POST-EARTHQUAKE SOLID WASTE MANAGEMENT STRATEGY
(for the City of Vancouver and the Surrounding Area)

by

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Abstract

The Lower Mainland of British Columbia faces a high risk of a devastating seismic event occurring at any moment. Such damaging earthquakes generate tremendous amounts of disaster debris, and present great challenges for the solid waste management system. Global experience with disasters has indicated that preplanning and mitigation are of substantial value in earthquake response, recovery and reconstruction. The current lack of such measures has extensive socio-economic and environmental repercussions, and grave solid waste management implications. Consequently, a strategy for the cleanup of all solid waste generated during an earthquake, as well as during the recovery stages, was developed for the Lower Mainland. The need for a post-earthquake municipal solid waste management strategy, and a separate strategy for disaster debris is identified. The main feature of the former is the strategy’s dependence on the current solid waste management system. The main premise of the latter is the recognition of the similarity in waste characteristics and handling requirements between disaster debris and demolition, landclearing and construction waste. The proposed Post-Earthquake Solid Waste Management Plan (Plan) presents an Action Plan Procedure (Action Plan), recommends Preplanning Actions, and identifies Strategy Options. The Plan also acknowledges the necessity for finalizing an Operational Plan once an earthquake occurs and the damage is known. The Action Plan, which is independent of the magnitude and time frame of an earthquake event, provides a framework for developing the Operational Plan. The Preplanning Actions identify the tasks that should be undertaken prior to an earthquake occurrence, in order to facilitate the recovery effort. The Strategy Options Report (Report) provides a sample waste characterization scheme, an action prioritization scheme, various handling options, and a number of decision-making criteria. Furthermore, the Report proposes a series of procedures that address five damage severity scenarios. In conclusion, the proposed Plan confirms that earthquake related solid waste management issues must be addressed on a regional basis. Unconventional and alternative solid waste management methods should be researched and considered for utility in earthquake recovery. Narrow scope and prescribed methodology are advantageous to the preparation of a management plan.
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PART I: INTRODUCTION
1. INTRODUCTION

1.1 Overview
The Lower Mainland is facing a high risk of a devastating earthquake at any time (PEP, 1992). The probability of tremendous damage, resulting in unthinkable quantities of disaster debris, is being acknowledged by all levels of the government. Emergency preparedness work is being conducted regularly in British Columbia by the Provincial Emergency Program, in order to ensure the provision of basic immediate response. Conversely, plans for recovery and reconstruction from such an earthquake, with solid waste management implications, are practically non-existent.

The recent global realization of the consequences of not planning for disaster debris management has motivated many countries, including the US and Japan, to mandate preparedness in this respect. The global earthquake experience dictates that the social, economic and environmental consequences are unacceptable under the current reactionary system of response, and must be mitigated through planning before a disaster occurs.

Billions of dollars have been spent on recovery from earthquakes, including the 1989 Loma Prieta and the 1994 Northridge Earthquakes. Social and environmental standards are compromised for extended periods of time in the aftermath of earthquakes, often with irreparable damages which are only indirectly related to earthquakes. At the root of these issues is the unprepared and insufficient solid waste management system. The limited preplanning for disaster debris management has been documented to provide substantial savings during earthquake recovery to the affected area, and the parent country at large. Preplanning saves money by:
- identifying cost-effective debris management options;
- improving administrative efficiency;
- increasing control over debris management;
- preventing costly mistakes; and avoiding generation of more waste.

In addition, preplanning speeds up the process of recovery and reconstruction, and shortens the time of misery. It also allows for the consideration of issues which may be overlooked when rapid action is required.

1.2 Purpose
The purpose of the Thesis is to develop a solid waste management strategy for a post-earthquake situation in the Lower Mainland. The final product and application of the Thesis is a Post-Earthquake Solid Waste Management Plan (Plan) for the City of Vancouver and the Greater Vancouver Regional District (GVRD).

1.3 Objectives
The main objectives of the Thesis include:
- identification of the solid waste issues most likely to arise in a post-earthquake situation;
- identification of alternative actions to address these issues;
- consideration of the strengths and weaknesses of the proposed course of action;
- proposition of a comprehensive post-earthquake solid waste management strategy; and
- recommendation of mitigative actions to be undertaken before an earthquake occurs.
The strategy proposed in the Thesis addresses the following:

- solid waste generated during an earthquake, such as structural debris;
- solid waste generated during response to, recovery and reconstruction from an earthquake;
- municipal solid waste generated following an earthquake, whose composition and volume is impacted by the event;
- time aspects, including time frame of earthquake occurrence, and phases of earthquake cleanup;
- the unique geographical characteristics of the earthquake impacted area, and their effects on solid waste generation;
- transportation issues;
- collection and disposal of solid waste; and
- responsibility for cleanup after an earthquake, in terms of decision-making and provision of funds.

1.4 Beneficiaries

The research and the development of the Plan have been sponsored by the City of Vancouver and the Greater Vancouver Regional District. While the majority of the work has been an independent endeavour, there was significant cooperation and mutual exchange of ideas and information with the Disaster Debris Subcommittee of the Joint Emergency Liaison Committee.

Although the Plan has been developed for the City of Vancouver, with financial contribution from the GVRD, the Plan has a region-wide application (i.e., applies to all of Lower Mainland). The region-wide application of the Plan should be recognized as having the intrinsic implication that planning for post-earthquake solid waste management must be done on a regional basis.

A separate and more concise document, featuring the contents of the Plan, is prepared for use by the City of Vancouver and the GVRD.

1.5 Thesis Content

The Thesis Document (Thesis) presents the contents and methodology of the Plan, as well as the pertinent research work that was conducted. While attempting to conform with the required thesis format, the nature of the results of the Thesis (i.e., the Plan) necessitates an anomaly in the format (e.g., Strategy Options is a self-contained report which appears in Section 12). The nature of the research work required in developing the Plan (i.e., the range of topics explored) presents additional difficulties in information organization within the formal thesis format. The information is generally presented as to enhance the readability of the Thesis as one document, and accommodate referencing of specific topics. Since the raw data for the Thesis (which would typically be located in appendices) consists of facts and information, it is presented in its entirety within the body of the Thesis. An exception to this information organization rule constitutes another formatting anomaly (i.e., the Strategy Options Report contains a number of tabular appendices).

The Thesis consists of 15 sections, which are grouped into seven parts. These are briefly summarized in a list format for easy referencing.
Thesis Report Organization

PART I: INTRODUCTION

- Section 1 - Introduction
  - provides a brief introduction to the issue at hand
  - presents the motivation behind, and purpose of the current work
  - explains the format of the Thesis Document
  - identifies the utility of the Thesis and the Plan

PART II: BACKGROUND

- provides a context for the current work
- presents the need and justification for the current work
- each section introduces the following topics:

Section 2 - Background - Earthquakes
- the concept of seismicity
- the effects of earthquakes
- the earthquake potential in the region of interest

Section 3 - Background - Solid Waste Management System
- the principles of the current solid waste management system
- the probable composition of earthquake debris
- the means of dealing with nuisance premises

Section 4 - Background - Authority and Funding for Earthquake Recovery
- the role and authority of governments in earthquake recovery
- the sources and amounts of funding potentially available for earthquake recovery
- the sources of resources other than funding

PART III: EXISTING PLANS AND METHODOLOGIES

- provides guidance for developing plan methodology
- presents the experience for engineering a solution
- each section presents the following topics:

Section 5 - Existing Plans and Methodologies - Canadian Perspective
- the federal guidelines for disaster debris management planning
- the current provincial undertaking in earthquake response and recovery planning
- the local earthquake response plans

Section 6 - Existing Plans and Methodologies - United States Perspective
- the US federal guidelines for disaster debris management planning
- the California state guidelines and previous earthquake recovery experiences
- the existing earthquake recovery plan for the City/County of San Francisco

PART IV: RESULTS

- investigates the solution options
- presents the experience for engineering a solution
- each section discusses the following topics:

Section 7 - Results - Lessons Learned
- the 1989 Loma Prieta Earthquake in San Francisco
- the 1994 Northridge Earthquake in Los Angeles
- the 1999 White Rock Floods in the Lower Mainland

Section 8 - Results - Lessons Applied
- the estimation of potential disaster debris quantities that may be generated in the Lower Mainland during a devastating earthquake
- the disposal options available in the Lower Mainland
- the vulnerability of the current solid waste management system to earthquake effects
Thesis Report Organization

PART V: POST-EARTHQUAKE SOLID WASTE MANAGEMENT PLAN
- presents the contents of the Plan
  - Section 9 - Plan - Introduction
    - provides a context for the Plan within the Thesis
    - presents the components of the Plan, which include Action Plan Procedure, Preplanning Actions, Strategy Options Report, and Operational Plan
  - Section 10 - Plan - Action Plan Procedure
    - provides a framework for the entire earthquake recovery plan, and for the finalization of an Operational Plan after an earthquake occurrence
  - Section 11 - Plan - Preplanning Actions
    - presents tasks to be fulfilled immediately, before an earthquake occurs
  - Section 12 - Plan - Strategy Options Report
    - presents a management strategy dependent on the magnitude and time frame of earthquake damage

PART VI: CONCLUSIONS AND RECOMMENDATIONS
- Section 13 - Conclusions and Recommendations
  - provides highlights of the Thesis and the Plan
  - provides insights into the process of preplanning for the post-earthquake management of solid waste
  - provides insights into Thesis development process
  - provides recommendations for Thesis utilization
  - provides recommendations for Plan utilization

PART VII: BIBLIOGRAPHY
- provides a list of references used in preparation of the Thesis, and material for further reading
  - Section 14 - Bibliography - Literature and Internet References
  - Section 15 - Bibliography - Personal Communication References

1.6 Thesis and Plan Utility
The main utility of the Thesis is to provide background information to the content and methodology of the Plan.

The main utility of the Plan is to reduce and mitigate the damage to the socio-economic and environmental aspects of a society devastated by an earthquake. The Plan will reach a greater utility potential if it is recognized as a regional plan, and adopted as such by all Municipalities within the Lower Mainland. Additional work may be required by each Municipality to customize the Strategy Options and Preplanning Actions according to each Municipality’s resources and state of preparedness for earthquake recovery (not just response). The Action Plan Procedure is applicable on any scale or level of utilization.

The Plan can also be used as a sample plan for use by other regions in developing their Disaster Recovery Plans, and for planning for disasters other than earthquake.
PART II: BACKGROUND
2. BACKGROUND - EARTHQUAKES

Developing a strategy that addresses the problems of a future and unprecedented situation, such as a damaging earthquake event, requires an increased knowledge and understanding of:

- the probability of occurrence of such an event in a particular region;
- the effects that can be expected;
- the costs associated with recovery, particularly the cost savings of a preplanned recovery versus an unanticipated and reactionary recovery; and
- the terminology associated with such an event.

Such a basis of understanding provides the context for the current work. Furthermore, this background knowledge of the magnitude of the potential problem presents the necessity of and justification for the development of a recovery plan before such a situation becomes a reality.

The following sections provide an introduction to seismicity, as well as present the seismic situation in the Lower Mainland. The understanding of the magnitude of the potential problem is complemented by a summary account of the damaging effects of past earthquakes. Although it is impossible to accurately quantify the repercussions of an earthquake, attempts have been made at predicting earthquake damage based on past experiences. These earthquake damage predictions are also provided in the following sections, emphasizing the need for considering recovery methods and options prior to a devastating earthquake.

2.1 Seismicity

2.1.1 General

2.1.1.1 Causes of Earthquakes

- The Theory of Continental Drift and Plate Tectonics
  
  Earthquake tremors are typically the effect of a re-balancing of forces arising from the collision of continuously moving plates of rock that float upon the earth’s molten interior. The supercontinent that was originally the concentrated mass of the crust of the earth, began breaking up approximately 200 million years ago, and presently consists of about 20 thick tectonic plates that drift across the molten mantle of the earth (Yanev, 1990).

- The Adjustments of Plate Frictions
  
  When two plates meet, tremendous pressures buckle the earth’s surface. The younger, and thinner (oceanic) plate is forced downward by the heavier (continental) plate. As the younger, thinner plate is propelled below the heavier plate and melts into the earth’s core, the edge of the heavier plate is pushed continually upward. At the same time, friction causes a temporary lock between the two plates. As stresses build up from the resistance to movement of adjacent plates, energy is accumulated. The inevitable and frequent failures of this bond release the excess energy in the form of ground shaking, causing deep and powerful earthquakes. Some of the largest faults—breaks in the rock of the earth’s upper crust—are formed between tectonic plates. About 90 percent of the world’s earthquakes occur at faults along the boundaries of the earth’s major crustal plates (Yanev, 1990; and NAHB, 1994).
2.1.1.2 The Mechanism of Earthquakes

- The Theory of Elastic Rebound

The edges of the plates have a certain amount of elasticity, and tend to hold their positions along the fault. Portions of the fault frequently remain locked in this way, under tremendous stress, for several years or even centuries. Finally, when the accumulated sliding force exceeds the frictional force that binds portions of the plates, and prevents their natural movement, the distorted rocks along the two sides of the fault suddenly slip past one another. Such an explosive movement allows a new position of equilibrium. This slippage, termed "elastic rebound", produces powerful vibrations, which can sometimes rupture the earth’s surface, and shift the positions of the fault sides by several feet both horizontally and vertically. Earthquakes are the result of these violent adjustments of a temporarily locked fault (Yanev, 1990).

Shallow-focus earthquakes, with an average depth of 5 to 15 km (3 to 10 miles) below the surface of the earth, result from the slippage of primarily laterally moving plates. Deep-focus earthquakes usually occur where the plates are directly colliding, and one plate is forced below the other. The destructiveness of an earthquake is closely related to its depth. The shock waves of deeper earthquakes are generally dissipated as they rise to the surface, and thus, are less damaging to buildings. On the other hand, deep-focus tremors usually affect a much wider area (Yanev, 1990).

- Faults, Fault Zones, Faulting and Creep

Faulting is defined as the displacement of ground (vertical and/or horizontal) along a surface/subsurface discontinuity during an earthquake. Such a displacement results in abnormal topographical formations of scarred, crumpled and upthrusted rock and soil. Consequently, major and recently active faults are visibly delineated (Yanev, 1990).

An earthquake can be defined as the movements in rock structures along faults producing a sudden rupture, which results in perceptible vibrations (Bolt, 1993).

Fault creep occurs when two sides of a section of a fault avoid locking completely and move past one another at an infinitesimally slow and gradual rate of fractions of an inch per year (Yanev, 1990).

Most structural damage to property during an earthquake is directly related to the intensity of the shock waves in the ground, and the intensity of ground shaking is usually very strong along the fault. Even if there is no faulting (i.e., visible demarcation of a fault on the earth’s surface), any building located on or within the zone of a fault will be exposed to very strong ground vibrations (Yanev, 1990).

- Types of Seismic Waves in Earthquake Shaking

Earthquake shaking and damage is the result of three basic types of elastic waves. Two of the three propagate within a body of rock, and the third is a surface wave (Bolt, 1993).

The faster of these two body waves is called the primary, or P-wave. Its motion is the same as that of a sound wave in that, as it spreads out, it alternately pushes (i.e., compresses) and pulls (i.e., dilates) the rock. The P waves are able to travel through both solid rock, such as granite mountains, and liquid material, such as volcanic magma or the water of the oceans. When P-waves emerge at the surface from deep in the earth, a fraction of them may be transmitted into the atmosphere as sound waves, audible to animals and humans at frequencies greater than 15 cycles per second (Bolt, 1993). This explains the "rumbling" sound associated with earthquakes (NAHB, 1994).
The slower wave through the body of rock is called the secondary, or S-wave. As an S-wave propagates, it shears the rock sideways at right angles to the direction of travel. The S-waves cannot propagate in the liquid parts of the earth as liquids do not resist shear (Bolt, 1993). S-waves may be amplified or dampened depending on local variations in ground properties, the surrounding topography, and the magnitude of shaking in underlying bedrock (NAHB, 1994).

The actual speed of P- and S-waves depends on the density and the elastic properties of the rocks and soil through which they pass. The P-waves, which are felt first, have a sonic boom effect that bumps and rattles window. Several seconds later, the S-waves arrive with their up-and-down and side-to-side motion, shaking the ground surface vertically and horizontally. This is the wave motion that is so damaging to structures (Bolt, 1993).

The slower the seismic wave speed, the greater the amplitude. P-waves tend to be faster and have lower amplitude than S-waves. P-waves also tend to attenuate (i.e., lessen in magnitude) more quickly than S-waves (NAHB, 1994).

As sand layers liquefy in earthquake shaking, there is a progressive decrease in the amount of S-wave energy that is able to propagate in the liquefied layers, and ultimately, in the amount of P-waves that can pass through (Bolt, 1993). Soil liquefaction is discussed in greater detail in Section 2.1.1.5.

The third general type of earthquake waves is called a surface wave, because its motion is restricted to near the ground surface. Such wave corresponds to ripples of water that travel across a lake. The horizontal shaking of the surface waves is particularly damaging to the foundations of structures (Bolt, 1993).

Aftershocks are caused by the continuing readjustment of stresses at different locations along a ruptured fault, and its subterranean fault plane after the main shock. Because of the varied geology along the fault plane, all of the accumulated energy is not released at once by an earthquake, and the process of localized readjustment continues indefinitely. A very large shock is often followed by hundreds and sometimes thousands of discernible aftershocks for months after the main event (Yanev, 1990).

From the standpoint of building damage, the larger aftershocks can be quite destructive. For example, a month after the major Kern County, California earthquake in 1952, an aftershock centered near Bakersfield was strong enough to cause more damage to the shaken and weakened city than the initial earthquake because it struck much nearer to the city than the main shock (Yanev, 1990).

2.1.1.3 Tectonics and Earthquake Documentary Videos
A number of films are available at the Justice Institute of British Columbia, which help broaden the general knowledge and understanding of plate tectonics and the effects of earthquakes. The following is a list of the videos, with a short description of film content, which were viewed while conducting research for this document. The viewing of these films was responsible for clarifying and enforcing the understanding of the extent of potential earthquake effects. In addition, the content and presentation of the films generated new ideas for recovery efforts that may be required following an earthquake.
2.1.1.4 The Measurement of Earthquakes

There is a number of different methods of expressing the magnitude of an earthquake. These methods are only indirectly related, in that each scale increases in magnitude with the increase in earthquake energy release. However, there is no formula that relates the various scales.

The method most appropriate for use depends on the context in which it is being used. The following are the definitions of the most common, and the most distinct means of measuring earthquake magnitudes. The context for the most appropriate usage of each method is also indicated.

The definitions of the various scales of earthquake magnitude rely on the prior understanding of the terms associated with the location of an earthquake. These terms are defined at the onset.

- **Epicenters and Hypocenters**

Hypocenter, or focus, of the earthquake is the location deep in the crust of the earth where a fault slippage first begins. The epicenter is the projection of the hypocenter on the ground surface, and is always the point on the surface closest to the initial slippage (Yanev, 1990). The difference between these two points is illustrated on Figure 2-1.

The epicenter should not be confused with the point in the affected area which experiences the strongest or the longest shaking. The fault, not the epicenter, is almost always the center of the greatest earthquake intensity, and therefore, the greatest potential for damage. Since the fault may be at an angle other than 90 degrees to the ground surface through the bedrock, the active fault may be some distance away from the epicenter (Yanev, 1990). Figure 2-1 illustrates the relationship between the epicentre and the point of most intense shaking (i.e., surface fault trace), for two different fault plane orientations.
The Richter Magnitude Scale

Earthquake magnitude, a measure of the total energy released by an earthquake, is a measurement taken on a seismograph located at a distance of 100 km from the center of surface energy release (i.e., epicenter) by the shock. The Richter scale is logarithmic, with each whole number representing a magnitude of energy release that is approximately 31.5 times the lower number (Yanev, 1990). The Richter scale is limited in its accuracy to earthquake magnitudes of less than 7 (Finn, 1998a). The Richter scale is the most commonly known and utilized scale by the general public.

The severity of an earthquake is commonly represented by a measurement known as the Richter Local Magnitude ($M_L$), which provides a relative comparison of the severity of ground shaking. Newer methods of measuring earthquake severity such as the Moment and Surface Wave Magnitudes ($M_w$ and $M_s$) are also used, but they describe somewhat different aspects of a given earthquake event (NAHB, 1994). Typically, the Richter magnitude is reported as an earthquake measure, and is denoted with the letter M without a subscript. This convention is used throughout the Thesis, unless otherwise specified.

A commonly accepted measure for earthquakes that relates magnitude and damage terms a "great earthquake" as one that has a Richter magnitude of 7.7 and above, a "major earthquake" at 7 to 7.7, and a "moderate earthquake" at 6 to 7. For example, the 1971 San Fernando earthquake (magnitude 6.5) was in the category of the moderate-sized shock that can be expected approximately every four years somewhere in California. The 1989 Loma Prieta earthquake (magnitude 7.1) was a major earthquake, which typically occurs in California on or off shore on the order of every 15 years (Yanev, 1990).

The duration of an earthquake is related to its magnitude, which is a measure of the total amount of energy released by the shock. An earthquake of magnitude 5 or 6 might cause 5 to 10 seconds of strong motion, followed by noticeable but very weak movements. An earthquake of Richter magnitude 6.5 usually lasts 15 or more seconds. An earthquake of magnitude 7.1 typically lasts about 20 to 30 seconds. A great earthquake of magnitude 8.2, such as the one in San Francisco in 1906, might last 40 to 60 seconds (Yanev, 1990).

The Modified Mercalli Intensity Scale

Intensity scales, such as the Modified Mercalli Intensity (MMI) scale, measure the effects rather than the energy release of an earthquake. Because the scale categories are mainly related to effects on people and buildings, intensity scales are also known as the "man-scaring, building-busting" earthquake scales (Yanev, 1990). A more detailed definition of this scale appears in Appendix 12.10-C in Section 12.10.

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Figure 2-1: Differentiation among Epicentre, Hypocentre and Point of Most Severe Shaking (Adapted from Yanev, 1990)
2.1.1.5 Effects of Earthquakes
Earthquake effects manifest themselves in a variety of ways. A number of earthquake effects that present
the greatest dangers to inhabited areas are discussed below.

- The Relative Hazards of Various Geologic Foundations
  The intensity of shaking always diminishes with distance, but softer, vibration-prone soil many miles
  from the fault can produce more damage than a strong rock formation only a few hundred feet away from
  the source of the earthquake (Yanev, 1990).

  Bedrock or hard, densely compacted soils are the safest type of geological formation during earthquakes.
  This type of foundation is the most preferable, and structures built on it sustain the least amount of
damage. There is nearly no or very little shock wave amplification in bedrock and very hard soils. In
  fact, there is a great deal of ground motion attenuation as seismic waves travel through bedrock (Finn,
  1998a).

  Soft soils, or less dense mixtures of soil found in certain landfills are unstable, and act much like jelly in
  a bowl. They respond to and then amplify the earthquake motions further. The shock waves are
  transformed from rapid, small-amplitude vibrations in the bedrock into slower and more damaging large-
  amplitude waves. The chaotically undulating motions of these waves can be devastating at the surface,
  particularly in landfill and water-saturated soils (Yanev, 1990).

  The highest earthquake-hazard areas are always the natural alluvial soils and man-made landfills in the
  valleys, and near the coast and bays. Post-earthquake studies have consistently shown that structures
  built on rock near the fault or epicenter of an earthquake fare better than much more distant buildings on
  soft soils (Yanev, 1990).

- Soil Liquefaction
  Soil liquefaction is a very common effect of earthquakes in low-lying coastal areas, or wherever soft soils
  and high water tables exist (near bays, lakes, rivers, deltas and marshlands). The compaction of the soil
  from earthquake vibrations increases the pore pressure of saturated soils, resulting in the loss of effective
  stress. This in turn causes the water to displace, and usually flow upward. The sandy or muddy soils
  become liquefied into a kind of quicksand. The most dramatic example of liquefaction occurred in the
  coastal city of Niigata, Japan, during a magnitude 7.3 earthquake in June of 1964. Numerous buildings,
  automobiles and other heavy objects gradually settled into the "quicksand" (Yanev, 1990).

  Liquefaction is also defined as all phenomenon giving rise to a loss of shearing resistance (through the
  increase in pore water pressure), or to the development of excessive strains as a result of transient or
  repeated disturbance of saturated cohesionless soil. When liquefaction occurs, liquefaction induced
  displacements are usually a major cause of damage (Watts et al., 1992).
Problems Along Cliffs and Ridges

Ocean cliffs in the vicinity of large faults present special risks during earthquakes. Because the cliffs are unsupported by ground and rock on one side, they experience more earthquake motion than the ground some distance from the cliff. In addition, as the shock waves emerge from the ground, they are reflected back from the cliff face and cause further amplification of the vibrations (Yanev, 1990). This latter effect is comparable to the reflection and amplification of seismic waves traveling from the epicentre as they reach the ground surface (Finn, 1998a).

A similar effect occurs in harbours and at river banks, since these are also unsupported by ground or rock on one side. This has a detrimental impact on structures such as bridges and bridge piers that are built in their immediate vicinity (Finn, 1998a).

Houses on ridges are also exposed to a higher risk. The energy of the earthquake waves appears to get trapped within the peak of the ridge, causing great amplification in a very local area. This effect leads to much larger forces on buildings, which results in greater damage, and often in catastrophic failure (Yanev, 1990).

Tsunamis

Tsunamis—seismic sea waves—are caused by faulting or other abrupt ground movements on the ocean floor or on shore during large earthquakes. In the open ocean, the waves are not much above normal height, but they move at very high velocities—sometimes reaching 650 km/h (400 mph)—and when they approach a shoreline, the slope can raise them to heights of as much as 15 m (50 ft) (Yanev, 1990).

2.1.2 Lower Mainland

The current work proposes an earthquake recovery strategy for the Lower Mainland. Therefore, in addition to gaining an appreciation for earthquake effects in general, an understanding of the earthquake hazard that is present in this region is essential. Increased awareness of the earthquake potential in western B.C. provides the context and justification for the current work. The seismic situation in the Lower Mainland, and the potential of earthquake hazards are discussed in the following sections.

2.1.2.1 Ongoing Seismic Activity

A major earthquake that would result in widespread damage to southwestern British Columbia has been predicted by geologists to occur every 300 to 500 years (PEP, 1992).

The three distinct source regions of earthquakes that may present a hazard to southwest BC are:

1. crustal earthquakes;
2. deeper earthquakes within the subducted plate; and
3. very large subduction earthquakes on the boundary between the two lithospheric plates (Rogers, 1992).
The relative locations of earthquake source regions are illustrated on Figure 2-2.

![Figure 2-2: Source Regions of Earthquakes in Southwestern British Columbia](Adapted from Rogers, 1992; and Hyndman, 1995)

- **Crustal Earthquakes**

  Most of the ongoing small earthquakes occur at considerable depth within the crust (on the order of 20 km) of the North American continental plate. Due to the substantial depth of the earthquakes, and the absence of a distinct pattern of the earthquake epicentres, there appears to be little correlation with mapped surface faults. This depth range places most of the seismicity in this region deeper than earthquakes in California. There, most earthquakes occur in the top 10 km of the crust, and events deeper than 15 km are rare. The deeper source of most of the crustal events in southwest B.C. means that a much wider area is affected (Yanev, 1990). It also means that there are fewer aftershocks than for typical California earthquakes. The extra thickness of the brittle portion of the crust where earthquakes can occur is a direct result of the subduction environment off the coast of B.C. (Rogers, 1992).

  There have been three large crustal earthquakes affecting southwest B.C. in historic time: in 1918 (M=7) and in 1946 (M=7.3) on Vancouver Island; and in 1872 (M=7.4) in northern Washington State, in the Lake Chelan region, south of Hope, B.C. It should be noted that these large earthquakes occurred away from the southern Georgia Strait-Puget Sound lowland which is the most intense region of seismicity reflected by the pattern of small earthquakes (Rogers, 1992).

  A subset of the ongoing small earthquakes occurs in the upper 10 km of the crust. A number of the larger of these very shallow events had long aftershock sequences typical of California earthquakes, and may have occurred on faults that ruptured the surface. The November 30, 1975 earthquake (M=4.9) in central Georgia Strait, and the April 13, 1990 Deming, Washington earthquake (M=4.8) just south of Abbotsford, B.C., are two such events. The extremely shallow earthquakes, although rare, can have very high accelerations in close proximity to them (Rogers, 1992).

  There is a growing amount of geological evidence that is interpreted as a prehistoric earthquake in the magnitude 7 range that ruptured the surface in central Puget Sound near Seattle, Washington about 1100 years ago (Rogers, 1992).
Subcrustal Earthquakes
Subcrustal earthquakes refer to earthquakes within the subducting Juan de Fuca Plate. The maximum size of earthquake is well constrained to the 7 to 7.5 magnitude range. The band of subcrustal seismicity within the Juan de Fuca plate is limited to two regions on the descending face of the plate:
1. beneath Vancouver Island, where a bend occurs as the plate goes from horizontal in the deep ocean to a shallow dip of 10 to 20 degrees; and
2. below the Strait of Georgia and Puget Sound, where the plate bends further to a steeper dip of about 30 degrees, at depths of approximately 45 to 65 km (Rogers, 1992).

Subduction Earthquakes
The controversy regarding the capability of the Cascadia subduction zone off the coast of B.C. to generate a giant "megathrust" earthquake presently still exists. Various theories have been proposed, supported by corresponding evidence. However, further research is required to shed more light on, and resolve this issue.

The simple Cascadian subduction earthquake model stipulates that the ongoing convergence of two tectonic plates (i.e., North American and Juan de Fuca plates) results in tremendous pressures that drag down the seaward nose of the continent. Consequently, an upward flexural bulge is generated further landward (the vertical uplift rate ranges from 1 to 4 mm per year). This phenomenon is illustrated on Figure 2-3.

Figure 2-3: Simplified Subduction Earthquake Cycle
(Hyndman, 1995)
There is also a region of crustal shortening (on the order of 7 mm per year over 400 km), which is illustrated on Figure 2-4. The younger, thinner plate (the Juan de Fuca oceanic plate) is forced down by the older, thicker plate (the North American continental plate) at a rate of approximately 40 mm per year. At depths of approximately 100 km, the oceanic plate melts into the earth’s core. As the plates converge, they slip past one another in “elastic rebound”, which results in earthquakes. Consequently, the seaward portion of the continent springs back, generating great tsunami waves. The flexural bulge collapses, causing sudden coastal subsidence (Hyndman, 1995; and Yanev, 1990). The simplified subduction earthquake cycle is depicted on Figure 2-3.

Figure 2-4: Elastic Shortening of Continental Plate
(Hyndman, 1995)

Certain proponents of the theory that the Cascadia subduction zone is capable of generating large subduction earthquakes base their hypothesis on the seismic activity of other subduction zones around the Pacific Rim. Since three of these subduction zones have produced "mega" (greater than M=9) earthquakes in historical times, and since Cascadia has not, then Cascadia must be "stuck", and will inevitably rupture in a similar fashion (Campbell and Rotzien, 1992). Rogers (1988) suggests that the Cascadia zone could be capable of a magnitude 9.2 earthquake.

Campbell and Rotzien (1992) negate this theory by pointing out that most Cascadia geological and seismological characteristics differ substantially from the other known giant earthquake zones within the Pacific Rim. Furthermore, the authors remark on the fact that many other subduction zones throughout the world (much larger than Cascadia, and with greater similarities to the existing "mega" earthquake zones) have long seismic histories of very well recorded earthquakes, none of which have exceeded magnitude 8.5.
According to Campbell and Rotzien (1992), that Cascadia makes a poor candidate for a giant earthquake. For instance, unlike the others, Cascadia has a smooth surface. This indicates that the frictional forces (responsible for locking plates against relative movement) are lower, and may not be sufficient to cause plate displacement by sudden rupture. It is also evident that Cascadia is a much younger zone, and it is moving at a lower rate. The strain energies built up in this subduction zone, even if it were locked, would be substantially lower than in the other three zones. And finally, the historical seismicity indicates that the maximum magnitude experienced by Cascadia is much lower than those experienced by the other three zones, providing no historical basis for the postulated greater than 9 magnitude.

Campbell and Rotzien (1992) further reject the assertion that the Cascadia zone is "stuck" on the basis that large earthquakes are common on Cascadia, and release any potentially built-up strain energies. For example, in one week in August of 1991, four earthquakes of magnitude 5.9, 5.6, 6.9 and 4.4 occurred on the subduction zone. Hence, the authors conclude that the Cascadia zone is not "stuck", but rather that it is progressing very satisfactorily.

Yanev (1990), another proponent of the Cascadia "megathrust" earthquake theory, disputes the latter argument of Campbell and Rotzien (1992) by reintroducing the definition of the Richter scale. The author states that the occurrence of many small earthquakes in one area does not completely deplete the fault stresses, and reduce the possibility for a large shock. On the contrary, since the Richter scale is logarithmic in nature, it would take about 500 shocks of the magnitude of the San Fernando earthquake (M=6.5), or more than 40 Loma Prieta earthquakes (M=7.1) to equal the energy released by a single great San Francisco earthquake of 1906 (M=8.2). On the same basis, it would require about 1,000 San Fernando earthquakes to equal the energy of the 1964 Alaska earthquake (M=8.5). Since such large numbers of such big earthquakes are not occurring, there is probably a great deal of energy being built up along the faults where the earthquakes of smaller magnitudes are occurring Yanev (1990).

Hyndman (1995) attempts to explain the apparent inactivity of the Cascadia subduction zone in terms of generating great or "mega" earthquakes in historical times. He offers three possible explanations:
1. the Juan de Fuca plate is no longer converging and underthrusting the North American Plate;
2. convergence and underthrusting are continuing, but they are accommodated by smooth stable sliding, void of the intermittent stick-slip behaviour of earthquakes; and
3. the thrust fault is truly locked with not enough motion to generate even small earthquakes.

In addressing the first explanation of Hyndman (1995), continuing underthrusting is evidenced by the strong folding and faulting visible in deep seismic reflection acoustic images of the sediments beneath the continental slope. In addition, the recent major volcanic eruption of Mt. St. Helens in 1980 negates this explanation, since such eruptions have their origin in melting that occurs when the underthrusting oceanic crust reaches a depth of about 100 km beneath the continent (Hyndman, 1995). Therefore, the first explanation offered by Hyndman (1995) can be rejected.

Studies of paleoseismicity (the trace of past great earthquakes preserved in the geological record), and measurements of present elastic strain build-up in the continent near the coast provide evidence contrary to the second explanation offered by Hyndman (1995). Presently, the crustal shortening is occurring at 7 mm per year between Victoria, on the coast, and Penticton, 300 km inland. The observed deformation corresponds to that expected for a locked thrust fault (Hyndman, 1995).

Consequently, according to Hyndman (1995), the third explanation remains: great earthquakes do occur, but the last one was prior to the historical written record. According to tree ring and radiocarbon studies, and paleoseismicity the last event occurred about 300 years ago.
The potential for large earthquakes on the subduction interface of the Juan de Fuca-North American Plates in the Cascadia subduction zone has been constrained to a depth of approximately 30 km, placing the potential rupture zone in the region of the outer coast of Vancouver Island (Rogers, 1992).

Studies have shown that, except for the northern part of Vancouver Island, the ground shaking from the expected subduction earthquake will be smaller than that from the crustal earthquakes (Finn, 1998c). For instance, in their ground motion simulation study of the Cascadia subduction zone (hypothesized M=8 earthquake), Cohee et al. (1991) found that ground accelerations at the distance of Vancouver from subduction zone would be smaller than those that would be expected from larger subcrustal earthquakes. A soil liquefaction study in the Fraser Delta suggests that the expected subduction earthquake occurs too far from Vancouver to be the major threat to the Lower Mainland. Therefore, due to the estimated distance of the potential subduction source from Victoria and Vancouver, seismic design in these cities is not controlled by the subduction earthquake, but rather by the conventional probabilistic approach (Finn, 1998b). The probabilistic (also known as Cornell) method has been developed for areas where the seismic mechanisms are not clearly identified (Campbell and Rotzien, 1992).

It is also recognized that the main hazard of subduction earthquakes is the long duration of strong shaking associated with large ruptures, and the large area of shaking involved. The long duration can adversely affect certain types of structures, and the liquefaction potential of saturated soils. This can result in more damage in the earthquake-stricken area (Rogers, 1992; and Finn, 1998c).

2.1.2.2 Earthquake History
At least once a week an earthquake of sufficient magnitude to be noticeable occurs somewhere in the province of B.C. (PEP, 1992). Although most of the approximately 200 earthquakes that are recorded each year in the Lower Mainland and on Vancouver Island are too small to be felt, an earthquake capable of causing some structural damage can be expected to occur somewhere in the area about once every ten years (Angel, 1992). Severe earthquakes capable of causing serious damage in coastal areas occur every 25 to 40 years (PEP, 1992).

The numerous earthquakes that have occurred in the recent history, which have affected western B.C., illustrate the current seismic risk present in the Lower Mainland. The details of these earthquakes are summarized in Table 2-1. The locations of these earthquakes are depicted on Figure 2-5. It should be noted that the documentation of the physical and financial damage sustained during past substantial earthquakes in western B.C. is very limited. This lack of documentation can be attributed to:
- the dated occurrence of the earthquakes (i.e., no significant earthquakes in the recent past, when detailed documentation of such events has become more significant and more streamlined);
- the location of the epicentres of the earthquakes (i.e., most occurring off shore, or at remote, uninhabited locations, where no or very small human populations are affected); and
- the population density of the impacted area at the time of the earthquake, along with the prevalent construction type (i.e., immediate financial repercussions of earthquake is proportional to population density, which in the past was much less significant, and required significantly less documentation).
### Table 2-1: Historical Earthquakes in Western British Columbia

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Date</th>
<th>Time</th>
<th>Magnitude</th>
<th>Epicentre Details</th>
<th>Impact Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1872</td>
<td>Washington-British Columbia</td>
<td>December 15, 1872</td>
<td></td>
<td>7.4</td>
<td>east of Vancouver towards Mount Baker in Washington State</td>
<td>widely felt</td>
</tr>
<tr>
<td>1918</td>
<td>Vancouver Island</td>
<td>December 6, 1918</td>
<td>12:41 am</td>
<td>6.9</td>
<td>near the west coast of Vancouver Island</td>
<td>damage to Estevan Point lighthouse, and to a wharf at Ucluelet</td>
</tr>
<tr>
<td>1918</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>awakened people throughout Vancouver Island, and in the Greater Vancouver</td>
</tr>
<tr>
<td>1929</td>
<td>Queen Charlotte Islands</td>
<td>May 26, 1929</td>
<td></td>
<td>7.0</td>
<td>in the Pacific Ocean, just south of the Queen Charlotte Islands</td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1946</td>
<td>Vancouver Island</td>
<td>June 23, 1946</td>
<td>10:15 am</td>
<td>7.3</td>
<td>in the Forbidden Plateau area of central Vancouver Island, just west of Courtenay and Campbell River</td>
<td>considerable damage along the east coast of Vancouver Island</td>
</tr>
<tr>
<td>1946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>felt as far as Prince Rupert, B.C., and Portland, Oregon</td>
</tr>
<tr>
<td>1946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>knocked down 75% of chimneys in nearby communities, and some in Victoria</td>
</tr>
<tr>
<td>1946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>one of the best documented B.C. earthquakes</td>
</tr>
<tr>
<td>1949</td>
<td>Queen Charlotte Islands</td>
<td>August 22, 1949</td>
<td></td>
<td>8.1</td>
<td>in the Pacific Ocean, west of the Queen Charlotte Islands</td>
<td>only slight damage on Queen Charlotte Islands, because of the sparse population of the Islands</td>
</tr>
<tr>
<td>1949</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>felt over a wide area of western North America</td>
</tr>
<tr>
<td>1970</td>
<td>Queen Charlotte Islands</td>
<td>June 24, 1970</td>
<td></td>
<td>7.4</td>
<td>in the Pacific Ocean, south of the Queen Charlotte Islands</td>
<td>widely felt</td>
</tr>
<tr>
<td>1970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>too far off shore to do any damage</td>
</tr>
<tr>
<td>1976</td>
<td>Vancouver Island</td>
<td>December 20, 1976</td>
<td></td>
<td>6.7</td>
<td>in the Pacific Ocean, west of Vancouver Island</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>Vancouver Island</td>
<td>December 17, 1980</td>
<td></td>
<td>6.8</td>
<td>in the Pacific Ocean, west of Vancouver Island</td>
<td></td>
</tr>
</tbody>
</table>

(NRCan, 1996, 1999a through e; and Angel, 1992)
2.1.2.3 Liquefaction

After years of seismic research and soil testing in the Lower Mainland, it appears that the controversy surrounding the integrity of soil deposits in the Fraser Delta still exists. Successive soil tests have been performed to determine its susceptibility to liquefaction, with contradictory results.

