1995; Kuwagata et al., 1997; Tanaka et al., 1998). In addition, in her review of hospital disaster preparedness in Greater Victoria, Jaswal (unpublished Master's thesis, 2012, p. 106) cites a local health care emergency manager who states, with respect to a subduction or shallow earthquake event affecting Greater Victoria, that "there are 11 [BCAS] ambulances for 350,000 people. The chances of getting an ambulance after that earthquake strikes will be nil."

To address these potential issues, VIHA should be prepared to have EMBC contact the Joint Rescue Co-ordination Center on CFB Esquimalt to call in Canadian Forces' 442

Transport and Rescue Squadron Cormorant helicopters and CH-124 Sea King helicopters to carry the injured (Sgt. Andy Gervais, Canadian Navy Pacific Fleet, 443 Maritime Helicopter Squadron, personal communication, May 30, 2012). If multiple helicopters converge on RJH at the same time, additional landing space would be ideal. Two vacant lots near the existing RJH helipad, (see Figure 20) could serve this purpose.

Recommendation 8:

8) If liabilities and/or Transport Canada regulations do not preclude such emergency use of these sites, VIHA should try to arrange contingency helipad use of the St. Patrick's School yard, and the similar use of the other lot with its owner(s). VTOL aircraft could be a rate-determining step in assisting those earthquake victims who require sustained intensive care.

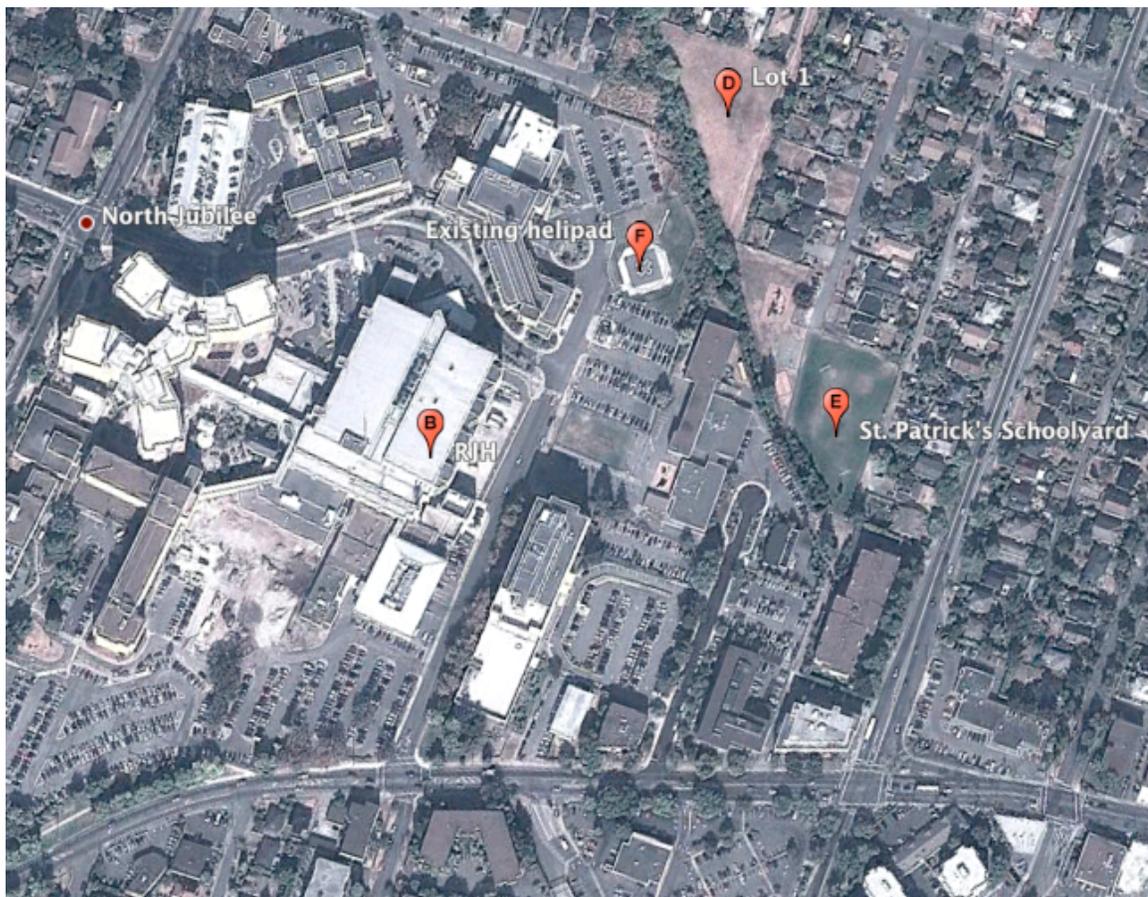


Figure 19. Google Earth image showing the locations of RJH (B), its existing helipad (F), and potential additional landing areas. Locations D and E offer potential landing area for additional helicopters. 1cm = 40m. Google Earth, 2013.

As a partial alternative to simultaneous helicopter flights to RJH or VGH, and to counteract any loss of capacity due to damage to local hospitals, BC's mobile medical unit (MMU) could set up in Greater Victoria, either where many casualties had occurred, or near a damaged or undamaged hospital that has key departments and computers functioning and additional supplies available. The MMU could be ferried, with additional blood supplies, via Swartz Bay, or if Swartz Bay were closed, travel by highway from Nanaimo at least to Duncan, if not to Greater Victoria. The MMU offers capability in: surgery, critical care, diagnostic imaging, MRI, CT, C-Arm (medical imaging and radiology equipment), ultrasound, portable X-ray, laboratory, blood and blood products, and pharmacy (Appleton, 2011). However, a VIHA manager advised that in a post-subduction quake scenario, the MMU would likely remain in the Lower Mainland.

#### **5.1.4 Flexible Preparedness: Coping with Likely Local/Regional Impacts of Any Damaging Quake**

A severe shallow earthquake or a subduction event could heavily damage one or more Greater Victoria transfusing hospitals and its/their capacity to store, inventory, process, and test blood, and leave one or more of the TM Labs without *any* electrical power. VIHA and the TM lab/bloodbank function would likely have the options of relocating the function or sheltering in place. Relocation may mean moving to another (structurally sound) room in the same hospital, to another hospital in Greater Victoria, or selecting one or more of the other options identified by VIHA staff, and discussed in this section. A degree of flexibility in blood storage techniques, mentioned in the next paragraph, could facilitate either of these options.

##### *Considerations Regarding Relocating a TM Laboratory*

Three TM staff members indicated that in considering the relocation of a TM laboratory, their management would first verify the condition of refrigerators, inventory, and TM labs at VIHA hospitals and facilities that store or/and administer blood products, and then forward that information to the CBS and the VIHA EBMC. Other TM team members verified that if refrigeration capacity at RJH or/and VGH is damaged, and if temperatures in coolers rise, 100% of RBCs, plasma, and cryoprecipitate would be at risk. At least some of these pre-stored blood products could be re-distributed, and new orders

delivered post-quake, to wherever the appropriate cooling units *were* working. VIHA informants indicated that various facilities in Greater Victoria have backup fridges and freezers in their TM lab areas, and that Operating Room refrigerators could be used for TM purposes. TM Labs at both RJH and VGH have repackable cooler boxes validated for 24 hours, they noted. If boxed blood was young enough, staff could maintain it using some ice packs, usually available for redistributive shipments.

The VIHA TM function is wise to embrace flexibility in its response approach. Three respondents added that VIHA TM staff can trade places for basic blood bank duty at facilities outside of Greater Victoria. Another suggested using some damaged locations in Greater Victoria as triage MASH model bases for stabilizing casualties, and then sending these patients to Vancouver for further treatment (anticipated for a shallow scenario), or to facilities further east (subduction case). Teron Moore, an EMBC seismologist, (personal communication, May 25, 2012), verified these evacuation scenarios.

According to four TM staff, the prime alternate sites for the RJH TM operations in South Vancouver Island are firstly Victoria General Hospital and Saanich Peninsula Hospital (see Figure 18), and then Cowichan District Hospital or Nanaimo Regional Hospital. VIHA operates 5 other labs (potential operations sites) in Greater Victoria (VIHA, 2011a). The Canadian Armed Forces Health Services Center in Esquimalt (Royal Canadian Navy (RCN), 2012), some Life Labs, and blood collection agency facilities also offer potential for this purpose. The simultaneous preparations for the surge *and a relocation*, however, could govern the rate of assistance to casualties requiring blood at a few facilities.

A VIHA manager elaborated some additional considerations regarding relocation of a TM laboratory. Planners at the VIHA Emergency Operations Center would evaluate the relocation possibilities, based, in part, upon the anticipated duration of operations at the new site. They would consider, among other things, the current and probable (relocated) levels of functionality, replacement equipment needed, logistics involving ambulances, buses, and medical records; how to house a pharmacy, and how to transport patients with various needs. TML team respondents noted that at the EOC, the Risk Management or Safety Officer would help plan for the safety of staff and patients, and ensure re-validation of the TM Lab. Others would coordinate internal/external communications and financing. An Evacuation Co-ordinator would help

ensure that all aspects progressed as logically, safely, and quickly as possible. The VIHA Facilities, Maintenance and Operations (FMO) department could construct in its shop necessary items such as laboratory benches, and could use contractors to help their own transport crew with the relocation. The FMO mechanical stores has spare centrifuges that could replace damaged ones in a TM Lab.

The resupply of blood products from CBS Vancouver following a CSZ subduction quake may depend in part upon factors in the Lower Mainland such as quake damage to CBS facilities, weather conditions, the supply of and demand for blood products there, and the state of roads, ground vehicles, runways, aircraft and electrically-powered fuel pumps. Any *simultaneity of high demand* for blood products amongst Greater Victoria hospitals may affect possibilities for local transfer of blood products, or influence blood transfusion rates at these hospitals. Having extra blood products stored, or extra storage capacity, in all three major hospitals in Greater Victoria is therefore useful.

**Recommendations 9 to 11:**

9) Before any TM disaster response "relocation" exercises are held, VIHA Emergency Management planners should have on hand, and appropriate members of VIHA FMO, Transfusion Medicine, Emergency, Surgery, Medical Imaging and Risk Management should review, technical drawings and applicable details of various rooms that potentially could serve as temporary/alternate TM labs in VIHA transfusing hospitals.

10) The VIHA TM function should practice "trial" relocation scenarios in successive exercises, beginning with a paper exercise of relocating a TM laboratory within the same hospital, followed by actual relocation exercises, (a) to different hospital site, and then (b) using mainly the MMU lab facilities.

11) VIHA, in its business continuity plan, should develop user-modifiable table files listing considerations and criteria regarding relocation or rerouting decisions, and have them available in print and on a laptop computer.

Regarding using a BC Ferries craft as a temporary blood bank/transfusion facility, a TM team member stated that a planner would need to consider, *inter alia*, whether services such as HAZMAT response could be made available on board. Respondents indicated that defining a location for temporary TML operations hinges on: obtaining

transport/transfer support, plus accurate and timely information, among other things. This dynamic, urgent situation could evolve as aftershocks occurred, and as new information/cases came in, and therefore requires a flexible response. A TM function at any location may require extra key materials, ideally supplied via the TM supply chain.

#### *FMO Potential Contribution*

The VIHA Facilities Maintenance and Operations (FMO) department can make shims for levelling needed instruments and equipment in a TM Lab, should earthquake forces heave the floor beneath such equipment, and can rewire damaged electrical circuits. FMO has floor jacks, small cranes, considerable other equipment, and a welding shop, that could support self-reliance at a healthcare facility in an earthquake response situation.

**Finding 3:** The VIHA Facilities Maintenance and Operations (FMO) department *at RJH* has considerable resources and expertise that could be essential in post-quake circumstances. Beside the assets and capabilities mentioned above, the VIHA FMO repairs and maintains the telecommunication repeaters/transmitters atop RJH buildings, and the sensors and alarms that indicate the levels of oxygen and nitrogen. If in an earthquake the medical gas supply system is damaged, FMO could likely temporarily re-route supply and distribution lines, then purge them and test that they meet applicable standards before they are put back into service. The FMO also has various hoists to lift heavy materials and equipment, plus can employ portable devices to move injured patients and TML staff down to lower levels of a hospital if elevators are not functioning, and/or stairways are unsafe.

**Finding 4:** From the discussion so far in section 5.1.4, it is evident that VIHA Emergency Management and TM management and staff have done considerable analysis and research regarding relocating a TM function from a damaged hospital. They reflect preparedness in their flexible thinking and their awareness of various options.

**Finding 5:** However, responses to interview questions regarding VIHA business continuity indicated that no particular buildings have been identified as definite alternate sites for TM Labs, or for the storage of key reagents or other TM supplies that could be essential post-quake. This is in part because the nature of damage to potential alternate

locations for blood banks/TM laboratories or key supply depots in Greater Victoria will not be known until *after* a damaging earthquake. However, facilities in some general areas may be pre-determined as less vulnerable to an initial quake or an aftershock. CBS Vancouver Center and the VIHA TM Laboratory in the Nanaimo Regional General Hospital (NRGH), for example, have identified an “off site” spaces for blood storage and redistribution centers as part of their contingency plans.

#### **5.1.5 Mitigation: Vulnerability Reduction Within the VIHA TM Supply Chain**

One interview question was: has a basic hazard, risk, and vulnerability assessment regarding seismicity (including likely effects of amplification of ground motion, liquefaction, tsunami, and of triggered events such as fires, explosions, rapid slope processes, dam-burst flooding, or releases of materials that are dangerously flammable, toxic, or invasive (such as volcanic dust)) been conducted regarding the vendors of supplies and materials, and the likely or possible transportation routes and modes, *critical to the VIHA TM function?*

The Province did conduct *all-hazards* hazard, risk, and vulnerability analyses (HRVA) for its *regional health authorities* in 2005 (BC Ministry of Health Services, 2005). However, an assessment of vendors of supplies and materials critical to the VIHA TM function has apparently not been conducted.

#### **Recommendations 12 to 14:**

12) That VIHA conduct a hazard, risk, and vulnerability analysis as identified immediately above. Recommendation 9 is ranked as significant, since, for example, certain reagents, sterile connection devices, or a thawing bath may be important to TM post-quake operations, and an ensuing blood transfusion may save an earthquake victim's life (College of Physicians and Surgeons of Alberta, 2012).

13) That if a primary vendor of several products required by the VIHA TM function is located in a zone of elevated risk regarding several dangers identified in the HRVA, Health Shared Services BC (HSSBC) should initially increase TM function orders from that supplier, and, if possible, secure a secondary supplier located in an area that is, for example, seismically less risky and more likely to be accessible post-quake (AABB, 2008a). The increased volume of such material may require additional space, but the

measures should reduce supply chain vulnerability.

14) VIHA should develop a process for notifying HSSBC and TM function suppliers--including the CBS--immediately after an earthquake or earthquake-triggered event that has damaged a TM facility, medical supplies, or threatens to disrupt delivery of supplies (e.g., damage to required transportation infrastructure) (AABB, 2008a). Secondly, the VIHA TM function should share its "earthquake" checklist of critical supplies with HSSBC and the appropriate suppliers, initially proposing resupply orders based on the hospitalizations estimated in this paper, and allowing for some loss of certain supplies and equipment due to earthquake damage. Immediately post-event, VIHA can re-estimate hospitalizations from initial damage surveys of Greater Victoria and other centers, perhaps generate an averaged estimate, and place orders for the needed supplies and materials.

#### **5.1.6 Preparedness: Planning for Post-earthquake Decision Making**

##### *Decision-making within an EBMC*

In such post-quake circumstances, the VIHA TM function and the VIHA Emergency Blood Management Committee (EBMC, later elaborated) would consider, *inter alia*, the following factors in deciding (a) how much additional blood product to order from CBS Vancouver in the first day or two, where to have it delivered, and (b) what else to communicate to the CBS:

i) What blood products will likely be needed, and how quickly will each type be used?

A respondent noted that thoracic and cardiovascular traumas come to RJH, which then may need more platelets, plasma, and volume expanders for the initial stage of some related treatments. Therefore, the EBMC or TM Director should alert CBS to consider calling in more donors, in order to harvest more group O RBCs, AB plasma, and platelets, to maximize overall inventory in a post-quake Code Red situation. A third team member stated that those haemorrhaging will often require specialized products to replenish plasma clotting factors. After the initial surge, clinicians would re-assess the demand for blood. The rates of usage of the various products at different locations in this circumstance are difficult to predict. But with early and accurate information

regarding the number and types of injuries, those managing the blood supplies could better approximate the usage rate and life expectancy of product on hand.

ii) What factors will increase the demand for blood products, and what implications will increased demand have for blood product inventory and storage, supporting lab work, and staffing?

Those haemorrhaging will drive the demand for blood products. One member of the TM team advised that in terms of blood storage, the TM function in Greater Victoria should cope via utilizing blood products and storage capacity at the three major hospitals in Greater Victoria. Blood boxes could be gathered from VIHA facilities up island, and sent to Victoria, to create temporary storage space or, after a shallow quake, to prepare for transporting blood to more functional TM facilities north of Victoria. Other than in the Mobile Medical Unit, there is apparently no mobile storage, and no *particular* temporary storage site so far designated, for blood products in Greater Victoria.

TM staff held that for a TM lab to function well, it requires effective clinical support from elements such as the central laboratory, but increased demand for supporting work could affect TM staffing, since there is limited staff overlap. Functional collapse may occur at a hospital if the surge of casualties overwhelms physical capacity, or if staff are exhausted because their replacements are casualties or are caring for other injured people at home (Matsuoka et al., 2000). Thankfully, the MoH Disaster Psychosocial Services program and BC Emergency Social Services Council have plans to address this potential problem (British Columbia Disaster Worker Care Committee, 2007; BC MoH, 2012). The peak demand for treatment following a deep or a shallow event will likely span post-quake days 1 to 3, with minor trauma medical services required for at least 10 days (Brown, 1999; Liang et al., 2001). In a subduction quake, the response period may be twice as long, since infrastructure damage and casualties would be more widespread, especially if a tsunami destroys some parts of communities on the west coast of Vancouver Island (Nollet, Ohto, Yasuda, and Hasegawa, 2013). The TM fan out telecommunication plan, identified by 5 TM team members and in the TM disaster response procedure, is crucial for contacting the right additional staff to quickly increase surge capacity. A severe quake would signal uninjured staff to prepare to come to work, but *coordination* of staffing would be essential (EMBC, 2011).

**Recommendations 15 and 16:**

15) Arranging an appropriate 'staff mix' per shift and location in the days immediately after a damaging quake could be challenging. Since maintaining the appropriate staff mix at a TM Lab(s) will be essential during the first week post-quake, the person(s) involved in co-ordinating this should have a work scheduling program on a laptop, and some extra staff assistance available.

16) As a contingency measure to help ensure that the appropriate staff mix can be provided, VIHA should consider (1) re-credentialing for five years post-retirement those retired Transfusion Medicine employees who consent to volunteer for the purpose of filling appropriate disaster response roles within that same five-year period, (2) whether any employees of private labs could be credentialed to serve in post-disaster circumstances, (3) agreements to, if and when necessary, call and bring in appropriate staff from those BC RHAs not affected drastically by the earthquake and (4) working with the other RHAs to develop common employment conditions and provisions for the pool of staff who work in BC disaster response conditions. Having enough qualified staff in place, and able to rotate and benefit from timely debriefings and stress reduction assistance, is essential to preserving the health of those injured in a damaging quake.

iii) How will incoming blood products be transported, distributed, and then cooled on site?

Two members of the CBS Vancouver Center team indicated that for emergency transportation, the CBS can use air, ground, and marine transportation modes, depending on what is necessary and available. CBS BC & Yukon has a Memorandum of Understanding with the BC Ambulance Service (BCAS); the BCAS can deliver blood via ground or air ambulance on behalf of the CBS, *if no other option is available*. The VIHA ground vehicle fleet, and/or taxis, regularly *redistribute* blood amongst local hospitals.

The transportation of casualties *and blood products* to and from facilities in and near Greater Victoria will depend on the state of local transportation infrastructure, and of the various health care facilities within or relatively near Greater Victoria. It also may depend upon the post-quake capability, workload, and priorities of local police and fire departments. Each of the 13 municipalities in the Greater Victoria area has its own policing and fire services. This means that (a) considerable coordination could be

required to clear a path amongst fallen trees, power poles and lines, and other debris in order for blood products to be transported with a police escort across Greater Victoria, and (b) a common means of telecommunication amongst these various agencies would be valuable for this and other post-quake purposes.

VIHA could use 4x4 quads to redistribute blood products between facilities within Greater Victoria, as mentioned by a couple of VIHA TM technicians. VIHA security would therefore need a comparable vehicle in order to escort blood transporters through debris-strewn streets. Smaller amounts of blood products could be moved via bicycle, but in doing so, VIHA couriers would be more vulnerable than when using larger, faster vehicles. If the Canadian Forces assisted the response, military vehicles could possibly transport blood products.

**Recommendation 17:**

17) On behalf of its TM function, VIHA should pre-arrange with/via the Capital Regional District, BC Hydro, and the RCMP to have, if necessary, priority "clearing" for vehicles that it uses to transport blood products in a post-quake situation. Clearing could involve utilizing BC Hydro linemen and vehicles to clear fallen trees, power poles and lines, and/or having appropriate municipal crews shut off water main flow to allow vehicular passage through a flooding segment of a street. VIHA should also pre-arrange the "when-necessary" complimentary use, or lease of, 4x4 quads to redistribute blood products between facilities within Greater Victoria. These vehicles should be equipped with some system to retain and recharge laptop computers and handheld devices. This can be regarded as an essential and *significant* service.

iv) Could TM staff likely maintain safety and security, and ensure that their work and working conditions meet required standards?

The VIHA Senior Lab Tech conscientiously arranges the proper mix of staff, with their various skills, for staff safety and quality control. VIHA has employed an external quality control consultant and used a purchased quality control analysis computer program to determine if there were significant differences in productivity between automated versus manual operations. Senior technicians revise the TML disaster procedure manual and develop best-practice validated laboratory procedures for normal *and manual* operating conditions, and staff practice them in mock drills and quizzes as part of their training

and competency assessments. TML staff strive to be familiar with the hospital and laboratory disaster response processes, and know their own response roles, but need time to review such documents, while meanwhile, performing their ongoing TML duties.

Blood typing, plus group and antibody screening are likely to be required of a TM/Lab function immediately following an earthquake. A VIHA TM team member advised that the TML has slide kits for manual ABO-type testing of blood samples. If blood needed is atypical, staff can spin ABO crossmatches, versus doing computer-assisted crossmatches. For a post-quake power outage situation, another VIHA TM respondent identified a battery-operated point-of-care analyzer for haemoglobin testing. The VIHA TM function and the MoH should monitor the health electronics industry for development of other handheld devices that may be very useful in a post-quake power-off situation.

