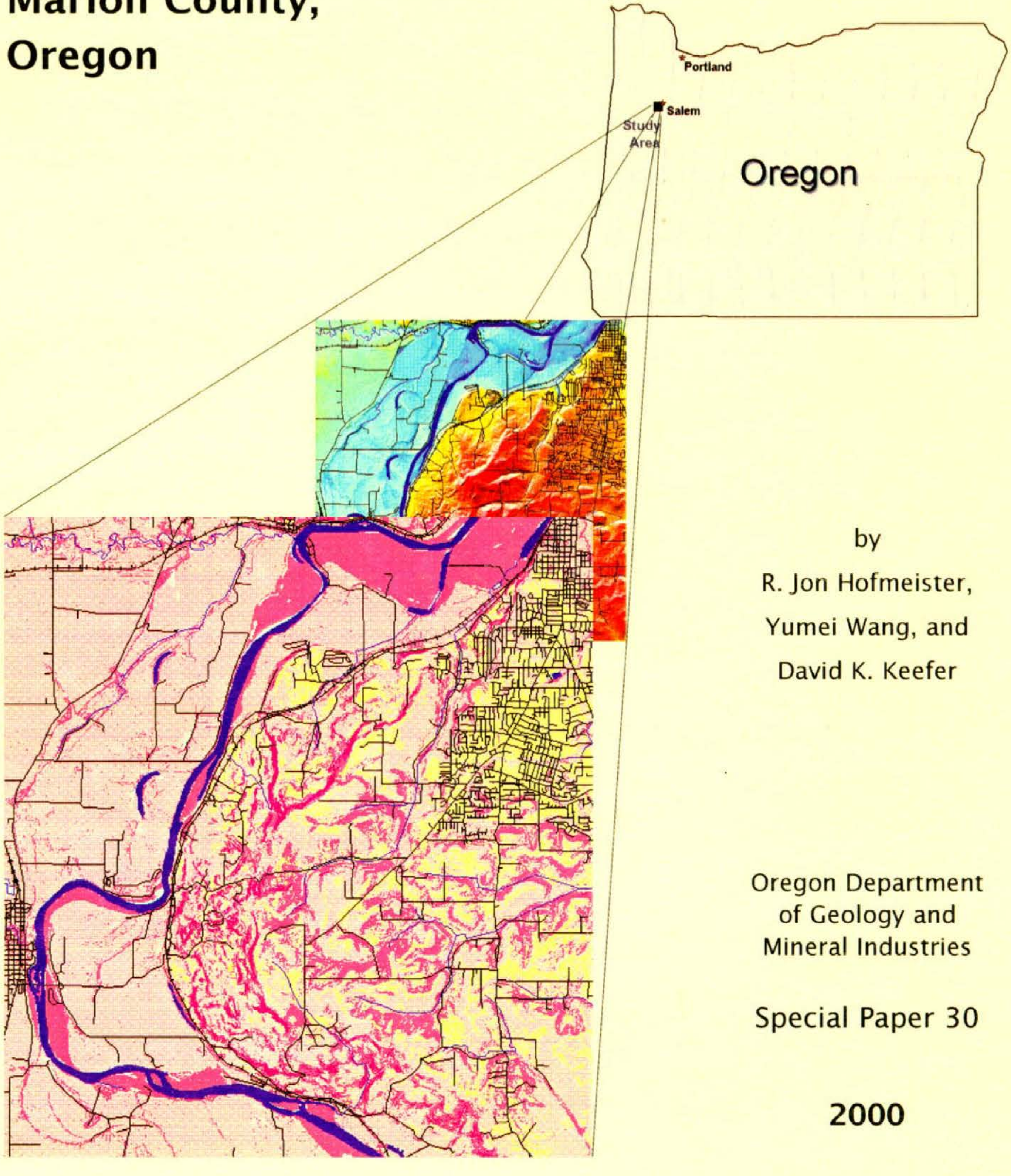
Earthquake-Induced Slope Instability: Methodology of Relative Hazard Mapping, Western Portion of the Salem Hills, Marion County, Oregon



by

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Special Paper 30

2000

Oregon Department of Geology and Mineral Industries Special Papers, ISSN 0278-3703
Published in conformance with ORS 516.030

This report contains the detailed description of a study conducted in the Salem Hills, Oregon. The study resulted in the publication of Interpretive Map Series map IMS-17. The method used to produce IMS-17 was also applied to a study of the eastern portion of the Eola Hills in Salem, which produced Interpretive Map Series map IMS-18.

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SPECIAL PAPER 30

Earthquake-Induced Slope Instability: Methodology of Relative Hazard Mapping, Salem Hills and Eola Hills, Marion and Polk Counties, Oregon

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2000

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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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INTRODUCTION

Salem is the third largest city in Oregon, and development in the Salem Hills area is expected to continue to accelerate. Policy makers, planners, engineers, owners, and many others have both an interest in and a responsibility for identifying and evaluating natural hazards in developed and to-be-developed areas. Relative hazard maps are one of the vital tools in making realistic judgements regarding land use, development, and public-safety decisions.

The goal of this project was to produce hazard maps for earthquake-induced slope instability, suitable to serve as aids to both specialists and nonspecialists in evaluating relative hazards within the Salem Hills vicinity. The resulting hazard maps provide a rational basis for evaluating the spatial variability of landslide hazards within the Salem area. They are intended to help guide regional decisions by planners, emergency management officials, and others responsible for planning and implementing measures aimed at minimizing potential loss of life and property damage from future earthquake events.

Slope instability hazards are of particular concern in the Salem area. Several rainfall-induced slides have recently caused damage to development in the study region. Also, as population growth has expanded the city boundaries, new development has spread into the marginal, steeper areas south of downtown Salem. Extensive portions of the Salem Hills vicinity, particularly along the north and west flanks, are characterized by jumbled, "hummocky" terrain resulting from major historical landslide events. These features are a noteworthy reminder

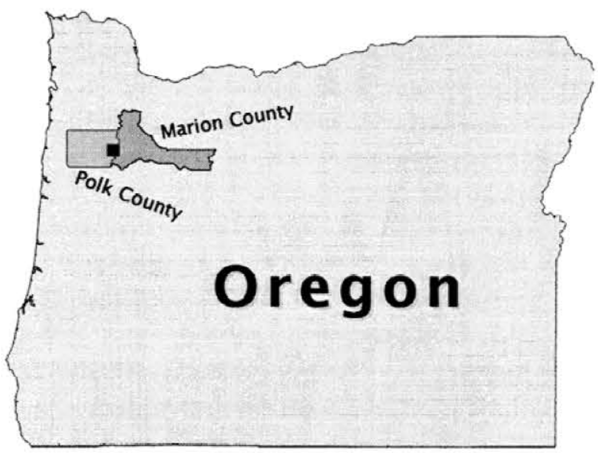

Figure 1. Vicinity map of the Salem Hills study area (black square).

that this area has been unstable in the past and that portions will inevitably move again in the future.

To address the hazard in both developed and as yet undeveloped areas, we applied scientific and engineering methods of slope stability analysis that use Geographic Information System (GIS) tools. The calculations were performed on the basis of a 10-m × 10-m grid spacing, and the final hazard maps depict zones of *Very Low*, *Low*, *Moderate*, and *High* potential for earthquake-induced slope instability.

While this paper describes the applied methodology mainly in reference to the Salem Hills, it has equal significance for the companion project of hazard mapping for earthquake-induced slope instability in the eastern portion of the Eola Hills in West Salem, Polk County.

PREVIOUS WORK

This project builds upon previous earthquake hazard mapping in the Salem area by the Oregon Department of Geology and Mineral Industries (DOGAMI) in 1996 (Wang and Leonard, 1996). The Wang and Leonard analysis included an evaluation of ground shaking amplification, landslide, and liquefaction hazards in the Salem East and Salem West 7½-minute quadrangles. Those quadrangles include the northern portion of the region evaluated in this new study.

The landslide hazard categories in the Wang and Leonard project were purely a function of calculated slope angles. In addition to expanding the geographic area mapped, this present study bolsters the slope stability portion of their analysis by augmenting topographic data with soil-property and other physical data to further differentiate areas of relative hazard within the critical Salem Hills vicinity.

In addition to expanding mapping efforts in the Salem region, the seismic slope stability analysis in this study further refines a methodology recently developed by David Keefer of the U.S. Geological Survey (USGS) and Yumei Wang of DOGAMI (Keefer and Wang, 1997). Their methodology is specifically intended for implementation within a GIS and utilizes common methods for scientific and engineering analysis of slope stability. The Kiefer and Wang methodology was applied initially to a portion of the Eugene-Springfield, Lane County, metropolitan area, later to the entire metropolitan area (Wang and others, 1998; Black and others, 2000). This Salem study is the second project based on that methodology.

This mapping effort for earthquake-induced landslide hazards is part of a larger effort addressing slope hazards in the Salem area. A complementary part of the project was to evaluate rainfall-induced landslide hazards in the Salem area. Results have been published as DOGAMI Interpretive Map Series maps IMS-5 and IMS-6 (Harvey and Peterson, 1998 and 2000). They consist of generalized hazard maps depicting relative hazard zones graded from 1 to 6 (low to high susceptibility) and associated texts outlining development recommendations for each zone.

The study region (Salem Hills) used for the present study of earthquake-induced slope instability includes the areas analyzed for rainfall-induced landslide hazards. The two map projects together will serve as useful complements for evaluating critical hazard areas in the Salem vicinity.

PROJECT OBJECTIVES

Public and private agencies that create regional hazard maps can benefit from the use of a standardized regional hazard mapping methodology. The methodology should be uniform, yet flexible enough to remain appropriate for, and verifiable across, vast and geographically diverse regions. The ideal is to produce the most accurate maps possible (that is, the best predictors of high-risk versus low-risk areas) in the least amount of time and at the lowest cost.

The Keefer and Wang (1997) methodology was chosen as the most promising current tool for evaluating slope stability hazards on a regional scale. This Salem study area includes some challenging and complex geologic conditions and provides a unique opportunity to test that methodology. Field evaluation by David Keefer, Yumei Wang, consulting geologist Robert Murray, and this author in March 1998 confirmed both the geologic complexity and the geographic importance of the study region.

Within this framework, this project had three complementary objectives:

1. To create an accurate and representative hazard map of earthquake-induced slope instability for the vicinity of the Salem Hills.

2. To implement and evaluate the Keefer and Wang (1997) methodology for assessing regional earthquake-induced slope instability, using GIS tools; and to refine the method, where applicable, for subsequent regional mapping efforts in Oregon and elsewhere.

3. To apply good engineering judgment in employing the most rigorous method the data can support, balancing time and economic constraints.

SALEM STUDY AREA

Geographic setting

Figure 1 is a map showing the location of the study area, and Figure 2 shows some of the local political boundaries. The Willamette River separates Polk County on the west from Marion County on the east. The study region is approximately 13.5 km (8.4 mi) north/south by 12.3 km (7.6 mi) east/west and includes the southwestern portion of the Salem urban growth area. The topography is predominately flat in the low-lying alluvial plains in the western portion of the study area, with moderate to steep slopes in the Salem Hills area to the east. Elevations range from approximately 38 m (125 ft) along the banks of the Willamette River to 345 m (1,130 ft) in the Salem Hills.

Geologic setting

The study area lies in the central portion of the Willamette Valley, an approximately 200-km-long, north/south-oriented structural basin separating the Coast Range to the west from the Cascade Range to the east. The basement material in the central portion of the Willamette Valley is a mixture of extrusive basaltic rocks and sedimentary marine deposits of early Eocene age. This material is unconformably overlain by interfingered marine and nonmarine volcaniclastic sedimentary rocks and Columbia River basalt. In the valleys and stream drainages, these bedrock deposits are covered by alluvial deposits that range in age from Pliocene to Holocene. A surficial geology map is shown in Figure 3 and is accompanied by Table 1 which lists the types of geologic material modeled in the study. Detailed descriptions of geologic rock units from Bela (1981) are included in Appendix A. Other geologic mapping and unit descriptions can be found in McDowell (1991), Burns and others (1992), Crenna and others (1994), and Wang and Leonard (1996).

Extensive portions of the west and south sides of the Salem Hills are mapped as "landslide topography" by Bela (1981). The landslide terrain is distinguished by weathered headscarps, hummocky topography, mixed geologic materials, translated blocks of bedrock, interspersed sag ponds, and complex drainage patterns. The upslope topography of the eastern portion of the study area is marked by more regular topography and drainage patterns.

Seismic setting

The Willamette Valley is located approximately 150 km inland from the Cascadia subduction zone, a convergent plate boundary where the Juan de Fuca plate is being subducted beneath the North American plate (see Figure 4). Similar environments exist off the coasts of Japan, Mexico, Alaska, and Chile, where the largest recorded historical earthquakes have occurred. Three potential earthquake sources are associated with colliding tectonic plates: subduction zone, intraplate, and crustal events.

In the Pacific Northwest, as in other similar settings, there is a great deal of uncertainty in estimating the size and location of future earthquakes because the events are infrequent and the mechanisms are not fully understood. Based on our current understanding, however, we estimated probable magnitude (M) and source-to-site distance (R) for subduction, intraplate, and crustal sources that could affect the study area.

Subduction zone earthquakes

Subduction zone earthquakes occur along the interface between the overriding North American plate and the subducted Juan de Fuca plate. The largest earthquakes ever recorded, the 1960 Chilean (M 9.5) and the 1964 Great Alaska (M 9.2) earthquakes, were subduction zone events (Kanamori, 1977). Based on geologic evidence gathered primarily in the Puget Sound region (Atwater, 1988), along with comparisons to similar geological settings in other parts of the world, it is generally accepted that there is a real threat of a large subduction zone earthquake along the Cascadia mar-

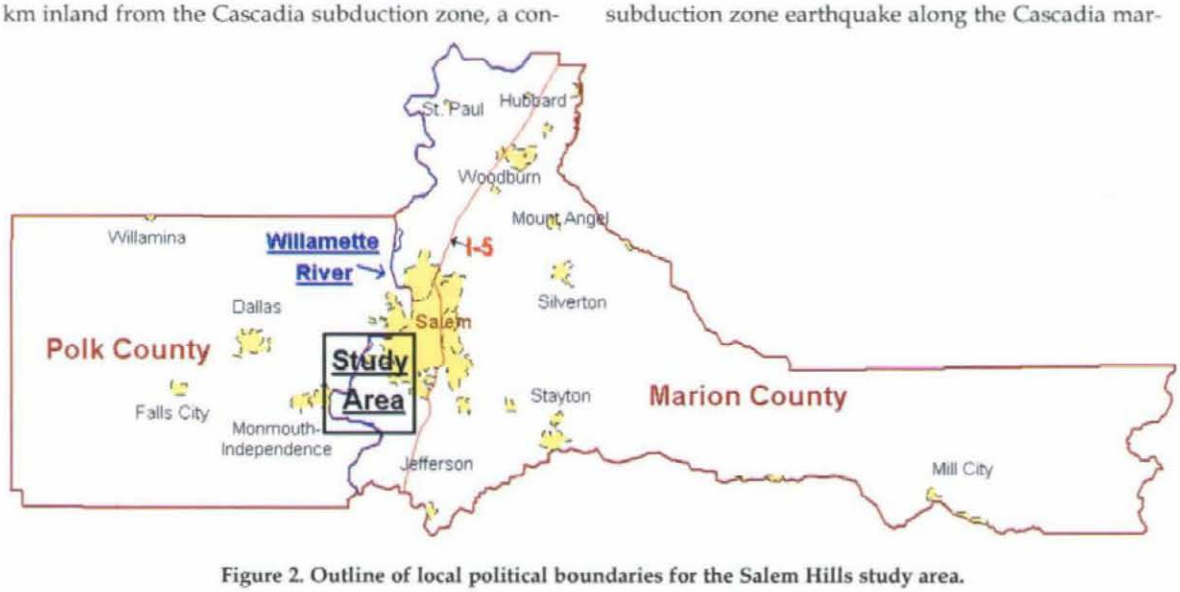

Figure 2. Outline of local political boundaries for the Salem Hills study area.

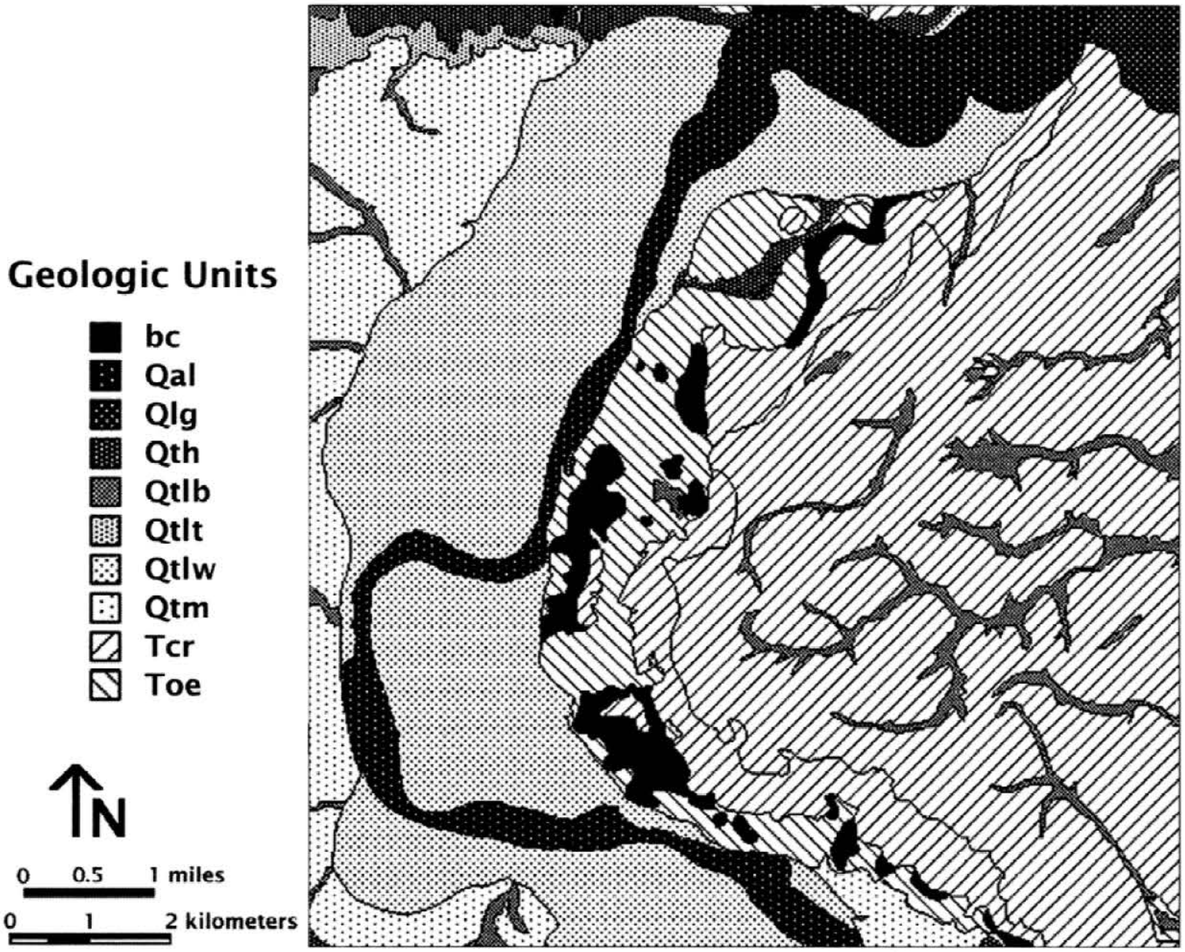

Figure 3. Surficial geology map (adapted from Bela, 1981).

gin. Published estimates range from moment magnitude M_w = 8.0 to M_w > 9.0, and information regarding the location and geometry of the subduction zone indicates that source-to-site distances of 60 to 80 km are probable (Weaver and Shedlock, 1989).