Most of the deposits that make up the Fraser Delta are glacial and glacial-fluvial in origin, and are not susceptible to liquefaction. Only a number of locally distributed near-surface deposits have been found to be potentially prone to liquefaction, based on sample borings (Campbell and Rotzien, 1992). However, according to Finn (1998b), liquefaction in the delta can be caused by relatively low levels of base motion.

An investigation by the Geological Survey of Canada (GSC) of soil liquefaction at six sites in the Fraser Delta suggests that liquefaction in this area occurred less than about 1,500 years ago. Considering the relative ease with which liquefaction can be caused in the delta, this evidence suggests that the Lower Mainland has not been subjected to very strong shaking even during the last large subduction earthquake, which was estimated to have occurred approximately 300 years ago. This evidence tends to confirm the findings from seismic studies conducted by the GSC, that the subduction earthquakes occur too far from Vancouver to be the major threat to the Lower Mainland (Finn, 1998b). Campbell and Rotzien (1992) suggest that the absence of evidence of liquefaction in the deeper (glacial) deposits over such a long time period could alternatively indicate that the deeper material in the delta deposits is not liquefiable.
2.1.2.4 Tsunamis

Earthquakes produce tsunami amplitudes that are the greatest within their immediate areas. Tsunami-generating earthquake simulations for the southwest coast of B.C. indicate that shallow waters dampen water waves (Murty, 1992).

It is generally believed that the probability of occurrence of a major tsunami-generating earthquake inside the Strait of Georgia-Juan de Fuca Strait-Puget Sound (GFP) system is small (Murty, 1992). The low risk of a tsunami in the Georgia Strait-Puget Sound region is also based on the fact that no significant tsunamis have been generated by earthquakes which have occurred in recorded history in this region. However, the subject of tsunami risk has never been adequately addressed (APEBC, 1988).

One tsunami modelling study indicates, that unless the earthquake occurs in the GFP system, the threat of a major tsunami within this system is not realistic. If a great earthquake (e.g., Richter magnitude greater than 8) does occur within this system, a major tsunami with amplitudes of almost 3 m could result. In addition, submarine slides (e.g., into Howe Sound or in the Strait of Georgia) could generate local tsunamis (Murty, 1992).

It is also believed that the largest populations centres in the Lower Mainland are protected from open ocean tsunamis by Vancouver Island (APEBC, 1988). Notwithstanding this presumption, the results of a simulation of a megathrust earthquake off the coast west coast of Vancouver Island showed a maximum wave amplification of approximately 1 m in the Vancouver area. Therefore, the low-lying areas, such as Richmond, are subject to threats of flooding when the tsunami arrives at high tide (Murty, 1992). It is also the opinion of Dr. Bill Crawford, a research scientist with the Canadian Hydrographic Service in Sidney, B.C., that warnings to get to higher ground will be issued in the Strait of Georgia, Vancouver and Victoria when a megathrust earthquake occurs. The warning time for a tsunami after an earthquake could be as little as 20 minutes (The Vancouver Sun, 1998).

2.2 Damaging Effects of Earthquakes

Earthquakes cause various types of damage, from physical disturbances to earth’s surface; to altering vegetation patterns (e.g., by volcanic eruptions, tsunamis); to damage or collapse of infrastructure created by man, which then also often leads to loss of human life. The greatest concern of earthquakes to the general population is the direct effects they have on people, in terms of disruption of daily life, cost of recovery, and risk of death. The following sections review several of these latter effects of earthquakes, in order to gain a greater understanding of the aftermath of earthquakes. In addition, methods that attempt to quantify the damage of future earthquakes are also discussed.

2.2.1 Western United States Earthquake Experience

As the earthquake history of Lower Mainland presented in Section 2.1.2 indicates, the likelihood of a damaging earthquake in a densely populated area is very high in this part of Canada. In developing an earthquake recovery strategy for this region, it is essential to acknowledge that this region lacks first-hand experience in recovery from such a devastating situation. Therefore, the current work draws upon the earthquake experience in other parts of the world, particularly south of the border. A number of recent earthquakes in California and Washington has devastated highly populated urban centres. The documentation of these accounts vary, but are nonetheless substantial.
The earthquake history in these two western States is reviewed in the following sections, and is summarized in Table 2-2. This review emphasizes the physical and financial damages incurred during the most significant events. It should be noted that none of these recoveries followed a preplanned course of action, since no such planning had taken place prior to these events. This situation has been rectified in certain parts of the western States. As of the last severe earthquake in 1994 in Northridge, California, several earthquake recovery plans currently exist in these areas. These plans are discussed in Section 6.

In addition, the earthquakes that have affected Western United States demonstrate the magnitude of damaging effects that can result from such earthquakes. The details of the earthquakes that have occurred in the recent history in California and Washington are summarized below.

Table 2-2: Recent Earthquakes in California and Washington

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1906</td>
<td>San Francisco Earthquake</td>
<td>epicentre a few kilometres from the Golden Gate Bridge in San Francisco, California severe shaking for approximately 40 seconds a long, 430 km rupture of the San Andreas Fault occurred the offset along the fault (west side moving northwest relative to the east side) was mainly horizontal and reached up to 6 m north of San Francisco the maximum vertical displacement across the fault was less than a metre</td>
</tr>
<tr>
<td>1965</td>
<td>Seattle-Tacoma Earthquake</td>
<td>epicenter was placed 20 km southeast of downtown Seattle, Washington, in Puget Sound intensity MMI=VII (small pockets of MMI=VIII in Seattle and surrounding suburbs)</td>
</tr>
<tr>
<td>1989</td>
<td>Loma Prieta Earthquake</td>
<td>epicentre in the Santa Cruz Mountains, near San Francisco, California (“Loma Prieta” = “the dark rolling mountain”) severe shaking for approximately 15 seconds earthquake was produced by rupture of a 40 km segment of the San Andreas Fault, where it traversed the Santa Cruz Mountains</td>
</tr>
<tr>
<td>1994</td>
<td>Northridge Earthquake</td>
<td>epicentre in the San Fernando Valley, northeast of Los Angeles, California severe shaking for 15 to 20 seconds one of the most densely populated urban areas in the country at least 14,000 recorded aftershocks, including eleven of 5.0 or greater.</td>
</tr>
</tbody>
</table>

(Bolt, 1993; FEMA, 1995; French, 1990; NAHB, 1994; and Wright et al., 1979)
2.2.1.1 1906 San Francisco Earthquake
The population of San Francisco at the time of the 1906 earthquake was 400,000 people. At the time, it was a mixture of old and new buildings: the downtown area was dotted with steel-frame high rises (e.g., 19-story Spreckels building, and 16-story Chronicle building), although it was still dominated by older buildings of wood and unreinforced brick. Farther away from the Bay were two- and three-story wooden Victorian homes, which were very combustible (Bolt, 1993).

Heavy damage occurred at Los Banos, 30 km east of the San Andreas Fault (i.e., the epicentre of the earthquake), and at the southern end of San Francisco Bay (including the present city of San Jose). The soil conditions were conducive to causing such heavy damage, since the surficial material in these areas is alluvium or recent fluvial deposits. Towns along the east side of San Francisco Bay, such as Berkley, 25 km east of the San Andreas Fault, suffered little damage. However, more destructive than the earthquake, was the fire that broke out almost immediately after the earthquake, and raged for three days. The fire produced perhaps 10 times more damage than did earthquake shaking. (Bolt, 1993).

The casualties totaled 700 lives, but higher (although controversial) figures were reported (Bolt, 1993).

2.2.1.2 1965 Seattle-Tacoma Earthquake
Although there was lack of any major earth surface damage, direct damages totaled approximately $US 12.5 million. Despite the high damage costs, the earthquake was not an intensely destructive event. Only two houses were reported completely destroyed, and only three suffered major damage. An additional 8,000 houses suffered minor damage—mostly falling chimneys, cracked plaster, and other minor structural failures. The total number of housing units in the Greater Seattle area at the time of the earthquake was estimated at 444,000. Loss to the public sector was mainly limited to two school buildings, both older structures of the multistory, masonry-type construction (Wright et al., 1979).

2.2.1.3 1989 Loma Prieta Earthquake
The strong motion instruments showed that there was great variability in the ground motion strength and duration in the San Francisco Bay Area due to significant changes in the type and thickness of soils. In the rocky parts of the hills around the Bay, the horizontal acceleration of the ground lasted for a second or two of intense, but not excessive force. At the same distance from the epicenter, buildings on soft soils and areas of filled ground were subject to about three times those forces, and five times the duration of shaking (Bolt, 1993).

The city of Watsonville was badly damaged in the earthquake, as were older buildings in downtown Santa Cruz. The highest intensity levels have been assigned to isolated sites in San Francisco and Oakland. In San Francisco, an area along the waterfront, called the Marina District, suffered a great deal of ground failure (e.g., liquefaction), and many collapses of timber-framed houses. Certain soils which moved were underlain by debris from the 1906 earthquake. Fires also broke out in the 1989 earthquake, but were extinguished by firefighters using water from the Bay (Bolt, 1993).

In the city of Oakland (population 350,000) there was considerable damage to a number of important buildings, such as the historical City Hall, and a large department store. Much of the damage was caused by unstable soil conditions and liquefaction. Many old unreinforced masonry structures throughout this area also suffered structurally. Approximately 5 percent of the total urban infrastructure of San Francisco Bay Area was damaged (Bolt, 1993, and French, 1990).
The upper span of the East Bay section of the Bay Bridge, connecting downtown Oakland and San Francisco, failed during the earthquake. The failure resulted from severed connecting bolts, which allowed the span to be pulled off one of its supports (Bolt, 1993).

The second major collapse was the double-decked freeway structure, called the Cypress Street Viaduct, in Oakland. The severe earthquake shaking in this area, due to the thick soil deposits under the section, caused a long portion of the viaduct to collapse. This structural failure was the most tragic consequence of the earthquake, with 41 people dying (Bolt, 1993). Coincidentally, a 60 year old building by the Cypress Street Viaduct survived intact, while the freeway failed (French, 1990).

Property damage estimates amounted to $US 5.6 billion (Bolt, 1993). Total damage to buildings, transportation facilities and services was on the order of $US 10 billion (CMHC, 1990). It was found that 20 to 25 percent of earthquake damage (in terms of cost) was from urban infrastructure. A number of landslides destroyed sections of streets (French, 1990). Over 1,300 buildings were destroyed, and 20,000 buildings were damaged. Out of over 4,000 bridges in the area affected by the shaking, only 13 state-owned and five locally owned bridges were closed following the earthquake (Bolt, 1993). The City/County of San Francisco earthquake response generated 25,500 tonnes (28,000 tons) of debris (Recycling By Nature, Inc., and J.Edwards and Associates, Inc., 1997).

The casualties totaled 63 lives, 3,757 injuries, and 8,000 people made homeless (Bolt, 1993).

2.2.1.4 1994 Northridge Earthquake
The magnitude of the earthquake was estimated at $M_L=6.4$ on the Richter Scale, $M_w=6.7$ Moment Magnitude, and $M_S=6.8$ Surface Wave Magnitude (NAHB, 1994).

- Single-Family Detached (SFD) Homes
  Structural damage was most common in the foundation system in 2 percent of SFD homes. Interior and exterior finishes fared much worse than foundations and framing, with 50 percent of the homes experiencing at least some damage. The majority of damage was limited to the lowest level of damage. Most finish damage was related to stucco and drywall/plaster cracks at the foundation or at openings in walls (NAHB, 1994).

- Multi-Family Low-Rise and Single-Family Attached (MFLR/SFA) Homes
  Damage to SFA construction appeared to reflect a level of performance similar to that reported for the SFD homes. Conversely, structural damage to MFLR construction was notably more dramatic and costly to lives, especially for certain construction types located in the San Fernando Valley. The more remarkable structural failures were associated with older MFLR buildings situated on soft-story (defined in Section 2.2.2) garage foundations (NAHB, 1994).

The 15 to 20 second duration of the Northridge Earthquake created particularly severe loads for short period structures, such as low-rise buildings less than four stories in height. Strong, short-duration pulses of energy concentrated the impact on the lowest story of many structures, particularly in soft-story construction (NAHB, 1994).
Extent of Damage
The reported damage areas covered 5,675 square kilometres (2,192 square miles) in Los Angeles, Ventura and Orange counties. Assessed damage costs were estimated at $US 25 billion, plus additional losses from reduced productivity, and business loss. Federal expenditures were estimated at $US 12.5 billion, with $US 8 billion made available from the US Federal Emergency Management Agency (FEMA) (FEMA, 1995).

Approximately 114,000 residential and commercial structures were damaged. The casualties totaled 72 deaths, with 11,846 people having received hospital treatment for earthquake related injuries (FEMA, 1995).

2.2.2 Construction Vulnerable to Earthquake Damage
The following are selected examples of the types of construction that are most susceptible to earthquake damage. These types of construction are common in the current building inventory of the Lower Mainland, particularly in the older structures that were built prior to the inclusion of seismic design requirements in the building code.

- Unreinforced Brick Buildings
In 1989, the California Seismic Safety Commission estimated that there were between 30,000 and 50,000 unreinforced masonry buildings throughout California. Downtown Santa Cruz, Whittier and Coalinga have inadvertently corrected their problem—most of the unreinforced masonry buildings were destroyed in their respective earthquakes of 1989, 1987 and 1983. In Soviet Armenia, the earthquake of 1988 resulted in more than 50,000 deaths and destruction of two cities, mainly due to unreinforced brick construction (Yanev, 1990).

- "Soft-Story" Buildings
"Soft-story" buildings are structures with many of the solid shear walls removed at the ground level to make room for garage doors or more windows. Much of the damage to a building occurs due to the failure of the soft-story, while the remainder of the failed building remains intact (Yanev, 1990).

- Concrete Tilt-Up Buildings
The concrete tilt-up building is the most common in most modern industrial parks. It is one of the least costly industrial and commercial structures to build. The concrete foundations and base slab are poured in place; next, the walls are poured in place, lying horizontally on the ground, and are then tilted up, like cards, on top of the foundation. Usually, a wood roof is then built, with only a few slender columns supporting it in the interior. During an earthquake, the columns punch through the roof, causing the structure to fail (Yanev, 1990).

2.2.3 Earthquake Damage Prediction
Earthquake damage prediction is not an exact science. However, application of the experience from past earthquakes provides a range of best estimates of potential damage, which is crucial in seismic design and earthquake recovery planning. A number of studies have been conducted, both in the Lower Mainland and in California, that attempt to qualify and quantify the effects of potential earthquakes. The results of such studies vary from identifying the nature of potential damage, to quantifying the debris that could be generated, to quantifying the financial losses that could be incurred. The following sections present a collection of such studies, which predict the earthquake effects for the Lower Mainland, and identify a number of tools that could be used in making such predictions. The studies are presented such that the most recent information appears first.
### 2.2.3.1 Seismic Prediction in Lower Mainland

The common practice values associated with earthquake prediction, and used in structural design in the Lower Mainland are presented in Table 2-3. The Ecowaste Industries Ltd. "Report on Site Investigations and Conceptual Design - Proposed Ecowaste Landfill Expansion", for instance, uses these common practice values in its analyses (Golder Associates Ltd., 1994). These common practice values were confirmed with Golder Associates Ltd. in 1999.

<table>
<thead>
<tr>
<th>Table 2-3: Lower Mainland Common Practice Values for Seismic Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>• earthquake magnitude</td>
</tr>
<tr>
<td>• location of epicentre</td>
</tr>
<tr>
<td>• earthquake return interval</td>
</tr>
<tr>
<td>• ground acceleration</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

(Personal Communication, Colin Wong)

### 2.2.3.2 New Westminster Damage Estimate Study

The most recent and most comprehensive earthquake damage prediction study conducted in the Lower Mainland is presented in a 1998 report, entitled "Preliminary Seismic Risk Research Studies for New Westminster - Draft Report" (UBC, 1998). The study provides preliminary estimates of structural and non-structural damage in buildings in New Westminster that may be expected as a result of ground shaking consistent with the ground motions specified for design in the 1995 National Building Code of Canada. The study was conducted by the Seismic Risk Research Group at the University of British Columbia. The key features and limitations of the study include:

- ground motions considered are the predicted result of crustal earthquakes;
- ground motions have been calculated for firm ground; and
- damage to buildings has been quantified as a percentage of the replacement cost of the structures.

The Building Inventory for New Westminster indicates that the majority of the construction is wood, with approximately equal amount of concrete and masonry construction (both types much less common than wood).

The peak ground accelerations for the New Westminster area are expected to be approximately 0.19g, based on the earthquake return period of 475 years.

Two earthquake intensities were considered: MMI=VII and MMI=VIII. The structural damage for MMI=VII is estimated to be mainly in the range from 2 to 5 percent, with some damage in the range of 5 to 10 percent. The structural damage for MMI=VIII is estimated to be mainly in the range from 5 to 10 percent, with some damage in the range of 10 to 100 percent.

Non-structural damage refers to damage to partition walls, parapet walls, cladding, plumbing and piping, mechanical equipment, furniture, and other building contents. The estimated non-structural damage for MMI=VII is mainly in the range of 5 to 10 percent, with some damage in the range of 2 to 5 percent.
2.2.3.3 San Francisco Damage Estimation

In the preparation of the “Disaster Debris Recovery Plan for the City/County of San Francisco” (San Francisco Plan), damage estimates for the next major earthquake in the San Francisco area were obtained (Recycling By Nature, Inc., and J.Edwards and Associates, Inc., 1997). The estimates were calculated using a FEMA program, called HAZUS, which projects deaths and physical damage resulting from the input of various earthquake scenarios. The estimating program contains an extensive database of earthquake and infrastructure information, including a building inventory. Among other features, the HAZUS program quantifies the projected debris, describes the debris composition, and estimates the aerial extent of that damaging effects of the earthquake.

The San Francisco Plan presents the results of HAZUS damage predictions for an earthquake scenario involving a magnitude 7 earthquake on the Northern Hayward Fault in the vicinity of the city. The following are select projections presented in the San Francisco Plan.

<table>
<thead>
<tr>
<th>HAZUS Prediction of San Francisco Earthquake Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ amount of debris generated in the next major earthquake → 450,000 to 2.25 million tonnes (500,000 to 2.5 million tons)</td>
</tr>
<tr>
<td>□ percentage of total debris generated in 4.5% of the city/county area → 22%</td>
</tr>
<tr>
<td>□ percentage of inert debris (concrete, asphalt, dirt, red clay brick, and metals) → 84% by weight</td>
</tr>
<tr>
<td>□ percentage of concrete and rebar debris → 58% by weight</td>
</tr>
</tbody>
</table>


The HAZUS program is an excellent example of an earthquake damage estimation tool that could be developed for the Lower Mainland. Furthermore, due to the similarities between the San Francisco and Vancouver areas indicated in a study discussed in Section 2.2.3.5, the results of the HAZUS predictions could be used as an approximate range of values for the Lower Mainland.

2.2.3.4 Economic Impact in Lower Mainland

In 1992, the Munich Reinsurance Company of Canada (Munich) produced a report, entitled “A Study of the Economic Impact of a Severe Earthquake in the Lower Mainland of British Columbia”, in which the total expected economic loss was calculated (Munich, 1992). The results were generated by a comprehensive and integrated economic model, using a magnitude 6.5 crustal earthquake in the Strait of Georgia. The corresponding intensity of damage was estimated to be MMI=V in Richmond and Delta, and MMI=VII-VIII in the other areas of the Lower Mainland, including the city of Vancouver.
The following are the loss estimates calculated in the Munich study.

### Direct Economic Loss in Lower Mainland

<table>
<thead>
<tr>
<th>Category</th>
<th>Lower Bound ($)</th>
<th>Upper Bound ($)</th>
<th>Range ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>shock damage to buildings and contents</td>
<td>$8,250</td>
<td>$15,890</td>
<td>$7,640</td>
</tr>
<tr>
<td>fire damage</td>
<td>$3,390</td>
<td>$6,200</td>
<td>$2,810</td>
</tr>
<tr>
<td>inundation</td>
<td>$621</td>
<td>$1,167</td>
<td>$546</td>
</tr>
<tr>
<td>electricity</td>
<td>$165</td>
<td>$570</td>
<td>$405</td>
</tr>
<tr>
<td>airports</td>
<td>$188</td>
<td>$563</td>
<td>$375</td>
</tr>
<tr>
<td>ports</td>
<td>$70</td>
<td>$280</td>
<td>$210</td>
</tr>
<tr>
<td>roads</td>
<td>$21</td>
<td>$212</td>
<td>$191</td>
</tr>
<tr>
<td>bridges</td>
<td>$50</td>
<td>$100</td>
<td>$50</td>
</tr>
<tr>
<td>sewage</td>
<td>$49</td>
<td>$97</td>
<td>$48</td>
</tr>
<tr>
<td>water supply</td>
<td>$38</td>
<td>$78</td>
<td>$40</td>
</tr>
<tr>
<td>natural gas</td>
<td>$39</td>
<td>$77</td>
<td>$38</td>
</tr>
<tr>
<td>mass transit</td>
<td>$9</td>
<td>$66</td>
<td>$57</td>
</tr>
<tr>
<td>oil</td>
<td>$9</td>
<td>$58</td>
<td>$49</td>
</tr>
<tr>
<td>B.C. Rail</td>
<td>$2</td>
<td>$10</td>
<td>$8</td>
</tr>
</tbody>
</table>

(Munich, 1992)

#### 2.2.3.5 Damage in San Francisco and Projection to Greater Vancouver

The Canadian Mortgage and Housing Corporation (CMHC) conducted a study of the damage caused by the 1989 Loma Prieta earthquake in San Francisco (CMHC, 1990). The purpose of the study was to derive specific lessons for earthquake mitigation planning in British Columbia.

The 1989 earthquake in San Francisco can be used as a model for the seismic risk faced by the Greater Vancouver area because of many similarities with a design earthquake in the Vancouver area. The similarities include:

- earthquake magnitude and duration;
- location of epicentre relative to population centres;
- range of recorded ground accelerations; and
- similarities in type of construction.

Account also needs to be taken of the expected essential differences. Such differences include:

- the level of seismic design forces for engineered construction, and for residential requirements for buildings;
- extent of soft soil deposits; and
- the specific ground accelerations measured, and soil amplifications observed at particular locations.

The estimates of major damage in the Greater Vancouver area are greater than what was experienced in San Francisco for the following reasons:

- the design level for earthquake resistance is lower than in San Francisco;
- the seismic requirements for residential construction are less stringent than in San Francisco;
- the extent of soft soils in populated areas is larger than in San Francisco; and
- the recorded ground motions in the most populated areas, San Francisco and Oakland, were from one half to two thirds the design earthquake in Vancouver.
These factors point to the conclusion that the expected damage in Vancouver from a "design earthquake" that is defined in the National Building Code of Canada would be somewhat greater than that observed in the San Francisco region in October of 1989.

In addition, emergency preparedness in the San Francisco area was at a high level. This presented significant advantages in the rescue efforts, in dealing with the chaos created by the earthquake, in restoring normal functions, and in returning to near-normal operating conditions within a short time after the earthquake. This could serve as a model for a preparedness plan for the Vancouver area.

Additional contents of this study are referred to in Section 8.1.1.

2.2.3.6 GVRD Damage Prediction Study
In 1988, Robinson Dames and Moore completed the first phase of a GVRD Earthquake Damage Prediction Study (Robinson et al., 1988). The first phase of the study included three tasks:
1. selection of the appropriate earthquake to be evaluated;
2. quantification of soil and rock response to the selected earthquake; and
3. preparation of an earthquake soil hazard map.

Three earthquake scenarios were considered.

1. Maximum earthquake that could occur near Vancouver
   Based on a deterministic approach, a 7.5 Richter magnitude earthquake centred off the north tip of Galiano Island was selected. At that location, the geologic fault and earthquake records indicate a potential weakness zone.

2. Large subduction zone earthquake off Vancouver Island
   Based on a deterministic approach, a 9.2 magnitude earthquake located along a 100 km wide, shallow dipping zone that extends eastward from the Continental Shelf was selected. The centre of this earthquake would be about 160 km from Vancouver. The acceleration would be about 0.15g. The duration of this earthquake would be several minutes (rather than seconds). Such long duration would increase the relative potential damage to tall structures.

3. Probabilistic earthquake
   Based on the 1985 National Building Code of Canada, an earthquake with an annual probability of occurrence of 1 in 475 was selected.

   Based on attenuation curves and a computer program "SHAKE", it was determined that the accelerations across the Lower Mainland from the earthquake scenarios would vary from 0.2g to 0.3g. Furthermore, the analysis indicated that for most soft soil conditions, the acceleration would be slightly lower than for rock and hard soils. It was also found that a subduction zone earthquake would have less potential to cause liquefaction than the other two scenarios.

The analysis of soil conditions throughout the Lower Mainland lead to the development of an earthquake soil hazard map. The map indicates that much of the GVRD area has good foundation conditions—primarily very dense glacial tills and rock. The areas of most concern are the flat deltas and floodplains of the Fraser River. In these areas the potential for liquefaction is high, which could result in a number of problems including structures sinking into the sand, dyke failures, and bridge abutment settlements. Fortunately, most larger buildings have reasonable foundations such as piles, although they would be subjected to larger forces than buildings on dense soil or rock. Light structures such as houses should generally float on the upper clay zone over the liquefied sand. The damage to tall and older structures would be greater on such soft liquefiable soils than if they were located on dense soil.
The goal of the second phase of the study was to estimate the degree of damage to buildings and lifelines that would result from the three earthquake scenarios, along with other earthquake effects. However, the second phase was never conducted (Personal Communication, Norecol Dames and Moore, and GVRD).

2.3 Conclusion to Background on Earthquakes
The preceding sections introduced the first component of the background of an earthquake recovery plan. The topics that were discussed include:
- the concept of seismicity;
- the effects of earthquakes; and
- the earthquake potential in the region of interest.

An appreciation for the magnitude and complexity of the physical and financial problem that earthquakes present is the first building block of the earthquake recovery plan. Next, an understanding of the components of the solution to the earthquake recovery problem is required. There are two main solution components, which are discussed in Sections 3 and 4, respectively:
1. the solid waste management system of the region, which will be expected to handle the consequences of an earthquake; and
2. the financial means and authority to implement the solution.
3. BACKGROUND - SOLID WASTE MANAGEMENT SYSTEM
Developing a strategy that includes the use of an existing system as part of the solution, requires that the ability and capacity of such a system to handle the problem be reviewed and evaluated. The earthquake recovery problem, introduced in Section 2, has numerous repercussions, not the least of them being the solid waste management challenges it presents. The volumes of disaster debris (DD) that are generated during earthquakes, and the costs associated with their removal and disposal, as well as the potential problems earthquakes cause to the municipal solid waste collection systems, are the issues that the existing solid waste management system will be faced with during earthquake recovery. Reviewing and evaluating the capability of this system to address such vast potential problem ahead of time is crucial to a safe, timely and economic recovery.

The following sections provide an introduction to the principles and operational details of the current solid waste management system available in the Lower Mainland. A brief discussion of demolition, landclearing and construction (DLC) waste is also provided. The capacity and component facilities of the solid waste management system are discussed further in Sections 8.2.1 and 12.3.3, and in Appendix 12.10-A in Section 12.10. The following sections also introduce the current means of addressing various types of debris deposited or abandoned on private property.

3.1 GVRD Solid Waste Management Plan
The 1995 Greater Vancouver Regional Solid Waste Management Plan (1995 Plan) was designed to achieve the following objectives in a cost-effective and environmentally sound manner.

**GVRD Solid Waste Management Plan Objectives**
- reduction of per capita garbage disposal in the year 1995 by at least 30% (1990 base)
- reduction of per capita garbage disposal in the year 2000 by at least 50%
- simultaneous with responsible management of residual waste

(GVRD, 1995)

The 1995 Plan was also intended to support the following guiding principles.

**GVRD Solid Waste Management Plan Guiding Principles**
- the 5R hierarchy: Reduce, Reuse, Recycle, Recover, Residual Management
- the Polluter Pay Principle
- commitment by all levels of government to fulfilling their roles and responsibilities in the new Plan
- bringing about fundamental changes to the perception and management of waste
- minimization or elimination of cross-subsidization of programs unless essential for the success of programs
- sufficiently flexible programs and systems to accommodate and take advantage of future changes

(GVRD, 1995)
A summary of the Plan is provided in Table 3-1.

<table>
<thead>
<tr>
<th>Table 3-1: Summary of GVRD Solid Waste Management Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>- the 1995 Plan lists initiatives that government, industry and the public need to carry out in order to meet or exceed the goal of a 50% reduction in per capita solid waste requiring disposal by the year 2000</td>
</tr>
<tr>
<td>- key initiatives</td>
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<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>- source of debris determines the rate of recycling</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>- weather affects disposal tonnages</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>- unanticipated circumstances greatly impact regular operations</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

(GVRD, 1995)
3.2 Demolition, Landclearing and Construction Waste

Experience shows that earthquake debris tends to resemble DLC waste most closely (Recycling By Nature, Inc., and J.Edwards and Associates, Inc., 1997). Therefore, it is reasonable to expect that earthquake debris will be handled by the existing, and most likely expanded DLC waste management system. For these reasons, it is essential to examine the composition and quantities of current DLC waste in order to determine the capacity of the current system. In addition, the characteristics of the pre-earthquake DLC waste will provide an insight into the probable composition of earthquake debris.

3.2.1 Current Quantities

The GVRD estimates that waste from demolition, landclearing and construction which ends up in the local landfills is on the order of 500,000 tonnes per year. This represents approximately 18 percent of the 2.7 million tonnes of waste generated in the GVRD each year. The total quantity of DLC waste generated in the GVRD is on the order of 1.0 million tonnes per year (GVRD, 1999).

3.2.2 Waste Sources

The breakdown of the sources of the total DLC waste tonnage in B.C. is as follows:
- 70% non-residential construction and demolition;
- 14% residential renovation;
- 13% residential demolition; and
- 3% new residential construction (SPARK, 1991).

Statistics Canada data indicates that approximately 2.5 tonnes of waste per new dwelling is generated in B.C. According to the Canadian Home Builders Association, the volume of waste from renovation is on average four times greater than new construction (SPARK, 1991).

3.2.3 Waste Composition

Waste materials from demolition activities include actual building components such as full length studs, concrete slabs and plaster. No statistics were found describing the composition of demolition waste in B.C. The following is the average North American demolition waste composition by weight and volume. The amount of wood from demolition is likely to be underestimated, since more wood is used in British Columbia than in many other areas of North America (SPARK, 1991).

<table>
<thead>
<tr>
<th>Demolition Waste Composition North American Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constituents</td>
</tr>
<tr>
<td>concrete</td>
</tr>
<tr>
<td>brick and clay products</td>
</tr>
<tr>
<td>wood products</td>
</tr>
<tr>
<td>metals</td>
</tr>
<tr>
<td>other</td>
</tr>
</tbody>
</table>

(SPARK, 1991)
For construction waste, Canadian statistics have been obtained. The following is the waste composition based on the construction of a 2,000 ft$^2$ house.

### Canadian Construction Waste Composition

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Percent Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>dimensional lumber</td>
<td>25%</td>
</tr>
<tr>
<td>manufactured wood</td>
<td>15%</td>
</tr>
<tr>
<td>drywall</td>
<td>12%</td>
</tr>
<tr>
<td>masonry and tile</td>
<td>10%</td>
</tr>
<tr>
<td>cardboard</td>
<td>10%</td>
</tr>
<tr>
<td>asphalt</td>
<td>6%</td>
</tr>
<tr>
<td>fibreglass</td>
<td>5%</td>
</tr>
<tr>
<td>other wastes</td>
<td>5%</td>
</tr>
<tr>
<td>metal</td>
<td>4%</td>
</tr>
<tr>
<td>plastic and foam</td>
<td>4%</td>
</tr>
<tr>
<td>other packaging materials</td>
<td>4%</td>
</tr>
</tbody>
</table>

(CMHC, 1991)

3.3 Municipal By-Laws Regarding Nuisance Properties

The current means of addressing untidy, nuisance properties in Vancouver are intended to maintain a certain standard of appearance within the city. Earthquake debris which is scattered throughout the city, and is not removed within a reasonable amount of time, can present a grave nuisance, as well as a safety problem. Establishing an adequate response system in advance, and announcing the consequences of not complying with the region’s requirements for a speedy recovery, will keep the problem from escalating beyond control. The unmanageable financial and environmental repercussions will also be minimized.

3.3.1 Vancouver Charter

The City of Vancouver has a Charter, which lists, among other things, the authority of the City Council in addressing solid waste related problems. The following is an excerpt from the Charter, which addresses the Municipal authority over solid waste, and over the general appearance of the city.

323. The Council may make by-laws providing

- Removal of rubbish: (m) for requiring the owner or occupier of any real property to remove therefrom any accumulation of rubbish, discarded materials, garbage, ashes, or filth, or any unsightly accumulation of graffiti, and lawfully to dispose of the same, and for providing that in default of such removal the City may, by its workmen or others, enter and effect such removal at the cost of the person so defaulting;

- Standard of maintenance: (u) for requiring the owners or occupants of real property to maintain the said property in a neat and tidy condition and in keeping with a reasonable standard of maintenance prevailing in the neighbourhood; and, where the premises are not occupied by the owner thereof, for providing (after the giving of notice as hereinafter provided) that in default of such maintenance the City may, by its workmen or others, enter and effect such maintenance at the cost of the person so defaulting; no such work shall be undertaken by the City until the expiration of 60 days after the date of service of a notice to that effect has been given by registered mail to the owner or has been posted on the premises;

(City of Vancouver, 1997a)
Furthermore, the Vancouver Charter states the Council’s role in the enforcement of provisions of the Nuisance By-Law. The following is a summary of the Council Policy.

**Enforcement of Provisions of By-Law Re Nuisance:**

Council Policy:

Section 324A of the Vancouver Charter enables Council by resolution or by-law to declare any building, in or upon any private or public lands a nuisance or dangerous to the public safety or health and by such by-law or resolution, to order that building to be removed by the owner, agent, lessee or occupier thereof.

(City of Vancouver, 1999)

3.3.2 **Vancouver By-Law No. 4548: "Untidy Premises By-Law"**

Effective February 17, 1997, By-Law 4548: “Untidy Premises By-Law”, was passed to prevent the existence of untidy premises within the city of Vancouver. The following are the key points of the by-law which may be applicable to disaster debris during earthquake recovery and reconstruction.

**Vancouver By-Law No. 4548: "Untidy Premises By-Law"**

2. Every owner or occupier of real property shall maintain the said property in a neat and tidy condition in keeping with a reasonable standard of maintenance prevailing in the neighbourhood.

3. No owner or occupier of any real property shall allow any accumulation of rubbish or discarded materials upon such real property.

5.  

(1) Where the owner or occupier of any real property fails to remove from such property any accumulation of rubbish or discarded materials, […], the Director of Permits and Licenses may cause a notice to be served upon the owner of the real property requiring such owner to remedy the condition within ten days. Any such order shall be sufficiently served upon the owner by sending the same by return registered mail to the address shown on the current year’s real-property assessment roll.

(2) In the event of default by the owner in remedying the condition within the time limited, as specified in the notice referred to in subsection (1) hereof, the Director of Permits and Licenses and any person authorized by the Director of Permits and Licenses may enter upon the real property for the purpose of remedying the condition referred to in the said notice. The costs incurred in carrying out any work pursuant to this subsection shall be recoverable by the City from the owner by action in any Court of competent jurisdiction, or, in the alternative, if the costs and expenses incidental to the work are not paid to the City by the owner within thirty days after a demand for payment has been sent to the owner, the Director of Finance may cause such costs to be added to and form part of the taxes payable in respect of that parcel of real property.

7.  

(1) Every person who commits an offence against this by-law is punishable on conviction by a fine of not less than $100.00 and not more than $2,000.00 for each offence or, in the alternative, by imprisonment for a period not exceeding two months.

(2) Every person who commits an offence of a continuing nature is liable to a fine not exceeding $50.00 for each day such offence is continued.

(City of Vancouver, 1997d)
3.3.3 Cases of Application of Statute 324A of Vancouver Charter

The following are the summaries of four cases of application of Statute 324A of the Vancouver Charter by the City Council of Vancouver. The details of the cases are based on the City’s Administrative Reports.

It is apparent from each of the following cases, that Statute 324A is insufficient in preventing and addressing “untidy” premises in the best of times. Following an earthquake, the number of properties requiring debris removal and “tidying up” can be expected to be in the hundreds, if not in the hundreds of thousands. With the current means of enforcement of the Nuisance By-Law, where it can take over 10 years, and a lot of effort and resources to resolve an occasional case, the process of earthquake recovery will be extremely lengthy and expensive. It is imperative to address this issue, and develop a more adequate response system, before such a situation becomes reality.

Case 1: Demolition of Nuisance/Dangerous Building - 331 East 38th Avenue

- Date: June 09, 1997
- Request for extension of time

Recommendation

- that Council deny the extension request and instruct the City Building Inspector to proceed with the demolition of the building as per Council’s Resolution of July 9, 1996.

Highlights

- January, 1986 - single family dwelling extensively damaged by fire
- 1986 - 1996 - several orders to board up building and clean up the site (no repairs to fire damage carried out)
- March 12, 1997 - re-inspection confirmed no substantial work done

Discussion

- Staff have had numerous meetings and discussions with the occupant over the past year wherein they have urged him to hire a competent crew to assist him in completing the work. The occupant appears determined to work on the building virtually on his own, and at his own pace. Consequently, there has been very little progress as of the date of this report.
- The building as it stands today, has no roof, only partial exterior sheathing, no exterior finishings such as stucco, windows or doors. This building is not adequately secured and is accessible to the public. The owner and the occupant have had over eight months since issuance of the Building Permit, yet have not demonstrated their ability to complete the job.
- The property owner has been kept up to date on the issues with respect to the property but appears to have taken a back seat to the occupant’s involvement. Both parties have been advised that the City will deal with the property owner on all future matters unless the occupant is confirmed to the legal authority to act on the owner’s behalf.

Conclusion

- As of the writing of this report, staff have no confidence that the occupant or the owner have the means or inclination to complete the work on the building within a specified time frame, and feel that another extension will only prolong detrimental impact on the neighbourhood and the inevitable demolition action.

(City of Vancouver, 1997b)
Case 2: Demolition of Nuisance/Dangerous Building - 2284 McLean Drive

- Date: November 05, 1996

- Recommendation
  - that Council declare that the above building is a nuisance and dangerous to public safety, pursuant to Section 324A of the Vancouver Charter.
  - that Council approve the attached Resolution and order the Registered owner of the property to remove the building and all demolition debris from the site within 14 days of a copy of the resolution being served.
  - that in the event of non-compliance the previous order, Council further orders and hereby authorizes the City Building Inspector to have the building and all demolition debris removed at the expense of the owner.
  - that the City Clerk be directed to file a 336D Notice Against the Certificate of Title to the Property in order to warn prospective purchasers that as a result of the condition of the building and Council's resolution, the purchaser could suffer a significant expense if the by-law were enforced against him.

- Discussion
  - This site contains a single family dwelling that has been vacant since 1989.
  - The City has received numerous complaints regarding debris and discarded materials on site, as well as the building being open and accessible to transients.
  - The City has issued several orders to the property owner requiring that the building be boarded up and the site be cleaned up. With no response from the owner, the City hired private contractors to carry out the required work. Further, because the owner failed to reimburse the City for the costs of the work carried out, the charges have been applied to the tax roll.
  - The Vancouver Police Department reported several incidents of transient gaining entry to the building. The Health Department reported numerous complaints about rats infesting this property and house.
  - To date, there has been no response from the owner to the October 2, 1996 letter, requesting that the owner obtain a demolition permit and demolish the building.

- Resolution
  - that the building and discarded materials situated on the Property, is declared to be a nuisance and to be dangerous to public safety.
  - that the owners are hereby ordered to pull down the building and remove the resulting debris and the discarded materials from the site within 14 days of the date from a copy of this Resolution being served.
  - that in the event that the owners do not comply with the order set forth in the preceding paragraph, the City Building Inspector is hereby ordered and authorized to pull down the building and remove the resulting debris and discarded material from the site at the cost of the owners and dispose of it by selling to the demolition contractor any material he may agree to purchase, and delivering the rest to a disposal site.

(City of Vancouver, 1996)
Case 3: Nuisance Property - 1250 Rossland Avenue

Date: February 3, 1999

Recommendation

- that Council declare that the condition of the property at 1250 Rossland is a nuisance pursuant to Section 324A of the Vancouver Charter.
- that Council approve the attached Resolution and order the Registered owner of the property to remove the two dismantled vehicles, and miscellaneous items and materials, from the site within 14 days of a copy of the resolution being served.
- that in the event of the failure of the owner to comply with the order of Council, Council further orders and hereby authorizes the City Building Inspector to have the two dismantled vehicles and miscellaneous items and materials removed at the expense of the owner.