Recommendation 18:

18) If VIHA has not invested heavily in mains-powered electronic systems designed to accelerate and make safer the processes of "inventory management, labelling, logging in blood units, sample management, temperature sensors, remote issue in hospital blood banks, bedside clerical check and documentation (writing to the digital medical record)" (Boyer, 2011, n.p.), it should *consider* the use of radiofrequency identification (RFID) technology. RFID technology can achieve these benefits with battery-powered handheld devices, *without requiring mains or back up electricity from, or an interface with, the hospital*, and recent tests did not detect any obvious adverse effects of RFID technology upon RBCs, for example (Kozma, Speletz, Reiter, Lanzer, and Wagner, 2011).

Four TM staff noted that any of several processes, including receiving requests, sampling, testing, or issuing product to nurses, could become a *bottleneck* in preparations for blood transfusions. Restoring operability on backup power may take hours, and having a ready source of "power-off" blood analysis supplies and equipment is important. Therefore, it may be prudent to keep in the Mobile Medical Unit and/or in one-storey buildings near transfusing hospitals sets of forms, spare equipment and supplies, such as reagents, required for manual pre-transfusion procedures necessary to test blood samples from would-be recipients.

*Telecommunication and Coordination*

Abolghasemi et al. (2008), Johnston et al. (2012), Kelm (2008), Mujeeb and Jaffery (2007), Tekeli-Yeşil (2006) and Thompson (2011), plus the presence of coordinating units and roles in EMBC (Central Coordination Group and the Provincial Emergency Coordination Center, and BCERMS as coordinating and integrating system) and the MoH EMU (comprehensive emergency management program coordinating role), speak to the importance of the coordination role within emergency management. Due to geographic location and separation of community health care facilities, telecommunication capacity is crucial to coordinating local emergency response efforts, and to the transportation of people and materials between communities, in the broader response. Hence, a few of the following discussions and recommendations pertain to these topics.

**Recommendations 19 to 22:**

19) VIHA and the CBS should obtain and have readily accessible in print and in computer database, contact information for engineers at the Ministry of Transportation and Infrastructure, Transport Canada, Vancouver Island logging companies, and at various municipalities in the VIHA jurisdictional area, and in Greater Vancouver for the CBS. These "external" agencies could link with an "outside shell" of the E-Team system used by the MoH EMU, BCAS, VIHA and its EOC, EMBC, the BC EBMC, and the CBS, to instantaneously update these parties. Immediately following a damaging earthquake, VIHA and the CBS will need information about transportation assets and critical infrastructure in many locations—what is still available, where significant gaps exist, areas that are still vulnerable to landslides, tsunamis or seiches, and harsh weather.

Recommendations 20 to 22 are details, but in a disaster response situation, some details (21 and 22) can become very important. These details add depth and nuance to the discussion, and are based on background research regarding emergency response to earthquakes, and upon assumptions that certain post-quake conditions will prevail in an earthquake-damaged VIHA hospital(s).

20) Keep a supply of masks adequate for and available to all hospital staff and patients, since the shaking and/or the collapse of any hospital buildings or their components may

release considerable dust, and possibly harmful chemicals, into the air within parts of a hospital (Government of BC, 2011; WHO (Europe), 2005).

21) Designate *who* will post, in a conspicuous location, printed information regarding any *new* audible and/or visual alarms installed as a result of replacing damaged equipment in a TM Lab, and will, verbally and in writing, inform appropriate/incoming members of staff of the changes and posting.

22) Post-quake, update descriptions of the facilities and equipment that now refrigerate red blood cells and other blood products, using the headings: type of refrigerator(s) or cooler(s), temperature monitoring device(s), temperature recording, alarm system, maintenance program, and document any resultant implied changes to the TM internal disaster response procedure. This may be part of an overall *re-validation process* for a TM lab, but the process may occur in increments dictated by initial and aftershock damage, and the availability of external engineers and any required parts. VIHA should pre-identify suitable external engineers and technicians who, post-quake, could be part of the re-validation process for a TM lab (Allard et al., 2012; Flanagan, 2011).

#### **5.1.7 Response to a Subduction Earthquake: Transporting Blood and/or Blood Transfusion Patients to Hospitals Outside Greater Victoria**

A couple of TM team members explained that the outcomes of injuries involving heavy internal bleeding (common in severe earthquakes) are unpredictable, for as health care workers search to locate the profusely bleeding internal vessel(s), a patient may lose more blood. The urgency for replacing the blood of haemorrhaging victims suggests that to best deal with the aftermath of a subduction earthquake, TM staff at *rural* VIHA facilities located near bases for aircraft—ideally helicopters—capable of carrying blood boxes and a person qualified to transfuse blood, should be prepared to pack and supply those blood products. It also implies that immediately after a subduction earthquake, a number of VIHA doctors and nurses who are experienced in performing blood transfusions, should fly from larger VI centers to these rural “helicopter base” locations, such as Port McNeil or Gold River. They would then be able to travel with the blood and victims in these non-BCAS helicopters.

Other factors that may help govern the disaster response in relatively remote areas include leadership, team development, plus individuals' knowledge of their respective roles, and of telecommunication practices. Heavy equipment will likely be required for rescue of some victims, while back-up generators with sufficient fuel may be key support assets for diagnosing, stabilizing and initially treating victims. TM staff will need psychological support, perhaps day care for their children, and timely shift rotations.

Transportation, the capacity to pump sufficient fuel for vehicles, plus patient telecommunications with relatives in distant hospitals are also potential needs. Some BCAS air ambulance trips that *bring out* those seriously injured from small, remote communities could also move additional blood products *into* these locations.

Urgency may also imply a need for agreements with the operators of the commercial helicopters, and with logging companies for shared use of telecommunication linkages, ambulances, and heavy equipment. Many logging companies have their own ambulances and first aid attendants for initially treating and transporting injured workers, and their heavy equipment may prove useful for clearing debris that is blocking access to or use of a TM facility. Before operating in remote field locations, logging companies are supposed to notify the nearest aviation service every morning and confirm the availability of an aircraft, in case an air evacuation might be required due to a logging accident (BC Forest Safety Council, 2012). Telecommunication linkages with logging companies could help both parties coordinate the use of aircraft following a subduction earthquake.

An array of available assets, possibly provincial or federal, or both, may be needed to transport blood products, or casualties, or both, in a post-earthquake situation. VIHA can approach the Health Emergency Co-ordination Center for emergency transportation resources, and EMBC can request federal resources for this purpose. Federal and provincial departments can arrange for other aircraft upon request (EMBC, 2008a; Wikipedia, 2011b). The Canadian Armed Forces would likely control the air space over BC, and if requested, could move blood products and casualties in helicopters stationed nearby, with the assistance of their Search and Rescue Technicians.

**Finding 6:** VIHA appears to have relatively quick access to helicopters and/or fixed wing aircraft that can land post-quake in any community within its jurisdiction, in order

to deliver or pick up blood products or seriously injured people. However, whether the appropriate aircraft would be available *where and when needed* awaits a crucial answer.

**Recommendations 23 to 32:**

23) TM staff in remote VIHA facilities should contact nearby logging companies to have their ambulance attendants prepared to contact these facilities immediately after the attendants encounter casualties with quake-driven serious injuries. This would help the VIHA TM Medical Director and VIHA EBMC plan the allocation of blood products.

24) The MoH EMU should assure themselves that Transport Canada, in its post-quake systems restoration plan, ranks the restoration of any electrical/electronic systems required for the control—and fuelling systems needed for the movement—of emergency air traffic in southern and central BC, very high as a preparedness priority.

Regarding telecommunications and coordination, the BC MoH has collaborated with the Justice Institute of British Columbia (JIBC) to integrate the E-Team program into an emergency management training program for paramedic, health, and emergency medical services personnel (BC MoH and NC4, 2009).

25) For this E-Team effort, the VIHA EOC should ensure that units of the Canadian Armed Forces (CAF) who, if called upon, would provide air transportation, security, and possibly air traffic control in southwestern coastal BC, can telecommunicate with VIHA from aboard military aircraft involved in transporting blood and casualties. This capability would help *efficiently* coordinate the movement of casualties, blood products, and those who administer the blood products.

26) The VIHA EOC should consider providing an operator who can monitor the needs and whereabouts of mobile casualties and health care workers, ambulances and blood products as directed and monitored via E-Team or alternative means. This person could advise Air Traffic Controllers operating via Civil Aviation Contingency Operations (Transport Canada, 2011), regarding anticipated ensuing air traffic. The person in this role could also assist by advising EMBC to dispatch aircraft (EMBC, 2011b) that VIHA required, but that did not belong to the BCAS or to the Canadian Forces.

27) For its rural facilities where blood is taken or received, VIHA should negotiate and sign agreements with the owners of, in order of preference, (1) helicopters or/and (2)

fixed-wing aircraft based nearby, to secure their post-quake services in order to move blood products and VIHA doctors and nurses between health care facilities, or to other locations where they are urgently needed (Gaillard and Mercer, 2013). Similarly, VIHA should negotiate and sign agreements with local logging companies to enable both parties to share telecommunications and the use of companies' ambulances and these aircraft where and when necessary, to coordinate movement of urgently-needed blood products, VIHA staff, or/and casualties.

28) That VIHA examine the possible benefits and drawbacks associated with having members of their nursing staff who work in rural communities occasionally take part in local logging company emergency response drills, if the drills are held in relatively remote locations. As a result, those emergency nursing staff would know better what clothing, footwear, equipment/instruments, and telecommunication devices and practices work well in that type of setting. They might also become familiar with the related operational procedures and limitations of these companies and the aircraft used.

29) For a subduction scenario exercise, the TM function should jointly plan and practice telecommunications utilizing the E-Team program. The TM function, BCAS, and remote VIHA facilities, plus VIHA Emergency and Surgery Departments (especially those at hospitals that deal with trauma – blunt force, with thoracic and abdominal haemorrhages) should be connected to and by the E-Team program. The exercise could also involve the operations of commercial air transport and logging companies based near some of the relatively remote Vancouver Island communities.

30) For clearing debris at, or access to, its more remote health care facilities, VIHA should pre-arrange priority contracts for heavy equipment services that local companies engaged in logging, mining, or road-building could provide.

31) To help shorten post-subduction quake response and rescue time, the Province should lobby the federal government for increased CAF assistance in the form of health care, transportation, and logistics capability--especially a Regular Force Field ambulance Unit, aircraft, and a Regular Force Engineer Regiment (Wikipedia, 2012b)--to be based in southwestern BC.

Maritime Forces Pacific (MARPAAC) consists of one base with several satellite units. The Canadian Fleet Pacific is the operational organization. Together, they represent a combined military and civilian workforce of approximately 6,000 people (RCN, 2012a).

32) VIHA should work with EMBC and MARPAAC to beef up regional logistics at CFB Esquimalt, which has a well-developed emergency response function that has adopted the BCERMS terminology and organizational structure. The MoH, EMBC, and Canadian Maritime Forces Pacific and Joint Task Force Pacific (MARPAAC/JTFP) can work at the provincial level, while CFB Esquimalt collaborates with neighbouring municipalities.

### **5.1.8 Preparedness: VIHA and TML Emergency Response Assets**

*VIHA emergency management: nested approach, and telecommunication tools*

**Finding 7:** VIHA emergency management is fortunate to have several different telecommunication linkages available, and to operate within an integrated systems context, with broad support from the general BC emergency management community. This combination of resources provides considerable built-in redundancy and flexibility in the telecommunications aspect of its response, and the integrated and nested response capability provides access to most of the resources needed for VIHA to rapidly improve its post-quake circumstances and capacities.

**Finding 8:** VIHA is relatively well-equipped for co-ordinating its disaster response in Victoria. The Royal Jubilee Hospital Patient Care Center has been designed to current seismic standards. It houses a regional disaster command center, with stored food and water, a 100-person conference facility, and other emergency coordination facilities (Sorenson/Journal of Commerce, 2008). It also features the following redundant telecommunication systems: power fail analog telephones auto switched to satellite telephones, disaster radio, VHF and amateur radio bands and operators, a Capital Region Emergency Service Telecommunications (CREST) network station, and a channel for direct communications with Emergency Management BC (EMBC, 2011a). The CREST station connects public safety organizations in Greater Victoria via one frequency, and its upcoming Next Generation Public Safety Broadband Long Term Evolution system will have an exclusive radio frequency spectrum, so first responders can have quicker access to information in order to make more informed decisions, and execute even quicker responses (CREST, 2013).

VIHA could request that EMBC arrange that amateur radio operators on Vancouver Island provide backup teleconference capacity, if required. The array of telecommunication resources available via EMBC, identified in Appendix N, would prove valuable post-quake, by ensuring communication between VIHA satellite transfusing sites in Victoria and elsewhere on Vancouver Island, with the CBS in the Lower Mainland, or amongst physically separated members of the VIHA Emergency Blood Management Committee (later elaborated). VIHA has an emergency telecommunications protocol, while each regional health authority has satellite phones and radios available for use at its EOC. A VIHA Telecommunications function ensures that its Priority Access Dialling information is up to date, by updating the contact list monthly. Via a few avenues, VIHA can coordinate its network of TM functions with those of other regional health authorities regarding blood contingency and disaster response activities.

In a blood contingency, members of the VIHA Emergency Blood Management Committee (EBMC) would telecommunicate with hospitals on Vancouver Island and the CBS. Telecommunication resources available for this purpose include the cell phones, power-fail analog landlines, e-mail, computer teleconferencing, and a dedicated teleconference line. VIHA staff noted that the suggested procedure for telecommunicating between the VIHA transfusing facilities and the CBS Vancouver Center during a blood product contingency is by fax and telephone. The fallback procedure(s) could possibly include one or more of the following:

- texting - PIN-PIN on Blackberry, by satellite telephone, or e-mail
- amateur radio, including packet digital airmail between amateur radios (amateur radios could be interfaced with individual computers and Local Area Networks, to restore part of a network)
- a Blackberry conferencing chat piece, VIHA's video link to hospitals
- power fail analog teleconferencing capabilities
- a *satellite*-Blackberry conference call chat piece.

However, in disasters, satellite link systems can rapidly become crowded with busy signals (Kevin Hartley, Industry Canada, personal communication, November 23, 2011).

### *Emergency Telecommunications at Royal Jubilee Hospital*

Royal Jubilee Hospital (RJH) has a sound-powered system of ten *internal* power-fail analog phones; these are dedicated lines to be used in special circumstances. At least one FMO supervisor has a radiotelephone that enables him to talk to local hospitals while he is mobile within Greater Victoria.

Walkie-talkies are used everyday in VIHA transfusing hospitals for the following:

- Emergency Departments, labs, phlebotomists, and runners relaying messages
- any place that needs emergency draws/retrievals of blood products
- Patient Access and Flow, Critical Care, and
- in practice exercises, to enable direct telecommunication with the EOC.

The VIHA Transfusion Medicine function, via VIHA, EMBC and other resources, appears to be well-prepared for telecommunications following an internal/external disaster such as a damaging earthquake. However, VIHA staff may experience challenges in terms of the devices used, and the flow, occasional volumes, and sharing of information, in the first few hours and days after a damaging earthquake affects Vancouver Island. Delays could occur in obtaining information on casualties and blood product inventory from remote communities that may have relatively little redundancy in terms of telecommunication media, although the TM Director would likely be able to accurately estimate the current blood product inventories in most of them. Conversely, “log jams” of information regarding (a) pre-existing patients who may need regular blood transfusions (b) local casualties, (c) the state of hospitals and critical infrastructure, (d) incoming casualties redirected from smaller facilities, and (e) other concerns, may occur. Although various department heads on the EBMC may receive information that is important to their own departments, some of them may be preoccupied and neglect to share such information with them *soon enough*.

### **Recommendations 33 to 38:**

33) To prepare for frequent and important communications, the main site hospital should ensure that at its EOC there are sharers who are aware of what information each department should receive, and who ensure that such information is forwarded to them.

34) Although the E-Team program can handle information flow from the central command to the periphery of the response effort and vice-versa, if this asset is not functioning, VIHA should have effective backup means. The backup should adequately handle telecommunications of data, images, reports and other information from the top down and bottom up (Patricelli, Beakley, Carnevale, Tarabochia, and Von Lubitz, 2009). VIHA staff should be well-trained in using E-Team technology for disaster response.

35) If, after a subduction earthquake, CBS Vancouver Center does not respond within the first 15 minutes to VIHA attempts to contact it, then the VIHA TM function should try to contact CBS Calgary. VIHA TM management agreed with this alternative approach. The number of casualties requiring blood transfusion at the same time in both Vancouver and Victoria could be significant. Therefore, quickly establishing telecommunication with one CBS source of supply or another could be important for multiple RHAs.

To support the planning of surge and evacuation efforts, and TM function preparations, VIHA should pre-arrange to make connections, ideally via E-Team technology, with some first responders locally and in remote locations, to obtain casualty numbers and information on the nature of injuries as early as possible.

36) The VIHA TM function could pre-arrange that EMBC, in its initial post-quake Greater Victoria damage assessment, count the buildings from which glass and cornices have fallen, and check the grounds below for casualties. Ideally, EMBC, local police and Urban Search and Rescue (USAR) units observing similar scenes could then alert local hospital EOCs regarding casualties that may require treatment with blood products. Helicopters involved in damage assessment flights should immediately notify the appropriate fire department(s) concerned regarding fires. Lines for 911 may be clogged with calls, so notification may be faster from helicopters (Scawthorn, 2008).

37) VIHA should pre-arrange to have logging companies forward as soon as possible, via radio or other telecommunication, information regarding anyone injured by landslides, falling trees or rock, or tsunami surges, and in transit in logging company ambulances.

38) VIHA should pre-arrange connections by radio or e-mail with (a) the Tofino Canadian Coast Guard station and its Auxiliary, and (b) the Joint Rescue Coordination

Center. Following a subduction earthquake, these channels could help Vancouver Island hospitals obtain information as early as possible regarding injured tsunami survivors rescued from coastal waters adjacent to Vancouver Island (Wikipedia, 2011b).

If messages regarding incoming casualties, blood product inventory data and/or damage to facilities can be burst transmitted over VIHA satellite phone to multiple recipients simultaneously, or if VIHA can have amateur radio operators available at all of its transfusion facilities to send and receive packet airmail, the telecommunication time between the VIHA EOC, VIHA EBMC, and VIHA transfusing hospitals on Vancouver Island may be reduced. These hospitals should be aware of these options, in case aftershocks preclude some of the previous assumptions and/or arrangements.

While VIHA and its TM function have considered and initiated numerous measures that target disaster/earthquake response and business continuity, so has the CBS.

## **5.2 Canadian Blood Services: Assets, Operations, and Options**

### **5.2.1 CBS Operations on Vancouver Island**

Demand for blood products depends upon the extent to which blood diseases are present in a populace, and upon what recent injuries requiring treatment involving blood products have occurred. A CBS Field Logistics Supervisor for Vancouver Island coordinates supply services and transportation for the Victoria permanent site clinics and two separate mobiles daily to the north and south on Vancouver Island.

### **5.2.2 CBS Preparedness for Disaster Response in BC: CBS Inventories**

#### *Blood Products*

During his visit to interview CBS informants in Vancouver, the author toured the CBS Vancouver Center processing facility. In one area, he observed numerous containers of blood products on many wheeled carts and multi-shelved racks that had design features to reduce their instability, and consequently, damage to them, in an earthquake. However, the brakes were not set on the carts, nor were the racks bolted to the floor.

Recommendation 39:

39) Management of the CBS Vancouver Center should set a policy that these built-in design features are used consistently, in order to reduce the risk of losing blood

products in a significant earthquake. This recommendation is indeed significant, as it applies to criteria categories 1 to 4 of Table 15.

Critical levels of blood products may vary over the anticipated length of any given shortage situation (e.g., Amber or Red phase), by blood group, and by component (see Appendix G); each component can be in a different inventory phase versus other ones, at any given time (BC Transfusion Medicine Advisory Group (BCTMAG, CBS, AND PBCO), 2009). Both the anticipated ability of CBS to increase blood inventories via imports and/or increased collections, and the actual inventory on any one day determine whether an Amber or Red phase will be declared (BCTMAG, CBS, AND PBCO, 2009). Such a declaration likely would be made if (a) CBS had a sudden significant decrease in inventory levels due to quake-driven damage to its Vancouver Center blood production and storage facility, and (b) multiple casualties increased regional demand for blood products in general. Generally, CBS BC & Yukon have 5 to 7 days supply of blood products on hand, strictly monitored daily. Information regarding current blood product inventory and demand for blood products is shared between hospitals and within the CBS, both locally and nationally.

CBS managers indicated that CBS BC & Yukon could fly in extra staff to help manage a blood shortage. Flights from Edmonton and Calgary via Abbotsford airport also may accelerate the delivery of blood products from those centers, and the shipment of specimens to Calgary for testing. Although the CBS has versatility in terms of its collection/storage sites and ability to move blood products to where they are needed, all blood collection agencies occasionally have difficulty filling type-specific product orders.

#### *Inventory of Blood-handling and –processing Supplies*

An inventory buffers uncertainties in the demand for, and the supply and movement of, materials for extracting, processing, and shipping blood products. CBS BC & Yukon has a computerized SAP proprietary inventory system in which minima and maxima counts trigger new shipments. In a temperature-controlled warehouse at the CBS Vancouver Center, the CBS maintains a one-month inventory of processing materials, based upon the rate of usage, delivery time, and manufacturer of the product.

### 5.2.3 CBS Emergency Management and Emergency Response Capability

#### *Awareness of Integrated Systems, and Links to Emergency Management Networks*

CBS respondents noted that CBS BC & Yukon has established relationships with numerous emergency response agencies, such as the Canadian Armed Forces, Emergency Services in Greater Vancouver, and the Canadian Border Agency, in order to help coordinate and make more robust its communication and transportation options in a blood contingency situation. It regularly meets with other emergency management planners throughout the province, and is included in the EMBC communications system. CBS also has a Business Continuity Group, networks nationally with many emergency response agencies, and is consulted frequently regarding disaster scenarios.

**Finding 9:** the CBS appears to have effective working relationships with numerous agencies involved in emergency response at various jurisdictional levels, in order to help ensure and coordinate communication regarding, and transportation of, blood.