Intraplate earthquakes

Another source of seismicity associated with the Cascadia margin are deep events within the subducting Juan de Fuca slab. These earthquakes, referred to as intraplate events, are associated with internal deformation and volume changes due to high temperature and pressure gradients within the earth's crust. Several intraplate events have occurred in the Pacific Northwest, including the 1949 Olympia earthquake (M_S = 7.1), and the 1965 Tacoma-Seattle earthquake

Table 1. Descriptions for geologic units shown in Figure 3. Detailed lithologic descriptions from Bela (1981) are included in Appendix A

Symbol	Unit
bc	Basaltic colluvium and/or landslide debris
Qal	Recent river alluvium
Qtlw	Lower terrace deposits of the Willamette River
Qtlt	Lower terrace deposits of tributary rivers and streams (Quaternary)
Qtlb	Lower terrace deposits of alluvial bottomlands
Qtm	Middle terrace deposits (Quaternary)
Qlg	Linn gravel (Quaternary–upper Pleistocene)
Qth	Higher terrace deposits (Quaternary–middle Pleistocene)
Tcr	Columbia River Basalt Group (Miocene)
Toe	Oligocene–Eocene sedimentary rock (middle and lower Oligocene and upper Eocene)

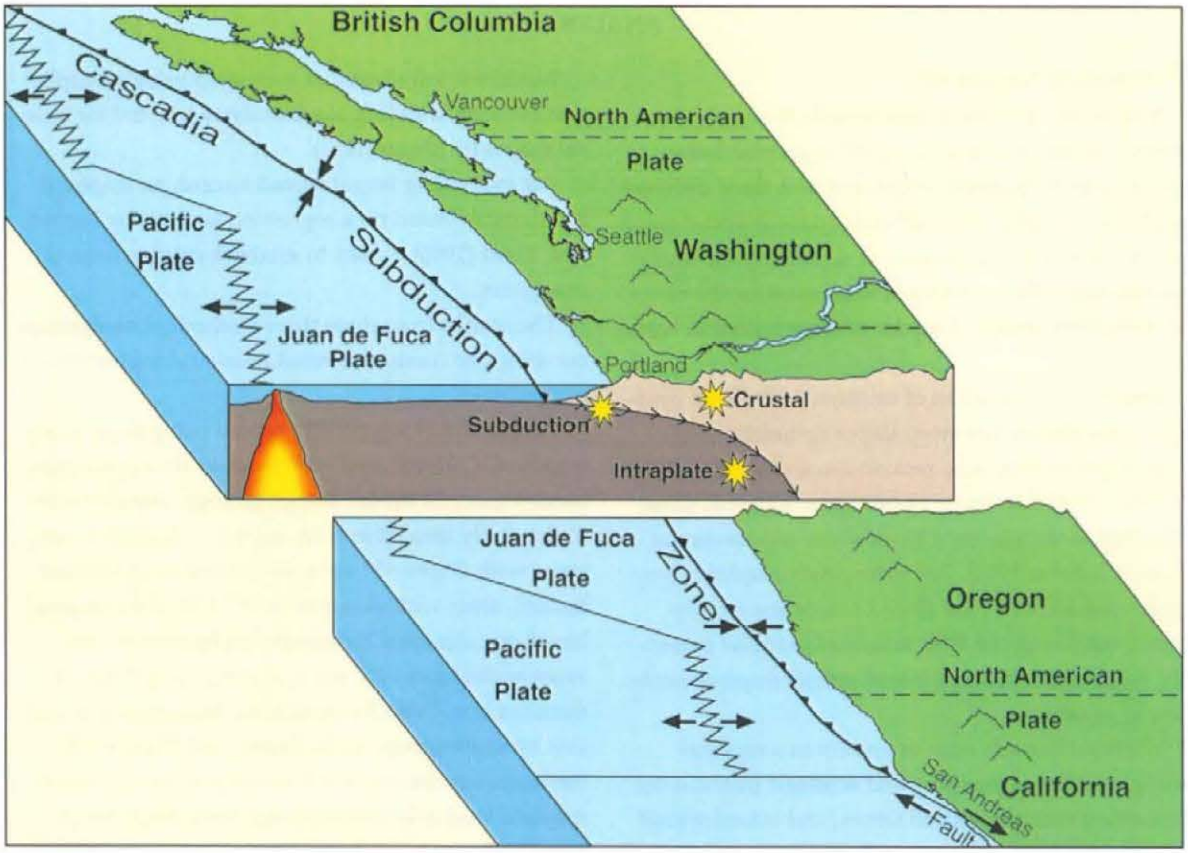

Figure 4. Schematic of the Cascadia subduction zone showing typical locations for the three types of earthquake sources in the Pacific Northwest: subduction, intraplate, and crustal.

(M_b = 6.5). Based on historical (approximately the st 200 years) seismic records in the Pacific North- est and on comparisons with active convergent ate margins in other parts of the world, estimates of maximum magnitudes associated with intraplate events along the Cascadia margin range from Richter magnitude (M_L) 7.0 to 7.5. Models of the location and geometry of the plates within the Cascadia subduction zone indicate that minimum focal distances of 40 to 60 kilometers are probable (Weaver and Shedlock, 1989).

Local crustal earthquakes

The third potential source for earthquakes in the Pacific Northwest is associated with deformation within the overriding North American plate. These events, referred to as crustal earthquakes, occur at shallower depths (typically 10–20 km) and are usually associated with fault zones within the crust. Several crustal earthquakes greater than magnitude 5 have occurred in the Willamette Valley over the last 150 years (Bott and Wong, 1993), the most recent being the magnitude 5.6 Scott Mills earthquake in 1993 (Madin and others, 1993). Estimates of the maximum probable magnitude for a crustal event in the Salem area range from Richter magnitude 5.5 to 6.5. The focal distance depends on the fault zone modeled, and probable estimates vary considerably. A range of 10 to 25 km is commonly used for seismic analysis in the Salem area.

ANALYSIS

Methodology framework

The Keefer and Wang (1997) methodology is designed for implementation with Geographic Information System (GIS) applications and uses three different methods to evaluate overall earthquake-induced slope stability hazard. The purpose in separating the analysis into three distinct facets is to account for the range of commonly observed modes of slope failure in earthquake events.

Empirical observation of earthquake-induced landslides has shown that steep slopes (generally rock) tend to fail as rock falls, rock slides, and debris slides (Keefer, 1984). Moderate slopes (generally soil) most often fail as translational block slides and rotational slumps (Keefer, 1984). For more gently sloping topography, the soil and rock slope hazards are usually lower, but in regions with saturated granular materials, liquefaction-induced lateral spread displacements can be significant.

All three hazards may be present in a regional study, and the engineering and scientific methods for evaluating rock slopes, soil slopes, and lateral spread hazards are quite different. Different methods are selected for modeling each of these hazards, taking into account technical merit and applicability for regional GIS analysis.

For steep rock slopes, an empirical decision tree developed by Keefer (1993) is used. The method is based on the empirical correlation between recorded landslide concentrations (number of landslides per km^2) and material properties including degree of weathering, cementation, fracture spacing and openness, and degree of saturation.

Moderate soil slopes are evaluated using a simplified Newmark sliding block analysis adapted for natural slopes by Jibson (1993).

For evaluating lateral spread hazard, an empirical relationship based on a regression analysis by Bartlett and Youd (1995) is used to establish relative hazard categories.

The results from these three methods of analysis are combined to create an overall relative slope instability hazard map.

Keefer and Wang (1997) propose using slope groupings of <5°, 5°–25°, and >25° to select the appropriate hazard analysis model. For all geologic deposits within the study area other than mapped landslide zones, areas with slopes <5° are analyzed for lateral spread hazard, areas with slopes from 5° to 25° are evaluated based on calculated Newmark displacements, and areas with slopes >25° are evaluated using Keefer's decision tree. Table 2 summarizes the methods of analysis by slope group. In the Keefer and Wang (1997) methodology, no analytical techniques are applied to mapped landslide areas; instead, these areas are assigned a "very high" hazard rating.

Modified methodology

The approach implemented in this study maintains the intent of the gentle, moderate, and steep groupings, but the methodology is slightly modified. Changes for the Salem study include:

1. A six-percent (3.4°) slope value is used to distinguish between gentle and moderate slope groups, rather than the 5° break used by Keefer and Wang (1997). The six-percent value corresponds to the maxi-

Table 2: Summary of hazard analysis methodology by slope group (After Keefer and Wang, 1997)

	Gentle slopes	Moderate slopes	Steep slopes
Typical materials	Loosely-consolidated sediments	Semi-consolidated soils	Rock
Dominant hazard	Liquefaction-induced lateral spread	Soil slides	Rock falls, rock slides and debris slides
Analysis method based on	Regression analysis by Bartlett and Youd (1995)	Simplified Newmark sliding block analysis adapted by Jibson (1993)	Decision tree analysis by Keefer (1993)

mum slope used in the regression analysis performed by Bartlett and Youd (1995).

2. The six-percent slope value does not function as a strict cut-off between the Bartlett and Youd and simplified Newmark analyses. Lateral spread hazards may be significant on steeper slopes, particularly along cut banks in river and stream channels. Therefore, lateral spread hazard ratings are assigned to all susceptible sedimentary deposits, including those with calculated slopes of greater than six percent.

3. The simplified Newmark analysis is used to evaluate all applicable soil deposits, including some sites with less than six-percent slope and some sites with >25° slope.

4. Steep slope cut-off values are incorporated in the soil slide portion of the analysis to ensure reasonably conservative hazard ratings in steep terrain.

5. Mapped preexisting landslide areas are assigned reduced residual strength values and analyzed using the simplified Newmark method. Large portions of the north and west flanks of the Salem Hills have experienced movement in the past. Grouping these regions into a uniform high hazard category does not provide information on relative hazards within these extensive zones and would limit the usefulness of the final hazard map for planning and other uses. Incorporating a strength reduction factor and performing the simplified Newmark method allows the inclusion of other parameters, such as slope and material property variations, and differentiation of the relative hazards within these important zones.

These modifications result in dual hazard analyses for some slopes, and as a result there is a less obvious differentiation between the three modes of slope failure that are modeled. These changes, however, expand the applicability of the methodology and ensure that each area is analyzed for all potential hazards that may be relevant. Figure 5 presents a schematic flow chart of the Keefer and Wang methodology as modified for this study.

Four general steps are designated on the flow chart. The first step outlined is to select the applicable regions for each hazard type (lateral spread, soil slide, and rock slope). This step involves a consideration of the types of materials that are susceptible to each of the hazard groups. It also requires an evaluation of the best and most appropriate sources of information for each method of analysis. After gathering the information available for the study area, the next general step is to assign the corresponding input parameters for each of the three analytical techniques and perform the analyses. This is typically the most time-consuming portion of the method and depends greatly on the nature and resolution of the data available within a

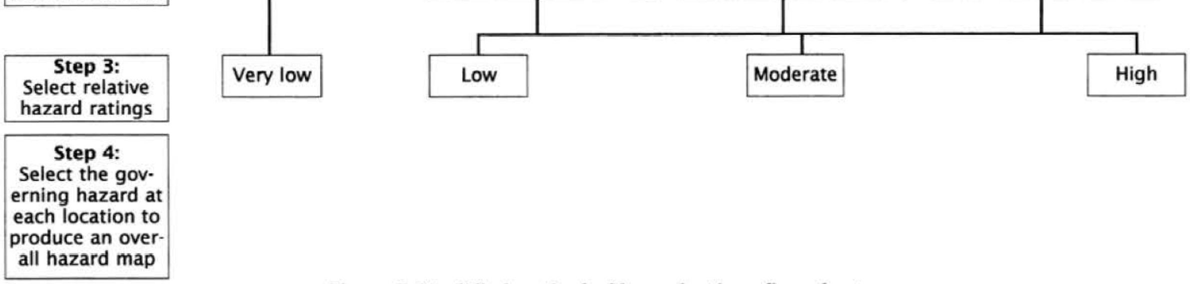

Figure 5: Modified method of hazard ratings flow chart.

given study region. For this study, a lateral spread analysis, using equations developed by Bartlett and Youd (Bartlett and Youd, 1995), is performed for all Quaternary sedimentary deposits delineated on a surficial geologic map. The soil slide analysis, based on a simplified Newmark analysis (Jibson, 1993), is performed for all soil units contained in databases obtained from the Natural Resource Conservation Service (NRCS). The rock slope analysis, based on the decision tree developed by Keefer (Keefer, 1993), is performed for all bedrock units on the geologic map with calculated slopes >25°. Details on each of these three analyses will be provided in following sections.

The final steps outlined on the flow chart include translating the outputs from each analysis into relative hazard ratings, then combining the results to generate an overall hazard map. These steps require the application of good professional judgement and depend to some extent on the particulars of the region that is analyzed. For this study, the three hazard types are first evaluated as separate data layers and then combined (by selecting the governing hazard for each location, as discussed later) to create an overall earthquake-induced slope instability map.

Geographic Information System applications

As mentioned previously, the Keefer and Wang (1997) methodology is designed for implementation using Geographic Information System (GIS) applications. GIS is a category of computer applications that are specifically designed for working with geographic databases and manipulating spatial data. The power of GIS programs lies in that they allow to overlay, combine, and analyze various layers of information accurately and efficiently. Most GIS applications also augment spatial capabilities with database management and analytical tools. The combination of these tools allows for convenient updating and modification of existing spatial databases within one environment. In this project, the GIS application MapInfo™ was used, and the modified Keefer and Wang methodology implemented, to produce a relative earthquake-induced slope instability hazard map. A number of other applications were used in conjunction with MapInfo™, including Vertical Mapper™, 3D Mapps™, ArcView™, and IDRISI (Eastman, 1990, 1993).

Data availability

The ability to model and evaluate earthquake-induced hazards in GIS applications is constrained by the amount and quality of data that can be economically gathered. The Salem Hills study area was selected, in part, because of the range of available and useable geologic, topographic, and geotechnical data. In preparation for and throughout the analysis, various data sources were utilized. They are summarized below, organized by subject. Filled bullets indicate that data were available in, or were converted to, digital formats.

Topographic data

- ● 1:24,000-scale USGS 7½-minute topographic map series (10-ft contour interval)
- ● DOGAMI 10-m Digital Elevation Model
- ● USGS 30-m Digital Elevation Models

Geology/soils

- ● 1:24,000-scale DOGAMI geologic map GMS–18
- o Geologic information in Burns and others (1992), McDowell (1991), Crenna and others (1994), and Wang and Leonard (1996)
- ● U.S. Natural Resource Conservation Service map of Polk County (Knezevich, 1982)
- ● U.S. Natural Resource Conservation Service map of Marion County (Williams, 1972)
- ● Oregon Water Resources Department water well database
- o Borehole and laboratory data collected by DOGAMI

Other sources

- o U.S. Army Corps of Engineers color infrared (CIR) photographs, 1:30,000-scale, taken on September 11, 1979
- o Black-and-white aerial photographs, 1:48,000-scale, taken on April 6, 1986
- o Geotechnical consultant reports collected by DOGAMI

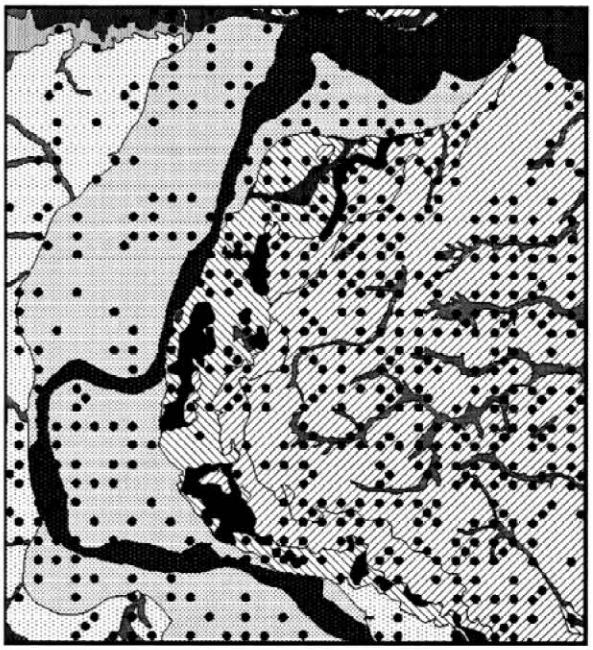

Figure 6. Water well points (filled circles) overlaid on the geologic map (Bela, 1981) shown in Figure 3.

The locations of the water well points within the study area are shown in relation to the digitized geologic map by Bela (1981) in Figure 6.

The digitized soils map for the Salem Hills study area, derived from the Soil Conservation maps of Marion and Polk Counties, is shown in Figure 7.

As noted in the list under "Data availability" above, the geology, soils, and topographic information was converted to digital formats. When working with digital spatial information within a GIS, resolution of the data is an important consideration. For the topographic data, a Digital Elevation Model (DEM)[1] with a 10-m grid spacing was used. An illustration of the significance of resolution is shown in Figure 8, where a 10-m, 30-m, and an approximately 90-m DEM of the same area are shown side by side. The superimposed arrow points out a drainage ditch, which is visible in the 10-m DEM but is difficult to distinguish in the 90-m elevation file due to the larger sample spacing. While the 90-m and 30-m DEMs are USGS products that have been produced in digital format for most of the United States, 10-m DEMs are not as widely available. For the Salem study area, DOGAMI funded the creation of a 10-m DEM from the 10-ft contour interval USGS quadrangle. A shaded relief map derived from the DOGAMI DEM is shown in Figure 9.

The 10-m DEM formed the basis for the generation of a slope map using the GIS program Vertical Mapper.™ The calculated slope values are stored at the same grid points as the original DEM data. The slope map shown in Figure 10 was the database used for reporting hazard values. The slope map was overlaid on both the geology and soils map layers, and the properties associated with each were assigned to the slope grid points. A schematic of the GIS overlay operation to create a single database with slope, geology, and soils data stored at grid points is shown in Figure 11. The subsequent hazard analyses outlined in the following sections were performed on this combined data file with values stored at a 10-m grid spacing throughout the study area.

Lateral spread analysis

For modeling lateral spread hazard, a Bartlett and Youd (1995) analysis was performed. Lateral spread is a liquefaction-related phenomenon, where overlying soil deposits move downslope along liquefied zones. The movement is gravity driven and occurs when the ground shaking reduces the shear strength of a slope to below the static shear stress required to maintain equilibrium (Kramer, 1996). The phenomenon of liquefaction is explained well by Noson and others (1988): "Liquefaction occurs when saturated sand or silt is shaken violently enough to rearrange its individual grains. Such rearrangement has a tendency to compact the deposit. If the intragranular water cannot escape fast enough to permit compaction, the load of overlying material and structure may be temporarily transferred from the grains of sand or silt to the water, and the saturated deposit becomes 'quicksand'."

Loose, uniform, saturated sands are most susceptible to liquefaction flow failures. In general, susceptibility decreases with increasing geologic age, fines content, gradation, particle angularity, density, and overburden pressure. The amount of displacement that results from liquefaction initiation ranges from slight to

[1] A DEM is a regularly spaced series of points (a grid) with an elevation value and geographic coordinates (e.g., latitude, longitude) stored for each point. Grid spacing is the distance between the points.

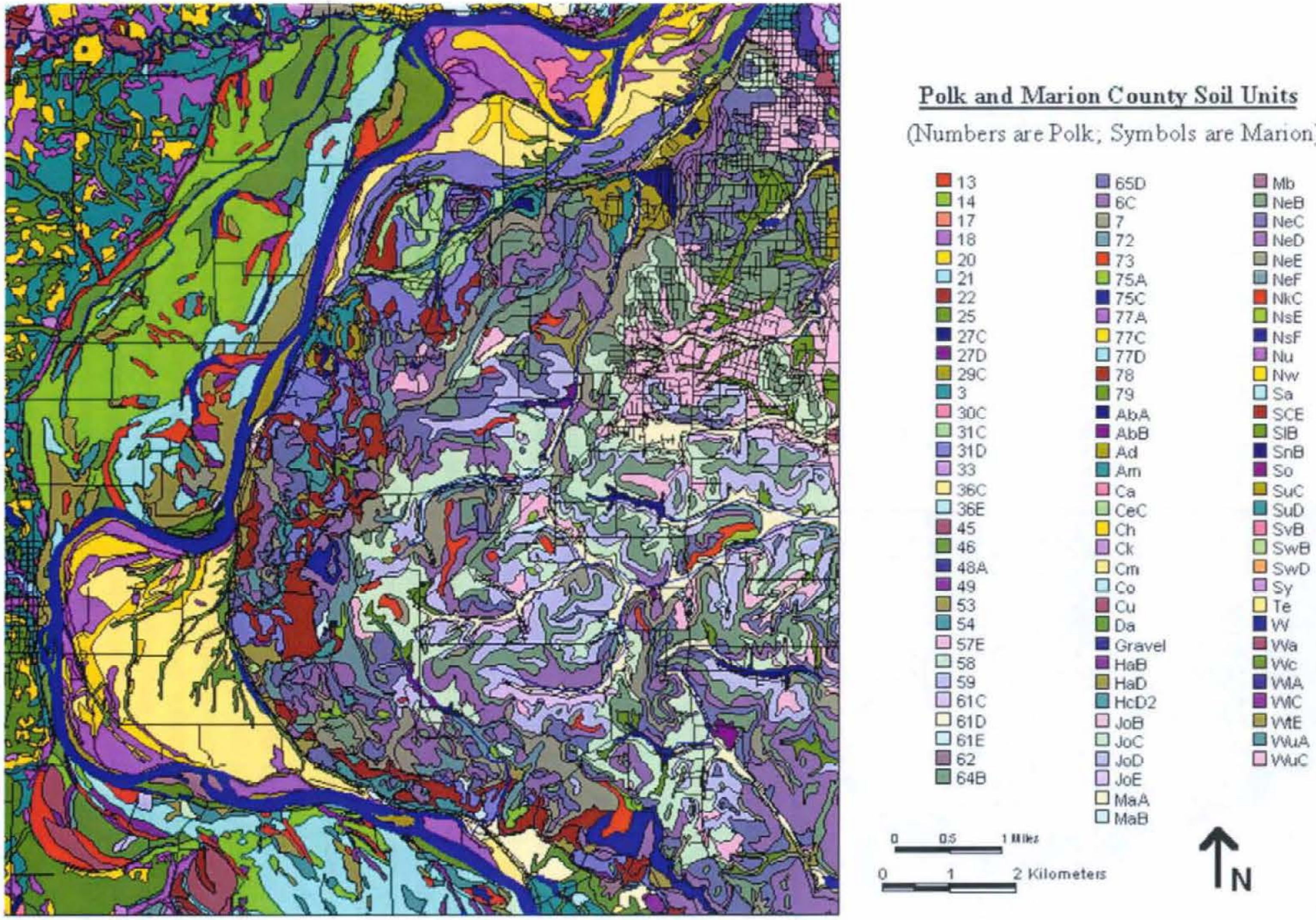

Figure 7. Soils map for the Salem Hills study area, after Williams (1972) and Knezevich (1982). Soil unit names and selected properties are given in Appendix B.

