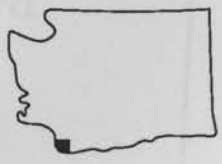
Relative Earthquake Hazard Map for the Vancouver, Washington, Urban Region

by Matthew A. Mabey, Ian P. Madin, and Stephen P. Palmer

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Geologic Map GM-42
December 1994

The information provided in this map cannot be substituted for a site-specific geotechnical investigation, which must be performed by qualified practitioners and is required to assess the potential for and consequent damage from soil liquefaction, amplified ground shaking, landsliding, or any other earthquake hazard.



Location of quadrangles

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

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Relative Earthquake Hazard Map for the Vancouver, Washington, Urban Region

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INTRODUCTION

During the late 1980s, the scientific understanding of earthquake hazards in the Vancouver metropolitan area advanced significantly. It is now widely accepted that damaging earthquakes much larger than any in the historical record are possible and that it will be necessary to employ a wide variety of mitigation measures to minimize economic losses and casualties resulting from these future earthquakes. These mitigation measures should be based on a thorough assessment of the likely extent and distribution of earthquake damage.

The accompanying mapping is a synthesis of our assessment of three specific hazards associated with future earthquakes in the Vancouver urban area—Plate 1 covers the western half, and Plate 2 covers the eastern half. They are presented as two halves of one map product intended to provide land-use planners, emergency-response personnel, business owners, and private citizens with a qualitative assessment of the *relative* degree of the earthquake hazard throughout the Vancouver area. The mapping covers the Vancouver and Orchards 7.5-minute quadrangles and the portions of the Portland and Mount Tabor 7.5-minute quadrangles in Washington State (Fig. 1). Similar relative earthquake hazard maps have been produced for the portions of the Portland and Mount Tabor 7.5-minute quadrangles in Oregon.

Three earthquake hazards were evaluated: soil liquefaction, amplification of ground shaking, and earthquake-induced landsliding. Maps delineating areas more or less susceptible to each of these hazards were merged into a combined hazard map (presented as Plates 1 and 2) for the urban area. In this combined hazard map, we segregated the study area into four hazard categories, ranging from the most hazardous (category A) to the least hazardous (category D). The rankings are relative because they can only be used to compare the combined hazard at a given location to that at some other location in the study area. These rankings cannot be used to predict the level of structural damage resulting from these hazards during an earthquake. The actual damage will depend on the location and size (magnitude) of the earthquake, the site-specific response of the soil and geologic material beneath the structure, and the construction details of the structure.

At present the potential earthquake sources in the Vancouver area are not sufficiently well understood to permit an exact assessment of the size and location of future earthquakes. Our assessment of the seismic hazards is based on detailed geologic mapping of the greater Vancouver region and state-of-the-practice analyses of specialized geophysical and geotechnical measurements. Plates 1 and 2 cannot be used to directly ascertain either (1) which of the hazards may affect a particular site during an earthquake or (2) the severity of these hazards and the likelihood of catastrophic consequences. *Only a site-specific geotechnical investigation performed by a qualified practitioner can adequately assess the potential for and consequent damage from soil liquefaction, amplified ground shaking, landsliding, or any other earthquake hazard.*

Each of the three earthquake hazards considered in this study is a distinct and separate phenomenon. When they act in concert, the severity of the total hazard dramatically increases. As an example, the buildings damaged or destroyed in the Marina District in San Francisco during the 1989 Loma Prieta earthquake were subject to both strongly amplified ground