#### *CBS Vancouver Center: Emergency Management and Disaster Response Capacity*

CBS representatives explained that the CBS Vancouver Center processing facility has a Local Emergency Response Team (LERT), with two key personnel (one as a backup). In a blood shortage circumstance, these two expect to be active in the BC Emergency Blood Management Committee (EBMC). CBS Vancouver Center also houses a designated LERT Emergency Response Room, (EOC) equipped with special Blackberry phone for emergency use, plus satellite phone, fax/scan system, and e-mail. LERT reports to the CBS National Emergency Response Team, (NERT). The CBS Vancouver Center LERT EOC is linked in terms of relationships, and electronically, to the EMBC communications hub in Surrey, which has satellite and amateur band radios, to the E-comm 911 call center on Hastings Street in Vancouver, which provides dispatch service for 30 police and fire departments in Metro Vancouver (E-Comm 911, 2011), and to the British Columbia Ambulance Service (BCAS) call center, (separate from police and fire 911) mobile systems, and the BCAS Helijet Air Medical operations.

The CBS Vancouver facility has a Facilities Building and Systems Technician. If required post-earthquake, this technician would be part of the team that could re-validate the 'cold chain' devices (see Glossary) used to ensure that certain blood products and

reagents have been continuously maintained in temperature conditions that ensure their quality (Hardwick, 2008).

#### **Recommendations 40 and 41:**

40) If temperature probes located in several items of CBS or VIHA cold chain equipment are linked to their respective central computers, within minutes after an earthquake, it may be prudent to increase the frequency of temperature sampling/reporting, to cope with potential effects of expected aftershocks (Hardwick, 2008). This may ultimately help to ensure the usability of the blood products stored at these separate locations.

Blood would likely be a critical health care system component in post-disaster circumstances, which makes this a significant recommendation.

41) If the CBS does not have a re-validation process and protocol, it should begin developing a Re-validation Master Plan and team--with some alternate external members--now.

#### *Approach to Disaster Response*

CBS respondents advised that in post-earthquake situations, CBS technicians would implement its standard operating procedures, plus retain the flexibility to adapt to unforeseen circumstances. The organization would use the best options amongst all the relationships that it has developed, and would exercise its ability to improvise workable, effective solutions to challenging circumstances. CBS would collaborate to ensure that essential telecommunications took place, and would be prepared to modify its response plan to accommodate changing circumstances.

#### **5.2.4 CBS Business Continuity**

CBS Vancouver Center Management advised that (a) CBS is currently working to:

- enhance its "Command and Control" infrastructure
- build ongoing Business Continuity Maintenance awareness and education amongst LERT teams and employees
- conduct readiness assessments and quarterly planned exercises
- facilitate external liaisons with other organizations, plus integrate and align best practices to enhance the organization's business capacity and resiliency,

and

(b) CBS Vancouver keeps a three-month stock of critical supplies on hand. Their backup generator, tested monthly, supports all critical functions of the processing center, and has on-site fuel for 72 hours. Contracts ensure sufficient emergency deliveries of diesel so that Vancouver Center operations can continue beyond this time period. CBS has a manual backup process for receiving, processing and issuing orders of blood products. Their Progesa computer system tracks donors, blood processing, labelling, and testing. If it goes down, there is no manual back up procedure, but two extra servers are located in Ontario. Even if quake-driven damage compromises their generator as well as their mains power supply, CBS Vancouver should be able to quickly locate and expedite a new generator locally, and/or suitable supplies of blood products from eastern Canada.

#### *Communications Capacity*

CBS has an in-house communications specialist; communication relationships link the PBCO, CBS, and all 88 transfusing hospitals in BC and the Yukon. CBS and its customers have established some protocols for emergency *telecommunication* via fax, e-mail, paging, and call group paging, plus through Blackberry Messenger.

#### *CBS Telecommunications Devices/Capabilities*

The CBS intend to convert to the E-Team emergency telecommunications/GIS system as well, which apparently would connect with their pagers. Backups include the Blackberry PIN-PIN messaging system, and satellite phones. The CBS BC & Yukon Customer Liaison Specialist has a teleconference line; laptops and cell phones potentially add redundancy to the CBS telecommunications capabilities.

#### **Recommendation 42:**

42) VIHA, the CBS, the PHSA, and RHAs in the Lower Mainland should accelerate and coordinate their efforts to train their employees to use the E-Team system proficiently in a networked manner, as they would all likely be affected by a subduction earthquake. This item pertains to criteria 2 to 7 of Table 15, and therefore is a significant recommendation.

### *Possible Alternate CBS Bases for Storing and Distributing Blood Products*

A severe *shallow* earthquake, especially, (Balfour, 2011; CREW, 2010) could damage the CBS Vancouver Center operation such that it would need to cease operations until sufficient repairs were made or operations relocated. In 2011, the CBS pursued a Memorandum of Understanding with the Abbotsford Hospital Administration that, if accepted, would enable the CBS to set up emergency storage and distribution operations there. Another option would be to move the CBS Vancouver Center supply of unprocessed blood to CBS facilities in Calgary or Edmonton.

### *Transportation of Blood Products to and on Vancouver Island*

Since there are few paved highways linking northern Vancouver Island and southern Vancouver Island, the post-subduction quake transportation of blood products between facilities at or near the ends of Vancouver Island could be problematic if: collapsed bridges, landslides, subsidence, and/or fallen trees and power poles/lines cause closure of significant stretches of highway, or if waters from a breached dam or tsunami waves inundate or wash out a segment, *because* demand for air transport would likely outstrip availability.

Fortuitously, a VIHA TM employee recently developed detailed transportation plans that involved making Vancouver Island more self-sufficient in blood products for a period of at least 24 consecutive hours. For emergency transportation, the CBS can use air, ground, and marine transportation modes, depending on what is available. The BCAS can deliver blood on behalf of the CBS *if no other option is available*. For details on these BCAS services, see Appendix O. CBS can also obtain permission to use the helipad at Women and Children's Hospital, next door to the CBS Vancouver Center facility, when the CBS Medical Director declares an urgent need to ship blood products.

### **Recommendation 43:**

43) CBS BC & Yukon should designate an alternate who, if the Medical Director is absent or incapacitated during a disaster, is empowered to officially declare that the need to ship blood products is very urgent.

The CBS delivers blood products only to Health Canada-licensed hospitals, but RHAs *redistribute* specific blood from smaller hospitals to major hospitals, for example, in

order to ensure that the products are used before their due dates. Drivers of CBS fleet vehicles telecommunicate with cell phones or if necessary, on trips between Vancouver and Kelowna—via *satellite* phone. CBS Vancouver fleet vehicles have placards and stickers enabling them to use Greater Vancouver Disaster Response Routes. Their relationships with EMBC and HEMC provide for emergency transportation. Appendix P lists the available modes for transporting CBS Vancouver blood products, in addition to other alternate transportation routes to and in Greater Victoria. Some of the transportation vulnerabilities could likely be reduced significantly by having the CAF use their larger Search and Rescue aircraft conduct the transport.

**Recommendations 44 to 47:**

44) Since a tsunami may damage docks at the Victoria Inner Harbour aerodrome, VIHA should consider the following option to complete a possible “last mile” in the transfer of blood products:

purchasing a small, reliable Zodiac-style powerboat that can be launched quickly, to get blood shipments from a floatplane to the Inner Harbour shore, and keeping the craft in a ready state at the Ministry of Health parking garage on Blanshard Street.

45) If the CBS does not have a high clearance, short wheelbase, 4-wheel drive vehicle in its Vancouver Island fleet, it should acquire one, to travel logging roads if other routes are impassable due to landslides or damage to bridges.

46) In addition, if they do not already, VIHA, the BCAS, and CBS should have satellite phones in their vehicles that operate in the northern half of Vancouver Island. This technology could facilitate telecommunication to and from remote areas that either do not have cell phone coverage, or where a subduction earthquake or aftershock has incapacitated cell phone towers. A backup, or alternative, may be to use radios that can operate on logging company frequencies, and, with their permission, using their repeater towers via Internet Radio Linking software, or equivalent technology.

47) The Province should enact legislation that enables a designated TM contact at each transfusing facility to empower the driver of a road courier or BCAS ambulance to transfer a blood product shipment to the nearest suitable aircraft, (or water taxi when the destination is within 40 km on the same coastline), provided that:

- that driver accompanies the blood product shipment to its destination;

- the intended road is impassable and there are no alternate ground transportation routes,
- the aircraft or watercraft has (a) dependable means to ensure cold chain continuity for the product(s) during the journey, and (b) a good chance of reaching the destination, safely and in time;
- the operator of the aircraft or watercraft has on board some working means to telecommunicate directly with the destination facility, from within a 20 km range.

This recommendation also implies that VIHA should, if it has not already,

(c) acquire for the EOCs of its transfusing facilities one or more laptop computers capable of running the E-Team program, and as a back-up, a radio(s) capable of transmitting and receiving on the marine VHF frequency and the VHF frequency that aircraft pilots use;

(d) train and license some designated staff at each of its transfusing facilities to be able to use the radio(s) effectively;

(e) have these staff practice using this equipment in disaster response exercises.

Although at the instant of an earthquake, remote communities with VIHA facilities for transfusing blood may have enough blood products on hand, some of this inventory could be lost due to quake-driven damage. In that case, recommendation 47 would be significant.

### **5.3 Blood Contingency in BC Following a Cascadia Subduction Earthquake**

CBS involvement in a recent multiple-agency emergency planning exercise in Greater Vancouver revealed that groups such as CBS would need to cope on their own for a significant period immediately after a subduction quake. While other agencies' own damage is being assessed and their people tracked and located, few of them will be available immediately to assist the CBS. Police, ambulance, and fire departments will have rescue of people as their next priority immediately following a subduction quake.

**Finding 10:** Based upon the evidence and considerations so far presented in this paper regarding subduction quakes and health asset vulnerabilities in southwestern coastal

British Columbia, it is likely that a subduction event that initiates in the northern CSZ would lead quickly to a blood contingency in this region.

**Recommendations 48 to 50:**

48) VIHA transfusing hospitals and other VIHA facilities should assess their respective capabilities to carry out blood sample analyses, surgeries, transfusions, and other procedures requiring blood products, and communicate their information to the VIHA EBMC, who can help rationalize the allocation of casualties and staff, generally to the most functional of these facilities.

49) Since a couple of VIHA respondents indicated that post-subduction-quake there would be high demand for air transportation, the provincial government should dedicate and keep on call two helicopters and two fixed-wing aircraft, to pick up and drop off blood products and other critical supplies at sites on Vancouver Island.

50) In the event of a subduction earthquake, VIHA should contact BC Hydro as soon as possible, to try and determine whether any of the three dams on the Campbell River system has failed, or will likely fail as a consequence of the main shock or aftershocks. If such failure has occurred or is imminent, VIHA should forthwith notify the BCAS in Courtenay and the Red Cross to be prepared to assist, if possible, in Campbell River.

#### **5.4 Multiple-Agency Response to a Blood Contingency in British Columbia**

*The British Columbia Blood Contingency Plan*

The BC Blood Contingency Plan (BCBCP) is intended to ensure that during a blood shortage in British Columbia, as many patients as require them have access to safe blood transfusions (BC Transfusion Medicine Advisory Group (BCTMAG), CBS, and the Provincial Blood Co-ordinating Office (PBCO), 2009). In a Red phase blood product inventory situation, inventory of certain product(s) is insufficient to ensure that patients with non-elective indications for transfusion will receive the required transfusion(s), and the Standard Operating Procedure calls for all requests for blood to be screened (BCTMAG, CBS, and PBCO, 2009). A second important objective of the BCBCP is to “ensure that blood contingency planning is integrated into existing emergency preparedness plans in the province, and that blood-related activities are part of a

coordinated response in the event of an emergency” (BCTMAG, CBS, and PBCO, 2009, p. 6). The plan addresses red blood cells, platelets, frozen plasma, and cryoprecipitate (BCTMAG, CBS, and PBCO).

#### *Emergency Blood Management Committees*

To complement the BCBCP, the BC health care system has defined Emergency Blood Management Committees (EBMCs) at the provincial, Regional Health Authority (RHA), and hospital levels, to be prepared for and respond to, shortages of blood components in these jurisdictions, via those levels of blood contingency plans (National Advisory Committee on Blood & Blood Products and Canadian Blood Services, 2009). The BC EBMC is responsible, *inter alia*, for (1) communicating its recommendations effectively during blood contingencies, (2) assisting TM Directors to deal with blood contingencies in their respective RHAs, and (3) helping to integrate the BCBCP with provincial emergency response plans (BCTMAG, CBS, and PBCO, 2009, p. 12). A quorum is not required in the BC EBMC, and decisions are made by consensus of 80% (or greater) of the members present (BCTMAG, CBS, and PBCO, 2009). Respondents felt that the VIHA EBMC would enable rapid decision-making and coordination in order to administer blood products and services in a situation where both a blood supply shortage and an *urgent* and high demand for blood products prevailed.

If a blood product contingency likely will or does affect more than one BC RHA, CBS will alert the BC EBMC to meet and decide on the phase of the shortage and steps to be taken (BCTMAG, CBS, AND PBCO, 2009). If the situation is a localized contingency, the CBS and the relevant RHA oversee the response (BCTMAG, CBS, AND PBCO, 2009).

#### **Recommendation 51:**

51) VIHA should develop multiple-level plans to deal with multiple-casualty, massive haemorrhage injury situations, and that stress and utilize the significance of education and communication (Stanworth, 2012). As multiple-casualty incidents such as earthquakes are likely to involve a significant scale of casualty retrieval, stabilization, and evacuation to distant facilities, the author examined some of the implications of that transportation process in detail. Appendix Q considers and lists some of the factors likely to affect post-subduction quake delivery of blood products and casualty retrieval

via combined trips, while Appendix R identifies a couple of plausible dilemmas that could arise in such a situation.

*Some Implications of a BC Blood Contingency Due to a CSZ Subduction Earthquake*

Assume that following a CSZ subduction earthquake, Greater Victoria casualties of the order of magnitude predicted herein, the loss of some blood stored in Greater Victoria, and parallel occurrences in the Lower Mainland (including partial loss of inventory at the CBS facility), lead the CBS to (a) declare that a blood contingency exists in BC, and (b) convene the BC EBMC.

To best manage a blood shortage, decision-makers must have information about total blood inventory, including inventories in hospitals (BCTMAG, CBS, and PBCO). A large fraction of the total blood product inventory within the BC blood system at any given time is stored in hospital blood banks. The inventory levels corresponding to a contingency phase definition vary depending on the scale considered—total CBS inventory, CBS BC&Yukon, Vancouver Center inventory, or total BC inventory (CBS BC&Yukon, plus hospitals) (BCTMAG, CBS, and PBCO, 2009).

VIHA transfusing hospitals and satellites may require considerable time to transmit to the CBS information regarding their available inventory of blood products, their capability to carry out procedures involving or requiring blood products, plus their anticipated and actual hospitalizations. Possible delays in telecommunicating blood demand information and hospital inventory levels to the Provincial EBMC may complicate, at the provincial level, the processes of (a) predicting inventory levels and demand, and (b) allocating blood products at or among hospitals.

The standing VIHA arrangement is for the Medical Director, Hematopathology, to request a reasonable “block” of blood products, to satisfy the initial post-quake need within VIHA. As information regarding the earthquake-driven numbers and types of casualties came in, the VIHA Medical Director, Hematopathology, (MDH) and staff would then continue defining needs for blood products. The VIHA EBMC would likely consult *at least* the Nanaimo Regional Hospital, Saanich Peninsula, Royal Jubilee, and the Victoria General before allocating blood for transfusions in Greater Victoria. VIHA blood transfusing laboratories and facilities further north on Vancouver Island would keep their

blood supplies intact. The VIHA EBMC would, if necessary, help arrange commitment and transportation for additional blood products from unaffected facilities in other BC health authorities. The TM Medical Directors of the RHAs would then attempt to operate a loop telecommunication pattern, contacting RHA- and hospital-level EBMCs to acquire as much pertinent information from them as possible. The information regarding BC-wide blood inventory would be shared within the BC EBMC, and the TM Medical Directors of the RHAs would then place their respective blood orders with the CBS. It would repeat this process to ultimately satisfy blood requirements in BC.

Although the ideal response to a blood shortage in an RHA(s) may be stepwise reduction of blood use by gradually increasing restrictions down to critical levels, until the BC EBMC has received sufficient information on (a) physical damage to high consumption hospitals in major urban centers and their blood product inventories, and (b) the numbers of actual and anticipated hospitalizations, that body might as well implement the most extreme conservation measures directly, to be able to ensure that enough blood products are ultimately available to allocate to those in greatest need.

### **Recommendations 52 and 53:**

If, in a post-subduction quake circumstance, telecommunications are immediately disrupted for a few consecutive hours, and provided that no other large scale blood contingency exists or is imminent in Canada,

52) to save precious time, and to initiate the import and/or collection and production of additional (likely required) blood products, the CBS, RHAs, transfusing hospitals, and other players involved in providing the blood supply for southern coastal BC should *assume, as soon as a subduction quake occurs, that there is a shortage of blood products in the region* (Nollet et al., 2013; Tadokoro, 2011; van Essen, 2012). EBMCs should then proceed immediately to implement Red Phase blood austerity measures, verify their respective supplies, anticipated or initial levels of demand, and communicate them to CBS, who can decide whether there actually is, or soon will be, a regional shortage of one or more blood products.

53) VIHA should arrange (a) a standing order for the CBS to increase the normal three-day supply of platelets, plasma, and cryoprecipitate to Vancouver Island hospitals to reflect the hospitalizations anticipated from a subduction earthquake, and (b)

government assurance that these products will be transported as soon as possible from CBS Vancouver or further east.

Communication plans and roles are fairly well defined in the BCBCP, but at CBS Vancouver Center, a subduction event *or* a local shallow quake may cause spillage and/or disorganization of blood products, damage to the building and to blood processing and telecommunications equipment, plus injuries amongst the CBS players in this plan, complicating the communications process.

*Decision-Making: The VIHA EBMC and Medical Director, Hematopathology*

The VIHA Medical Director, Hematopathology, in deciding how much additional blood product to order from CBS Vancouver in the first day or two, and *where* to have it delivered, might consider numerous variables, some of which are listed in Appendix Q.

#### **5.4.1 CBS Procedure in a BC Blood Contingency**

*Situational awareness and updates in a regional blood contingency*

In a regional blood contingency, CBS would update the BC EBMC on actions taken to ensure that an adequate supply of blood products is, or will be, available in BC over the expected duration of the contingency. As a first response, the CBS would import prepared blood from centers further east. As information came in, RHAs/transfusing hospitals and their EBMCs that could view the PBCO website would see what blood products are available within the province, and then appropriately modify their decisions regarding ordering blood products. After consulting with the BC EBMC, CBS BC&Yukon would declare (a) the different phases of blood component shortages and (b) the start of recovery from such shortages in BC, and decide the distribution of blood components, in accordance with demand and with the guidelines for each blood component inventory phase (BCTMAG, CBS, and PBCO, 2009). CBS would consult with the BC EBMC as soon as possible, and undertake its own LERT activities. CBS Vancouver management feel that if their staff and facility were not drastically affected by the earthquake, they would be able to significantly boost the rate of collecting and producing blood products. They could launch a media campaign and collect *sufficient* local donations, then send that product to Calgary for testing. Or, they could bring in staff from Edmonton and/or Calgary and process some of the whole (unprocessed) blood in the Vancouver Center.

The CBS Hospital Liaison representative for BC would consult with the VIHA hospitals; LERT team members would help restore production capacity at CBS Vancouver. The two LERT team members feel that they would be able to manage essential functions following a subduction quake that affects CBS processing capacity.

*The Recovery Stage of a Blood Product Supply Contingency*

Blood products should be used judiciously for a few weeks following a subduction earthquake. Aftershocks could damage both hospital functions and blood product inventory, generate more hospitalizations, and complicate the recoveries of casualties treated earlier. Ideally, transfusion sites should return in a slow, step-wise manner to normal utilization levels (ORBCon, 2008).

## **5.5 Summary of Risks, Capacities and Vulnerabilities for Key Agencies**

The findings and recommendations presented in this Chapter imply cross-cutting risks, capabilities and vulnerabilities that pertain indirectly to the population of southwestern BC, and more directly to the agencies involved in sustaining VIHA TM business continuity post-quake. Table 16 lists many of those risks (except the possible impacts that could be added or extended by aftershocks), plus capabilities and vulnerabilities, and provides a useful synthesis of the analysis presented in this Chapter. The general public in southwestern BC should be made aware of these probable liabilities, as they may have unrealistic expectations that the healthcare system will be able to respond efficiently in post-quake circumstances (Carr, Caplan, Pryor, and Branas, 2006; Schultz, Koenig, and Noji, 1996).

**Table 16. Summary of Risks, Capacities and Vulnerabilities for Key Agencies**

<b>Risks</b>
lives, health and safety of many people, potentially including some staff of VIHA TM and CBS ( <b>subduction quake</b> )
capability to transmit electrical power to and within VIHA facilities, gas stations (fuel shortage?), and water and sewage treatment plants?
some supplies of blood products stored in VIHA facilities, and VIHA equipment used to store and process patients' blood samples
CBS Vancouver facilities and equipment used to store, track, and process donated blood ( <b>subduction quake</b> )
VIHA's <i>quick</i> access to historic health information on would-be recipients of emergency transfusions
<b>Capacities</b>
VIHA/MoH to lever resources that could help (a) provide access or transport to, or shore up, crucial healthcare facilities, (b) re-validate cold chain assets, or (c) provide access to alternate telecommunication equipment, and to additional healthcare assets and logistical capability
VIHA to gather information about casualties, the state of TM staff, stocks of blood products, condition and functionality of facilities, and access thereto
VIHA/MoH/CBS/BCAS and others to telecommunicate, to plan, and to flexibly coordinate response efforts to support the TM function, post-quake, including use of the E-Team program ( <b>CBS - subduction quake</b> )
VIHA TM function to cope, likely at a reduced level or rate of service, with demand for blood products. Depends on whether--and if so, how severely--TM assets (staff, equipment, and storage facilities) are damaged; to utilize the MMU assets if needed following a shallow earthquake
VIHA TM function/CBS to inventory their supplies of blood products immediately post-quake capability to re-route telecommunications via various singular or combined devices?
VIHA FMO and parallel CBS unit to modify and repair key damaged facilities, to sustain their respective functions ( <b>CBS - subduction quake</b> )
CBS to (a) assess and help manage BC blood supply, (b) resupply blood products rapidly, from nearby or more distant sources (c) lever transportation and telecommunication assets;
VIHA to lever resources that could help redistribute blood products, staff, and stabilized casualties rapidly as part of a rational and flexible plan
VIHA EBMC and CBS to implement BCBCP and help coordinate administration of blood products ( <b>especially subduction quake</b> )
multiple agencies to integrate updated knowledge of possible post-quake contingencies, and their abilities to coordinate and integrate collective assets and capabilities, into the design of future multi-agency disaster response training exercises
VIHA TM Director/EBMC to assess incoming information and make decisions to allocate blood products effectively
<b>Vulnerabilities</b>
CBS to continue its Vancouver Center operations, restore and revalidate its raw blood processing operations ( <b>subduction quake or shallow quake localized near Greater Vancouver</b> )
no physical facility identified as logical alternate Greater Victoria location for blood bank/TM Lab and/or reagent cache
VIHA/MoH/CBS may lack expertise or arrangements to assess structural damage to healthcare facilities and equipment ( <b>CBS - subduction quake</b> )
likely not enough aircraft available at one time to address casualty retrieval from all communities or areas ( <b>subduction quake</b> )
no HRVA has been conducted regarding the effects of such earthquakes on vendors of supplies and materials, and the related likely or possible transportation routes and modes, <i>critical</i> to the VIHA TM function
possible understaffing of some TML roles if staff or their family members are injured in an earthquake
VIHA mobile telecommunication in some remote areas of Vancouver Island, and their ability to telecommunicate <i>directly</i> and in a timely manner with people in those aircraft, vessels, or vehicles moving blood products or/and casualties

## 5.6 Chapter Summary

This Chapter has integrated the results of the consultation process with relevant material from primary and secondary literatures. It has identified risks, vulnerabilities, and capabilities (listed in Table 16) associated with the business continuity preparedness of key agencies that would be involved (a) with providing blood products and (b) in a blood product contingency, both anticipated as consequences of earthquakes that could affect southwestern BC.