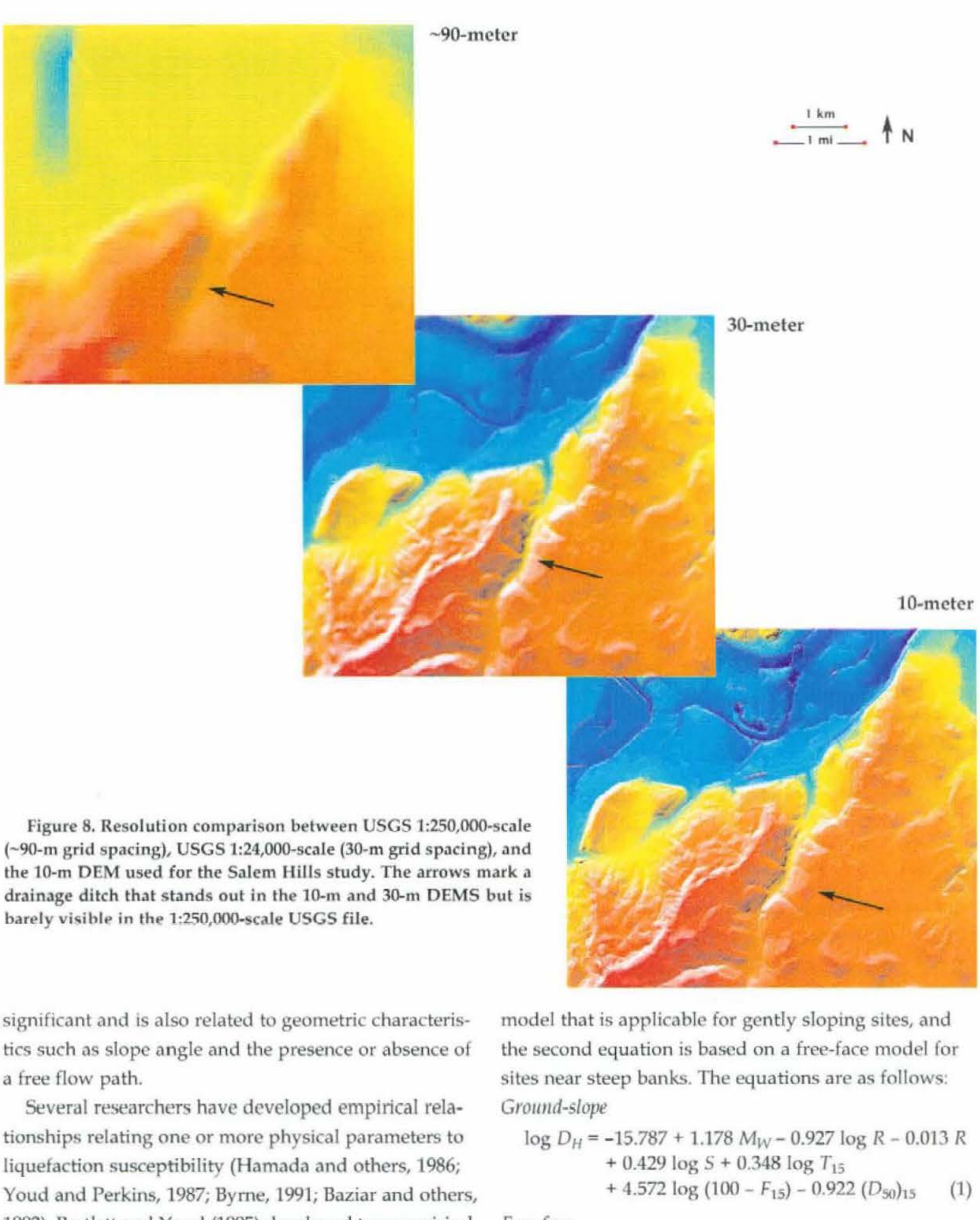

Figure 8. Resolution comparison between USGS 1:250,000-scale (~90-m grid spacing), USGS 1:24,000-scale (30-m grid spacing), and the 10-m DEM used for the Salem Hills study. The arrows mark a drainage ditch that stands out in the 10-m and 30-m DEMS but is barely visible in the 1:250,000-scale USGS file.

significant and is also related to geometric characteristics such as slope angle and the presence or absence of a free flow path.

Several researchers have developed empirical relationships relating one or more physical parameters to liquefaction susceptibility (Hamada and others, 1986; Youd and Perkins, 1987; Byrne, 1991; Baziar and others, 1992). Bartlett and Youd (1995) developed two empirical relationships, using a multiple linear regression analysis on a number of U.S. and Japanese case histories. One equation was developed using a ground-slope model that is applicable for gently sloping sites, and the second equation is based on a free-face model for sites near steep banks. The equations are as follows:

Ground-slope

$$\log D_H = -15.787 + 1.178\, M_W - 0.927 \log R - 0.013\, R + 0.429 \log S + 0.348 \log T_{15} + 4.572 \log (100 - F_{15}) - 0.922\, (D_{50})_{15} \quad (1)$$

Free-face

$$\log D_H = -16.366 + 1.178\, M_W - 0.927 \log R - 0.013\, R + 0.657 \log W + 0.348 \log T_{15} + 4.572 \log (100 - F_{15}) - 0.922\, (D_{50})_{15} \quad (2)$$

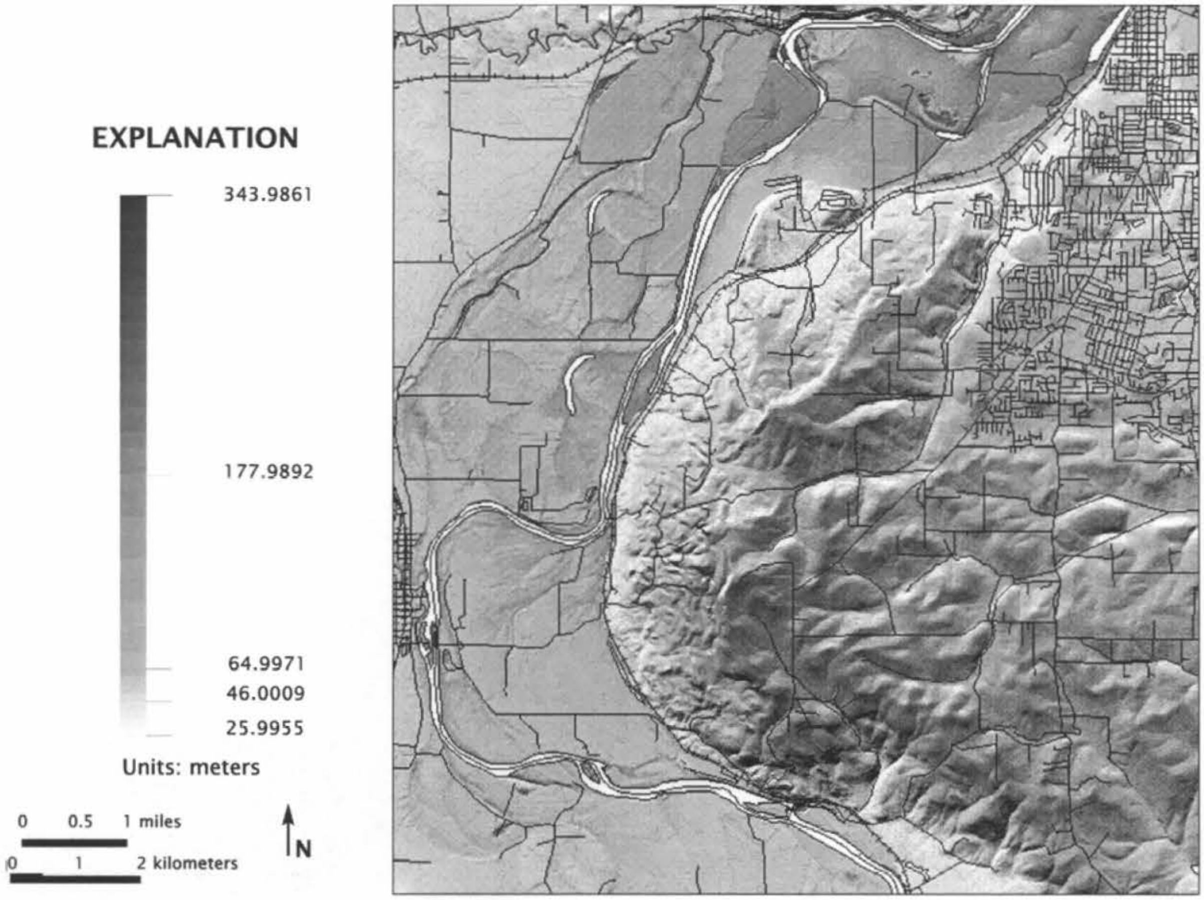

Figure 9. Shaded relief map from the 10-meter DEM used for the Salem Hills study area.

where

- D_H is the lateral spread displacement in meters,
- M_W the moment magnitude of the earthquake,
- R the horizontal distance from the seismic energy source in kilometers,
- S the ground slope in percent,
- T_{15} the cumulative thickness of saturated granular layers with Standard Penetration Test (SPT) $(N_1)_{60}$ values ≤ 15 in meters,
- F_{15} the average fines content for the granular layers comprising T_{15} in percent,
- $(D_{50})_{15}$ the average mean grain size for the granular layers comprising T_{15} in millimeters, and
- W the ratio of the height of the free face to the horizontal distance between the base of the free face and the point of interest in percent.

Equations 1 and 2 are applicable within a range of input parameters as summarized in Table 3 below:

Table 3. Range of applicable values for Bartlett and Youd (1995) equations 1 and 2

Input parameter	Range of values
Magnitude	$6.0 < M_W < 8.0$
Thickness of loose layer	$0.3\ m < T_{15} < 12\ m$
Fines content	$0\% < F_{15} < 50\%$
Mean grain size	$0.1\ mm < (D_{50})_{15} < 1.0\ mm$
Ground slope	$0.1\% < S < 6\%$
Free-face ratio	$1.0\% < W < 20\%$
Depth to section bottom	Depth to bottom of liquefied zone < 15 m

The Bartlett and Youd equations (equations 1 and 2) are the tools with which relative lateral spread hazard ratings were assigned for the Salem study area. From previous work by DOGAMI in the Salem vicinity, a number of geotechnical consultant reports and boring

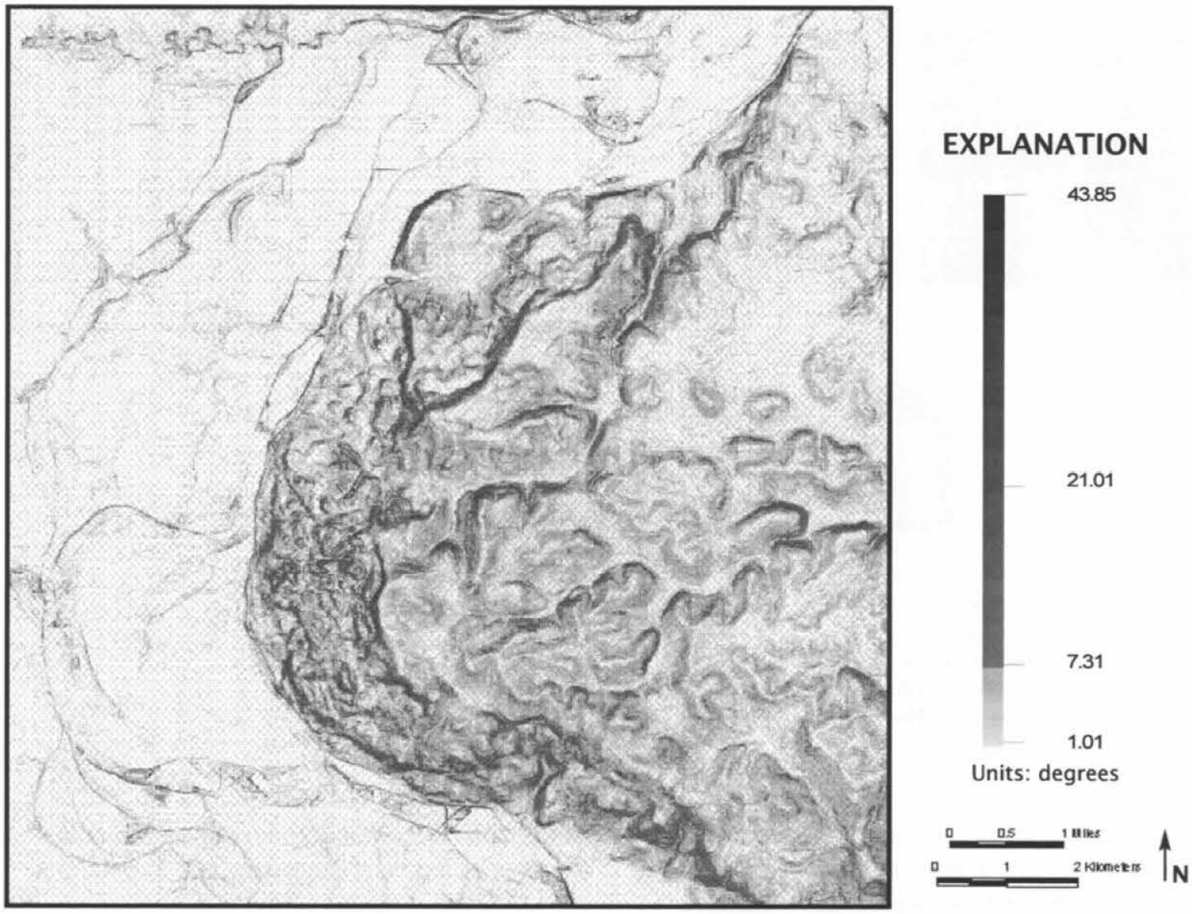

Figure 10. Slope map for the Salem Hills study area.

logs were made available. Of these, 27 boring logs contain data on SPT blow count, fines content, and mean grain size variation with depth. For each of these boring log profiles, inputs of average T_{15}, F_{15}, $(D_{50})_{15}$ values were tabulated. Most of the alluvial deposits in the Salem vicinity are at the low end of the range for average grain size and at the high end of the range for fines content. For all but four of the borehole profiles, the average mean grain size of the T_{15} material was ≤ 0.1 mm, and all but three had average fines contents greater than or equal to 50 percent. For these profiles, a $(D_{50})_{15}$ of 0.1 mm and an F_{15} of 50 percent were conservatively assumed, in order to stay within the limits of the equation.

Given the sparse distribution of the boring log data points, it was determined that the liquefaction hazard should be aggregated based on the geologic map polygons. From an evaluation of Figure 7 versus Figures 3 or 6, it can be seen that the level of detail of the soils map is much greater than that of the geologic map. The limited number of borehole logs was not considered to be adequate to support the higher level of detail, thus each borehole log was grouped on the basis of the corresponding geologic map unit. After assigning Bartlett and Youd (1995) input parameters and grouping the boreholes by geologic material type, we used equations 1 and 2 to evaluate the range of average displacement values for a number of scenarios.

Because the T_{15}, F_{15}, and $(D_{50})_{15}$ values were fixed from the profiles, the relative relationship between the geologic units did not change for different earthquake scenarios. Several scenarios were run instead to determine the magnitude of displacements that could be expected in the area. Results for two sample earthquake

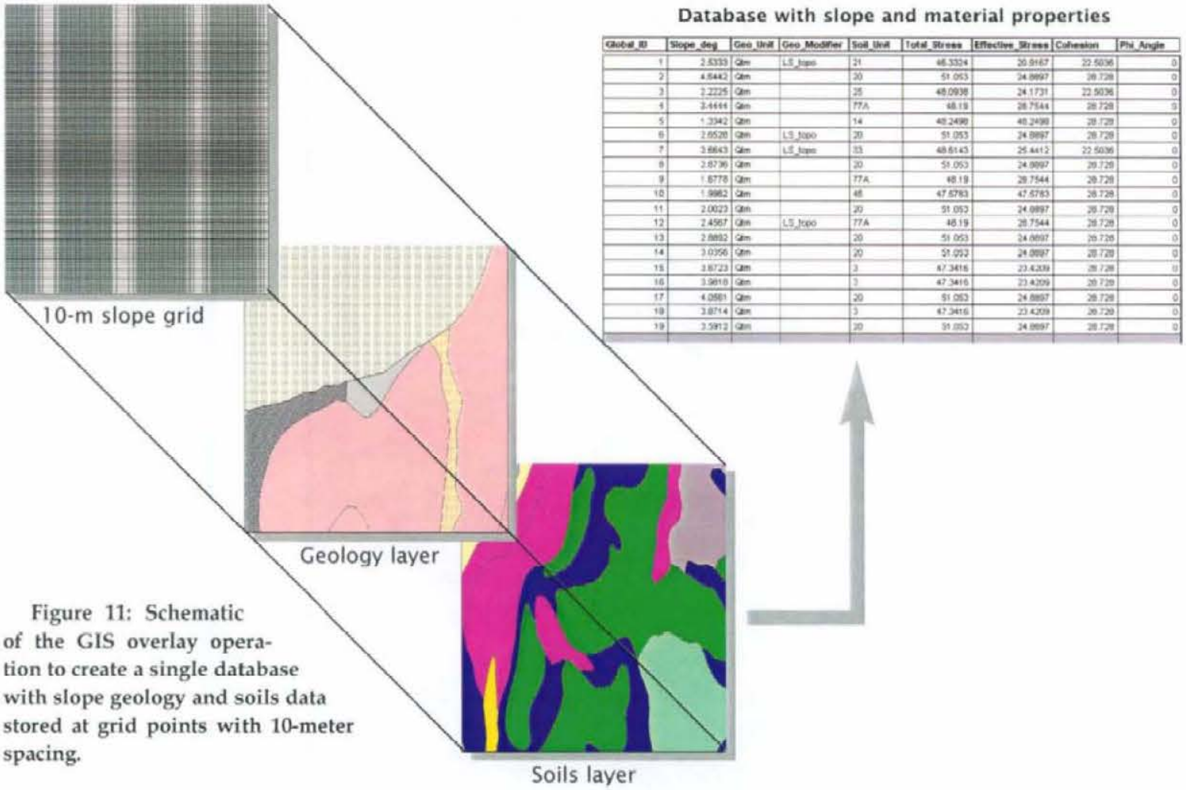

Figure 11: Schematic of the GIS overlay operation to create a single database with slope geology and soils data stored at grid points with 10-meter spacing.

events, a M_W = 6.5 at 20 km and a M_W = 8 at 70 km, are shown in Table 4. These two events correspond to reasonable potential source parameters discussed above, in the section "Seismic setting." The Bartlett and Youd displacements for each event were calculated using a number of slope (S) and free-face ratio (W) combinations. Displacements for hypothetical slope values of 1 percent and 6 percent in the ground-slope model, and a free-face ratio of 20 percent in the free-face model are included in Table 4.

