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DONALD A. HULL, STATE GEOLOGIST

Relative Earthquake Hazard Map of the Linnton Quadrangle, Multnomah and Washington Counties, Oregon

1996

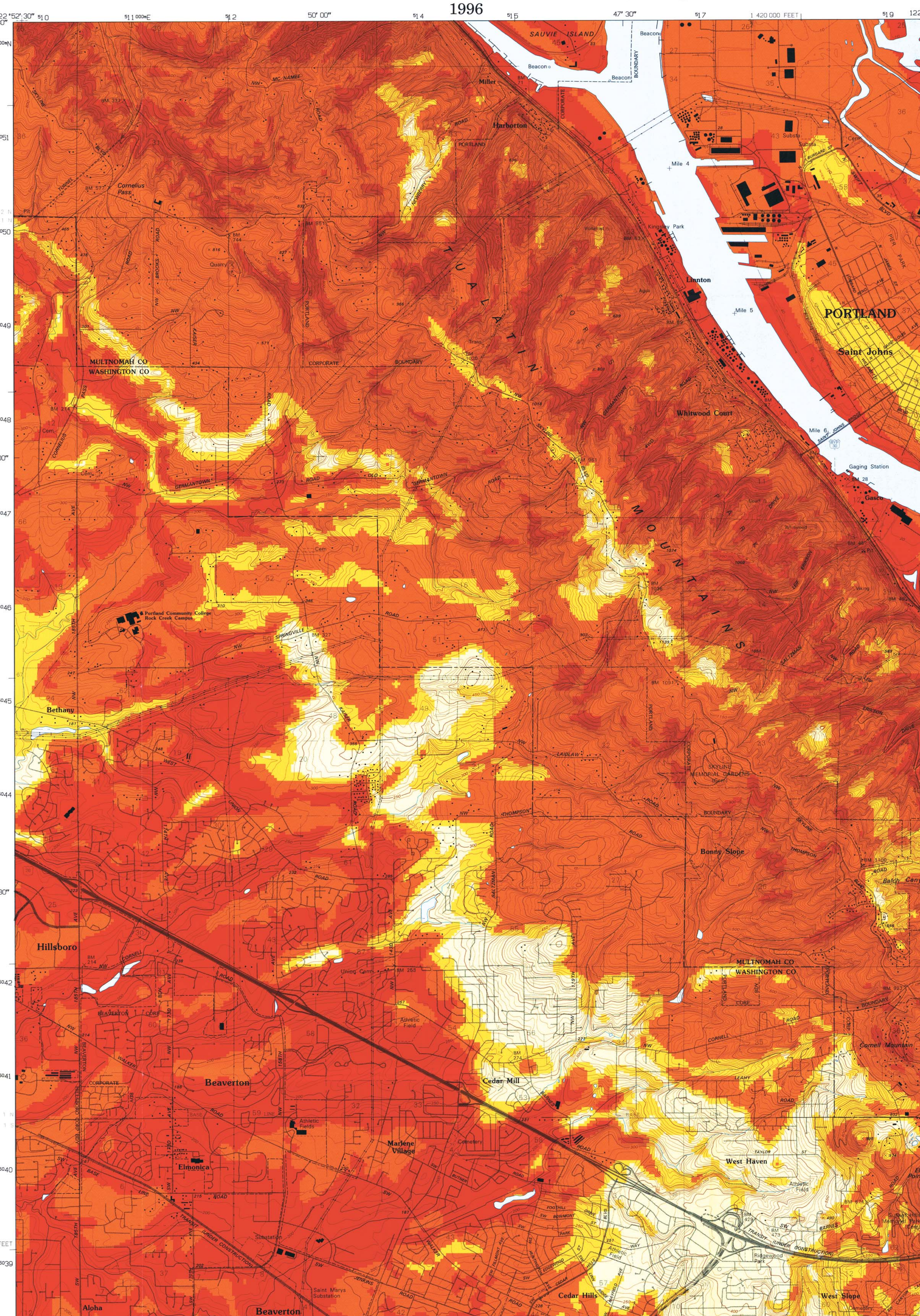
GMS-104

Relative Earthquake Hazard Map of the Linnton Quadrangle, Multnomah and Washington Counties, Oregon

By M.A. Mabey and others

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award numbers 1434-93-G-2324 and 14-08-0001-A0512. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

This Relative Earthquake Hazard Map of the Linnton Quadrangle was developed to depict areas at relatively greater risk, compared to other areas, due to local geologic conditions. On a neighborhood-to-neighborhood scale, the local geologic conditions contribute as much as, or more than, any other factor to the hazard portion of a risk assessment. Showing in relative terms on a single map the hazard contribution of three different earthquake-related hazards assists a nongeologic and nonengineering audience in working more effectively toward reducing the risk to life and property through planning policy and mitigation measures. This composite hazard map was developed by combining single hazard maps for ground motion amplification, liquefaction, and slope instability. The single component maps were developed to show geographic patterns of stronger earthquake effects for a variety of likely earthquake sources. Zones that are expected to have the most pronounced damage in any damaging earthquake are shown on the map as having the greatest hazard.