On the one hand, the BC Blood Contingency Plan, various levels of Emergency Blood Management Committees, the BCAS, the PBCO, resources available via Emergency Management BC, and upcoming blood contingency exercises are effective tools that extend and enhance the disaster response capacity of VIHA and the CBS. On the other, various findings and recommendations address both entities' business continuity gaps, identified from the interviews with key informants, peer-reviewed reference literature, documents or web pages accessible on the VIHA and MoH websites, and from selective on-site observations.

This work addresses needs for post-quake situational awareness, planning, transportation, and telecommunications, especially within and among VIHA, its Transfusion Medicine (TM) function, the BCAS, and the CBS. Various findings confirm that co-ordinated and reliable telecommunication and transportation functions will be crucial to an effective response to any of the types of earthquakes. In a post-subduction situation, the demand for telecommunication and transportation over both short and long distances will be elevated. Telecommunication with vehicles, including aircraft, used to transport blood products, other health care supplies, and casualties will be essential.

The thesis re-iterates the need for criteria that could be used to pre-define suitable locations for alternate TM labs, and for sites where blood, reagents, and other Transfusion Medicine supplies could be stored. Decisions made using such criteria may avert the loss of precious staff time, monetary resources, and perhaps desperately-needed blood products, following a damaging earthquake. The research also provides recommendations to create tools or entities such as

- a decision tree support system useful in ordering additional blood supplies and determining where they should be sent, post-quake
- a plan for a rationalized post-quake computer/cybersystem restoration sequence amongst Greater Victoria hospitals
- a coordinated and standardized approach by VIHA, the BCAS, the CBS, and other key regional health care players--one that makes effective and efficient use of their respective E-Team systems to support rapid decision and action response to an earthquake (Yasui, 2012).

Conducting a hazard, risk, and vulnerability analysis that addresses implications (including direct consequences and triggered effects) of earthquakes upon the blood product supply chain could prove valuable. The analysis should consider those vendors of supplies and materials--and the likely or possible routes and modes of transportation--critical to the VIHA TM function, in order to identify any vulnerabilities in that supply chain. And finally, a review of pertinent operations research of should be conducted, especially as it applies to transportation planning, and specifically the provision of appropriate aircraft for the movement of casualties and the rapid delivery of vital supplies in post-quake situations within the VIHA jurisdiction.

Local and regional agencies involved in emergency management must understand their own and each other's roles, responsibilities, capacities, and priorities in order to mount a coordinated and integrated response to an earthquake disaster. The capacity and level of preparedness of the weakest link in the health care earthquake response and casualty treatment process would affect the efficiency and effectiveness of other departments and functions involved in that process. All of the suggested measures address the relationships among risk, capacity and vulnerability within the BC health care system, especially with respect to its ability to provide blood products where and when needed in a post-quake circumstance.

## **Chapter 6: Summary, Evaluation, and Conclusions**

### **6.1 The Purpose and Scope of the Investigation**

This research project was intended to identify ways to strengthen the Transfusion Medicine (TM) emergency response management function within the Vancouver Island Health Authority (VIHA) such that its TM component will be better able to deal with the direct and indirect impacts, especially in Greater Victoria, that it would likely face as a result of possible earthquake events. The objectives of the study apply to three different post-earthquake circumstances:

- to provide realistic estimates of the numbers of local hospitalizations (and types of injuries) that would likely result if any of these different types of earthquakes were to affect Greater Victoria.
- to briefly examine the inventory monitoring, communication, decision-making, transportation, and blood product distribution components—plus the hazard mitigation, vulnerability reduction, and capacity development aspects—that could be incorporated within an earthquake-specific blood contingency plan for VIHA blood handling facilities.
- to plan for supplying new blood products, related materials, and services to maintain the function of the TM Laboratory role within transfusing hospitals in Greater Victoria, or elsewhere on Vancouver Island—during post-earthquake circumstances in which some of the VIHA facilities for storing, monitoring, preparing, analyzing, or transfusing blood products are inoperable.

### **6.2 Addressing the objectives of the study**

#### **6.2.1 Objective One**

The author produced an Estimates Package that identified the numbers of local hospitalizations and types of injuries mentioned in the first objective. Pre-quake conditions such as types of anaemia, exacerbated by the shock of a quake, will in part drive the demand for blood products, as mentioned on pages 53 and 54. Health care

planners should be aware that the numbers of hospitalizations derived are of the appropriate *order of magnitude* given specified earthquake magnitudes, distances to epicenters, and likely intensities of shaking, but could be significantly larger than these estimates indicate, mainly due to the following considerations.

#### Sources of Uncertainty in the Estimates of Injuries and Hospitalizations

##### *Incomplete or Inconsistent Data*

The estimates are approximate because they are based on data sources that are diverse, non-homogenous, or incomplete. Wagner, Jones, & Smith (1994) noted that quake-generated injuries are often vaguely and inconsistently defined, and may include some harms that are not earthquake-related. Regarding the 1999 Taiwan shallow earthquake, some authors reported 7,600–8,700 injured, while others quoted numbers in the 9,400–11,300 range (Chan et al., 2006). This discrepancy may involve measurement at different times, or of differing geographical areas, errors made in abstracting medical records, plus a lack of consistent reporting, and/or misclassification, of injuries. Naghii (2005) noted that following the Loma Prieta quake in California, up to 60% of those who had earthquake-related injuries either treated themselves or were not treated in hospitals. The numbers of persons with mental trauma were difficult to extract from the data, and many who suffered *delayed* health effects may have been excluded. Appendix J illustrates an example of quantified uncertainty regarding data on some injuries from the 1995 Kobe earthquake.

##### *Calculation and Evaluation of Population Densities*

Insufficient information will reduce confidence levels regarding the relationship between the population density ratio for a given area and its rate of hospitalizations due to an earthquake. In a few instances in this research, uncertainty resides in the likely, but unconfirmed areal extent and/or population of a jurisdiction that was affected by an earthquake decades ago. Even with complete information regarding an areal unit, the population density in it typically varies—spatially and temporally—and over various levels of resolution.

The available spatially-averaged population density ratios allowed proportional allocation

of the weights of the known source unit serious injuries and/or hospitalizations to the target or scenario unit, in a spatial unit matching methodology. The averaging involves much more than computation. It ignores the differing spatial supports, and may result in inaccurate cross-scale relationships (Gotway and Young, 2002). Therefore, the use of population density as a factor contributing to injury and hospitalization during an earthquake is simplistic. In addition, high population density is a major factor—but not the sole one—contributing to the number of hospitalizations in an areal unit.

#### *Uncertainty in Comparing Victoria Scenarios to Actual Earthquakes*

Do quakes with equivalent magnitudes create identical MMIs in different locations? No, because attenuation relationships and ground motion amplification factors differ due to geologic variation, and because the frequency and wavelengths of the shaking vary rapidly over time. Shoaf et al. (1998, n.p.), in comparing the Northridge and Loma Prieta quakes with respect to injury types by geographic area, also found that “those in MMI VIII areas have higher rates of injury than those...in MMI IX...”

#### *Pre-quake Mitigation Efforts, and Their Geographic Distribution*

Pre-quake mitigation measures, and how effectively they are implemented, also will affect the number and nature of injuries that result from a damaging earthquake. How realistically and frequently disaster management plans have been exercised and improved may help determine the speed, appropriate prioritization, and overall adequacy of disaster response. Regarding the built environment, adequate research on soils and structural design, and the proper construction or seismic retrofitting of buildings and structures are essential pre-quake mitigation measures. Education designed to induce indoor self-preservation behaviour, such as the drop, cover, and hold routine, may also help reduce human injuries due to damaging earthquakes.

#### *Post-quake Response Efforts*

The initial damage assessment aerial survey(s) may rapidly produce a rough estimate of casualties and an associated needs assessment that is accurate, complete, timely, concise, and standardized (Maury and Russbach, 2004). Although both road access between Greater Victoria hospitals and downtown Victoria, and USAR efforts to safely enter partially- or fully-collapsed buildings and extract seriously injured people will likely

be difficult and time-consuming, first responders' skills in timely organization, triage, and emergency first aid should ensure that at least those more accessible who need to be hospitalized are admitted as soon as possible, helping to reduce mortality. However, a few of the seriously injured will be tsunami victims, and several more, the casualties of landslides in relatively remote areas. The factors of response coordination, available resources, degree of structural vulnerability of buildings, health care skills and technology available, plus the location and initial reaction of those subject to the shaking in different settings, will help determine who needs to be hospitalized post-quake.

### **6.2.2 Objective Two**

Objective Two involved examining the inventory monitoring, communication, decision-making, transportation, and blood product distribution components—plus the hazard mitigation, vulnerability reduction, and capacity development aspects—that could be incorporated within an earthquake-specific blood contingency plan for Greater Victoria transfusing hospitals. The interview questions and process, and analysis of results focused upon gathering and accurately interpreting the information on these facets of the blood system in British Columbia. The following segments comment on how effectively this objective was addressed and achieved.

#### *Strengths and limitations of the consultation methodology*

##### Strengths

The author developed the question protocol after preliminary meetings with appropriate health care professionals, and with reference to emergency management practices and related psychological studies. Blood bank operational guides, peer-reviewed papers on emergency response, and on quake-driven damage to medical facilities and people complemented the BC Blood Contingency Plan, presentations regarding VIHA Transfusion Medicine operations, and the E-Team program, as secondary data sources providing perspective that helped to shape the questions and interpret the answers given. After providing the informants with copies of the interview questions in advance, the author gathered information directly from 12 key VIHA and CBS professional and technical personnel involved in transfusion medicine and the blood system in BC. In Chapter 5, the researcher integrated the information given by the informants along with

data from the secondary sources listed above, all placed in the context of the two earthquake disaster situations expected to have drastic impacts upon the health care system. Thus, empirical data from the literature, verified in sessions with key informant health professionals and emergency planners, assisted with triangulation of the findings.

### Limitations

The number of key respondents was relatively small, and did not include VIHA TM team members from outside Greater Victoria, due in part to time constraints within the health care/blood system. Understandably in terms of security, the author could not obtain a progress report on VIHA plans for restoring computer systems that (a) control automated TML processes and (b) provide clinical information within VIHA hospitals. The author planned to hold a focus group at which he would present his preliminary findings to a group of the key informants so they could verify facts and interpretations and perhaps contribute additional ideas, but most of them apparently did not have time to participate in that session. However, as stated earlier, the VIHA Medical Director of Hematopathology did review a nearly final draft of Chapter 5, providing verification of the results of the interviews, their analysis, and their synthesis with secondary data.

As with any social research, the respondents bring their own biases to a project, and the researcher brought his, with respect to the qualitative information sought, its analysis, and interpretation. These biases stem mainly from (a) his interest in, and limited knowledge of, geology; (b) his father's concerns with local hazards, disaster preparedness, and telecommunications capacity; and from the author having (c) updated a community's disaster response plan, and coordinated its response to a mock tsunami. His fascination with seeing earthquake waves rippling through a deck in Tahsis in 1996, plus his awe and respect for an intense and powerful BOOM! heard and felt in a 2002 event near Victoria, have led the author to advocate greater public awareness of the implications of surrounding geology, and of the scale and intensity of earthquakes.

The perspective carried through into the analysis and interpretation by looking within the health care matrix to identify business continuity factors such as rate-determining steps that might be affected or bottlenecks that could be exacerbated, by earthquake disruption. Therefore, the author briefly researched pre-TM system capacities such as triage and the likely rate at which earthquake victims might be assisted in typical VIHA

Emergency Departments (EDs), and how these factors might affect TM operations at various VIHA hospitals. Evidence from the MoHS (2003), and more recently from a VIHA staff member suggests that the flow rates then, and perhaps still, typical in BC Emergency Departments reflect a "whole system problem that requires collaborative planning across all sectors" (MoHS, 2003a, p. 9). Emergency Departments are not likely the only choke points in the multiple-casualty flow path, but the author's view is that it is time to address all of them.

### **6.2.3 Objective Three**

Objective three was to plan for supplying new blood products, related materials, and services to maintain the function of the TML role within transfusing hospitals in Greater Victoria during post-earthquake circumstances in which some of the Greater Victoria facilities for storing, monitoring, preparing, analyzing, or transfusing blood products have been rendered inoperable. Several measures, some identified in the paragraph below dealt with this objective.

#### **Strengths**

The author asked questions and researched decision-making regarding the alternatives of (1) having a TM Laboratory/blood bank shelter in place (2) rapidly relocating such a facility within or near Greater Victoria and/or (3) transporting earthquake victims to hospitals outside of Greater Victoria. The researcher posed questions regarding the transportation of blood products from CBS sources—in Vancouver, and further east in Canada—to VIHA transfusing hospitals. Other questions drew responses about the supply of goods and services required to keep both CBS Vancouver Center and VIHA TM facilities functioning efficiently, and the telecommunication required to do so. Via this process, the researcher and respondents identified considerations and criteria regarding how decisions could be made to appropriately direct the flow of blood products, the required supply of goods and services, and injured people, when some of the Greater Victoria facilities for storing, monitoring, preparing, analyzing, or transfusing blood products have been rendered inoperable.

## Limitations

Uncertainty—regarding the post-quake condition of critical infrastructure, health care facilities, and various blood system suppliers, plus the levels of supply of, and demand for, blood products within and beyond the VIHA jurisdiction, and where that specific demand exists geographically—makes planning for this objective difficult.

### **6.3 Contributions of the Research**

No previous study has explicitly addressed seismic hazard in southwestern BC with respect to the transfusion medicine function or the blood supply system in BC. The study has also considered broader implications of earthquakes for the health care sector on Vancouver Island in general, and for health care-related post-quake situational awareness, planning, transportation, and telecommunications, especially.

In addressing Objective One, this research has considered hazard and risk as it pertains to the preparedness of a regional health care system to respond to an earthquake hazard and event. It has also added credence to the community of justifiable concern regarding the implications of shallow or subduction earthquakes for health care facilities and capabilities in rural and urban communities in southwestern coastal BC. Discussions related to Objectives Two and Three highlighted the complex, urgent and geographical considerations that will likely be involved when the health care system must react to earthquake damage to health care assets and to simultaneous increased demand for services. The argument also pointed out that if individuals remain more vulnerable to large-scale hazards than *they* need be, their health system will likely be more vulnerable to overload and functional collapse than *it* need be, when a damaging earthquake occurs. *Individual* preparedness is as important as having a resilient health care system.

This study has also identified what, besides human health, is at risk at several locations that would be important in disaster response and casualty treatment following a damaging earthquake. Triage capacity, blood supply, and TM support infrastructures are vital to human health at various locations. The research highlighted vulnerabilities in transportation infrastructure--assets that might be key to moving blood products and injured people from place to place. A nearby subduction earthquake event may drive home how essential our telecommunications links *between places* and *between mobile*

*transportation vehicles* are, for transmitting and receiving relevant and timely information.

Turning more specifically to the TM function, a further contribution of the study has been to identify the need for criteria that could be used to pre-define suitable locations for alternate TM labs, and for sites where blood, reagents, and other TM supplies could be stored, to avert the loss of precious staff time, monetary resources, and perhaps desperately-needed blood products. In this regard, the Province and VIHA might logically plan for the rapid and *simultaneous* structural and functional assessment, post-subduction event, of as many medical facilities and as much essential equipment as possible throughout its geographic jurisdiction.

Similarly, the findings point to the priority of developing a rationalized post-quake computer capability restoration sequence amongst Greater Victoria hospitals to augment response plans. The research also led to the concept of a decision-tree analytical tool which, if fully developed, may assist the VIHA Medical Director of Hematopathology in ordering blood products and determining their destination(s) in post-quake circumstances.

In relation to telecommunications, the study confirms the importance of developing a coordinated and standardized approach by VIHA, the BCAS, the CBS, and other key health care players to make effective and efficient use of their respective E-Team systems to support rapid decision and action response to an earthquake event (Yasui, 2012).

Finally, regarding all aspects of post-quake response preparedness and TM system restoration, the findings imply the need to take account of the high likelihood of earthquake aftershocks and therefore to plan for a *gradual, wary transition* back to normal operating procedures.

#### **6.4 Suggestions for further research**

Several priorities for further research stem from the main findings and contributions of this study. As noted, the development of a fully-elaborated computerized decision-tree or operations analytical tool would assist the VIHA Medical Director of Hematopathology

and the provincial Emergency Blood Management Committee in ordering blood products and determining the corresponding means of transport and destinations in post-quake circumstances. Secondly, conducting an all-hazards assessment of hazard, risk, and vulnerability (HRVA) that addresses seismicity (including direct consequences and triggered effects) that could affect those vendors of supplies and materials--and likely or possible transportation routes and modes--critical to the VIHA TM function, would serve to identify vulnerabilities in that supply chain. Thirdly, a probabilistic, block-by-block and building-by-building damage projection in downtown Greater Victoria, coupled with block face population statistics, should provide more accurate numerical estimates, and a profile, regarding those from that area likely to be injured and hospitalized in a damaging quake. Fourthly, a review of pertinent operations research should be conducted, especially as it applies to transportation planning, and specifically the provision of appropriate aircraft for the movement of casualties and the rapid delivery of vital supplies in post-quake situations.

Finally, researchers and practitioners could support VIHA and the other BC RHAs by disseminating research results to the TM professional community through such fora as the World Association for Disaster and Emergency Medicine.

## **6.5 Conclusions**

This research project offers four significant conclusions:

- a) The earthquake hazard in southwestern coastal British Columbia poses *real* risks of heavy damage to cultural infrastructure, and of major outcomes for human health and safety.
- b) This study shows that VIHA, its TM function, the MoH Emergency Management Unit, the CBS, the BCAS, and the Provincial Health Services Authority have developed well-designed plans and programs, and overall have implemented many appropriate mitigation and preparedness measures to promote and enable organizational business continuity and to lessen the impact of any destructive earthquake upon the VIHA health care assets and jurisdiction, including the TM function.

c) Yet the findings and recommendations of this study also identify additional measures that could be implemented to advance and enhance the individual and collective efforts of the responsible agencies to improve disaster response capability and TM business continuity, especially with respect to telecommunications and transportation regarding the supply of blood products and evacuation of casualties.

d) The VIHA TM function is relatively well-prepared and organized to operate smoothly in post-quake circumstances, although it may be forced to offer a restricted range of services. However, the capacity and level of preparedness of the weakest link in the health care earthquake response and casualty treatment process would influence the efficiency and effectiveness of other departments involved.

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## Appendix A: List of Abbreviations

ABO - A, B, and O blood types  
AEOC - Area Emergency Operations Center  
BCAS - British Columbia Ambulance Service  
BCBCP - British Columbia Blood Contingency Plan  
BCERMS - British Columbia Emergency Response Management System  
BCTMAG - British Columbia Transfusion Medicine Advisory Group  
CAF - Canadian Armed Forces  
CBS - Canadian Blood Services  
CRCS - Canadian Red Cross Society  
CRERCC - Capital Region Emergency Radio Coordinators Committee  
CREST - Capital Region Emergency Service Telecommunications (Incorporated)  
CSZ - Cascadia Subduction Zone  
DERT – Disaster Emergency Response Team  
EBMC - Emergency Blood Management Committee  
EMB - Emergency Management Branch, British Columbia Ministry of Health  
EMBC - Emergency Management British Columbia  
EMU - MoH Emergency Management Unit  
EOC - Emergency Operations Center  
FMO - (VIHA) Facilities Maintenance and Operations  
HAEOC - (Regional) Health Authority Emergency Operations Center  
HEICS – Health Emergency Incident Command System  
HEMC - Health Emergency Management C  
HRVA - Hazard, Risk, and Vulnerability Analysis  
IBTO - Iranian Blood Transfusion Organization  
ICS - Incident Command System  
IM/IT - (VIHA) Information Management/Information Technology team  
JIBC - Justice Institute of British Columbia  
JMA - Japan Meteorological Association  
JRCC - Joint Rescue Coordination Center for SAR, Victoria Search and Rescue Region  
LERT - CBS Local Emergency Response Team

LMPMG - Laboratory Medicine, Pathology and Medical Genetics (includes TM)  
MARPAC - Maritime Forces Pacific component, Royal Canadian Navy  
MASH - Mobile Armed Services Hospital  
MCTS - (Canadian Coast Guard) Marine Communications and Traffic Services  
MMI - Modified Mercalli Intensity scale  
MMU - (MoH) Mobile Medical Unit  
MDH - Medical Director, Hematopathology  
MoH - BC Ministry of Health  
NAC - National Advisory Committee on Blood & Blood Products  
NBS - British National Blood Service  
NERT - CBS National Emergency Response Team  
NGO - Non-governmental Organization  
NRGH - Nanaimo Regional General Hospital  
NZBS - New Zealand Blood Service  
PAACC - BCAS Provincial Air Ambulance Coordination Center, Greater Victoria  
PBCO - Provincial Blood Co-ordinating Office  
PERCS - Provincial Emergency Radio Communications Society  
PHSA - Provincial Health Services Authority  
PREOC - Provincial Regional Emergency Operations Center  
RBCs - units of red blood cells  
RHA- Regional Health Authority component of BC health administration  
RJH - Royal Jubilee Hospital  
SAR - Search and Rescue  
SEOC – Site Emergency Operations Center  
SPH - Saanich Peninsula Hospital  
STOL - Short Take-off or Landing  
TM - Transfusion Medicine component of VIHA's Department of LMPMG  
URM - buildings with weight-bearing walls of unreinforced masonry  
USAR - Urban Search and Rescue, in various Greater Victoria municipalities  
VGH - Victoria General Hospital  
VTOL - Vertical Take-off or Landing

## Appendix B: Glossary of Terms

**Cold Chain** - The blood cold chain is a series of interconnected activities involving equipment, personnel and processes that are critical for the safe storage and transportation of blood from collection to transfusion (WHO, 2005, p. 1).