It is apparent that there is a separation in the data between unit Qal and the others. The values of calculated Barlett and Youd displacements are on the order of 6 to 51 cm for Qal, and 0.8 to 15 cm for the other Quaternary deposits. Qal represents "recent river alluvium," which is the youngest deposit in the study area, and is composed primarily of unconsolidated granular materials on the banks of the Willamette River. The other Quaternary sedimentary deposits in the study area are older and generally more compacted and typically have a high fines content. As one would expect, the calculated displacements for each

Table 4. Bartlett and Youd (1995) displacements (in cm) for a M_W = 6.5 event occurring at R = 20 km and a M_W = 8.0 event curring at R = 70 km for both ground-slope and free-face conditions (using S = 1%, S = 6%, and W = 20%)

	M_W = 6.5, R = 20 km, using:			M_W = 8.0, R = 70 km, using:		
	Ground-slope		Free-face	Ground-slope		Free-face
Unit	S = 1%	S = 6%	W = 20%	S = 1%	S = 6%	W = 20%
Qlg	0.84	1.82	1.59	3.33	7.19	6.29
Qth	1.81	3.90	3.41	7.15	15.43	13.51
Qtm	1.56	3.37	2.95	6.19	13.35	11.69
Qtlw	1.60	3.45	3.02	6.34	13.68	11.98
Qal	6.00	20.01	11.34	23.77	51.30	44.90

Quaternary deposit are significantly higher for steeper slopes (see S = 1% versus S = 6%) and free-face conditions.

The relative lateral spread hazard ratings selected for the Quaternary units account for both the higher calculated displacements of Qal and the increase in displacement for steeper slopes and/or free-face conditions. Since the data on thickness, fines content, and mean grain size were based on such sparse information, however, it was not considered appropriate to calculate Bartlett and Youd displacement on a point-by-point basis within the GIS database. Instead, Quaternary deposits with slope values <6 percent were assigned ratings that roughly correspond to Bartlett and Youd ground-slope conditions. Based on the range of calculated displacements from the borehole data in the Salem vicinity, a lateral spread hazard category of *Moderate* was considered to be most appropriate for unit Qal; the other Quaternary units were ascribed a lateral spread hazard of *Low*. For slopes >6 percent, the expected displacement values are expected to be significantly higher. A *Moderate* hazard rating was considered to still be appropriate for Qal, but the lateral spread hazard categories were increased from *Low* to *Moderate* for the other Quaternary units.[2]

Mapped bedrock areas (units Toe and Tcr) with slope values <6 percent were considered to have a *Very Low* lateral spread hazard. For areas with slopes > 6 percent that were not mapped as Quaternary deposits, the soil and rock slope analyses were considered to be more appropriate for assigning hazard ratings. These areas, therefore, were not evaluated for lateral spread hazard.

The resulting liquefaction-induced lateral spread hazard layer is shown in Figure 12.

Soil slide analysis

For moderately steep soil slopes, a simplified implementation of the Newmark sliding block analysis (Newmark, 1965) was selected to model the relative earthquake-induced landslide hazard (Jibson, 1993). Typical engineering means of evaluating the stability of soil slopes subjected to seismic loading include the pseudostatic approach, Newmark's method, and finite element modeling. Newmark's method provides a balance between the pseudostatic analysis, which provides no information on the amount of movement, and the more rigorous finite element method. The original Newmark method involves evaluating the factor of safety of a slope, calculating the critical acceleration at which the mass will move, and then obtaining displacement by double-integrating a selected time history of acceleration for portions which exceed the threshold acceleration.

Newmark's model assumes that the landslide mass moved as a rigid-plastic body with no internal deformation. In addition, the block is assumed to undergo plastic deformation along a discrete basal shear surface when the critical acceleration is exceeded and to undergo zero displacement below the critical acceleration (Jibson, 1993). These assumptions are most appropriate for translational, coherent slides (block slides and slow earth flows) (Wilson and Keefer, 1985).

Newmark first introduced the method to estimate displacements in dams and embankments. It has subsequently been field and laboratory tested in a number of ways and has been adapted to more general applications by Wilson and Keefer (1983, 1985), Wieczorek and others (1985), Jibson (1993, 1996), and Jibson and Keefer (1993). For regional hazard studies, the selection of appropriate digitized strong-motion records and the implementation of the double-integration steps can be quite difficult and time consuming. Simplified models relating one or more parameters to Newmark displacement are generally more applicable for regional analyses. Jibson (1993) outlines one such approach based on an empirical equation relating Newmark displacement to critical acceleration and Arias Intensity. Using strong-motion records with Arias Intensities between 0.2 and 10.0 m/s and a range of accelerations between 0.02 and 0.40 *g*, Jibson developed the following equation based on a best fit multivariate regression analysis:

$$\log D_N = 1.460 \log I_a - 6.642\, a_c + 1.546 \qquad (3)$$

where

D_N is the mean Newmark displacement in centimeters,

[2] By comparison, hazard ratings in the Eugene-Springfield study area were assigned as follows: *No hazard* for displacements of 0–1 cm, *low hazard* for displacements of 1–10 cm, *moderate hazard* for displacements of 10–100 cm, and *high hazard* for displacements of >100 cm (Black and others, 2000).

I_a the Arias Intensity in meters per second, and

a_c the critical acceleration in terms of g, the acceleration due to earth's gravity.

The critical acceleration is calculated using an equation developed by Newmark (1965) related to the static factor of safety and landslide geometry:

$$a_c = (FS - 1) \sin \alpha \tag{4}$$

where

a_c is the critical acceleration in terms of g,

FS the static factor of safety, and

α the thrust angle (equivalent to the slope angle for a planar slip surface parallel to the slope as in an infinite slope model)

The Arias Intensity can be estimated using a relationship developed by Wilson and Keefer (1985):

$$\log I_a = \mathbf{M} - 2 \log R - 4.1 \tag{5}$$

where

I_a is the Arias Intensity in meters per second,

M the moment magnitude of the design earthquake, and

R the earthquake source-to-site distance in kilometers

To implement the Jibson method, three main inputs are required. Earthquake source characteristics are necessary to determine the Arias Intensity, and material and geometric properties are necessary to calculate the static factor of safety and critical acceleration.

For the Salem study area, rather than postulate a specific event with magnitude and source-to-site distance, a uniform Arias Intensity of 2.5 m/s was assumed. The use of a uniform value does not incorporate potential variations due to travel path, topographic and material amplification, directivity and other ef-

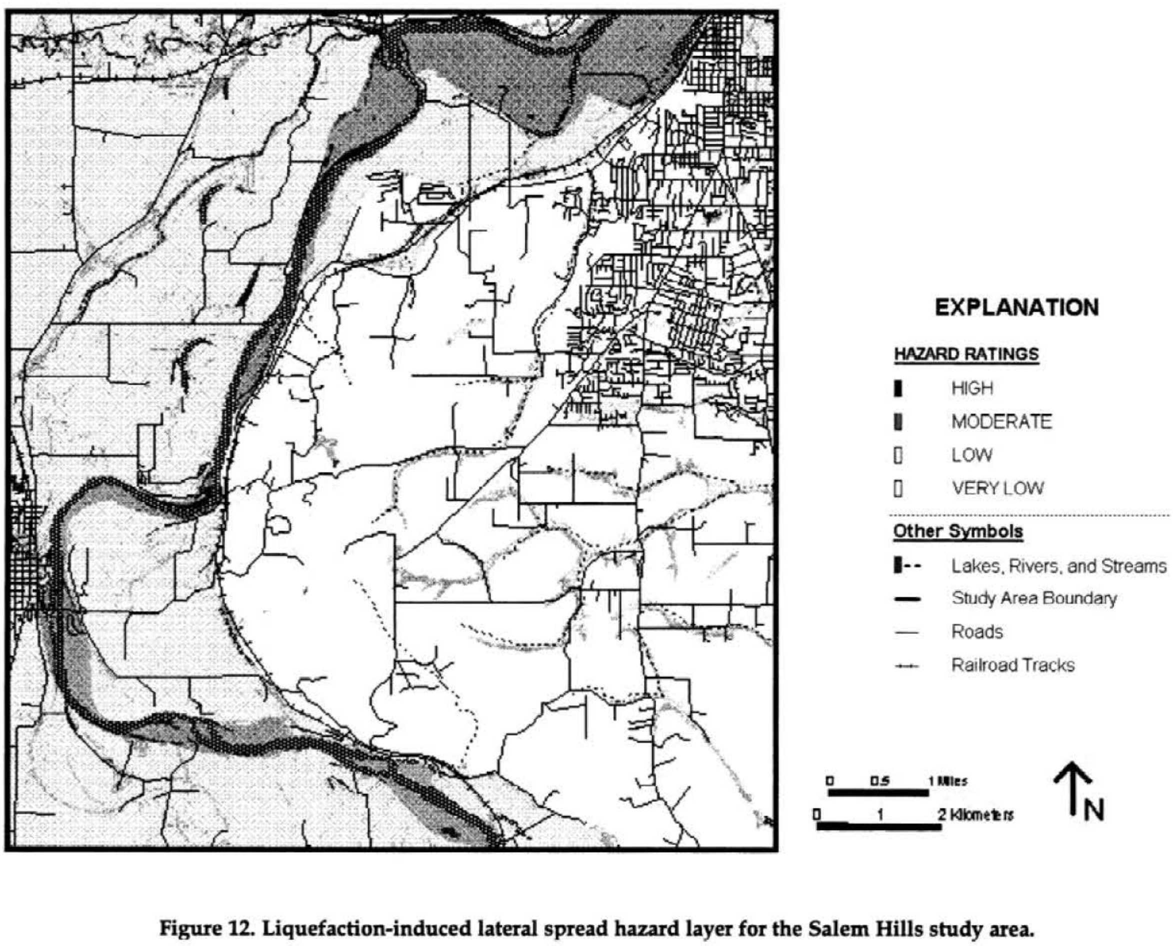

Figure 12. Liquefaction-induced lateral spread hazard layer for the Salem Hills study area.

fects. The uncertainty in modeling the influence of these phenomena is large, and the use of a uniform intensity value ensures that the relative hazard between locations is instead distinguished by the material and geometric properties. The specific Arias Intensity value of 2.5 m/s corresponds to reasonable estimates of local seismic sources discussed in the section "Seismic setting." According to equation 5, an Arias Intensity of 2.5 m/s could represent any of the following magnitude and source-to-site distance combinations: **M** 8.5 at 100 km, **M** 8 at 56 km, **M** 7.5 at 32 km, **M** 7 at 18 km, **M** 6.5 at 10 km, or **M** 6 at 6 km. The value of 2.5 m/s is also consistent with the analysis performed for the Eugene-Springfield case study (Black and others, 2000).

While the Arias Intensity was held constant, critical acceleration values (based on the static factor of safety and thrust angle) vary throughout the study area. The calculation of the static factor of safety, therefore, provides the basis for the assignment of relative hazard ratings. A number of factors had to be determined and/or assumed to calculate the factor of safety. First and foremost, the choice of the type of landslide mechanism (e.g., deep-seated rotational failure versus shallow, translational displacement) drives the type of engineering slope stability analysis to be performed (e.g., method of slices versus infinite slope). Based on discussions with professional engineers who work in the area, it was determined that modeling relatively shallow, translational sliding is most appropriate for this study. There is a mix of potential failure modes in the Salem Hills, but most of the recent rainfall-induced failures in the Salem Hills have been predominately characterized by translational movement. In addition, the use of the translational model throughout the study area, rather than mixing failure mechanisms, ensures that the comparison and evaluation of relative hazards between individual sites is consistent. Thus, the analysis was performed as the equivalent of a site-specific infinite slope analysis at 10-m grid spacing throughout the study area.

The infinite slope stability model assumes a soil layer of constant thickness overlying a planar basal failure surface. A number of forms of the factor of safety equation are available, depending on conditions assumed. For the Salem area, seepage parallel to the slope was assumed.[3]

The particular static factor of safety equation used for the infinite slope analysis is the following:

$$FS = \frac{c + \sigma' \cos(\theta) \tan(\phi)}{\sigma \sin(\theta)} \qquad (6)$$

where

c	is the soil cohesion,
σ'	the effective normal stress,
θ	the slope angle,
ϕ	the soil friction angle, and
σ	the total normal stress.

The factor of safety calculation thus requires inputs of slope angle, depth to the failure plane (= thickness of soil mass), unit weights for each soil layer, depth to ground water table, and strength properties (cohesion and friction angle) along the basal failure surface. Slope angles were obtained from the slope map. The values of the other parameters were grouped according to the soil unit boundaries. The soils layer was selected over the geology coverage because the level of detail of the polygons is more defined (see Figure 6 versus Figures 3 or 5), and because several useful engineering properties are contained in the Natural Resources Conservation Service (NRCS) database (Williams, 1972; and Knezevich, 1982).

Among other properties, the NRCS database includes laboratory information on Unified Soil Classification System (USCS) classification, bulk densities, liquid limits, plasticity indices, clay contents, and average thickness values for each layer. For each unit (consisting of multiple layers), depth to seasonal high water table and depth to bedrock are also given if encountered in subsurface exploration. These NRCS data provided the basis for assigning the properties used to compute the total and effective stresses for each soil unit. A number of assumptions were made in translating the available NRCS database material as follows:

Depth to failure plane: The failure plane was assumed to be at the soil-bedrock interface if tabulated in the

[3] The central Willamette Valley has an extended wet season with an average annual rainfall of approximately 40 in. and an average of 145 rainy days (precipitation >0.01 in.) per year (Oregon State Climate Service).

NRCS database. If bedrock was not encountered in the depth of the survey, failure was assumed to occur at a depth of 2.74 m (9 ft), based on field observations and recommendations from local practicing engineers.

Thickness of soil units: The upper and lower depths of each layer are given for the soil units. For units where bedrock was not encountered, the thickness of the bottom layer is listed as ">" (greater than) the depth of the survey. For these units, the properties of the lowest reported layer were assumed to extend to the depth of the failure plane.

Density: The soil survey reports provide a range of "moist bulk density." These values are derived from laboratory measurements of "field" moisture contents on samples generally collected during the dry summer months (U.S. Department of Agriculture [USDA], 1996). Since the measurements are likely to represent dry or nearly dry samples, the average of the "moist bulk density" range was assumed to represent the dry density of the sample. This assumption was implemented in the Eugene-Springfield study, and the dry density values assigned in the Salem study area closely match values contained in geotechnical consultant reports collected in the vicinity by DOGAMI.

Unit weight: The unit weights were calculated based on 90-percent saturation, consistent with other assumptions of "wet" conditions throughout the analysis.

Depth to water table: "Depth to seasonal high water table" values are given in the soil survey reports. If the tabulated value was below the failure plane, it was defaulted to the failure depth for subsequent data verification purposes. In these cases, total and effective stresses are equal.

The tabulated depths, unit weights, and depth to ground water table values used to compute the total and effective stress for each soil unit are given in Appendix B.

In order to evaluate factors of safety, strength properties were also assigned to each unit. The soil survey reports contain Unified Soil Classification System (USCS) designations and ranges of plasticity-index values for each unit. A number of empirical correlations can be found in the literature for estimating *drained* strength parameters based on USCS classifications (USDA, 1994) and plasticity index (Holtz and Kovacs, 1981; Hammond and others, 1992; USDA, 1994). During earthquakes, however, cohesive geotechnical materials generally exhibit *undrained* behavior, as excess pore pressure is unable to dissipate during rapid cyclic loading. For the purposes of assigning strength values to the soil units, therefore, granular and cohesive materials were separated. This was done based on USCS classification: Sands and gravels (SM, SW, GM, GW) were assumed to exhibit drained (c', ϕ') behavior, while all others were assigned undrained (c, $\phi_T=0$) strength parameters.

The effective friction angles for granular materials (SM, SW, GM, GW) were assigned based on correlations between effective friction angle and USCS soil type. The ranges that were used are shown in Table 5. The range represents a spread of relative densities (higher D_r, higher ϕ), and specific values assumed for the NRCS units were scaled within the range based on high and low density values. To account for the high fines content present in most of the granular materials in the study area, low effective cohesion values were also assumed. For units with average clay contents <30 percent, an effective cohesion value of 2.4 kPa (50 psf) was assumed. For units with clay contents >30 percent, an effective cohesion value of 4.8 kPa (100 psf) was assumed.

Neither root strength nor the effect of tree surcharge was specifically included in the assignment of unit properties, but the addition of these effective cohesion values may be considered to compensate partially for root strength.

Table 5. Range of assigned effective friction angles for granular units

USCS classification	Effective friction angle (f) in degrees
GW	36–40
GP, GM, GC	35–39
SW	33–38
SP, SM, SC	32–36

For cohesive materials, the total (undrained) cohesion values were assigned based on laboratory data collected from geotechnical consulting reports in the

Salem area. Silts (MH, ML) were considered cohesive materials for the purpose of assigning strength parameters.[4] The range of undrained cohesion values from unconsolidated-undrained (UU) triaxial and other strength test data was significant for the various materials: from 28.7 kPa (600 psf) to 134.1 kPa (2,800 psf) for silts, and from 22.5 kPa (470 psf) to 80.0 kPa (1,670 psf) for clays. Given the large spread in the data and the absence of clearly defined breaks, a uniform cohesion value of 28.7 kPa (600 psf) was assigned to silts (ML and MH) as well as to low-plasticity clays (CL). For high plasticity clays (CH), a lower cohesion value of 22.5 kPa (470 psf) was assumed.

Substantial portions of the north and west flanks of the Salem Hills have been mapped as "landslide topography." Residual-strength test data on materials from these areas indicate significant strength reductions as compared to materials outside the landslide zone. To incorporate the reduction in strength from previous shearing in mapped landslide areas within the study area, a uniform strength reduction of 25 percent was used (i.e., residual value = 75 percent of the assigned value). The arbitrary 25-percent reduction was chosen based on limited laboratory data and on a compromise between two laboratory and field verified observations:

1. Laboratory measurements of residual versus peak strength ratios vary considerably but tend to be on the order of ½ to⅔ for typical soil deposits (Terzaghi and others, 1996).

2. Laboratory-based estimates of residual strength generally underestimate the shear strength mobilized during earthquake loading due to strain-rate dependence. Using the low residual strengths can lead to unrealistically high calculated Newmark displacement values (Vessely and Cornforth, 1998).

The selection of the factor of 75 percent was considered reasonable to take into account the loss of strength due to previous shearing while not grossly overestimating the relative hazard in the mapped historic landslide zones.

Based on the strength and soil property assumptions, the calculations of the static factors of safety, critical accelerations, and Newmark displacements were performed with 10-m grid spacing throughout the study area. As discussed previously, the soil unit properties were assigned to 10-m grid points by overlaying the slope grid on the soils map. The GIS database thus contained slope value, total and effective stresses, and strength properties stored at each point. With the information stored in separate fields in the GIS database, values of FS, a_c and D_N were calculated using equations 6, 4, and 3, respectively.

Since the Arias Intensity is held constant for each grid cell, the assignment of relative hazard categories could be based on any one of the output values (FS, a_c, or D_N). For completeness, however, the values for each were computed, and the relative hazard ratings were established, based on Newmark displacement (D_N) values. The actual hazard groups were selected from an inspection of a histogram of the calculated displacement values for the Salem study area, rather than on arbitrary groupings. Most of the data points (88.76 percent) had D_N values <0.1 cm and were assigned a Newmark hazard of *Low*; 11.18 percent of the values fell within 0.1 to 10 cm and were assigned a Newmark hazard of *Moderate*; and 0.06 percent of the cells had D_N values >10 cm and were assigned a Newmark hazard of *High*.

The computed Newmark displacement values were lower than typically calculated for site-specific studies. A partial explanation for this is that the slope values computed from Digital Elevation Models tend to be lower because of the spread in sampling. Periodic spatial sampling results in a topographic "smoothing" of features. Another contributing factor is the use of representative, rather than conservative, strength properties. The strength properties were assigned in a systematic way intended to (1) establish reasonable strength ranges for materials encountered in the study area; and (2) establish relative hazard relationships between the units. In the steps leading to the selection of strength values, factor-of-safety calculations were performed at various potential slope angles. The tabulation of factor-of-safety values for the soil units at a hypothetical slope angle of 22.5° is shown as an example in Appendix C. Using the strength property assign-

[4] Many of the MH and ML deposits in the study area are lateritic soils with high clay contents (i.e., "clayey silts").

ments previously discussed, four soil units yield factors of safety of <1, indicating that 22.5° slopes in these units would not be expected to be stable. Also noteworthy, though, is that the factors of safety for several units are very high, all the way up to $FS = 14.3$ for unit SCE. Higher factors of safety correspond to very low or nil Newmark displacement.

For soil units with a thin layer (≤5 ft) of cohesive soil over bedrock (e.g., the Steiwer, Hazelair, and Silverton units within the study area), the calculated static factors of safety were particularly high. The USCS units with relatively thin soil strata over bedrock exhibited high factors of safety such that, even on very steep slopes, the calculated Newmark displacements were minimal. A quick sensitivity study performed for the Hazelair soil unit, for example, indicated that the factor of safety is still much greater than 1 ($FS = 2.1$) at a slope angle of 44°, which represents the maximum calculated slope in the study area. The critical acceleration for the hypothetical slope is 0.75 g, and the corresponding Newmark displacement would be nil.