Discussion

- Since 1991, the owner of this single family dwelling has been issued three building permits for the construction of a detached garage at the rear of this site. Construction of the garage has not progressed beyond the foundation stage and consequently, all three building permits have expired in succession. During this time frame, the owner has accumulated and stored a large amount of new and used building materials and other miscellaneous items at the rear of the site. These materials have not been protected from the elements and many of them are no longer salvageable. There are also two dismantled vehicles stored on site.
- Resulting from complaints from the neighbourhood with respect to the unsightly condition of the property, the City has issued several orders to the property owner requiring that the dismantled vehicles be removed and that the site be cleaned up. Charges have been laid on three occasions and on one occasion the City hired a private contractor to clean up the debris and discarded materials (exclusive of the building materials) from the site. To date, the site still remains in an unsightly condition.
- A recent site inspection by the District Property Use Inspector and a private contractor revealed that of the wood materials on site, approximately 50% was salvageable. It was also noted that the trusses on site that have been exposed to the elements since Spring of 1998, would have to be inspected by a Structural Engineer to determine whether or not they were still useable.

Conclusion

- Because of the foregoing, it is recommended that Council declare the condition of the property a nuisance and order the owner to remove the dismantled vehicles and materials.

(City of Vancouver, 1999)
Case 4: Demolition of Nuisance/Dangerous Building - 1063 Barclay Street

Date: April 08, 1997

Recommendation

- that Council declare that the above building is a nuisance and dangerous to public safety, pursuant to Section 324A of the Vancouver Charter.
- that Council approve the attached Resolution and order the Registered owner of the property to remove the building and all demolition debris from the site within 14 days of a copy of the resolution being served.
- that in the event of non-compliance the previous order, Council further orders and hereby authorizes the City Building Inspector to have the building and all demolition debris removed at the expense of the owner.
- that the City Clerk be directed to file a 336D Notice Against the Certificate of Title to the Property in order to warn prospective purchasers that as a result of the condition of the building and Council's resolution, the purchaser could suffer a significant expense if the by-law were enforced against him.

Discussion

- This site contains a single family dwelling that has been vacant since 1995.
- The City has received numerous complaints regarding the building being open and accessible to transients.
- The City has issued several orders to the property owner requiring that the building be boarded up.
- The Vancouver Police Department reported 23 incidents of transient gaining entry to the building since December of 1996.
- To date, there has been no response from the owner to the March 7, 1997 letter, requesting that the owner obtain a demolition permit and demolish the building.
- An inspection by the Police on March 27th revealed that transients were again in the building. The Police cleared out the building and has it re-boarded by the City.

Resolution

- that the building and discarded materials situated on the Property, is declared to be a nuisance and to be dangerous to public safety.
- that the owners are hereby ordered to pull down the building and remove the resulting debris and the discarded materials from the site within 14 days of the date from a copy of this Resolution being served.
- that in the event that the owners do not comply with the order set forth in the preceding paragraph, the City Building Inspector is hereby ordered and authorized to pull down the building and remove the resulting debris and discarded material from the site at the cost of the owners and dispose of it by selling to the demolition contractor any material he may agree to purchase, and delivering the rest to a disposal site.

(City of Vancouver, 1997c)
3.4 Conclusion to Background on Solid Waste Management System
The preceding sections introduced the second component of the background of an earthquake recovery plan, which constitutes a part of the solution to the earthquake recovery problem. The topics that were discussed include:

- the principles of the current solid waste management system;
- the probable composition of earthquake debris; and
- the means of dealing with nuisance premises.

An essential aspect of any plan is the financial feasibility of its implementation. Although the earthquake recovery plan does not work with a predesignated budget (whereby funds for earthquake recovery are theoretically unlimited), every single aspect of the plan is dependent on the availability of funds. The financial considerations of, as well as the authority for earthquake recovery are discussed in Section 4.
4. BACKGROUND - AUTHORITY AND FUNDING FOR EARTHQUAKE RECOVERY
During earthquake recovery, which may last several years, the driving factor of solution implementation will be the availability of funds. This approach is contrary to the one undertaken during earthquake response, when the urgency for and extent of action are dictated by life saving considerations, and when no expense is spared. In earthquake response, the urgency for and extent of action are partly due to the concern for public safety. They are mainly dictated by the inconvenience of living with the consequences of an earthquake, which does not justify excessive spending. Since funding for earthquake recovery will not be unlimited, it must be taken into account when proposing recovery strategies.

In planning for earthquake recovery, proposed strategies must consider the amount, type and source of funding that is likely to be available at the time of plan implementation. This makes the actual implementation of a suggested strategy more realistic. Without considering the financial feasibility of a proposed strategy, the effectiveness of the planning process is diminished. Discovering that a strategy is based on unrealistic sources of funds at the time of implementation will:
- defeat the purpose of planning for recovery in the first place;
- provide a false sense of security to the general public; and
- prolong the process of recovery, making it more expensive.

Similarly, the authority for earthquake recovery needs to be established before such a situation occurs. This will save a lot of confusion and bureaucratic administration at the time when action is needed.

The following sections present the extent of current designation of authority over earthquake recovery, including the provision of funds, in the Lower Mainland. Sources of funds and other resources for disaster debris management, and the deficiencies in the ability of the current system to provide these are identified.

4.1 Authority for Earthquake Recovery
4.1.1 Responsibilities of the Three Levels of Government in Disaster Response
The roles and responsibilities of the municipal (local), provincial and federal governments have been summarized in a Provincial Emergency Program (PEP) document, "A Strategy for Response" (PEP, 1992). The following are the key points presented in the PEP 1992 document regarding the roles of the various levels of government in B.C. in disaster response.
Roles of the Three Government Levels in Disaster Response

- Municipal Government
  - responsible for providing the initial response to most emergencies occurring within their municipal boundaries
  - a municipality may request assistance from neighbouring municipalities, private sector agencies, the provincial government or the local offices of the federal government
  - the responsibility for the overall direction and control of response operations remains that of the local government

- Provincial Government
  - responsible for emergency response operations in unorganized areas of the province, where there is no local government structure
  - responsible for the direction and control of response operations in an organized area of the province if:
    - there has been a catastrophic event which has rendered the local government incapable of providing direction and control
    - there is an emergency situation of such a nature that the local government cannot provide adequate direction and control, and has requested the provincial government to assume responsibility, and the provincial government has agreed that in the circumstances the request is reasonable
    - the emergency situation falls under provincial jurisdiction
  - responsible for providing assistance in emergency response when requested
  - when requested, the provincial government is responsible for providing material support, advice, expertise or any other assistance
  - the Province may request assistance from local government, private sector agencies, or the federal government

- Federal Government
  - responsible for the direction and control of emergency response operations on federal lands within the province, and has primary jurisdiction over certain kinds of emergencies, such as aircraft crashes
  - when requested, the federal government is responsible for providing assistance in emergency response

(PEP, 1992)

4.1.2 Federal Government Policy

Federal institutions in Canada recognize the need for action to minimize losses from future natural disasters. Canadian policy-makers, in the economic interest of the country, and in accordance with sustainability initiatives have begun to give disaster mitigation strategies serious consideration. Mitigation is becoming a compelling component of federal disaster policy (John Newton Associates, 1997).

In Canada, perceptions of disaster mitigation are diffuse and individual in the absence of formal federal policy statements, or focused delivery systems. Certain officials see mitigation as primarily post-disaster reconstruction and rehabilitation, while others are attempting to embrace non-structural approaches. Regardless of perspective, when mitigative activities do occur in Canada, they tend to be disaster-specific, and at the post-recovery stage of the emergency management cycle. Long-term mitigation initiatives are not currently a prime component of Emergency Preparedness Canada’s mandate (John Newton Associates, 1997).
At present, an integrated national loss reduction strategy remains elusive in the Canadian hazards community, though few, if any, would deny the necessity of mitigative actions. The evolution of Canadian federal action in the natural hazards field has historically taken focuses which, while including activities with mitigative components, have not specifically targeted mitigation in a comprehensive manner (John Newton Associates, 1997).

In structure, Canadian legislation provides a framework of authority within which federal actions may take in support of provincial/territorial programs and activities. Federal officials in Canada facilitate response, and support lead agencies, unlike the US federal government. Through FEMA, the US government has substantive, direct involvement with local governments and individual citizens (John Newton Associates, 1997).

A focused development of mitigation legislation, policies and programs has yet to evolve in Canada. To date, development of mitigation initiatives has been constrained by the apparent success of historical disaster reduction practices, as measured by the level of federal payouts. Consequently, development of mitigation measures to reduce disaster losses has lacked the pull of public demand, and the push of escalating federal expenditures (John Newton Associates, 1997).

Experience in Canada demonstrates a diversity of response capabilities and readiness within the institutional organizations responsible for emergencies. Continued focus on preparedness and response follows naturally from these established capabilities, but will likely show diminishing returns for future investments. The contradiction here is that beyond a certain level of preparedness and response capability, additional investment to further enhance response may save lives, but only after lives have been lost and property damaged in the primary impact. These underlying limitations of a response-oriented approach have drawn attention to the social character of disasters, and the potential of mitigation to realize loss reductions (John Newton Associates, 1997).

4.1.3 Role and Responsibility of Provincial Government

In the "1988 Brief to the British Columbia Government" (1988 Report), the Association of Professional Engineers of British Columbia determined and recommended that the provincial government should assume the leading role in disaster mitigation and preparedness, particularly in the case of earthquakes. The 1988 Report also states that the provincial government should arrange for adequate funding before a catastrophic earthquake occurs, since doing so after the earthquake is really too late (APEBC, 1988).

The Inter-Agency Emergency Preparedness Council of British Columbia drafted a document which outlines a strategy to enhance emergency response management within the Government of British Columbia. The strategy defines the responsibilities of the three levels of government (i.e., local, provincial and federal), and assigns roles to provincial ministries and crown corporations (PEP, 1992).

The document identifies the Provincial Government Emergency Response Management Structure, which is presented on Figure 4-1. and the Key Ministries responsible for various hazards affecting British Columbia.
Each Key Ministry responsible for a hazard affecting British Columbia is endowed with the task of preparing a response plan for that hazard, in consultation with the PEP.

**Key Ministries for Particular Hazards**

- **Ministry responsible for agriculture**
- **Contagious plant and animal diseases**
- **Mining accidents**
- **Natural gas/oilfield fires and leaks**
- **Marine oil spills**
- **Hazardous material spills, discharges and emissions**
- **Landslides, mudslides and debris flow**
- **Dam failures**
- **Major industrial accidents**
Key Ministries for Particular Hazards

- Ministry responsible for forests
  - Forest fires
  - Interface fires in unorganized areas
- Ministry responsible for health
  - Epidemics
  - Spills of radioactive substances
- Ministry responsible for policing
  - Public order emergencies
  - Aircraft crashes
- Ministry responsible for the Provincial Emergency Program
  - Earthquakes
  - Tsunamis
  - Volcanic eruptions
  - Severe storms
  - Drought and emergency water supply
- Ministry responsible for highways
  - Major floods

(PEP, 1992)

The following is a number of the emergency response tasks of several of the Provincial Government Ministries and Crown Corporations that may be particularly applicable to earthquake recovery.

Emergency Response Tasks

- Ministry of Agriculture, Fisheries and Food
  - Coordinate the emergency evacuation and care of livestock and/or poultry.
- Ministry Of Attorney General
  - Provide funds through the Emergency Assistance Vote to cover incremental costs incurred by local governments, ministries and crown corporations in responding to an emergency.
- Ministry Of Environment, Lands And Parks
  - Provide professional and technical advice and direction at hazardous material/pollution spills.
  - Ensure the proper disposal of hazardous wastes and pollutants.
  - Ensure legal action and recovery of cleanup costs where appropriate.
- Ministry Of Forests
  - When available, provide Ministry of Forests manpower, equipment, supplies and telecommunications equipment to assist in non-forestry response operations.
- Ministry Of Government Services
  - Provide government aircraft and vehicles.
  - Provide for the leasing or purchase of emergency supplies and equipment
- Ministry Of Transportation And Highways
  - Coordinate and arrange for transportation, engineering and construction resources.
- British Columbia Building Corporation
  - Provide priority allocation of government building for operational accommodation, storage, or other emergency requirements.
  - Assist in the identification of, and make emergency rental or lease arrangements for private sector buildings or other infrastructure requirements.

(PEP, 1992)

4.1.4 Responsibility for Waste Disposal

The Provincial Waste Management Act regulates waste disposal in B.C. This Act requires that permits be acquired for any waste discharge. The permits define operating practices for landfills. The regulating body that monitors the permits in B.C. is the Ministry of Environment, Lands and Parks (SPARK, 1991).
4.1.5 Responsibility for Disaster Debris Management
At the time of the earthquake, the Mayor in Council will have to make the decision as to what to do with the debris. Initially, it will most likely have to be stockpiled somewhere, until the Mayor decides what to do with it. The Attorney General's Office is encouraging the type of planning that will establish what will be done with debris from a disaster, such as an earthquake, and who will be responsible for making the operational decisions at the time of the disaster. Despite such encouragement from the senior government, no such planning is currently taking place in the Province. (Personal Communication, Dave Gronebeck)

4.2 Funding for Earthquake Recovery
4.2.1 Federal Disaster Assistance
The federal government can provide financial assistance to provincial and territorial governments through the Disaster Financial Assistance Arrangements (DFAA) to help them meet the basic costs of response and recovery (EPC, 1997). Under DFAA, federal assistance is paid to the Province/Territory, not to individuals or communities.

The provincial/territorial government pays out money to individuals and communities in accordance with its provincial disaster assistance program.

This federal assistance takes effect when eligible provincial/territorial expenditures incurred in connection with the emergency response and recovery exceed an amount equal to $1 per capita of the provincial/territorial population.

The provincial government designs, develops and delivers disaster financial assistance to the victims of emergencies and disasters, deciding the amounts and types of assistance which will be provided. The federal government places no restrictions on provincial or territorial governments in this regard.

There is a provision for advance payments, which may be based on estimated expenditures. This provision is employed when a catastrophe is so large, relative to the provincial economy, that otherwise would incur an undue fiscal burden on the Province/Territory.

There is no fixed budget for disaster financial assistance. The amount of this federal compensation is determined by a formula based on provincial population (i.e., per capita sharing formula). The federal compensation amount is calculated in accordance with Table 4-1.

<table>
<thead>
<tr>
<th>Provincial Eligible Expenditures</th>
<th>Federal Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>First $1 per capita</td>
<td>Nil</td>
</tr>
<tr>
<td>Next $2 per capita</td>
<td>50%</td>
</tr>
<tr>
<td>Next $2 per capita</td>
<td>75%</td>
</tr>
<tr>
<td>Remainder</td>
<td>90%</td>
</tr>
</tbody>
</table>

(EPC, 1997)
Table 4-2 presents a sample calculation of federal compensation, based on:
- a provincial population of 1 million people; and
- eligible disaster related expenses of $10 million.

Table 4-2: Sample Calculation of Federal Compensation

<table>
<thead>
<tr>
<th>Provincial Eligible Expenditures</th>
<th>Financial Responsibility</th>
<th>Provincial Share</th>
<th>Federal Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>First $1 per capita</td>
<td>(100% provincial)</td>
<td>$1 million</td>
<td>$ Nil</td>
</tr>
<tr>
<td>Next $2 per capita</td>
<td>(50-50 share)</td>
<td>$1 million</td>
<td>$1 million</td>
</tr>
<tr>
<td>Next $2 per capita</td>
<td>(75% federal)</td>
<td>$500,000</td>
<td>$1,500,000</td>
</tr>
<tr>
<td>Remainder</td>
<td>(90% federal)</td>
<td>$500,000</td>
<td>$4,500,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>$3 million</td>
<td>$7 million</td>
</tr>
</tbody>
</table>

(EPC, 1997)

The following are examples of the expenses which are or are not eligible for cost sharing under DFAA, which may be particularly applicable to earthquake recovery.

DFAA Cost Sharing Eligible Expenses Applicable to Earthquake Recovery
- provincial/territorial eligible expenses incurred during the immediate response period
  - security measures, including the removal of valuable assets and hazardous materials from a threatened area
- provincial/territorial eligible reimbursements to individuals
  - costs of damage inspection, appraisal and cleanup
- provincial/territorial eligible costs of restoring public sector infrastructure
  - clearance of debris and wreckage from roads, waterways, reservoirs
  - removal of damaged structures constituting a threat to public safety
  - restoration of roadways, bridges, wharves and docks to pre-disaster condition
- provincial/territorial non-eligible expenditures
  - damage for which costs could be recovered through insurance
  - assistance to large businesses and industries
  - normal operating expenses of a municipal or provincial government department or agency

(EPC, 1997)

4.2.2 Provincial Financial Assistance
The provincial government can provide financial assistance to individual residents and municipal (local) governments through the Disaster Financial Assistance (DFA)Program (PEP, 1997a through e). The DFA Program is administered by the Ministry of Attorney General, through the Provincial Emergency Program (PEP).
### 4.2.2.1 Disaster Financial Assistance Program

The following are the highlights of the DFA Program, outlining the provisions for applicability.

#### Provincial Disaster Financial Assistance Program

<table>
<thead>
<tr>
<th>Eligibility</th>
<th>DFA applies to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>homeowners and renters</td>
</tr>
<tr>
<td></td>
<td>small businesses</td>
</tr>
<tr>
<td></td>
<td>farm operations</td>
</tr>
<tr>
<td></td>
<td>charitable and non-profit organizations</td>
</tr>
<tr>
<td></td>
<td>local governments</td>
</tr>
<tr>
<td></td>
<td>DFA does not apply to:</td>
</tr>
<tr>
<td></td>
<td>large businesses and Crown Corporations</td>
</tr>
<tr>
<td></td>
<td>items for which insurance was reasonably and readily available</td>
</tr>
<tr>
<td></td>
<td>recreational/seasonal residences</td>
</tr>
<tr>
<td></td>
<td>luxury goods and recreational items, including rec rooms</td>
</tr>
<tr>
<td></td>
<td>damage to landscaping and land loss through erosion</td>
</tr>
<tr>
<td></td>
<td>buy-out of homes or property damaged by the disaster</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Form of Assistance</th>
<th>funds for:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>replacement or restoration of essential items</td>
</tr>
<tr>
<td></td>
<td>restoration of municipal infrastructure</td>
</tr>
<tr>
<td>alternate accommodation through:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>local office of the Ministry of Human Resources</td>
</tr>
<tr>
<td></td>
<td>local Emergency Social Services volunteer organization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amount of Assistance</th>
<th>provisions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>maximum allowable</td>
</tr>
<tr>
<td></td>
<td>payment formula</td>
</tr>
<tr>
<td></td>
<td>for alternate accommodation</td>
</tr>
<tr>
<td></td>
<td>limitations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application Procedure</th>
<th>an adjuster will:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inform each claimant of DFA regulations and requirements</td>
</tr>
<tr>
<td></td>
<td>visit each claimant to review damage</td>
</tr>
<tr>
<td></td>
<td>prepare final claim settlement to be submitted to PEP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DFA Requirements</th>
<th>evidence of damage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>visual inspection by adjuster or photographs</td>
</tr>
<tr>
<td></td>
<td>list of damaged items</td>
</tr>
<tr>
<td></td>
<td>log of cleaning time when cleaning own property</td>
</tr>
<tr>
<td></td>
<td>receipts and invoices when contracting work or renting equipment</td>
</tr>
</tbody>
</table>

(PEP, 1997a)
4.2.2.2 Interpretation of Disaster Financial Assistance Program

Further investigation into the availability of funds for earthquake recovery, with specific application to disaster debris management, brought forth the following results. (Personal Communication, Susan Laroy)

- Recovery Plans
  It is very crucial for municipalities to prepare recovery plans in order to be eligible for provincial financial assistance. Such plans are typically prepared by consultants, and are submitted to PEP in Victoria for approval. Notwithstanding a municipality’s effort to have a recovery plan, the municipality will be responsible for at minimum 20 percent of the total costs incurred.

- Declaration of Emergency
  A national, provincial or local emergency does not need to be declared in order for funds to be available under the DFA Program. The local government can within its powers declare a state of local emergency. As an example, on March 3, 1999, the Corporation of Delta declared a state of local emergency when a section of its seawall failed. However, such a declaration is not necessary for obtaining funds.

- Floodplains
  Section 15 of Part 2 of the DFA regulations states that no assistance will be provided for structures built in a floodplain area, as designated under the Municipal Act, if they are damaged in a flood. There are no provisions for when the flood is the result of an earthquake. Furthermore, there currently are no areas designated as floodplains under the Municipal Act.

- Hazardous Waste
  The cost of removal and disposal of HW would be covered by the provincial government only if constituted a public threat. Large businesses faced with the problem of cleanup of significant quantities of HW are typically not covered by the DFA Program. They will presumably be able to get assistance, for example, from the Ministry of Environment, Lands and Parks.

- Assistance to Residents
  The details of the type and amount of assistance available to residents are presented at the beginning of this section. Although each local government has different rules, and some may provide their residents with financial assistance after a disaster, it is typically the provincial government’s role and responsibility.

- Properties without Owners
  If there is no owner to claim responsibility for the cleanup of debris on a property, the debris will not be removed unless it constitutes a public safety issue. If the local government chooses to clean it up, it would be solely the local government’s financial responsibility.

- Assistance to Local Government
  In order for local government to be reimbursed for the management of disaster debris, the following information must be documented in detail:
  - overtime;
  - materials, supplies and rented equipment;
  - service contracts;
  - fuel costs, etc. for local government equipment;
  - GST (only 42.86% is recoverable); and
  - damage description.
Separate documentation and accounting is required for disaster related work, from other every-day activities. All actions undertaken, and funds spent must be described in a recovery plan, and approved by PEP prior to implementation.

Costs related to the following activities are not eligible for recovery from the provincial government:
- regular hours and equipment;
- landscaping; and
- stockpiling.

Local government can apply for financial assistance under the DFA Program only for itself and its structures. A city-wide program to assist residents in debris removal would not be recoverable under the current DFA Program. Residents would need to individually apply for DFA for themselves and their structures. Furthermore, the term ‘recovery projects’ only refers to government structures, and would not include a municipality hiring a contractor to pick up debris set out by residents at curbside.

Reimbursement would only be available for the least expensive disposal option. The DFA Program covers replacement costs, and does not cover improvements on the pre-disaster system. Any improvement works would have to be covered by the local government. This includes implementing new disposal techniques that were not available before the disaster, since that would constitute an improvement to the system.

Funds under the DFA Program will be made available to the local government for as long as deemed necessary by both the local and provincial governments.

- Eligible Expenses
  As a clarification to the contents of Schedule 1, Section 1.e. of the DFA regulations, regarding the costs eligible for reimbursement to residents, the following costs would also be covered under the DFA Program:
  - demolition costs;
  - disposal fees;
  - processing fees;
  - transportation/collection fees; and
  - hired manpower costs.

  As a clarification to the contents of Part 3, Section 20(1).f. of the DFA regulations, regarding the reimbursement of City employees, the following costs would also be covered under the DFA Program:
  - cost of hiring new City staff solely for the purpose of disaster debris management; and
  - although City staff would not be compensated for regular hours even if working solely on disaster debris response/recovery, overtime hours would be covered under the DFA Program.

- Source of Funds
  The funds disbursed under the DFA Program are made available from general revenue by an emergency vote legislation. Due to the nature of disasters, the total amount of funds that can potentially be made available cannot be specified, and thus, it is unlimited. The funding under the DFA Program is strictly in the form of grants (i.e., not loans), unless an application is involved in a civil litigation.
The provincial government actually contributes only a partial amount of the funds distributed under the DFA Program, and needs to apply for the remainder to the federal government. The provincial-federal cost sharing is presented in Table 4-1 in Section 4.2.1. Upon receiving an application from the provincial government, the federal government must ensure the approval of the Treasury Board. It can take up to several years before the provincial government obtains the requested funds from the federal government. On occasion, advances on DFA funding can be requested and obtained.

The waiting period for reimbursement from the Province depends on complexity of claim. The process generally lasts weeks or days rather than months or years,

4.2.2.3 Applicability of Disaster Financial Assistance Program

Another consultation with a PEP representative, regarding the availability of funds for earthquake recovery, with specific application to disaster debris management, provided the following information. (Personal Communication, Dave Gronebeck)

- Large-Scale Local Government Assistance to Residents
  There are no provisions in the provincial DFA regulations for local government assistance to residents. This issue is addressed in general terms in the "Manual to Assist in the Interpretation of Federal Disaster Financial Assistance Guidelines". This document states, that although repair of damage to property is generally the responsibility of the owner of the property, when the damage in a major disaster is widespread, local, provincial and federal governments can offer assistance to help restore the property to its pre-disaster condition (EPC, 1999).

The DFA Program is not the source of funds which will be required for large scale assistance. It is the local government's responsibility to clean up disaster debris. Local government should, and most likely will be able to pay for it. Within the local government, it will be the responsibility of the public works and/or sanitation department to clean up debris.

- Provisions for Funding
  Provincial and federal assistance will only be made available if absolutely necessary. The decision regarding availability of funds will be made at the time. There are no provisions in place at present, and probably will not be put in place prior to the occurrence of a major disaster, since there is no one willing to commit.

- Applicability of Disaster Financial Assistance Program
  The DFA Program does not apply to costs incurred from earthquakes, since earthquake insurance is cheap and readily available. Currently, the DFA Program applies only to floods, since flood insurance is not readily available.

4.2.3 Social Assistance

The groups and organizations that can be counted on for performing social and volunteer services include:

- Community Services (listed in the Yellow Pages of the local telephone directory), including Community Services Centres and Volunteer Centres;
- Social Service Organizations (listed in the Yellow Pages of the local telephone directory); and
- Church Volunteers.
4.2.4 Mutual Aid Agreements
Investigation into the existence of mutual aid agreements in the Lower Mainland, for both response and recovery phases, indicates the following facts:
- the emergency mutual aid agreement idea originated with fire departments;
- any agreements that may exist in the Lower Mainland would be for response only;
- there is more of the memorandum-of-understanding-type of agreements than actual mutual aid agreements;
- there is a Pacific Northwest Emergency Management Agreement between the Province of British Columbia, Yukon Territory and State of Washington;
- the Pacific Northwest Agreement stipulates that the requesting party pay for all the costs incurred in relation to mutual aid to the providing party;
- there are no mutual aid agreements between the individual municipalities within the Lower Mainland;
- it is unspecified whether the existing emergency mutual aid agreements are for emergency response only, or whether they also extend into emergency recovery, if required; and
- it is unlikely that any agreements for emergency recovery exist.
(Personal Communication, John Oakley)

4.3 Conclusion to Background on Authority and Funding for Earthquake Recovery
The preceding sections introduced the third component of the background of an earthquake recovery plan, which is an integral part of the solution to the earthquake recovery problem. The topics that were discussed include:
- the role and authority of governments in earthquake recovery;
- the sources and amounts of funding potentially available for earthquake recovery; and
- the sources of resources other than funding.

This concludes Part II of the Thesis—the Background of the earthquake recovery plan. A general understanding should have been gained of seismicity and the earthquake potential in the Lower Mainland; of the solid waste management system; and of the authority and sources of funding for earthquake recovery.

Next is Part III of the Thesis—the Methodology of the earthquake recovery plan. The following sections introduce and review several existing plans that address the issue of planning for earthquake recovery. The methodology of the current work is based on the methodologies utilized in these existing plans.
PART III: EXISTING PLANS AND METHODOLOGIES
5. EXISTING PLANS AND METHODOLOGIES - CANADIAN PERSPECTIVE

In order to increase the effectiveness of the current work, it is necessary to review the extent of earthquake recovery and disaster debris management planning in Canada. This review revealed a very limited planning groundwork, diverse in detail and sparse in applicability. No comprehensive disaster recovery plan was identified, although federal guidelines for preparing such a plan have been developed.

The following sections document existing plans that were identified as the most relevant to the current work. The identification and review of these documents were integral to the development of the methodology of the proposed Plan.

5.1 Canadian Disaster Debris Management Report

A recent "Disaster Debris Management" report prepared at the Disaster Preparedness Resources Centre (DPRC) at the University of British Columbia, identifies the issues surrounding disaster recovery (Solis, 1995). The DPRC work was sponsored by Emergency Preparedness Canada (EPC). The intent of this report was to serve as a guide for the development of local or regional disaster debris management plans.

Solis (1995) proposes that a disaster debris management plan incorporates the following:
- allocation of responsibility;
- policy making;
- human factors;
- debris management;
- cost reduction; and
- administrative procedures.

This report recognizes the potential impacts of disasters on the existing solid waste management system, the environment and the local economy.

The report by Solis (1995) proved to be a very useful tool in the development of a disaster debris management plan. It was an excellent starting point for subsequent disaster recovery planning work. Since it would be redundant to summarize the contents of this report, only a reference is provided in this section. It should be noted that the current work does not exhaust the utility of the Solis (1995) report.

5.2 City of Vancouver Emergency Response Procedures Manual

In anticipation of an earthquake disaster, the Sanitation and Landfill Operations Branches of the City of Vancouver has developed an "Emergency Response Plan" (City of Vancouver, 1998). This report is an action plan for immediate response to an emergency that generates debris. The following is a summary of the key points made in this report.

- Role of Emergency Planning
  Emergency planning must be a combination of preplanned action (i.e., mitigative actions), and of preparation to react to various circumstances as they arise.

- Role of Sanitation and Landfill Operations Branches
  The Sanitation and Landfill Operations Branches are part of the Solid Waste and Information Services Division of the City of Vancouver. The personnel from these branches will be responsible for the:
  - collection;
  - handling; and
  - disposal
  of earthquake debris, residential and commercial garbage, and hospital wastes.
Plan Objectives
The objectives of the City of Vancouver Emergency Response Plan include:
- safe and expedient removal of all forms of waste for the overall public good;
- disposal of waste in best available manner, including storage, recycling and final disposal; and
- provision of fresh and salt water by flusher truck fleet.

Components of Emergency Procedures
The following is a summary of the emergency procedures

City of Vancouver Solid Waste Management Emergency Procedures

- Mobilization of Emergency Staff
  - responsibility for mobilization
    - Sanitation Superintendent
    - Landfill Manager
  - location of Field Command Centre
    - Manitoba Yards
    - contingency plan: Cambie Yards, Terminal Avenue Yards
  - chain of command
    - Emergency Fan-Out List
    - responsibilities of unavailable staff reassigned to supervisor

- Mobilization of Emergency Equipment
  - responsibility for mobilization
    - Sanitation Superintendent
    - Landfill Manager
  - prepared resource inventory
    - Sanitation Branch and Landfill Operations equipment
    - alternate sources for leasing equipment
    - pre-qualified contractors

- Damage Assessment
  - responsibility
    - Emergency Operations Centre (EOC)
    - City Structural Engineers
    - competent personnel
  - purpose of debris quantity estimation and characterization
    - crew requirements
    - materials and equipment requirements
    - requirement of temporary storage and recycling sites

- Damage Prioritization
  - ultimate priority
    - major transportation routes (based on snow emergency routes)
  - priority criteria
    - urgency of site clearance
    - amount of debris generated
    - type of debris
    - disaster site characteristics
    - debris recycling possibilities
    - geographic complications
City of Vancouver Solid Waste Management Emergency Procedures

- Removal of Solid Waste
  - management goals
    - diversion preference through recycling
    - source-separation of debris
    - prevention of debris stockpiling and concentration
    - minimization of transportation requirements
  - operational strategy
    - heavily based on the Los Angeles, California system used in the aftermath of 1994 Northridge Earthquake
    - City responsible for coordination of cleanup effort
    - collection contractors to be trained approved by the City
    - City-inspection and monitoring of field activities
    - utilization of source-separated and mixed debris recycling facilities
    - application of incentives and non-compliance fines
    - no mention of source of funding
- disposal options
  - landfill (Burns Bog)
  - transfer station (Manitoba Yards)
  - tennis courts and parks
  - undeveloped park sites
  - vacant City-owned lots
  - other Lower Mainland landfills
- processing sites (for sorting and recycling)
  - recycling station (Manitoba Yards)
  - tennis courts and parks
  - undeveloped park sites
  - vacant City-owned lots
  - privately owned recycling facilities
- waste types (other than debris directly related to the disaster)
  - hospital waste to be directed to Burnaby Incinerator, or funeral home incinerators
  - animal wastes and carcasses to be directed to SPCA incinerator, or Burnaby Incinerator
  - HW to be isolated, and subsequently, properly disposed
  - residual waste to be directed to the landfill, or temporarily retained at origin

(City of Vancouver, 1998)

5.3 JELC Disaster Debris Management Report

As part of provincial emergency preparedness planning, a committee within the Joint Emergency Liaison Committee (JELC) was formed to provide disaster debris management recommendations to the GVRD. The Disaster Debris Committee (Committee) consisted of personnel from the GVRD; the Ministry of Environment, Lands and Parks; the Ministry of Transportation and Highways; the Provincial Emergency Program; the University of British Columbia; and the solid waste industry. The Committee was lead by the Regional Emergency Planning Coordinator.

The Committee met approximately once a month to identify and discuss disaster debris issues, with occasional input from other organizations not represented on the Committee. The result of the work performed by the Committee was the "Disaster Debris Management Report". This report provides guidance and recommendations for disaster debris management planning in the GVRD (GVRD, 1999).
5.4 Emergency Preparedness

5.4.1 Sample Emergency Preparedness Plans
Several Emergency Preparedness Plans were reviewed to elicit ideas on content, format and user-friendliness, to be applied in the preparation of this document. The most notable documents are:
- City of Port Coquitlam Emergency Response Plan (Emergex Planning Inc., 1996); and

5.4.2 Provincial Emergency Program
There have been several minor changes made to the 1992 British Columbia Earthquake Response Plan, which came into effect in May 1999. There will not be any changes made to "Appendix 2 - Earthquake Threat", which considers the subduction earthquake to be the greatest hazard to B.C. Although the crustal earthquake, with a higher probability of occurrence, is believed to be the one to cause the greatest damage in southwest B.C., the Provincial Earthquake Response Plan takes into account the largest extent of earthquake effects by addressing the subduction earthquake. (Personal Communication, Dave Gronebeck)

5.5 Conclusion to Canadian Perspective of Existing Plans and Methodologies
The preceding sections introduced the extent of Canadian earthquake recovery preparedness. The documents that were reviewed were also used for the development of the methodology of the current work. The Canadian breadth of earthquake recovery planning includes:
- the federal guidelines for disaster debris management planning;
- the current provincial undertaking in earthquake response and recovery planning; and
- the local earthquake response plans.

The limited Canadian experience in planning for and executing disaster recovery is well complemented by the US experience in this area. The most significant US experience in earthquake recovery planning, particularly in the western States, is reviewed in Section 6.
6. EXISTING PLANS AND METHODOLOGIES - UNITED STATES PERSPECTIVE

The western States of the United States of America, in particular, have recently experienced a high number of earthquakes in densely populated regions. The physical and economic consequences of these events have caused a heightened awareness for the role that recovery planning can play in the mitigation of these effects. As a result, a number of reports and planning documents have been prepared, summarizing invaluable recovery experience, providing guidance for recovery planning, and detailing proven and proposed strategies for future earthquake recovery.

The following sections review the earthquake recovery documents prepared by the federal, state and local governments for use in the western States. In addition to containing vast quantities of pertinent information, these documents also provide sample methodologies which can be applied in the preparation of subsequent earthquake recovery plans. The current work has greatly benefited from the insights presented therein. Furthermore, the US experience identifies the various components of earthquake response and recovery, which should be considered when planning for a similar situation elsewhere.

6.1 California Integrated Waste Management Disaster Plan

The State of California prepared a document entitled, "Integrated Waste Management Disaster Plan", which provides detailed guidance to local governments for developing a disaster debris management plan (IWMB, 1997). It presents a great deal of information, and is based on extensive disaster recovery experience. The aim of the IWMB (1997) report is to assist local governments in minimizing the costs associated with recovery from disasters that generate large quantities of debris. This document is substantial in size, and comprehensive in content. While it is not worthwhile to summarize this document, the information presented in the document, and ideas generated by its review have been incorporated into the current work.

6.2 Environmental Protection Agency Guide

The US Environmental Protection Agency (EPA) prepared a short guide, entitled "Planning for Disaster Debris", which contains a great deal of information for developing a disaster debris management plan (EPA, 1995a). The EPA guide highlights the needs for communities to plan for the cleanup of disaster debris. This guide is not limited to earthquakes, but applies to all natural disasters experienced in the US. Based on the lessons learned from communities with first-hand knowledge of recovery from such events, this guide provides information to assist communities in preparing for and recovering from the increased solid waste generated by a disaster. Many of the ideas presented in, and generated by the EPA guide were implemented in the current work.

6.3 San Francisco Disaster Debris Management Plan

In anticipation of another earthquake disaster, the City and County of San Francisco retained the consulting companies Recycling By Nature, and J. Edwards and Associates to develop a disaster debris management plan. The report that contains this plan is entitled "City/County of San Francisco Disaster Debris Recovery Plan" (Recycling By Nature, Inc., and J. Edwards and Associates, Inc., 1997). The following is a summary of several of the key points made in the San Francisco Plan.

☐ General

Based on the experience of disaster response and recovery of other regions, it is recognized that construction and demolition (C&D) processing is very similar to disaster debris processing. (The US terminology of C&D is synonymous with the Canadian terminology of DLC, and for the purpose of this section only, the US terminology is used.) Expansion of an existing C&D system can be of tremendous benefit to an area’s ability to respond to a disaster.
The main goals of the San Francisco Plan were:
- the integration of debris recycling strategies into any disaster response;
- the maximization of disaster debris diversion; and
- the implementation of diversion in a cost-effective manner without hindering other response responsibilities.

Deconstruction, the process of maximum salvage through systematic disassembly of buildings, greatly increases the diversion potential of the waste material through recycling. Older, wood and brick buildings are ideally suited for intensive C&D recycling activity.

- Decision-Making Factors
The following factors will affect the level of earthquake response provided by the City/County, and the choice of debris management system that is used:
- amount of debris generated;
- type of debris generated;
- concentration of debris;
- damage to City infrastructure;
- geographic location of damage;
- collection scale and timeline; and
- number of building demolitions required.

- Components of Disaster Plans
The basic components of any disaster plan include:
- the players responding to the disaster;
- the types of materials generated;
- the contract mechanisms for collection contractors and/or facilities; and
- the components of a comprehensive disaster debris recovery program.

The players involved in disaster response and recovery include:
- City team, with the support of senior governments, to respond to the needs of those affected by the disaster;
- contractors to collect debris, conduct repairs, demolish buildings;
- facilities to receive debris either for recycling or disposal;
- sites for overflow of both debris and equipment; and
- citizens/generators, including owners and occupants of structures, private businesses, institutions, and government agencies.

In certain circumstances a locality will contract for total overall project management (in lieu of City staff responsibility).

- Debris Categorization
Materials generated in a disaster can be divided into three general categories:
1. source separated (wood, clean inerts, metals, red clay brick, and other salvageables);
2. mixed inerts with up to 10 percent trash; and
3. mixed debris.
Debris Removal Stages
Debris removal from disasters occurs in three stages:
1. immediate clearing of emergency routes (to allow rescue crew entry to hard hit areas);
2. removal of debris from streets (to return traffic flow to normal patterns, and to repair road and structural damage); and
3. longer process of private repair of damage (to local structures).

Facilities
There is a number of waste facilities that have different functions in debris management.

Facility Functions

- Solid Waste Facilities
  - include transfer stations, which consolidate debris

- C&D Processing Facilities
  - accept one or more of the three categories of materials

- Source Separated Processing Facility
  - receives a single type of material for processing and consolidation (metal, paper, wallboard, wood, yard trimmings, concrete grinding, asphalt grinding)
  - one or two laborers are used to remove pieces of contaminating debris (inerts, paper, plastics)
  - materials are fed into the grinder for size reduction, and are then conveyed either for direct shipping, or storage
  - typical diversion rates are over 98%

- Mixed Inerts Processing Facility
  - receives inert materials (concrete, asphalt, red clay brick, and dirt) with up to 10% of miscellaneous debris (plastic, paper, salvageables, wood)
  - hand separate miscellaneous debris, and then, size-reduce the inerts, or mechanically size and separate inerts from miscellaneous debris
  - diversion rates of 90%

- Mixed Debris Processing Facility
  - any combination of wood, yard trimmings, metal, plastic, gypsum, durables, concrete, asphalt, red clay brick, dirt, and other C&D material with residual material (plastic, paper, salvageables, painted wood)
  - diversion rates vary dramatically depending on equipment, labor use, marketing knowledge
  - optimal diversion rates of 80%


Staging Sites
The usage of staging sites should be limited to short-term processing, and should not be used for stockpiling of debris. Temporary stockpiling could be allowed for facility overflow, to be processed on second and third shifts. Stockpiling for more than one week can result in aesthetic, health and safety impacts. A potential problem with allowing short-term stockpiling is that materials may end up being stockpiled for much longer than expected due to contractual or processing issues.