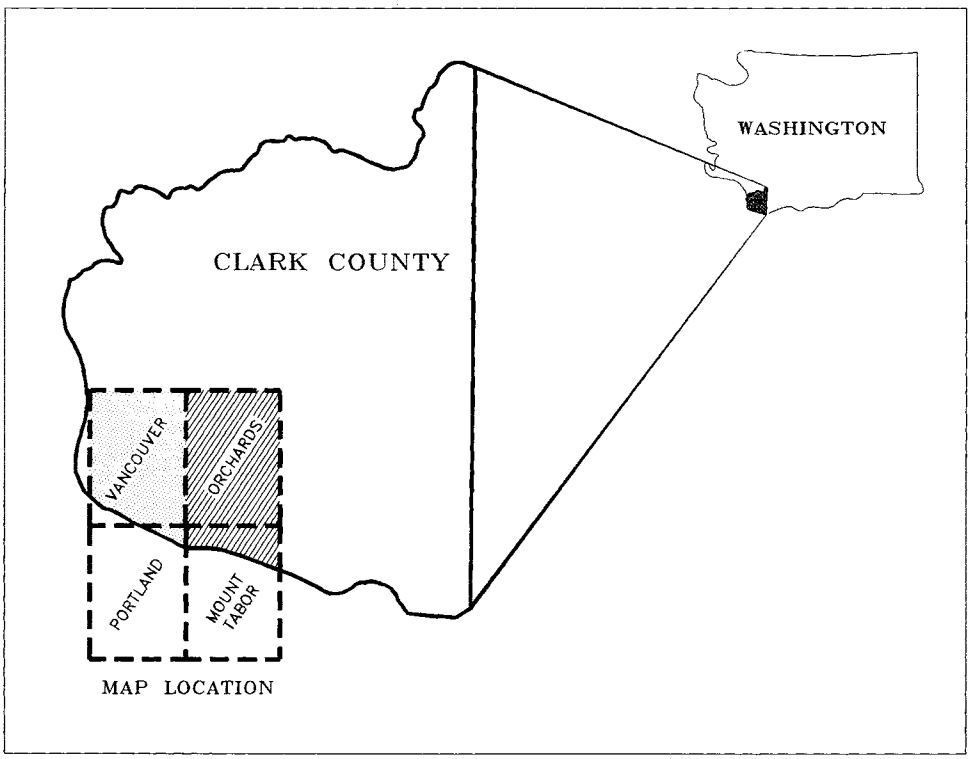

Figure 1. Location map showing the boundaries and names of the 7.5-minute quadrangles covering the Vancouver urban area and the study area. The stippled pattern corresponds to the area shown on Plate 1, and the hatched pattern corresponds to the area shown on Plate 2.

shaking and widespread liquefaction of the underlying soils. The distinction between each of the hazards is important to technical specialists, but it is not as useful to a nontechnical audience. We resolved that a single map expressing the total severity of the combined individual hazards would be the most effective way to present this information to nonspecialists.

All of the seismic hazard analyses were compiled and recast as a map using a Geographical Information System (GIS). Because these maps and the supporting analyses have been developed as data layers in a GIS environment, they can easily be incorporated with specific earthquake source information to produce scenarios that can be used in emergency response planning, facility siting studies, lifeline vulnerability assessment, etc.

SOURCES OF EARTHQUAKES

Scientific research conducted in the last decade has greatly increased our understanding of the sources of earthquakes that could cause major damage in western Washington. We now understand that three distinct types of earthquakes may affect the Vancouver region.

Crustal earthquakes occur between 5 to 10 miles (8 to 16 kilometers) below the surface along shallow faults in the Earth's crust; this is the type of earthquake that affects most of California. The Scotts Mills earthquake that occurred in northwest Oregon on March 25, 1993, was a shallow crustal earthquake. At magnitude 5.6, this was the largest earthquake in the Portland–Vancouver area since the 1962 magnitude 5.5 Portland earthquake, which was also a shallow crustal event that actually occurred beneath downtown Vancouver.

In the past few decades, earth scientists have recognized that the outer crust of the earth is composed of a small number of mobile plates. The Pacific Northwest (British Columbia, Washington, Oregon, and northern California) lies on the leading edge of the North America plate where it overrides the Juan de Fuca plate (Fig. 2). The process of plate convergence is termed subduction, and the boundary of the two plates is termed the subduction zone. Estimates of the relative movement between the Juan de Fuca and North America plates suggest that they are converging at approximately 1 to 1.5 inches per year (3 to 4 centimeters per year). Worldwide, subduction zones are typically expressed as deep submarine troughs, or trenches, that lie offshore of a landmass. In Washington and northern Oregon, the Cascadia subduction zone starts at a subdued trench about 50 miles (80 kilometers) offshore at the base of the continental slope. In the subduction zone, the Juan de Fuca plate is pushed beneath the North America plate (Fig. 2). Consequently, the Juan de Fuca plate is at a depth of approximately 30 miles (50 kilometers) beneath Vancouver.