While these thin soil units may be more stable than others in the study area, it was considered that there should be physical limits above which steeper slopes in the study area be assigned higher slope instability hazard ratings. To incorporate reasonable limits into the hazard database, arbitrary slope breaks were selected above which the hazard ratings are increased. These slope breaks do not affect areas that were already given a higher hazard rating but rather ensure that steeper slopes do not have anomalous low hazard ratings. A summary of the selected slope breaks is shown in Table 6.

For slopes greater than 15° (the upper 2.4 percent of the slope values), the hazard category was increased to *Moderate* if it had been assigned a *Low* hazard rating. A total of 0.6 percent of the entries were increased in this manner. For areas of mapped landslide topography, a lower cutoff value of 10° was selected. A total of 4.6 percent of the entries within the landslide areas were increased from *Low* to *Moderate* by this operation. For deposits with slopes >15° for landslide and >20° for non-landslide topography, the values were uniformly assigned a hazard rating of *High*. This operation accounted for an overriding of 1.5 percent of the Newmark hazard classes.

Table 6. Summary of slope breaks

	Slope (degrees)	Hazard rating increase
Non-landslide deposits	>15	Low ⟶ Moderate
	>20	Moderate ⟶ High
Mapped landslide deposits	>10	Low ⟶ Moderate
	>15	Moderate ⟶ High

For gentle slopes, composed of Quaternary sedimentary deposits, the lateral spread analysis was considered to be more appropriate for assigning slope instability hazards. Slopes <6 percent and mapped as Qal, Qlg, Qth, Qtlb, Qtlt, Qtm, or Qtlw, therefore, were not assigned hazard classifications by the simplified Newmark method. Similarly, gentle bedrock slopes (<6 percent slope) were considered to have minimal soil slide hazard and were not assigned soil slide hazard ratings.

The resulting soil slide hazard layer is shown in Figure 13.

Rock slope analysis

The potential for dynamic rock slope instability was analyzed using a method based on field outcrop mapping developed by Keefer (Keefer, 1993). Rock slope hazards are a primary concern, because rock failure events often occur suddenly and catastrophically, posing a significant threat for loss of life and extensive damage to structures. Rock fall susceptibility can be related to factors such as the orientation of bedding planes and discontinuities, fracture spacing and openness, degree of weathering, hydrologic conditions, and material strength properties, to name a few. Some of these criteria are more applicable for evaluating regional earthquake-induced rock landslide hazards than others. Through cataloging and mapping landslides associated with 24 historical earthquakes, Keefer developed a decision tree based on the geologic properties that he found to influence most greatly the relative hazards in steep-slope terrain. A copy of the decision tree is reproduced as Figure 14. The susceptibility ratings *Extremely high* to *Low* in Figure 14 were selected based on empirical associations between material characteristics and recorded landslide concentrations (number of landslides per km^2).

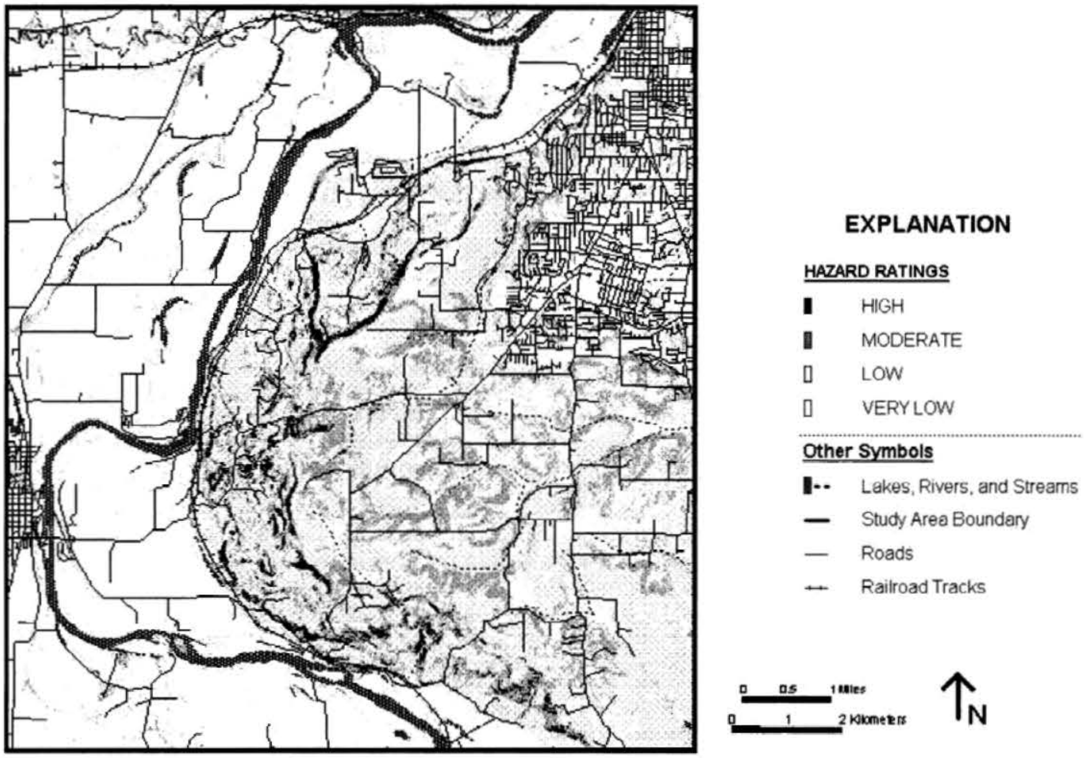

Figure 13. Soil slide hazard layer for the Salem Hills study area.

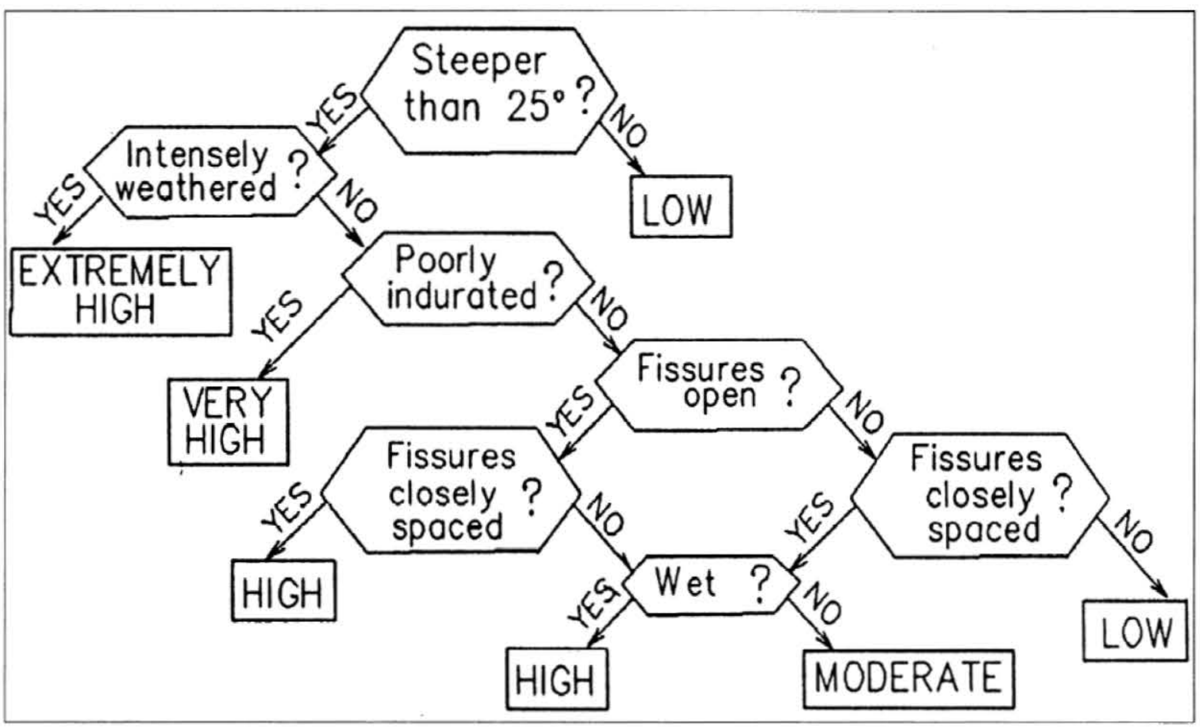

Figure 14. Decision tree for rating the susceptibility of rock slopes to earthquake-induced landslides (from Keefer, 1993).

Keefer's decision tree can be applied to regional hazard analyses by reversing the process and correlating field-evaluated outcrop characteristics to landslide susceptibility groupings. The first step in the Salem study was to evaluate bedrock outcrops and to classify them according to the observed degree of weathering, strength of induration, openness of fissures, spacing of fissures, vegetation, and moisture conditions. 112 sites in the Salem Hills were evaluated in late March and early April of 1998 by Robert B. Murray, a registered geologist hired by DOGAMI for this study. Each of the outcrops was grouped by geologic-material type and assigned a Keefer (1993) susceptibility class based on Figure 14. "Wet" conditions were assumed in all cases for assigning susceptibility classes.

Only two bedrock geology units, Tcr and Toe, are found in the Salem Hills. (One other unit, Bela's [1981] Ts, is found in the extreme southwest corner of the study area.) Of the 112 sites evaluated, 76 were grouped into unit Tcr, 20 were grouped into unit Toe, and none were mapped as Ts. On the basis of the Tcr and Toe outcrop susceptibility ratings, landslide concentration values, i.e., number of landslides per square kilometer (LS/km^2), were calculated using an equation developed by Keefer in which observed landslide concentrations are related to the susceptibility classes from Figure 14. The equation is as follows:

$$LS/\text{km}^2 = 32\ LS/\text{km}^2 * (\text{percent } \textit{Extremely High}) + 8\ LS/\text{km}^2 * (\text{percent } \textit{Very High}) + 2\ LS/\text{km}^2 * (\text{percent } \textit{High}) + 0.5\ LS/\text{km}^2 * (\text{percent } \textit{Moderate}) + 0.125\ LS/\text{km}^2 * (\text{percent } \textit{Low}) \qquad (7)$$

The calculated landslide concentration values for each unit in the study area are shown in Table 7. Ts has been added to the table based on data gathered for a comparable geologic unit in the Eugene-Springfield study area. The hazard ratings selected for the three units found within the study area are also given in Table 7. These ratings were selected based on consistent cutoff values used for the Eugene-Springfield study (Black and others, 2000) and a test study conducted by Keefer and Wang (1997). For both of these projects, geologic units with calculated landslide concentrations >2 LS/km^2 were given a *High* hazard rating, those with between 1 and 2 LS/km^2 were given a *Moderate* rating, and those with <1 LS/km^2 were assigned a *Low* hazard rating.

Table 7. Steep slope hazard ratings in terms of bedrock geology units

Unit	Rock type	Landslide concentration	Hazard rating
Tcr	Basalt	22.9 LS/km^2	High
Toe	Marine sedimentary	13.2 LS/km^2	High
Ts	Sandstone	5.3 LS/km^2	High

GIS implementation of the rock slope hazards was a relatively straightforward, two-step process. The method is only applicable for steep slopes (>25°), so the first step was to select the higher slope values from the database. With the >25° slope values selected, a *High* hazard was assigned if the area was mapped as bedrock geology units Tcr, Toe, or Ts. Only 0.11 percent of the study area is rated *High* for rock slope hazard.

The resulting rock slope hazard layer is included as Figure 15.

Combined hazard map

The overall relative hazard map of earthquake-induced slope instability in the Salem Hills is shown in Figure 16 and has been published as DOGAMI map IMS–17. The map depicts areas of *Very Low*, *Low*, *Moderate*, and *High* hazard and is the combination of the lateral spread, soil slide, and steep slope analysis layers. For grid points mapped in more than one layer, the higher of the two ratings was selected for the overall hazard map. This occurred only for grid points with >6 percent slope that were evaluated for both soil slide and lateral spread hazards. Rock slopes >25° were evaluated for both rock slope and soil slide hazards, but the ratings are *High* for both. As one would expect, the hazard ratings in the Salem Hills portion of the study area are governed primarily by the soil slide and the rock slope susceptibility ratings. For the more gently sloping alluvial deposits in the low-lying areas, the hazard ratings primarily reflect the lateral spread hazard ratings.

The relative nature of the hazard ratings warrants highlighting. The zones of *Very Low* to *High* hazard were developed using potential earthquake scenarios and include a number of regional assumptions. The extent and severity of slope instability that occurs dur-

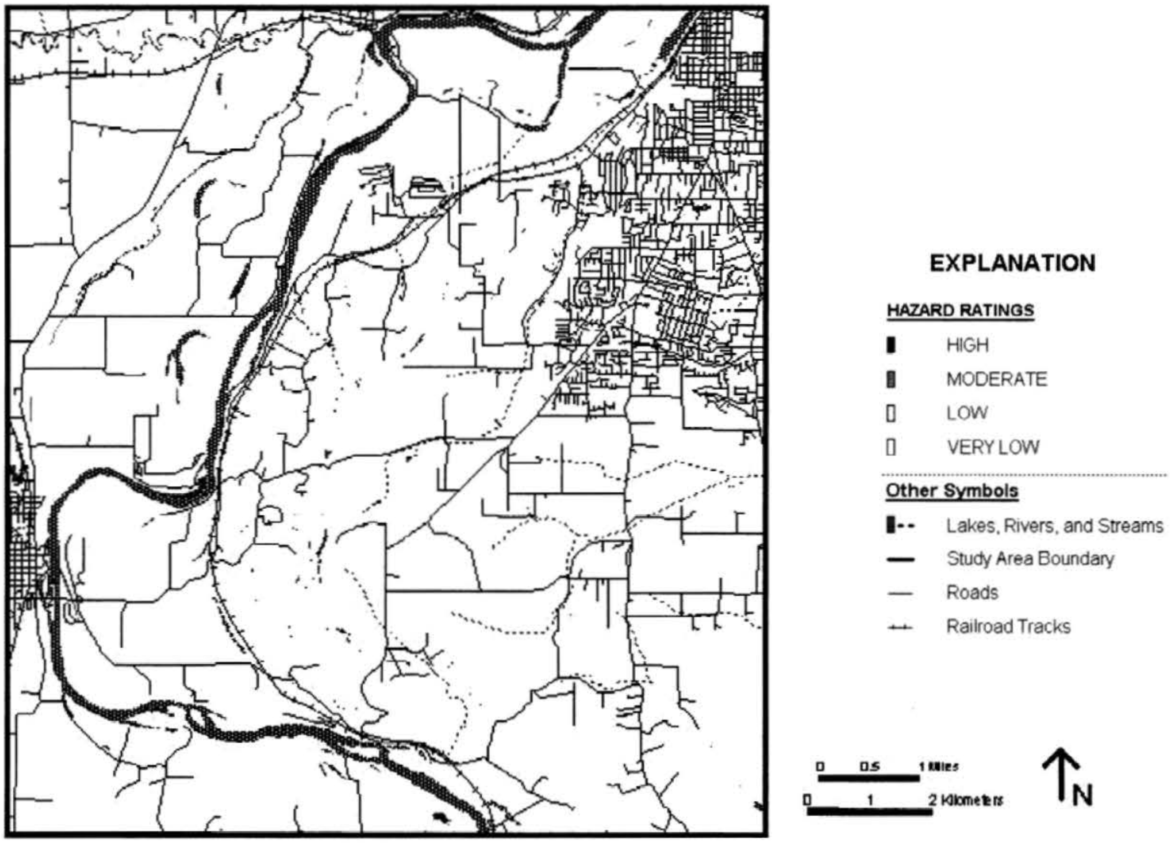

Figure 15. Rock slope hazard layer for the Salem Hills study area.

ing an actual earthquake depends on the size and location of the event. A hazard rating of *High* does not necessarily mean that a slope will fail in any earthquake, and a rating of *Very Low* does not mean that there is no potential for movement. In a large earthquake event, there may, in fact, be instability in *Moderate*, *Low*, and *Very Low* zones as well as *High*. For small earthquakes, there may be only slight damage even in *High* zones. In general, however, one would expect a higher percentage of earthquake-induced ground failures in *High* zones than in the *Moderate*, *Low* and *Very Low* zones in any given earthquake event.

CONCLUSION

A useful regional mapping methodology utilizes computer capability to provide representative results in the most efficient manner possible. The Keefer and Wang (1997) methodology, modified for this study, is one of the most promising approaches available for accurately mapping earthquake-induced slope instability hazards within reasonable time and cost. The successful completion of this study advances DOGAMI's ongoing efforts to map hazards in major population areas statewide.

The analysis was performed with the best data available and with what were considered to be the most appropriate models. Yet, several limitations are worth noting. These limitations underscore that any relative hazard map is generally useful for regional applications but should not be used as an alternative to site-specific studies in critical areas.

- While it is possible to check for errors in the GIS and database operations, it is not feasible to fully verify the original data on which the analysis is based.
- Changes in input data layers subsequent to the period

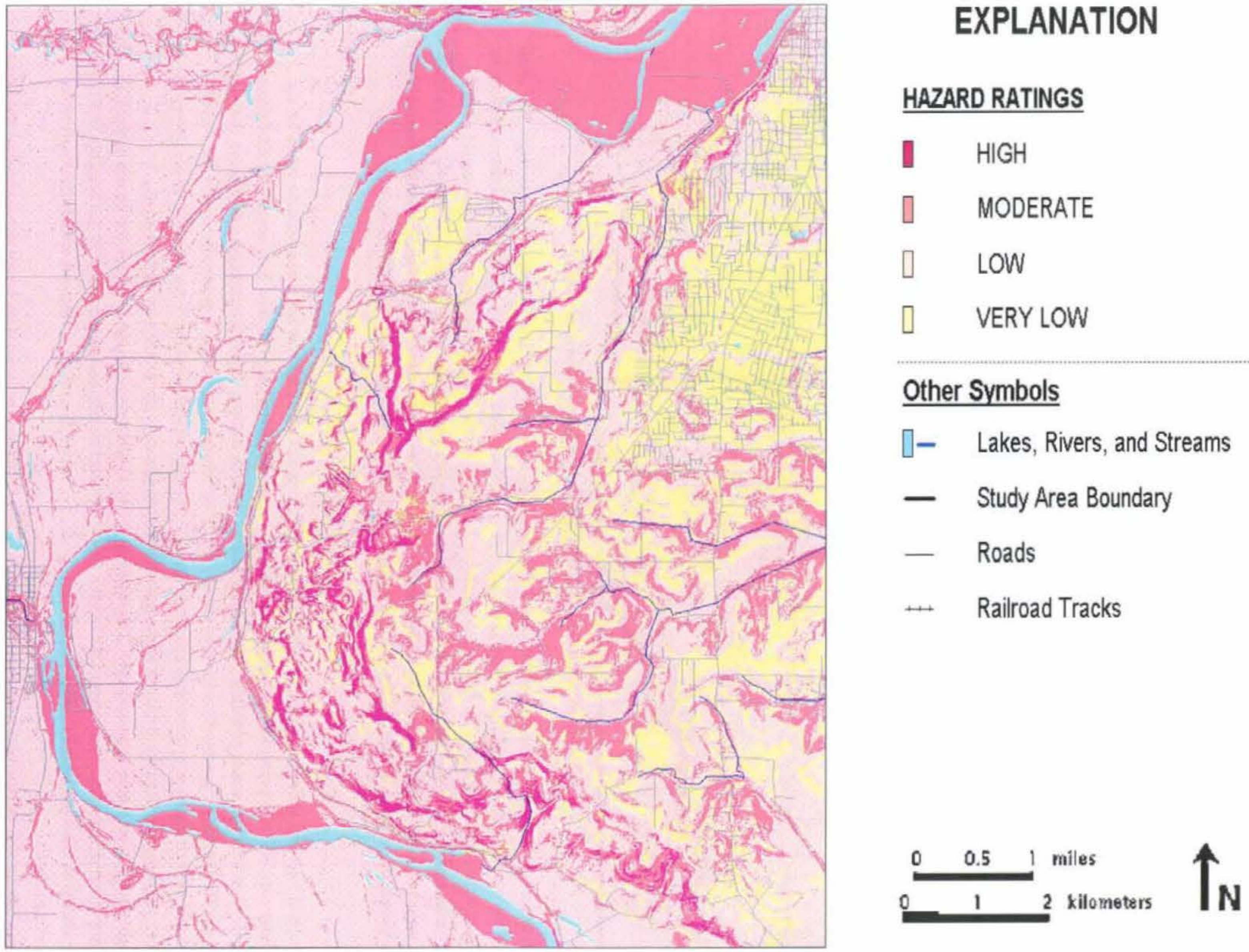

Figure 16. Overall relative hazard map of earthquake-induced slope instability in the Salem Hills.

of mapping, such as advancement of rock quarry boundaries, construction of large structures, and other land modifications could affect the hazard ratings in some areas. Land modification is not expected to be a significant source of error, but it could have localized relevance.