Base map by U.S. Geological Survey, rev. 1990
Control by USGS, NOS/NOAA, and State of Oregon
Lambert conformal conic projection. 1927 North American Datum
National geodetic vertical datum of 1929
10,000-foot grid based on Oregon coordinate system, north zone
1000-meter Universal Transverse Mercator grid ticks, zone 10

QUADRANGLE LOCATION

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET

NORTH

Earthquake hazard analysis by Matthew A. Mabey, Ian P. Madin, and Gerald L. Black, Oregon Department of Geology and Mineral Industries; and Dan B. Meier, Woodward-Clyde Consultants

Cartography by Mark E. Neuhaus

This map is available in digital formats

EXPLANATION

(see accompanying text for complete explanation)

The relative earthquake hazard zones shown below range from zone A, which shows areas of greatest hazard, to zone D, which shows areas of least hazard. The degree of relative hazard was based on the factors of ground motion amplification, liquefaction, and slope instability, shown on smaller scale maps on left side of sheet.

Zone A

Zone B

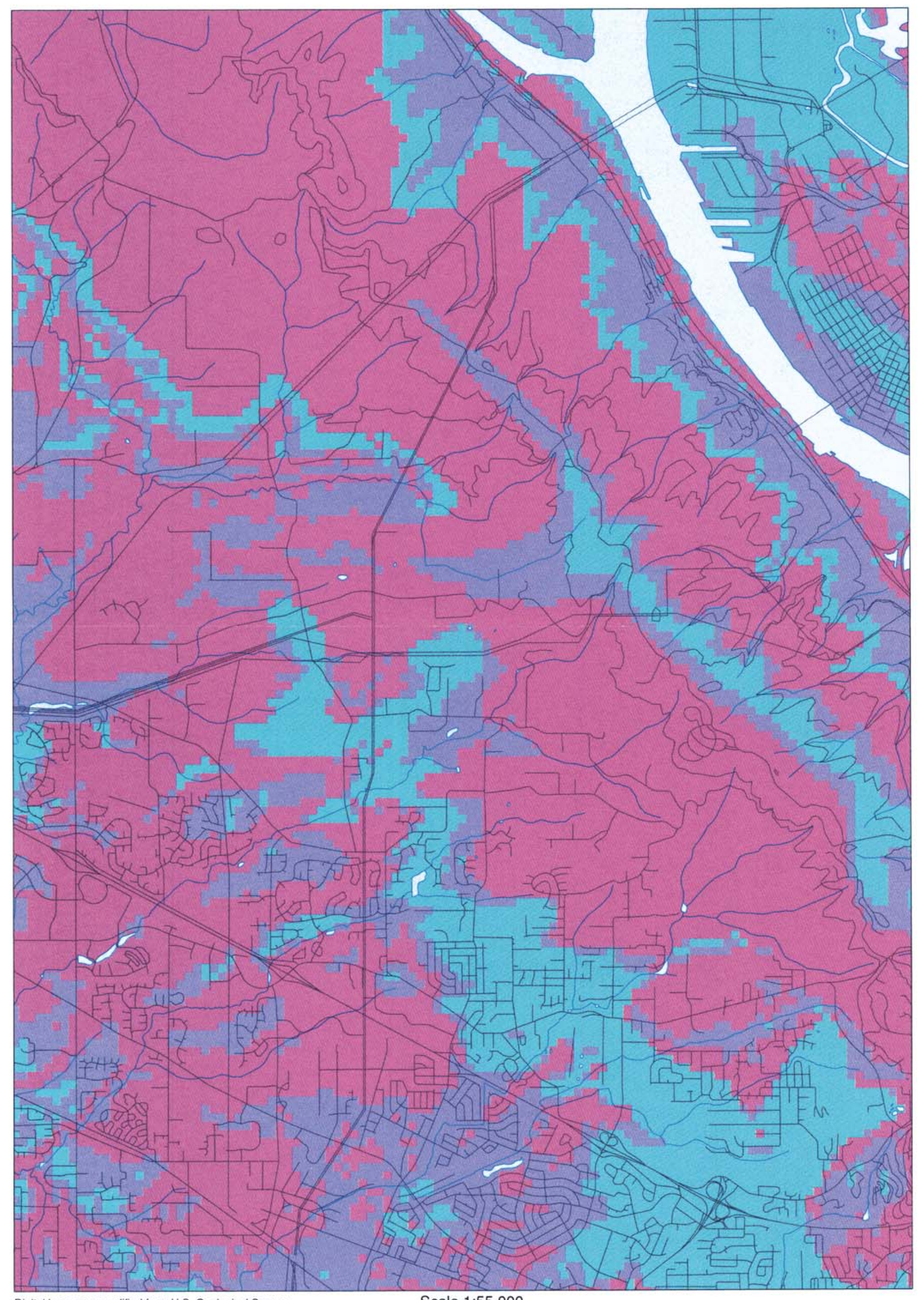
Zone C

Zone D

Disclaimer

The information provided on these maps cannot be substituted for a site-specific geotechnical investigation. The site-specific potential for and consequent damage from soil liquefaction, amplified ground shaking, landsliding, or any other earthquake hazard should be assessed by qualified practitioners working on a site-specific basis.