Intraplate earthquakes occur as the Juan de Fuca plate breaks up beneath the North America plate. The 1949 and 1965 Puget Sound earthquakes (magnitudes 7.1 and 6.5, respectively) were intraplate earthquakes. Those who lived in Vancouver in 1949 may recall that Portland suffered some damaging and frightening effects during that earthquake, even though the epicenter was nearly 125 miles (200 kilometers) away. Small (magnitudes less than 3) intraplate earthquakes occur as far south as the Portland area, and there is some possibility that a large intraplate earthquake could occur closer to Vancouver.

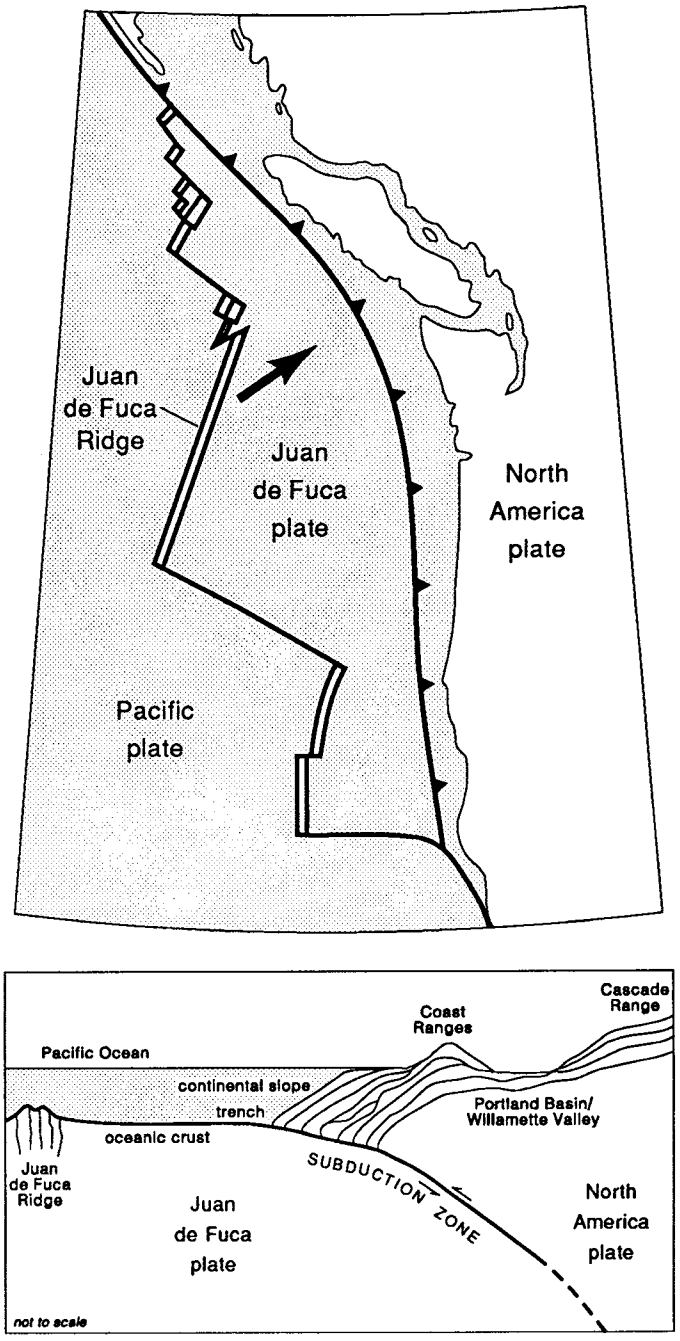

Figure 2. (Top) Map showing the geometry of the North America and Juan de Fuca plates. Arrow indicates the motion of the Juan de Fuca plate relative to a fixed (nonmoving) North America plate. The barbed line indicates the line of convergence of the two plates and the approximate location of the trench. (Bottom) A vertical slice through the earth (cross section) showing the Juan de Fuca plate thrust beneath the North America plate.