The potential uses of staging sites should be limited to:
- temporarily holding of overflow from processing facilities;
- debris processing with mobile equipment;
- designated drop-off/consolidation points for selected source-separated recyclables; and
- designated drop-off sites for reusables/salvageables.

Greater Vancouver Post-Earthquake Solid Waste Management Strategy
March 2000
Markets for Recycled Materials
The existence of viable markets for materials generated from a disaster is the most important factor in determining the overall success of a debris recovery and recycling program. In addition, two basic conditions must be satisfied for a material to enter a marketplace:
1. recovered material must meet certain specifications; and
2. there must be sufficient demand for the commodity in the secondary materials marketplace

### Markets for Recycled Materials

- **Metals**
  - value of recycled metal
  - ferrous: $US 5.50 - $US 22 per tonne ($US 5 - $US 20 per ton)
  - non-ferrous: $US 44 - $US 330 per tonne ($US 40 - $US 300 per ton)
  - handling costs
    - typically the largest cost in metals recycling
    - the larger the volume, the more economic it is for metal dealers to recycle metal
    - dealers will provide more favorable prices, or free services, such as free hauling to customers with large loads of high quality materials
  - retrieval and transportation
    - large quantities of rebar can be retrieved during the concrete crushing process
    - if there is a sufficient volume generated, barges can be used to move metal to recycling facilities

- **Wood**
  - end uses
    - fiberboard requires very clean wood, which is chipped and pressed; usually demolition wood is not accepted due to paint and other types of contamination
    - co-generation using high end quality wood for steam generation in electrical turbines; low end quality wood for central heating; and in parallel with another fuel
    - composting of demolition and new construction wood, which is chipped with green waste and/or food, for residential, commercial, and agricultural uses
    - replacement of virgin wood
  - problems
    - wood generated from outdoor structures may be pressure treated and contain creosote sealers which contain arsenic (not acceptable in ash or air emissions)
    - during a disaster, pressure treated and lead painted wood is generated in large quantities, and additional pickers must pull contaminated wood out as trash

- **Aggregates/Clean Inerts**
  - end uses
    - oversize material for rip rap
    - mixed material for artificial reef projects
    - in production of concrete ready mix
    - Caltrans (as of July 1996) states that recycled aggregates can technically be used without special provisions
  - composition
    - inert based, crushed materials such as rock, concrete, asphalt, and up to 5% soils (free of contamination), previously used in construction projects

- **Asphalt**
  - end uses
    - old asphalt pavement is used as a feedstock in the production of new asphalt
Markets for Recycled Materials

- Mixed Rubble
  - End uses
    - Local scrap yards
    - Industrial uses such as parking lot and driveway road base
    - Stockpile for "winter deck" landfill roadway use
    - Backfill
    - Landfill cover
  - Composition
    - Inert materials less than ½ inch in diameter, with a significant percentage of red clay brick and/or other inert contaminants that preclude the rubble's use in roadwork projects
  - Problems
    - Due to the lower quality of aggregate, and when large quantities of clean recycled aggregate are available, mixed rubble is less likely to be recycled

- Red Clay Brick
  - End uses
    - Whole red clay brick for use in neighborhood beautification projects
    - Strong market exists in US for pelletized red clay brick
    - Pelletized brick for ballpark infield base, roofing aggregate, to landfills for "winter deck" and/or daily cover (when mixed with other, more stable aggregates)

- Dirt
  - End uses
    - Landfill cover
    - Source separated dirt for backfill

- Wallboard
  - End uses
    - New drywall
    - As soil amendments
    - Cement production
    - Stucco additive
    - Sludge drying
    - Water and manure treatment
    - Animal bedding
    - Flea powder
    - Grease absorption
    - Athletic field markers
  - Composition
    - Wallboard/drywall core of pure gypsum, paper facing
  - Problems
    - Use of lead paint on wallboard causes problems for determining end uses

- Carpet
  - End uses
    - Reuse on the job to protect interior wall from damage during renovations
    - Reuse if in good condition
    - Reuse by animal care agencies for animal use
    - Reprocessing for non-carpet use
  - Problems
    - With handling and diversion

Costs Related to C&D Waste
The following are the factors that affect the total cost of debris handling and disposal:
- facility tipping fees;
- markets and revenues for recyclables;
- travel distance;
- trucking equipment;
- other equipment;
- on-site labor costs;
- special services;
- type and quantity of debris; and
- knowledge of waste management options.

Cost Control Mechanisms
The mechanisms available to the City to control C&D disaster debris recycling costs include:
- creating markets for the materials by specifying use of recycled materials in City contracts;
- using grant programs to encourage salvage and reuse of materials; and
- using economic development funding to encourage markets for materials currently difficult to recycle

In order to be cost-effective, a debris management strategy should:
- increase competition;
- promote the development of markets; and
- educates contractors.

Disposal rates at local landfills can determine the viability of recycling. A discounted earthquake disposal rate at landfills may result in the cost of recycling being higher, and therefore, may discourage diversion.

Recycling/Diversion Rate
The following is an example of how the recycling/diversion rate at a mixed processing facility can affect the cost per tonne of materials recycled compared to the tipping fee per tonne of materials processed.

<table>
<thead>
<tr>
<th>Tipping Fee for Processing</th>
<th>Recycling Rate</th>
<th>Tonnes Processed per Tonne Recycled</th>
<th>Cost per Tonne Recycled</th>
</tr>
</thead>
<tbody>
<tr>
<td>$US 70 per tonne</td>
<td>40%</td>
<td>2.5</td>
<td>$US 175</td>
</tr>
<tr>
<td>$US 70 per tonne</td>
<td>90%</td>
<td>1.1</td>
<td>$US 78</td>
</tr>
</tbody>
</table>


An increase in the recycling rate from 40 percent to 90 percent results in savings of $US 97 per tonne of materials recycled.

Processing Mixed Inerts
Processing inerts with up to 10 percent contamination may raise the tipping fees from $US 3 to $US 30 per tonne. This increased cost is still only half the cost of a $US 60 per tonne transfer station tipping fee plus travel costs for a 10 tonne truck load, even at 2 to 3 hours round-trip.
Contracts for Debris Collection

There are two basic contract types that can be used to hire contractors for debris collection.

**Contracts for Debris Collection**

- **Time and Materials**
  - used at the outset of the disaster to provide rapid response to clear debris from structures and roadways
  - also used in areas requiring additional attention, or have special needs
  - contractors are paid based on time, not performance

- **Unit Price (Lump Sum)**
  - minimize costs as contractors have an incentive to remove and recycle debris in the most efficient manner
  - fixed cost per load
  - contracts awarded based on lowest cost per cubic yard (i.e., unit price divided by bin size) to ensure largest bin usage
  - only full trucks (95% full by volume, or full by gross truck weight) are compensated
  - facilities certify that loads are full


- **Non-Compliance**
  A non-compliance fee of $US 400/load should be charged for not using City-authorized facilities, or for not meeting contract requirements.

- **Payment of Tipping Fees**
  There are two options for payment of tipping fees in a city-wide debris removal program, paid for by government funding. The tipping fee should only be paid for by the City when waste materials are delivered to a City-authorized processing facility.

**Tipping Fee Payment Options**

- **Reimbursement**
  - contractor pays for disposal of debris, and is reimbursed following the return of copies of weight tickets
  - requires less monitoring and oversight of the facility
  - requires close supervision of contractors by City inspectors

- **Authorization Letter**
  - City pays directly by use of authorization letter
  - small contractors do not have the cash flow to pay tipping fees up-front
  - payment is a standard rate by type of facility
  - facility performance monitoring required


- **City Staff Functions**
  Based on the experience of city-wide debris removal program after the 1994 Northridge Earthquake in Los Angeles, the engineering department is responsible for:
  - contract preparation and management;
  - recycling program office;
  - tipping fee negotiation; and
  - field monitoring of facilities performance.
Inspection by City Staff
City inspectors and project managers should monitor:
- contracts;
- usage of proper facilities;
- collection of all debris in designated area;
- use of proper equipment (large bins); and
- for the thorough and timely completion of work.

6.4 City of Los Angeles Emergency Operations Organization
The Emergency Operations Organization (EOO) is an inter-disciplinary "department without walls" in the City of Los Angeles, in existence since 1980 (City of Los Angeles, 1997). It comprises all agencies of city government. The organization centralized and streamlined the City's command and information coordination, in order to effectively manage the City's resources during emergencies. The EOO is responsible for the City's emergency preparations (i.e., planning, training and mitigation), response and recovery operations. The experience of such an agency provides valuable lessons for other regions facing high risk of a major disaster.

Emergency Operations Centre Divisions
The EOO is divided into the following 14 functional areas:
1. police;
2. fire suppression and rescue;
3. transportation;
4. public works;
5. utilities;
6. general services;
7. building and safety;
8. personnel and recruitment;
9. public welfare and sheltering;
10. harbour;
11. recovery and reconstruction;
12. airports;
13. animal services; and
14. information technology.

California Standardized Emergency Management System
The EOO is compliant with the California Standardized Emergency Management System (SEMS). SEMS is a management system, based on the Incident Command System (ICS) used by fire services. The system was established as a result of the 1991 East Bay Hills Fire in Oakland, in order to improve the coordination of state and local emergency response. SEMS facilitates the following activities:
- the flow of emergency information and resources within and between the organizational levels;
- coordination between responding agencies; and
- the rapid mobilization, deployment, use and tracking of resources.
Mutual Aid Assistance

The EOO relies on Mutual Aid Assistance. Very strict protocols exist for obtaining mutual aid resources, including the California National Guard. Following these protocols is critical. If an elected official personally initiates a mutual aid request with the Governor or the President, involved City staff must ensure that appropriate liaison and coordination are established with applicable local, state and federal authorities. Failure to do so can result (and has resulted) in misdirection of the resource, once it arrives in the Los Angeles area, or can cause the resource to be directed to a destination other than that which was intended by the City.

Employee Emergency Responsibilities

Whenever a disaster strikes, Angelenos look to City employees for leadership and assistance in mitigating its impacts. It is important for every City employee to recognize that they represent a valuable resource which may be called upon in response to the disaster.

6.5 Conclusion to US Perspective of Existing Plans and Methodologies

The preceding sections introduced the extent of earthquake recovery preparedness in Western US. The documents that were reviewed were also utilized in developing the methodology of the current work. The type of information that was reviewed includes:

- the US federal guidelines for disaster debris management planning;
- the California state guidelines and previous earthquake recovery experiences; and
- the existing earthquake recovery plan for the City/County of San Francisco.

This concludes Part III of the Thesis—the review of Existing Plans and Methodologies for earthquake recovery planning. The limited extent of earthquake recovery planning in Canada was presented. The Canadian information was supplemented by the US earthquake recovery experience.

Next is Part IV of the Thesis—the research Results. The following sections present the disaster recovery lessons that have direct solid waste management repercussions. The lessons learned come from the most recent earthquakes that devastated large urban centres in California. The main contribution to this research was obtained during the research trip to Los Angeles and San Francisco. Lessons learned from the most recent disaster experience in the Lower Mainland, as well as from the earthquake experiences in other parts of the world, are also provided. Finally, the application of these lessons in the development of the earthquake recovery plan for the Lower Mainland is presented.
PART IV: RESULTS
7. RESULTS - LESSONS LEARNED

Solid waste management is an essential part of earthquake recovery. It affects every other aspect of earthquake recovery. The lessons learned from previous disasters are most valuable, though rarely documented for future use. The first significant, though not only partial, documentation of the solid waste management repercussions of earthquakes, and of the lessons learned during earthquake recovery took place after the 1994 Northridge Earthquake. Therefore, additional information regarding the implications of solid waste management on earthquake recovery was investigated during the course of the current work.

The following sections present the information obtained during the research trip to California. This well complements the information available on the management of solid waste during Northridge Earthquake recovery.

The lessons from the most recent disaster in the Lower Mainland—the 1999 White Rock Floods—are also presented in the following sections.

7.1 Northridge Earthquake Recovery Documentation

Following the 1994 Northridge Earthquake, the City of Los Angeles produced two detailed documents: "Earthquake Demolition Recycling Program - Final Report - December 1995" and "Northridge Earthquake Response Effort - Final Report: Recycling Activities for City Sponsored Earthquake Debris Removal Program - September 1995", which proved to be important for the current work (Biagi et al. 1995a and b). These two documents provide an account of the activities, successes and problems that took place during the cleanup of the damage caused by this earthquake. These documents are quite comprehensive, such that it is not feasible to summarize the information contained within them. It is recommended that these reports be consulted and reviewed in their entirety. Information presented in these documents was used to generate ideas essential for the development and preparation of this document.

7.2 Research Trip to California

7.2.1 Purpose of Research Trip

In April of 1998, a research trip was made to Los Angeles and San Francisco in California. These two large urban centres have the greatest, the most recent, and best-documented experience in earthquake response and recovery to draw on. Such experience is invaluable to developing an earthquake recovery plan for another region faced with a similar seismic risk.

The need for the trip resulted from an extensive review of the available earthquake recovery documentation from California, and from other parts of the world. The main objectives of the trip were:

- to further investigate issues not discussed in the available documents;
- to clarify the operational approaches that were utilized, but only briefly discussed;
- to establish the applicability of successful and unsuccessful ideas and strategies used in the Californian experience to the Lower Mainland; and
- to observe first-hand the characteristics of the regions, and their systems and facilities, in order to gain a better understanding of the recommendations that emerged out of those experiences.
7.2.2 Establishing Contacts
Identifying and locating the key persons involved either in the actual earthquake recovery from the most recent earthquake, or in the recovery planning for the next earthquake proved to be challenging. Many of the personnel involved in disaster debris management at the time of the 1994 Northridge and the 1989 Loma Prieta Earthquakes have moved to other departments, or are no longer with the government.

The planning for future earthquake recovery in California appears to have stopped after 1997, upon the completion of the Integrated Waste Management Disaster Plan, discussed in Section 6.1. It should be noted that this extensive document was developed to only provide guidance to local governments in preparing disaster debris management plans. In that same year, the City/County of San Francisco prepared their Disaster Debris Recovery Plan.

The contacts that were established for the research trip consisted mainly of the current solid waste management professionals (some of whom were involved with the preparation of the IWMB (1997) report) in the following government agencies:
- California Integrated Waste Management Board (IWMB);
- California Environmental Protection Agency (EPA);
- City of Los Angeles;
- City of San Francisco;
- City of Santa Clarita;
- City of Oakland; and
- Office of Emergency Services.

Other sources of contacts included:
- Los Angeles County Fire Department;
- J. Edwards and Associates, Inc.;
- Community Recycling and Resource Recovery, Inc. (commingled DLC waste recycling facility); and
- Newman and Sons, Inc. (source-separated concrete and asphalt recycling facility).

7.2.3 Itinerary
The itinerary for the trip included:
- Earthquake Preparedness Fair;
- meetings with contacts established prior to field trip;
- meetings with newly established contacts;
- site tours of DLC waste recycling facilities; and
- observation of the physical details of the areas historically affected by earthquakes to determine applicability of recovery methods from those areas to the Lower Mainland.
7.2.4 *Emergency Preparedness Fair*

The research trip to California was scheduled to coincide with an annual Emergency Preparedness Fair in Los Angeles. The following are the key suggestions prompted by the Fair for organizing similar events elsewhere:

- when starting out with emergency preparedness programs, especially in areas that have not experienced disasters, it is essential to combine an emergency preparedness fair with another event, where public attendance will be ensured;
- it is a good idea to hold the fair near a public entertainment facility (e.g., in a zoo or a popular park);
- it is very worthwhile to use a lot of visuals, especially police, ambulance, fire department vehicles and other equipment, in order to impress upon the public the idea that these life-saving agencies are also getting prepared;
- it encourages attendance and makes lasting impressions to include lots of attractions for the kids;
- providing free items, such as information packets and sample products, also encourages attendance and serves as a reminder when residents return home to actually implement a number of the ideas they were presented with at the fair;
- it is important to be innovative; for example, as an attraction, include an earthquake simulation booth to have people experience what it could be like to experience an earthquake; and
- it is very important to staff booths with enthusiastic personnel.

7.2.5 *Results*

The issues and findings of the research trip are discussed in this section. These findings are based on personal interviews conducted with the following persons:

- Al Aguilar, County Fire Department;
- Jim Doty, Environmental Management Department;
- Joan Edwards, J. Edwards and Associates, Inc.;
- Janet Ervin, Assistant Director of Earthquake Recovery;
- Nicole Forte, Commercial Recycling Department;
- John Hasselbrink, Building and Safety;
- Kelly Ingalls, Recycling Department;
- Ken Newman, Newman and Sons, Inc. (source-separated asphalt and concrete);
- Deidre Reyes, Finance and Accounting Department;
- John Richardson, Community Recycling and Resource Recovery, Inc. (mixed debris); and
- Andy Santamaria, Deputy City Engineer.

The topics that were addressed during these interviews include:

- strategy;
- applicability of experience;
- timing;
- cost;
- information keeping;
- public information;
- transportation;
- alternatives to disposal;
- temporary storage/processing facilities;
- hazardous/special waste;
- municipal solid waste;
- demolitions;
- contractors and contracts; and
- incentives.

The details corresponding to each of these topics are summarized in table format for easy referencing.
**Strategy**

- **General Findings**
  - remove inerts first, mixed debris second
  - look for markets for each material
  - after the Northridge Earthquake, a new Disaster Debris Department was organized at the City, with a total of approximately 180 people

- **Collection Alternatives**
  - Santa Monica used roll-off bins
  - initially, during a pilot project, Los Angeles hired contractors to remove debris by appointment from private property, but complaints of additional damage being caused by the contractors resulted in modification of the collection program
  - Los Angeles used curbside collection method, which proved to be very expensive, and required constant monitoring

- **Acquiring Contractors**
  - the City only hired contractors who had: a State license (C-21) for demolition, a license to do business in Los Angeles, insurance and workers’ compensation ($US 1,000,000 general liability)

- **Problems**
  - FEMA inspectors arrived after six months to inspect for non-earthquake debris being set out at curbside
  - City needed to set up surveillance in areas where illegal dumping was occurring

**Applicability of Experience**

- **General Findings**
  - the strategy used in California is heavily dependent on funding from FEMA
  - without such a funding source, city-wide collection programs are not feasible, because of the tremendous costs involved, and the limited local government budgets

- **Earthquake Characteristics**
  - location of epicentre: San Fernando Valley, alluvial plain, 19 km below surface, rupture on a blind thrust fault, up to 5 km below surface

- **Damage Characteristics**
  - landslides were not a problem
  - in the Northridge Earthquake, most of the damage, and the most severe damage occurred in the area of the epicentre
  - the north side of the Santa Monica Mountains was at the greatest danger, and had most damage due to the direction of the cutting plains in the mountain (perpendicular to length of mountain, directed towards the valley); very unstable for house foundations since not very good anchorage capability (e.g., stilts broke, cables stretched)
  - liquefaction occurred in Santa Monica, Marina del Ray, Rodando Beach (i.e., south of the epicentre, along the coastline)
  - liquefaction was accompanied by sandboils
  - the south side of the Santa Monica Mountains had good anchorage capability, and did not experience much damage
  - much of the damage in the San Francisco area occurred in the Marina District

- **Geographical/Topographical Characteristics**
  - the majority of the land in the city of San Francisco was actually filled in from the late 1800’s
  - presently, large sky rises are built on deep pile foundations that reach to bedrock
### Timing

**General Findings**
- public demand for weekly disaster debris (DD) collection over an extended period of time
- within one week, the City began receiving calls for assistance with debris removal from residents, recording the addresses of those requesting assistance

**Debris from Response Activities**
- initially, all debris was delivered to local landfills
- initial loads of DD are most easily recycled
- possible to divert DD, provided that it is presorted and diversion facilities exist

**Diversion**
- diversion to recycling facilities began approximately one month after the earthquake

**Waste Type**
- initially, DD consisted of concrete garden walls and patio covers
- DD composition changed dramatically with time

### Cost

**General Findings**
- only complete demolitions were reimbursed by FEMA
- typically, cost sharing occurs at 75% Federal, 18.75% State and 6.25% local
- in the Northridge Earthquake, the cost sharing was 90% Federal, and 10% State

**Government Funding**
- government funding was available for removal and disposal of debris from right-of-way and the good of the public
- all demolition, removal and disposal was done by the City, and paid for by FEMA, unless the owners wished to do the work and pay for it themselves
- residents were not required to pay for participating in the City debris collection program
- after the Loma Prieta Earthquake, City of San Francisco hired one contractor to oversee the entire cleanup operation, and FEMA provided reimbursement funds
- the contractor chose to deliver all of the DD to a recycling facility in San Jose

**Costs to Residents**
- some residents chose to clean up their own properties; they hired private contractors, and paid for removal and disposal
- some residents chose not to participate because they either had earthquake insurance, couldn’t wait for the City to do the work for them, or felt that it was their property, and therefore, their responsibility
- City was officially not collecting non-earthquake debris, and charged residents for any non-earthquake debris set out at curbside (usually after several notices to residents to remove and not to include non-earthquake debris)
- after the Loma Prieta Earthquake, many residents hired and paid for private contractors to have debris removed
### Information Keeping

**General Findings**
- it is imperative to keep accurate and detailed records of all activities during earthquake recovery in order to be eligible for FEMA reimbursement

**Organization**
- much of the information regarding the location of required collection was delivered to the City by telephone, by residents calling in requesting service (approximately 300 calls per day)
- type of information recorded: location, name, contact number, nature of debris
- once a day, this information was compiled, organized geographically, sent to inspectors in the field, and once a day, there was a reply to show what was done

**Contractors**
- City needed to keep track of contracts and daily reports from contractors, invoices, legal disputes between contractors and sub-contractors, and complaints
- large databases were used for this purpose

**Labour**
- residents who were affected were generally hired to do much of the manual labour, office work, and servicing the phones (e.g., 800-number)

### Public Information

**General Findings**
- the success of any diversion program depends on the level of public awareness

**Mail Service**
- experienced no interruption

**Newspapers**
- negotiate for ad space for debris cleanup information before an earthquake occurs
- use ads to direct people what to do with debris

**Telephones**
- install an 800-number for a debris removal hotline, with at least 10 lines
- record information from callers
- route collection vehicles according to information obtained from the public
- send inspectors to verify locations of debris concentration before dispatching collection contractors

**Special Needs**
- ensure that elders, etc. are taken care of in terms of debris removal and earthquake recovery
- census figures can be used to identify special needs populations
## Transportation

### General Findings
- failures along transportation routes did not impede debris removal and disposal
- there are no load restrictions on roads in California to restrict access for heavy equipment
- transportation infrastructure failure was infrequent
- after the Loma Prieta Earthquake, transportation infrastructure failure was not an issue in debris removal since the transportation route chosen (i.e., from San Francisco to San Jose) did not cross any bridges

### Infrastructure Debris
- can potentially generate large quantities of debris
- did not pose a significant problem, since debris is easily recyclable

### Problems
- the only problem that failures along transportation routes presented was traffic
- debris transportation can be worked around the failures

## Alternatives to Disposal

### General Findings
- alternative disposal options should be investigated prior to disaster
- funds and manpower cannot be spared to follow up on new suggestions and potential disposal alternatives, when reacting to the disaster, and when trying to run the day-to-day tasks

### Usage of Disposal Alternatives
- other than recycling and reuse, no other methods of diversion were utilized
- export of waste to another state was considered, but transportation costs proved to be prohibitive (e.g., disposal of Northridge Earthquake debris in Utah canyons)
- ships from Japan expressed interest in using disaster debris from Los Angeles as ballast, but details were never worked out due to insufficient staffing at the City
- ocean disposal was not necessary, as debris quantities were manageable by other means (mainly disposal and recycling)

### Suggested Disposal Alternatives
- using inert materials for construction of breakwaters and reefs
- offering valued waste materials to other locations for free (e.g., for building roads in poorer locations)
- using the lumber industry to process wood disaster debris
- utilizing the "empty space" leaving a city by ship, truck and train
**Temporary Storage/Processing Facilities**

- General Findings
  - avoid using temporary storage sites
  - do not stockpile debris for future processing
  - temporary processing facilities are a good idea if sufficient space is available
  - insist on required separation by property owners before collection and transportation to a temporary facility

- Time Limit
  - set a limit of one week by which debris must be removed
  - when a site is large enough, there is a recycling/processing facility on site, and the material is inert and source-separated, stockpiling is feasible
  - currently, there remains one stockpile site containing processed crushed concrete in the Los Angeles area, for which a market is still to be found

- Monitoring
  - essential to ensure that illegal dumping does not become a problem

- On-Site Debris Accounting
  - weight tickets were issued in triplicate
  - contractors had to submit load tickets on a daily basis
  - recycling companies were required to periodically audit their recycling rates (approximately once a month to once every three months)

- Sample Audit Procedure
  - at one recycling facility, the site was periodically cleared of all debris (by not accepting any more debris until all debris on site was processed and shipped out, during which time, debris was sent straight to the landfill)
  - when site was empty, it would accept materials for a specified period of time (keeping track of all incoming load weights) - approximately a week - and then, it would stop accepting materials again, and process the known amount
  - weights had to be recorded of all different processed materials leaving the site to a given market destination
  - all unaccounted weights were considered as trash
  - company was only paid by the City for recycled portion
  - trash had to be paid for by company
  - company had a transfer station sister-company next door where they could send their trash

- Implications of Temporary Sites
  - temporary storage sites were not utilized in the recent earthquakes in Los Angeles, nor in San Francisco
  - the "temporary site" was at the point of generation
  - uncertain how the choice and availability of sites for temporary storage of debris would be affected by the need for temporary human shelter sites
### Hazardous/Special Waste

<table>
<thead>
<tr>
<th>General Findings</th>
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<tbody>
<tr>
<td>• use existing hazardous materials procedures in a disaster situation as well</td>
</tr>
<tr>
<td>• separate and isolate HHW from other DD</td>
</tr>
<tr>
<td>• problem can be minimized by knowing the location of hazardous materials prior to an earthquake occurrence</td>
</tr>
<tr>
<td>• implement a HHW Collection Program, to increase public awareness, and to decrease chance of contamination of other DD, HHW requires regular periodic collection, usually a scheduled event</td>
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<tr>
<td>• not a major earthquake recovery problem in California</td>
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<tr>
<th>HW Handling</th>
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<tr>
<td>• falls under the jurisdiction of the County fire department</td>
</tr>
<tr>
<td>• also, Hazardous Waste Air Quality Management District in charge</td>
</tr>
<tr>
<td>• local resources are required to handle the HW; federal resources are used when National Emergency is declared</td>
</tr>
<tr>
<td>• HW handling procedure: material identification, identification of potential environmental impacts, field identification of hazardous material, identification of mitigative actions, and implementation of mitigative actions</td>
</tr>
<tr>
<td>• asbestos handling procedure: demolition order, building inspection for asbestos by engineers, if none found building demolished and recycled, if found dealt with “appropriately”</td>
</tr>
<tr>
<td>• no special identification was used for transportation of HW loads, other than an indication on weight tickets</td>
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<thead>
<tr>
<th>Disposal of HW</th>
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<tr>
<td>• all HW and debris contaminated with hazardous waste (e.g., building containing asbestos) disposed of at special waste landfill</td>
</tr>
<tr>
<td>• electrical transmission towers should be disposed in same manner as in pre-earthquake conditions, specific procedures should be in place</td>
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<tr>
<th>Inspection for HW</th>
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<tbody>
<tr>
<td>• City inspectors required to inspect debris piles for asbestos prior to pickup</td>
</tr>
<tr>
<td>• inspector’s signature required on authorization letter for delivery of each load of DD to a specified pre-authorized facility</td>
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<tr>
<th>HW Spills during Earthquake</th>
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<tbody>
<tr>
<td>• no known incidents of hazardous material spills, or transportation related incidents during the earthquakes</td>
</tr>
<tr>
<td>• during the Northridge Earthquake, several instances of small spills and tank leaks, but all within containment areas, no loss of control of hazardous material</td>
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<tr>
<th>Debris from Fires</th>
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</thead>
<tbody>
<tr>
<td>• certain amount was recycled</td>
</tr>
<tr>
<td>• recycling should be required</td>
</tr>
<tr>
<td>• demolition of buildings with partial fire damage, resulting in commingled fire and regular debris</td>
</tr>
<tr>
<td>• only inerts are recoverable, since flammable debris is usually consumed in the fire</td>
</tr>
<tr>
<td>• FEMA reimbursement was available for the 1980 Oakland Fires, and arson related fires during the 1991 Civil Unrest in Los Angeles</td>
</tr>
<tr>
<td>• in the Oakland fires, all general fire debris was considered hazardous material, under guidelines of the Alameda County Department of Environmental Health; consequently, the debris had to be kept in dedicated cells away from the active municipal solid waste disposal areas</td>
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</tbody>
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<tr>
<th>Debris Containing Human Remains</th>
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<tbody>
<tr>
<td>• City was not involved in demolition and removal of buildings containing human remains</td>
</tr>
<tr>
<td>• handled by private contractors hired by property owners</td>
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</tbody>
</table>
### Municipal Solid Waste

- **General Findings**
  - after earthquakes, there was no interruption of regular municipal solid waste (MSW) collection
  - there was also no major disruption in MSW collection in terms of handling increased quantities
  - garbage trucks would only pick up MSW and not disaster debris
  - it is generally very difficult to distinguish between the two waste streams

- **Usual Collection**
  - MSW collection occurs at curbside in both cities
  - domestic recycling waste is commingled, and separated in sorting facilities
  - there is no pre-sorting by collection trucks at source
  - Los Angeles tried source-separating the recyclables, but since it didn’t work perfectly, commingled recycling was implemented

- **Problems**
  - increased traffic after earthquakes
  - longer hours as regular MSW crews had to work a bit longer to accommodate the slight increase in MSW after earthquakes

### Demolitions

- **General Findings**
  - only a small number of large buildings required complete demolition
  - Building and Safety Office responsible for designating buildings for demolition (permission for demolition given typically within one week)

- **Damage Assessment**
  - buildings were tagged with red, yellow or green tags according to the severity of damage, and hazard level for entry to a building
  - property owner was given “x” number of days to fix the problem; if no response from the owner, building could be demolished by the City

- **Imminent Immediate Hazard**
  - City has the right to demolish such buildings
  - regular process should be speeded up
  - the Bearington Medical Building, deemed an imminent immediate danger, was demolished by Cleveland Wrecking Company hired by the City

- **Costs**
  - City demolishes at no cost to owner
  - City pays for demolition, removal, and disposal
  - paid for/reimbursed by State Emergency Services Office and FEMA

- **Problems**
  - certain areas with apartment buildings determined unsafe for occupation, were boarded up and properties fenced
  - in high crime areas, drug dealers and prostitutes occupied such buildings
  - City needed to work with police and guards
  - low interest loans can be given to investors to address the issue of buildings abandoned by people who can’t afford to pay for repairs
Contractors and Contracts

- General Findings
  - City should be in charge of debris management, not a contractor
  - will need to consider extended hours, 7 days a week

- Management of Contractors
  - master list of contractors was implemented on a rotational basis, where contractors were assigned in random order
  - 30 contractors were awarded contracts in each contract period (approximately every two weeks) for a maximum of $US 100,000 per contract
  - contracts were kept small to allow changes in contract procedures
  - 361 debris removal contractors (rotated 70 companies/day)
  - there are two steps before contractor actually starts work: awarding of contract, and presentation of start-notice

- Purpose of Contractors
  - curbside debris removal
  - fencing unsafe properties (including swimming pools in Los Angeles)
  - demolition of unsafe properties
  - cleaning up ghost towns

- Problems
  - some contractors tried to cheat as much as possible, which required close monitoring by the City
  - some contractors had to be taken off the City list of authorized contractors for not complying with City’s requirements

Incentives

- General Findings
  - enforce non-compliance penalties; double the penalties for repeated offenses

- Delivery to Recycling Facilities (Diversion)
  - contract provisions to recycle, and to deliver to a specified facility, designated according to debris type
  - one person from the City office coordinated the system, by matching up debris types picked up by contractors to available facility types
  - monitoring by City inspectors
  - City funding only available when using City-authorized recycling facility
  - before contractors are allowed to commence work, they should be briefed on contract requirements, contract changes, recycling requirements, and any other pertinent details
  - contractors should be required to sign a statement indicating full understanding of recycling requirements

- Recycling Rates
  - memorandum of understanding - agree to recycle to maximum amount feasible

- Non-Earthquake Debris
  - cancel contracts if non-earthquake debris is picked up
  - reconstruction debris should not be picked up. although it was in Los Angeles, because of insurance issues

- Contractor Pre-Qualification
  - indicate potential revenue during a disaster if company is on the City’s list
7.2.6 Site Tours of Recycling Facilities
Two recycling facilities were visited and documented during the research trip. The following are summaries of the information obtained during the site visits.

**Mixed DLC Waste Recycling Facility**

- Community Recycling and Resource Recovery, Inc.
  9189 DeGarmo Avenue, Sun Valley, California

- **Site Operations**
  - entire operation occurs entirely outdoors
  - potential problems include rain (if material is too moist, it is inappropriate for screening), and wind (only a problem if greater than 30 km/h (20 mph))
  - screening is done by people and air classification
  - screening pilot project that uses a water bath
  - potential problem is if debris contains too much dirt, water bath turns to mud
  - recycling facility used their own end dump trucks to collect debris set out at curbside; to increase effectiveness, the city was broken up into sections
  - trucks picked up debris from streets, and delivered materials to recycling facility from 7 am - 4 pm, where it was stockpiled for the day, processed, and shipped out as product to markets in the evening and at night

- **Processing**
  - recycling process includes two screening runs
  - excavator is used for initial segregation of materials, and to load up for screening
  - during the first screening run, large materials are screened out (e.g., oversized materials, such as fridges and carpet, large rock, asphalt, brick); small materials are separated by air classifier, and removed at bottom (e.g., small rock, sand, small wood, dirt)
  - materials such as large rock, asphalt, brick go through secondary screening
  - metals are picked out and recycled

- **Debris Composition**
  - initially, debris consisted of wood fences, block wall, concrete from sidewalks
  - in 30 - 60 days, materials changed to stucco, wood shingles, carpet, interior debris, furniture, brick from chimneys, which increased labor and trash

- **Debris Quantities**
  - processing before the earthquake at a rate of 100 tons/8 hr shift (day)¹
  - processing following the earthquake at a rate of 300 tons/day (24 hrs per day, 7 days a week)
  - processing currently at a rate of 400 - 500 tons/day
  - however, immediately following the earthquake, on the 1st day when the facility began accepting DD for processing, it received 1,000 tons; 2nd day, it received 1,200 tons; on the 3rd day, it received 1,500 tons
  - the facility had to invest in equipment (rented) to process 1,500 tons/day
  - the increased capacity was still insufficient, such that the facility needed to set up a remote location, at Chiquita Landfill, that processed 2,500 tons/day
  - additional resources required included water tanks and pumps for dust control, and for use against fires, and scales
## Mixed DLC Waste Recycling Facility

**Timeline**
- Feb. 17, 1994 - began 30-day pilot project at recycling facility
- Mar. 15, 1994 - received contract from the City to process mixed debris
- Apr. 15, 1994 - capacity increased to 1,500 tons/day
- such quantities required 20 people working two-11 hour shifts, 7 days a week
- Jul. 15, 1994 - additional recycling facility at landfill site, with capacity up to 2,500 tons/day
- at second facility, quantities required 30 people working two-11 hour shifts, 5 days a week
- the new facility at landfill were set up within 90 days, including ordering equipment, site setup, and acquiring manpower

**Markets/End Product**
- worked with adjacent companies that received their product (e.g., concrete)
- clean concrete and asphalt sent to a rented quarry and used as landfill ("solid fill")
- wood ground onsite by a hired grinder company; product used for boiler fuel
- local markets for metals
- furniture landfilled
- washer and dryer sent to scrap metal dealers
- air conditioners and fridges checked for freon prior to being sent for scrap metal

1 ton = 0.9 metric tonne  
(Personal Communication, John Richardson)

## Source-Separated Concrete and Asphalt Recycling Facility

- Newman and Sons, Inc.  
  9005 Bradley Avenue, Sun Valley, CA

**Change in Operations**
- approximately five-fold increase in the amount of material being delivered following the earthquake
- used larger stock piles during this time
- no additional equipment required
- no traffic problems
- worked slightly longer hours

**Operations**
- only clean materials (concrete and asphalt) accepted
- loads inspected for contaminated materials, and if present, loads sent away
- small amounts of contamination hand picked before processing, during processing
- magnet used during processing for isolating metals

**Accounting**
- material arriving at the facility, as debris, charged by volume
- material leaving the facility, as final product, charged by weight

**Markets/End Uses**
- crushed concrete mixed with asphalt used by Caltrans as roadbase (subbase/base)

(Personal Communication, Ken Newman)
7.2.7 Demolition and Debris Removal Program Summary

The Los Angeles Engineering Department kept detailed records of quantities handled, and funds spent. In addition, the Department produced weekly summary reports for the Demolition and Debris Removal Program, tallying all the activities that took place since the beginning of the program. The following is summary of the final Weekly Report, prepared two years after the Northridge Earthquake.

January 17, 1996 Weekly Report

- **General**
  - total length of Demolition and Debris Removal Program: 17 months
  - no or very limited collection in weeks 9-13 due to cash flow problems at the City

- **Cost**
  - total funds spent to date: $US 235.3 million, including the following:
    - $US 146 million for debris collection
    - $US 52 million for debris recycling/disposal
    - $US 19 million for project management
    - $US 5 million for demolitions
    - $US 3.4 million for cleanup of abandoned properties (ghost towns)
    - $US 1.5 million for fencing of danger areas

- **Quantity**
  - 2.4 million tons (approximately 350,000 loads) of debris collected and recycled/disposed
  - approximately 10,000 piles of evident non-disaster debris tagged, generator given first notice
  - approximately 90% of the suspect piles removed by generator after several notices
  - remaining 10% removed by the City at own expense with attempt at cost recovery
  - 304 structures demolished
  - 253 abandoned properties cleaned up by the City
  - collection of up to 1,400 loads/day

- **Contracts**
  - 361 contractors on City list (used on rotational basis)
  - total contracts signed: 1,805
  - 151 contracts for demolition only
  - 54 contracts for cleanup of abandoned properties

- **Calls for Assistance**
  - 182,000 calls for debris removal, with numerous sites requesting repeat service
  - 92,000 sites logged as requiring debris removal service
  - approximately 300 - 600 calls for assistance per day
  - peak of calls for assistance of over 4,000 calls/day, just before termination of debris removal program after 17 months

(Personal Communication, Jim Doty)
7.3 Investigation of White Rock Floods Disaster

In the Spring of 1999, the city of White Rock, south of Vancouver, experienced serious flooding as a result of heavy precipitation. The event constituted a local emergency, and generated significant quantities of debris. The resulting debris consisted mainly of mud and silt. Approximately five large bins of waste were generated on private properties, with some additional damaged items (Personal Communication, Doug Stone).

- **Cost**
  The cost for the cleanup of DD and MSW from private properties in this disaster was approximately $5,000. This cost was relatively small compared with the recovery cost which totaled approximately $155,000 (initially paid by the City). The City was reimbursed by the Provincial Emergency Program (PEP) for 100 percent of the recovery cost, and for 80 percent of the $330,000 rehabilitation cost. The remaining 20 percent (or $66,000) was the City's responsibility. Most of the cost for residential cleanup and recovery was covered by insurance (Personal Communication, Doug Stone).

- **Disposal**
  According to the City of White Rock, the silt and mud debris was disposed at a clean fill dump site in Langley, east of Vancouver. The MSW was to be disposed at the Vancouver Landfill (Personal Communication, Doug Stone). According to the City of Vancouver, although the White Rock flood debris was scheduled to arrive at the Vancouver Landfill, the bulk of the expected quantity was never received. A small amount of debris was delivered by a local refuse company as part of a community cleanup program (Personal Communication, Paul Henderson). The confusion associated with the final destination of the White Rock Floods debris, and the unaccountability of debris quantities generated and disposed during this relatively small and very localized disaster illustrates the potential for loss of control of the situation during a more severe and wide-spread disaster.