Relative Amplification Hazard Map of the Linnton Quadrangle

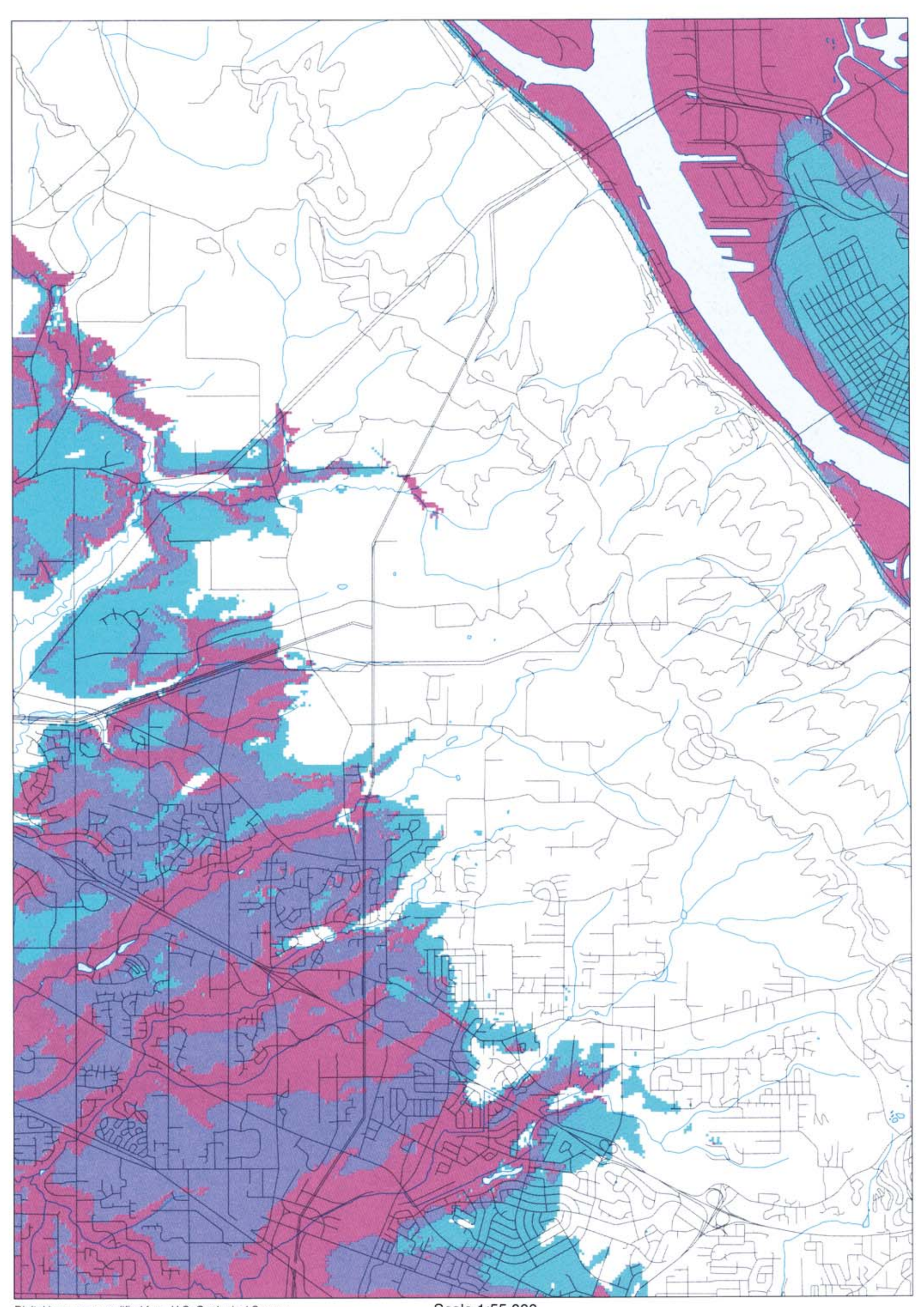


Digital base map modified from U.S. Geological Survey   Scale 1:55 000

Categories are arranged so that highest number (3) indicates greatest hazard and lowest number (1) indicates least hazard. See text for explanation of numbers.