Subduction zone earthquakes occur when two converging plates, such as the Juan de Fuca and North America plates, become 'stuck' together along their interface directly down dip from the trench. As the plates continue to converge, the strain energy across this locked interface builds until the plates abruptly slip along the interface as the strain is released. This unlocking and slippage causes an earthquake. Subduction zone earthquakes are consistently among the most powerful recorded. For example, the 1964 Good Friday

earthquake in southern Alaska caused large land-level changes and severe damage throughout southern Alaska (including Anchorage), and the tsunami generated by the earthquake destroyed a number of coastal villages and towns in Alaska and the Pacific Northwest. The Good Friday earthquake had a magnitude of 9.2 and is the second largest earthquake this century.

Geological research initiated in the mid-1980s has demonstrated that large subduction zone earthquakes have occurred in the Pacific Northwest, although none has occurred during our historical record, which extends back about 200 years. These studies indicate that around the year 1700 there was a large earthquake on the Cascadia subduction zone along the Oregon and Washington coast. Geologic evidence left by this event includes indications of land-level changes similar to those near Anchorage in 1964, sand deposited by a large tsunami that immediately followed the earthquake, and signs of soil liquefaction occurring possibly as far inland as the Sandy River delta and Reed Island, approximately 15 miles (25 kilometers) east of Portland. Further investigation has shown that there have been several other subduction zone earthquakes off the northwest Oregon and southwest Washington coast in the last few thousand years and that they occurred every 400 to 600 years on average. There is every reason to believe that similar earthquakes will occur in the future.

The Vancouver urban area faces a more significant earthquake hazard than is indicated by the historical record, even though there is currently significant uncertainty about the exact location, size, and timing of future earthquakes. It is certain, however, that damaging earthquakes will be a part of the Vancouver area's future.

EARTHQUAKE EFFECTS

The relative hazard map (Plates 1 and 2) presented in this report is based on our evaluation of three earthquake effects: amplification of ground shaking, soil liquefaction, and earthquake-induced landsliding.

Ground Shaking Amplification

The intensity of the ground shaking caused by an earthquake can be significantly modified by the soils and poorly consolidated sedimentary rocks near the surface. This modification can increase (or decrease) the strength of shaking or change the frequency content of the shaking. For example, the shaking could be changed from a rapid vibration (like a jet flying low overhead) to a long rolling motion (like being on a boat in a storm). The nature of these modifications is determined by the thickness of the geologic materials and their physical properties, such as shear-wave velocity. Using measurements of these characteristics, sophisticated computer programs can estimate the effects of the local geology on ground shaking and can broadly delineate areas where the ground shaking will tend to be strongest.

Mapping of the amplification resulting from near-surface geology has been done in other areas, such as the San Francisco Bay region and Mexico City. For example, damage to the Nimitz Freeway during the Loma Prieta earthquake was confined to areas of the Cyprus Street Viaduct where the ground shaking was strongly amplified by near-surface soft soils. These areas had been previously recognized and delineated as prone to strong amplification of ground shaking. Recent studies of the Loma Prieta earthquake have shown that the majority of the total property loss was concentrated in areas with significantly amplified ground shaking.

Soil Liquefaction

Liquefaction is a phenomenon in which strong shaking of a soil causes it to rapidly lose its strength and to behave more like a liquid than a solid. Typically, loose sandy soils that have been deposited in the last few thousand years are most susceptible to liquefaction. However, liquefaction will only occur if all pore space between sand grains is filled with water (that is, the sand is saturated). Soil liquefaction is typically triggered by strong ground shaking during a large earthquake.

When soil strength is lost during liquefaction, the consequences can be catastrophic. For example, the liquefied soil layer, and everything lying on top of it, can move downhill, even on very shallow slopes. Movement of liquefied soils can rupture pipelines, move bridge abutments, and pull apart the foundations and walls of buildings. Buried objects, such as underground storage tanks, can float upward through the liquefied layer, and heavy objects, such a tall buildings, can sink into it. Liquefaction and consequent ground movement caused massive damage to highway and railway bridges throughout southern Alaska during the 1964 Good Friday earthquake.