  Part of the debris delivered to the Landfill from the City of White Rock was charged a tipping fee. Debris collected through the community cleanup program was accepted without cost (Personal Communication, Paul Henderson).

- **Operations**
  The City of White Rock received approximately 158 calls for assistance in a two-hour time span. The majority of the calls were related to transportation problems (e.g., washing out of roads, debris on roads). The majority of the debris from the floods was cleaned up within one week. Residents were informed through newspaper adds and television announcements what to do with their debris (i.e., set out for free collection) (Personal Communication, Doug Stone).

7.4 Conclusion to Results of Lessons Learned

The preceding sections introduced the various lessons that were learned from investigating the solid waste management implications during the following disasters:

- the 1989 Loma Prieta Earthquake in San Francisco;
- the 1994 Northridge Earthquake in Los Angeles; and
- the 1999 White Rock Floods in the Lower Mainland.

The application of the lessons learned to the development of the earthquake recovery plan for the Lower Mainland is discussed in Section 8.
8. RESULTS - LESSONS APPLIED
A great deal of the research for the current work resulted from the lessons learned from previous earthquake recovery experiences. The implementation of several of these lessons is presented in the following sections.

The lessons that are applied in the following sections include:
- the estimation of the magnitude of the disaster debris problem prior to the occurrence of an earthquake, in order to determine whether the current solid waste management system will be capable of handling the situation;
- the identification and preliminary investigation of the disposal options available within the region;
- the identification of the vulnerability of the current solid waste management system to earthquake effects in order to determine whether the current system will be available after the occurrence of an earthquake to aid in the recovery process.

Further application of these lessons takes place in the Plan presented in Part V.

8.1 Debris Quantity Estimation
8.1.1 Disaster Debris Committee Estimates
In cooperation with the Disaster Debris Committee (i.e., a subcommittee of the Joint Emergency Liaison Committee (JELC)), the amount of DD that could be generated from structural damage within the GVRD during an earthquake was calculated. Two earthquake scenarios were considered:
1. a design earthquake; and
2. a major earthquake

The estimated quantities were calculated by applying damage factors to the 1998 residential, commercial and industrial real estate inventory in the region. The damage factors used in this calculation—Estimated Loss Ratios (ELR)—are expressed as a percentage of replacement cost of a building. The ELR values were adopted from a CMHC (1990) study "Earthquake Damage in the San Francisco Area and Projection to Greater Vancouver". A summary of the ELR values for the different types of structures that are prevalent within the Lower Mainland is provided in Table 8-1.

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Estimated Loss Ratio (ELR, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design Earthquake</td>
</tr>
<tr>
<td>Single family home</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Low and medium rise apartment buildings</td>
<td>2 - 5</td>
</tr>
<tr>
<td>High rise apartments buildings</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Commercial retail and office</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Industrial</td>
<td>2 - 5</td>
</tr>
</tbody>
</table>

(CMHC, 1990)
A summary of the potential quantities of DD from the two earthquake scenarios is presented in Table 8-2. This data should be considered a minimum estimate of the potential quantity of earthquake related waste, since the following sources of DD have not been included:

- institutional infrastructure such as hospitals, schools, etc.;
- transportation infrastructure such as roads, bridges, overpasses, etc.;
- debris from reconstruction; and
- building contents.

Table 8-2: Potential Disaster Debris Estimates for GVRD

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Design Earthquake</th>
<th>Major Earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tonnage</td>
<td>Volume (m$^3$)</td>
</tr>
<tr>
<td>Annmore</td>
<td>200</td>
<td>800</td>
</tr>
<tr>
<td>Belcarra</td>
<td>200</td>
<td>800</td>
</tr>
<tr>
<td>Burnaby</td>
<td>222,500</td>
<td>584,800</td>
</tr>
<tr>
<td>Coquitlam</td>
<td>62,500</td>
<td>189,500</td>
</tr>
<tr>
<td>Delta</td>
<td>68,800</td>
<td>205,000</td>
</tr>
<tr>
<td>Langley$^1$</td>
<td>56,200</td>
<td>168,900</td>
</tr>
<tr>
<td>Maple Ridge</td>
<td>29,100</td>
<td>93,500</td>
</tr>
<tr>
<td>New Westminster</td>
<td>78,000</td>
<td>197,000</td>
</tr>
<tr>
<td>North Vancouver$^2$</td>
<td>96,200</td>
<td>276,400</td>
</tr>
<tr>
<td>Pitt Meadows</td>
<td>19,000</td>
<td>51,000</td>
</tr>
<tr>
<td>Port Coquitlam</td>
<td>30,700</td>
<td>92,600</td>
</tr>
<tr>
<td>Port Moody</td>
<td>23,000</td>
<td>63,100</td>
</tr>
<tr>
<td>Richmond</td>
<td>141,600</td>
<td>393,800</td>
</tr>
<tr>
<td>Surrey</td>
<td>173,800</td>
<td>533,600</td>
</tr>
<tr>
<td>UBC</td>
<td>4,500</td>
<td>12,500</td>
</tr>
<tr>
<td>Vancouver</td>
<td>676,100</td>
<td>1,766,700</td>
</tr>
<tr>
<td>West Vancouver</td>
<td>45,200</td>
<td>121,500</td>
</tr>
<tr>
<td>White Rock</td>
<td>6,900</td>
<td>25,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,734,500</td>
<td>4,777,000</td>
</tr>
</tbody>
</table>

$^1$Data for Langley includes the City and the Township
$^2$Data for North Vancouver includes the City and the District

(Personal Communication, Greg Arnold; and GVRD, 1999)

To put these figures in perspective, it may be useful to compare these estimates to the total annual waste generation rates in the GVRD. The 1997 solid waste generation figures, presented in Table 12-1 in Section 12.3.3.1, were used for comparison. A design earthquake would generate 1.73 million tonnes of DD, or 60 percent of the total annual waste generated in the region. A major earthquake would generate 9.94 million tonnes of DD, or approximately 3.6 times the total annual waste generated in the region.

It may also be useful to compare these debris estimates to the currently permitted landfill capacity presently available to the region. There is currently approximately 30 million tonnes of permitted disposal capacity. The debris resulting from structural damage experienced during a major earthquake would use nearly one third of this capacity.
8.1.2 Earthquake Recovery Planning Exercise - Gastown Scenario

An earthquake damage scenario was developed for the historic part of Vancouver—Gastown. This part of the city was chosen because of the type and age of construction that is typical of this area. Such construction (i.e., unreinforced masonry structures) is the most susceptible to earthquake damage. This scenario estimates the quantities of DD that could be generated, and attempts to quantify the cleanup effort that would be required. The scenario identifies the options which could potentially be utilized to remove the DD out of the Gastown area. The following is the Gastown Earthquake Damage Scenario.

### Expected Disaster Debris Quantities

- **Given**
  - construction comprises largely of masonry, with brick road surface

- **Assumptions (full collapse of all buildings)**
  - 6 city blocks
  - 10 buildings/block
  - 3 stories/building (including basement)
  - 5,000 sq.ft./building/story
  - 4 sq.ft./yd$^3$
  - 13 sq.ft./tonne

- **Debris Generated**
  - 60 buildings
  - 180 stories
  - 900,000 sq.ft.
  - 225,000 yd$^3$
  - 69,500 tonnes

### Handling Capacity

#### Truck Transportation

- **Assumptions**
  - 10 tonnes/truck/trip
  - 0.5 hrs to load up/load
  - 2 hrs round-trip travel time to disposal facility/load
  - 2 shifts/day
  - 10 hrs/shift

- **Trucks Required for Cleanup**
  - 4 trips/shift/truck
  - 8 trips/day/truck
  - 80 tonnes/day/truck
  - 868 truck days

- **Limitation: # of Trucks Available**
  - 10 trucks available each day
  - 87 days to clean up
  - 3 months (approx.)

- **Limitation: # of Days for Cleanup**
  - 30 days to clean up
  - 1 month (approx.)
  - 29 trucks required each day

#### Barge Transportation

- **Assumptions**
  - 2500 tonnes/barge container
  - 2 hrs to load up/load
  - 4 hrs round-trip travel time disposal facility/load
  - 2 shifts/day
  - 12 hrs/shift

- **Barges Required for Cleanup**
  - 2 trips/shift/barge
  - 4 trips/day/barge
  - 10,000 tonnes/day/barge
  - 7 barge days

- **Limitation: # of Barges Available**
  - 2 barges available each day
  - 3 days to clean up
  - 0.1 months (approx.)

- **Limitation: # of Days for Cleanup**
  - 7 days to clean up
  - 0.2 month (approx.)
  - 1 barges required each day
### Access Routes to Gastown

<table>
<thead>
<tr>
<th>Roads</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>East</strong></td>
<td>Carrall Street</td>
</tr>
<tr>
<td></td>
<td>Main Street</td>
</tr>
<tr>
<td></td>
<td>Powell Street</td>
</tr>
<tr>
<td><strong>South</strong></td>
<td>Hastings Street East</td>
</tr>
<tr>
<td></td>
<td>Cambie Street</td>
</tr>
<tr>
<td><strong>West</strong></td>
<td>Hastings Street West</td>
</tr>
<tr>
<td></td>
<td>Cordova Street</td>
</tr>
<tr>
<td></td>
<td>Richards Street</td>
</tr>
<tr>
<td></td>
<td>Howe Street</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bridges</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>North</strong></td>
<td>First Narrows</td>
</tr>
<tr>
<td></td>
<td>Second Narrows</td>
</tr>
<tr>
<td><strong>South</strong></td>
<td>Cambie Street</td>
</tr>
<tr>
<td></td>
<td>Granville Street</td>
</tr>
<tr>
<td></td>
<td>Burrard Street</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rail</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
</tr>
<tr>
<td><strong>North</strong></td>
<td>Coal Harbour off Burrard Inlet</td>
</tr>
<tr>
<td></td>
<td>access out of the area via First Narrows to Strait of Georgia</td>
</tr>
</tbody>
</table>

### 8.2 Disposal Options

Californian experience dictates that standard waste disposal options are not sufficient to handle the overwhelming amount of debris left after a disaster. The disposal dilemma is compounded by the fact that municipalities are reluctant to overburden or deplete their existing disposal capacity with disaster debris (EPA, 1995a).

The definition of the word “disposal” for the purpose of this section is quite broad. The definition includes landfill disposal, incineration, and recycling, as well as the more innovative alternative disposal methods of ocean disposal, reuse of material for construction of large earthworks, and disposal in earth’s cavities. Fifteen disposal options have been identified, and investigated in varying degree of detail in the following sections.

#### 8.2.1 Disposal in Municipal Solid Waste Landfill

There are two MSW landfills that service the Lower Mainland. Table 8-3 presents the currently authorized capacities and total permitted footprint areas of the two landfills.

| Table 8-3: Municipal Solid Waste Landfill Capacity |
|---|---|---|
| **Landfill** | **Authorized Capacity** | **Footprint Area** |
| Vancouver Landfill | 20 million tonnes as of 1997 | 635 ha. |
| Cache Creek Landfill | 3.5 million tonnes | 48 ha. |

(Personal Communication, Ken Carrusca)
Acceptable Materials
The MSW landfills accept mainly municipal solid waste, which includes waste from industrial, commercial and institutional sources. In addition, the Vancouver Landfill has a compost facility, which accepts wood and yard waste (Personal Communication, Ken Carrusca).

Unacceptable Materials
There are several materials that have been banned from disposal. Furthermore, restrictions have been placed on paper products entering the landfill. All DLC materials are also not accepted at the MSW landfills, unless there is a specified need for this material type (e.g., landfill foundation, roadbase). Finally, the Vancouver Landfill also accepts certain salvageable items, which are separated and stockpiled at the entrance to the landfill (Personal Communication, Ken Carrusca). The following are examples of materials not accepted for disposal at MSW landfills.

<table>
<thead>
<tr>
<th>Materials Rejected from Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banned</td>
</tr>
<tr>
<td>gypsum drywall</td>
</tr>
<tr>
<td>batteries</td>
</tr>
<tr>
<td>oil filters</td>
</tr>
<tr>
<td>liquids</td>
</tr>
<tr>
<td>Restricted</td>
</tr>
<tr>
<td>recyclables</td>
</tr>
<tr>
<td>cardboard</td>
</tr>
<tr>
<td>office paper</td>
</tr>
<tr>
<td>DLC materials</td>
</tr>
<tr>
<td>Separated Out</td>
</tr>
<tr>
<td>used bed mattresses</td>
</tr>
<tr>
<td>white goods</td>
</tr>
<tr>
<td>HHW</td>
</tr>
</tbody>
</table>

8.2.2 Disposal in Demolition, Landclearing and Construction Landfill
Landfilling is the major disposal method for construction and demolition waste. Its popularity is assured because of its low cost. However, as landfills are filling rapidly and the need for post-closure monitoring and mitigating is becoming a more urgent reality, and space for new landfills is becoming more scarce, cost of landfilling is rising (SPARK, 1991).

Disposal Cost Comparison
The tipping fees at private (DLC) landfills, which are permitted to accept only inert materials, are based on a straight volume charge. Hauling costs to transport wastes also vary according to the distance of landfill from an urban centre, and the composition of the load (SPARK, 1991). The tipping fee for DLC waste at a DLC landfill can range from $325 - $480 per 30 m³ load (Ecowaste, 1996).

In comparison, the MSW landfills in the GVRD charge $69 per tonne for wastes, resulting in tipping fees ranging from $165 - $930 per 30m³ load. This excludes transportation fees to the MSW landfills (SPARK, 1991).
The following is a sample calculation based on the range of tipping fees charged at DLC and MSW landfills. This example illustrates the costs associated with disposal of DLC waste from a single house demolition. Furthermore, it presents the savings associated with diversion of DLC waste from an MSW landfill. Finally, by considering the costs of reusing and recycling of building components, it provides a platform for additional savings by diverting this waste from landfills all together.

**Demolition Quantities**

- **Given**
  - a single house generates five 40 yd³ dumpsters (total of 150 m³)

(CMHC, 1991)

### Cost Savings with Diversion

<table>
<thead>
<tr>
<th>Disposal Option</th>
<th>Quantity of Debris</th>
<th>Cost per 30 m³</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSW Landfill</td>
<td>150 m³</td>
<td>$165 - $930</td>
<td>$825 - $4,650</td>
</tr>
<tr>
<td>DLC Landfill</td>
<td>150 m³</td>
<td>$75 - $125</td>
<td>$375 - $625</td>
</tr>
<tr>
<td>Cost Savings</td>
<td>maximum range¹</td>
<td></td>
<td>$200 - $4,275</td>
</tr>
</tbody>
</table>

¹Maximum range refers to the comparison between the lowest price at MSW landfill and the highest price at DLC landfill, and vice versa.

The disposal costs of waste generated during construction of a new house in Canada is also striking. New construction generates, on average, 2.5 tonnes of waste (CMHC, 1991). Construction waste can be reduced, reused, and diverted much easier than demolition waste. Therefore, the potential for savings is even greater during reconstruction after an earthquake.

- **Site Tour of DLC Landfill**

The Ecowaste Landfill in the Lower Mainland was visited and documented in the Fall of 1998. The following is a summary of the information obtained during the site visit.

### DLC Landfill

- Ecowaste Industries Ltd.
  15111 Williams Road, Richmond, British Columbia

- **Site Operations**
  - tipping fee is material dependent; on the order of $10/yd³
  - the largest remaining DLC landfill (at Richmond Landfill)
  - operates a composting facility for green and wood waste
  - gypsum, concrete and metals are separated out, and delivered to appropriate recycling facilities

- **Waste Material Composition**
  - materials permitted for landfill
    - demolition waste (from buildings, parking lots, bridges, roads, sidewalks, and other man-made structures; does not include building contents)
    - construction waste (from buildings, parking lots, bridges, roads, sidewalks, pipes, and other man-made structures)
    - excavation waste (from excavations for building foundations, bridge footings, pipes, and other man-made structures)
DLC Landfill

- materials not permitted for landfill
  - special waste
  - automobiles, white goods, household appliances, metallic car parts, large metallic objects, tires (other than small utility tires which cannot be recycled)
  - food waste and other putrescible refuse, dead animals
  - gypsum board (in excess of 1% of any load, 5% in the case of fire damaged material)
  - heavily contaminated soil
  - asbestos and materials containing asbestos

- materials acceptable for compost facility
  - leaves, grass clippings, brush, branches up to 100 mm (4in.) diameter, plants, flowers, land clearing or tree pruning waste which has been hogged, chipped or ground

- materials unacceptable for compost facility
  - stumps, limbs over 100 mm (4in.) diameter, mill waste, cedar over 25% of load, plastic, metal, glass, paper bags, sod or turf, concrete, brick, rock, dirt, anything not listed as acceptable

Markets/End Uses

- gypsum products are transferred to New West Gypsum for recycling
- concrete is recycled by Columbia Bitulithic and RichVan Materials
- metals are recycled
  - steel
    - sent to Tacoma, US
    - a commodity
    - generally recycles well (as do most metals)
- aluminum
  - sent to Washington, US
  - recycled by Kinemat
  - processed into aluminum siding, and curtain wall/cladding in office buildings

Additional Information

- http://www.ecowaste.com

(Ecowaste, 1998; and Personal Communication, Stuart Somerville)

8.2.3 Recycling

Utilization of wastes generated either by a natural disaster, or from human controlled activities provides opportunities for saving energy, time and resources. From a purely economic point of view, recycling of building waste is only attractive when the recycled product is competitive with natural resources in terms of cost and quality. Furthermore, recycled materials will normally be competitive where there is a shortage of both raw materials, and suitable deposit sites. With large recycling projects, such as renovation of motorways, and clearing of disaster related damages, the economic model will be dominated by transportation costs. These transportation costs involve the removal of demolition products, and supply of new building materials. In these cases, the use of recycled materials is very attractive (De Pauw and Lauritzen, 1994).

There are other factors which contribute to the success, or failure of a recycling effort. For example, in 1980, the Belgian government sponsored a pilot project for the recycling of building waste after the Algerian earthquake. From a technical point of view, the pilot project was successful. However, the strategy was not extended to the remainder of earthquake recovery and reconstruction effort due to reasons that included political and sociological ones (De Pauw and Lauritzen, 1994).
In its effort to promote and support diversion of waste from landfills, the GVRD compiled numerous informational tips on recycling aimed at the DLC industry. The information is presented in two brochures. The following are summaries of the contents of these brochures.

**GVRD Informational Brochures**

- Both informational brochures provide:
  - an overview of 3Rs Code of Practice for the building industry
  - the benefits of implementing the 3Rs
  - recommended actions for implementation of the 3Rs

- Demolition and Salvage - A Guide for Developers and Renovators
  - discusses the concept of deconstruction as opposed to demolition
  - provides a recycling directory, listing demolition and salvage contractors, used building material yards, hazardous material abatement companies, structural movers, and local recycling depots

- Job Site Recycling - A Guide for Builders and Developers
  - lists steps to be undertaken in implementing a recycling program at a job site
  - provides a recycling directory, listing hauling services, local recycling depots, and BC Materials Exchange

(GVRD, 1998a and b)

Two DLC waste recycling facilities in the Lower Mainland were visited and documented in the Fall of 1998. The following are summaries of the information obtained during the site visits.

**Wood Waste Recycling Facility**

- Pacific Coast Fibre Ltd.
  920 Derwent Way, Annacis Island, Delta, British Columbia

- Site Operations
  - tipping fee of $38 per tonne
  - facility operates a digital truck scale
  - central location to a number of municipalities, with access by road, river and rail
  - two types of operation
    - negative pick for 95% clean wood, contaminants are picked out by hand
    - positive pick for 50% clean wood, wood is picked out by hand

- Processing
  - processing begins with sorting out all large objects (e.g., concrete pieces) as they are delivered
  - two piles are created depending on the percentage of contamination in each load of wood waste
  - an excavator operates outside the large main building, loading up roughly sorted materials for screening by manual pickers
  - manual pickers separate other recyclables (e.g., metals, cardboard) and refuse (e.g., plastics) from the wood
  - processed end product is compacted and packaged for shipment

- Waste Material Composition
  - mainly wood waste from construction sites

- Processing Quantities
  - 2,000 tonnes/month (approximately 20 - 30 trucks/day)
  - load size ranges from pickup trucks to 80 yd³ demo trailers

- Markets/End Uses
  - wood chips sold to Canadian Forest Products Ltd. for fibreboard production

(Personal Communication, Desmond Dong)
Mixed DLC Waste Recycling Facility

Urban Wood Waste Recyclers Ltd.
110 East 69th Avenue, Vancouver, British Columbia

Site Operations
- tipping fee of $20 per tonne

Processing
- processing begins with sorting out all large objects
- large objects, such as pieces of concrete, are separated out as they are delivered
- two excavators operate inside the large main building, roughly sorting waste by material type (e.g., cardboard, concrete, commingled materials), and picking out individual objects (e.g., toilets)
- an excavator loads up roughly sorted materials for screening by manual pickers
- metals, plastics, paper, and other valuable resources are collected in bins
- processed end product is compacted and packaged for shipment

Waste Material Composition
- waste is sorted into three groups
  - wood
  - garbage (residual)
  - recyclables (concrete, metals, dirt, cardboard, paper)

Processing Quantities
- quantities processed at a rate of 60,000 tonnes/year
- in the winter, waste delivery rate of 65 x 30 yd³ containers/day
- in the summer, waste delivery rate of 85 x 30 yd³ containers/day
- potential processing capacity up to 600 - 700 tonnes/day

Market Value
- clean mixed metals
  - recycling revenue $15 per tonne
  - disposal cost for large quantities (on the order of 10’s of tonnes) $25 - $35 per tonne at landfills that accept metals, since metals cannot be legally disposed in landfills due to leachate problems
- clean concrete and asphalt
  - recycling cost $1.50 per tonne ($15 per load)
  - disposal cost $15 - $20 per tonne
- wood
  - usually a break even commodity (i.e., recycling cost = disposal cost)
  - when processed under stringent criteria, recycling revenue $0 - $35 per tonne

Other Mixed DLC Waste Processing/Recycling Facilities
- Inner City Recycler (Mitchel Island)
- North Shore Disposal (Coquitlam Landfill)
- Wastech (Coquitlam Landfill)

(Personal Communication, Sean Mabberley)
Materials recycling capabilities are further illustrated by the numerous innovative practices in and outside British Columbia. The following are a few examples.

- **Asphalt**
  
  Much of the asphalt from highways is recycled, mainly in-situ. In addition, asphalt and concrete are recycled for road building in B.C. Studies show recycled pavement is similar to asphalt made from virgin materials. Cold mix asphalt is being produced by American Reclamation Corporation (AmRec) of Massachusetts from a blend of oil contaminated soil, asphalt roofing materials, and varying amounts of concrete; brick and tile (SPARK, 1991). An example of a highway renovation in 1985 in Wyoming, where the aggregate was a mixture of recycled and natural materials, demonstrates an economic saving of 16 percent. The example further showed that a saving of $US 35,000 - $US 100,000 per mile (1 mile = 1.6 kilometres) can be achieved by incorporating recycled materials (De Pauw and Lauritzen, 1994).

  Unlike the readily recyclable road asphalt, roofing asphalt is difficult to recycle in the Lower Mainland. The process is currently being explored, but so far without success. Separating the felt backing component is causing the greatest problem. The roofing asphalt may have value as fuel (Personal Communication, Mike Stringer). Otherwise, when an appropriate and cost-effective method is found, asphalt shingles could be used as an additive to road paving (CMHC, 1991).

  While the asphalt aggregate is currently available locally within the Lower Mainland, the remaining components of asphalt are imported from Alberta (Personal Communication, Mike Stringer).

- **Cardboard**
  
  Cardboard is a valuable resource, but only when clean. In 1991, Paperboard Industries in Burnaby paid $40 per tonne for cardboard delivered to its plant. Cardboard is readily contaminated by other wastes, and can lose its recycling value quickly. Source separation takes place at construction sites to a certain extent, with additional diversion at landfills (SPARK, 1991). The main product made of recycled corrugated cardboard is boxboard, which can have up to 50 percent recycled content. It is also found in other products, such as cores for carpet rolls, parts of new corrugated cardboard, drywall paper, fibreboard, and floor underlay (CMHC, 1991).

- **Concrete**
  
  Scrap ready-mix concrete is cast into large blocks used in gravity retaining walls. Formerly, concrete waste was landfilled, or crushed for reuse as aggregate. In the early 1990's, the process of using waste concrete to cast large blocks was recovering 50 percent of the concrete waste stream. Concrete from demolition is recycled by certain road building companies and ready-mix operators. Concrete can be crushed to form aggregate for use as road bases, and can be used to make new concrete. Processes also exist for using waste material, such as flyash, as a cement replacement in concrete. Crushed glass, waste concrete and used tires are also being experimented with for road building (SPARK, 1991).

  In the early 1980s, a technical committee was established in RILEM (the International Union of Testing and Research Laboratories for Materials and Structures) on demolition and recycling of concrete. The committee’s report states that the quality of concrete with recycled aggregates is virtually the same as, or only slightly lower than that of concrete with natural aggregates (De Pauw and Lauritzen, 1994).

- **Glass**
  
  Any window glass that is salvaged during demolition is typically removed as a whole unit with the window frame. Alternatively, glass can be crushed for usage as drainage blanket, or as aggregate (Personal Communication, Mike Stringer).
Gypsum
Gypsum is recovered from scrap wallboard and recycled. Gypsum poses an environmental problem when it anaerobically decomposes in wet landfills, creating noxious hydrogen sulphide gas. All gypsum wallboard waste used to be disposed in the ocean. New West Gypsum in New Westminster, B.C. developed a method to separate gypsum from the paper coating. This process resulted in a 90 percent recycling rate of waste gypsum wallboard. As a result, the volume of material which is disposed in the ocean dramatically decreased. Recovered gypsum is made into new board with a 20 percent recycled content (SPARK, 1991).


Metals
Metals recycling has been done for a long time. High quality heavy gauge metals are refined into ingots by local companies. Most of the steel collected locally is sent by scrap dealers to the US or overseas (SPARK, 1991). Metals which are reprocessed in the Lower Mainland are shipped to Asia, to Ontario and to the US. New steel is currently imported from Eastern Canada and the US (Personal Communication, Mike Stringer).

Plastic
Plastic recycling in the Lower Mainland is still in its infancy. Fibre glass recycling also faces similar fate. Any recycling of these materials is not done locally (Personal Communication, Mike Stringer). Where plastic processing does occur, plastics can be recycled into construction related items, such as drainage tile, sump liners, and wood substitutes. Recycled plastics are also found as components of garbage bags, composters and castors (CMHC, 1991).

Rubble
There are processes that use ground and sorted demolition rubble to produce bricks and building panels, for use in new construction (SPARK, 1991).

8.2.4 Resource Recovery
Resource recovery is the process of reclaiming recyclable components and/or energy from the post-collection solid waste stream. This process includes manual and machine sorting (SPARK, 1991).

Lower Mainland Experience
Wastech Services Ltd. in Coquitlam, B.C. is one of a number of resource recovery facilities in the Lower Mainland. Wastech operates three of the region’s transfer stations, where it recovers recyclable materials from the municipal, industrial and commercial waste destined for the landfill. Historically, when the paper content of the waste stream was higher, fuel pellets were formed from the recovered burnable wastes, and were sold to local industries. This operation no longer takes place since most of the paper products are removed from the waste stream through the regional recycling programs (SPARK, 1991; and Personal Communication, Louie Devent).
The type of waste, and the level of contamination determines the disposal cost. In addition, Wastech is paid by the GVRD for the waste it diverts from the landfill. This payment system from the GVRD is structured to favour recycling over the production of refuse diverted fuel (SPARK, 1991; and Personal Communication, Louie Devent).

Representatives from Wastech state that clean materials must be regularly generated in truck load quantities of at least 20 tonnes to be of interest to recyclers. However, the quality, rather than the quantity of waste materials, is of greatest importance to recyclers (SPARK, 1991; and Personal Communication, Louie Devent).

Californian Experience
Natural disasters can produce immense quantities of solid waste. Historically, this waste was often hastily burned or landfilled, so that communities could be rebuilt as quickly as possible. In the wake of recent natural disasters, such as the 1994 Northridge Earthquake in Los Angeles, floods in the Midwest, and hurricanes in Hawaii and Florida, waste managers and local officials have found better ways to manage disaster debris. They are turning wreckage into a resource. By adhering to preferred waste management techniques such as waste prevention and recycling, even during disaster cleanup, communities can save years of landfill capacity, recover valuable materials, and lessen the amount of hazardous materials entering the waste stream (EPA, 1995b).

When an earthquake occurred in Los Angeles in January of 1994, the City already had a successful disaster debris cleanup experience. In 1992, the City recycled 80 percent of the C&D debris from buildings that had to be torn down after the civil disturbances. Relying on this experience and a strong waste management infrastructure, Los Angeles recycled and reduced earthquake rubble from the 1994 Northridge Earthquake in the following ways.

**Reduction and Recycling of Earthquake Debris in Los Angeles**

- **Information Dissemination**
  - only two days after the earthquake, the City made certain that the over 2,700 private contractors expected to help in cleanup efforts had the information they needed to access C&D recyclers
  - in addition, the City instructed its own haulers on how to deliver sorted earthquake C&D materials to recyclers whenever possible

- **Materials Recovery**
  - the City required residents to separate and sort their earthquake debris for recycling collection
  - since not every citizen was able to sort while cleaning up, a portion of unsorted recyclables ended up in landfills
  - for this reason, one neighborhood began collecting unsorted debris, and then, relied on a specialized materials recovery facility to perform the necessary separation
  - this effort proved to be both efficient and cost-effective

- **Materials Exchange**
  - the City hired community groups to sort, clean and stack bricks that otherwise might not have been recovered
  - the organizations received a small remuneration from the City, as well as the chance to use the bricks in their own projects

(EPA, 1995b)
8.2.5 Processing and Composting Green and Wood Waste

- **Composting**
  Waste from landscaping can be composted. Very green material is ground, and can be composted to form a low grade potting soil (SPARK, 1991). The Vancouver Landfill operates a yard waste composting facility. Green and wood waste is delivered either directly to the facility at the Landfill, or is routed through the transfer stations.

- **Processing**
  Landclearing waste is shredded into hog fuel for light farm roads. The chipped material is either burnt or recovered as fibre to be made into manufactured goods (SPARK, 1991).

  A portion of the wood waste is ground to reduce volume, and a portion is used for energy generation. E.P.S. Recycling, a company in Aldergrove, B.C, grinds wooden demolition waste, reducing its volume before trucking it to a landfill (SPARK, 1991). Ground woody debris, in the form of mulch, can be used as boiler fuel, in the landfill for erosion control, closure and contour (Gray, 1998).

  Waste Conversions Incorporated (WCI) in Toronto, Ontario processes wood waste, including: plywood, particle board, sawdust, broken skids, brush and treated woods. The end product is a shredded mixture of hard and soft wood. WCI sells the mulched material to the regional government for ground cover (SPARK, 1991).

  Pacific Coast Fibre in Delta, B.C. recovers wood from the GVRD waste stream from construction, demolition, logging and industrial sources. In addition, the company accepts pallets, dunnage, dimensional lumber, mill ends, and other clean wood materials. The materials are processed and converted into a wood fibre. The wood fibre is utilized in production of fibreboard, as well as in the pulp and paper industries. The main consumer of Pacific Coast Fibre's end product is Canadian Forest Products (also in Delta) (PCF, 1997).

  A large obstacle in the reuse of wood is that dimensional lumber is difficult to recover. Furthermore, new wood is readily available within B.C. (Personal Communication, Mike Stringer).

- **Cost Savings**
  The following is a sample calculation, provided by Pacific Cost Fibre, that illustrates the cost savings associated with diversion of wood from the landfill.

### Wood Waste Quantities

- **Given**
  - 50 - 60% of residential construction is wood
  - A 70,000 sq. ft. wood frame “Polygon” site produced fifteen 40 yd³ bins of waste

- **Assumptions**
  - 5 tonnes of wood waste per bin

### Cost Savings with Diversion

<table>
<thead>
<tr>
<th>Disposal Option</th>
<th>Quantity of Waste Wood</th>
<th>Cost per Tonne</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill Disposal</td>
<td>75 tonnes</td>
<td>$55 - $65</td>
<td>$4,125 - $4,875</td>
</tr>
<tr>
<td>Recycling</td>
<td>75 tonnes</td>
<td>$38</td>
<td>$2,850</td>
</tr>
<tr>
<td>Cost Savings</td>
<td></td>
<td></td>
<td>$1,275 - $2,025</td>
</tr>
</tbody>
</table>

(Personal Communication, Desmond Dong)
• Sorting
A company in California, called Norcal, developed a special patented process, which uses floatation ponds to separate wood from concrete and asphalt rubble. A conveyor pulls settled debris from the bottom, and another skims wood from the surface. The wood is ground up for fuel. Metal scraps are re-smelted, and the remaining building rubble is crushed and sold as fill (SPARK, 1991).

• Management Example
In the aftermath of Hurricane George in Florida, trucks delivered green and woody debris for processing. The volume of material in each truck was estimated manually, by strategically placed workers on overlook towers. The quantities were entered into a computer database. Contaminants, such as metals and plastics, were separated out upon delivery to a processing facility. Processed material that is not clean enough for land application can be burned as fuel (Gray, 1998).

8.2.6 Handling and Disposal of Hazardous Waste
Existing regulations in B.C. prohibit the demolition of a building unless the building is certified free of HW. For example, asbestos regulations require building owners to have an asbestos survey done if a building contains asbestos. The purpose of such a survey is to assist in establishing an asbestos management program (Enviro-Vac Systems, 1998, and Personal Communication, Jim Klassen). Paints, solvents and sealants all classify as HW, with surface coatings accounting for 70 percent of the total HHW (CMHC, 1991).

The cleanup of HW after a building is demolished is possible, but usually at a far greater cost than if the HW is removed prior to demolition. The added costs are due primarily to having to contain and isolate the hazardous substance. In addition, contamination of an entire building with hazardous materials increases the disposal volume, and consequently, the disposal cost. All building components must be cleaned, or disposed as HW (Personal Communication, Jim Klassen).

The asbestos tipping fee at the Vancouver Landfill is $65 per tonne, plus an additional $150 per container. The tipping fee does not include costs associated with transport, packaging, decontamination, labour etc., which constitute the bulk of the cleanup cost (Personal Communication, Jim Klassen).

The most common hazardous substances that can be found in buildings include substantial quantities of asbestos, PCBs in transformers, and minor amounts of mercury (e.g., in thermostats) and CFCs (e.g., in air conditioning units). Lead paint in buildings has not yet become a disposal or removal problem (Personal Communication, Jim Klassen).

Asbestos materials were used extensively in building construction up until late 1970s, when asbestos containing (sprayed) products were banned by the Workers' Compensation Board (WCB). Therefore, virtually all buildings in the Lower Mainland that predate 1982 should be considered to contain asbestos. Asbestos can be found in spray on concrete and structural steel, ceiling tiles, floor coverings, drywall and plaster, window caulking, insulation on heating/plumbing pipes and boilers, roofing material, stucco, acoustic and decorative ceiling texture, attic and wall spaces, and many other building products (Personal Communication, Jim Klassen).

When removed from a building, asbestos and asbestos-contaminated building components must be bagged in labeled bags, and buried in an approved landfill. PCB waste is destroyed in Swan Hills, Alberta at a specially designed incinerator. Mercury is sent for treatment to New York, and CFCs are collected and recycled (Personal Communication, Jim Klassen).
### 8.2.7 Waste Transfer Facilities

- **DLC Waste Transfer Stations**
  Smaller private companies are known to operate waste transfer facilities throughout British Columbia. These facilities accept loads of construction and demolition waste without a high number of contaminants, and special or hazardous materials. At these operations, the loads are dumped and spread apart by a back-hoe or a cat. Any materials which are valuable, such as metals, are picked out by hand, and sent to appropriate locations for recycling. The remainder is repackaged and sent to a landfill (SPARK, 1991).

  Repackaging typically results in densification of waste. Since the tipping fee at such transfer facilities (which is charged on a per volume basis) is comparable to the fees charged at DLC landfills, the densification of waste generates a profit for the waste transfer facilities (SPARK, 1991).

  Often contaminants are present in a load of waste. These are picked out, and the waste hauler is charged a premium for their removal. The undesirable contaminants which commonly occur include: gypsum wallboard, plastics, metals, cardboard, tires, batteries and mattresses (SPARK, 1991).

- **MSW Transfer Stations**
  The MSW transfer stations in the Lower Mainland accept primarily MSW, and only small quantities of incidental DLC waste. There is significant amount of land at or around certain MSW transfer station sites, which could be used as a DLC waste transfer point. Two Lower Mainland MSW transfer stations were investigated for this purpose: the Coquitlam Transfer Station and the North Shore Transfer Station. (Personal Communication, Louie Devent)

- **General Findings**
  The introduction of additional vehicles delivering and removing DLC waste to and from the transfer station sites would certainly result in traffic problems. This would also present a limitation on the quantities and rates of waste being transferred at these locations.

- **Coquitlam Transfer Station**
  This site has the potential for stockpiling of 10,000 tonnes of material. The operation at this transfer station would be limited to stockpiling, as there is insufficient space for sorting equipment on site.

- **North Shore Transfer Station**
  This site has the potential for stockpiling of 5,000 tonnes of material. The operation at this site could include sorting, since there is sufficient space for sorting equipment.

- **Storage Area at Vancouver Landfill**
  There is currently a plan in place at the Vancouver Landfill not to fill a 40-hectare area of the footprint. The plan is to use that area as a storage yard. This presents a potential site for the temporary storage of disaster debris (Personal Communication, Paul Henderson).

### 8.2.8 Incineration

- **Municipal Incinerator**
  The common practice of burning of a large portion of DLC waste on site, or at local landfills is being severely restricted due to air quality concerns. Modern incineration facilities with controls on the quality of air emissions may be an effective alternative to landfilling. In addition, the energy produced by this process can be sold for profit. With the rising cost of landfills, the demand for waste incineration may rise in the near future (SPARK, 1991).
An example of such a modern facility is the incinerator in the GVRD. Based on the 1998 waste disposal figure of 1.4 million tonnes, the incinerator burns 18 percent of the region’s municipal waste (i.e., just under 250,000 tonnes). It should be noted, that the total amount of waste generated within the GVRD in 1998 was approximately 2.7 million tonnes, half of which was recycled (Personal Communication, Ken Carrusca). The steam that is produced in the incinerator is sold to local industry. Other industries burn certain wood wastes in their own power boilers (SPARK, 1991).

Air Curtain Incineration System
Burning of wood waste is an acceptable way of getting rid of woody debris. However, open burning is usually not permitted near residential locations. In order to minimize transportation costs, a mobile unit that operates with air emissions well below regulatory guidelines is a desirable solution. An example of such a unit is an air curtain incineration system provided by a company in the US, called Air Burners, Inc. (ABI, 1998).

The operating principle of the air curtain within an incineration device lies in the introduction of controlled high velocity air across the upper portion of the combustion chamber in which wood is loaded. The powerful curtain of air is actually a rotating mass of high temperature air (1,260°C or 2,300°F, or more) that has been trapped in the chamber. The system provides complete combustion of wood, while achieving a significant reduction of emissions compared to open burning (ABI, 1998).

The applications for the residual also provide a benefit. For example, ash from typical wood waste is a very useful soil additive. It can be marketed as a commodity to plant nurseries, farms, etc. (ABI, 1998).

Disposal of Animal Carcasses
Historically, the carcasses of animals that perished of disease were usually buried. Certain pathogens living in these animals have been known to survive over fifty years in the soil. The only known practical approach to the elimination of diseased carcasses is high temperature incineration. The air curtain incineration system is ideally suited for such a purpose. It produces an organic ash, which is safe for land application. Approval for usage of this system can be obtained from the US and Canadian authorities (ABI, 1998).

Ocean Disposal
Ocean disposal is currently being investigated in the Lower Mainland as an alternative for handling certain types of materials (i.e., inerts) which are typically generated during earthquakes. As of 1998, a letter was to be sent to Ottawa, requesting that a discussion be initiated to investigated using ocean dumping as an option to dispose of inert debris in a disaster (Personal Communication, JELC Disaster Debris Subcommittee).

Administration of Part IV of the Canadian Environmental Protection Act (Formerly the Ocean Dumping Control Act)
Conservation and Protection (formerly Environmental Protection Service) has administered the requirements of the Ocean Dumping Control Act (O.D.C.A.) in the Pacific and Yukon Region since December 13, 1975. Activities covered under the Act include stockpiling construction aggregates in a submarine location (Sullivan, 1987). Since 1988, the disposal of materials in the ocean is regulated by Environment Canada and the Ocean Disposal Program under the Canadian Environmental Protection Act (CEPA) (Environment Canada, 1999).
A permit system was instituted to regulate the deliberate disposal of any substance from ships, aircraft, platforms and other man-made structures at sea, and the disposal of substances considered harmful to the marine environment under special circumstances. A permit is not required when materials are placed in the sea for construction purposes, i.e., breakwaters, foreshore extension projects (Sullivan, 1987).