3
2
1

Relative Liquefaction Hazard Map of the Linnton Quadrangle

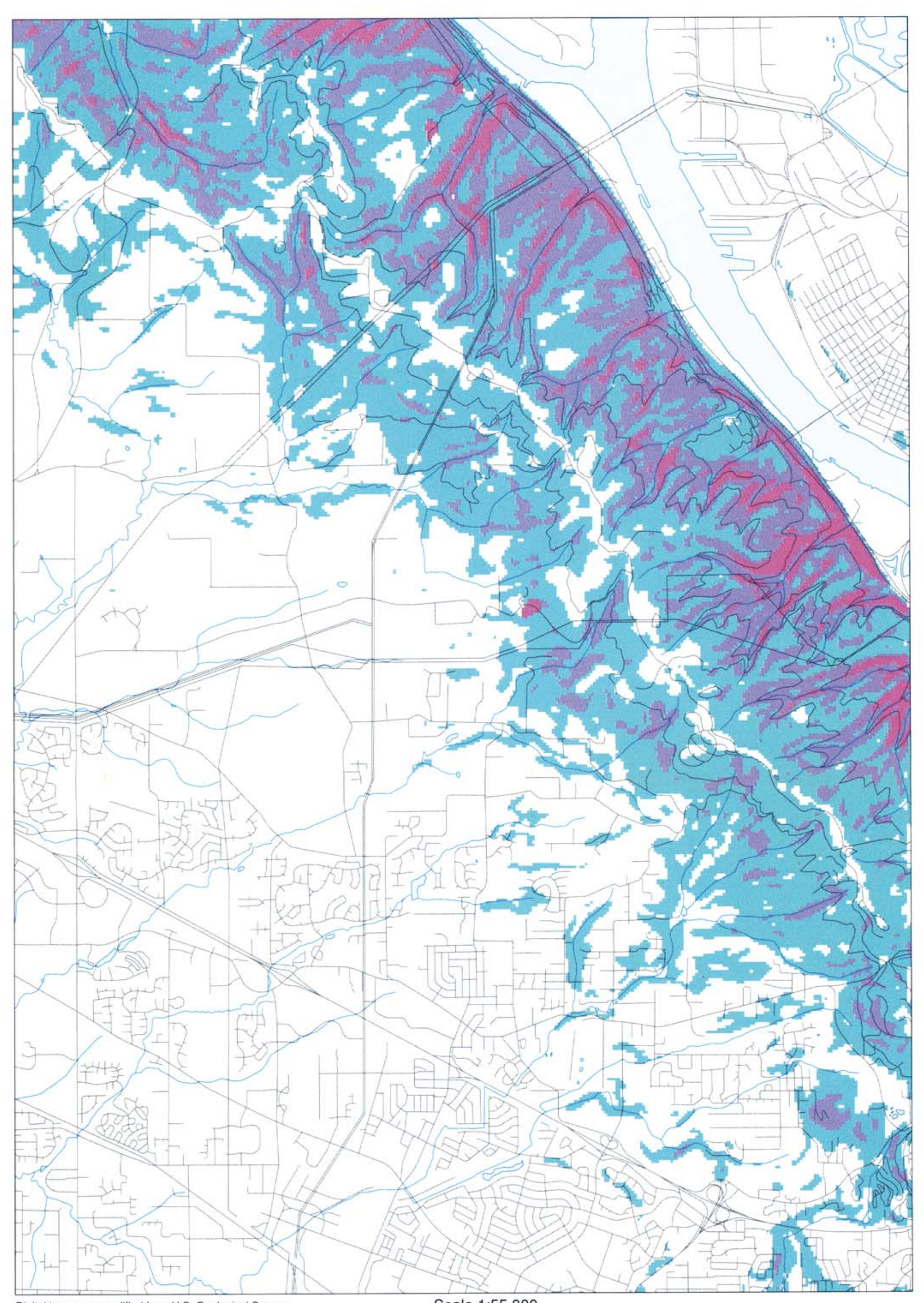


Digital base map modified from U.S. Geological Survey   Scale 1:55 000

Categories are arranged so that the highest number (3) indicates the greatest hazard and lowest number (1) indicates least hazard. White indicates areas where liquefaction is possible only where there are unusual local conditions. See text for explanation of numbers.

3
2
1

Relative Slope Instability Hazard Map of the Linnton Quadrangle



Digital base map modified from U.S. Geological Survey   Scale 1:55 000

Categories are arranged so that the highest number (3) indicates the greatest hazard and lowest number (1) indicates least hazard. White indicates areas where slope instability is possible only where there are unusual localized conditions. See text for explanation of numbers.

3
2
1

State of Oregon
Department of Geology and Mineral Industries
Donald A. Hull, State Geologist

GMS-104
Relative Earthquake Map of the Linnton Quadrangle,
Clackamas and Washington Counties, Oregon
By M.A. Mabey and others

Relative Earthquake Hazard Map of the Linnton Quadrangle, Multnomah and Washington Counties, Oregon

1996

By Matthew A. Mabey, Ian P. Madin, and Gerald L. Black,
Oregon Department of Geology and Mineral Industries,
and Dan B. Meier, Woodward-Clyde Consultants

ABSTRACT

This *Relative Earthquake Hazard Map of the Linnton Quadrangle* was developed to depict areas at relatively greater risk of damage from earthquakes, compared to other areas, due to local geologic conditions. On a neighborhood-to-neighborhood scale, the local geologic conditions contribute as much as, or more than, any other factor to the hazard portion of a risk assessment. Showing in relative terms on a single map the hazard contribution of three different earthquake-related hazards allows a nongeologic and nonengineering audience to work more effectively toward reducing the risk to life and property through planning policy and mitigation measures. This composite hazard map was developed by combining single hazard maps for ground motion amplification, liquefaction, and slope instability. The single component maps were developed to show geographic patterns of stronger earthquake effects for a variety of likely earthquake sources. Zones that are expected to have the most pronounced damage in any damaging earthquake are shown on the map as having the greatest hazard.