Earthquake-Induced Landsliding

Landslides are a problem familiar to inhabitants of the Pacific Northwest. They occur when the soil on a slope does not have sufficient strength to resist the downslope force due to the soil's weight. The shaking resulting from an earthquake tends to cause existing landslides to move as the shaking simply adds to the downhill force driving the failure. Likewise, earthquakes can create new landslides where the strength of the soil is exceeded by the dynamic forces caused by the earthquake shaking.

The steepness of a slope and thickness of soils are indicators of the slope's landslide potential. In addition, existing landslide masses can be identified and mapped. By investigating these known landslides, criteria can be developed that will allow delineation of other potentially unstable slopes. Landslide hazard maps developed using this general approach have been produced for many urban areas, including Clark County.

RELATIVE EARTHQUAKE HAZARD MAP

We evaluated three earthquake hazards (ground shaking amplification, liquefaction, and landsliding) and prepared maps delineating areas more or less susceptible to each of these hazards. The resulting relative earthquake hazard map shows which areas will have the greatest tendency to experience damage due to any one of, or a combination of, these individual hazards.

A qualitative rating scale ranging from 0 to 3 was devised as part of the mapping of each individual hazard. A 0 rating was assigned to areas having the lowest likelihood of being affected by the hazard, and areas having the greatest likelihood were assigned a rating of 3. For every point in the map area, the rating for each individual seismic hazard was squared and the resulting numbers were summed. The square root of this sum was then rounded to the nearest whole number. A result

of 4 was assigned to category A (the highest relative hazard rating), a result of 3 was assigned to category B, etc. Category D was assigned to a numerical result of 1. In this ranking scheme, a numeric result of 0 or 5 is theoretically possible, but in practice neither value is likely to occur. In those instances where a 0 or 5 rating did occur, they were assigned respectively to the D or A category on the relative hazard map.

Example: Suppose that the block that includes your house had a ground shaking amplification rating of 2, a liquefaction rating of 2, and a landslide rating of 0. We would take the ground shaking amplification rating of 2 and square it to get 4. We would do the same with the liquefaction rating and also get 4. Squaring the landslide rating of zero gives zero. So we add 4 + 4 + 0 to get a sum of 8. The square root of 8 is 2.828, which rounds to 3, placing your block in a category B relative hazard rating. Because B is the next to the highest rating, your block is thus of greater concern, from an earthquake hazard standpoint, than would be a block a few miles away that has a hazard rating of D.

Generally, areas with a high rating (3) from a single individual earthquake hazard (for example, liquefaction) have a relative hazard rating of B (next to highest overall hazard rating) for that area. The highest relative hazard category (A) typically results from a high rating for two or more individual hazards (for example, both liquefaction and amplification). However, a relative hazard rating of B can result from a single very severe hazard that may result in considerable property damage. In fact, 48 percent of the study area comprises category A and B hazard zones, and the remaining 52 percent falls in category zones C and D. Thus, categories A and B represent a relative hazard higher than 'average' in the Vancouver area, and similarly categories C and D represent a relative hazard lower than 'average'. The highest relative hazard category (A) covers only 10 percent of the map area and is primarily concentrated in the present flood plain of the Columbia River and tributary creeks.

SUMMARY

We evaluated three earthquake hazards (soil liquefaction, amplification of ground shaking, and earthquake-induced landsliding) and constructed maps of the Vancouver region delineating areas more or less susceptible to each of these hazards. These individual hazard maps were combined into a relative earthquake hazard map presented as Plates 1 and 2. This map subdivides the Vancouver urban area into four categories of relative earthquake hazard ranging from the most hazardous (category A) to the least hazardous (category D). Categories A and B represent a relative hazard higher than 'average' in the Vancouver area, and similarly categories C and D represent a relative hazard lower than 'average'. Only 10 percent of the study area, mainly concentrated in the present flood plain of the Columbia River, falls in the highest category of relative earthquake hazard. The category rankings are relative because they can only be used to compare the combined hazard at a given location to that at some other location in the study area. These rankings cannot be used to predict the level of structural damage resulting from these hazards during an earthquake. The actual damage will depend on the location and size (magnitude) of the earthquake, the site-specific response of the soil and geologic material beneath the structure, and the construction details of the structure.