Under CEPA, all materials to be disposed and/or loaded for the purpose of ocean disposal require a permit (approval). The regular permitting process for ocean disposal takes up to four months. There are certain provisions in the ocean disposal legislation for emergency ocean disposal permits, which state that a permit can be issued on a very short notice with the approval of the minister of the environment (Personal Communication, Dixie Sullivan).

- Accepted Waste

In B.C., the forest industry continues to be the major source of material approved for ocean disposal. Materials disposed from this industry include wood wastes, sediments and logs. The logs that are permitted for ocean disposal are those which were originally designated for storage and sorting, but were unused due to spoilage or unavailability of market. The second major source of materials disposed in the ocean is dredged soil. This material comes from the maintenance of channels, harbours, marinas, bridges, wharves, ferry terminals and berthing areas, in order to maintain acceptable depth (Sullivan, 1987; and Personal Communication, Dixie Sullivan).

In the Pacific and Yukon Region, approved materials for which no beneficial use or practical land-based disposal can be identified may be disposed of in the ocean. The majority of this material includes:

- dredged material;
- clean, excavated native till;
- inert, bulky items such as concrete;
- organic material of natural origin; and
- vessels (Environment Canada, 1999).

Much of the excavation waste in B.C. is destined for ocean disposal. Quantities of excavated native till on the order of 200,000 tonnes/year are currently being disposed in the ocean. The total amount of waste materials disposed in the ocean in B.C. in the late 1990's was approximately 1 million tonnes/year (Personal Communication, Dixie Sullivan).

CEPA prohibits the ocean disposal of substances which may be harmful to the marine environment. The disposal of hazardous wastes in Canadian marine waters is prohibited (Environment Canada, 1999).

Gypsum and gypsum recycling residual (e.g., gypsum contaminated cardboard) has historically been permitted for ocean disposal. Current gypsum recycling practices provide a sufficient means for handling all quantities and components of gypsum wallboard destined for disposal in B.C. Therefore, gypsum and gypsum containing products are no longer permitted for ocean disposal (Personal Communication, Dixie Sullivan).
8.2.10 Dyke Construction

It is possible that the river and sea dykes, which protect the low-lying areas in the Lower Mainland, will suffer damage from an earthquake. Using inert debris materials in dyke repair and reconstruction were considered. While providing a disposal option for the large quantities of DD, this alternative also restores a beneficial use to what otherwise would be a waste material.

- Seismic Vulnerability of Dykes
  There is recognition that earthquake forces may damage dykes through instability, or even possibly liquefaction. However, these forces were deemed to exceed both the financial means of the Fraser River Flood Control Program, and the intended confidence level of the flood protection works. The current flood protection system is not built to withstand earthquake forces. The economic deficiency to provide more earthquake-resistant dykes raises the issue of expeditious repair should a future major earthquake severely damage the system (Woods, 1996).

- Role of Dykes in Lower Mainland
  Flood protection dykes are owned and operated by local authorities and dyking districts. The provincial government regulates these activities under authority of the Dyke Management Act (Woods, 1996).

  Sea dykes were designed to accommodate high tide and storm conditions originating in Georgia Strait. Depending on the location, sea dykes vary in elevation from about 3.3 to 3.6 m in Delta and Richmond. River dykes were constructed to protect against a recurrence of the record flood. River dyke profile (including freeboard) is about elevation 4.2 m at the upstream end of Lulu Island (Woods, 1996).

  The historical flood damage in the Lower Mainland demonstrates the necessity for and reliance on dyke protection. For instance, the 1948 flood was a significant event with respect to the effects on human habitation, and the lasting impact on flood control and floodplain management. This flood cut off all land transportation from the interior of B.C., inundated 22,300 hectares of land, destroyed or damaged 2,000 homes, and caused some $20 million in damages (in 1948 dollars). Such figures provide an indication of the damage and cost of floods, and thus, the value of dykes. The presence of flood protection dykes prevented an even more catastrophic situation downstream of New Westminster, where only isolated flooding occurred (Woods, 1996).

  As a result of this experience, approximately 217 km of existing dykes were reconstructed, and 17.4 km of new dykes were built. Currently, the total length of dykes in the Lower Fraser Valley amounts to approximately 257 km. The dykes were improved over the period of 1968 to 1995, at a cost of $146 million (Woods, 1996).

  Currently, Burnaby and Vancouver do not have dykes. Areas with dykes include Abbotsford, Chilliwack, Delta, Kent, Mission, New Westminster, Peat Meadows, Port Coquitlam, Richmond and Surrey (Personal Communication, Fred Wodtke).

- Dyke Construction Materials
  The greatest restriction on the type of material used in river and sea dyke construction is the specified permeability. Materials typically used include sand, dredged sands, larger broken rock rip-rap for the bottom of the outside face, and sand and gravel for the bottom of the dyke (Personal Communication, Peter Woods). Soils must be well graded and easily compactable. Rip-rap materials used for river bank protection need to be angular in shape, and must fall within the 0.5 m$^3$ to 20 cm$^2$ range (Personal Communication, Fred Wodtke). A proper dyke design also includes a filter system. In general, dyke construction is similar to berm construction (Personal Communication, Peter Woods).
• Source of Dyke Construction Materials
New rock used in dyke construction is typically mined in quarries throughout the Lower Mainland. Several rock quarries are located in the vicinity, including on Texada Island on the Sunshine Coast, in the Fraser Valley east of Mission, in Kent, and the Granite Quarry on Pitt River. In recent years, new mined rock is getting significantly more difficult to obtain. There is a shortage of gravel in the Lower Mainland, and the transportation cost of quarried rock is increasing. In addition, noise disturbance by-laws are limiting the mining of rock from quarries (Personal Communication, Fred Wodtke).

• Reuse of Concrete
The use of waste concrete in dyke construction is very controversial, and is not currently practiced (Personal Communication, Peter Woods). Use of crushed concrete is limited to the emergency plugging of breaches in dykes (Personal Communication, Fred Wodtke).

A concrete flood wall may be used instead of a dyke where space is limited (e.g., by a rail yard). In order for waste concrete to be considered for application in concrete flood walls, it must be very crushed and well aggregated. A limitation of flood wall application is that it is only 1 to 1.2 m high, and 20 cm thick, and can only withstand waves of up to 0.6 m in height (Personal Communication, Fred Wodtke).

Certain dykes are too high, and concrete wall construction is too expensive. In that case, earthwork construction is preferable (Personal Communication, Fred Wodtke).

The environmental opposition is rooted mainly in river/estuary fish habitat issues, and protection of wildlife. There is the possible, however unsubstantiated, risk of leaching of materials from used concrete. The structural opposition can be attributed to poorly shaped and wrongly sized concrete materials (Personal Communication, Peter Woods).

8.2.11 Artificial Reef Construction

• Brief History of Artificial Reef Construction
For centuries, the creation of artificial reefs on flat, featureless, sandy sea bottoms has been a form of enhancement for commercial and sport fishing practices in certain countries. Rubble from demolitions of old concrete and stone buildings has also been used for constructing artificial reefs. The design of artificial reefs has not been based on quantitative data, but rather on trial and error, and on previous experience (Waldichuk, 1998).

• Use and Effectiveness of Artificial Reefs in the United States
Offshore artificial reef building was reintroduced to the United States in 1950 with construction of McAllister Grounds off Long Beach, New York with debris from Manhattan building demolition. In the late 1950’s, the typical objects used in reef building in the US were primarily car bodies and damaged concrete pipes. A study evaluating a concrete block reef in the Virgin Islands in early 1960’s indicated that the standing crop of fish on the artificial reef was 11 times greater than on an adjacent natural reef (Randall, 1963). Building artificial reefs proved to enhance sport and commercial fishing (Stone, 1985).
Japanese Experience
Compared to the US, Japan has had much greater experience and longer history of enhancing its food production from the sea with the use of artificial reefs. Also, there has been governmental support in Japan for marine enhancement on a scale not equaled in any other country (Mottet, 1981). Although artificial fishing reef technology in Japan still remains very much in the status of an (empirical) art, rather than a technology, it is by far the most advanced in the world (Grove and Sonu, 1983). Much can be learned about artificial reef building from the Japanese experience.

Purpose of Artificial Reef Construction
The intent of the coastal enhancement projects is to improve the environment for or to attract desirable species of animals and plants. Poor fisheries or maricultural production can typically be attributed to an area's susceptibility to storm damage, or to the lack of suitable substrate and habitat. Enhancement can be achieved by placing structures, such as artificial reefs, in the environment that either provide habitat or control water movement (Mottet, 1981). It may be generally stated that alien objects of virtually any kind placed in the water cause fish to congregate (Grove and Sonu, 1983).

Artificial reefs are usually designed to optimize only one of the following three characteristics:
1. to provide substrate for attaching organisms;
2. to increase habitat complexity by providing vertically defined spaces; and
3. to change the wave and current patterns (Mottet, 1981).

Materials Used in Reef Construction
Concrete is the most preferred and utilized material in artificial reef design since it is relatively inexpensive and durable in sea water. Concrete structures are quite heavy, which is desirable when they are placed in shallow water exposed to storm waves and surge. The drawback of concrete reefs is the high transportation cost. Plastics and metals are being increasingly used, especially in chamber structure construction. However, plastics are expensive, and metals rapidly corrode in sea water unless they are specially coated (Mottet, 1981).

The fish recognize the shape and size of a structure, not the material. Therefore, the consideration of material is mainly affected by structural, economical and handling requirements. The material which is currently being used for fishing reef in Japan is primarily concrete or reinforced concrete. Steel is being considered as a means of reducing the weight for large reef modules. Corrosion rate of steel in sea water is primarily a function of dissolved oxygen, salinity, temperature and abrasion. Most severe corrosion occurs in is associated with the splash zone, where the dissolved oxygen in sea water is at its maximum (Grove and Sonu, 1983).

Scrap Materials Usage in Artificial Reef Construction
Use of materials otherwise destined for disposal has the potential for enhancing the marine environment while concurrently reducing the problem of disposal on land. Scrap material is usually readily available, and is often free. On the other hand, the specially manufactured designs, using more durable materials, have been found to be more effective, and more profitable in the long run. Specially manufactured reefs tend to enhance fish productivity, and decrease labor and other reef construction costs. While in Japan the emphasis in artificial reef development has been on the usage of manufactured components, the US practice has been to build nearly all fishing reefs using scrap materials (Mottet, 1981).
Main Drawback of Scrap Reefs
The major problem with most scrap reefs is not their effectiveness as fish attractors, but their durability. The most durable scrap materials are concrete rubble, and tires. The major challenge in using this type of scrap is in developing techniques for piling it high enough to produce an effective fish attractor that is also sufficiently stable to resist being dispersed during storms (Mottet, 1981).

Building Fishing Grounds
Artificial reef design involves factors such as unit design, overall reef size and configuration, and the orientation and spacing of the units within a reef. Final design takes into consideration site-specific conditions, and reef objectives (Sheehy, 1985). The smallest volume of structures which constitute "enhanced fishing grounds" that may attract fish in commercial quantities is in the range between 400 and 800 m³ (Mottet, 1981). In the US, the minimum reef volume generally varies from 400 m³ to 2000 m³, with a minimum unit spacing interval of 10 to 50 m. Results of a number of studies suggest that large individual reef units properly spaced and oriented are more effective per unit volume than an equivalent solid or continuous structure (Sheehy, 1985).

Artificial Reef Construction in the United States
Artificial reef construction in the United States has been limited primarily to the use of scrap and surplus materials or rocks, brush and wood. This has been partly due to the fact that many reef projects have solid waste disposal as a secondary, or even a primary objective. Conversely, in East Asia, the emphasis in artificial reef construction is on the use of designed and prefabricated reefs. The motives behind artificial reef construction in Japan include:
- commercial and recreational fisheries development;
- extensive aquaculture; and
- rehabilitation or enhancement of areas impacted by land reclamation, pollution and overfishing.

The US is also beginning to consider other applications for artificial reefs than solely for direct recreational fishing benefits (Sheehy, 1985).

The current approach to reef design is to create, in a cost-effective manner, those aspects of reefs which are important to the desired target species. This differs from the earlier approach, using scrap materials or rocks, in which attempts were made to recreate the complexities and surface area of natural reefs. Natural reefs may be effective in attracting and supporting fish populations, but they do not necessarily optimize attractive features or carrying capacities for the target species (Sheehy, 1985).

8.2.12 Land Reclamation and Reshaping
The practice of land reclamation is quite common within the Lower Mainland. There are numerous areas in the region which have been reclaimed by being filled in materials from landclearing activities elsewhere. The enormous volumes of inert waste materials that can be generated from an earthquake present a great potential for expansion of this technique. This technique is also very common in Japan, where approximately 40 percent of construction waste in the Tokyo area is disposed by reclaiming land (De Pauw and Lauritzen, 1994).

A very unconventional alternative method of debris disposal is proposed in Japan. This method includes raising the level of low-lying areas by transporting in construction rubble from the entire area affected by an earthquake. A slightly different approach to this method is to accumulate the rubble evenly over the disaster-stricken land. In the second approach, only the land upon which reconstruction will take place is boosted, leaving the roads at their original level. A concrete box would be constructed on the original road, providing a conduit for all lifelines, and a surface, level with the boosted ground, for new transportation routes (De Pauw and Lauritzen, 1994).
8.2.13 Disposal in Earth’s Cavities
Disposal of disaster debris in open cavities and excavation pits from mining activities is an option to be considered. There are several such locations within a reasonable distance from the Lower Mainland. The following sites are examples of old mines and excavations pits.

**Sites of Historic Mining Activity**

- **Island Copper**
  - located on northern tip of Vancouver Island
  - cavity from an old mine
  - approximate size 2 km x 1 km x 400 m deep
  - flooded with salt water upon closure
  - current usage includes diving area

- **Texada Island**
  - located near Powell River on the Mainland of British Columbia
  - old limestone mine

- **Sparwood Rail Hall**
  - located in southeastern British Columbia
  - accessible by rail
  - old coal mine

- **Highland Valley Copper**
  - located near Kamloops in the interior of British Columbia
  - previous mining activities include extraction of copper, zinc, lead

- **Pipeline Road Gravel Pits**
  - located on the east side of Westwood Plateau near Coquitlam
  - approximate size 1 mile long

(Personal Communication, James Atwater, and Mike Stringer)

Other sites which have been suggested for potential stockpiling of DD include:

- areas by the Fraser River (e.g., in Surrey, New Westminster, Vancouver);
- heavy industrial lands along the Fraser River;
- gravel pits (e.g., near Pitt River, Pitt Lake, Coquitlam River, Aldergrove, Stokes Pitt in Surrey); and
- areas in False Creek (Personal Communication, Paul Henderson).

It is unspecified under whose authority the disposal of debris in earth’s cavities would fall. Sand and gravel pits and quarries are regulated as mines under the Mines Act. The Mines Act regulates worker and public safety, and environmental impacts. The Act is administered by the Ministry of Energy and Mines. Land use concerns are not addressed in the Mines Act permitting process, and must be clarified by the local government rather than by the Ministry of Energy and Mines (MEM, 1999).

8.2.14 Disaster Debris Disposal Site
An alternative to all other disposal methods is disposal at a site specifically designated for disaster debris. Instead of trying to hide the debris, or spread it all over the city, a suitable site can be chosen where all the debris can be removed to. In effect, a mountain or a hill can be constructed, and covered with grass and planted trees. The structural integrity of this man-made landscape would be quite high, since disaster debris material is very heavy, and can be well compacted. This engineered terrain would probably perform better than certain naturally occurring soils, such as the soft sandy soils in Richmond (Personal Communication, Stuart Somerville).
8.2.15 Waste Exchange and Export
The British Columbia Waste Exchange is a government supported directory which identifies companies that produce reusable or recyclable waste. There is large potential for expansion of the information network, and for the identification of uses for the various waste materials. Waste exchange reduces waste producers’ disposal costs, and gives the waste material consumer a new source of raw materials (SPARK, 1991).

A portion of the waste generated in B.C., particularly HW, is exported nationally and internationally (Personal Communication, Jim Klassen). A considerable amount of high value processed waste, such as metals, is exported to foreign markets (SPARK, 1991).

The use of debris as ballast on ships leaving the Lower Mainland waters was investigated as a disposal option. In general, there is more export of goods from the Lower Mainland rather than import, limiting the amount of “empty space” leaving the Vancouver Port. Ships that deliver cargo to the Lower Mainland use ballast water, although they do not take new water in from the Vancouver harbour. Port Authorities are mainly concerned about the possible release of substances into the harbour from import ships (Personal Communication, Darrel Desjardin).

8.3 Vulnerability of Current Solid Waste Management System
8.3.1 Stability of Landfills
In April 1999, a paper on the stability of landfills, was presented at the 8th Canadian Conference on Earthquake Engineering. The paper is entitled “Seismic Design of Solid Waste Containment Facilities” (Kavazanjian, 1999). The following is a summary of the most relevant findings.

- Seismic Performance of Landfills
  Solid waste landfills can sustain very strong shaking with limited damage, and without a harmful discharge of contaminants. In general, unlined landfills have performed extremely well when subject to strong shaking in earthquakes. Numerous landfills have been subjected to ground motions in excess of 0.1g in earthquakes of magnitude as great as 7.4 without serious damage. Based on observations of dry solid waste landfills in California, there are no documented incidents of an earthquake-induced release of contaminants harmful to humans or to the environment from an engineered waste containment facility.

- Landfills with Geosynthetic Liner
  None of the solid waste landfills with a geosynthetic cover system have ever been subjected to strong ground shaking. Under static conditions, two landfills with geosynthetic liners have suffered dramatic failures. There are also numerous cases of failures of geosynthetic cover systems.

- Seismic Design of Landfills
  Seismic design of waste containment facilities is still in its early developmental stage due to significant uncertainties with respect to the physical and mechanical properties of waste, and the lack of documented case histories. It has previously been suggested that solid waste landfills can unconditionally attenuate earthquake motions. However, strong motion instrument data provides conclusive evidence of the potential for amplification of seismic motion by solid waste landfills.

- Failures of Landfills
  Independent of seismic loading, excess pore pressures generated by liquid recirculation triggered a massive flow slide at the Dona Juana Landfill in Colombia. This type of failure is of particular importance with respect to the seismic stability of landfills in wet climates, landfills that receive liquids, and landfills that recirculate liquids.
Another failure unrelated to seismic loading is that of the Rumpke Landfill in Cincinnati Ohio. There, slope failure occurred, whereby a significant quantity of solid waste slid into an excavation at the toe of the waste slope.

Such failures present great implications when considering the nature of seismic loads.

8.3.2 Stability of Vancouver Landfill

A stability analysis study was conducted for the Vancouver Landfill by Golder Associates in 1995. The study concluded that the Landfill is very stable, and the risk of failure very low. Features of potential failure include:

- side slope failure;
- toe failure;
- buckling of peat around the Landfill; and
- rupture of gas line on west side of Landfill (Personal Communication, Paul Henderson).

A solution to a geotechnical failure at the Landfill is to dig a ditch around the failed section. The risk of a gas line failure is not expected to increase in the future, since the fill in the area of the gas line is shallow, and no additional fill is planned for that location. Furthermore, the Landfill is founded on peat moss. As the Landfill is filled, and the peat loaded, the peat consolidates, and the Landfill becomes more stable (Personal Communication, Paul Henderson).

8.3.3 Waste Transfer Stations

Two of the waste transfer stations in the Lower Mainland were investigated to determine their vulnerability to earthquake motions. The following are the results of the investigation. (Personal Communication, Louie Devent)

- Coquitlam Transfer Station

The Coquitlam Transfer Station was designed to the 1988 Building Code. The prevalent construction type at the transfer station consists of concrete panel tilt-up walls. Inside the main building is an open floor, where front end loaders operate to move incoming wastes out into the bailer. A large hydraulic bailer is located outside of the main building.

The majority of the waste from this transfer station is destined for the Cache Creek Landfill. A small amount is delivered to the Burnaby Incinerator and the Vancouver Landfill. The operation of the transfer station is mainly dependent on accessibility via the Port Mann and/or Pattullo Bridges.

The regular throughput of waste at this transfer station is approximately 1,200 tonnes/day.

- North Shore Transfer Station

The North Shore Transfer Station is located on the north side of the Second Narrows Bridge, and is dependent on for access. The waste from this transfer station is destined for the Burnaby Incinerator and the Cache Creek Landfill.

The North Shore Transfer Station is similar in construction and operation to the Coquitlam Transfer Station.
- **Capacity Expansion**
  Both transfer stations have the capability of expanding their daily throughput to 2,000 tonnes/day, but only on a short-term basis. The facilities are open 7 days a week, but they receive the majority of the waste on weekdays. The potential for capacity expansion exists if waste is also delivered to the transfer stations on weekends. The capability for expansion on a daily basis is limited by bailer operation speed, and availability of truck to transport compacted waste from the transfer stations. An increase in the number of vehicles accessing the site would most likely cause traffic problems on and off site.

- **Points of Weakness**
  Structural vulnerability of the main building at each transfer station is of greatest concern, specifically concrete panel failure. The hydraulic bailers are not expected to suffer damage, since being mounted on load tilts, they have the ability to absorb shocks. Power outage would not cause significant problems, since the transfer stations can operate without using the bailers, although at a much lower rate. Neither transfer station is capable of handling large, heavy debris such as concrete. The trucks currently in use present another limitation for handling such debris.

### 8.3.4 Transportation Routes
There are several ways in which transportation of waste may affected after an earthquake.

- **Roads**
  Where highways and roads are constructed on rock or firm non-liquefiable ground, they are expected to sustain very little damage. It is possible that roads will be damaged either by ruptures in the earth’s surface, due to differential settlement of soft soils, or by landslides, especially in hilly or mountainous areas, preventing passage to all vehicles (APEBC, 1988). Rerouting of traffic around such road failures could impede solid waste and debris collection and removal.

- **Bridges**
  The current solid waste management system is dependent on the functionality of bridges within the Lower Mainland. A number of the key (large) bridges have either been built or retrofitted to the seismic provisions in the Building Code. The status of seismic retrofitting of bridges is presented in Appendix 12.10-B in Section 12.10. Furthermore, the approach structures and abutments of bridges are commonly constructed on alluvial material. Settlements of these structures could occur during a major earthquake, precluding access to the bridges during the critical period just after the earthquake (APEBC, 1988). In addition, although it is unspecified, it is highly unlikely, that the majority of the numerous overpasses and interchanges throughout the Lower Mainland are seismically resistant.

- **Barge Alternative**
  Barges can be used as an alternate means of transportation to move large quantities of materials between points of debris generation and points of disposal. The usage of barges will be determined by the following factors:
  - availability of barges;
  - accessibility to barges from land at points of generation and disposal;
  - cost/tonne of material being transported;
  - capacity of barges relative to amount of debris at a given location; and
  - speed of loading the barges.

Private companies own and operate barges in the Lower Mainland. The Port of Vancouver serves only as a “landlord” to ship and barge operations. The Port does not actually operate port facilities (Personal Communication, Darrel Desjardin).
A barge company was consulted to determine the main operating costs and requirements of using barges. The following results were obtained.

**Barge Operating Details**

- **Cost**
  - depends on loading and unloading locations
  - depends on quantity of material
  - for example, approximately $2,500 from Vancouver to New Westminster
  - for example, rates can vary from $400 - 800/day, or $250 - 275/hr

- **Capacity**
  - typical river barge capacity in the range from 1,500 to 5,000 tonnes

- **Loading Speed**
  - typical load requires 8 hours to load, and 8 hours to discharge

(Personal Communication, Mr. Jacobson)

8.4 Conclusion to Results of Lessons Applied

The preceding sections presented the results of the application of several of the lessons learned from previous earthquake recovery experiences. The topics that were discussed include:

- the estimation of potential disaster debris quantities that may be generated in the Lower Mainland during a devastating earthquake;
- the disposal options available in the Lower Mainland; and
- the vulnerability of the current solid waste management system to earthquake effects.

This concludes Part IV of the Thesis—the presentation of the Results of Lessons Learned and Applied. The information gathered during the research trip that investigated the undocumented implications of earthquake recovery with respect to solid waste management was presented. The application of the lessons learned to the current work was also presented.

Next is Part V of the Thesis—the Post-Earthquake Solid Waste Management Plan. The Plan incorporates the ideas and recommendations presented by the available information on past earthquake recovery experiences. There are four components to the Plan, which are discussed and presented in the following sections.
PART V: POST-EARTHQUAKE SOLID WASTE MANAGEMENT PLAN
9. PLAN - INTRODUCTION

Although the Post-Earthquake Solid Waste Management Plan (Plan) is a part of the larger Thesis Document (Thesis), it is designed to be a stand-alone document. A schematic of the components of the Thesis and the Plan are presented on Figure 9-1. The Plan has been prepared for the City of Vancouver and for the Greater Vancouver Regional District (GVRD).

The Plan consists of four components:
1. Action Plan Procedure;
2. Preplanning Actions;
3. Strategy Options; and
4. Operational Plan.

The fourth component of the Plan (i.e., the Operational Plan) will need to be prepared after an earthquake occurs, and once the severity of damage, and the extent of required response are known.

It is imperative that the Plan be read in its entirety prior to implementation of any of the recommended actions. The Action Plan Procedure (Action Plan) is the framework for the entire Plan. It appears in a checklist format, in order to ensure that all of the identified actions are performed prior to and following an earthquake. The Action Plan is formulated to increase the success of earthquake response, recovery and reconstruction. The success of the Action Plan for earthquake recovery relies heavily on the completion of the Preplanning Actions.

Due to the uncertainty associated with earthquakes, the Action Plan is the also the framework for establishing an Operational Plan immediately following the occurrence of a earthquake. Therefore, the Action Plan is entirely independent of the magnitude and time frame of an earthquake event.

The Strategy Options provide guidance for the formulation of the Operational Plan after an earthquake. The Strategy Options are presented in a report format, and are referred to as the Report. The Report is also a stand-alone document, and thus, contains all the sections typical of a report (i.e., summary, introduction, body, conclusions and recommendations, glossary, references and appendices).

The information contained within the Plan is based on, and supported by the preceding sections of the Thesis. The Plan contains additional information essential to the formulation of the Operational Plan.

In addition to the Thesis Document, a separate document has been prepared for use by the City of Vancouver and the Greater Vancouver Regional District. The components of this stand-alone document are ordered differently from the information presented in the Thesis. The formal thesis format requires that information be presented in the order of derivation of the information and the results (i.e., the product of the thesis is found at the end of the document). In the document prepared for use by the various government bodies, the information is presented in the order of importance (i.e., the overall summary of a plan appears first in the document, followed by more detailed, supporting documentation).
Figure 9-1: Schematic of Thesis Components

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10. PLAN - ACTION PLAN PROCEDURE
The main feature of the Action Plan Procedure (Action Plan) is that it is independent of the magnitude and time frame of an earthquake. The Action Plan provides a checklist of actions that need to be performed prior to and following an earthquake related to solid waste management. It also presents the main issues that will arise, and will need to be addressed during earthquake response, recovery and reconstruction.

A flowchart of the Action Plan is provided on Figure 10-1 in order to illustrate the complexity of an earthquake event in terms of solid waste generation and cleanup. Many of steps within the flowchart are iterative, in that the procedure is not entirely chronological. The iteration has been omitted in this diagram in an attempt to simplify the schematic, while presenting the general concept. The details of the Action Plan are presented following the figure.
### Action Plan

<table>
<thead>
<tr>
<th>Topic</th>
<th>Reference For Details</th>
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<tbody>
<tr>
<td><strong>Preplanning</strong></td>
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<tr>
<td>- funding (long- and short-term)</td>
<td>Actions 1 and 2</td>
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<tr>
<td>- contingency plan at disposal facilities</td>
<td>Action 3</td>
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<tr>
<td>- expansion of DLC recycling</td>
<td>Action 4</td>
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<td>- hazardous waste</td>
<td>Action 5</td>
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<td>- stockpiled waste materials</td>
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<td>- neglected DD (by choice, and due to incapability)</td>
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<td>- contracts and union requirements</td>
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<td>- mutual aid</td>
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<tr>
<td><strong>Emergency Response</strong></td>
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<td>- information dissemination</td>
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<td>- contingency plan at disposal facilities</td>
<td>Action 3 and Scenario 1</td>
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<td>- of number of buildings requiring demolition</td>
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<td>Action Plan</td>
<td>Reference For Details</td>
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<tr>
<td>• selection of collection method/program</td>
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<td>• implementation</td>
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<td>• answering questions</td>
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<td>• announcing changes in the recovery program</td>
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<td>Alternative Disposal Techniques</td>
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<tr>
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<td>Monitoring</td>
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<td>• of compliance with requirements</td>
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<tr>
<td>• keep track of and verify materials for &quot;disposal&quot; (diversion and recycling rates)</td>
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<td>• enforcing non-compliance consequences</td>
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<tr>
<td>Evaluation of Cleanup Effort</td>
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<td>• periodic review of current plan, and revision where necessary</td>
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<tr>
<td>• final evaluation of earthquake response, recovery and reconstruction</td>
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<td>• reflection on lessons learned</td>
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11. PLAN - PREPLANNING ACTIONS

The completion of thirteen preparatory actions (Preplanning Actions) has been identified as crucial to the success of recovery from an earthquake related to solid waste management. The rationale for each action has been provided, in terms of presenting the current state of preparedness in the Lower Mainland. In addition, the experience gained in California during the most recent earthquakes is utilized to emphasize the need and importance of each Preplanning Action. The advantages of having completed each Preplanning Action are clearly stated. The success of the entire strategy proposed in the Post-Earthquake Solid Waste Management Plan is contingent on having addressed the preplanning issues before an earthquake occurs.

Immediately following the Preplanning Actions is a summary of the reference sections in the Thesis that support the presented arguments.
Preplanning: Action 1

- Review, and establish where necessary, options for provision of funds for post-earthquake solid waste management.

**Current Situation**

- hierarchy of payment and recovery of disaster related costs:
  - private owner pays for work done to private property
  - private owner can apply to provincial government under Disaster Financial Assistance (DFA)
  - Municipality pays for work done to municipal infrastructure
  - Municipality can apply to provincial government under DFA
  - Province pays out money to private owner and Municipality
  - Province can apply to federal government under Disaster Financial Assistance Arrangements (DFAA)
  - federal government pays out money to the Province
- provincial DFA is not applicable to earthquake related costs, since private insurance is reasonably and readily available
  - although DFA applies to cleanup and debris removal from disasters, earthquake related debris would not be covered
- any city- or region-wide cleanup program for private residents will have to be funded by the local government (i.e., City or Municipality)
  - potential cost recovery from provincial government, only if such recovery is deemed absolutely necessary, but this is not covered by current DFA regulations
- there are no provisions for financial assistance for cleanup and disposal of earthquake related debris

**Californian Experience**

- availability of funds determines degree and method of debris cleanup and disposal
  - in the Northridge earthquake, the local government provided a region-wide, free-of-charge cleanup program, including demolition, collection and disposal
  - the existing recycling and diversion program was expanded to include most of DD
- prior knowledge of the existence of provisions for funding, such as the Federal Emergency Management Agency (FEMA) program:
  - allows for establishment of short- and long-term response and recovery programs (e.g., preplanning is necessary to implement a curbside collection program in a timely manner, and funding is necessary to implement the program at all)
  - saves time after an earthquake in terms of having to establish such provisions
  - saves costs after an earthquake in terms of avoiding expenditures which will not be reimbursed, and response actions which tend to be more expensive than if preplanned

**Preplanning Advantage**

- will assist in establishing recovery programs, and determine the extent of City/Municipality involvement
Preplanning: Action 2

☐ Determine how DD removal and handling will be paid for initially before provincial and/or federal assistance becomes available (e.g., loans, vouchers, credit, user fees, reallocation of existing budget).

☐ Current Situation
  - there are no provisions for how payments will be made for required demolitions, debris removal
    - contractors will not work without payment for very long
    - equipment will not be made available without making at least a partial deposit

☐ Californian Experience
  - financial assistance to the local government was made available only on reimbursement basis, and the local government had to pay for everything up front
    - the local government had to reallocate their existing budget to pay for their program
    - there was a month long interruption in the debris collection program due to cash flow problems in the third month of recovery
    - two payment options were utilized: contractor reimbursement with returned weight tickets, and authorization letter; the City was able to utilize these options since it had funding from FEMA available for the debris removal program

☐ Preplanning Advantage
  - will help prevent unnecessary delays in cleanup effort when contractors refuse to perform additional work due cash flow problems
  - will provide greater flexibility to use equipment and manpower
Preplanning: Action 3

☐ Establish a contingency plan at disposal facilities, e.g., landfills, for accepting of disaster debris immediately following an earthquake (i.e., during emergency phase), and develop procedures for implementation at the occurrence of an earthquake.

☐ Current Situation
- there is no plan for the removal or disposal of disaster debris, in general
- no contingency plan exists at disposal facilities for accepting disaster debris
- of the DLC waste generated, concrete and asphalt are the easiest to recycle
  - concrete construction is expected to exhibit more damage than woodframe construction
  - relatively widespread usage of unreinforced masonry in the Lower Mainland is expected to generate large quantities of brick debris
- therefore, a large portion of debris can be expected to consist of concrete and brick
- waste received at disposal facilities is quantified, and the bulk weights and/or volumes are documented; the type and quality of materials are generally not documented

☐ Californian Experience
- unless there is a plan before an earthquake occurs, for what to do with debris, disaster debris will be taken to and disposed at a solid waste facility (i.e., landfill)
  - in the Northridge Earthquake, it took approximately a month before DD began being diverted from the landfill to recycling facilities
  - during this “waiting period”, all DD was taken and disposed on the working face at the landfill, irreversibly lost as a potential commodity
- the most easily recyclable debris arrives at landfills in the initial loads after an earthquake
  - initially, DD composition includes mainly DLC-type material (e.g., concrete and brick)
- quantification and detailed documentation of weights, volumes and types of waste received at disposal facilities was crucial to the success of the earthquake recovery and waste diversion programs
  - FEMA reimbursement provisions require that least cost disposal is used, which can only be proven with detailed documentation
  - the evaluation of the success or failure of a diversion program (e.g., recycling rate) is only possible when all waste is accounted for
  - detailed documentation of an experience increases the chance of success in response to, and recovery from future disasters

☐ Preplanning Advantage
- will help avoid undesirable and uncontrolled disposal, especially of easily recyclable debris which tends to arrive in the first loads at the landfill, and which is the least commingled and contaminated
- detailed documentation of wastes received disposal facilities will help evaluate and ensure responsible waste management (i.e., diversion from MSW landfill)
- detailed documentation will be invaluable to future earthquake response and recovery
Preplanning: Action 4

Promote the expansion of DLC recycling capacity, and markets for processed waste materials as a long-term plan.

Current Situation
- Limited DLC recycling capacity is found in the Lower Mainland
  - Construction waste is recycled to a greater extent than demolition waste due to the quality of the waste material (i.e., construction waste is cleaner, easier to source separate)
  - Approximately half of the DLC waste generated is currently recycled
- A number of DLC recycling techniques and approaches are used in the Lower Mainland, but the uses for the final product of recycling are still very limited
  - Recycling product is viewed as inferior to raw materials

Californian Experience
- Disaster debris and construction and demolition waste processing are very similar
  - The Northridge Earthquake proved the need for and usefulness of DLC waste processing and recycling in the Los Angeles area, in that it grew from being very limited before the earthquake, to being very extensive following the earthquake, to remaining very significant to the present day
- The limited DLC processing system at the time of an earthquake, impedes the diversion effort
  - In the Northridge Earthquake, it took approximately a month before DD began being diverted from the landfill to recycling facilities

Preplanning Advantage
- Will help maximize the waste diversion effort by immediately providing alternate processing options
- Will provide a long-term solution for all DLC waste, pre- and post-earthquake
Preplanning: Action 5

- Investigate and identify potential sources of HW and HHW (e.g., houses and structures containing asbestos).

- **Current Situation**
  - demolition of a building is prohibited unless the building is certified free of HW
    - there are no regulations that specify the removal of a building that has collapsed due to natural causes (e.g., earthquake), but is suspected of containing HW

- **Californian Experience**
  - unidentified or undiscovered HW, or DD contaminated with HW ends up being disposed or recycled along with “clean” DD
    - this increases the health and safety risks to the persons unknowingly handling the contaminated DD, as well as to the general public
  - large quantities of demolition waste end up being disposed due to small amounts of HW detected only after demolition takes place, since it was unknown prior to demolition that the building contained HW
    - prior knowledge of sources of HW prevent entire buildings from being demolished with HW inside them, which could be removed prior to demolition

- **Preplanning Advantage**
  - knowing the location and type of HW and large quantities of HHW will help determine which buildings should be dealt with more care, and how such care should be exercised, saving costs of disposing large quantities of possibly contaminated debris
## Preplanning: Action 6

- Establish mechanisms to ensure that temporarily stockpiled waste materials are removed and processed/recycled as promptly as possible.

<table>
<thead>
<tr>
<th>Current Situation</th>
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<tbody>
<tr>
<td>there are no provisions for enforcing the removal and processing of stockpiled materials</td>
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</table>

<table>
<thead>
<tr>
<th>Californian Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>the use of temporary storage sites is not recommended, unless absolutely necessary</td>
</tr>
<tr>
<td>daily/weekly stockpiling on site of processing/recycling facilities is advised, provided that the requirement to remove the waste material within a specified time is included in the operating license of the facility</td>
</tr>
<tr>
<td>use of temporary storage sites presents illegal dumping potential</td>
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<table>
<thead>
<tr>
<th>Preplanning Advantage</th>
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<tbody>
<tr>
<td>will help prevent temporary sites from becoming permanent</td>
</tr>
<tr>
<td>will help maximize the waste diversion effort by decreasing the opportunity for contamination and commingling of separated materials</td>
</tr>
</tbody>
</table>
Preplanning: Action 7

- Investigate the feasibility of utilizing alternate disposal options (e.g., artificial reef construction, ocean disposal, landfilling in man-made cavities).

- Current Situation
  - Opportunities exist, with certain alternatives being utilized on a small scale for regular DLC waste, but none have been investigated as post-earthquake solid waste management solutions
    - The features of the Lower Mainland consist of the ocean, mines, excavations, incinerator, on-going construction, open spaces, etc., all of which can accept various amounts of DD type material
    - Ocean disposal is currently being used as a disposal method for dredged soils, for example, and land reclamation is taking place
    - No unconventional solid waste management option has yet been investigated for management of disaster debris

- Californian Experience
  - Time is crucial after an earthquake, and although good ideas and opportunities may present themselves, there just isn't time to investigate them, and the available, conventional options are the ones that get used
    - In the Northridge Earthquake, the City had the opportunity to provide other communities/jurisdictions with their disaster debris as a commodity, but this opportunity was not realized due to shortage of time and manpower to investigate it

- Preplanning Advantage
  - Will assist in ensuring that the most responsible course of action is taken
  - Will assist in ensuring that the economics, and the environmental and social impacts of the chosen disposal method are given due and equal consideration, which is only possible when time is not of the essence (i.e., prior to an earthquake)
  - Will provide guidance for developing a contingency plan in case the current disposal facilities (e.g., landfill) are not available (either due to structural integrity failure, or inaccessibility due to transportation system failure)
Preplanning: Action 8

Identify, or establish mechanisms that address DD that is not being cleaned up within a certain time limit following an earthquake event, either because the debris has no owner (e.g., abandoned property), or the owner chooses not to remove the debris.

Current Situation
- Municipalities have Nuisance By-Laws which can order property owners/occupants to clean up anything that presents a nuisance or danger (e.g., fire-damaged buildings, buildings left vacant for several years, constructions and additions to existing structures left uncompleted for several years).
  - Actions undertaken by the City Council ordering building demolitions or debris removal have taken years to decades to resolve in pre-earthquake circumstances, where such incidents are relatively limited in numbers.
  - Such lengthy durations for ordered cleanup of properties should be unacceptable in pre-earthquake circumstances, and can become utterly unmanageable in post-earthquake circumstances due to the probability of increased instances of occurrence.
- Municipalities have no provisions in their by-laws for dealing with nuisance or dangerous properties on a larger scale than the occasional instances that occur in pre-earthquake circumstances, such as can be expected in the aftermath of an earthquake.