INTRODUCTION

During the late 1980s, the scientific understanding of earthquake hazards in the Portland metropolitan area advanced significantly. It is now widely accepted that damaging earthquakes much larger than any in the historical record are possible (Weaver and Shedlock, 1989; Madin, 1990; Yelin and others, 1994). To minimize economic losses and casualties in these future events, a wide variety of mitigation measures may be necessary. These measures should be based on the best possible assessment of the likely extent and distribution of earthquake damage.

It is difficult to predict the amount of damage any individual structure will sustain in an earthquake. The amount of damage depends on the size, type, and location of the earthquake; the response of the soil and geologic materials at the site; and the characteristics of the structure. More needs to be known about sources of earthquakes that might affect the Portland area before scientists can accurately assess the size and location of future earthquakes. Scientists can, however, measure and predict the behavior of geologic and soil columns at any site. This map depicts the relative degree of earthquake hazards for areas within the U.S. Geological Survey (USGS) Linnton 1:24,000 quadrangle for any given earthquake. This map does not depict the absolute degree of earthquake hazard at any site, which means that in any given earthquake it is possible that damage in even the highest relative hazard category will be light. Conversely, in a severe earthquake even the lowest relative hazard category could experience severe damage. The *Relative Earthquake Hazard Map,* which appears on the accompanying map sheet, also contains no information about how frequently earthquake damage of any level is likely to occur.

This assessment of relative hazard is based on detailed mapping of the geology of the area and specialized geophysical/geotechnical measurements, which are combined with state-of-the-practice geotechnical analysis and Geographic Information System (GIS) methodology and tools. The result is a map that categorizes the map area into one of four relative hazard categories. The categories are ranked from greatest hazard (category A) to least hazard (category D).

The map has been developed as data layers in a GIS and can be easily combined with earthquake source information from selected hypothetical events to produce earthquake scenarios. The map also can be combined with future maps of earthquake probability to provide an assessment of the absolute level of hazard and an estimate of how often that level will occur.

EARTHQUAKE HAZARD

The understanding of earthquake hazards within the Portland area has been undergoing rapid change in the last six years. Recently published geologic and seismologic studies have detailed the potential for earthquakes from three different sources (Weaver and Shedlock, 1989, Madin, 1990). In Portland, the most common are crustal earthquakes, which occur at depths of 6-10 mi below the surface. The few moderate earthquakes that have originated in Portland in its brief recorded history have been this type.

Intraplate or Wadati-Benioff earthquakes are the type that severely rocked the Puget Sound region in 1949 and again in 1965. Those who lived in Portland in 1949 may recall that the Portland area suffered some damaging and frightening effects of that earthquake. Intraplate earthquakes occur within the remains of the ocean floor that has been shoved (subducted) beneath North America. It is now believed that this type of earthquake could occur closer to Portland, perhaps 25-35 mi directly beneath the city.

Great subduction zone earthquakes occur around the world in subduction zones, where continent-sized pieces of the earth's crust are shoved deep into the body of the earth. These earthquakes consistently are among the most powerful recorded, often having magnitudes of 8 to 9 on the moment magnitude scale. The Cascadia Subduction Zone, which has long been recognized off the coast of Oregon and Washington, has had no great subduction earthquakes during our short 200-year historical record. However, in the past five years, a variety of studies have found widespread evidence that these great events have occurred repeatedly in the past, most recently about 300 years ago. The best evidence available suggests that these great earthquakes have occurred, on average, every 350 to 600 years, and there is every reason to believe that they will continue to occur in the future.

Portland is threatened by all three types of earthquakes, but scientists are only now beginning to answer the questions of where, how often and how big future earthquakes will be. Traditional probability-based (probabilistic) approaches to hazard mapping, which would provide information about absolute levels of ground shaking to be expected and how often such levels might be reached, must await these answers to these questions. When reliable probabilistic ground motion maps become available, they can be integrated with the relative hazard mapping presented here.

EARTHQUAKE EFFECTS

That damaging earthquakes will be a part of the Portland area's future is certain. The exact details of those future earthquakes are still vague, and we will not be able to predict exactly when, where, and how big the next one, or ones, will be. It is possible, however, to evaluate the influence of site geology on potential earthquake damage. This can be done while the exact sources of the earthquake shaking still are being evaluated.

The most severe damage done by an earthquake is commonly concentrated in limited areas. The damage in these areas is generally caused by one or more of the following phenomena:

- Amplification of ground shaking by a "soft" soil column.
- Liquefaction of water-saturated sand, creating areas of "quicksand."
- Instability of slopes triggered by the shaking of the earthquake.

These effects can be evaluated before the earthquake if good data are available on the thickness and nature of the geologic materials and soils at the site (Bolt, 1993). The exact nature and magnitude of these effects are useful to technical professionals such as geologists and engineers, and these data will be made available separately for the Linnton quadrangle. For others, what is more significant is that these effects increase the damage caused by an earthquake and localize the most severe damage.