**CREST** - Capital Region Emergency Service Telecommunications (Incorporated) provides radio telecommunications for the Capital Region emergency services via a wide-area radio system that links emergency telecommunications for police, ambulance, fire, and other safety service providers (CREST, 2013).

**Health Shared Services BC (HSSBC)** - the BC health care system manages health equipment and supplies for normal operations and emergencies by using a centralized approach involving HSSBC and its component entities. The HSSBC emergency preparedness and disaster response role involves:

- Acquiring, maintaining emergency and disaster inventories of equipment and supplies, pre- and post-disaster , and
- Distributing inventory elements in a post-disaster situation as required (BC MoH, 2012).

**Magnitude** - a number that symbolizes the relative size of an earthquake, in terms of the amount of energy released. Levels are based on

measurement of the maximum seismograph-recorded motion during an earthquake. The most commonly used magnitude scales are (1) local magnitude (ML), or "Richter magnitude," (2) surface-wave magnitude (**Ms**), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited applicability and do not capture the size of the largest earthquakes. The moment magnitude (Mw), based on seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute. All magnitude scales should yield approximately the same value for any given quake (USGS, 2009c, n.p.).

**PGA** - effective peak ground acceleration, or PGA, is a quantitative measure of the level of ground shaking (a short-period ground-motion parameter), expressed as a

percentage of  $g$ , the acceleration of gravity, and is proportional to force (FEMA, n.d.; Shedlock, Giardini, Grünthal, & Zhang, 2000).

## Appendix C: Components of Selected Risk Assessment Methodologies

**Table C. Components of Selected Risk Assessment Methodologies.**

Component	Description
Hazard assessment	Identifies and describes hazards. Also called threat assessment
Hazard identification	Identifies hazards of interest
Hazard description	Describes hazards, including probabilistic estimates of their occurrence, intensity, extent, and duration
Process analysis	Analyzes process leading to an event
Hazard mapping	Maps hazards and their characteristics to geographic coordinates
Probability analysis	Analyzes underlying causes of an event; includes probabilistic estimates of occurrence of underlying causes of an event; may include construction of a fault tree to describe relationship between event and its causes
Dose-response Assessment	Assesses relationship between dose of hazard and its effects
Exposure assessment	Assesses potential exposure; $\text{exposure} = (\text{concentration}) \times (\text{time})$
Community description	Describes community or system at risk, including its geographic location
Criticality assessment	Assesses criticality of components of system impacted by an event
Risk characterization	Characterizes risk in form relevant to risk management
Public perception analysis	Analyzes public perception of risk
Risk aversion	Identifies minimum risk the system is willing to accept
Hazard prioritization	Prioritizes hazards for emergency management

Sources:

1. Arnold (2005)

## Appendix D: Criteria for Effective Disaster Management

**Table D. Criteria for Effective Disaster Management**

Criterion	Health system implications
Recognize differences between response- and agent-generated demands. Agent-generated needs vary with disaster impact and specific agent; response-generated demands (coordinating/mobilizing personnel and resources, and clear task delegation) are common to all disasters.	
Adequate conduct of general functions that may be used in various disaster events, such as setting up temporary settlements and rescue and first-aid activities	Supply chain issues, communication with field staff, disposal of sewage and garbage; finance
Effective mobilization of personnel and resources	Exercising emergency plan, creative staffing practices
Appropriate delegation of tasks and division of labour	
Adequate processing of information	Verification of communications, brief discussion of implications of messages, interpreting surveillance data
Proper decision making	Regarding issues of triage, planning, resource allocation
Development of overall coordination	Clear role definition, lines of authority
Blending emergent and established organizational behaviour	Constructive approach; build upon strengths
Provision of appropriate reports for the news media	Templates can be developed pre-event for some types of events
Establishment of a well-functioning emergency operation center	Assessment of scale of problem; dedicated team needed to operate one effectively

Sources:

1. (Quarentelli, 1997)

## Appendix E: Levels VII to XII, Modified Mercalli Intensity Scale

The Modified Mercalli scale indicates some of the perceived effects due to the shaking generated by an earthquake, at a given place, on natural features, on industrial installations, and on human beings.

**Table E: Levels VII to XII, Modified Mercalli Intensity Scale**

Level	Indicative Phenomena
VII	Standing is difficult; suspended objects quiver. Trees and bushes shake moderately to strongly. Waves occur on ponds, lakes, and running water. Water becomes turbid. Some sand or gravel stream banks cave in. Damage is negligible in well- designed and -constructed buildings, slight to moderate in well-built ordinary structures, and considerable in poorly built or badly designed structures. Some weak chimneys, numerous windows, and cornices crack up and break. Heavy furniture is often overturned.
VIII	Trees and bushes shake strongly, and some branches break off. Temporary or permanent changes may occur in the flow regimes of springs and wells. In specially-designed structures, damage is slight; considerable damage or partial collapse affects substantial buildings. Damage is significant and serious in poorly built structures. Chimneys, factory stacks, columns, monuments, masonry-cemented walls may twist and fall. <i>Very</i> heavy furniture may be displaced significantly, or overturned.
IX	Damage is considerable in seismically designed structures; well-designed frame structures deform out of plumb. Damage great in substantial buildings, with partial collapse. Buildings are often shifted off foundations, and reservoirs may be damaged seriously.
X	Cracks a meter wide may open in the ground. Permanent changes may occur in the flow regimes of springs and wells. Some well-built wooden structures are destroyed; most masonry and frame structures destroyed with foundations. Serious damage would likely occur to dams, embankments, well-built wooden structures, and bridges. Dangerous structural cracks develop in walls, destroying most masonry and frame structures, and their foundations. Railroad rails may bend slightly, and buried pipelines may be torn apart, or buckle in earth. Cement sidewalks and asphalt road surfaces often crack and fold.
XI	Many and widespread ground disturbances occur, varying with ground material. Broad fissures, earth slumps, and land slides are likely in soft, wet ground. Large amounts of water charged with sand and mud are ejected. Seiches are common. Damage is often severe to wood-frame structures, dams, dikes, embankments especially near shock centers. Few, if any (masonry), structures remain aligned or standing. Supporting piers, or pillars of large well-built bridges are wrecked. Flexible wooden bridges may be affected less. Pipelines are destroyed.
XII	Damage is widespread, and few cultural features are untouched. Numerous and significant shearing cracks, landslides, slumps, and rockfalls are likely. Large fault slips may occur in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, may be disturbed and modified greatly. Waves seen and felt on ground surfaces will distort lines of sight and level. Upward thrust may propel objects into the air.

Sources:

1. Wood and Neumann (1931).

## Appendix F: Classification of Areas with Vulnerable Buildings

Onur (2001, p. 42) derived the prototype categories shown in Figure 15 and Table F from the Applied Technology Council document ATC-13 (ATC, 1985), as modified for southwestern BC building practices. Buildings were initially grouped by type of structural construction material, with those groups subdivided according to the heights, structural systems, and ages of the buildings. For further detail regarding these prototypes, see Appendix B of Onur (2001).

**Table F. Classification of Key Buildings Identified in Figure 14.**

Materials	Building Prototype	Code
Concrete	Concrete frame with concrete walls high rise	CFHR
	Concrete frame with concrete walls low rise	CFLR
	Concrete frame with concrete walls medium rise	CFMR
Masonry	Reinforced masonry shear wall low rise	RMLR
	Unreinforced masonry bearing wall low rise	URMLR
	Unreinforced masonry bearing wall medium rise	URMMR
Wood	Wood light frame low rise commercial/institutional	WLFCI
	Wood light frame low rise residential	WLFLR
	Wood light frame residential	WLFR

Sources:

1. Onur (2001, p. 43).

## Appendix G: Phases of the BC Blood Contingency Plan

Implementation of segments of the BC Blood Contingency Plan is based on three phases, each of which corresponds to the inventory of blood products then available in British Columbia. The phases are coded by color, and are further elaborated in Table G:

1) Green: Normal blood component inventory levels exist and supply generally meets demand. This phase includes a broad range of inventory levels ranging from an ideal inventory to shortages that occur periodically and can be managed with existing CBS/hospital actions.

2) Amber: Blood inventory is not sufficient to continue with routine transfusion practices and hospitals will be required to implement specific measures, as outlined in this plan, to reduce blood use.

3) Red: Blood inventory is insufficient to ensure that patients with non-elective indications for transfusion will receive the required transfusion(s) (BCTMAG/PHSA/BCPBCO, 2009, p. 9).

**Table G: CBS Inventory Levels that Correspond to BC Blood Contingency Plan Phases**

Phase	CBS Inventory level (hours/days on hand)			
	RBCs	Platelets*	Frozen Plasma	Cryoprecipitate
Green	> 72 hours	50 to 100% of daily national requirement	> 10 days	> 20 days
Amber	48 to 72 hours	25 to 50% of daily national requirement, recovery expected within 12 hours	3 to 10 days	6 to 20 days
Red	< 48 hours	< 25% of daily national requirement, no recovery expected within 12 hours	< 3 days	< 6 days

Platelet inventory levels appear as a percentage of the daily national requirement rather than as hours or days on hand. Platelets have a shelf life of just 5 days, and the CBS typically has merely a 1.5-day inventory on hand.

Sources:

1. BCTMAG/PHSA/BCPBCO (2009, p. 10).

## **Appendix H: Rationale for Increasing the Documented Rates of Rural Risk, Injury, and Hospitalization, Regarding Fires Following Earthquakes**

Zhao (2010, p. 83) asserts that "the losses from fires following earthquake...have sometimes been greater than the direct losses caused by...[an] earthquake itself ". Faggiano and Mazzolani (2011) echo that concern, adding that the *multiple simultaneous ignitions* that often occur during or following an earthquake probably are contributing factors. A monograph by Scawthorn, Eiding, and Schiff (2005) is regarded as the American reference regarding fire following earthquakes, and Scawthorn (2008) reflects their findings. Kelly and Tell (2011) note, however, that Scawthorn et al. (2005) provide no estimates of how many fires--warranting fire department responses--may *not* have been reported to fire departments, due to occupants of affected dwellings being immobilized by earthquake-driven injury, or physically unable to reach or use a telephone. In addition, such occupants may have been unable to *connect* with fire departments, due to damaged telephone lines or cell towers, or to saturation--busy signals due to numerous other calls to fire departments for rescue, traffic accidents, or other fires (Kelly and Tell, 2011). This under-accounting, though, would not likely increase significantly the rates of ignition of fires following earthquakes.

However, the Jones et al./USGS (2008) initial ratios mentioned on page 77 are founded on fire incidents that occurred largely under *normal* conditions. The following factors make *post-quake circumstances and fires* more hazardous, warranting increases in the ratios. Once a response to a post-quake fire is initiated, trucks may be delayed by debris from building collapse and downed power lines in the streets, and traffic disruptions due to non-functioning traffic lights (Kelly and Tell, 2011). Such delays could increase the likelihood of both accelerated burning and serious injury. At the scene, earthquake-induced damage to the burning structures may already have (a) disabled both active and passive fireproofing systems (Mousavi, Bagchi, and Kodur, 2008) and (b) distorted the original compartments such that air/oxygen is much more readily available for combustion within them (Nishino, Tanaka, and Hokugo, 2012). On the other hand, unless water pressure and flow in a dwelling unit drop due to breaks in the street mains or the exterior connections thereto, water may initially spray from breaks in the household interior piping, diminishing the rate of combustion in certain areas of the unit. Neither the frequency nor the significance of such interior wetting in these circumstances appears to have been documented, however.

At some locations, due to broken water mains, water from may not be available for fire suppression. If dwellers are trapped under fallen debris, evacuation would be more difficult, if not impossible. Firefighters would likely spend more time assessing the safest rescue route into and out of a building whose structural and load-bearing members have *already* been damaged by the earthquake (Faggiano and Mazzolani, 2011; Nishino et al., 2012). Furthermore, Scawthorn (2008, p. 10) suggests that "about half of all ignitions would be electrical related, a quarter gas-related, and the other due to a variety of causes, including chemical reaction." If fire in a partially collapsed multiple-unit residential building has a high fuel load equivalent density consisting partially of natural gas, it may spread and become hotter more quickly than when, in the same setting, natural gas is not leaking. The combustion of this added, contiguous fuel, at least in upper pockets in the structure, likely would diminish the chances of escape for residents of the upper floors.

The aforementioned factors provide justification for slight increases in the rates of injury, hospitalization, and rural risk associated with those fires that follow damaging

earthquakes. Therefore, those rates have been marginally increased, and used in calculations on page 78, and in Appendix G.

### **Appendix I: Potential Hospitalizations Due to Injuries Created by Fire Following an Earthquake--Subduction and Shallow Types**

Assume that a subduction earthquake shakes all of Greater Victoria at level of MMI VII to VIII. From the calculations for the deep scenario earthquake, it is evident that these levels of shaking do not generate any hospitalizations due to fire following.

Assume that the *shallow* quake subjects 45% of the Greater Victoria population to shaking at MMI IX, and that the balance are shaken at MMI VIII. Scawthorn (2008) produced a table showing the reducing residential floor area involved per single fire ignition as MMI increases. Table I shows that gradation, and its relationship to population in a conurbation. The calculations below illustrate how the added population equivalents were derived.

At MMI VIII, there is one ignition of a post-quake fire requiring fire department response per either 10.5 million ft<sup>2</sup>, or per every 25,000 of an urbanized population (Scawthorn, 2008). As MMI levels increase, the minimum floor area required for an ignition decreases (Scawthorn, 2008).

$$\text{MMI IX } 4.5 \text{ million ft}^2 / 10.5 \text{ million ft}^2 = .42857 \quad 25,000 \times .42857 = 10,714$$

$$\text{MMI X } 1.5 \text{ million ft}^2 / 10.5 \text{ million ft}^2 = .142857 \quad 25,000 \times .142857 = 3,571$$

**Table I. Floor Area (in Millions of Square Feet) vs. One Fire Ignition at a Given MMI**

MMI	VII	VIII	IX	X
1 ignition per million ft <sup>2</sup>	18 million	10.5 million	4.5 million	1.5 million
Population equivalent	42,857	25,000	10,714	3,571

Source: (ignitions) Scawthorn (2008)

Recall from page 78 that about 75,000 (.203) of Greater Victorians live in a relatively *rural* setting

$$75,000 / 369,775 = .203$$

$$369,775 \times .45 = 166,394 = \text{number shaken at MMI IX}$$

Assume that the number of *rural* residents shaken at MMI IX is  $166,394 \times .203 = 33,779$

$33,779/10,714 = 3.15$  fires among *rural* residents shaken at MMI IX

$3.15 \times .05 \times 3.0 = .4725 \times .35 = .1654$  hospitalization, *rural* group shaken at MMI IX

That leaves  $166,394 - 33,779 = 132,615$  *urban* residents shaken at MMI IX

$132,615 / 10,714$  per ignition = 12.38 fires among *urban* residents shaken at MMI IX

$12.38 \times .05 = .619 \times .35 = .2167$  hospitalization, *urban* residents shaken at MMI IX

$369,775 \times .55 = 203,376$  shaken at MMI VIII

$203,376 \times .203 = 41,285$  in the *rural* group shaken at MMI VIII

$41,285/25,000 = 1.651$  fires requiring fire department response among *rural* residents shaken at MMI VIII

$1.651 \times .05 \times 3.0 = .2477 \times .35 = .0867$  hospitalization, *rural* residents shaken at MMI VIII

$203,376 - 41,285 = 162,091$  *urban* residents shaken at MMI VIII

$162,091/25,000 = 6.484$  fires requiring fire department response

$6.484 \times .05 = .3242 \times .35 = .1135$  hospitalization, *urban* residents shaken at MMI VIII

$.1654 + .2167 + .0867 + .1135 = .5823$  hospitalization, which is  $< 1$

Therefore, no hospitalizations are likely, due to fires following a shallow earthquake in or near Greater Victoria.

## Appendix J: Abridged Estimates Package

### 1. Purpose of This Document

This document provides key informants with information about the regional seismic hazard and the methodology used to estimate the injuries and hospitalizations likely to result from three types of earthquakes that could affect Greater Victoria. Key informants' answers to the researcher's questions would be useful to help draft an earthquake-

specific blood contingency plan for VIHA Transfusion Services, and to help refine MoH earthquake preparedness elsewhere.

## **2. Impacts of the Hazard Being Manifest as a Damaging Earthquake**

A damaging earthquake may cause some or all of the following consequences:

- building damage: in the 1999 Taiwan earthquake, 80/180 hospitals were damaged, 14 of them severely (Tseng, Hemenway, Kawachi, Subramanian, and Chen, 2010).
- disrupted/damaged transportation routes (often bridges), and communication links, making these now *potential* links especially valuable;
- reduced hospital operations due to loss of services such as electricity, water, sewage disposal, suction/vacuum, and just-in-time delivery of medical supplies and gases;
- traffic overload on telephone lines and other telecommunication media;
- some limitations on the ability of police, fire, and medical aid units to respond;
- serious injuries to hospital staff, patients and the general public (VIHA, 2007)
- asbestos to be liberated within older buildings due to shaking (Tierney, 1999).

The human consequences of earthquakes relate to factors such as: population density in the affected area; injury mechanisms; and the age, location, behaviour, and state of health (mobility, strength, plus physical endurance and psychological resilience) of victims at the time of the quake (Naghii, 2005; Shoaf et al., 1998).

## **3. Typical Injuries and Victims, and Admissions Surge**

Non-structural items falling on people caused most of the injuries in the Loma Prieta and Northridge earthquakes (Bourque, Siegel, and Shoaf, 2002). Peek-Asa et al. (1998), regarding the 1994 Northridge quake, found that extremity injuries prevailed among those hospitalized. Many who were hospitalized had fallen or had been hit by objects, or were burned, or injured in or by a motor vehicle (Peek-Asa et al., 1998). Tables J1 and J2 elaborate on earthquake-related injuries and conditions expected to result in hospitalizations.

**Table J1. Typical Earthquake-driven Injuries and Conditions Likely to Require Hospitalization**

Source	Injuries	Injuries/Triggered Events	Complications	Complications
Naghii (2005) (1)	cervical spine injuries with neurologic impairment; heart attack; damage to intraabdominal, intrathoracic, and intrapelvic organs	fractured skull with intracranial haemorrhage; increased rates of premature births, abortions, and normal deliveries	multiple organ failure, adult respiratory distress syndrome, and crush syndrome	systemic effects: hypovolaemic shock, hyperkalemia, renal failure, fatal cardiac arrhythmias; hypothermia, secondary wound infections
Tsai, Lung, and Wang (2004) (2)			3.6 X acute heart attack admissions post-quake, versus same period of previous year	
Kuwagata et al. (1997) (3)	crush syndrome, vital organ injuries			
Emami et al. (2005) (4)	fractures of the spine, ribs, and/or pelvis			

Sources:

1. Naghii (2005, p. 219)
2. Tsai, Lung, and Wang (2004)
3. Kuwagata et al. (1997)
4. Emami et al. (2005)

**Table J2. Categories of Injuries and Hospital Admissions from the Taiwan Earthquake, 1999**

Source				
Chan et al. (2006) (1) <b>Hospitalizations</b>	open wounds (61%)	limb fractures (16%)	closed head injury (9%)	burns (3%)
Chan et al. (2006) (1) <b>Injuries only</b>	head injury (33%)	traumatic shock (29%)	asphyxiation (29%)	(9%) - organ damage, spinal cord injury, burns, and carbon monoxide poisoning

Sources:

1. Chan et al. (2006)

Quake-driven injuries in downtown Victoria may result from glass falling onto people. If glass cuts a victim's critical vessels or organs, considerable blood will be required initially, and likely during the next few weeks, for orthopaedic and plastic surgery (Gilcher, 2001). In a study of 814 *clinics* that assisted victims of the Kobe earthquake, those injuries dealt with during the first week post-quake and classified by Goto (2009) as serious or critical totalled to 2% of injured people assisted during that period. Table J3 also illustrates how the case mix evolved after day one; these same categories totalled 8.9% of the total for that day (Goto). Data from earthquakes in Armenia and California indicate that children between 5 and 9 years old, adults over 60 years of age, women, and the chronically ill are apparently at elevated risk for injury and death as a result of earthquakes (Armenian, Melkonian, Noji, and Hovanesian, 1997; Peek-Asa et al., 1998; Peek-Asa, Ramirez, Seligson, and Shoaf, 2003).

**Table J3. Clinical Patients and the Severity of Their Conditions (814 Clinics)**

Timing	Minor	Serious	Critical	Total
Day of quake	7,303 (91%)	590 (7.4%)	121 (including 109 DOA) (1.5%)	8,014
1 <sup>st</sup> week following quake	103,440 (98%)	1,894 (1.8%)	221 (0.2%)	105,555

Sources:

1. Goto (2009, p. 3).

#### **4. Injuries and Their Degrees of Gravity**

Shoaf, Seligson, Peek-Asa, and Mahue-Giangreco (n.d.), in laying out a proposed standardized injury categorization scheme for earthquake-related injuries, used a number of classification tools. Their injury severity categories are based on the Abbreviated Injury Scale (AIS) and Injury Severity Scale (ISS) that were current in 1990; ISS values were meant to be applied to the overall level of injury to the individual (Shoaf et al., n.d.). In this research, the term *serious* is applied to those injuries or conditions classified as warranting hospitalization; this term includes the following broad categories of injury and treatment, as provided by Shoaf et al. (n.d., n.p.).