Californian Experience
- Buildings that are unsafe for occupation, and are not being demolished or cleaned up, or are abandoned present an additional safety concern.
  - In the Northridge Earthquake, such buildings were being used for illegal purposes, and resulted in an increase in crime within such areas, as well as being inhabited by homeless persons.
  - This presents a danger to the illegal occupants, as well as to society at large.
- Debris not being cleaned up by property owners, or the City, resulted in illegal dumping problems.
  - In the Northridge Earthquake, City-sponsored debris collection began within days of the earthquake, but still required cooperation from residents to set out debris at the curbside according to City requirements.
  - Numerous properties (e.g., occupied by elderly or physically challenged) were not being cleaned up.
  - Back alleys, where debris was accidentally or intentionally deposited, became illegal dumping locations.

Preplanning Advantage
- Knowing the strict consequences of not cleaning up debris at the onset of recovery effort will help deter conscious lack of action by property owners and occupants.
- Will speed up the cleanup process.
- Will help prevent health risks and further environmental impacts that the debris may cause.
- Will save the City the cost associated with attempting to recover the incurred cleanup costs.
Preplanning: Action 9

☐ Identify the classes within the affected population which may require extensive assistance, or which may be entirely dependent on City assistance for DD removal and disposal, because they cannot do the work themselves and/or do not have the financial means to hire someone to do it for them (e.g., the elderly, the uninsured).

☐ Current Situation

☐ there are numerous volunteer organizations within the Lower Mainland which may be relied on for assistance in physical labour, but do not have the financial means to pay for the costs associated with debris collection and disposal

☐ in order to make this kind of assistance available, the populations requiring extensive assistance need to be identified; performing this task after an earthquake occurs will take much longer, and will postpone delivery of such assistance

☐ Californian Experience

☐ certain populations within the affected area are not capable of removing their own debris, and require extensive assistance

☐ in the Northridge Earthquake, inability of certain property owners and occupants to remove their own debris prolonged the cleanup process, resulted in added stress to the earthquake victims, had health and safety related consequences

☐ Preplanning Advantage

☐ will help expedite the cleanup effort throughout the entire affected area

☐ will decrease health and safety risks within such areas and populations which may be caused by neglected debris
Preplanning: Action 10

- Review, and augment where necessary, contracts and union requirements for haulers, equipment owners and/or operators, facility owners and/or operators to ensure inclusion of provisions for extraordinary circumstances, such as an earthquake event.

- Current Situation
  - Contractors, equipment and facility owners and/or operators do not have anything written as to what will be expected of them
  - They do not have any contractual obligation to conform with the requests of the local government to assist
  - The local and provincial governments may request the assistance of the private sector, but cannot ultimately invalidate all the rules of business operations (e.g., union requirements)

- Californian Experience
  - Much time, money and effort is wasted with technicalities (e.g., contract bidding process, written contracts, and resolution of disputes), when there are no provisions in place for extraordinary circumstances, such as recovery from an earthquake
  - In the Northridge Earthquake, within two days of the earthquake, the City disseminated recycling requirements to over 2,700 private contractors that were expected to assist in the cleanup
  - The number of debris removal contractors actually used by the City was 360, since a very large number of contractors did not meet the City's requirements (e.g., did not pass safety regulations, did not have valid operating license or insurance, did not abide by the City's specifications to perform a job)
  - It took several months to finalize the operating list of contractors used by the City
  - It took several days or weeks before a contractor was allowed to proceed on a job, since the City required that a contract be entered into, that the contractor attend a safety meeting, and that a start-work notice was issued, in order to avoid many legal disputes that were resulting from the earthquake cleanup effort

- Preplanning Advantage
  - Will help prevent unnecessary delays in the cleanup effort due to potential disputes and bureaucracy
  - Will provide greater flexibility to use equipment and manpower
  - Will provide an indication of the type and quantity of resources that will be available locally on after an earthquake
Preplanning: Action 11

☐ Determine the extent to which mutual aid is required, and can be counted on regionally, provincially, nationally and internationally.

☐ Current Situation

☐ there are no mutual aid agreements for equipment, manpower, or funds which may be required for debris removal and disposal during earthquake recovery

⇒ emergency response mutual aid agreements cease when disaster emergency is over, and do not extend to disaster recovery

⇒ there is a general mutual aid agreement (i.e., the Pacific Northwest Emergency Management Agreement) between Province of British Columbia, Yukon Territory and State of Washington

⇒ there are no mutual aid agreements between the municipalities within the Lower Mainland

☐ Californian Experience

☐ California's disaster planning is based on a statewide system of mutual aid, which is the first option that a jurisdiction will use to get additional staffing and equipment

⇒ very strict protocols exist for obtaining mutual aid resources

⇒ most cities and counties in California have adopted a Master Mutual Aid Agreement, which creates a formal structure for maintaining, giving and receiving resources

⇒ failure to follow the strict protocol can result (and has resulted) in the misdirection of resources

☐ Preplanning Advantage

☐ knowing that equipment, manpower and funds can be made available and from where, will expedite the response and recovery process
**Preplanning: Action 12**

- **Increase public and contractor awareness of post-earthquake solid waste issues and management goals.**

  - **Current Situation**
    - there is no mention in earthquake preparedness plans and information packages, of the problems that solid waste can cause
    - much of the public is unaware of, or is indifferent to the current solid waste management goals, does not view solid waste generation as a social problem, and is oblivious to the effects solid waste has on them personally
      - due to lack of user fees for residential collection based on quantities generated
      - due to the "out of sight, out of mind" effect
    - many contractors are unaware of, or disbelieve the cost savings associated with waste reduction, reuse and recycling

  - **Californian Experience**
    - public and contractor awareness of the damaging effects of earthquakes is heightened, and they are generally better prepared for earthquakes
      - the seismic requirements for residential construction are more stringent
    - practice and experience leads to increased success
      - initially, there were many piles of debris containing non-disaster debris that were tagged and the generators were notified
      - initially, the source separation of recyclable disaster debris was not performed in accordance with City requirements, and the generators were given correction notice
      - as the debris recycling program became more familiar to residents, the quality of waste materials improved
      - non-compliance fees were utilized to enforce adherence to regulations

  - **Preplanning Advantage**
    - understanding why things are being done a certain way, and how things affect an individual will increase compliance with collection and processing/disposal requirements
    - instilling in the public and in contractors a certain mentality toward solid waste in general in pre-earthquake circumstances, and making certain solid waste objectives common practice, will help reach the post-earthquake solid waste management goals
    - public awareness of the types of damage that can occur, and the types of waste that are typically generated as a result of an earthquake, will promote earthquake preparedness efforts by overall strengthening of structures and securing of building contents against damage, resulting in lower rates of debris generation
### Preplanning: Action 13

**Prepare informational brochures on waste diversion methods, and waste diversion facilities.**

<table>
<thead>
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<th>Current Situation</th>
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<tbody>
<tr>
<td>information on waste diversion methods exist and has been compiled for regular, pre-earthquake solid waste, including DLC waste</td>
</tr>
<tr>
<td>→ the similarity between DLC waste and DD is not acknowledged in the available pamphlets</td>
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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>time is crucial after an earthquake, and implementation of a plan is difficult enough without having to perform such time-consuming activities as compilation of existing information</td>
</tr>
<tr>
<td>→ in the Northridge Earthquake, the City recognized the similarity between DLC waste and DD</td>
</tr>
<tr>
<td>→ within two days of the earthquake, the City disseminated recycling requirements to over 2,700 private contractors that were expected to assist in the earthquake cleanup</td>
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<thead>
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<tbody>
<tr>
<td>knowing how to properly comply with requirements will increase the rate of success of earthquake response and recovery programs</td>
</tr>
<tr>
<td>recognizing the similarity of DD and DLC waste, and making it common knowledge prior to an earthquake will increase the rate of success of diversion of DD from landfills</td>
</tr>
<tr>
<td>having gathered and put together information pamphlets on DD handling in the preplanning process will save valuable time and manpower following an earthquake, which can be allocated elsewhere</td>
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## Reference Sections for Preparatory Actions

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<td>8.2.3</td>
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<td></td>
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<td>8.2.4, 6.3</td>
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12. PLAN - STRATEGY OPTIONS REPORT

12.1 Summary

The risk of a seismic event with devastating effects is very high within the Lower Mainland. While such a risk is being recognized in this region, the benefits of preplanning for disaster recovery and debris cleanup are being recognized globally. The cost savings alone should be a tremendous incentive to prepare for the cleanup and recovery from a disaster. Time is another factor to consider—preplanning will save time in a situation where time is of the essence. Many standards may be compromised, including those concerning safety and the environment, when reactive decisions are made.

A Post-Earthquake Solid Waste Management Plan (Plan) has been developed for the Lower Mainland, with funding provided by the City of Vancouver and the Greater Vancouver Regional District (GVRD). The Plan was prepared as a part of a Thesis Document (Thesis). The Plan incorporates the valuable lessons documented from the most recent earthquake events throughout the world, particularly in California. The Plan proposes a management strategy for cleaning up all solid waste attributable to a devastating earthquake in the Lower Mainland.

The Plan comprises of four parts:
1. Action Plan Procedure,
2. Preplanning Actions;
3. Strategy Options; and
4. Operational Plan to be prepared after an earthquake occurs.

The first three parts of the Plan are presented as a stand-alone document. They are based on extensive research documented in Parts II through IV of the Thesis, and constitute the basis for the fourth part—the Operational Plan.

The Strategy Options Report (Report) supplements the proposed Action Plan Procedure, and the recommended thirteen Preplanning Actions. These two parts of the Plan are presented separately outside of the Report, in Sections 10 and 11, respectively, of the Thesis.

The Report defines the scope of the management strategy. Based on the different handling and disposal requirements, the Report identifies the need for a post-earthquake municipal solid waste (MSW) strategy, and a separate strategy for disaster debris (DD). As one of the requirements for developing an Operational Plan, a characterization scheme of the typical post-earthquake solid waste composition is proposed. The waste characterization is based on material type and/or handling requirements.

The main feature of the post-earthquake MSW management strategy is the use of the existing solid waste management system. A prioritization scheme is developed for collection of various waste types. The aspects of the existing solid waste management system most vulnerable to the damaging effects of earthquakes are identified. Solutions to potential breaches in the system are offered.

The main feature of the DD management strategy is the recognition of the similarity between DD and demolition, landclearing, and construction (DLC) waste, in terms of waste composition and handling requirements. The strategy is strongly dependent on current and potential DLC waste management practices.

The strategies contained within the Report acknowledge and accommodate the various phases of response to, recovery and reconstruction from an earthquake event. The DD management strategy also recognizes the variability of and dependence on the actual magnitude of earthquake damage. The strategy is presented as a series of procedures that address a number of damage scenarios, increasing in damage severity.
It is further recognized in the Report, that regardless of the extent of damage or time frame in which an earthquake occurs, there are certain basic solid waste management principles that remain unaffected. The strategic methodology used to develop the Plan also remains valid.

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12.3 Introduction
The vulnerability of the Lower Mainland to the devastating effects of a significant seismic event is at last being recognized. The emergency response preparatory effort has been given its deserved attention over the recent years. The cleanup and recovery requirements have not.

Only within the last decade have the repercussions of the lack of planning for cleanup after a natural disaster been recognized. Billions of dollars are spent on recovery from natural disasters, such as earthquakes, and environmental and social standards are compromised. Only recently, too, have the savings and other benefits of preplanning for disaster cleanup been roughly quantified. One of the most significant, and best documented examples is the recovery from the 1994 Northridge Earthquake in Los Angeles. The lessons learned by other cities and regions have been used to prepare the Post-Earthquake Solid Waste Management Plan (Plan) for the City of Vancouver and the surrounding area.

The majority of the ideas incorporated in this Strategy Options Report (Report), including the methodology for the disaster debris (DD) management strategy, are rooted in the recent Californian experiences, and, although to a lesser extent, in experiences elsewhere. The main supporting documents that were utilized include the 1997Integrated Waste Management Disaster Plan, the 1997 City/County of San Francisco Disaster Debris Recovery Plan, and the 1995Earthquake Demolition Recycling Program and Northridge Earthquake Response Effort reports (IWMB, 1997; Recycling By Nature, Inc., and J.Edwards and Associates, Inc., 1995; and Biagi et al. 1995a and b). In addition, information applicable specifically to the Lower Mainland was obtained during a research trip to Los Angeles and San Francisco in the Spring of 1999. The evaluation of the state of preparedness for earthquake recovery, with respect to solid waste management, in the Greater Vancouver Regional District (GVRD) is primarily based on the 1995Greater Vancouver Regional Solid Waste Management Plan, and the work with the Joint Emergency Liaison Committee (JELC) Disaster Debris Subcommittee (GVRD, 1995; and Personal Communication, JELC Disaster Debris Subcommittee). All supporting information utilized in preparation of the Plan is presented in Parts II through IV of the Thesis Document.

It is imperative to recognize the importance of developing an action plan for the inevitable catastrophic earthquake. It can mean tremendous savings in cost, time and effort, as was proven and documented during the recovery from the 1994 Northridge Earthquake in California. It is equally crucial to recognize the importance of doing certain preparatory work before an earthquake strikes. In addition to saving money, time and effort, preparatory work presents the advantage of having the time to optimize a solution rather than to react with irreparable consequences. Preparatory work also facilitates decision-making when time is of the essence after an event.

The Strategy Options Report presents the essential components of a management strategy for handling post-earthquake solid waste. The Report provides the scope and rationale for the Plan and for the proposed strategies. The Report is the third of the four parts of the proposed Plan. The first part, Action Plan Procedure, provides the framework for establishing the whole Plan. The second part, Preplanning Actions, identifies a number of simple, but key preparatory actions that need to be performed prior to an earthquake event. The fourth part, the Operational Plan can only be finalized once an earthquake occurs, and the magnitude of the damage and the required cleanup effort are known.
12.3.1 Scope of Proposed Strategy
The proposed strategy is quantity-based. It remains flexible to accommodate a wide range of earthquake damage, and the resulting quantity of debris.

The strategy is two-tiered. It addresses:
1. post-earthquake municipal solid waste (MSW); and
2. post-earthquake disaster debris (DD).

Furthermore, the proposed strategy recognizes the three phases of earthquake aftermath:
1. response;
2. recovery; and
3. reconstruction.
Each phase has its own solid waste management implications.

The strategy is also time-dependent. The relative magnitude of the problem that an earthquake event causes, in terms of solid waste management, will change with time.

12.3.2 Time Dependency of Proposed Strategy
As time lapses, structures within the Lower Mainland are being built and/or retrofitted to become more earthquake-resistant. The older, non-earthquake-resistant structures are being replaced by new, stronger, more earthquake-resistant ones. Where the older structures are retained, they are being seismically upgraded. Residents of this region also acknowledge the risks associated with the inherent earthquake potential, and tend to secure their belongings and building contents against earthquake force effects. These result in decreasing the potential quantity of debris generated.

Transportation links, such as bridges and overpasses, also become more earthquake-resistant with time, as construction practices and retrofits incorporate the earthquake-hazard potential. A stronger, more resistant transportation system greatly facilitates the cleanup effort of earthquake related damage, by allowing unrestricted movement of equipment and materials.

With the increasing awareness of the earthquake hazard, earthquake insurance becomes more readily available. This has a direct effect on the expediency of recovery, and cost to the government (which also translates to increased opportunity for innovative solid waste handling alternatives).

The regional goal of waste diversion from MSW landfills drives recycling opportunities and markets. With time, as the recycling capacity increases, it provides a more sustainable solution to the post-earthquake solid waste management problem. On the other hand, the decreasing landfilling capacity within the Lower Mainland (especially at the MSW landfills) tends to place increasing restrictions on the post-earthquake solid waste handling options. Ultimately, alternative uses (other than as landfill) may be found for most of the waste that is generated on a regular basis. This, too, will have an impact on the alternatives for post-earthquake solid waste management.

Notwithstanding the changes in the situation within the Lower Mainland discussed above, which will affect the relative impact of an earthquake event, post-earthquake solid waste cannot be eliminated. Therefore, the basic principles, objectives, and strategic methodology contained within the proposed strategy will apply regardless of the state of the situation in the Lower Mainland. Certain adjustment to the operational detail of the proposed strategy may be required, depending at which point in the future an earthquake devastates the region.
12.3.3 Pre-Earthquake Solid Waste Management System

The capacity and variety of management options for handling solid waste at the present time are determined by the quantity and composition of solid waste currently generated. As evidenced by the numbers presented in Table 12-1 and Table 12-2, the current, pre-earthquake solid waste management system has only marginal room to handle additional quantities of solid waste. As a result, it is unrealistic to solely rely on the current solid waste management system to handle the vast quantities of waste materials that can potentially be generated during an earthquake. Following an earthquake event, the solid waste management system will require rapid expansion, both in terms of capacity and alternative methods.

12.3.3.1 Pre-Earthquake Solid Waste Generation

The current annual solid waste generation rate in the GVRD is on the order of the 1997 figures listed in Table 12-1.

Table 12-1: Regular Waste Quantities Generated Annually

<table>
<thead>
<tr>
<th>Source</th>
<th>Generated</th>
<th>Recycled</th>
<th>Disposed</th>
<th>% Recycled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>665,000</td>
<td>196,000</td>
<td>469,000</td>
<td>29%</td>
</tr>
<tr>
<td>IC&amp;I</td>
<td>1,138,000</td>
<td>438,000</td>
<td>700,000</td>
<td>38%</td>
</tr>
<tr>
<td>DLC</td>
<td>936,000</td>
<td>512,000</td>
<td>424,000</td>
<td>55%</td>
</tr>
<tr>
<td>Total</td>
<td>2,739,000</td>
<td>1,146,000</td>
<td>1,593,000</td>
<td>42%</td>
</tr>
</tbody>
</table>

Quantities expressed in tonnes (GVRD, 1999)

12.3.3.2 Available Solid Waste Disposal Options

The details of the types and locations of solid waste facilities and options that are currently available within the GVRD are presented in Appendix 12.10-A in Section 12.10. A summary of the solid waste disposal options and capacities is presented in Table 12-2.

Table 12-2: Summary of Solid Waste Facilities

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Total Number</th>
<th>Total Authorized Capacity</th>
<th>Waste Types Handled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling Facilities</td>
<td>150(^1)</td>
<td>N/A</td>
<td>“blue-box” recyclables</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DLC recyclables</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>compostables</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>tires</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HHW</td>
</tr>
<tr>
<td>Transfer Stations</td>
<td>8</td>
<td>4,780 tonnes/day</td>
<td>MSW</td>
</tr>
<tr>
<td>MSW Landfills</td>
<td>3</td>
<td>23.5 million tonnes(^1)</td>
<td>MSW</td>
</tr>
<tr>
<td>DLC Landfills</td>
<td>2</td>
<td>3 million tonnes(^1)</td>
<td>DLC</td>
</tr>
<tr>
<td>Incinerators</td>
<td>1</td>
<td>240,000 tonnes/year</td>
<td>MSW</td>
</tr>
<tr>
<td>Waste Exchange/Export</td>
<td>limited options</td>
<td>N/A</td>
<td>HW</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HHW</td>
</tr>
</tbody>
</table>

\(^1\)Approximate figures
(Personal Communication, Ken Carrusca, Stuart Somerville, Mike Stringer, and JELC Disaster Debris Subcommittee)
12.3.4 Report Organization

The introduction to the Strategy Options Report presents the status of the existing solid waste management system, and the current demand for the system. The inadequacy of the current system for handling post-earthquake solid waste quantities is evident. The urgency for a post-earthquake solid waste management plan is presented.

The remainder of the Report contains four sections, which comprise the proposed post-earthquake solid waste management strategy for the City of Vancouver. The strategy extends to, and has repercussions for all of the GVRD.

Section 12.4 defines the post-earthquake solid waste stream. It provides a basis for waste characterization, which will be an integral part of strategy implementation. The report recognizes two distinct waste streams, which are differentiated according to handling and disposal requirements.

Section 12.5 presents the post-earthquake municipal solid waste management strategy. It considers the role of the pre-earthquake solid waste management system after an earthquake event. Priorities for, and phases of post-earthquake MSW management are defined. Potential problems for the MSW management system associated with the effects of an earthquake event are outlined. Solutions to potential shortfalls are offered.

Section 12.6 presents the post-earthquake disaster debris management strategy. It delegates the responsibility for DD management. It considers the role of the pre-earthquake solid waste management system in the management of DD. Priorities for, and phases of DD management are defined. The dependence on the magnitude of earthquake damage to determine the extent of DD cleanup requirements is discussed. A quantity-based strategy is presented, along with general principles governing any DD management strategy.

Section 12.7 summarizes the ideas presented in the Report. The Plan’s proposal of an Action Plan Procedure in Section 10 of the Thesis is introduced. This section also indicates that the Plan recommends thirteen Preplanning Actions in Section 11 of the Thesis.

Section 12.8 defines the terminology used throughout the Report.

Section 12.9 provides a short list of documents recommended for further reading, which were crucial to the preparation of the Report. The Thesis provides a more comprehensive list of reference materials.

Section 12.10 presents the appendices to the Report.
12.4 Post-Earthquake Solid Waste Composition

To facilitate quantity estimation and decision-making regarding the handling and disposal of all post-earthquake solid waste, it is useful to classify post-earthquake solid waste into categories. A sample classification scheme is presented, which can be used as a basis when characterizing actual wastes generated following an earthquake.

12.4.1 Post-Earthquake Solid Waste Stream

In addition to regular municipal solid waste (MSW), and regular demolition, landclearing and construction (DLC) waste, a new solid waste stream is generated after an earthquake. The new waste stream is referred to as disaster debris (DD). The majority of DD closely resembles the DLC waste stream. A small portion of the DD waste stream falls under MSW designation. Post-earthquake solid waste can be classified by material type according to the layout on Figure 12-1.

Figure 12-1: Post-Earthquake Solid Waste Classification

12.4.2 Post-Earthquake Municipal Solid Waste Stream

Regular MSW originates from residential, and industrial, commercial and institutional (IC&I) sources. The main components of the regular MSW stream are putrescibles, packaging and containers, and personal items. The regular MSW stream also includes household hazardous waste (HHW).

The composition and volume of regular MSW will be changed by the occurrence of an earthquake. Post-earthquake MSW stream will inevitably include waste generated either directly by an earthquake event, or by secondary effects. Secondary effects of an earthquake include:

- power failure;
- flooding; and
- fires.
A sample classification scheme for post-earthquake MSW, based on waste handling and disposal options, is presented on Figure 12-2.

**Figure 12-2: Sample Post-Earthquake Municipal Solid Waste Classification**

### 12.4.3 Disaster Debris Waste Stream

After the occurrence of an earthquake, the regular DLC and DD waste streams can be regarded as one waste stream for several reasons. The two waste streams are similar in material composition, which has been proven by California’s earthquake recovery experience. Furthermore, the regular DLC waste stream can be controlled by demolition permits. The issuing of demolition permits can be strategically restricted to earthquake damaged sites. With the majority of DLC activity being related to earthquake recovery and reconstruction, the quantity of regular DLC waste would decrease following an earthquake.

Notwithstanding the ability to significantly limit DLC activity to earthquake recovery and reconstruction, it may be crucial to keep separate accounting of wastes related strictly to the effects of an earthquake. The potential availability of funding from the provincial and/or federal governments for handling DD will depend on such separate accounting. The cost of handling and disposal of regular DLC waste will have to be covered by the generator as in pre-earthquake conditions.
Disaster debris which resembles DLC waste presents a management problem because of:
- the enormous volumes that may be generated and will require handling (e.g., soil from landslides, concrete from numerous building demolitions);
- the degree of commingling of different material types; and
- the potential contamination of otherwise clean and easily handled waste material with hazardous substances (e.g., a building which requires demolition because it represents a structural safety hazard, but contains small amounts of asbestos).

A sample classification scheme for post-earthquake DD, based on waste source, degree of separation, and potential disposal options, is presented on Figure 12-3.

![Diagram of waste classification](image)

**Figure 12-3: Sample Post-Earthquake Disaster Debris Waste Classification**

### 12.4.3.1 Processed Waste Materials

Once DD (both source-separated and commingled) is processed, the processed material may still constitute waste unless a market exists for it. If a market for this material cannot be found, it will need to be stockpiled or disposed. Materials that are the end product of DD processing include:
- crushed concrete and asphalt;
- chipped wood;
- whole or crushed brick;
- gypsum from dry wall;
- steel from structural reinforcement;
- metals from piping, electrical wiring; and
- glass from windows.

*Greater Vancouver Post-Earthquake Solid Waste Management Strategy*

*March 2000*
12.5 Post-Earthquake Municipal Solid Waste Management Strategy

12.5.1 Principal Strategy for Post-Earthquake Municipal Solid Waste Management
Post-earthquake MSW will be handled by the existing waste management system, provided that all components of the system are operational and accessible. However, the volume and composition of MSW will change from pre-earthquake conditions.

12.5.2 Time Aspect of Post-Earthquake Municipal Solid Waste Management Strategy
There are three phases of MSW generation following an earthquake event, which are described in Table 12-3. Each phase tends to generate a different volume and composition of MSW. This will require a flexible post-earthquake MSW management strategy, which will accommodate the changing waste stream.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase Event</th>
<th>Consequence of Phase Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1:</td>
<td>Satisfaction of basic survival needs</td>
<td>increase in amount of food containers and packaging from increased consumption of canned and prepackaged food, and bottled water</td>
</tr>
<tr>
<td>Phase 2:</td>
<td>Cleanup of damage in households and businesses</td>
<td>increase in quantity of damaged household and office items</td>
</tr>
<tr>
<td>Phase 3:</td>
<td>Repair of damage</td>
<td>introduction of DD into the post-earthquake MSW stream if DD cleanup effort is insufficient, too slow, or unavailable due to prohibitive costs</td>
</tr>
</tbody>
</table>

In addition, waste collection after an earthquake requires prioritization due to the nature and source of MSW. Three levels of priority of post-earthquake MSW handling are described in Table 12-4.

<table>
<thead>
<tr>
<th>Priority Level</th>
<th>Event</th>
<th>Rationale for Given Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Priority</td>
<td>Collection from temporary shelters</td>
<td>to minimize health hazards</td>
</tr>
<tr>
<td></td>
<td>Removal of putrescibles</td>
<td></td>
</tr>
<tr>
<td>2nd Priority</td>
<td>Collection from multi-family units</td>
<td>difficult to store at point of generation</td>
</tr>
<tr>
<td></td>
<td>Removal of recyclables and HHW</td>
<td>to maximize diversion from the landfill</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to minimize health hazards, and contamination with HHW</td>
</tr>
<tr>
<td>3rd Priority</td>
<td>Collection from single-family units and businesses</td>
<td>source reduction, and storage at point of generation can be implemented relatively easily</td>
</tr>
<tr>
<td></td>
<td>Disposal of residual waste, and household and office items</td>
<td>to minimize commingling with DD</td>
</tr>
</tbody>
</table>
12.5.3 Vulnerability of Existing Solid Waste Management System

12.5.3.1 Physical Infrastructure

The existing solid waste management system includes a number of facilities that may be vulnerable to an earthquake. The components of each type of facility that are the most susceptible to earthquake effects are identified in Table 12-5.

Table 12-5: Vulnerability of Solid Waste Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Components Essential to Operations</th>
<th>Components Vulnerable to Earthquakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling</td>
<td>housing structure, equipment (excavators, conveyor belts, sorting)</td>
<td>structural integrity, partial damage, or full collapse of housing structure</td>
</tr>
<tr>
<td>Transfer</td>
<td>housing structure, equipment (bulldozers, compactors - can operate without, but with much lower efficiency)</td>
<td>structural integrity, partial damage, or full collapse of housing structure</td>
</tr>
<tr>
<td>Incinerator</td>
<td>housing structure, bunker and cranes, boilers, air filtration system (pipes, monitoring equipment), stack</td>
<td>structural integrity, foundation damage to bunker, partial damage, or full collapse of housing structure</td>
</tr>
<tr>
<td>Landfills</td>
<td>liner, leachate collection system, gas collection system, waste structure</td>
<td>structural integrity, failure of side slope, break in pipe network, differential subsidence</td>
</tr>
</tbody>
</table>

12.5.3.2 Transportation

The existing solid waste management system is dependent on access routes for collection, and delivery of MSW to solid waste facilities. Disruption along the transport routes can result from:
- tunnel, bridge, and access ramp failures (structural damage, or full collapse);
- road damage from surface rupture, or due to landslides;
- road blockage by fallen debris, or by DD set out for collection;
- increased amounts of MSW per collection location (i.e., increase of collection time, and decrease of collection area per vehicle);
- increased numbers of collection vehicles; and
- increased traffic due to the above.
A number of the bridges within the Lower Mainland have either been built, or have been seismically retrofitted to the current bridge code. The status of seismic retrofitting of bridges is detailed in Appendix 12.10-B in Section 12.10.

Collection vehicles currently used for MSW will be used only for the compressible wastes in the post-earthquake MSW stream. These vehicles are not capable of handling disaster debris, which is not compressible.

12.5.3.3 Volume and Composition of Waste

The existing solid waste management system has a finite capacity, which is based on pre-earthquake MSW quantities. This capacity is further defined by permits and/or physical limitations of facilities, and transportation links. An increase in the volume of MSW after an earthquake will either strain the existing system, or entirely overwhelm it.

Post-earthquake MSW can be expected to contain an increased amount of large non-compressible items, such as broken furnishings, kitchen contents, carpeting, etc. Such a change in composition of MSW will pose difficulties for collection vehicles, and certain transfer stations. Most MSW collection vehicles, and certain transfer stations utilize hydraulic compressors, which are intended to handle mainly small compressible materials.

12.5.4 Solutions to Breaches in Existing Solid Waste Management System

Disruption to the solid waste management system may last from hours to months. Several contingency plans that can be implemented are presented in Table 12-6.

Table 12-6: Solid Waste Management System Contingencies

<table>
<thead>
<tr>
<th>Breach in Solid Waste Management System</th>
<th>Contingency Plan</th>
</tr>
</thead>
</table>
| • Failure along Transportation Route   | • use alternate bridge  
|                                        | • use land access (bridge detour)  
|                                        | • use barges or ferries  
|                                        | • use temporary storage sites |
| • Structural Failure at Solid Waste Facility | • promote waste reduction at source  
|                                           | • storage of waste at point of generation with health hazard considerations  
|                                           | • divert waste to other facilities  
|                                           | • use temporary storage sites |
| • Increase in MSW Quantities            | • strictly limit the amount of MSW collected from each generator (thereby encouraging waste reduction, and storage at point of generation)  
|                                        | • transport more MSW directly to a landfill  
|                                        | • use temporary storage sites  
|                                        | • use additional collection vehicles  
|                                        | • extend collection hours |
| • Change in MSW Composition             | • limit collection to small compressible wastes (and require generators to contract for disposal of problematic items)  
|                                        | • supplement collection routes with vehicles capable of handling large non-compressible items  
|                                        | • transport loads containing large non-compressible items directly to a landfill |
12.6 Post-Earthquake Disaster Debris Management Strategy

12.6.1 Responsibility for Disaster Debris Management

Since DD is similar in most aspects to DLC waste, and DLC waste is managed by the local governments, it will be the responsibility of local governments to take a leading role in the management of DD. Depending on the availability of funds, the local government may choose to delegate the waste removal and transportation responsibility. Setting the direction for, and coordinating a management strategy rests entirely with the local governments.

Notwithstanding the local governments' responsibility to manage the DD within their jurisdictions, a regional management strategy should be utilized in the GVRD. The sources of DD may be numerous, and scattered throughout the region. Conversely, waste handling and disposal options will be relatively few. Based on current location of solid waste facilities, municipalities will need to rely on one another for handling and disposal of their DD. Furthermore, an organized effort in handling DD regionally will inevitably reduce costs, and expedite the process.

12.6.2 Time Aspect of Disaster Debris Management Strategy

The recovery from an earthquake event occurs in a number of phases. Three distinct phases of debris handling following an earthquake are identified in Table 12-7

<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase Event</th>
<th>Function of Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1:</td>
<td>Immediate clearing of emergency and essential</td>
<td>to allow entry for rescue crews and law</td>
</tr>
<tr>
<td>Response</td>
<td>access routes</td>
<td>enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to resume critical services</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to perform damage assessment of critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facilities and utilities</td>
</tr>
<tr>
<td>Phase 2:</td>
<td>Removal of debris from streets, and imminent</td>
<td>to restore traffic flow</td>
</tr>
<tr>
<td>Recovery</td>
<td>hazard demolitions</td>
<td>to minimize further damage and injuries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to perform initial assessment of damage</td>
</tr>
<tr>
<td>Phase 3:</td>
<td>Long-term process of damage repair</td>
<td>to reconstruct structures</td>
</tr>
<tr>
<td>Reconstruction</td>
<td></td>
<td>to replace damaged belongings</td>
</tr>
</tbody>
</table>

The type of waste generated in each of these phases is quite different in composition, volume, and urgency for removal. For instance, the main components of the disaster debris waste stream during the response phase are concrete and brick, while during the reconstruction phase there are more furnishings and personal items in the waste stream. In practice, the different phases of debris handling following a disaster will occur at the same time within a region. Most often depending on the availability of funds to local governments and individuals, certain areas may still be recovering from a disaster, while other areas may have begun reconstruction. Therefore, the regional DD management strategy must be capable of addressing the waste generated by all three phases simultaneously.
Disaster debris collection after an earthquake requires prioritization due to the nature and source of the waste. Three levels of priority of DD handling are described in Table 12-8. Notwithstanding the levels of priority of DD handling, MSW is given collection priority, due to increased health hazards associated with putrescibles.

Table 12-8: Priority Levels of Disaster Debris Handling

<table>
<thead>
<tr>
<th>Priority Level</th>
<th>Event</th>
<th>Rationale for Given Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Priority</td>
<td>• Removal of compostables</td>
<td>• to minimize health hazards</td>
</tr>
<tr>
<td></td>
<td>• Essential facilities (e.g., hospitals, transportation routes)</td>
<td>• to maintain basic life functions</td>
</tr>
<tr>
<td>2nd Priority</td>
<td>• Removal of source-separated waste materials</td>
<td>• to maximize diversion from the landfill</td>
</tr>
<tr>
<td></td>
<td>• Removal of recyclables and HW</td>
<td>• to minimize health hazards, and contamination with HW</td>
</tr>
<tr>
<td></td>
<td>• Business buildings</td>
<td>• to minimize impact on the economy</td>
</tr>
<tr>
<td>3rd Priority</td>
<td>• Removal of commingled waste materials</td>
<td>• reduced value of waste materials</td>
</tr>
<tr>
<td></td>
<td>• Disposal of residual waste</td>
<td>• uneconomical to divert from landfill</td>
</tr>
<tr>
<td></td>
<td>• Residential buildings, non-essential facilities (e.g., recreational facilities)</td>
<td>• availability of temporary alternatives</td>
</tr>
</tbody>
</table>

12.6.3 Magnitude of Disaster Debris Problem
The amount of DD generated will dictate the extent of City involvement, and the extent to which the proposed strategy is utilized. In order to determine the details of the DD management approach in the aftermath of an earthquake event, it will be necessary to assess the situation using the four assessment criteria described in Table 12-9.

Table 12-9: Assessments Required Following an Earthquake Event

<table>
<thead>
<tr>
<th>Assessment Criteria</th>
<th>Implications</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Amount of DD</td>
<td>• extent of City involvement</td>
<td>• during response, recovery and/or reconstruction phases</td>
</tr>
<tr>
<td></td>
<td>• time required to handle DD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• requirement of temporary storage sites</td>
<td></td>
</tr>
<tr>
<td>□ Type of DD</td>
<td>• type of facilities required to handle DD</td>
<td>• source-separated recycling facilities</td>
</tr>
<tr>
<td></td>
<td>• extent of landfill use</td>
<td>• commingled processing facilities</td>
</tr>
<tr>
<td>□ Location of DD</td>
<td>• transportation costs to deliver DD to most appropriate facilities</td>
<td>• use temporary storage sites as transfer points if access routes are unavailable</td>
</tr>
<tr>
<td></td>
<td>• transportation options</td>
<td>• use various size trucks, barges, rail</td>
</tr>
<tr>
<td></td>
<td>• collection routing to minimize traffic, and maximize recycling of source-separated materials</td>
<td>• use area drive-throughs, or pickup on request from an area on given day or only certain materials</td>
</tr>
<tr>
<td>□ Concentration of DD</td>
<td>• type of contract used by waste haulers</td>
<td>• divide affected area into collection zones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• concentrated DD - unit price contracts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• scattered DD - time and materials contracts</td>
</tr>
</tbody>
</table>
These assessments can be made from:
- the air (by helicopter and from tall structures already declared safe);
- the ground (by vehicle and on foot);
- the water (by boat and barges); and
- reports (by media and telephone hotlines).

The inspections to determine the effects of an earthquake with respect to DD can be made by:
- City employees and other professionals (building inspectors, engineers, MSW collectors);
- media personnel; and
- residents/DD generators.

**12.6.4 Disaster Debris Handling Options**

There are numerous options available for the collection, intermediate handling, and final disposal of DD, and processed waste materials. The implementation and usage of the different handling options listed in Table 12-10 will depend on the following factors:
- quantity of DD (related to magnitude of earthquake event and extent of damage);
- material type and quality;
- availability of funds (to the local government and to individual generators);
- duration of option usage;
- public acceptance; and
- health, safety, and environmental issues.

<table>
<thead>
<tr>
<th>Handling Stage</th>
<th>Collection (Section 12.6.4.1)</th>
<th>Storage (Section 12.6.4.2)</th>
<th>Disposal (Section 12.6.4.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determining Factor</td>
<td>Availability of funds</td>
<td>Duration of storage DD</td>
<td>Material type and quality</td>
</tr>
<tr>
<td>Options</td>
<td>self-haul</td>
<td>point of generation</td>
<td>reuse, recycling/resource recovery, and salvaging</td>
</tr>
<tr>
<td></td>
<td>city-wide pickup of piles from individual residences, businesses, etc.</td>
<td>curbside or back alley</td>
<td>energy recovery (e.g., wood as boiler fuel)</td>
</tr>
<tr>
<td></td>
<td>use of large waste containers (e.g., roll-off bins)</td>
<td>temporary storage sites (e.g., specify usage of site for source-separated, commingled, processed and/or HW materials)</td>
<td>landfilling at MSW and DLC landfills (i.e., expansion of active and closed landfills)</td>
</tr>
<tr>
<td></td>
<td>contract for DD removal</td>
<td>non-essential transportation routes</td>
<td>landfilling in man-made or natural surface/subsurface cavities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>transportation vehicles (e.g., trucks, barges, rail cars)</td>
<td>ocean disposal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>construction of sea and river dykes, and river bank protection structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>construction of artificial reefs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>export of waste</td>
</tr>
</tbody>
</table>
12.6.4.1 Criteria for Setting Handling and Tipping Fees

Several criteria which require consideration in establishing the level of fees charged for handling and disposal of post-earthquake solid waste are described in Table 12-11.

Table 12-11: Handling and Tipping Fee Setting Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Considerations</th>
<th>Level of Fees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management Goal</td>
<td>promotion of 5R hierarchy of solid waste management (i.e., promotion of waste diversion from MSW landfill)</td>
<td>highest</td>
</tr>
<tr>
<td></td>
<td>economics</td>
<td>lowest</td>
</tr>
<tr>
<td></td>
<td>environmental consequences</td>
<td>use of MSW landfill</td>
</tr>
<tr>
<td></td>
<td>social acceptance</td>
<td>use of alternate disposal facilities</td>
</tr>
<tr>
<td>Quality of Waste Material</td>
<td>degree of separation</td>
<td>highest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>intermediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lowest</td>
</tr>
<tr>
<td>Type of Disposal Facility</td>
<td>benefit of disposal option</td>
<td>highest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>intermediate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lowest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>use of MSW landfill, transfer station, incinerator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temporary storage site, staging area, DLC landfill, alternate disposal option</td>
</tr>
<tr>
<td></td>
<td></td>
<td>recovery/salvage facility, recycling facility</td>
</tr>
<tr>
<td>Type of Generator</td>
<td>availability of funds</td>
<td>highest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lowest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>private industry, public agency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>resident</td>
</tr>
</tbody>
</table>
12.6.4.2 Criteria for Selecting a Temporary Storage Site

Several criteria which require consideration in designating a site for temporary storage of post-earthquake solid waste are described in Table 12-12.