The *Relative Hazard Map of the Linnton Quadrangle* is a composite hazard map depicting the relative hazard at any site due to the combination of all three effects. It delineates areas that likely will experience the greatest effects from any earthquake. Those effects could range from people waking from their sleep to buildings collapsing or gas lines rupturing. These simple composite hazard maps can be used by planners, lenders, insurers, and emergency responders for first-order hazard mitigation and response planning. It is very important to note that the relative hazard map predicts the tendency of a site to have greater or lesser damage than other sites in the area. These zones, however, should not be used as the sole basis for any type of restrictive or exclusionary policy.

HAZARD MAP METHODOLOGY

Geologic Model

The geology of the Linnton quadrangle is relatively simple. A more detailed description is available in Madin (1990). The Tualatin Basin, a major structural downwarp, occupies most of the quadrangle. A structural high, the northwest-trending Tualatin Mountains block, separates the Tualatin Basin from the Portland Basin, which occupies the northeast corner of the quadrangle. The local bedrock or geologic basement consists of hard, dense lava flows of the Columbia River Basalt Group. These basalts occur in the subsurface in the Tualatin and Portland basins. They occur at or near the surface in the Tualatin Mountains, where they are commonly mantled by a thin veneer (a few meters) of wind-blown silt (loess). In the basins the basalts are overlain by up to hundreds of meters of Plio-Pleistocene (?) siltstone, mudstone, and sandstone (Sandy River Mudstone equivalent of Trimble, 1963; Madin, 1990). In the Portland Basin (northeast corner of the quadrangle), the Sandy River Mudstone is overlain by the Troutdale Formation, which is composed of pebble and cobble gravel and conglomerate. This unit is absent in the Tualatin Basin. Along the western flank of the Tualatin Mountains, basaltic flows of the Boring Lava overlie the older units. These flows, like the Columbia River basalt, are mantled by loess. In both the Tualatin and Portland basins, older units are covered by units deposited by catastrophic floods at the end of the last ice age. In the Portland Basin, the flood sediments are divided into a lower gravel layer and an upper sand and silt layer. In the Tualatin Basin, the lower coarse-grained layer is absent. The flood sediments are in turn covered by alluvial sand, silt, and clay along and adjacent to the channel of the Columbia River in the Portland Basin and tributaries of the Tualatin River in the Tualatin Basin.

Hundreds of boreholes drilled for water wells and foundation investigations were used to determine the thickness of each of the geologic units over the entire map, and these data were entered into a GIS database. This information defines the soil and rock beneath any location on the map so that their effects on earthquake damage can be assessed.

To assess the effects of the local geologic materials, data on more than just their thicknesses are needed. Many of the required measurements, such as the Standard Penetration Test (SPT), are acquired in the normal course of a foundation investigation. Thus, the needed information is available from many of the same sources as the thickness information.

In addition to the data acquired from existing borehole records, the assessment technique requires shear-wave velocities. Measurements of shear-wave velocities were made at dozens of carefully selected sites by using both conventional drilling and cone penetrometer techniques. Six sites were on the Linnton quadrangle. The others were at other locations in the Portland metropolitan area.

All this information combines to give a detailed computer map of what lies beneath the surface throughout the map area. With this information, the response to earthquake shaking at a specific location can be assessed.

HAZARD ANALYSIS

An earthquake causes damage through such effects as ground shaking, liquefaction, landslides, fault rupture, tsunamis, and seiches (Bolt, 1993). The severity of any one of these effects, or hazards, is influenced by a number of factors. Many of these factors can be assessed in relative terms without knowing the exact details of the earthquake itself.

The *Relative Earthquake Hazard Map* integrates three separate earthquake hazard components. They are (1) ground shaking amplification, (2) liquefaction, and (3) earthquake-induced landsliding. Each of these phenomena is a distinct and separate hazard and in concert with others can increase the severity of the total hazard at a given locality. The distinction between each component is important to technical specialists, but the distinctions are not useful to a nontechnical audience. It therefore makes sense to generate a map of each of the individual hazard components that will be available to those able to use them and to then combine the individual maps into a simple, unified hazard map that generalizes the issues in a way useful to nonspecialists. IDRISI, a raster-based GIS (Eastman, 1990), was used with custom software to perform the map analyses.

Ground Shaking Amplification

Bedrock ground shaking caused by an earthquake can be modified by the soils and soft sedimentary rocks near the surface. This modification can increase the strength of shaking (or alternatively decrease it) or change the frequency of the shaking. For example, the shaking could be changed from a rapid vibration (like hearing 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. With these parameters, sophisticated computer programs can estimate the effects of the local geology on ground shaking. In this way, areas where the ground shaking will tend to be strongest have been identified. The computer program SHAKE91 (Schnable and others, 1972; Idriss and Sun, 1992) was used for this map.