Injury Severity:

1. Severe: The injuries seriously threaten the life of the individual, and require immediate medical attention. (AIS: At least one level 5, severe injury, or at least three

regions with level 3 or 4 injuries (ISS 25 - 75)

2. Moderate: Injuries are survivable, but without medical attention, could become severe. (AIS: No more than two injuries with severity above 3 or 4 (ISS = 13 – 24))

Treatment: A. Level of Treatment

Treatment generally refers to the level of training required to treat the most serious injuries that a person has. The level of treatment needed is based on the apparent severity of the injury.

1. Trauma – This highest level of treatment assumes that the seriously injured require specialized care. This level of treatment is available in trauma hospitals and specialized care hospitals, which have sub-specialists who treat cases complicated by age, type of injury, or multiple traumas.

2. Emergency – At this level, a victim needs access to advanced life support, anaesthesia, surgery, or other services generally only available in a hospital with an emergency department.

B. Immediacy

Immediacy refers to how soon the seriously injured person needs advanced care. Ranking is based on the triage system used by emergency medical personnel in dealing with multiple casualty incidents. Prioritization of treatment is systematically applied, although rankings may differ, depending on the resources available. The four levels are: green (minor); yellow (delayed care); red (immediate care); and black (deceased).

1. Red – First priority: These injuries will likely be a serious threat to life within an hour and the person requires immediate hospitalization. Included in this grouping are injuries with airway, breathing and shock problems, major burns, uncontrolled or severe bleeding, or decreased mental status.

2. Yellow – Secondary priority: These people will need care in a hospital but transport can be delayed temporarily without threat to life. The injuries include burns without airway complications, back problems (with or without spinal cord complications), major or multiple bone or joint fractures, and controllable moderate haemorrhage.

1. Shoaf, Seligson, Peek-Asa, and Mahue-Giangreco (n.d.).

### 5. Estimates of Hospitalizations by Type of Earthquake

Table J4 displays estimates of hospitalizations likely to result from three types of earthquakes that would generate strong ground movement of or above MMI VII, and physically damage Greater Victoria. A shallow quake may bring the most hospitalizations, as MMI could reach IX (CREW, 2010). All of the estimates contain significant uncertainty, as discussed in Chapter 6. The uncertainties are similar in magnitude to those identified by Trendafiloski, Wyss and Rosset (2009), who compared numbers of *observed* seriously injured (SI) from six Peruvian earthquakes to their mean estimates of those SI, which had error of approximately  $\pm 40\%$ .

**Table J4. Estimated Hospitalizations, by Type of Earthquake Affecting Greater Victoria**

Type of earthquake	Details	Number of serious injuries expected/uncertainty	Number of hospitalizations expected
<i>shallow</i> localized earthquake	MMI is felt VII to IX throughout the City of Victoria	403/factor of 1.5	403
M8 subduction quake	MMI is felt VII to VIII across Vancouver Island (1); peak ground acceleration of about 1.8m/sec/sec over an area 300km by 500km	324/factor of 1.5	324
<i>deep</i> earthquake	MMI is felt VI to VII across southern Vancouver Island	40/factor of .5	40

Sources:

1. Atkinson and Boore (2003)

### 6. Methodology for Estimating the Source and Target Hospitalizations

The key factors considered in order to estimate the numbers of hospitalizations in Greater Victoria due to damage from the respective earthquake types are (1) the average population densities and numbers of serious injuries or known hospitalizations in areas intensely affected by earthquakes of a given type, (2) how far such settled areas are from their respective earthquake epicenters, and (3) the ratios of destruction within the areas intensely affected. The last segment of this package contains tables (J6, J7, and J8) that display details regarding the actual earthquakes and scenarios considered.

Translating, for each type of quake, the cumulatively averaged numbers of recorded hospitalizations or *serious* injuries from *source* unit areas, all with similar averaged population density—into the numbers likely hospitalized in a *target* unit area with similar averaged population density values—has involved attempts to determine the relationships between data of different levels of population density and aggregation. Such relationships are shaped by numerous variables, including the “packing” of the aggregation, the intensity of shaking, the building construction types, surficial geology, and human behaviour, within the respective spaces (Gotway and Young, 2002). The derived estimates of hospitalizations are of the appropriate *order of magnitude* given specified earthquake magnitudes, distances to epicenters, and likely intensities of shaking, but involve considerable uncertainty, as discussed in Chapter 6 and below.

### **Uncertainty in Comparing Victoria Scenarios to Actual Earthquakes**

Do quakes with equivalent Ms create identical MMIs in different locations? No, because attenuation relationships and ground motion amplification factors differ due to geologic variation, and because the frequency of the shaking varies rapidly over time. In applying hybrid-empirical ground-motion relations (which use M to predict SGM) for quakes in Cascadia, Atkinson (2004) suggests an overall epistemic uncertainty of a factor of 1.5 to 2. In Table J5, Petersen et al. (2008) provide a useful perspective on epistemic uncertainties within a typical probabilistic seismic hazard assessment (PSHA) logic tree for considering the seismic hazard within the CSZ. Atkinson and Casey (2003) analyzed ground motions from the 2001 M 6.8 in-slab earthquakes in Nisqually and Japan, and, based upon computed theoretical amplification functions for typical generic soil profiles for each region, suggest that sites in Japan would have larger ground motion amplification at high frequencies of motion, while sites in Cascadia will have peak amplification at low frequencies. The Composite Relative Earthquake Hazard Map of Greater Victoria (Monahan, Levson, Henderson, and Sy, 2000a) indicates approximately where ground motion may be amplified. However, Shoaf et al. (1998, n.p.), in comparing the Northridge and Loma Prieta quakes with respect to injury types by geographic area, also found that “those in MMI VIII areas have higher rates of injury than those...in MMI IX...”

### **Epistemic Uncertainty in Data on Earthquake-driven Injuries: Example**

(Monahan, Levson, Henderson, and Sy, 2000a) and Tanaka et al. (1998), for different purposes, examined the records from 48 of 51 *key* hospitals affected by the 1995 Kobe earthquake. Matsuoka et al. state that their dataset included more than 75% of newly-admitted patients—omitting nearly 25%. Additional uncertainty exists in the description of the *severity* of injuries and illnesses that afflicted the Kobe earthquake victims. Patients treated in intensive care comprised just 15.79% of the total number of admissions. Of the 5611 new admissions, 2,255 were transferred, in some cases to facilities with specialized equipment. However, the authors state that “there was no notable difference in the percentage of intensive care patients and non[-]intensive care patients transferred to backup hospitals” (Tanaka et al., 1998, p. 439). This may imply either that all transferees had severe illnesses or injuries, or that  $2,255 \times .50 = 1127$ , (20% of those admitted) may *not* have had severe injuries or illness.

To that we add error regarding the precise number of hospitalizations *per areal unit*, which introduces some aleatory uncertainty, as well. Matsuoka et al. (2000, p. 250) employed an estimated *illness* morbidity ratio in each area, which was “the ratio of the actual number of patients observed in each area to the corresponding number of patients expected on the assumption that the 14 areas would have approximately the same morbidity rates for illness...for the first 15 days following the earthquake.” This ratio likely involves 5% to 10% error. In addition, the same assumed ratios were used to apportion the numbers of *injuries* amongst the areal units, thereby likely incorporating the same level of error across the dataset.

With respect to these data, the following issues were identified: (1) an estimated omission error of nearly 25% regarding the total number of people injured or made ill from this earthquake who were admitted, or warranted hospitalization; (2) an estimated uncertainty of 20% regarding the gravity of the included admissions; and (3) an estimated maximum error of 10% regarding the geographic distribution of these earthquake victims. Therefore, within these Kobe earthquake injury/illness data sources, an estimated 55% epistemic uncertainty exists with respect to the total number of hospitalizations derived.

**Table J5. Epistemic Uncertainties in Probabilistic Seismic Hazard Analysis, Cascadia Subduction Zone**

Fault model segment	Magnitude model segment	Rupture-depth model, thermal segment	Rupture-depth model, elastic segment	Ground-motion models segment
.067 for the entire CSZ, and 0.33 for the floating magnitude model (1)	Uncertainty in magnitude models ranges 0.2 to 0.6 (1)	Uncertainty averages to 0.5 (1)	Uncertainty ranges 0.2 to 0.4 (1)	Uncertainty ranges 0.25 to 0.5 (1)

Sources: 1. Petersen et al. (2008).

## 7. Tables Detailing the Earthquakes and Scenarios Examined

**Table J6. *Shallow* Earthquakes and Shallow Earthquake Scenarios Examined to Derive Usable Data**

Name of Earthquake	Location and Magnitude	Depth and Other Notable Features
Kobe, Japan, 1995	Greater Kobe, M=7.2	14 km deep; basin effects confirmed; 15 seconds of MMI 11-12 (1)
"Chi-Chi", Taiwan, 1999	Central Taiwan, M=7.6	1-7 km deep; MMI VIII-IX; (2); basin effects suspected (3)
Loma Prieta, California, 1989	Loma Prieta Section, northern San Andreas Fault; Epicenter 15.12 km east of Santa Cruz; M=7.1 (4)	17.5 km; 7 to 15 seconds, MMI VIII in Santa Cruz and Watsonville; damaged properties 100 km from epicenter, 2X distance of normal instances, due to deep clays amplifying ground motion (5)
Northridge, California, 1994	Northwestern Los Angeles County; M=6.7 (6)	16.6 km deep; MMI VII-X for 7 to 15 seconds; (7); (8)
Southern California (Shakeout) <i>Scenario</i>	on the San Andreas fault in southern California, M 7.8	13-16 km deep; strong shaking for up to 100 seconds (9)
Olympia Area-Seattle Fault <i>Scenario 1</i> (Thurston County)	Seattle Fault zone 4- to 7-km wide; (11); M=6.7	5-15 km (10)
Seattle Fault <i>Scenario 2</i>	M=6.7	5-15 km (12)
Puget Sound Area, Washington <i>Scenario</i>	M7.0 – 7.5	Up to 25 km deep; MMI VII - IX (13)
Christchurch, N.Z., 2011	M 6.3 (15)	5 km deep; MMI VII - IX (15); 164/594 admissions were serious (14)
Greater Victoria Shallow <i>Scenario</i>		MMI of VII to IX throughout Victoria

Sources:

1. Ukai (1997)
2. Chen, Chen, and Malilay (2003)
3. Liao et al. (2003)
4. USGS (2009b)
5. Holzer (1994)
6. USGS (2009b)

7. Earthquake Engineering Research Institute and Washington Military Department Emergency Management Division [EERI/WMDDEMD] (2005)
8. Jones et al./USGS (2008).
9. Jones et al./USGS (2008).
10. TRPC (2009)
11. Johnson, Potter, and Armentrout (1994)
12. EERI/WMDDEMD (2005)
13. CREW (2010)
14. Vervaeck and Daniell (2011)
15. USGS (2012b)

**Table J7. Subduction Earthquakes and Subduction Earthquake Scenarios Examined**

Name of Earthquake	Location and Magnitude	Depth and Other Notable Features
1964 Alaska earthquake	Prince William Sound, M=9.2	tsunami killed more than the quake
February 27, 2010, Chile	offshore near Maule, Chile, M=8.8	35 km (1); MMI VII in Curico, Constitution, and Rancagua; VIII in Talcahuano (2); 2.3m tsunami waves hit Constitution and Talcahuano (3)
August 15, 2007, Peru	near Chincha Alta, Peru, M=8.0	39 km (4); 2.6 minutes (5)
Cascadia Subduction Earthquake <i>Scenario</i>	SW BC, Washington, Oregon, and northern California, M=8	MMI VII – VIII locally (6); tsunami waves unlikely to damage Greater Victoria to a great extent (7)

Sources:

1. USGS (2010a)
2. USGS (2010b)
3. ReliefWeb, G-MOSAIC Project (2010b).
4. USGS (2007)
5. Taucer, Alarcon, and So (2009)
6. CREW (2005)
7. Capital Regional District (2006).

**Table J8. Deep (Intraslab) Earthquakes and Deep Earthquake Scenarios Examined**

Name of Earthquake	Location and Magnitude	Depth and Other Notable Features
Nisqually, 2001	17.6 km NE of Olympia, Wa., M=6.8; (1)	15-20 seconds; felt over 350,000 km <sup>2</sup> (2)
Seattle Fault, 1965	19.4 km north of Tacoma, Wa., M=6.5	64.4 km; VII; pockets of MMI VIII; (3)
Puget Sound (Olympia) Area, 1949	13 km NNE Olympia; M=7.1 (4)	54 km; MMI VIII for 20 seconds; (5)
Greater Victoria Deep Earthquake <i>Scenario</i>	within 30 km; M=7.2	40 km; MMI VI–VII; 15 to 20 seconds

Sources:

1. Washington Military Department Emergency Management Division [WMDDEMD] (2009)
2. Molnar, Cassidy, and Dosso (2004)
3. Washington State Emergency Management Division [WSEMD] (2007)
4. Thurston Regional Planning Council [TRPC] (2009)
5. WMDDEMD (2009)

## **Appendix K: Some Nearby Federal Resources That Could Assist VIHA in its Response to a Damaging Earthquake**

### *The Joint Rescue Coordination Center - Aircraft Resources*

The Joint Rescue Co-ordination Center, (JRCC) located in Greater Victoria on Canadian Forces Base Esquimalt, coordinates the Search and Rescue response to air and marine incidents within British Columbia and the Yukon, plus searches on the marine waters off British Columbia (Wikipedia, 2011b). Once an EMBC request for federal air transportation resources is made, the JRCC can arrange, for example, for the Canadian Forces' 442 Transport and Rescue Squadron, located at Comox, to provide both fixed wing and helicopter transportation (Wikipedia, 2011b). The 442 Squadron operates five Cormorant helicopters (two typically serviceable) and six de Havilland Canada DHC-5 Buffalo fixed-wing aircraft (four typically serviceable) (Captain Kennedy, JRCC, personal communication, May 30, 2012; Captain Scott Goebel, CFB Comox, personal communication, May 30, 2012; Wikipedia, 2011b). Each Cormorant can carry up to 12 stretchers with medics effectively in marine and mountain environments (Royal Canadian Air Force (RCAF), 2012a). The Buffalo can easily land or take off in the length of a soccer field, has low speed manoeuvrability, can function well in mountainous terrain, and transport 24 stretchers (RCAF, 2012b; Wikipedia, 2011c). CH-146 Griffon helicopters, which can carry up to 6 stretchers, plus two pilots and a flight engineer, at speeds of up to 260 kmph (RCAF, 2012g, 2012g; Wikipedia, 2012g), could be called in to BC. CH-124 Sea King helicopters are from time-to-time on station at Patricia Bay, just north of Victoria. Configured for search and rescue, a Sea King can carry up to 22 survivors, or 9 stretchers and 2 medical officers (Airforce-technology.com, 2012). All of these Canadian Forces' SAR-capable aircraft can be airborne with two hours' notice (Sgt. Andy Gervais, Canadian Navy Pacific Fleet, 443 Maritime Helicopter Squadron, personal communication, May 30, 2012).

### *Marine Transportation and Telecommunication Resources*

The Canadian Coast Guard and the Canadian Coast Guard Auxiliary together provide the primary marine rescue resources to the federal search and rescue system. Their operations based at Victoria and Tofino would most likely be involved following a nearby

subduction earthquake and tsunami. In theory, a hovercraft or Coast Guard vessel obtained via the JRCC could be used.

To help ensure public safety in British Columbia's southern coastal inside waters, the Canadian Coast Guard Marine Communications and Traffic Services (MCTS) base Victoria, located at Patricia Bay, provides radar coverage, plus Coast Guard Radio and Vessel Traffic coverage via VHF radio (Fisheries and Oceans Canada/Canadian Coast Guard, (F&OC/CCG) 2008). The Vancouver-bound/outbound deep draught vessels, and the active tugboats and coastal freighters involved in Washington-to-Alaska trade, pass through the marine zone regulated by the Victoria MCTS (F&OC/CCG, 2008). This traffic, plus the local commercial trade, create numerous traffic movements involving sizable vessels (F&OC/CCG, 2008).

#### *Other Local Capabilities, Canadian Forces*

CFB Esquimalt also has a new base fire hall and emergency response center that features five drive-through bays for emergency vehicles, and is seismically designed to be operational following an earthquake (National Defence Canada, 2012a). The auxiliary oiler replenishment ship HMCS *Protecteur* is stationed at CFB Esquimalt. This vessel has 365 officers and crew, sizable boilers, a steam turbine that can generate significant electrical power for localized use, and the capability to land most Canadian Navy helicopters (Wikipedia, 2012d). CFB Esquimalt is also home base for 4 or 5 *Halifax* class patrol frigates that each have two gas turbines that combined have a maximum output of 35,400 kW, plus a cruise diesel with a maximum output of 6,600 kW (Wikipedia, 2012e; 2012f). This power generation capacity may be very valuable in a post-quake situation.

At Patricia Bay, Canadian Forces 443 Squadron has constructed a new facility that houses nine CH-148 Cyclone helicopters, operational and maintenance support spaces and equipment, plus 350 personnel (National Defence Canada, 2012a). Up to five Cyclone helicopters can be parked on the new aircraft apron adjacent to the facility (National Defence Canada, 2012a).

## **Appendix L: Letter of Information and Consent Form**

Thank you for considering this invitation to engage in research regarding an earthquake-specific blood contingency plan for the British Columbia Health System.

You may verify the ethical approval of this study, or raise any concerns you might have regarding the conduct of the research, by contacting the Human Research Ethics Office at the University of Victoria at 250-472-4545 or [ethics@uvic.ca](mailto:ethics@uvic.ca), and the VIHA Research Ethics office at 250-370-8620. My Ethics Protocol Number is J2009-70.

### *The Researcher*

This document provides information that you should consider in order to decide whether you will participate in this research project. My name is Bruce Sanderson. I am the Principal Investigator regarding this research, and a graduate student in the Department of Geography, University of Victoria. You can verify this via the following means:

- a) Contacting the University of Victoria Geography Graduate Secretary at 250-721-7350, or by e-mail at [geograd@mail.geog.uvic.ca](mailto:geograd@mail.geog.uvic.ca);
- b) Contacting my Supervisor, Dr. Martin Taylor, at 250-721-7231, or by e-mail at [onet@uvic.ca](mailto:onet@uvic.ca);
- c) Reading the information on the attached business card

### *Funding of the Research*

The British Columbia ministries of (1) Health Services, and (2) Energy, Mines, and Petroleum Resources have funded the initial portion of this research. Funding provided through my supervisor, Dr. Martin Taylor, has supported much of the latter work.

### *The Goal and Key Objectives of This Research Project*

The overarching goal of this study is:

to strengthen the Transfusion Medicine (TM) emergency response management function within the Vancouver Island Health Authority such that the TM component will be better able to deal with the impacts that it would likely face as a result of any of three types of earthquakes that could cause significant damage in Greater Victoria.

The Objectives of this Project

For three different post-earthquake event circumstances, the objectives are:

- To provide realistic estimates of the local hospitalizations that would likely result if these different damaging earthquakes were to affect Greater Victoria
- To briefly examine the staffing, inventory monitoring, communication, decision-making, transportation, vulnerability reduction, operating procedures, and blood product distribution components that could comprise part of an earthquake-specific blood contingency plan for Greater Victoria transfusing hospitals
- To plan for supplying new blood products, related materials, and services, to maintain the function of the Transfusion Medicine role within Greater Victoria transfusing hospitals during post-earthquake circumstances in which some of their facilities or equipment for storing, monitoring, preparing, analyzing, or transfusing blood products have been rendered inoperable

#### *The Nature of the Questions*

The general objective of the questions is to confirm information already accumulated, and to gather knowledge and generate ideas in order to help create an earthquake-specific blood contingency plan. To assist participants, I will supply each of them with background material that contains estimates of the respective numbers of hospitalizations resulting from the likely earthquake scenarios that could affect Greater Victoria.

#### *The Duration of the Interview*

I estimate that each interview will require forty-five minutes to one hour.

#### *Total Time Commitment to Which a Participant Could Consent*

The consultations that I plan to carry out with each respondent involve, as a minimum, one interview, as identified above. I plan to ask some of the participants to continue their participation in one or both of two group situations: a focus group, and a final verification workshop. The Consent Form incorporated in this document provides for you to indicate your Free and Informed Consent to participate in any one, or all, of these three consultations.

In the 1.5 hour focus group, participants will discuss questions and suggestions that arise from the interviews, and some further logistical details and implications likely to apply in the three post-earthquake situations. They will consider these topics in the context of blood contingency planning at the levels of the hospitals, the regional health

authority, and provincially. With participants' permission, the event will be videotaped, for accuracy and speed in information gathering. I would then review the videotape(s), noting qualitative information that provides options for improving the TM response to and recovery from an earthquake disaster, and organize key information (pre-existing and resulting from the focus group) in a format useful for earthquake-specific modifications to the VIHA External Disaster Laboratory Response Process.

The final consultation would be a two-hour verification workshop, to be held on Friday, April 29, 2011. I will invite some of the interviewees to attend the workshop, along with members of the Earthquake Hazard Research Project Advisory Team, assembled by MoHS for the purpose of supporting the research. Workshop participants will help to evaluate and validate the research findings, and to identify any minor remaining issues. This feedback will help shape final recommendations. This event also will be recorded—on DVD, or on audiotape, or via taking written notes. The information gathered will be appropriately analyzed, and items critical to (1) constructing a usable earthquake-specific Internal/External Disaster Laboratory Response Process and (2) proposing any new MoHS policies to support this process, will be incorporated in the final project report.

*The Benefits that You May Experience by Participating in This Research*

You will likely experience a degree of satisfaction from contributing your knowledge, insights and advice to this research process. Your contribution may help save lives during the response to an earthquake, and may help reduce risk of injury to people and damage to crucial equipment when the workplace is subject to an earthquake. For your part in this project, you will, if you desire and agree to it, also receive written acknowledgement in the final report. Included in the Consent Form is a space for you to sign to signify your agreement for your name to be acknowledged in the final report. If you are a civil servant, I will not offer you any inducement to participate.

Society at large may derive benefits from the efforts of those who participate and help create a greater degree of earthquake preparedness within the British Columbia health system, but this will likely never be obviously evident to society.

An all-hazards blood contingency plan has already been developed by representatives from the Provincial Blood Coordinating Office, the Transfusion Medicine Advisory Group,

regional health authorities, and the Canadian Blood Services. An earthquake-specific plan is timely for coastal BC, as the risks of damaging earthquakes affecting densely populated areas such as Greater Vancouver and/or Greater Victoria are real.

#### *Regarding the Participant's Working Environment*

If your organization has policies regarding employees' participation in research about their organization (e.g., confidentiality agreements, employee oaths), the research inquiries involved in this project are not likely to create potential risks to participants' employment.