At present the potential earthquake sources in the Vancouver area are not sufficiently well understood to permit an exact assessment of the size and location of future earthquakes. Our assessment of the seismic hazards is based on detailed geologic mapping of the greater Vancouver region and state-of-the-practice analyses of specialized geophysical and geotechnical measurements. This map cannot be used to directly ascertain either (1) which of the hazards may affect a particular site during an earthquake or (2) the severity of these hazards and the likelihood of catastrophic consequences. Only a site-specific geotechnical investigation performed by a qualified practitioner can adequately assess the potential for and consequent damage from soil liquefaction, amplified ground shaking, landsliding, or any other earthquake hazard.

ACKNOWLEDGEMENTS

We greatly appreciate the contribution of Carl Harris, Division of Geology and Earth Resources, to this study through his expertise in GIS manipulation of the map data and cartographic rendering of the GIS map files as the final printed map. We thank Dan Meier, Woodward-Clyde and Associates, for his outstanding job managing the geotechnical drilling and testing phase of this study. We also thank Beth Reynosa of the Port of Vancouver for her help in compiling the agency's geotechnical reports and data and the Geotechnical Branch, Materials Laboratory, Washington Department of Transportation, for allowing access to their geotechnical files.

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WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

GEOLOGIC MAP GM-42

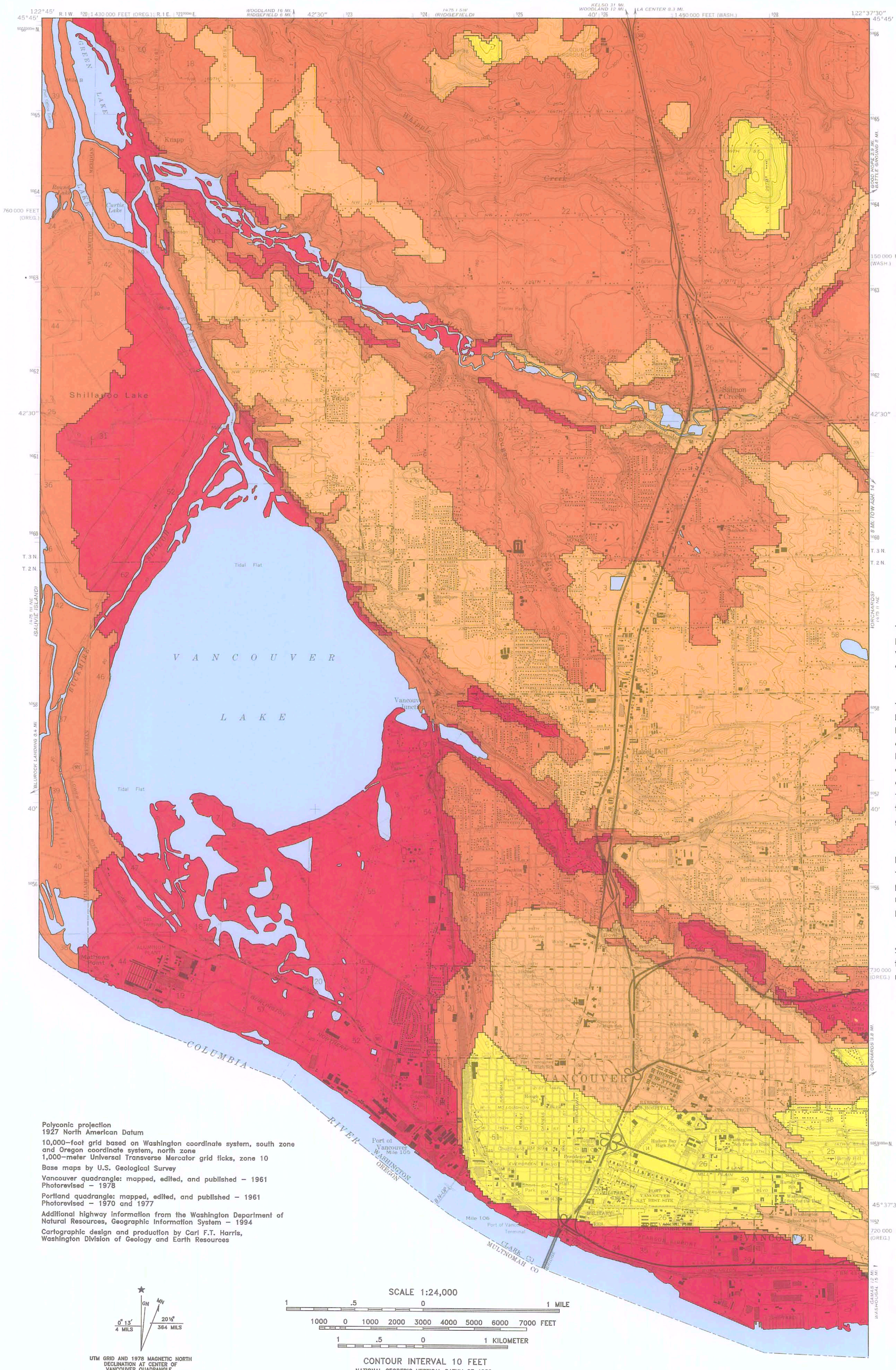
PLATE 1 - VANCOUVER AND PORTLAND
7.5-MINUTE QUADRANGLES

RELATIVE EARTHQUAKE HAZARD MAP OF THE VANCOUVER, WASHINGTON, URBAN AREA

by

Matthew A. Mabey and Ian P. Madin,
Oregon Department of Geology and Mineral Industries,
and
Stephen P. Palmer,
Washington Division of Geology and Earth Resources

1994



ZONE A ------ Greatest relative hazard

ZONE B

ZONE C

ZONE D ------ Least relative hazard

OPEN WATER