Mapping of the amplification resulting from near-surface geology has been done previously in other locations such as the San Francisco Bay area and Mexico City. Damage to the Nimitz Freeway during the 1989 Loma Prieta or "World Series" earthquake was localized by near-surface amplification. Fortunately, the areas of the Linnton quadrangle that are affected by large amplifications are small. The magnitude of the most severe amplifications in the Linnton quadrangle does not appear to be as great as has been found in other parts of the world.

The three amplification hazard categories were defined as follows:

(1) Areas with amplification less than 1.25
(2) Areas with amplification between 1.25 and 1.50
(3) Areas with amplification greater than 1.50

The *Relative Amplification Hazard Map* shown on the map sheet accompanying this report is the resulting three-category map of relative amplification hazard.

Liquefaction Analysis

Liquefaction is a phenomenon in which shaking or otherwise disturbing a soil causes it to rapidly change its material properties so that what was solid begins to behave like a liquid. Soils that have this problem tend to be fairly young, loose, granular soils (as opposed to clay) that are saturated with water (NRC, 1985). Unsaturated soils will not liquefy, but they may settle. If liquefaction is induced by earthquake shaking, several things can happen. The liquefied layer of soil and everything lying on top of it can either move downhill or oscillate back and forth with displacements that are large enough to rupture pipelines, move bridge abutments, and pull buildings apart. Light objects such as underground storage tanks can float up toward the surface, and heavy objects such as buildings can sink.

These displacements can range from inches to feet. Obviously, if the soil at a site liquefies, the damage caused by the earthquake is significantly increased over what the shaking would have done alone. Soils that are subject to liquefaction can be identified, as can their thicknesses and influence on the severity of the effects. This was done for the Portland quadrangle (Youd and Jones, 1993) and since has been done for the Linnton quadrangle.

Maps of liquefaction hazard similar to what has been done for this map have been done in many areas including Seattle, Washington, and Salt Lake City, Utah, where the maps have been incorporated into emergency response planning and development planning (Anderson and others, 1986; Grant and others, 1992).

The three liquefaction hazard categories were defined as follows:

(1) Areas with materials that are liquefiable when they are intermittently saturated.

(2) Areas with a thickness of liquefiable material (for the scenario earthquake) less than 20 ft (6 m) where the water table is 15-30 ft (4.5-6 m) deep.

(3) Areas with a thickness of liquefiable material (for the scenario earthquake) greater than 30 ft (9 m) where the water table is 15-30 ft (4.5-6.0 m) deep or areas with liquefiable material where the water table is less than 15 ft (4.5 m) deep.

The rest of the map that is not covered by one of these three categories is described as liquefiable only due to unusual localized conditions.

The *Relative Liquefaction Hazard Map* shown on the map sheet accompanying this report is the resulting three-category map of relative liquefaction hazard.

Landslide Analysis

Landslides are a problem familiar to Oregonians. The shaking resulting from an earthquake tends to cause existing landslides to move as well as generating forces that create new landslides. The steepness of a slope is the primary indicator of the stability of a slope. This one factor has been used to estimate the hazard of landslides in the map area (Varnes, 1978; Brabb, 1987; Mabey and others, 1993). Using the slope information, the authors rated the hazard as one of four categories ranging from 0 to 3.

The three slope instability hazard categories were defined as follows:

(1) A slope between 15 percent (8.5°) and 30 percent (16.7°).

(2) A slope between 30 percent (16.7°) and 45 percent (24.2°).

(3) A slope greater than 45 percent (24.2°).

The rest of the map is characaterized as having slope instability only in unusual localized situations.

The *Relative Slope Instability Hazard Map* with the three categories is shown on the map sheet accompanying this report.

Other Hazards

Other hazards have not been factored into the relative hazard map. Certainly bodies of water (e.g., the Columbia River) are subject to waves being generated by the ground motion accompanying an earthquake. Such waves are known as seiches. The effects of a seiche will be limited to the immediate vicinity of the water body, but the size of the waves can be damaging and deadly. The effects of any tsunami generated in the Pacific Ocean by an earthquake are likely to be small along the rivers in the Portland area. Although many faults have been identified and mapped in the Portland area, the hazard that the rupture of specific faults represents is still uncertain. The "activity" of these faults will be defined by studies in coming years. It should be noted that the magnitude 6 to 6.5 range is the threshold at which fault rupture begins to be commonly apparent (Bonilla and others, 1984). Because 6 to 6.5 is the likely maximum magnitude for any crustal earthquakes in the area, fault rupture is likely to be absent altogether or will be of very limited extent. Therefore, the number of structures affected and the severity of the effects also will be limited.

RELATIVE EARTHQUAKE HAZARD MAP

The *Relative Earthquake Hazard Map of the Linnton Quadrangle* was created to show which areas will have the greatest tendency to experience damage due to any one of, or a combination of, these hazards. Hazard maps were generated for each of the individual hazards. On these individual hazard maps, areas of the maps were categorized as zones 0, 1, 2, or 3, with 3 being the greatest hazard. For every point on the map, the zone rating for each individual hazard (amplification, liquefaction, and landslide) was squared, and the resulting numbers were added together. Then the square root of this sum was taken and rounded to the nearest whole number. A result of 4 is assigned to category A, a result of 3 is assigned to category B, a result of 2 is assigned to category C, and a result of 1 is assigned to category D.