#### *Participant's Option to Withdraw from Participation in the Research*

I thank you kindly for taking the time to consider participating in this research project. I would truly appreciate—and ultimately many others will benefit from—the contribution that you can make to this research project. Your participation in this research project would be voluntary and you may withdraw from an interview, or from this entire research process, at anytime without penalty. You need not give any explanation for your decision in this regard. After you inform me of your decision to withdraw, I will not approach you to ask you to continue your consent for involvement. If you have already contributed, I will, however, likely ask you for permission—regarding the upcoming consultations and final report—to use the information that you have already contributed.

#### *Anonymity and Confidentiality of Participant's Information*

The information that you provide would not be anonymous or exclusively confidential, only for the following reasons:

1. If you decide to take part in a group session(s), your contributions to the forum(s) will be known by the small number of other participants present when you make your comments or suggestions.

Furthermore, the findings of this research will be contained in a research thesis that constitutes a report to the British Columbia ministries of Health Services; and Energy, Mines, and Petroleum Resources. This document will be publicly accessible, through the University of Victoria, the Ministry of Health Services, and the Ministry of Energy, Mines, and Petroleum Resources, to name a few sources. I expect that the report will be forwarded to these ministries by October, 2011. However, to respect participants' privacy, I will not mention anyone's name as the source of a particular insight or

suggestion, and would ask the other 'group' participants to honour that practice.

If you wish to participate in consultations other than an interview, that option is provided in a Consent Form on page 6. I suggest that on this form, you select the type(s) of consultation that you are willing to consent to by signing your name and dating your signature below one or more of the options listed.

*Regarding Your Considering Participation in This Research Project*

I will follow up this Letter of Information and Consent Form by telephone within two weekdays of when you receive it. If you are at that time interested in participating in this research project, I will then discuss with you the elements of this document. This would constitute a process that may lead to your granting Free and Informed Consent to participate. Following that discussion, I will not contact you again for at least 24 hours, so you have 'unencumbered time' to consider your decision. You need not feel any obligation to participate in this project.

If you do consent, within two days of receiving written notification that you have consented, I will forward you the following information:

- (1) a brief background document that
  - (a) outlines the seismic hazard in southwestern BC,
  - (b) provides order of magnitude estimates of the numbers of hospitalizations likely to result from each of the three types of earthquakes that could affect Greater Victoria, and
  - (c) identifies a few of the implications that each type of earthquake would have for the Transfusion Laboratory Medicine disaster response role within Greater Victoria transfusing hospitals
- (2) a list of the questions that I plan to ask you in the interview, and
- (3) the dates and locations for (a) the focus group and (b) the final verification workshop.

*Record-keeping Regarding This Research*

The written records and recordings will be kept in a locked filing cabinet and then disposed of after seven years, by burning the audiotapes and videotapes, by re-writing over the compact discs, and by shredding all paper on which notes from interviews and group consultations have been written. Data committed to computer files will be stored

and backed up only on writeable compact discs; both versions would be password protected.

*Use of the Information Recorded and Incorporated in Ensuing Products*

The results of this study will be shared with those participants who so wish, and may be shared with others in presentations at scholarly meetings, in a thesis defense, and possibly in a published article.

**Form for Signifying Free and Informed Consent to Participate in the  
Earthquake-Specific Blood Contingency Research Project Conducted by  
Bruce Sanderson, MA Candidate, Department of Geography,  
University of Victoria**

Your signature below indicates that:

- you understand the above conditions of participation in this study,
- you have had the opportunity to have your questions answered by the researcher, Bruce Sanderson, and
- you understand that this document, when signed by you, constitutes your Free and Informed Consent to participate in the research project identified above.
- participating in an interview (duration: 45 minutes to one hour)

<b><i>Name of Participant</i></b>	<b><i>Signature</i></b>	<b><i>Date</i></b>
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- participating in a focus group (duration: 1.5 hours)

<b><i>Name of Participant</i></b>	<b><i>Signature</i></b>	<b><i>Date</i></b>
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- participating in the verification workshop (duration: 2 hours)

<b><i>Name of Participant</i></b>	<b><i>Signature</i></b>	<b><i>Date</i></b>
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**If you agree to have your name acknowledged in the final report, please print your name, and then sign and date this document, on the lines below.**

<b><i>Name of Participant</i></b>	<b><i>Signature</i></b>	<b><i>Date</i></b>
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Should you consent to participate in this research, a copy of your signed Consent Form would be provided to you, and the researcher would retain the original.

Thank you again for your thoughtful consideration. If you have any questions regarding this information, please contact the following for clarification:

Bruce Sanderson

Sincerely yours,

Bruce Sanderson

MA Candidate, Geography, University of Victoria

## **Appendix M: Interview Guide Questions**

### **Questions Regarding Earthquakes as Internal/External Disasters Affecting the Transfusion Medicine/Blood Transfusion Laboratory Function at Greater Victoria Transfusing Hospitals**

**by Bruce Sanderson, Principal Investigator**

#### **Introduction**

This document forms part of the methodology for a Master's level research project regarding the anticipated effects that three different types of earthquakes may have upon the Transfusion Medicine Laboratory component of the Blood Transfusion Laboratory Medicine, Pathology, and Medical Genetics Departments at Greater Victoria transfusing hospitals. Its content flows from the research goal and objectives identified for the project, as stated below.

This research involves examining both the (1) *elasticity* of the blood supply (the ability to expand production of blood products and/or compensate for sudden contraction of blood supply), and (2) the *fluidity* of the supply (the ability to move blood products to areas experiencing either disproportionate reduction in supply or extraordinary demand) (Jones, 2003). Especially in a damaging *shallow* earthquake, such as in New Zealand in 2011, there could be a significant reduction in supply, plus an immediate, significant

increase in demand—for blood products at Greater Victoria transfusing hospitals. In addition, decisions regarding the alternatives of (1) rapidly relocating a facility for the storage and/or transfusion of blood products within Greater Victoria or (2) transporting people injured in an earthquake directly to (a) transfusing hospital(s) outside Greater Victoria, or (3) both 1 and 2, may need to be made within the first few hours following a destructive earthquake. Information that could help develop decision trees for these and other post-quake circumstances will be elicited in the questions.

### *The Project Goal*

The overarching goal of this study is to strengthen the Transfusion Services (TM)/Transfusion Medicine Laboratory (TML) emergency response management function within the Vancouver Island Health Authority (VIHA) such that the TM/TML component will be better able to deal with the impacts that it would likely face as a result of any of three types of earthquakes that could significantly damage Greater Victoria. This study addresses aspects of the TM/TML functions of risk reduction, preparedness, response, and recovery regarding such earthquakes, commensurate with some of the risks defined by (1) hazard identification, (2) risk assessment, and (3) business impact analysis.

This research project is intended to contribute to the development of an accessible, *earthquake-specific*, tested, updated, and disseminated VIHA TM/TML plan for emergency preparedness, response and recovery that includes elements of risk mitigation, vulnerability reduction, and capacity development. Such a plan should also integrate the systems, guidelines, standard operating procedures, and protocols required for emergency management of this VIHA function.

### *The Objectives*

For three different post-earthquake event circumstances, the objectives are:

- To provide realistic estimates of the numbers of local hospitalizations (and types of injuries) that would likely result if these different types of earthquakes were to affect Greater Victoria or/and Vancouver Island
- To briefly examine the inventory monitoring, communication, decision-making, transportation, and blood product distribution components—plus the hazard mitigation,

vulnerability reduction, and capacity development aspects—that could comprise an earthquake-specific blood contingency plan for Greater Victoria transfusing hospitals

- To plan for supplying new blood products, related materials, and services to maintain the function of the TM/TML role within transfusing hospitals in Greater Victoria, or nearby, during post-earthquake circumstances in which some of the Greater Victoria facilities for storing, monitoring, preparing, analyzing, or transfusing blood products have been rendered inoperable

#### *Hazard Identification*

Identification of the local and regional earthquake (seismic) hazard was addressed earlier in this study, and is summarized within the document entitled “Estimates of Injuries and Hospitalizations in Greater Victoria from Three Types of Earthquakes”. Since the ground movement aspect of the regional seismic hazard cannot be reduced via human activity, a strategy of reducing what related risks exist in populated areas is sensible. A full risk assessment would help define the most effective means of related risk reduction for the TML function, but is beyond the scope of this project. However, additional information on the likely impacts of the earthquakes upon the people, operations, and facilities that comprise the TM/TM function will contribute to such a risk assessment and business impact analysis. Considerable of this information will hopefully be obtained via consulting various players involved in supporting the TM/TML function of VIHA.

#### *Some Key Objectives for the Risk Assessment*

For the purposes of confirming and improving the mitigation, preparedness, emergency response, and recovery of the TML function with respect to the three types of damaging earthquake events, two key objectives are:

- to identify how the TML function is vulnerable to these three types of severe seismic events;
- to affirm or determine how to reduce the risks of injuries to staff and patients, and the risks of having valuable equipment and/or facilities rendered inoperable due to *non-structural* damage to the TML area of (a) Greater Victoria transfusing hospital(s)

### *Business Impact Analysis*

Some considerations of business impact analysis (BIA) will build upon these risk assessment findings. A few critical business interdependencies, and associated resource requirements of the TM/TM function will be reviewed, with respect to instituting additional: mitigation measures, preparation activities, and emergency response planning, regarding the anticipated consequences of the destructive earthquakes that could affect Greater Victoria.

The pertinent questions are to be considered after interviewees have reviewed the information package entitled "Estimates of Injuries and Hospitalizations in Greater Victoria from Three Types of Earthquakes". Bruce Sanderson, a University of Victoria graduate student in geography, will follow up and ask the applicable questions in an informal interview. As the interview proceeds, other questions will likely arise from your comments and suggestions. With your permission, Mr. Sanderson will record the answers on audiotape; if that is not permissible, he will make only written notes.

Please feel free to mention other questions and suggestions that you think should be considered in developing an earthquake-specific Internal/External Disaster Plan for TM/Transfusion Medicine Laboratories at Greater Victoria transfusing hospitals.

### **Context**

These questions relate to VIHA transfusing hospitals in Greater Victoria, and their answers should be valuable in other locations in circumstances immediately follow a damaging earthquake. Several significant questions have been worded to elicit responses from as many key informants as possible. This wording may be misleading in that it may appear to ignore the fact that some of the activities inquired about are already carried out by the organization(s) concerned.

Some questions deal with recently-created emergency blood management committees (EBMCs). The Canadian Blood Services (CBS, 2009; 2010) has suggested that transfusing hospitals, regional health authorities, and Provinces across most of Canada establish EBMCs. EBMCs are tasked with helping decide the allocation of blood products and services in situations where a shortage of blood products prevails.

## **The Questions**

### *Vulnerability of Particular Blood Products*

i) Which blood products are likely to be the most vulnerable, in terms of storage complications, in post-quake circumstances such as possible temperature variations in blood storage facilities?

Which blood products, if any, are not typically used to help reduce grave threats to human life?

### *Monitoring the Inventory of Blood Products*

i) In the event of a power outage or physical damage to some computers and/or to the server(s) on which the blood product inventory information is stored, how would the different individuals or agencies monitoring that inventory determine from the database the most recent levels of products recorded, as a starting point for continued monitoring via a backup system?

What procedure might the organization that first identifies this starting level inventory information use to transmit such information to the other organizations that also require it, if the usual means of telecommunication are unavailable in the other organization(s)?

### *Operations and Procedures*

i) What are the basic and essential functions likely to be required of the TM/TML function immediately following each *type* of earthquake event? Please list the functions by quake type, if significant differences in the functions are likely, among the differing earthquake events.

### *Training, Securing and Moving TM/TML Staff Contingents for a Surge Situation*

i) What training measures for TM/TML staff do the likely consequences of the three types of earthquakes imply?

ii) What strategies have been or likely could be implemented to help ensure that TM/TML has a large enough complement of staff per shift in a post-earthquake surge situation?

Strategies that the TM/TML functions in other BC transfusing hospitals have *not* implemented in previous external disaster situations should be listed separately from any that have been.

iii) What elements should be included in a plan to help essential TM/TML staff get to and from the TM/TML facilities if roads are damaged or fuel for road vehicles is unavailable?

### **VIHA (EBMC and Transfusion Medicine) Communications**

i) What means should the Transfusion Medicine (TM) Director or delegate *initially try to use* to telecommunicate with staff *at other* Greater Victoria transfusing hospitals?

In case the telecommunication device used for this initial attempt does not work, should an order of usage preference be defined for a list of other telecommunication devices that could be tried?

If not, why not?

If so, should it be part of a *common* order of usage preference, so that the potential recipient(s) and the person(s) who transmit(s) the message is/are more likely to attend to the same devices at the same time?

Should the following blood system players also use such telecommunication devices in this way when attempting to telecommunicate with each other in a post-quake situation?

Canadian Blood Services

the Provincial Blood Co-ordinating Office (PBCO)

the VIHA Emergency Blood Management Committee (EBMC)

Hospital EBMCs

EBMCs in other BC Regional Health Authorities

the Provincial EBMC

the National EBMC, and

the Provincial Emergency Program (PEP)

If not, which alternative(s) would likely work better?

ii) How would a VIHA/hospital EBMC likely obtain *advance* information regarding the numbers, types, and severity of earthquake-related injuries?

**Demand for—and the Availability, Accessibility, and Allocation of—Blood Products Immediately After an Earthquake and Related Events**

*The Implications of Various Types of Injuries, and Their Severity, upon the Demand for Blood Products*

See the estimates package for information on typical injuries resulting from an earthquake.

i) Do the types of injuries that usually result from an earthquake suggest any significant implications for the VIHA TM/TML function in its general operations?

In ordering additional blood products?

If so, please identify the respective groups of implications beneath each segment of the question.

Alternate Blood Storage Sites

i) Is there a need for a local alternate blood storage site that, for instance, is about 55 km from VGH and RJH, and likely to remain functional following a *shallow* earthquake and aftershocks nearer to Victoria?

If so, what are some of the other criteria that this site and building should satisfy?

If not, what characteristics of the existing technology, procedures, and practices involved in the supply and storage of blood products in Greater Victoria outweigh this idea?

### The TM/TML Emergency Response: Further Considerations

i) The TM/TML function will likely need to temporarily increase its inventories of, storage capacity for, and rate of transfusion of, blood products. How is the TM/TML function prepared to do so?

Does scaling up the surge capacity of the TM/TML function usually involve assembling additional kits of various kinds?

If so, please identify the types of kits, and if possible, the components involved in each.

If so, have *volunteers* been identified and committed to partially complete this task pre-quake, with the remainder to be done post-quake?

If not, what might be a reasonable proportioning of such a task, over each of the two periods?

ii) For increasing the rate of transfusions, what usually are the key rate-determining steps?

iii) Please identify any equipment items and associated staff training which clearly do, (or would, if they were available) add one or more of the following attributes—greater speed, versatility, flexibility, and/or reliability—to the VIHA TM/TML function response to an earthquake emergency surge situation. Please list separately those available versus those not currently available. If you have accurate information about the current cost of items that VIHA might purchase, please mention the approximate cost per item.

Item that could be considered for purchase	Approximate cost

## Regarding a TM Laboratory That is Seriously Damaged by An Earthquake

*Evacuate or shelter in place? An Aspect of Business Impact Analysis*

i) What elements and materials should be included in shelter-in-place plans for three days, for the TM/TML function?

ii) What are some logical criteria to use in deciding whether to relocate a TML?

What are some logical criteria for determining *where* and *in which building* to relocate a TML?

iii) What pre-arrangement(s) have been—or could be—made for expediting the relocation of TM/TML operations, in the aftermath of a damaging earthquake?

## Decision-making for Transfusions and Allocating Blood Products

i) In your opinion, would the VIHA Emergency Blood Management Committee (EBMC) enable rapid decision-making in order to administer blood products and services in a situation where both a blood shortage and an *urgent* and high demand for blood products prevail?

If not, why not?

ii) What criteria could the VIHA EBMC use to rank patients who have different conditions that indicate equivalent urgency for transfusion?

iii) Is there a computerized group decision support system (GDSS)—in place, or identified—to help the VIHA EBMC make decisions rapidly while adhering to EBMC decision-making criteria?

If neither, might a computerized GDSS—that incorporates all or some of the three concepts listed below—be a useful tool in a situation where EBMC members must prioritize and decide who, from amongst several cases, should be the next person to have a blood transfusion?

1) **An analysis information system** that provides access to a series of decision-oriented databases and/or small models;

2) **An optimization model** that provides guidelines for action by generating an optimal solution consistent with a series of constraints;

3) **A suggestion model** that can perform the logical processing leading to a specific suggested decision for a structured, well-understood task.

Please comment regarding the concept of a GDSS, and whether it likely would be needed by and useful to an EBMC in a post-quake circumstance.

iv) What criteria could the VIHA EBMC use to define a cut-off point regarding the number of patients that the Greater Victoria TM/TML function could assist in a given time period?

*Other Factors That May Affect the Allocation of Blood Products and Services*

i) Which of the following (I-XX) procedures could be performed safely when *only backup power* is available?

Below each procedure that you identify as *possible* under these circumstances, please answer, and add any comments.

ii) Which of the following (I-XX) procedures logically could be provided in an alternate location(s) in post-quake Greater Victoria, via contracts or memoranda of understanding?

Below each procedure that you identify as *possible and logical* under these circumstances, please answer, and add any comments.

I) Antibody Identification

II) Blood Product Inventory Assessment

III) Blood Product Inventory Assessment, Order and Receipt, Solely within the VIHA Hospital Blood Bank System

IV) Releasing Allocated Blood Products

V) Ordering Blood Component Inventory from Canadian Blood Services (CBS)

*Considerations Regarding Ordering Blood Component Inventory from CBS after a Significant Deep Earthquake or a Shallow Earthquake:*

i) In the instance of a deep earthquake that damages one or more Greater Victoria transfusion hospitals and their collective capacity to store, inventory, process, and test blood,

What *factors* should the EBMC consider in deciding how much additional blood product to order from CBS Vancouver in the first day or two, and *where* to have it delivered?

ii) In the instance of a severe shallow earthquake that damages one or more Greater Victoria transfusion hospitals and their collective capacity to store, inventory, process, and test blood, and has left one or more of the TMLs without *any* electrical power,

What *factors* should the EBMC consider in deciding how much additional blood product to order from CBS Vancouver in the first day or two, and *where* to have it delivered?

*Regarding Transferring Blood Transfusion Cases to Hospitals Outside Greater Victoria*

i) What, if any, travel time would be permissible for transferring to hospitals outside Greater Victoria those injured people who are known to, or likely to, need blood transfusions?

VI) Receiving Blood Products from CBS

What, if any, potential issues do you foresee arising regarding this activity in a post-quake situation?

VII) Receiving Blood Products Transferred with a Patient

VIII) Entering Blood Products into Inventory

IX) Examining Platelets for High Titre Anti-A or Anti-B

X) Regrouping Red Cell Units

XI) Ordering Derivative Products

XII) Crossmatch

XIII) Derivatives Selection and Modification

- XIV) Emergency Release for Red Cells
- XV) Exchange Transfusion
- XVI) Neonatal Red Cell Transfusion
- XVII) Non-Red Cell Component Selection and Modification
- XVIII) Pre-transfusion Examination
- XIX) Red Cell Modification
- XX) Redistribution Shipment

### **Reducing the Risk of Earthquake-driven Damage to TM Lab Facilities**

- i) What measures and practices are now in place, or could be implemented, to prevent injuries and disruption due to *non-structural* damage within the TM/TML areas of Greater Victoria hospitals? Please list separately those measures and practices that are not yet in place.
- ii) In the TM/TML operational areas of Greater Victoria transfusing hospitals, freezers; (nearly immovable) fridges; (heavy but movable), plus shakers and thawing baths (neither heavy nor fixed) have been identified as the equipment items most crucial to proper treatment of casualties who require analysis or transfusion of blood products.

What, if any, additional measures could be taken that might prevent *non-structural* damage to these *particular* assets?

#### *Subduction scenario*

- i) At *differing times* following a subduction earthquake, regional health authority EBMCs in coastal British Columbia will likely receive estimates of the number, severity, and types of injuries that have resulted. This *staggered timing* in receiving information pertaining to the increased demand for blood products—and possible delays in communicating this information to the National EBMC or the Provincial EBMC—likely would complicate, at the provincial level, the processes of (1) predicting inventory levels and demand, and (2) blood product allocation at the hospital level.

How might the EBMC process of predicting inventory levels and demand allow for this scenario?

How might the VIHA—or appropriate level—EBMC blood product allocation process allow for this scenario?

ii) How many of the VIHA transfusing facilities should the VIHA EBMC need to hear from before making decisions regarding allocating blood for transfusions in Greater Victoria? (Far more people are located in Greater Victoria, versus in a smaller, remote center up Island).

iii) If a severe subduction earthquake damages one or more Greater Victoria transfusion hospitals and their collective capacity to store, inventory, process, and test blood, and has left one or more of the TMLs without *any* electrical power,

What *factors* should the EBMC consider in deciding how much additional blood product to order from CBS Vancouver in the first day or two, and *where* to have it delivered?

### **Regarding Canadian Blood Services (CBS) Operations**

Scenario: A Subduction Earthquake Damages, and Restricts, CBS Vancouver Operations

i) What might be the first priorities for CBS Vancouver staff if their processing facility is damaged and loses some of its prepared blood products and processing capacity, and the demand for blood products has now significantly increased in the Lower Mainland and on Vancouver Island?

ii) How might CBS Vancouver staff consult and advise the various BC Health Authorities' TML functions regarding the now restricted capacity of CBS Vancouver to collect, prepare, and supply blood products?

iii) A significant number of injuries in downtown Victoria may result from broken glass striking people. If glass penetrates a victim's critical vessels or organs, considerable blood will be required initially, and in the following few weeks, for orthopaedic and plastic surgery (Gilcher, 2001).

Given an earthquake that seriously damages buildings in downtown Victoria, how might CBS Vancouver plan to meet this demand in the weeks following the event?

## **Appendix N: Telecommunication Resources Available via EMBC**

EMBC uses the E-Team emergency response telecommunication and information management system (BC MoHS, 2008b), and has provided VIHA with expert telecommunications advice and access to the EMBC emergency radio channel. In Greater Victoria, EMBC Operations directs the Capital Region Emergency Radio Coordinators Committee under the BC Emergency Response Management System (BCERMS) model (Capital Region Emergency Radio Coordinators Committee, (CRERCC) 2011). Most municipal EOC radio rooms in Greater Victoria operate VHF Airmail Packet Radio stations 24/7 (CRERCC, 2011). The CRERCC features a range of robust and redundant telecommunications methods (CRERCC, 2011).