- Geologic material properties are assigned using field data with substantial scatter. The most representative values should be and were selected, but geologic materials vary regionally and locally.
- Features such as the presence of daylighting discontinuities, unfavorably dipping bedding planes, seams of local weakness, and other local slope stability factors cannot realistically be determined for each cell on a regional basis, yet these critical factors may govern the slope response in an earthquake event.
- This methodology focuses on earthquake events creating small- to medium-scale landslide hazards. Anomalously large events were not modeled.
- The 10-m scale of the input elevation file indicates that the resolution of the output hazard maps is at best 10 m and could be lower in some areas.

While these limitations indicate that the map should not serve as a replacement for site-specific studies in critical areas, the relative hazard map can, and should, serve as a useful tool for estimating the regional impact of future earthquake events. Creation of a regional hazard map is an initial step, which ideally is followed by hazard mitigation programs that focus efforts on the higher risk areas. Realistic evaluations of relative hazards are vital for planning and development purposes, for emergency response management, as inputs for damage and loss estimations, and in making informed land use decisions. Potential users may include public policy makers, land use planners, civil engineers, developers, insurance adjusters, public safety officials, home owners, and home buyers, to name a few.

The Salem area is growing at a rapid rate; some predict it may soon surpass Eugene to become Oregon's second-most populated urban area. In recent years, new development has steadily expanded southward, and this study covers an area that is likely to experience increased development in the near future. This map is intended to be used in conjunction with other available resources to make informed regional decisions regarding new development, as well as decisions regarding retrofit or other mitigation measures to limit the loss of life and property damage in future earthquake events.

ACKNOWLEDGMENTS

The Valle Scholarship Program provided financial support for author Hofmeister, who extends thanks to the program staff and specifically Dale Carlson, as well as to his generous and supportive University of Washington teachers and mentors, Professors Pedro Arduino, Robert Holtz, Steven Kramer, and Teresa Taylor, and his Stanford University teachers Professors Ronaldo Borja, Anne Kiremidjian, Gordon Brown, and David Pollard.

This project was funded, in part, by the Oregon Department of Geology and Mineral Industries, and thanks are owed to many members of its staff for providing resources, expertise, and support, especially its Director, State Geologist John D. Beaulieu and Geologist Gerald L. Black, who contributed greatly to this project by sharing practical insight from his work on similar mapping in the Eugene-Springfield area.

Andrew Harvey of Squier Associates, George Freitag of Geotechnical Resources, Inc., and William Leonard of AGRA Earth & Environmental, Inc., contributed valuable technical input. Critical data assistance was also received from Geologic Consultant Robert Murray, Brandi Baird of the USDA Natural Resource Conservation Service, Loren Mell of Group Health Cooperative, Tim Spear of the Oregon Department of Corrections, and Stephanie King of the Blume Earthquake Engineering Center.

REFERENCES CITED

Atwater, B.F., 1988, Geologic studies for seismic zonation of the Puget lowland: U.S. Geological Survey Open-File Report 88–016, p. 120–133.

Bartlett, S.F., and Youd, T.L., 1995, Empirical prediction of liquefaction-induced lateral spread: Journal of Geotechnical Engineering, v. 121, no. 4, p. 316–329.

Baziar, M.H., Dobry, R., and Elgamel, A.W.M., 1992, Engineering evaluation of permanent ground deformations due to seismically-induced liquefaction: National Center for Earthquake Engineering Research, State University of New York, Buffalo, Technical Report NCEER–92–0007.

Bela, J.L., 1981, Geology of the Rickreall, Salem West, Monmouth, and Sidney 7½′ quadrangles, Marion, Polk, and Linn Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–18.

Black, G.L., Wang, Z., Wiley, T.J., Wang, Y., and Keefer, D.K., 2000, Relative earthquake hazard map of the Eugene-Springfield metropolitan area, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–14.

Bott, J.D.J., and Wong, I.G., 1993, Historical earthquakes in and around Portland, Oregon: Oregon Geology, v. 55, no. 5, p. 116–122.

Burns, S.F., Caldwell, R.R., Mulder, R.A., Madin, I.P., and Mabey, M.A., 1992, Mapping geological earthquake hazards, Salem, Oregon: Association of Engineering Geologists annual meeting, 35th, Los Angeles, Calif., Proceedings, p. 291–296.

Byrne, P.M., 1991, A model for predicting liquefaction induced displacement: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Proceedings, v. 2, p. 1027–1035.

Crenna, P.A., Yeats, R.S., Levi, S., 1994, Late Cenozoic tectonics and paleogeography of the Salem metropolitan area, central Willamette Valley, Oregon: Oregon Geology, v. 56, no. 6, p. 129-136.

Eastman, J.R., 1990, IDRISI--a grid-based geographic analysis system: Worcester, Mass., Clark University Graduate School of Geography, 363 p.

Eastman, J.R., 1993, IDRISI Version 4.1: Worcester, Mass., Clark University Graduate School of Geography, 214 p.

Hamada, M., Yasuda, S., Isoyama, R., and Emoto, K., 1986, Study on liquefaction-induced permanent ground displacements: Association for the Development of Earthquake Prediction, 87 p.

Hammond, C., Hall, D., Miller, S., and Swetik, P., 1992, Level I Stability Analysis (LISA), documentation for version 2.0: USDA Forest Service, Intermountain Research Station, General Technical Report INT-285, 190 p.

Harvey, A.F., and Peterson, G.L., 1998, Water-induced landslide hazards, western portion of the Salem Hills, Marion County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–6, 1:24,000.

– – –2000, Water-induced landslide hazards, eastern portion of the Eola Hills, Polk County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–5, 1:24,000.

Hofmeister, R.J., and Keefer, D.K., 2000, Earthquake-induced slope instability: Relative hazard map, western portion of the Salem Hills, Marion County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–17, 1:24,000.

Hofmeister, R.J., and Wang, Y., 2000, Earthquake-induced slope instability: Relative hazard map, eastern portion of the Eola Hills, Polk County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–18, 1:24,000.

Holtz, R.D., and Kovacs, W.D., 1981, An introduction to geotechnical engineering: Englewood Cliffs, N.J., Prentice-Hall, 733 p.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Washington D.C., National Research Council Transportation Research Record 1411, p. 9–17.

– – –1996, Use of landslides for paleoseismic analysis: Engineering Geology, v. 43, p. 291–323.

Jibson, R.W., and Keefer, D. K., 1993, Analysis of the seismic origin of landslides: Examples from the New Madrid seismic zone: Geological Society of America Bulletin, v. 105, no. 4, p. 521–536.

Kanamori, H., 1977, The energy release in great earthquakes: Journal of Geophysical Research, v. 82, p. 2981–2987.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406–421.

– – –1993, The susceptibility of rock slopes to earthquake-induced failure: Association of Engineering Geologists Bulletin, v. 30, no. 3, p. 353–361.

Keefer, D.K., and Wang, Y., 1997, A method for predicting slope instability for earthquake hazard maps: Preliminary report, *in* Wang, Y. and Neuendorf, K.K.E., eds., Earthquakes – Converging at Cascadia. Symposium proceedings: Association of Engineering Geologists Special Publication 10/Oregon Department of Geology and Mineral Industries Special Paper 28, p. 39–52.

Knezevich, C.A., 1982, Soil survey of Polk County, Oregon: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with Oregon Agricultural Experiment Station, 250 p.

Kramer, S.L., 1996, Geotechnical earthquake engineering: Upper Saddle River, N.J., Prentice-Hall, 653 p.

Madin, I.P., Priest, G.R., Mabey, M.A., Malone, S., Yelin, T.S., Meier, D., 1993, March 23, 1993, Scotts Mills earthquake-western Oregon's wake-up call: Oregon Geology, v. 55, no. 3, p. 51–57.

McDowell, P.F., 1991, Quaternary stratigraphy and geomorphic surfaces of the Willamette Valley, Oregon, *in* Morrison, R.B., ed., Quaternary nonglacial geology: Conterminous U.S.: Boulder, Colo., Geological Society of America Decade of North American Geology, Geology of North America, v. K-2, p. 156–164.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Géotechnique, v. 15, no. 2, p. 139–159.

Noson, L.L., Qamar, A., and Thorsen, G.W., 1988, Washington State earthquake hazards: Washington Division of Geology and Earth Resources Information Circular 85, 77 p.

Shedlock, K.M., and Weaver, C.S., 1991, Program for earthquake hazards assessment in the Pacific Northwest: U.S. Geological Survey Circular 1067, 28 p.

Terzaghi, K., Peck, R.B., and Mesri, G., 1996, Soil Mechanics in Engineering Practice, 3d ed.: New York, N.Y., John Wiley & Sons, 549 p.

U.S. Department of Agriculture (USDA), 1994, Slope stability reference guide for national forests in the United States, volume I: Washington, D.C., USDA Forest Service Engineering Staff Report EM-7170-13.

– – –1996, Soil survey laboratory methods manual: USDA Natural Resources Conservation Service Soil Survey Investigations Report 42, version 3.0, 693 p.

Vessely, D.A., and Cornforth, D.H., 1998, Estimating seismic displacements of marginally stable landslides using Newmark approach, *in* Dakoulas, P., Yegian, M., and Holtz R.D., eds., Geotechnical earthquake engineering and soil dynamics III: American Society of Civil Engineers Geotechnical Special Publication 75, v. 1, p. 800–811.

Wang, Y., Keefer, D.K., and Wang, Z., 1998, Seismic hazard mapping in Eugene-Springfield, Oregon: Oregon Geology, v. 60, n. 2, p. 31–41.

Wang, Y., and Leonard, W.J., 1996, Relative earthquake hazard maps of the Salem East and Salem West quadrangles, Marion and Polk Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-105, 10 p., 4 maps, scale 1:24,000.

Weaver, C.S., Shedlock, K.M., 1989, Potential subduction, probable intraplate, and known crustal earthquake source areas in the Cascadia subduction zone, in Hays, W.W., ed., 3rd Annual Workshop on "Earthquake Hazards in the Puget Sound, Portland Area," Proceedings: U.S. Geological Survey Open-File Report 89-465, p. 11–26.

Wieczorek, G.F., Wilson, R.C., and Harp, E.L., 1985, Map showing slope stability during earthquakes in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257-E, scale 1:62,500.

Williams, L.H., 1972, Soil survey of the Marion County area, Oregon: U.S. Department of Agriculture, Soil Conservation Service, in cooperation with Oregon Agricultural Experiment Station, 132 p.

Wilson, R.C., and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the August 6, 1979, Coyote Lake, California, earthquake: Seismological Society of America Bulletin, v. 73, no. 3, p. 863–877.

– – –1985, Predicting areal limits of earthquake-induced landsliding, *in* Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 317–345.

Yeats, R.S., Graven, E.P., Werner, K.S., Goldfinger, C., and Popowski, T., 1991, Tectonics of the Willamette Valley, Oregon: U.S. Department of the Interior Geological Survey Open-File Report 91-441P, 47 p.

Yelin, T.S., Tarr, A.C., Michael, J.A., and Weaver, C.S., 1994, Washington and Oregon earthquake history and hazards: U.S. Geological Survey Open-File Report 94-226B, 11 p.

Youd, T. L., and Perkins, D. M., 1987, Mapping of liquefaction severity index: Journal of Geotechnical Engineering, ASCE, v. 113, no. 11, p. 1374-1392.

Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, 505 p.

APPENDIX A. DETAILED GEOLOGIC UNIT DESCRIPTIONS

Source: Bela, J.L., 1981, *Geologic Map of the Rickreall and Salem West Quadrangles, Oregon,* Oregon Department of Geology and Mineral Industries Geological Map Series map GMS-18

Unit	Explanation	Description
		Surficial geologic units
Qal	Recent river alluvium	Unconsolidated cobbles, coarse gravel, sand, and some silt and clay within active channels of Willamete River. Generally 15-45 ft thick, consisting of stratified sands and well-rounded pebbles, gravels, and cobbles of primarily basaltic and andesitic composition; often overlain by 3-15 ft of light-brown sand and silt overburden. Characterized by low relief, point-bar and channel-bar deposits; many areas unvegetated; others support dense stands of brush and phreatophytes, such as willows and cottonwoods. Subject to major flooding, critical stream-bank erosion, and lateral channel migration; includes many areas located between 1852 meander line and present channel that illustrate possible extent of future changes.
Qtlw	Lower terrace deposits of the Willamette River (Quaternary)	Unconsolidated to semiconsolidated cobbles, gravel, sand, silt, clay, muck, and organic matter of variable thickness (30-50 ft) on the flood plain and lowland terraces immediately above the Recent river alluvium (unit Qal); typically 5-20 ft of light-brown silt and clay or very fine sand overlying 10-45 ft of moderately well-sorted sand and locally cemented gravel. Surface topography characterized by a low, undulating, fluvial surface with abandoned channels, meander scrolls, oxbow lakes, and sloughs; subject to major and local flooding, some catastrophic channel migration of major scale, ponding, and high ground water. Flood-plain soils are predominantly well drained and somewhat excessively, drained silty clay loams, silt loams, and sandy loams; good ground-water yields generally of 100-500 gallons per minute.
Qtlt	Lower terrace deposits of tributary rivers and streams (Quaternary)	Unconsolidated to semiconsolidated gravel, sand, silt, clay, and organic matter generally 15-30 ft thick on lowland terraces and flood plains immediately above major tributary rivers of the Willamette River. Gravel deposits are very thin to variable in thickness, according to tributary drainage source, generally limited to active stream beds or former meander channels, and located at or near bed rock beneath 20-30 ft of sand, silt, and clay. Somewhat tortuous meandering streams entrenched 15-45 ft, often flowing on Tertiary sedimentary bedrock or semiconsolidated older valley-fill alluvium. Surface topography characterized by a low, undulating fluvial surface of swell and swale relief, abandoned meander loops, and oxbow lakes; subject to high ground water and ponding and major and local flooding; flood-plain soils are predominantly well drained and somewhat excessively drained silty clay loams, silt loams, and sandy loams. Some soft, compressible organic soils of low shear strength may occur locally, particularly within abandoned channels and oxbows. Major stream-bank erosion commonly occurs at outer bends of meander loops by shallow earthflow and slump due to undercutting. Groundwater yields generally small.
Qtlb	Lower terrace deposits of alluvial bottomlands (Quaternary)	Flat, moderately to poorly drained areas with soft, organic compressible soils of low shear strength locally; characterized by low relief, ponding, and high ground water. Deposits typically consist of somewhat stratified very fine sands, silty sandy clays, silty clays, and silty clay loams, with slight to moderate plasticity (ML-CL); 4-12 ft thick along bottomlands of interior drainages of low, rolling sedimentary bedrock units. Deposits locally may represent somewhat thicker accumulations of silt and silty clay materials of fluviatile and/or loessal origin derived in part from Willamette Silts. Similar deposits along creeks are associated with deposits of units Qtm and Qth and are often modified by ditching and field drainage for agriculture; typical examples are deep (more than 60 in.) clay (CH), silty clay (CH), and silty clay loam (CL or ML) black Bashaw clay soils of Baskett Slough (Rickreall quadrangle). Similar thicknesses of reddish-brown sandy silty material (ML-CH) is basaltic terrain (unit Tcr).
Qtm	Middle terrace deposits (Quaternary)	Semiconsolidated gravel, sand, silt, and clay forming very flat terraces of major extent along the Willamette River. Generally 10-30 ft of light-brown silty clay and interbedded very fine sand and silt (ML or CL-CH) surficial material; believed primarily related to Willamette Silts, including associated glacial erratics consisting of tiny fragments and pebbles up to boulders greater than 4 ft in diameter. Soils somewhat poorly drained

(Continued on next page)

Unit	Explanation	Description
		and poorly drained silt loams and silty clay loams to moderately well-drained and well-drained silt loams subject to seasonal high ground water and ponding. Sand and gravel (GP, SM), where present, usually occur below 30 ft depth; locally more abundant near Monmouth-Independence and in the lower part of Ash Creek. Total thickness 0-85 ft, but often only 40-50 ft; within Rickreall 7 1/2-minute quadrangle, 15-35g ft of brown clay or silt generally occurs above several to 30 ft of gravelly clay, black sands, and gravels. Generally small ground-water yields, except near Monmouth-Independence, where sand and gravel may yield up to 300 gallons per minute.
Qlg	Linn gravel (Quaternary-upper Pleistocene)	Stratified fine to course fluvial gravels deposited as an alluvial fan in the Stayton-Turner-Salem areas during an early stage of the Santiam River; of limited extent within the map area; uppermost few feet of gravels extensively oxidized and weathered, often chalky; thickness ranges from 30-40 ft to possibly as much as 300 ft. Regionally, the upper foot or so of gravel is cemented by an impermeable clay pan locally, which restricts drainage. Composition of gravels (mostly basalt, but also andesite, dacite, rhyolite, quartz, and diorite) essentially uniform. Within map area near Salem, soils are well drained and somewhat poorly drained gravelly silt loam and gravelly loam. Extensively utilized as source of sand and gravel. Good groundwater yields greater than 100 gallons per minute.
Qth	Higher terrace deposits (Quaternary-middle Pleistocene)	Generally semiconsolidated light-brown sand, silt, and clay of variable thickness (3-15 ft) on higher terraces and remnants of old higher terraces adjacent to sedimentary bedrock foothills; mantled by moderately well-drained and well-drained silt loam soils. Includes colluvium, slope wash, and alluvial fan deposits near sedimentary bedrock foothills; deposits thin where transitional with pediments. Material generally similar to unit Qtm, particularly in West Salem, containing glacial erratics related to Willamette Silt but also some gravelly alluvium. Some higher terrace deposits on west side of Salem Hills between Salem and Illahe Hill not shown due to scale. Also includes weathered (decomposed) cobbles and gravels which extend beyond the study area west of Rickreall (8-10 ft thick) and at southeastern margin of Sidney quadrangle (10-50? ft thick), where they are equivalent to the Leffler gravels of Allison (1953). These deposits also mantled by 3-15 ft of light-brown silt loam and silty clay loam soils. Generally little or no groundwater yield.
		Bedrock geologic units
Tcr	Columbia River Basalt Group (Miocene)	Medium-gray to black, fine-grained, even-textured to slightly porphyritic basalt; unweathered flows generally dense, fairly crystalline, exhibiting massive columnar jointing near base to diced or hackly jointing in entablature. Unit consists of weathered and unweathered basaltic lava flows with interflow zones characterized by vesicular flow-top breccia, ash, and baked soils. Maximum thickness generally ranges 400-600 ft, with thickness greatly modified by erosion and weathering in many places; individual flows range from 40 ft to more than 100 ft in thickness. Formations recognized within the Yakima Basalt Subgroup (M.H. Beeson, oral communication, 1980) include (1) Grande Ronde Basalt: two to four "low Mg" N_2 flows, including one to two "Winter Water" flow(s) at top (typical exposure at Dairy Queen, West Salem); one to two thick "low Mg" flow(s), 100-150 ft thick, extensively quarried throughout map area; one to two flow(s) of "high Mg" N_2 basalt, generally deeply weathered, occurring above the "Winter Water" flow(s); and (2) a thinner layer of younger Wanapum Basalt, represented by one to three flow(s) of the Frenchman Springs Member, observed only in Sourth Salem within the study area, although it also occurs outside the map area in the vicinity of Turner. Weathered flows consist of reddish-brown to grayish-brown, crumbly to medium-dense basalt. Weathering is variable and believed related to individual basalt flows; some exposures are altered to red clay (laterite) to depths of 30 ft, and occasionally as deep as 60-175 ft, while others are only slightly weathered at surface. Some locations in Salem Hills (generally between 500-900 ft elevations within area bounded by Pringle School-Prospect Hill-Jackson Hill) show extensive laterization which has resulted in deposits of bauxite (Corcoran and Libbey, 1956). Soils are reddish-brown, well-drained silty clay loams and gravelly silty clay loams. Unit yields small to large quantities of groundwater from permeable rubbly zones between flows.