This map is a synthesis of our assessment of geologic hazards associated with future earthquakes in the Vancouver urban area. It is intended to provide land-use planners, emergency-response personnel, the business community, and private citizens with a relative assessment of the overall earthquake hazard throughout the Vancouver area.

Three specific earthquake hazards were evaluated: soil liquefaction, amplification of ground shaking, and earthquake-induced landsliding. For each of these hazards, we constructed a map that delineates areas more or less susceptible to that hazard. These three hazard maps were then combined to produce this map, which qualitatively ranks the combined hazards into four categories ranging from greatest hazard (Zone A) to least hazard (Zone D). The rankings are relative because they only can be used for comparison of the combined hazard among localities within the study area. These rankings cannot be used to predict the actual level of damage resulting from the individual hazards during an earthquake. The actual damage will depend on the location and size (magnitude) of the earthquake as well as on the effects of strong ground shaking, liquefaction, and landsliding.

It is not possible using this map to directly ascertain which of these particular hazards may affect a site during a given earthquake. This map cannot be substituted for a site-specific geotechnical investigation, which must be performed by qualified practitioners and is required to assess the potential for and consequent damage resulting from soil liquefaction, amplified ground shaking, landsliding, or any other potential earthquake hazard.

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Polyconic projection
1927 North American Datum

10,000-foot grid based on Washington coordinate system, south zone and Oregon coordinate system, north zone
1,000-meter Universal Transverse Mercator grid ticks, zone 10

Base maps by U.S. Geological Survey

Vancouver quadrangle: mapped, edited, and published - 1961
Photorevised - 1978

Portland quadrangle: mapped, edited, and published - 1961
Photorevised - 1970 and 1977

Additional highway information from the Washington Department of Natural Resources, Geographic Information System - 1994

Cartographic design and production by Carl F.T. Harris,
Washington Division of Geology and Earth Resources