Through its Provincial Emergency Radio Communications Society, (PERCS) EMBC maintains an array of communications equipment, including amateur radio gear, at each of its six Provincial Regional Emergency Operations Centers (PREOCs) (Emergency Management BC (EMBC), 2011b). This allows both voice and digital (data) contact with local and regional EOCs through the volunteer Amateur Radio Relay League (EMBC, 2011b). Each PREOC has a core volunteer telecommunications unit that operates the equipment, while connecting with amateur radio groups that assist local governments and other key stakeholders throughout their respective regions (EMBC, 2011b). EMBC also has three *field* telecommunications kits that have telecommunications similar to PERCS. Radio Communications Support Teams operate these units, and can provide interoperability with Search and Rescue or support operations under BC Emergency Response Management System (BCERMS) umbrella (EMBC, 2011b).

## **Appendix O: British Columbia Ambulance Service - Key Services**

The air ambulance arm of the British Columbia Ambulance Service (BCAS) could be an extremely valuable asset immediately following a shallow earthquake or a subduction event that affected Greater Victoria and areas beyond. The BCAS Air Ambulance Program employs 6 dedicated fixed wing airplanes (2 turboprops and 1 jet, based in Vancouver, 2 in Kelowna and 1 in Prince George), and 3 helicopters (2 based in

Vancouver and 1 in Prince Rupert) (BCAS, 2011b). Helijet Air Medical operates the air ambulance Sikorsky S76 helicopters (cruise speed, 248 km/h) and Bombardier LearJet 31A airplanes (cruise speed, 800 km/h) under contract (Helijet, 2011). The BCAS also employs approximately 40 charter carriers throughout BC (BCAS, 2011). The Air Ambulance program employs highly skilled, advanced care, critical care and infant transport paramedics who have received aviation training (BCAS, 2011).

When time is a critical factor, BCAS Emergency Medical Dispatchers employ the BCAS Autolaunch Program to simultaneously send an air ambulance aircraft and a ground ambulance to a major incident scene (BCAS, 2011). Critical care paramedics used in this program are based on Vancouver Island at Nanaimo (BCAS, 2011). To complement this undertaking, the BCAS should consider developing the capacity to transfuse patients while airborne in helicopters, as done in Australia (Langford, 2009).

#### BCAS Special Operations

The BCAS deploys paramedics on bicycles and small all-terrain vehicles (Gators) within crowded environments in Greater Vancouver and Greater Victoria (BCAS, 2011). Gators can attain speeds of 50 km/hr, carry crew, medical supplies, and a mobile stretcher, and also access challenging back-country regions (BCAS, 2011). The BCAS also may want to consider whether a vehicle similar to a light, non-armoured civilian version of the Stryker Medical Evacuation Vehicle (General Dynamics Land Systems Canada (GDLSC), 2012) might be useful in disaster response. Such 8-wheel drive vehicles are able to carry a crew of 3 and at least 4 casualties on stretchers over steep, rough terrain, and across 1.6m-deep flowing streams, and small bodies of water (GDLSC, 2012).

#### BCAS Emergency Management Office

Based in Vancouver, the BCAS Emergency Management Office provides provincial oversight and direction in planning regarding multi-casualty incidents. The BCAS Multiple Casualty Incident plan calls for moving casualties to hospitals by air, ground ambulance, and *en masse* in specially commissioned buses (BC Ministry of Health and Ministry Responsible for Seniors and BC Ambulance Service, 2001).

## BCAS Telecommunications Technology

BCAS services are electronically integrated with E-Comm, (Emergency Communications for Southwest British Columbia Incorporated) the chief 911 answering service for that region, to allow simultaneous dispatch of fire first responders and ambulances (E-Comm, 2010). The BCAS and E-Comm utilize the same radio network and telephone platform, so implementing new NICE recording technology ensures BCAS additional interoperability, enabling the two agencies to further partner on strategies that enhance emergency response (NICE Systems, 2009). The NICE Inform system allows the parties to effectively manage multimedia incident information--audio, video, text, data, and streamlined information-sharing sources (NICE Systems, 2009). These capabilities enable improved collaboration and operational efficiency amongst agencies and command and control centers, to enhance safety and security (NICE Systems).

The BCAS recently implemented NetCAD, a computerized information platform intended to improve the communication of resource and event information among all Dispatch centers, first responders and field paramedics (BCAS, 2010a). With all Dispatch centers on a common computer platform, each can back-up another if a facility issue, technical failure, or other incident occurs (BCAS, 2010a). The system enables the use of new technologies such as mobile data terminals and Automated Vehicle Location (AVL) monitoring (BCAS, 2010a). The NetCAD innovation has helped reduce manual processes and has enhanced real-time reporting and operational analysis (BCAS, 2010a). In addition, the E-Comm Next Generation Radio Project (E-Comm, 2011a) will involve an IP-based phone system that runs through a data network, and enables first responders to receive images and video via handsets, completing a 'ring technology' for interoperability with other agencies.

The *Mobile* CAD project involved installing a Global Positioning Satellite (GPS) receiver and computing device in the cab of ambulances in urban and rural areas, to extend the NetCAD system into the ambulance, providing paramedics with valuable CAD information related to the call location, the best driving route, and the patient status (BCAS, 2010; 2011a). E-Comm's public safety and emergency response application, Emergency Event Map Viewer (E<sup>2</sup>MV) and geographic information system appears to be the equivalent of the E-Team program, and allows emergency services to share incident

data through a common operating picture (E-Comm, 2009, Springs).

In Vehicle Gateway (IVG) devices will establish a secure local area network connecting devices within and around the ambulance, as well as secure wide area networks involving outside systems (BCAS, 2010). WIFI wireless technology installed in hospitals and ambulance stations will provide alternate access points for downloading larger data sets (BCAS, 2010). The IVG allows paramedics to utilize existing and future Emergency Management System applications over network infrastructure that enables inter-network roaming, reduces network coverage gaps and interruptions, and manages bandwidth (BCAS, 2010).

#### Summary

BCAS air and ground ambulance services, Special Operations, and multi-casualty incident planning should prove useful and effective in post-earthquake situations within BC. If the NetCAD, In Vehicle Gateway, and E-Comm Next Generation Radio Project telecommunication capacities already do, or soon will, apply to at least Greater Victoria, VIHA will have added telecom redundancy and flexibility available for disaster response.

## **Appendix P: Alternate Modes and Routes for Moving Blood Products into Greater Victoria**

### **CBS: modes of transporting blood products**

#### *Ground transportation*

CBS fleet and commercial couriers deliver in Metro Vancouver, while DHL Courier delivers outside that area. At times, CBS uses taxis for small packages, or Dynamics/MTS for less-than-a-truckload (LTL) shipments. On an average day, CBS Vancouver makes about 65 deliveries (e.g., 36 via CBS Transport, taxi, and air carrier, and 29 by Dynamex/MTS and DHL).

#### *Marine transportation*

Major marine transportation assets include BC Ferries and Rail Ferries. In theory, a hovercraft or Coast Guard vessel from the Joint Rescue Co-ordination Center (JRCC) could be used. The JRCC, located on Canadian Forces Base Esquimalt, in Greater

Victoria, coordinates the Search and Rescue (SAR) response to air and marine incidents within British Columbia and the Yukon, plus searches on the marine waters off British Columbia (Wikipedia, 2011b).

#### BC Ferries

CBS to Tsawwassen Ferry terminal = 30.8 km.

Ferry travel time Tsawwassen to Swartz Bay 1 hour 35 minutes

CBS to Horseshoe Bay Ferry terminal = 26.8 km via Oak, King Edward, Granville, Seymour, Georgia, Lions Gate, Marine Dr., Taylor Way, Hwy. 1.

Ferry travel time to Nanaimo: 1 hour 40 minutes

Ferry travel time direct to *Victoria*: approximately 3 hours, 5 minutes (85 km)

#### *Transportation via Air*

The CBS can use multiple air carriers, and has established a relationship with a Vancouver-based air charter company, in order to rely upon it in an emergency. Helipads potentially available in Greater Vancouver and the Lower Mainland include those at: Women and Children's Hospital, Lions Gate Hospital, Royal Columbian Hospital, and Abbotsford Hospital. Helicopters may be the most secure way of transporting blood products from Vancouver to transfusing facilities on Vancouver Island, since airport runways could be buckled by stress lines or opened by surface faults, a tsunami could damage most floatplane bases located on the coast of Vancouver Island, and the helipad at Women and Children's Hospital is only 60m away from the CBS Vancouver Center. If a helicopter is not available, a floatplane could move blood products from relatively near the CBS Vancouver Center to downtown Victoria. The Victoria Inner Harbour Transport Canada-approved water aerodrome is 4.13 km from Royal Jubilee Hospital. A few water-landing locations that are relatively close to the major hospitals in Greater Victoria are listed below, (Google Earth, 2012) but not all have Transport Canada-approved water aerodrome status. Appendix M describes the air ambulance arm of BCAS, another air transportation asset.

### Floatplane Flights Originating in Greater Vancouver

If, due to a subduction earthquake, road traffic between the CBS Vancouver Center and ferry terminals is affected by collapsed overpasses and bridges, the CBS could use a shorter route--to the Coal Harbour floatplane base in Burrard Inlet, or to seaplane bases on the south shore of Sea Island.

Routes: only 7.2 km via Oak St. North, King Edward, Main, Union, W. Georgia, and Thurlow, a distance of just over 8 km to the Coal Harbour floatplane base in Burrard Inlet (Google Earth, 2012). If this path is blocked, the CBS may be able to access other floatplane bases, on the south side of Sea Island. The 8.85 km route to Sea Island would be via Oak St., SW Marine Drive/Grant McConachie Way, Russ Baker Way, Inglis Dr., to the Harbour Air Seaplanes base, or the West Coast Air terminal, both just east of Bell Irving St. (Google Earth, 2012). But in either case, the travelling time between the CBS Center and on of these bases could be significant if vehicular traffic is heavy.

Flight time one way from either Vancouver floatplane base: approximately 30 minutes

Cost: Cessna 185 (Harbour Air) chartered round trip, March, 2011 prices (no discount)

.....\$864.50 + HST

The minimum landing distance for a Cessna 185 on floats, 305m (Wipaire, Inc., 2011), has been accounted for in *identifying* some non-Transport-Canada-approved possible landing sites near the three transfusing hospitals in Greater Victoria.

### *Landing in Greater Victoria*

#### Royal Jubilee Hospital

dock at Oak Bay Marina (3.3 km from RJH, via Beach Dr., Bowker Avenue, and Cadboro Rd./Fort St.); (3.3km via Oak Bay and Richmond). However, there is no Transport-Canada approved water aerodrome at Oak Bay Marina.

dock at Harbour Air, Inner Harbour Transport-Canada approved water aerodrome (4.13 km from RJH)

dock at Patricia Bay approved water aerodrome (Widgeon Drive), 30.87km from RJH (via Royal Oak, Cordova Bay, Shelbourne, to RJH via Bay)

### Victoria General Hospital

dock at a private wharf on the ocean shore accessible from View Royal Avenue near Tovey Crescent (estimated road distance, 2.6 km). There is no Transport-Canada approved water aerodrome near Tovey Crescent.

use a private wharf on the ocean shore accessible from View Royal Avenue near Woodbine Court (estimated road distance, 2.9 km). Again, there is no Transport-Canada approved water aerodrome near Woodbine Court.

from Harbour Air, in the Inner Harbour, (with a Transport-Canada approved water aerodrome) the distance is approximately 9 km, via Wharf St., Johnston St. Bridge, Tyee, Craigflower, Island Hwy., and Helmcken.

from Patricia Bay, an approved water aerodrome, is 24.8 km, via Pat Bay to Royal Oak, and Wilkinson-Helmcken

### Saanich Peninsula Hospital

2.28 km from the dock at the east end of James Island Rd., (just NE of Mt. Newton X Rd.) via James Island Rd., Lochside Dr., Mt. Newton XRd. There is no Transport-Canada approved water aerodrome at the east end of James Island Rd.

5.67 km from Brentwood Bay Marina area, via Verdier Ave., Brentview, Stelley's, Wallace Dr., Mt. Newton XRd. There is no Transport-Canada approved water aerodrome at Brentwood Bay Marina.

from the Patricia Bay water aerodrome, the distance is 9 km, via Willingdon, E. Saanich Rd., Emard Terrace, Moxon Terrace, Amity Dr., Bourne Terrace, Central Saanich Rd, and Mt. Newton XRd.

9.3 km from the Patricia Bay base, via Willingdon, *Pat Bay Hwy.*, and Mt. Newton XRd.

### Helipads in Greater Victoria

The RJH helipad is on vital power, plus battery backup. Heavier Cormorant and Sea King military helicopters can land at VGH. There is no regulation helipad at Saanich Peninsula hospital, but there is adequate *room* to land a helicopter close by (Google

Earth, 2012). Other helipads include Pacific Heliport Services' Camel Point base, at elevation 5 m asl (Wikipedia, 2011d), Shoal Point, 570 m north of Camel Point, at 3 m asl (Wikipedia, 2012g), at least 5 pads on Kittyhawk Road, elevation 31m, 660m northwest of the Victoria International Airport terminal, and 7 more 1.4km north of that terminal (Google Earth, 2012).

### **Appendix Q: Factors Likely to Affect the Post-subduction Quake Delivery of Blood Products and Retrieval of Casualties**

VIHA may already have in place plans featuring a standardized methodology and pre-defined operational capacity to efficiently manage the post-subduction earthquake movement of blood products, associated material, casualties, and staff. If not, Ergun et al. (2012, n.p.) maintain that to establish and efficiently operate a post-disaster supply chain "hierarchical planning, multi[-]objective models, centralized/decentralized system trade-offs, standard procedures, information sharing platforms, [and] collaboration mechanisms...need to be developed and analyzed."

Giesen, Mahmassani, and Jaillet (2009) identified some useful developments in Information and Communications Technology that may be relevant to tracking (a) the movement of different survivors who need hospital care urgently, and (b) blood products that are either redistributed, or ordered directly from the CBS, and en route to various Vancouver Island destinations in a post-subduction quake situation:

1. Communication and tracking devices can accelerate and automate the input and transmission of information among computer systems linked to help achieve objectives (a) and (b) above
2. Commercial Vehicle Operations technologies allow supervisors to direct a fleet of vehicles in real time.
3. Decision Support Systems and partnering software can provide or enhance capabilities for processing related data at a particular location (Giesen et al., 2009).

Table Q identifies factors that could affect the post-subduction quake delivery of blood products to, and retrieval of seriously injured survivors from, northern Vancouver Island. This table involves the assumption that the same aircraft would carry out both deliveries

of blood and retrievals within a given trip. However, it may be wise to segregate the air transportation of blood products from that of casualties, because situations may arise where a health care worker aboard an aircraft has to choose or advise regarding *either* a delivery of blood products *or* the retrieval of an injured survivor(s).

Operational decisions regarding distribution/collection systems in situations following sudden-onset disasters are complex, since system status information is only gradually revealed, and because underlying problems may combine, and *do* unfold in real time, preventing the decision-maker(s) from evaluating all possible alternatives (Giesen et al., 2009). With real-time information on the status of system components, (i.e., changes in blood product demand per location, the state of staff on shift at a remote location and their assessment regarding extracting certain casualties, the condition of an aircraft landing area, and the route, load, speed, and location of an aircraft) response managers can make more efficient their choices and routing of vehicles, including various aircraft (Giesen et al., 2009).

In reviewing recent relevant literature, Caunhye, Nie, and Pokharel (2012) identified some key challenges in logistical planning for response to sudden onset disasters. For example, due to an earthquake and its aftershocks, added uncertainty often arises regarding route conditions, the "demand points" for urgently-needed health care, new safety issues, and changing facility capacities (Caunhye et al., 2012). An initial paucity of accurate real-time information regarding the demand for materials such as blood products, plus damaged telecommunication infrastructure and the involvement of many third parties, may exacerbate communication and coordination in the response to a specific disaster (Caunhye et al., 2012). And the scale of a disaster may overwhelm limited available resources, especially in smaller, more remote locations (Caunhye et al.). Caunhye et al. (2012) found that operations research has addressed those challenges via applying queuing theory, statistical and probabilistic models, simulations, fuzzy methods, decision theory, and most commonly, optimization techniques. The MoH and/or VIHA may want to explore the possibility of using one or more of these tools to help maintain the efficient and effective post-earthquake movement of blood products, associated material, casualties, and VIHA staff.

**Table Q. Factors Likely to Affect Post-subduction Quake Delivery of Blood Products and Retrieval of Casualties**

Objectives			Constraints			Other Decisions
Costs: minimize	Time: minimize	Other	Capacity	Requirements and bounds	Other	
travel distance	Decision and dispatch	Efficient robust	Vehicle: land, boat, or aircraft	Single or multiple casualty	Aircraft: VTOL or STOL	Assess primary roads and bridges as usable or not
number of vehicles	vehicle operator response	Storage: in vehicle, at DN	Mobile telecom	Link to NVI airbases, EMBC, BCAS, and marine vehicles	Need land transport to move more fuel to airstrip?	(2) Alternate land route? – as above (3) Aftershocks - Alternate land route? – as above
operational	travel	Dynamic addition of vehicles	Airborne transfusion	Low altitude, expert staff, computers connect	Aircraft: amphibious or on wheels	Location, speed & capacity for road clearing near DN:
fuel	drop off blood products	Rates: fuel use vs. fuel replenish, per base	T ° range and stability in vehicle	aircraft turnaround time	casualty: need land transport? PU/DO on water? last mile covered?	Flow of infrastructure repair teams decided by provincial government
Wages and salaries	Load up casualties	Re-fuelling schedule	Vehicle travel speed	security of aircraft on ground	damage due to aftershocks	Adjust decisions to aftershock damage
Time injured await transfer to ready health care facility	to update re: patient condition, aftershock damage, buy/repair assets, and change of course	Optimal equipment operability depends partly on weather, sea state, runway surface	Capacity- to carry blood products and keep them usable; to carry injured survivors	Quality of telecom signal and messages; confirmation of message	Safety - new hazards - in facilities; on roads; for landing/T-O, i.e., tsunami debris, newly-sunken coastline	Task assignments to groupings, some with changing deadlines
	to recalibrate shaken telecom equipment? Telecom connection with new destination	health center service load and service rate; inter-facility transfer?	Staff mix, en route & at terminus	Assign helicopters to base and pilots to aircraft; distance may dictate different vehicles and origins	Multiple chance constraint; radio traffic, interference; towers and repeaters damaged?	Zone per vehicle: allocate vehicles by comparing DN urgency rating, pre-commitments, present fuel, load and location when new need arises for blood delivery or casualty PU
	return		service capacity transfer **	Earliest delivery time; degree of urgency of demand points	Desired mix of usable resources	Dock/wharf/beach usable? Transfer from boat to amphibious aircraft, east coast VI?
	unload	Service start time of vehicles	service capacity expands, contracts, and shifts	Upper bound for number of tours; pilot-aircraft compatibility	Variable calculation Excess or shortage in demand	Course changes imply everyone monitor common radio frequency

\*\* may involve converting wards to operating rooms, clearing space for more resources, prioritizing resource usage and work efficiency, and scheduling operations to best assist casualties. Abbreviations: DO – drop-off; DN – destination; NVI – northern Vancouver Island; PU – pick up; STOL – short take-off or landing; T-O – take-off; T ° - temperature; VTOL - *vertical* take-off or landing.

## **Appendix R: Plausible Anticipated Dilemmas**

Multimodal (speedier) transport may be required if, in a ground-based ambulance, the condition of a child worsens drastically and rapidly, or if medical personnel on duty in nearby hospitals need to be rapidly relocated in order to serve more or other remote emergency units (Caunhye et al., 2012). Speed of response is an important factor since fatalities often result because rescue, or transportation to intensive care, or both, are delayed or are too long in duration (Caunhye et al., 2012). However, if an aircraft already has aboard a gravely-injured patient(s) (GIP) bound for a secondary or tertiary care hospital, unless onboard VIHA/BCAS staff assessment determines otherwise, that aircraft may not stop to pick up another GIP bound for same destination.

Equitability is the question, in that all demand points in the blood distribution and/or casualty retrieval system should have approximately equal opportunity for timely service. But if the first casualty picked up near the starting point in a multiple-casualty retrieval flight is in the gravest condition, that person would face a longer duration trip than other casualties picked up later in that same flight. This circumstance suggests that defined geographic zones should be serviced from separate origins that are directed via centralized command, and that even then, some of the aircraft trips may retrieve very few injured survivors, or just one casualty. However, if certain aircraft could carry blood and staff that can perform transfusions in flight, as in parts of Australia (Langford, 2009), additional casualties could possibly be transported per flight of larger aircraft.

## **Appendix S: Factors Affecting Post-Quake Decisions Regarding Ordering Blood Products from CBS Vancouver**

The VIHA Medical Director, Hematopathology, in deciding how much additional blood product to order from CBS Vancouver in the first day or two, and *where* to have it delivered, might consider numerous variables, including:

BC EBMC/CBS advice on current BC blood product inventory restrictions

Which VIHA TM staff are available where, when, and their overall skill mix

CBS capacity to supply blood to VIHA, and to import blood into BC, if necessary

which VIHA transfusing hospitals are functioning, and at what present and near-term capacity, in terms of their TM function, closely-related departments, blood inventory, and blood storage capacity

The estimated amount of blood needed for non-disaster operations/transfusions, the availability and current location of the PHSA-administered Mobile Medical Unit

Current inventory levels of Type O (both + and –) RBC available within the *VIHA blood products system*

Initial information about the numbers and types of casualties, where they are, plus whether they will be med-evaced from a Greater Victoria hospital to the Lower Mainland or further east, and if so, what blood products will need to be transported with them

The condition and location(s) of alternate or additional facilities that VIHA has identified for storing, inventorying, processing, and/or testing blood products, as part of a solution to this scenario

The criteria to use to determine whether to relocate the operations of a TML to an alternate facility

The current census of patients admitted post-quake to the SEOC hospital and those

referred to other Greater Victoria hospitals

Areas/routes in Greater Victoria that should be avoided because of barriers or new, significant hazards created by the disaster or aftershocks, and the locations of helipads and floatplane landing sites identified in Appendix N, provided landing/takeoff clearance is given for the particular location considered

Air transport resources available, including via BCAS, PEP Air, commercial floatplanes based in Vancouver, commercial helicopters and floatplanes near more remote VIHA facilities that take or administer blood products, and aircraft from the Canadian Forces' 442 Transport and Rescue Squadron.