(Continued on next page)

Unit	Explanation	Description
Toe	Eocene-Oligocene sedimentary rock (middle and lower Oligocene and upper Eocene)	Equivalent to tuffaceous marine sedimentary rocks (unit Tts) of Baldwin and others (1955), Illahe tuffs (Tit) of Mundorff (1939), Illahe Formation (Ti) of Thayer (1939), Eocene-Oligocene marine sedimentary rock (Tm) of Price (1967), and undifferentiated Tertiary rocks (Tu) of Gonthier (in press [1983]). Consists of two lithologic and faunal units west of Willamette River (Baldwin and others, 1955) but undifferentiated on this map due to poor exposures. Older unit light-gray to tan sandy-tuffaceous siltstone equivalent in age to early Oligocene Keasey Formation; thickest section near border of Amity-Rickreall 7½-minute quadrangles, where approximately 1,000 ft thick; other lower Oligocene stata well exposed in Yamhill River near Yamhill locks, where steeply dipping and complexly faulted. Younger unit is fine- to coarse-grained tuffaceous sandstone equivalent in age to middle Oligocene Pittsburg Bluff Formation; basal stratum approximately 150 ft of dark-gray, coarse-grained, calcareous cemented lithic sandstone, chiefly composed of detrital igneous rock fragments. White, fine-grained, massively bedded phase of pumiceous volcanic glass approximately 250 ft thick exposed for 3 mi along hillside south of Finzer (Salem West quadrangle); good exposures of pebbly tuff, tuffaceous conglomerate, and fine-grained platy tuff along Bunker Hill Road in Sidney 7½-minute quadrangle. Tuffaceous marine sandstone and siltstone of Oligocene sedimentary rock correspond to Oligocene Eugene Formation described by Hickman (1969), which contains early to middle Oligocene molluscan faunas. Recent foraminiferal analyses (McKeel, 1980) of oil and gas wells within the study area indicate unit contains almost 2,000 ft of upper Refugian and Refugian strata (Reichhold-Merrill #1, Sidney quadrangle) and 200-1,000 ft of basal siltstone, claystone, and shale of late Narizian (provincial West Coast late Eocene) age (Reserve-Bruer #1 and Reichhold-Merrill #1).
Ts	Upper Eocene sandstone	Equivalent to Helmick beds (unit Thb) of Mundorff (1939) and Spencer (unit Ts) of Gonthier (in press [1983]); very fine- to medium-grained, thinly laminated (fissile) to thin-bedded, as well as prominently more massive, light-gray to yellowish-brown moderately well-sorted micaceous, calcareous, lithic arkosic marine (tuffaceous) sandstones; frequently interbedded with fine-grained marine tuffaceous siltstone, thinly laminated clay shale, and claystone; comprised of almost equal proportions of quartz, feldspar, and rock fragments cemented with calcite (in concretions); minor constituents include approximately 2% glauconite, 4% mica (biotite, muscovite, and chlorite), and less than 1% authigenic pyrite; well compacted; carbonaceous material consisting of plant stems, leaves, and other organic fragments common; calcareous concretions, fossiliferous or containing carbonaceous material, prominent along Willamette River south of Buena Vista (Monmouth quadrangle); pebbly lenses, abundant organic matter, and paleoecology indicate strandline environment; provenance from chiefly volcanic terrain. Weathered outcrops of massive, very fine- to medium-grained sands, generally friable, ranging in color from white to yellowish-brown, pale-brown, or yellowish-orange. According to McKeel (1980), this unit is bracketed by upper Narizian strata in the Reichhold-Finn #1 well (Amity quadrangle), by upper Narizian strata and Narizian in the Reserve-Bruer #1 well (Amity quadrangle), and by upper Narizian strata in the Reichhold-Merrill #1 well (Salem West quadrangle). Average thickness about 800 ft.
		Other units
bc	Basaltic colluvium and/or landslide debris	Generally reddish-yellow or reddish brown basaltic colluvium and/or landslide debris, deeply weathered, overlying Oligocene sedimentary rock (unit Toe), generally within landslide topography or beneath steep cliffs capped by Columbia River Basalt Group (unit Tcr); includes alluvial fans and some earthflow and debris-flow topography. Probably generally 6-35 ft thick but may include some blocks of basalt of greater thickness. Soils well-drained silty clay loams and gravelly silty clay loams overlying silty clay and clay.
LS	Landslide topography	Large areas of deep bedrock failure characterized by irregular topography, disrupted stratigraphy, overall anomalous moderate to shallow slope, prominent arcuate headscarps, backward-tilted blocks, springs, sag ponds, and disrupted drainage patterns. Most prominent along west side of Salem Hills and south and west side of Eola Hills, where undercutting of soft marine sediments (Eocene to Oligocene sedimentary rock, unit Toe) has resulted in massive landsliding of blocks of more resistant unit Tcr. Subject to rockfall and debris avalanche along oversteepened escarpments and to slump in some areas (bowed and tipped trees). Deep bedrock slides within upper Eocene sedimentary rock (unit Ts) within Monmouth quadrangle are much smaller than those associated with units Tcr/Toe; characterized by small knobby blocks of sedimentary tock within general hummocky terrain.

Appendix A – References Cited in Bela (1981)

Allison, I.S., 1953, Geology of the Albany quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 37, 18 p.

Baldwin, E.M., Brown, R.D., Jr., Gair, J.E., and Pease, J.H., Jr., 1955, Geology of the Sheridan and McMinnville quadrangles, Oregon: U.S. Geological Survey Oil and Gas Investigation Map OM-155.

Beaulieu, J.D., Hughes, P.W., and Mathiot, R.K., 1974, Environmental geology of western Linn County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 84, 117 p.

Bela, J.L., 1979, Geologic hazards of eastern Benton County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 98, 122 p.

Corcoran, R.E., and Libbey, F.W., 1956, Ferruginous bauxite deposits in the Salem Hills, Marion County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 46, 53 p.

Gonthier, J.B., in press [1983], Groundwater resources of the Dallas-Monmouth area, Polk, Benton, and Marion Counties, Oregon: [Oregon Water Resources Department Groundwater Report 28, 50 p].

Helm, D.C., and Leonard, A.R., 1977, Groundwater resources of the lower Santiam River basin, middle Willamette Valley, Oregon: Oregon Water Resources Department Groundwater Report 25, 75 p.

Hickman, C.J.S., 1969, The Oligocene marine molluscan fauna of the Eugėne Formation in Oregon: Oregon Museum of Natural History Bulletin 16, 112 p.

McKeel, D.R., 1980, Micropaleontological study of five wells, western Willamette Valley, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-80-1, 21 p.

Mundorff, M.J., 1939, The geology of the Salem quadrangle, Oregon: Corvallis, Oreg., Oregon State College master's thesis, 79 p.

Price, D., 1967, Ground water in the Eola-Amity Hills area, northern Willamette Valley, Oregon: U.S. Geological Survey Water-Supply Paper 1847, 66 p.

Schlicker, H.G., 1977, Geologic restraints to development in selected areas of Marion County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-77-4, 41 p.

Thayer, T.P., 1939, Geology of the Salem Hills and North Santiam River basin, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 15, 40 p.

Vokes, H.E., Myers, D.A., and Hoover, L, 1954, Geology of the west-central border area of the Willamette Valley, Oregon: U.S. Geological Survey Oil and Gas Investigation Map OM-150.

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES[1]

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
1	AbA	ABIQUA	1	ML	0	21	0.53	27	40	35	40	10	15
2	AbA	ABIQUA	2	CH CL	21	54	0.84	35	50	40	55	15	30
3	AbA	ABIQUA	3	ML	54	72	1.37	30	45	35	50	10	20
4	AbB	ABIQUA	1	ML	0	21	0.53	27	40	35	40	10	15
5	AbB	ABIQUA	2	CH CL	21	54	0.84	35	50	40	55	15	30
6	AbB	ABIQUA	3	ML	54	72	1.37	30	45	35	50	10	20
7	Ad	ALLUVIAL LAND	1	--	0	8	0.20	--	--	--	--	--	--
8	Ad	ALLUVIAL LAND	2	--	8	60	2.54	--	--	--	--	--	--
9	Am	AMITY	1	ML	0	24	0.61	15	25	30	40	5	10
10	Am	AMITY	2	CL	24	37	0.33	27	35	40	45	15	20
11	Am	AMITY	3	ML	37	60	1.80	10	25	30	40	5	10
12	Ba	BASHAW	1	CH	0	14	0.36	55	70	70	90	40	60
13	Ba	BASHAW	2	CH	14	48	0.86	55	70	70	90	40	60
14	Ba	BASHAW	3	CH	48	60	1.52	50	70	60	90	35	60
15	CLD	CUMLEY	1	CL ML	0	9	0.23	27	35	35	40	10	15
16	CLD	CUMLEY	2	MH	9	60	2.51	40	55	50	60	15	25
17	Ca	CAMAS	1	GM SM	0	9	0.23	5	10	--	--	0	0
18	Ca	CAMAS	2	GP GP-GM	9	60	2.51	0	5	--	--	0	0
19	CeC	CHEHALEM	1	ML	0	16	0.41	20	27	25	35	5	10
20	CeC	CHEHALEM	2	MH	16	60	2.34	35	45	50	60	15	25
21	Ch	CHEHALIS	1	CL	0	9	0.23	30	40	40	50	20	30
22	Ch	CHEHALIS	2	ML	9	80	2.51	25	35	35	45	5	15
23	Ck	CLACKAMAS	1	GM ML SM	0	15	0.38	18	27	25	35	0	5
24	Ck	CLACKAMAS	2	CL GC SC	15	24	0.23	27	35	35	40	15	20
25	Ck	CLACKAMAS	3	GC GP-GC	24	60	2.13	27	35	35	40	15	20
26	Cm	CLOQUATO	1	ML	0	9	0.23	5	15	20	30	0	5
27	Cm	CLOQUATO	2	ML	9	41	0.81	5	15	20	30	0	5
28	Cm	CLOQUATO	3	SM	41	83	1.70	5	10	0	14	0	0
29	Co	CONCORD	1	ML	0	15	0.38	20	25	30	40	5	10
30	Co	CONCORD	2	CL	15	29	0.36	35	50	40	50	15	25

[1] Unit names and symbols correspond to Williams (1972) and Knezevich (1982). Please refer to the Soil Slide Analysis section of the report for an outline of assumptions. This is a comprehensive list of units; not all of these are located within the study area.

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
1	AbA	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
2	AbA	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
3	AbA	1.2	1.4	1.30	12.75	52	17.34	108	46.91	46.91	28.73	0
4	AbB	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
5	AbB	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
6	AbB	1.2	1.4	1.30	12.75	52	17.34	108	46.91	46.91	28.73	0
7	Ad	-	-	1.40	13.73	31	13.73	-	-	-	-	-
8	Ad	-	-	1.45	14.22	31	14.22	108	38.92	38.92	2.39	35
9	Am	1.2	1.45	1.33	13.00	45	16.97	-	-	-	-	-
10	Am	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
11	Am	1.2	1.45	1.33	13.00	45	16.97	8	46.68	21.76	28.73	0
12	Ba	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
13	Ba	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
14	Ba	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	22.50	0
15	CLD	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
16	CLD	1.3	1.4	1.35	13.24	52	17.83	33	48.81	30.12	28.73	0
17	Ca	1.3	1.5	1.40	13.73	32	16.56	-	-	-	-	-
18	Ca	1.4	1.6	1.50	14.72	29	17.28	108	47.23	47.23	2.39	37
19	CeC	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
20	CeC	1.2	1.4	1.30	12.75	52	17.34	11	47.33	23.16	28.73	0
21	Ch	1.1	1.25	1.18	11.53	52	16.12	-	-	-	-	-
22	Ch	1.25	1.45	1.35	13.24	52	17.83	108	48.53	48.53	28.73	0
23	Ck	1.2	1.4	1.30	12.75	35	15.84	-	-	-	-	-
24	Ck	1.3	1.5	1.40	13.73	42	17.44	-	-	-	-	-
25	Ck	1.3	1.5	1.40	13.73	31	16.47	11	45.17	21.00	2.39	35
26	Cm	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
27	Cm	1.3	1.5	1.40	13.73	45	17.71	-	-	-	-	-
28	Cm	1.3	1.5	1.40	13.73	35	16.82	108	46.85	46.85	2.39	35
29	Co	1.4	1.6	1.50	14.72	45	18.69	-	-	-	-	-
30	Co	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
31	Co	CONCORD	3	ML	29	60	2.01	20	35	30	40	5	10
32	Cu	COURTNEY	1	CL ML	0	12	0.30	27	35	35	40	10	15
33	Cu	COURTNEY	2	CH	12	24	0.30	50	60	60	80	35	50
34	Cu	COURTNEY	3	GC GM	24	49	0.64	27	35	35	40	10	15
35	Cu	COURTNEY	4	GP GW	49	60	1.50	0	5	0	14	0	0
36	Cu	COURTNEY	1	CL ML	0	12	0.30	27	35	35	40	10	15
37	Cu	COURTNEY	2	CH	12	24	0.30	50	60	60	80	35	50
38	Cu	COURTNEY	3	GC GM	24	49	0.64	27	35	35	40	10	15
39	Cu	COURTNEY	4	GP GW	49	60	1.50	0	5	0	14	0	0
40	Da	DAYTON	1	ML	0	13	0.33	15	20	30	35	5	10
41	Da	DAYTON	2	CH	13	46	0.84	40	50	55	70	35	45
42	Da	DAYTON	3	ML	46	60	1.57	15	30	30	40	5	15
43	HEE	HENLINE	1	GM	0	10	0.25	7	15	15	25	0	5
44	HEE	HENLINE	2	GM	10	30	0.51	7	15	15	25	0	5
46	HEF	HENLINE	1	GM	0	10	0.25	7	15	15	25	0	5
47	HEF	HENLINE	2	GM	10	30	0.51	7	15	15	25	0	5
49	HEG	HENLINE	1	GM	0	10	0.25	7	15	15	25	0	5
50	HEG	HENLINE	2	GM	10	30	0.51	7	15	15	25	0	5
52	HRD	HOREB	1	ML	0	14	0.36	10	20	20	30	0	5
53	HRD	HOREB	2	ML SM	14	36	0.56	18	27	25	40	0	10
54	HRD	HOREB	3	GM ML	36	60	1.83	18	25	25	40	0	10
55	HSC	HOREB	1	CL-ML GC-GM	0	40	1.02	18	25	20	30	5	10
56	HSC	HOREB	2	GP-GM	40	60	1.73	0	3	0	14	0	0
57	HSE	HOREB	1	CL-ML GC-GM	0	40	1.02	18	25	20	30	5	10
58	HSE	HOREB	2	GP-GM	40	60	1.73	0	3	0	14	0	0
59	HTD	HULLT	1	CL ML	0	15	0.38	27	32	35	40	10	15
60	HTD	HULLT	2	CL	15	55	1.02	25	35	30	40	10	20
62	HTE	HULLT	1	CL ML	0	15	0.38	27	32	35	40	10	15
63	HTE	HULLT	2	CL	15	55	1.02	25	35	30	40	10	20
65	HTF	HULLT	1	CL ML	0	15	0.38	27	32	35	40	10	15
66	HTF	HULLT	2	CL	15	55	1.02	25	35	30	40	10	20
68	HaB	HAZELAIR	1	CL	0	12	0.30	22	27	30	40	10	20
69	HaB	HAZELAIR	2	CL	12	28	0.41	35	50	40	50	20	25

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
31	Co	1.4	1.6	1.50	14.72	45	18.69	3	51.14	24.97	28.73	0
32	Cu	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
33	Cu	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
34	Cu	1.3	1.4	1.35	13.24	31	15.98	-	-	-	-	-
35	Cu	1.3	1.4	1.35	13.24	29	15.80	3	44.70	18.54	2.39	38
36	Cu	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
37	Cu	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
38	Cu	1.3	1.4	1.35	13.24	31	15.98	-	-	-	-	-
39	Cu	1.3	1.4	1.35	13.24	29	15.80	3	44.70	18.54	2.39	38
40	Da	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
41	Da	1.25	1.4	1.33	13.00	52	17.59	-	-	-	-	-
42	Da	1.3	1.4	1.35	13.24	45	17.22	3	47.54	21.38	28.73	0
43	HEE	1.2	1.4	1.30	12.75	29	15.31	-	-	-	-	-
44	HEE	1.2	1.4	1.30	12.75	29	15.31	30	11.67	11.67	2.39	38
46	HEF	1.2	1.4	1.30	12.75	29	15.31	-	-	-	-	-
47	HEF	1.2	1.4	1.30	12.75	29	15.31	30	11.67	11.67	2.39	38
49	HEG	1.2	1.4	1.30	12.75	29	15.31	-	-	-	-	-
50	HEG	1.2	1.4	1.30	12.75	29	15.31	30	11.67	11.67	2.39	38
52	HRD	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
53	HRD	1.1	1.3	1.20	11.77	41	15.39	-	-	-	-	-
54	HRD	1.1	1.3	1.20	11.77	35	14.86	35	41.38	23.19	2.39	36
55	HSC	1.1	1.3	1.20	11.77	44	15.66	-	-	-	-	-
56	HSC	1.2	1.4	1.30	12.75	29	15.31	108	42.36	42.36	2.39	38
57	HSE	1.1	1.3	1.20	11.77	44	15.66	-	-	-	-	-
58	HSE	1.2	1.4	1.30	12.75	29	15.31	108	42.36	42.36	2.39	38
59	HTD	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
60	HTD	1.1	1.3	1.20	11.77	52	16.36	55	22.86	22.86	28.73	0
62	HTE	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
63	HTE	1.1	1.3	1.20	11.77	52	16.36	55	22.86	22.86	28.73	0
65	HTF	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
66	HTF	1.1	1.3	1.20	11.77	52	16.36	55	22.86	22.86	28.73	0
68	HaB	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
69	HaB	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
70	HaB	HAZELAIR	3	CH	28	38	0.25	60	70	60	80	40	50
72	HaD	HAZELAIR	1	CL	0	12	0.30	22	27	30	40	10	20
73	HaD	HAZELAIR	2	CL	12	28	0.41	35	50	40	50	20	25
74	HaD	HAZELAIR	3	CH	28	38	0.25	60	70	60	80	40	50
76	HcD2	HAZELAIR	1	CL	0	12	0.30	27	40	30	40	10	20
77	HcD2	HAZELAIR	2	CL	12	28	0.41	35	50	40	50	20	25
78	HcD2	HAZELAIR	3	CH	28	38	0.25	60	70	60	80	40	50
80	Ho	HOLCOMB	1	ML	0	18	0.46	20	25	30	35	5	10
81	Ho	HOLCOMB	2	CL ML	18	24	0.15	25	30	30	40	5	15
82	Ho	HOLCOMB	3	CH	24	50	0.66	40	50	60	80	40	50
83	Ho	HOLCOMB	4	ML	50	60	1.47	25	40	30	50	5	20
84	HuB	HULLT	1	CL ML	0	15	0.38	27	32	35	40	10	15
85	HuB	HULLT	2	CL	15	55	1.02	25	35	30	40	10	20
87	HuD	HULLT	1	CL ML	0	15	0.38	27	32	35	40	10	15
88	HuD	HULLT	2	CL	15	55	1.02	25	35	30	40	10	20
90	JoB	JORY	1	ML	0	15	0.38	27	40	40	50	10	15
91	JoB	JORY	2	CL	15	63	2.36	45	60	40	50	15	25
92	JoB	JORY	1	ML	0	9	0.23	30	40	35	40	10	15
93	JoB	JORY	2	CL GC	9	36	2.51	40	50	40	50	15	25
95	JoC	JORY	1	ML	0	15	0.38	27	40	40	50	10	15
96	JoC	JORY	2	CL	15	63	2.36	45	60	40	50	15	25
97	JoD	JORY	1	ML	0	15	0.38	27	40	40	50	10	15
98	JoD	JORY	2	CL	15	63	2.36	45	60	40	50	15	25
99	JoE	JORY	1	ML	0	15	0.38	27	40	40	50	10	15
100	JoE	JORY	2	CL	15	63	2.36	45	60	40	50	15	25
101	KCD	KINNEY	1	MH	0	10	0.25	18	27	60	70	10	20
102	KCD	KINNEY	2	MH	10	40	0.76	22	30	55	65	10	20
103	KCD	KINNEY	3	MH	40	53	0.33	15	27	50	65	10	20
105	KCF	KINNEY	1	MH	0	10	0.25	18	27	60	70	10	20
106	KCF	KINNEY	2	MH	10	40	0.76	22	30	55	65	10	20
107	KCF	KINNEY	3	MH	40	53	0.33	15	27	50	65	10	20
109	KCG	KINNEY	1	MH	0	10	0.25	18	27	60	70	10	20
110	KCG	KINNEY	2	MH	10	40	0.76	22	30	55	65	10	20