UTM GRID AND 1978 MAGNETIC NORTH
DECLINATION AT CENTER OF
VANCOUVER QUADRANGLE

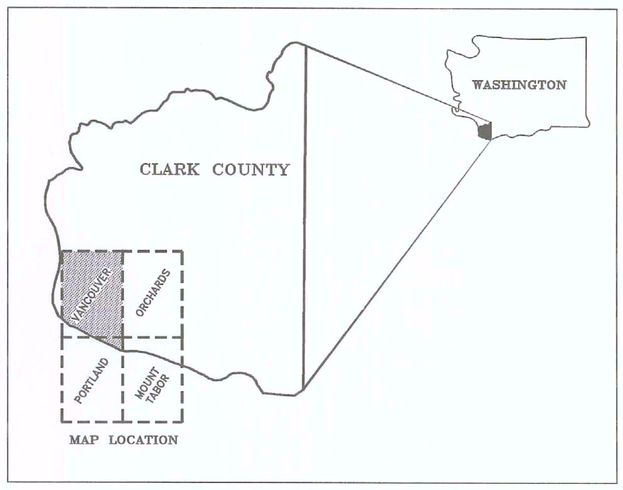
SCALE 1:24,000

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODEDIC VERTICAL DATUM OF 1929



MAP LOCATION

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GEOLOGIC MAP GM-42

PLATE 2 - ORCHARDS AND MOUNT TABOR
7.5-MINUTE QUADRANGLES

RELATIVE EARTHQUAKE HAZARD MAP OF THE VANCOUVER, WASHINGTON, URBAN AREA

by

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OPEN WATER

This map is a synthesis of our assessment of geologic hazards associated with future earthquakes in the Vancouver urban area. It is intended to provide land-use planners, emergency-response personnel, the business community, and private citizens with a relative assessment of the overall earthquake hazard throughout the Vancouver area.

Three specific earthquake hazards were evaluated: soil liquefaction, amplification of ground shaking, and earthquake-induced landsliding. For each of these hazards, we constructed a map that delineates areas more or less susceptible to that hazard. These three hazard maps were then combined to produce this map, which qualitatively ranks the combined hazards into four categories ranging from greatest hazard (Zone A) to least hazard (Zone D). The rankings are relative because they only can be used for comparison of the combined hazard among localities within the study area. These rankings cannot be used to predict the actual level of damage resulting from the individual hazards during an earthquake. The actual damage will depend on the location and size (magnitude) of the earthquake as well as on the effects of strong ground shaking, liquefaction, and landsliding.

It is not possible using this map to directly ascertain which of these particular hazards may affect a site during a given earthquake. This map cannot be substituted for a site-specific geotechnical investigation, which must be performed by qualified practitioners and is required to assess the potential for and consequent damage resulting from soil liquefaction, amplified ground shaking, landsliding, or any other potential earthquake hazard.

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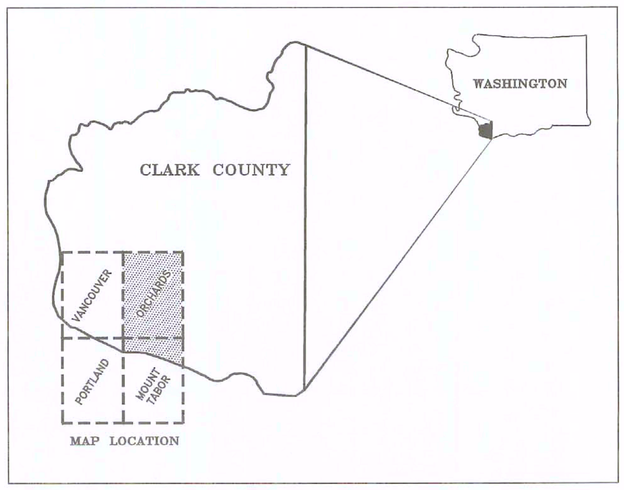
SCALE 1:24,000

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 10 FEET
NATIONAL GEODEDIC VERTICAL DATUM OF 1929



MAP LOCATION

Polyconic projection
1927 North American Datum

10,000-foot grid based on Washington coordinate system, south zone
1,000-meter Universal Transverse Mercator grid ticks, zone 10

Base maps by U.S. Geological Survey

Orchards quadrangle: mapped, edited, and published - 1961
Photorevised - 1970 and 1975

Mount Tabor quadrangle: mapped, edited, and published - 1961
Photorevised - 1970 and 1978

Additional highway information from the Washington Department of Natural Resources, Geographic Information System - 1994

Cartographic design and production by Carl F.T. Harris,
Washington Division of Geology and Earth Resources

0° 19'
6 MILS

20½°
364 MILS

UTM GRID AND 1975 MAGNETIC NORTH
DECLINATION AT CENTER OF MAP