Example: Suppose that the block on which your house sits 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 2.8284, which rounds to 3 or a rating of B for this hypothetical block. Since B is the next to the highest rating, this block is of greater concern from an earthquake hazard standpoint than would be a block a few miles away that has a rating of D.

It should be pointed out that, with this system, a numeric result of 0 or 5 is theoretically possible, but in practice neither is likely to be seen. If such a rating were to result, it would have been assigned to the D or A group, respectively.

The actual relative hazard map zones were smoothed using three iterations of IDRISI's low pass filter. Following each application of the filter, values of any cells that were reduced by the filtering process were increased back to their original value.

The result of this system is that areas with a high hazard from a single local effect are assigned the rating of B (next to highest overall hazard rating) as well as areas with a combination of lesser single ratings. The rating of A represents a combination of high ratings. The hazard category B should not be underrated, since it can result from a single hazard being very severe. This approach to arriving at a single relative hazard map is novel but has the benefit of quickly delineating areas of greater earthquake hazard without requiring a detailed understanding of the individual hazards or how they are measured.

USE OF THE RELATIVE EARTHQUAKE HAZARD MAP

The *Relative Earthquake Hazard Map of the Linnton Quadrangle* (on map sheet accompanying this report) delineates the areas where earthquakes present the greatest hazard on average. This information can be used to develop a variety of hazard mitigation policies. This information, however, should be carefully considered and understood in order to avoid inappropriate use.

Emergency Response and Hazard Mitigation

One of the key uses for this map is to develop emergency response plans. The areas indicated as having higher hazard will be the areas where the greatest and most abundant damage will tend to occur. Efforts and funds for both urban renewal and strengthening or replacing older and weaker buildings can be focused on the areas where the effects of earthquakes will be the greatest. The location of future urban expansion or intensified development certainly should consider earthquake hazards.

Requirements placed on development could be based on the hazard zone in which the development is located. For example, the type of site-specific earthquake hazard investigation that is required could be based on the hazard zone. Since the *Relative Earthquake Hazard Map* is part of the Metro's Regional Land Information System (an ArcInfo-based GIS), it can easily be combined with any of the other land use or hazard information in that system.

Lifelines

The *Relative Earthquake Hazard Map* and its component single-hazard maps are especially useful for mitigation and expected damage estimation for lifelines. The distributed character of lifelines precludes comprehensive site-specific evaluations. These hazard maps allow quantitative estimates of the hazard throughout a lifeline system. This information can be used for assessing vulnerability as well as indicating priorities and approaches for mitigation.

Engineering

The specific quantitative values calculated for this map of any single hazard are no substitute for site-specific evaluations based on subsurface information gathered at a site. The calculated values may, however, be used to good purpose in the absence of such site-specific information, such as at the feasibility study or preliminary design stage. In most cases, the quantitative values calculated for these maps will be superior to a qualitative estimate based solely on lithology or nonsite specific information. Any great deviation of observed site geology from the geologic model used in the analyses indicates the need for additional analyses at the site.

Relative Hazard

It is equally important is to recognize the limitations of the *Relative Earthquake Hazard Map,* which in no way includes information with regard to the probability of damage occurring. Rather, it shows that when the map area is shaken by an earthquake, the damage is more likely to occur or be more severe in the higher hazard area. The exact probability of such shaking occurring is yet to be determined.

Neither should the higher hazard areas be viewed as unsafe. Except for landslides, the earthquake effects that are factored into the *Relative Earthquake Hazard Map* are not life threatening in and of themselves. What is life threatening is the way that structures such as buildings and bridges respond to these effects. Locations are not necessarily unsafe or even less safe, but the structures there may be.

The map depicts trends and tendencies. In all cases, the actual threat at a given location can be assessed only by some degree of site-specific assessment. This is similar to being able to say demographically that a zip code zone contains an economic middle class, but within that zone there easily could be individuals or neighborhoods significantly richer or poorer.

In summary, just as some parts of the state are snowier than others, thus influencing the type of planning and development that occurs, some parts of the Portland area are more prone to earthquake effects than others. These maps provide one way this fact can be taken into account in planning, development, and decision making. This methodology is being applied to the remainder of the Portland metropolitan area as quickly as resources permit.

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Applied Geotechnology
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City of Portland, Bureau of Environmental Services
Cobb Rock
Cornforth Consultants
Dames and Moore
David J. Newton and Associates
Fujitani Hilts and Associates
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Geotechnical Resources Inc.
John McDonald Engineering
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Northwest Testing Laboratories
Oregon Department of Transportation
Pittsburg Testing Laboratory
Port of Portland
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Woodward-Clyde Consultants
Wright-Deacon and Associates

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Figures (on accompanying map sheet)

Figure 1. Relative ground shaking amplification hazard categories for Linnton quadrangle.

Figure 2. Relative liquefaction hazard categories for the Linnton quadrangle.

Figure 3. Relative slope instability hazard categories for the Linnton quadrangle.