Table 12-12: Temporary Storage Site Selection Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Considerations</th>
</tr>
</thead>
</table>
| Duration of Utility                     | • there may be a tendency to continue using temporary sites after they have been closed  
• processing of temporarily stored material may cease, resulting in a permanent deposit of waste |
| Proximity to Waste                      | • effect on transportation costs                                             |
| Generation/Processing/Disposal          | • convenience vs. nuisance near the point of generation                      |
|                                         | • availability of equipment and manpower at point of processing/disposal    |
| Site Utility/Operations                 | • type of usage:                                                              |
|                                         | → storage only                                                               |
|                                         | → storage and processing                                                     |
|                                         | → MSW and/or DLC and/or HW handling                                         |
|                                         | • physical requirements:                                                    |
|                                         | → housing structure (protection against the elements, minimizing hazards to public health and safety) |
|                                         | → perimeter fencing                                                          |
| Site Size                               | • sufficient space for:                                                     |
|                                         | → processing equipment                                                       |
|                                         | → transportation truck maneuvering                                          |
|                                         | → grouping waste types, and HW contingency plans                             |
| Site Accessibility                      | • effect on local traffic and traffic at the site                            |
|                                         | • effect on processing ability at the site                                  |
|                                         | • effect on transportation costs                                            |
12.6.5 *Disaster Debris Management Strategy*

The operational details of the DD management strategy can only be resolved once an earthquake strikes, and once the extent of damage resulting in generation of DD is known. However, certain basic principles will apply regardless of the magnitude of damage, and location of the earthquake event.

### 12.6.5.1 Basic Principles

The following are the basic principles which should be reflected in a DD management strategy.

<table>
<thead>
<tr>
<th>Basic Disaster Debris Management Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ DD management should not compromise:</td>
</tr>
<tr>
<td>☐ emergency response;</td>
</tr>
<tr>
<td>☐ public health and safety;</td>
</tr>
<tr>
<td>☐ the environment;</td>
</tr>
<tr>
<td>☐ the economic and social structure of the pre-earthquake system;</td>
</tr>
<tr>
<td>☐ the general standard of living; and</td>
</tr>
<tr>
<td>☐ the pre-earthquake solid waste management goals.</td>
</tr>
</tbody>
</table>

| ☐ Control over DD should be maintained at all times. |
| ☐ DD should be handled responsibly, and as expediently as possible. |

### 12.6.5.2 Objectives

In order to preserve these basic principles of the DD management strategy, it is essential to set several objectives. The following is a list of objectives, which also includes the goals and requirements needed to achieve the objectives.
## Objectives to Preserve Basic Disaster Debris Management Principles

### Maintain pre-earthquake solid waste management goals

<table>
<thead>
<tr>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>follow the 5R hierarchy of waste management (defined in 12.8)</td>
</tr>
<tr>
<td>conserve MSW landfill space for MSW by diverting waste materials, in order to minimize any resulting long-term negative economic and social impacts on MSW management</td>
</tr>
<tr>
<td>prevent permanent deposition at undesirable locations (i.e., illegal dumping)</td>
</tr>
<tr>
<td>minimize contamination of regular wastes with HW and HHW, and ensure proper handling/disposal of hazardous materials</td>
</tr>
</tbody>
</table>

### Objective Achievement Requirements

- DD separation and segregation at source
- temporary storage sites
  - only when absolutely necessary (e.g., for handling overflow at processing and recycling facilities, using temporary storage sites for stockpiling of waste materials delivered during the day to be processed at the facilities on additional shifts)
- tipping fees at DD handling and disposal facilities set to promote diversion from landfills

### Optimize resource allocation

<table>
<thead>
<tr>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>determine the scale of the DD cleanup effort</td>
</tr>
<tr>
<td>determine needs for facilities, equipment, and manpower</td>
</tr>
<tr>
<td>minimize total costs (e.g., avoid/minimize multiple handling costs associated with use of temporary storage sites)</td>
</tr>
<tr>
<td>justify additional funding requirements</td>
</tr>
<tr>
<td>monitor success of diversion</td>
</tr>
</tbody>
</table>

### Objective Achievement Requirements

- initial damage and waste quantification, and waste categorization
- tabulation of DD quantities handled by various waste management options (e.g., DD recycled, DD disposed in landfills)
- tracking the flow path of DD from point of generation to final end-use market or disposal (i.e., track the transfer of waste ownership)

### Achieve speedy DD cleanup

<table>
<thead>
<tr>
<th>Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>protect public health and safety</td>
</tr>
<tr>
<td>return to normalcy</td>
</tr>
<tr>
<td>minimize traffic problems (e.g., excessive queuing at recycling facilities)</td>
</tr>
</tbody>
</table>

### Objective Achievement Requirements

- issuing timely demolition permits that eliminate imminent hazards, and prevent DD surges
- additional processing facilities and temporary storage sites
- reinstatement of all laws and regulations following the end of emergency phase
12.6.5.3 Implementation Options
A series of scenarios is used to develop a range of strategic options for DD management. The scenarios are based on the increasing severity of earthquake damage. The twelve-level Modified Mercalli Intensity (MMI) scale (defined in Appendix 12.10-C in Section 12.10) is used to assist in defining the severity of earthquake damage of each scenario. The following are the details of the five damage severity scenarios.

**Damage Characteristics**

- **Scenario 1 (lower boundary, base scenario)**
  - minimal structural and non-structural damage
  - MMI=VI-VII
  - DD generation confined to isolated concentration points
  - no building demolitions required
  - minimal quantities of debris on streets
  - all transportation routes and links functional

- **Scenario 2**
  - up to 500,000 tonnes of DD generated (i.e., half of the average annual regular DLC waste quantity)
  - MMI=VIII
  - concentrations of DD in a number of areas throughout the region
  - some structural damage requiring building demolitions and/or structural repairs
  - some debris on streets
  - all essential transportation routes and links functional

- **Scenario 3**
  - from 500,000 to 1,000,000 tonnes of DD generated (i.e., half to one year of the average annual regular DLC waste quantity)
  - MMI=IX
  - large concentrations of DD in a number of areas throughout the region, with incidental DD generation in other areas
  - significant structural damage or failure requiring building demolitions, with some building collapses
  - significant debris on streets
  - some failures along essential transportation routes and links

- **Scenario 4**
  - from 1,000,000 tonnes of DD generated to a significant portion of the city still remaining in-tact and/or functional
  - MMI=X
  - extensive DD generation throughout the region
  - extensive structural damage or failure requiring building demolitions, with numerous building collapses
  - many streets blocked with debris
  - extensive failures along essential transportation routes and links

- **Scenario 5 (upper boundary, catastrophic event)**
  - most of the city in ruins
  - MMI=XI-XII
  - DD generation in all areas throughout the region
  - most buildings collapsed, or with structural damage or failure requiring building demolitions
  - most streets blocked with debris
  - essentially all transportation routes and links affected and non-functional
The DD management actions that should be undertaken by the local governments in each of the five damage severity scenarios are detailed below. Each successive scenario presents the management actions that should be undertaken in addition to, or in place of the management actions suggested in the preceding scenario.

**Damage Severity Scenario 1 (lower boundary, base scenario)**

At the minimum,

- **during the initial response (e.g., during the state of emergency)**
  - implement earthquake contingency plan at solid waste disposal facilities
  - ensure landfill operators are aware of, and are executing earthquake response procedure
  - stockpile incoming debris in pre-designated areas at landfills, and not on the working face along with other regular waste
  - weigh and document earthquake related waste (i.e., DD)
  - implement disaster payment procedure for work performed and to cover disposal costs

- **when the state of emergency is lifted**
  - reinstate all laws and regulations that may have been suspended or amended during the emergency response phase, in order to restore a sense of normalcy to the public

- endorse only minimal City intervention by:
  - removal of debris from streets
  - promoting the regular solid waste management goals
  - enforcing corresponding requirements
    - set tipping fees at processing, recycling and disposal facilities in order to control flow of waste to preferred facilities, thereby diverting from landfills
    - require separation and segregation of DD (with penalty for non-compliance) by generators and contractors at point of generation from the beginning of the debris removal effort
  - conducting initial damage and waste quantification, and waste characterization

- provide information, and educate contractors and generators about:
  - regional DD management strategy principles and goals
  - diversions methods (e.g., source separation for recycling)
  - generators' responsibility for their own DD cleanup (i.e., removal and disposal)

- seek out end-use markets for processed waste materials (examples are provided in Appendix 12.10-D in Section 12.10)

- provide drop-off points for HW and HHW

- offer City assistance to individuals who otherwise are incapable (physically and/or financially) of cleaning up their own DD
**Damage Severity Scenario 2**

In addition to the DD management actions outlined in Scenario 1,

- provide City assistance for:
  - overseeing required building demolitions (e.g., City inspectors, City funds)
    - timely demolition permits to include salvage and recycling requirements, which will also help control the flow of DD
  - coordinating the DD removal and disposal effort between generators and contractors
  - repair of any damage to transportation routes and links

- avoid moving DD from point of generation without having a final destination for waste materials, including potential end-use markets

- consider designating temporary storage sites for unexpected surges of DD that processing and recycling facilities are unable to handle, rather than transporting these waste materials for temporary storage at the MSW landfill
  - keeping stockpiles of DD near processing and recycling facilities on a short-term basis during peak periods will save transportation costs, and help ensure that these materials are processed/recycled

---

**Damage Severity Scenario 3**

In addition to the DD management actions outlined in Scenarios 1 and 2,

- designate temporary storage sites for:
  - debris when processing and recycling facilities are closed or overwhelmed, and unable to accept the additional quantities
  - salvageables
  - processed waste materials awaiting end-use markets

- promote and assist with mobilization of additional processing and recycling capacity, and new facilities

- investigate alternative disposal options

- investigate the need for mutual aid outside of the region, and the availability of assistance from neighbouring jurisdictions

- organize and provide temporary transportation alternatives
  - ferry and/or barge access
  - rail access
**Damage Severity Scenario 4**

In addition to the DD management actions outlined in Scenarios 1 through 3,

- look to the provincial and federal governments for:
  - financial assistance for a large scale recovery program
    - detailed DD quantification and characterization will be required
  - manpower and equipment augmentation
- mobilize and fund a "one-time" sweep of streets (by address) to collect only source-separated materials
  - may require repetition at monthly or bi-monthly intervals, or on an as-needed basis

**Damage Severity Scenario 5**

Since this scenario may appear to be virtually unimaginable, it will require rather drastic management solutions. Utilizing a number of the ideas suggested by the DD management actions listed in Scenarios 1 through 4,

- consider the following alternatives:
  - level the city and re-build on top of rubble
  - reuse majority of DD materials in reconstruction
    - reconstruction and cleanup of debris occurring simultaneously, and at the same rate
  - remove all DD from the affected area, deposit it into an adjacent area, and rebuild city "from scratch"
    - utilize stockpiled materials in reconstruction

- Contingency Provision

If funding for DD removal and disposal becomes available to the local government for the implementation of a city-wide cleanup program, these funds should be used for source-separated materials only. This will promote source separation and diversion from landfills of materials that are easily managed in other ways than landfill disposal. Commingled waste handling and disposal should be paid for by the generator.
12.7 Conclusions and Recommendations

The current solid waste management system available within the GVRD has been reviewed. It currently lacks specific provisions for the management of solid waste following a disaster, such as an earthquake. Emergency plans for the region also lack consideration for post-earthquake solid waste management, both in the operational approach, and in the provision of funds.

The Strategy Options Report (Report) is an integral part of the proposed Post-Earthquake Solid Waste Management Plan (Plan). The Report presents a management strategy for all solid waste generated in relation to an earthquake that impacts the Lower Mainland. The MSW strategy reflects the goals and basic principles of the current MSW system. The DD strategy is designed to also preserve certain basic solid waste management principles. The DD strategy sets out a number of objectives, which, when met, will ensure the preservation of the basic principles. The DD strategy also provides a number of options, spanning a wide range of damaging earthquake effects (i.e., damage severity scenarios). The final implementation details of the strategy, which will be outlined in an Operational Plan, will depend on the actual earthquake event.

Furthermore, the Report recognizes that the strategy needs to remain flexible and adaptable during implementation. Initially, the length of the post-earthquake solid waste management program will need to be set, based on the estimates of the extent of damage, and resulting quantities of solid waste. Frequent reevaluation of program activities, and adjustments in strategies must be allowed. The endpoint to the program will require a final review and account of all successes and failures that occurred throughout the duration of the earthquake cleanup effort.

The effects of an actual earthquake event will dictate which of the strategic options presented in the Report are implemented, and to what degree. Therefore, the Plan also provides an Action Plan Procedure which is independent of the magnitude of the earthquake damage. The Action Plan is presented in Section 10 of the Thesis.

The management strategy presented in the Strategy Options Report requires that certain preparatory work be completed prior to an earthquake, and the implementation of the strategy. There are 13 Preplanning Actions that are recommended in the Plan. The Preplanning Actions are outlined in Section 11 of the Thesis. The completion of the Preplanning Actions is crucial to the success of recovery from an earthquake.
### 12.8 Definition of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>5R hierarchy of waste management</td>
<td>reduce, reuse, recycle, recover, residual management (landfill)</td>
</tr>
<tr>
<td>C&amp;D waste (US terminology)</td>
<td>wastes originating from construction and demolition activities</td>
</tr>
<tr>
<td>commingled DD</td>
<td>DD waste handled as one waste type, but comprising of a number of material types mixed together</td>
</tr>
<tr>
<td>composting</td>
<td>regular MSW context: controlled biological decomposition of organic wastes at backyard, neighbourhood, and regional facilities</td>
</tr>
<tr>
<td></td>
<td>DD context: controlled biological decomposition of yard wastes, and green wastes at regional or privately owned facilities</td>
</tr>
<tr>
<td>DD</td>
<td>disaster debris; wastes generated as a result of, or in relation to a disaster (i.e., earthquake); excluding regular MSW; very similar</td>
</tr>
<tr>
<td></td>
<td>in nature and composition to regular DLC wastes; includes wastes associated with reconstruction after an earthquake</td>
</tr>
<tr>
<td>disposable</td>
<td>any product or material which is designated to be thrown away; includes residual materials from processing/recycling facilities</td>
</tr>
<tr>
<td>disposal</td>
<td>processes and actions required to handle wastes after removal from point of generation; includes deposition at temporary storage sites,</td>
</tr>
<tr>
<td></td>
<td>all diversion methods, and final disposal in landfills</td>
</tr>
<tr>
<td>diversion</td>
<td>process of keeping waste materials with potentially beneficial uses out of MSW landfills (e.g., by reuse, recycling, energy recovery),</td>
</tr>
<tr>
<td></td>
<td>and thereby, conserving MSW landfills for MSW</td>
</tr>
<tr>
<td>DLC waste</td>
<td>wastes originating from demolition, landclearing and construction activities</td>
</tr>
<tr>
<td>generator</td>
<td>any person or group of persons (e.g., residents), or business, or activity that contributes to the production of waste and/or DD</td>
</tr>
<tr>
<td>HHW</td>
<td>household hazardous waste; wastes originating from residential, IC&amp;I sources</td>
</tr>
<tr>
<td>HW</td>
<td>hazardous waste; dangerous goods, which pose health and safety risks, intended for treatment, disposal or storage</td>
</tr>
<tr>
<td>IC&amp;I waste</td>
<td>wastes originating from industrial, commercial and institutional sources</td>
</tr>
<tr>
<td>MSW</td>
<td>municipal solid waste originating from residential sources; excluding DLC wastes</td>
</tr>
<tr>
<td>point of generation</td>
<td>source of waste; site where earthquake related damage has occurred, resulting in generation of waste</td>
</tr>
<tr>
<td>post-earthquake</td>
<td>waste generated as a result of, or in relation to an earthquake event; also includes wastes defined as &quot;regular&quot;</td>
</tr>
<tr>
<td>processing</td>
<td>receiving, sorting, cleaning and/or packaging of waste materials for transport to subsequent recycling facilities, or to end-use markets</td>
</tr>
<tr>
<td>recovery</td>
<td>reclaiming of recyclable components and/or energy from post-collection solid waste stream</td>
</tr>
<tr>
<td>recycling</td>
<td>separation from the solid waste of products which are no longer usable in their present form, and use of the material content in the</td>
</tr>
<tr>
<td></td>
<td>manufacture of new products; includes composting</td>
</tr>
<tr>
<td>reduce</td>
<td>decreasing the volume, weight, or toxicity of material that enters the solid waste stream</td>
</tr>
<tr>
<td>regular</td>
<td>pre-earthquake composition and volume of wastes and/or materials; on-going, independent of an earthquake event</td>
</tr>
</tbody>
</table>

*Greater Vancouver Post-Earthquake Solid Waste Management Strategy* 
*March 2000*
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>regular DLC waste</td>
<td>pre-earthquake composition and volume of wastes originating from demolition, landclearing and construction activities</td>
</tr>
<tr>
<td>regular IC&amp;I waste</td>
<td>pre-earthquake composition and volume of wastes originating from industrial, commercial and institutional sources</td>
</tr>
<tr>
<td>regular MSW</td>
<td>pre-earthquake composition and volume of municipal solid waste originating from residential sources; excluding regular DLC wastes</td>
</tr>
<tr>
<td>residue management</td>
<td>disposal, in a responsible and environmentally safe manner, of waste materials from reduction, reuse, recycling, and recovery activities; includes alternative disposal options (alternative to disposal at MSW and DLC landfills)</td>
</tr>
<tr>
<td>reuse</td>
<td>repeated use of a product in the same form, not necessarily for the same purpose</td>
</tr>
<tr>
<td>solid waste facility</td>
<td>recycling facility; resource recovery facility; transfer station; incinerator; disposal facility</td>
</tr>
<tr>
<td>source-separated DD</td>
<td>DD waste sorted by specified material types at point of generation</td>
</tr>
<tr>
<td>temporary storage site</td>
<td>specifically designated area for stockpiling of DD or regular MSW, with potential provisions for processing</td>
</tr>
</tbody>
</table>

Glossary of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>APEBC</td>
<td>Association of Professional Engineers of British Columbia (Provincial) (presently, APEGBC - Association of Professional Engineers and Geoscientists of B.C.)</td>
</tr>
<tr>
<td>CMHC</td>
<td>Canadian Mortgage and Housing Corporation</td>
</tr>
<tr>
<td>DFA</td>
<td>Disaster Financial Assistance (Provincial)</td>
</tr>
<tr>
<td>DAAA</td>
<td>Disaster Financial Assistance Arrangements (Federal)</td>
</tr>
<tr>
<td>DPRC</td>
<td>Disaster Preparedness Resources Centre (UBC)</td>
</tr>
<tr>
<td>EOC</td>
<td>Emergency Operations Centre</td>
</tr>
<tr>
<td>EOO</td>
<td>Emergency Operations Organization (US Local)</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency (US Federal or State)</td>
</tr>
<tr>
<td>EPC</td>
<td>Emergency Preparedness Canada (Federal)</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency (US Federal)</td>
</tr>
<tr>
<td>GFP</td>
<td>Straight of Georgia-Juan de Fuca-Puget Sound</td>
</tr>
<tr>
<td>GSC</td>
<td>Geological Survey of Canada</td>
</tr>
<tr>
<td>GST</td>
<td>Goods and Services Tax (Federal)</td>
</tr>
<tr>
<td>GVRD</td>
<td>Greater Vancouver Regional District (Regional)</td>
</tr>
<tr>
<td>IWMB</td>
<td>Integrated Waste Management Board (US State)</td>
</tr>
<tr>
<td>MFLR</td>
<td>Multi-Family Low-Rise</td>
</tr>
<tr>
<td>MMI</td>
<td>Modified Mercalli Intensity</td>
</tr>
<tr>
<td>NRCan</td>
<td>Natural Resources Canada (Federal)</td>
</tr>
<tr>
<td>PEP</td>
<td>Provincial Emergency Program (Provincial)</td>
</tr>
<tr>
<td>PGA</td>
<td>Peak Ground Acceleration</td>
</tr>
<tr>
<td>RILEM</td>
<td>International Union of Testing and Research Laboratories for Materials and Structures</td>
</tr>
<tr>
<td>SEIMS</td>
<td>Standardized Emergency Management System (US State)</td>
</tr>
<tr>
<td>SFA</td>
<td>Single-Family Detached</td>
</tr>
<tr>
<td>SFD</td>
<td>Single-Family Attached</td>
</tr>
<tr>
<td>SPARK</td>
<td>Strategic Planning for Applied Research and Knowledge</td>
</tr>
<tr>
<td>SPCA</td>
<td>Society for the Prevention of Cruelty to Animals</td>
</tr>
<tr>
<td>UBC</td>
<td>University of British Columbia</td>
</tr>
</tbody>
</table>

Greater Vancouver Post-Earthquake Solid Waste Management Strategy
March 2000
12.9 References/Further Reading


Brett, Peter. (May, 1999). Chief Bridge Engineer, Bridge Branch, Ministry of Transportation and Highways.


Galambos, Allan. (May, 1999). South Coast Regional Office, Ministry of Transportation and Highways.


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Robertson, Merve. (May, 1999). Structures Department, City of Vancouver.


Sztto, Bill. (May, 1999). Seismic Rehab Engineer, Ministry of Transportation and Highways.


### Authorized Solid Waste Disposal Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Contact Information</th>
<th>Hours of Operation</th>
<th>Foot Print</th>
<th>Authorized Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver Landfill</td>
<td>City of Vancouver 946-2220 5400 - 72nd Street Delta</td>
<td>M-F 7:30 am - 6:00 pm Sat-Sun 9:00 am - 6:00 pm</td>
<td>635 ha.</td>
<td>20 million tonnes as of 1997</td>
</tr>
<tr>
<td>Ecowaste Landfill</td>
<td>Ecowaste Industries Ltd. 276-9511 15111 Williams Road Richmond</td>
<td>M-S 6:00 am - 7:00 pm Sun 7:00 am - 7:00 pm</td>
<td>166 ha.</td>
<td>3 million tonnes as of 1995/1996</td>
</tr>
<tr>
<td>Cache Creek Landfill</td>
<td>Wastech Services Ltd. 457-6553 1113 Maclean Drive Cache Creek</td>
<td>Daily 24 hours</td>
<td>48 ha.</td>
<td>3.5 million tonnes</td>
</tr>
<tr>
<td>Robert Brown Landfill</td>
<td>Delta Shake and Shingle 946-1801 8950 River Road Delta</td>
<td>M-S 6:00 am - 10:00 pm Sun closed</td>
<td>10.3 ha.</td>
<td>10,000 tonnes</td>
</tr>
<tr>
<td>Mission Landfill</td>
<td>District of Mission 826-9008 32000 Dewdney Trunk Road Mission</td>
<td>M-F 7:00 am - 5:00 pm Sat 8:00 am - 5:00 pm Sun closed</td>
<td>7 ha.</td>
<td>80,000 tonnes</td>
</tr>
<tr>
<td>Burnaby Incinerator</td>
<td>Montenay Ltd. 521-1025 5150 Thorne Avenue Burnaby</td>
<td>M-F 3:00 am - 6:00 pm Sat-Sun 7:00 am - 6:00 pm</td>
<td>N/A</td>
<td>240,000 tonnes per year</td>
</tr>
</tbody>
</table>

(Personal Communication, Ken Carrusca, Stuart Somerville, Mike Stringer, and JELC Disaster Debris Subcommittee)
### Authorized Solid Waste Transfer Stations

<table>
<thead>
<tr>
<th>Facility</th>
<th>Contact Information</th>
<th>Hours of Operation</th>
<th>Authorized Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver Transfer Station</td>
<td>City of Vancouver 323-7737 377 West Kent Avenue Vancouver</td>
<td>M-F 6:30 am - 6:00 pm Sat-Sun 9:00 am - 5:00 pm</td>
<td>1,200 tonnes per day max. of 1,000 tonnes on site at any time</td>
</tr>
<tr>
<td>Coquitlam Transfer Station</td>
<td>Wastech Services Ltd. 521-1715 1200 United Blvd. Coquitlam</td>
<td>M-F 6:30 am - 6:00 pm Sat 8:00 am - 5:00 pm Sun 10:00 am - 5:00 pm</td>
<td>1,200 tonnes per day max. of 3,000 tonnes on site at any time</td>
</tr>
<tr>
<td>North Shore Transfer Station</td>
<td>Wastech Services Ltd. 929-5471 30 Riverside Drive North Vancouver</td>
<td>M-S 8:00 am - 5:00 pm Sun 10:00 am - 5:00 pm</td>
<td>1,000 tonnes per day max. of 2,000 tonnes on site at any time</td>
</tr>
<tr>
<td>Maple Ridge Transfer Station</td>
<td>S.S.G. Holdings 466-9277 10092 - 236th Street Maple Ridge</td>
<td>M-F 9:00 am - 5:00 pm Sat 8:00 am - 5:00 pm Sun 10: am - 5:00 pm</td>
<td>50 tonnes per day max. of 9 tonnes on site at any time</td>
</tr>
<tr>
<td>Urban Woodwaste Transfer Station</td>
<td>Urban Woodwaste Recyclers Ltd. 327-5052 110 East 69th Street Maple Ridge</td>
<td>M-F 4:00 am - 10:30 pm Sat 6:00 am - 4:00 pm Sun closed</td>
<td>300 tonnes per day max. of 1,700 tonnes on site at any time</td>
</tr>
<tr>
<td>Inner-City Transfer Station</td>
<td>Inner-City Demolition Ltd. 327-0957 11640 Twigg Place Mitchell Island, Richmond</td>
<td>M-S 7:00 am - 5:00 pm Sun closed</td>
<td>260 tonnes per day max. of 1,000 tonnes on site at any time</td>
</tr>
<tr>
<td>Langley Transfer Station</td>
<td>Chinook Waste Systems 856-3020 1070 - 272nd Street Aldergrove</td>
<td>M-S 8:00 am - 5:00 pm Sun 10:00 am - 5:00 pm</td>
<td>70 tonnes per day max. of 8 tonnes on site at any time</td>
</tr>
<tr>
<td>Matsqui Transfer Station</td>
<td>Wastech Services Ltd. 853-0508 33621 Valley Road Abbotsford</td>
<td>M-F 7:00 am - 5:00 pm Sat 8:00 am - 5:00 pm Sun closed</td>
<td>700 tonnes per day max. of 1,000 tonnes on site at any time</td>
</tr>
</tbody>
</table>

(Personal Communication, Ken Carrusca, and JELC Disaster Debris Subcommittee)

### Appendix 12.10-B: Status of Seismic Retrofitting of Lower Mainland Bridges

<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>Route</th>
<th>Jurisdiction</th>
<th>Retrofitting Required</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lions Gate Bridge</td>
<td>99</td>
<td>Province</td>
<td>Yes</td>
<td>start soon, expected finish at end of 2000</td>
</tr>
<tr>
<td>Second Narrows Bridge</td>
<td>1</td>
<td>Province</td>
<td>Yes</td>
<td>started, expected finish at end of 2000</td>
</tr>
<tr>
<td>Oak Street Bridge</td>
<td>99</td>
<td>Province</td>
<td>Yes</td>
<td>started, expected finish at end of 2000</td>
</tr>
<tr>
<td>Knight Street Bridge</td>
<td></td>
<td>GVTA</td>
<td>Yes</td>
<td>assessment has been done, no detailed design</td>
</tr>
<tr>
<td>Alex Fraser Bridge</td>
<td>91 A</td>
<td>Province</td>
<td>No</td>
<td>new bridge &gt;10 years old (1984-1986)</td>
</tr>
<tr>
<td>Queensborough Bridge</td>
<td>91 A</td>
<td>Province</td>
<td>No</td>
<td>done, finished in 1997</td>
</tr>
<tr>
<td>Pattullo Bridge</td>
<td>99A</td>
<td>GVTA</td>
<td>Yes</td>
<td>assessment has been done, no detailed design</td>
</tr>
<tr>
<td>Port Mann Bridge</td>
<td>1</td>
<td>Province</td>
<td>Yes</td>
<td>construction to start in 2000, duration of 1-2 years</td>
</tr>
<tr>
<td>Mission Bridge</td>
<td>to Abbotsford</td>
<td>Province</td>
<td>Yes</td>
<td>under assessment</td>
</tr>
<tr>
<td>Pitt River Bridge</td>
<td>7</td>
<td>Province</td>
<td></td>
<td>under assessment</td>
</tr>
<tr>
<td>George Massey Tunnel</td>
<td>99</td>
<td>Province</td>
<td>Yes</td>
<td>plan to start assessment in fall 1999, pending funds</td>
</tr>
<tr>
<td>Arthur Lang Bridge</td>
<td>to Sea Island, Airport</td>
<td>Airport Authority (Federal)</td>
<td>No</td>
<td>done, finished in 1997-1998</td>
</tr>
<tr>
<td>Burrard Street Bridge</td>
<td>Burrard Street</td>
<td>Vancouver</td>
<td>Yes</td>
<td>being completed</td>
</tr>
<tr>
<td>Granville Street Bridge</td>
<td>Granville Street</td>
<td>Vancouver</td>
<td>No</td>
<td>done</td>
</tr>
<tr>
<td>Cambie Street Bridge</td>
<td>Cambie Street</td>
<td>Vancouver</td>
<td>No</td>
<td>new bridge &gt;10 yrs old, no need</td>
</tr>
<tr>
<td>No. 2 Road Bridge</td>
<td>No. 2 Road</td>
<td>Richmond</td>
<td>No</td>
<td>new bridge 4 yrs old, no need</td>
</tr>
<tr>
<td>Moray Bridge (Middle Arm)</td>
<td>Sea Island Way</td>
<td>Richmond</td>
<td></td>
<td>nothing has been done, no planning, not a major bridge</td>
</tr>
<tr>
<td>Dinsmore Bridge</td>
<td>from Sea Island, Airport</td>
<td>Richmond or Federal</td>
<td></td>
<td>nothing has been done, no planning, not a major bridge</td>
</tr>
</tbody>
</table>

1Greater Vancouver Transportation Authority
(Personal Communication, Peter Brett, Allan Galambos, Merve Robertson, and Bill Szto)
Appendix 12.10-C: Modified Mercalli Intensity Scale
The twelve unit Modified Mercalli Intensity (MMI) scale is used to qualify the severity of ground effects, structural and interior damage, and personal observations and sensations during an earthquake. Physical damage resulting in generation of DD occurs at MMI of VI and higher.

### Modified Mercalli Intensity Scale

<table>
<thead>
<tr>
<th>Value</th>
<th>Description of Earthquake Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>Felt by everyone.</td>
</tr>
<tr>
<td></td>
<td>Windows, dishes and glassware are broken; liquids spill; books and other standing objects fall; pictures are knocked from walls; furniture is moved or overturned.</td>
</tr>
<tr>
<td></td>
<td>Poorly built buildings may be damaged, and weak plaster will crack.</td>
</tr>
<tr>
<td>VII</td>
<td>Damage is negligible in buildings of very good design and construction, slight to moderate in well-built ordinary structures, considerable in poorly built or designed structures.</td>
</tr>
<tr>
<td></td>
<td>Some chimneys are broken; interiors and furnishings experience considerable damage; architectural ornaments fall.</td>
</tr>
<tr>
<td></td>
<td>Small slides occur along sand or gravel banks of water channels; concrete irrigation ditches are damaged.</td>
</tr>
<tr>
<td>VIII</td>
<td>Damage is slight in specially designed earthquake-resistant structures, considerable in well-built ordinary buildings.</td>
</tr>
<tr>
<td></td>
<td>Poorly built or designed buildings experience partial collapses.</td>
</tr>
<tr>
<td></td>
<td>Numerous chimneys fall; the walls of frame buildings are damaged; interiors experience heavy damage.</td>
</tr>
<tr>
<td></td>
<td>Frame houses that are not properly bolted down may move on their foundations.</td>
</tr>
<tr>
<td></td>
<td>Trees are damaged.</td>
</tr>
<tr>
<td>IX</td>
<td>Interior damage is considerable in specially designed earthquake-resistant structures.</td>
</tr>
<tr>
<td></td>
<td>Well-built ordinary buildings suffer severe damage with partial collapses; frame structures are thrown out of plumb, or shifted off of their foundations.</td>
</tr>
<tr>
<td></td>
<td>Unreinforced masonry buildings collapse.</td>
</tr>
<tr>
<td></td>
<td>Some underground pipes are broken.</td>
</tr>
<tr>
<td>X</td>
<td>Most masonry and many frame structures are destroyed.</td>
</tr>
<tr>
<td></td>
<td>Specially designed earthquake-resistant structures may suffer serious damage.</td>
</tr>
<tr>
<td></td>
<td>Some well-built bridges are destroyed, and dams, dykes and embankments are seriously damaged.</td>
</tr>
<tr>
<td></td>
<td>Large landslides are triggered by the shock.</td>
</tr>
<tr>
<td></td>
<td>Rails are bent slightly.</td>
</tr>
<tr>
<td></td>
<td>Many buried pipes and conduits are broken.</td>
</tr>
<tr>
<td>XI</td>
<td>Few, if any masonry structures remain standing.</td>
</tr>
<tr>
<td></td>
<td>Other structures are severely damaged.</td>
</tr>
<tr>
<td></td>
<td>Rails are severely bent.</td>
</tr>
<tr>
<td></td>
<td>Underground pipe lines and conduits are put completely out of service.</td>
</tr>
<tr>
<td>XII</td>
<td>Damage is total, with practically all works of construction severely damaged or destroyed.</td>
</tr>
<tr>
<td></td>
<td>Heavy objects are thrown into the air, and larger rock masses are displaced.</td>
</tr>
</tbody>
</table>

(Yanev, 1990.)
There are typically several distinct areas within an earthquake affected region, which correspond to varying MMI values (e.g., ranging from MMI of VI to VII). For example, Figure 12-4 illustrates the range of MMI values for the 1946 Vancouver Island Earthquake. The multiple MMI values for a single earthquake event are due to:

- the relative distance of an area from the epicentre and the active fault;
- the local soil conditions; and
- the state of earthquake preparedness in terms of seismic design of structures and the mobility of building contents within an area.

![Figure 12-4: Range of Modified Mercalli Intensity Values for 1946 Vancouver Island Earthquake (NRCan, 1999d)](image_url)
# Appendix 12.10-D: Ideas for End-Use Markets for Processed Waste Materials

## End-Use Markets

<table>
<thead>
<tr>
<th>Processed Waste Material</th>
<th>End-Use Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>asphalt</td>
<td>recycle in-situ</td>
</tr>
<tr>
<td>brick</td>
<td>crush and reuse in road base material</td>
</tr>
<tr>
<td></td>
<td>reuse whole bricks</td>
</tr>
<tr>
<td>burnt wood</td>
<td>grind up and compost for use as topsoil additive</td>
</tr>
<tr>
<td>carpet</td>
<td>use as a component to produce other products:</td>
</tr>
<tr>
<td></td>
<td>- auto parts</td>
</tr>
<tr>
<td></td>
<td>- plastic lumber</td>
</tr>
<tr>
<td></td>
<td>use as a fuel supplement in large industrial and utility boilers</td>
</tr>
<tr>
<td></td>
<td>reprocess into new carpet yarns by re-polymerization</td>
</tr>
<tr>
<td></td>
<td>reuse in subsidized housing projects, and in animal shelters</td>
</tr>
<tr>
<td>concrete</td>
<td>crush and reuse:</td>
</tr>
<tr>
<td></td>
<td>- in road base and subbase material</td>
</tr>
<tr>
<td></td>
<td>- as gravel road surfacing</td>
</tr>
<tr>
<td></td>
<td>- as base for building foundations</td>
</tr>
<tr>
<td></td>
<td>- as fill for utility trenches</td>
</tr>
<tr>
<td>drywall/gypsum</td>
<td>reuse as forms for gunite application</td>
</tr>
<tr>
<td></td>
<td>remove paper, and recycle gypsum into new drywall</td>
</tr>
<tr>
<td></td>
<td>use as soil amendment in:</td>
</tr>
<tr>
<td></td>
<td>- general agriculture</td>
</tr>
<tr>
<td></td>
<td>- mushroom growing</td>
</tr>
<tr>
<td></td>
<td>- forestry and mine reclamation</td>
</tr>
<tr>
<td></td>
<td>- nurseries, parks, and recreation areas</td>
</tr>
<tr>
<td></td>
<td>- residential lawns (sod)</td>
</tr>
<tr>
<td></td>
<td>- golf courses</td>
</tr>
<tr>
<td></td>
<td>use as compost, cement, and stucco additives</td>
</tr>
<tr>
<td></td>
<td>use for sludge bulking and drying</td>
</tr>
<tr>
<td></td>
<td>use in water treatment to settle dirt and clay particles</td>
</tr>
<tr>
<td></td>
<td>use in manure treatment to reduce odour</td>
</tr>
<tr>
<td></td>
<td>combine with wood shavings, and use as animal bedding</td>
</tr>
<tr>
<td></td>
<td>use in flea powder production</td>
</tr>
<tr>
<td></td>
<td>use as grease absorber in factories and mechanics' shops</td>
</tr>
<tr>
<td></td>
<td>use as athletic field marker</td>
</tr>
<tr>
<td>scrap metal</td>
<td>shred and sell to steel mills and smelters</td>
</tr>
<tr>
<td>wood</td>
<td>use for boiler fuel</td>
</tr>
<tr>
<td></td>
<td>grind up and use as:</td>
</tr>
<tr>
<td></td>
<td>- mulch</td>
</tr>
<tr>
<td></td>
<td>- animal bedding</td>
</tr>
<tr>
<td></td>
<td>- soil conditioner</td>
</tr>
<tr>
<td></td>
<td>- sludge bulking medium</td>
</tr>
<tr>
<td></td>
<td>- compost</td>
</tr>
<tr>
<td></td>
<td>chip up, and use in production of particle board</td>
</tr>
</tbody>
</table>
PART VI: CONCLUSIONS AND RECOMMENDATIONS
13. CONCLUSIONS AND RECOMMENDATIONS

Preplanning for the post-earthquake management of solid waste is a relatively new field, with very limited experience, while the occurrence of natural disasters is abundant. The opportunity for gaining experience in planning for earthquake recovery and disaster debris management is tremendous.

The Thesis presents the research into the documented and undocumented experience of earthquake recovery, and recovery planning prior to an earthquake occurrence. The documented information was obtained from available literature, whereas the undocumented experience was retrieved during a research trip to the locations of the most recent earthquakes in California. The lessons learned were used to identify and investigate the numerous earthquake recovery issues which have solid waste management implications. Upon gaining a general understanding of the seismic situation in the Lower Mainland, the current systems for solid waste management, disaster recovery funding, and emergency response were examined. Solutions to evident deficiencies of the current systems in addressing earthquake recovery were proposed. As the final product of the Thesis, a comprehensive post-earthquake solid waste management plan was prepared. The Plan includes an action plan procedure for pre- and post-earthquake activities, and a detailed account of the required pre-earthquake mitigative actions.

In the development of the Thesis and the Plan, much of the focus gravitated towards the earthquake experience in California, since this region is Lower Mainland's closest neighbour in space, life style and standards. The limited research conducted into earthquake recovery elsewhere in the world provided very unconventional and sometimes politically unpopular alternatives to debris management, which may in fact be worth considering. Extending the debris management research to more distant locations and cultures would be beneficial, and would generate additional interesting results.

Having had a relatively clear understanding of the issues involved in post-earthquake solid waste management at the onset of the thesis process, a more defined and strict research methodology would have been an asset. A more confined research methodology may have provided more systematic results, and decreased the scope of the work at an earlier stage. However, the sparse experience of planning for the management of post-earthquake solid waste prior to an earthquake is not very conducive to conventional or well-defined research methodology.

There were two breakthrough points in the strategy development process: the presentation of the topic at the 8th Canadian Conference on Earthquake Engineering; and the research trip to California. Had these events taken place at an earlier stage in the thesis, it would have greatly expedited the thesis process, and increased the extent of research into the feasibility of the proposed recovery strategies.

The Thesis Document contains a great deal of information, with varying degrees of relevancy to earthquake debris management planning. The Thesis is an excellent source for background information on debris management, as well as on other related issues, for example: seismicity; provision of funds for disaster recovery in Canada; preparedness for emergency response; and the benefits and shortfalls of the current solid waste management system in the Lower Mainland. The information in the Thesis can be used to re-evaluate current systems, and identify any apparent gaps that require filling.

The Post-Earthquake Solid Waste Management Plan has local and regional applications. Portions of the Plan can be used for any natural disaster that generates significant quantities of solid waste which have social, economic and environmental impacts. In the preparation of the Plan, the necessity and benefits of addressing earthquake related solid waste management issues on a regional basis were confirmed. Although the proposed strategy was prepared for the City of Vancouver, with financial contribution from the GVRD, in a region-wide disaster, such as an earthquake, the interdependence of Municipalities on one another, and their dependence on the Regional District was demonstrated.
PART VII: BIBLIOGRAPHY
14. BIBLIOGRAPHY - LITERATURE AND INTERNET REFERENCES


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http://www.city.vancouver.bc.ca/ctyclerk/cclerk/961126/a4.htm


¹ The exact date of document is unspecified. The provided date is the date of the last web page update or inferred from the contents of the document.


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March 2000


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