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
70	HaB	1	1.2	1.10	10.79	52	15.38	18	15.54	10.56	22.50	0
72	HaD	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
73	HaD	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-
74	HaD	1	1.2	1.10	10.79	52	15.38	18	15.54	10.56	22.50	0
76	HcD2	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
77	HcD2	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-
78	HcD2	1	1.2	1.10	10.79	52	15.38	18	15.54	10.56	22.50	0
80	Ho	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
81	Ho	1.3	1.4	1.35	13.24	51	17.75	-	-	-	-	-
82	Ho	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
83	Ho	1.3	1.4	1.35	13.24	52	17.83	11	48.63	24.46	28.73	0
84	HuB	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
85	HuB	1.1	1.3	1.20	11.77	52	16.36	55	22.86	22.86	28.73	0
87	HuD	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
88	HuD	1.1	1.3	1.20	11.77	52	16.36	55	22.86	22.86	28.73	0
90	JoB	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
91	JoB	1.3	1.5	1.40	13.73	52	18.33	108	49.71	49.71	28.73	0
92	JoB	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
93	JoB	1.1	1.3	1.20	11.77	43	15.57	36	42.89	42.89	28.73	0
95	JoC	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
96	JoC	1.3	1.5	1.40	13.73	52	18.33	108	49.71	49.71	28.73	0
97	JoD	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
98	JoD	1.3	1.5	1.40	13.73	52	18.33	108	49.71	49.71	28.73	0
99	JoE	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
100	JoE	1.3	1.5	1.40	13.73	52	18.33	108	49.71	49.71	28.73	0
101	KCD	0.85	0.95	0.90	8.83	45	12.80	-	-	-	-	-
102	KCD	0.9	1.2	1.05	10.30	45	14.27	-	-	-	-	-
103	KCD	0.9	1.2	1.05	10.30	45	14.27	53	18.84	18.84	28.73	0
105	KCF	0.85	0.95	0.90	8.83	45	12.80	-	-	-	-	-
106	KCF	0.9	1.2	1.05	10.30	45	14.27	-	-	-	-	-
107	KCF	0.9	1.2	1.05	10.30	45	14.27	53	18.84	18.84	28.73	0
109	KCG	0.85	0.95	0.90	8.83	45	12.80	-	-	-	-	-
110	KCG	0.9	1.2	1.05	10.30	45	14.27	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
111	KCG	KINNEY		MH	40	53	0.33	15	27	50	65	10	20
113	La	LABISH	1	OH	0	16	0.41	35	50	60	80	20	30
114	La	LABISH	2	OH	16	60	2.34	40	55	60	80	20	30
115	MUE	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
116	MUE	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
118	MUF	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
119	MUF	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
121	MUG	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
122	MUG	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
124	MYB	MINNIECE	1	ML	0	15	0.38	27	35	35	40	10	15
125	MYB	MINNIECE	2	MH	15	32	0.43	40	55	50	60	15	25
126	MYB	MINNIECE	3	MH	32	60	1.93	35	55	50	60	15	25
127	MaA	MCALPIN	1	CL ML	0	23	0.58	30	40	35	40	10	15
128	MaA	MCALPIN	2	CL	23	65	2.16	40	50	40	50	15	25
129	MaB	MCALPIN	1	CL ML	0	23	0.58	30	40	35	40	10	15
130	MaB	MCALPIN	2	CL	23	65	2.16	40	50	40	50	15	25
131	Mb	MCBEE	1	ML	0	10	0.25	27	35	35	40	10	15
132	Mb	MCBEE	2	CL ML	10	65	2.49	25	45	34	40	10	15
133	McB	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
134	McB	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
136	McC	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
137	McC	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
139	McD	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
140	McD	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
142	McE	MCCULLY	1	MH ML	0	10	0.25	30	40	45	55	15	25
143	McE	MCCULLY	2	CH MH	10	57	2.49	45	55	50	60	20	30
145	MID	MCCULLY	1	GM MH	0	10	0.25	30	40	50	60	5	15
146	MID	MCCULLY	2	MH ML	10	57	2.49	45	55	45	55	5	15
148	MmE	MCCULLY	1	GM	0	10	0.25	30	40	50	60	5	15
149	MmE	MCCULLY	2	MH ML	10	57	2.49	45	55	45	55	5	15
151	NeB	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
152	NeB	NEKIA	2	CL GC	9	36	0.69	40	50	40	50	15	25
154	NeC	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density--Low (kg/m³)	Moist Bulk Density--High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
111	KCG	0.9	1.2	1.05	10.30	45	14.27	53	18.84	18.84	28.73	0
113	La	0.7	0.9	0.80	7.85	52	12.44	-	-	-	-	-
114	La	1.3	1.4	1.35	13.24	52	17.83	8	46.73	21.81	28.73	0
115	MUE	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
116	MUE	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
118	MUF	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
119	MUF	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
121	MUG	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
122	MUG	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
124	MYB	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
125	MYB	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
126	MYB	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	28.73	0
127	MaA	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
128	MaA	1.2	1.4	1.30	12.75	52	17.34	23	47.58	26.40	28.73	0
129	MaB	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
130	MaB	1.2	1.4	1.30	12.75	52	17.34	23	47.58	26.40	28.73	0
131	Mb	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
132	Mb	1.2	1.4	1.30	12.75	52	17.34	27	47.58	27.40	28.73	0
133	McB	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
134	McB	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
136	McC	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
137	McC	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
139	McD	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
140	McD	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
142	McE	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
143	McE	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	22.50	0
145	MlD	1.25	1.35	1.30	12.75	35	15.84	-	-	-	-	-
146	MlD	1.25	1.35	1.30	12.75	52	17.34	108	47.20	47.20	28.73	0
148	MmE	1.25	1.35	1.30	12.75	29	15.31	-	-	-	-	-
149	MmE	1.25	1.35	1.30	12.75	52	17.34	108	47.06	47.06	28.73	0
151	NeB	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
152	NeB	1.1	1.3	1.20	11.77	43	15.57	36	14.42	14.42	28.73	0
154	NeC	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
155	NeC	NEKIA	2	CL GC	9	36	0.69	40	50	40	50	15	25
157	NeD	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
158	NeD	NEKIA	2	CL GC	9	36	0.69	40	50	40	50	15	25
160	NeE	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
161	NeE	NEKIA	2	CL GC	9	36	0.69	40	50	40	50	15	25
163	NeF	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
164	NeF	NEKIA	2	CL GC	9	36	0.69	40	50	40	50	15	25
166	NkC	NEKIA	1	CL ML	0	9	0.23	27	35	35	40	10	15
167	NkC	NEKIA	2	CL GC	9	36	0.69	40	60	40	50	15	25
169	NsE	NEKIA	1	CL ML	0	9	0.23	27	35	35	40	10	15
170	NsE	NEKIA	2	CL GC	9	36	0.69	40	60	40	50	15	25
172	NsE	NEKIA	1	GM	0	4	0.10	18	25	25	30	0	5
173	NsE	NEKIA	2	GC	4	19	0.38	25	35	35	40	15	20
175	NsF	NEKIA	1	CL ML	0	9	0.23	27	35	35	40	10	15
176	NsF	NEKIA	2	CL GC	9	36	0.69	40	60	40	50	15	25
178	Nu	NEWBERG	1	SM	0	10	0.25	7	15	20	25	0	5
179	Nu	NEWBERG	2	SM	10	60	2.49	5	15	20	25	0	5
180	Nw	NEWBERG	1	ML	0	10	0.25	7	15	30	35	0	5
181	Nw	NEWBERG	2	SM	10	60	2.49	5	15	20	25	0	5
182	SCE	STEIWER	1	ML	0	21	0.53	20	27	30	40	5	10
183	SCE	STEIWER	2	ML	21	32	0.28	27	35	40	50	5	15
185	SCE	STEIWER	1	ML	0	4	0.10	18	27	25	35	0	10
186	SCE	STEIWER	2	ML	4	12	0.20	20	30	30	40	5	10
188	Sa	SALEM	1	CL-ML GC-GM GM ML	0	9	0.23	15	20	25	35	5	10
189	Sa	SALEM	2	CL GM ML SM	9	30	0.53	25	35	35	45	10	20
190	Sa	SALEM	3	GP GP-GM SP SP-SM	30	60	1.98	0	15	0	14	0	0
191	SkB	SALKUM	1	CL	0	20	0.51	27	35	40	45	15	20
192	SkB	SALKUM	2	MH	20	40	0.51	40	55	50	65	15	25
193	SkB	SALKUM	3	MH ML	40	65	1.73	35	50	45	60	15	25
194	SkD	SALKUM	1	CL	0	20	0.51	27	35	40	45	15	20
195	SkD	SALKUM	2	MH	20	40	0.51	40	55	50	65	15	25
196	SkD	SALKUM	3	MH ML	40	65	1.73	35	50	45	60	15	25
197	SlB	SALKUM	1	CL	0	20	0.51	27	35	40	45	15	20

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density--Low (kg/m³)	Moist Bulk Density--High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
155	NeC	1.1	1.3	1.20	11.77	43	15.57	36	14.42	14.42	28.73	0
157	NeD	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
158	NeD	1.1	1.3	1.20	11.77	43	15.57	36	14.42	14.42	28.73	0
160	NeE	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
161	NeE	1.1	1.3	1.20	11.77	43	15.57	36	14.42	14.42	28.73	0
163	NeF	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
164	NeF	1.1	1.3	1.20	11.77	43	15.57	36	14.42	14.42	28.73	0
166	NkC	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
167	NkC	1.3	1.5	1.40	13.73	43	17.53	36	15.88	15.88	28.73	0
169	NsE	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
170	NsE	1.3	1.5	1.40	13.73	43	17.53	36	15.88	15.88	28.73	0
172	NsE	1.35	1.5	1.43	13.98	29	16.54	-	-	-	-	-
173	NsE	1.3	1.4	1.35	13.24	32	16.07	19	7.80	7.80	2.39	35
175	NsF	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
176	NsF	1.3	1.5	1.40	13.73	43	17.53	36	15.88	15.88	28.73	0
178	Nu	1.2	1.4	1.30	12.75	35	15.84	-	-	-	-	-
179	Nu	1.2	1.4	1.30	12.75	35	15.84	108	43.46	43.46	2.39	34
180	Nw	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
181	Nw	1.2	1.4	1.30	12.75	35	15.84	108	43.69	43.69	2.39	34
182	SCE	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
183	SCE	1.3	1.4	1.35	13.24	52	17.83	32	14.17	14.17	28.73	0
185	SCE	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
186	SCE	1.3	1.4	1.35	13.24	45	17.22	12	5.25	5.25	28.73	0
188	Sa	1.2	1.5	1.35	13.24	44	17.13	-	-	-	-	-
189	Sa	1.2	1.5	1.35	13.24	42	16.95	-	-	-	-	-
190	Sa	1.3	1.6	1.45	14.22	29	16.78	108	46.21	46.21	2.39	37
191	SkB	1	1.35	1.18	11.53	52	16.12	-	-	-	-	-
192	SkB	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
193	SkB	1	1.5	1.25	12.26	52	16.85	108	46.61	46.61	28.73	0
194	SkD	1	1.35	1.18	11.53	52	16.12	-	-	-	-	-
195	SkD	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
196	SkD	1	1.5	1.25	12.26	52	16.85	108	46.61	46.61	28.73	0
197	SlB	1	1.35	1.18	11.53	52	16.12	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
198	SlB	SALKUM	2	MH	20	40	0.51	40	55	50	65	15	25
199	SlB	SALKUM	3	MH ML	40	65	1.73	35	50	45	60	15	25
200	SnA	SANTIAM	1	ML	0	13	0.33	18	27	30	40	5	10
201	SnA	SANTIAM	2	CL	13	30	0.43	35	45	30	50	10	30
202	SnA	SANTIAM	3	CH	30	60	1.98	40	50	50	60	30	40
203	SnB	SANTIAM	1	ML	0	13	0.33	18	27	30	40	5	10
204	SnB	SANTIAM	2	CL	13	30	0.43	35	45	30	50	10	30
205	SnB	SANTIAM	3	CH	30	60	1.98	40	50	50	60	30	40
206	SnC	SANTIAM	1	ML	0	13	0.33	18	27	30	40	5	10
207	SnC	SANTIAM	2	CL	13	30	0.43	35	45	30	50	10	30
208	SnC	SANTIAM	3	CH	30	60	1.98	40	50	50	60	30	40
209	So	SEMIAHMOO	1	PT	0	30	0.76	0	0	0	14	-	-
210	So	SEMIAHMOO	2	PT	30	60	1.98	0	0	0	14	-	-
211	St	SIFTON	1	GM ML	0	17	0.43	-	-	30	40	0	5
212	St	SIFTON	2	GM ML	17	24	0.18	-	-	30	40	0	5
213	St	SIFTON	3	GP GP-GM SP SP-SM	24	60	2.13	0	5	0	14	0	0
214	SuC	SILVERTON	1	CL-ML ML	0	16	0.41	18	25	25	35	5	10
215	SuC	SILVERTON	2	CL	16	25	0.23	25	35	35	45	15	20
216	SuC	SILVERTON	3	CH CL	25	37	0.30	40	55	45	60	20	30
218	SuD	SILVERTON	1	CL-ML ML	0	16	0.41	18	25	25	35	5	10
219	SuD	SILVERTON	2	CL	16	25	0.23	25	35	35	45	15	20
220	SuD	SILVERTON	3	CH CL	25	37	0.30	40	55	45	60	20	30
222	SvB	STAYTON	1	ML	0	12	0.30	10	18	30	40	5	10
223	SvB	STAYTON	2	ML	12	19	0.18	12	18	30	40	5	10
225	SwB	STEIWER	1	ML	0	21	0.53	20	27	30	40	5	10
226	SwB	STEIWER	2	ML	21	32	0.28	27	35	40	50	5	15
228	SwD	STEIWER	1	ML	0	21	0.53	20	27	30	40	5	10
229	SwD	STEIWER	2	ML	21	32	0.28	27	35	40	50	5	15
232	Sy	STONY ROCK LAND	1	GP	0	60	2.74	0	0	-	-	0	0
233	Te	TERRACE ESCARPMENTS	1	CL-ML ML	0	8	0.20	18	27	25	35	5	10
234	Te	TERRACE ESCARPMENTS	2	CL-ML ML SC-SM SM	8	48	1.02	20	30	25	35	5	10
235	Te	TERRACE ESCARPMENTS	3	GC GM SC SM	48	60	1.52	27	35	35	40	10	15
236	WHE	WHETSTONE	1	SM	0	1	0.03	8	18	15	25	0	5

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
198	SIB	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
199	SIB	1	1.5	1.25	12.26	52	16.85	108	46.61	46.61	28.73	0
200	SnA	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
201	SnA	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
202	SnA	1.4	1.5	1.45	14.22	52	18.82	15	50.29	27.12	22.50	0
203	SnB	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
204	SnB	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
205	SnB	1.4	1.5	1.45	14.22	52	18.82	15	50.29	27.12	22.50	0
206	SnC	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
207	SnC	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
208	SnC	1.4	1.5	1.45	14.22	52	18.82	15	50.29	27.12	22.50	0
209	So	0.5	0.7	0.60	5.89	52	10.48	-	-	-	-	-
210	So	0.5	0.7	0.60	5.89	52	10.48	7	28.74	3.57	28.73	0
211	St	0.85	0.95	0.90	8.83	35	11.92	-	-	-	-	-
212	St	0.7	0.85	0.78	7.60	35	10.69	-	-	-	-	-
213	St	1.1	1.3	1.20	11.77	29	14.33	108	37.63	37.63	2.39	38
214	SuC	1.2	1.4	1.30	12.75	50	17.17	-	-	-	-	-
215	SuC	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
216	SuC	1.4	1.5	1.45	14.22	52	18.82	37	16.68	16.68	22.50	0
218	SuD	1.2	1.4	1.30	12.75	50	17.17	-	-	-	-	-
219	SuD	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
220	SuD	1.4	1.5	1.45	14.22	52	18.82	37	16.68	16.68	22.50	0
222	SvB	0.7	0.85	0.78	7.60	45	11.58	-	-	-	-	-
223	SvB	0.7	0.85	0.78	7.60	45	11.58	19	5.59	5.59	28.73	0
225	SwB	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
226	SwB	1.3	1.4	1.35	13.24	52	17.83	32	14.17	14.17	28.73	0
228	SwD	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
229	SwD	1.3	1.4	1.35	13.24	52	17.83	32	14.17	14.17	28.73	0
232	Sy	1.7	2.35	2.03	19.87	29	22.43	108	61.52	61.52	2.39	38
233	Te	1.1	1.4	1.25	12.26	50	16.68	-	-	-	-	-
234	Te	1.1	1.4	1.25	12.26	48	16.50	-	-	-	-	-
235	Te	1.2	1.4	1.30	12.75	31	15.49	108	43.76	43.76	2.39	36
236	WHE	1	1.2	1.10	10.79	35	13.88	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
237	WHE	WHETSTONE	2	ML SM	1	5	0.10	8	18	15	25	0	5
238	WHE	WHETSTONE	3	GM ML	5	19	0.36	8	18	15	25	0	5
239	WHE	WHETSTONE	4	GM	19	38	0.48	8	18	15	25	0	5
241	WHF	WHETSTONE	1	SM	0	1	0.03	8	18	15	25	0	5
242	WHF	WHETSTONE	2	ML SM	1	5	0.10	8	18	15	25	0	5
243	WHF	WHETSTONE	3	GM ML	5	19	0.36	8	18	15	25	0	5
244	WHF	WHETSTONE	4	GM	19	38	0.48	8	18	15	25	0	5
246	WHG	WHETSTONE	1	SM	0	1	0.03	8	18	15	25	0	5
247	WHG	WHETSTONE	2	ML SM	1	5	0.10	8	18	15	25	0	5
248	WHG	WHETSTONE	3	GM ML	5	19	0.36	8	18	15	25	0	5
249	WHG	WHETSTONE	4	GM	19	38	0.48	8	18	15	25	0	5
251	WHG	WHETSTONE	1	GM	0	10	0.25	7	15	15	25	0	5
252	WHG	WHETSTONE	2	GM	10	30	0.51	7	15	15	25	0	5
254	Wa	WALDO	1	CL ML	0	10	0.25	27	40	35	40	10	15
255	Wa	WALDO	2	CH MH	10	60	2.49	40	55	50	60	20	30
256	Wc	WAPATO	1	ML	0	16	0.41	27	35	35	40	10	15
257	Wc	WAPATO	2	ML	16	60	2.34	20	35	30	40	5	15
258	WlA	WILLAMETTE	1	ML	0	24	0.61	20	27	35	40	5	10
259	WlA	WILLAMETTE	2	CL	24	54	0.76	25	35	40	50	15	25
260	WlA	WILLAMETTE	3	ML	54	65	1.37	20	30	35	40	10	15
261	WlA	WILLAMETTE	1	ML	0	17	0.43	10	20	25	30	0	5
262	WlA	WILLAMETTE	2	CL	17	32	0.38	20	35	30	40	10	20
263	WlA	WILLAMETTE	3	CL-ML ML	32	68	1.93	15	30	25	35	5	10
264	WlC	WILLAMETTE	1	ML	0	24	0.61	20	27	35	40	5	10
265	WlC	WILLAMETTE	2	CL	24	54	0.76	25	35	40	50	15	25
266	WlC	WILLAMETTE	3	ML	54	65	1.37	20	30	35	40	10	15
267	WtE	WITZEL	1	GM	0	4	0.10	18	25	25	30	0	5
268	WtE	WITZEL	2	GC	4	19	0.38	25	35	35	40	15	20
270	WuA	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
271	WuA	WOODBURN	2	CL	17	32	0.38	20	35	30	40	10	20
272	WuA	WOODBURN	3	CL-ML ML	32	68	1.93	15	30	25	35	5	10
273	WuC	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
274	WuC	WOODBURN	2	CL	17	32	0.38	20	35	30	40	10	20

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
237	WHE	1.1	1.3	1.20	11.77	41	15.39	-	-	-	-	-
238	WHE	1.1	1.3	1.20	11.77	35	14.86	-	-	-	-	-
239	WHE	1.1	1.3	1.20	11.77	29	14.33	38	14.12	14.12	2.39	38
241	WHF	1	1.2	1.10	10.79	35	13.88	-	-	-	-	-
242	WHF	1.1	1.3	1.20	11.77	41	15.39	-	-	-	-	-
243	WHF	1.1	1.3	1.20	11.77	35	14.86	-	-	-	-	-
244	WHF	1.1	1.3	1.20	11.77	29	14.33	38	14.12	14.12	2.39	38
246	WHG	1	1.2	1.10	10.79	35	13.88	-	-	-	-	-
247	WHG	1.1	1.3	1.20	11.77	41	15.39	-	-	-	-	-
248	WHG	1.1	1.3	1.20	11.77	35	14.86	-	-	-	-	-
249	WHG	1.1	1.3	1.20	11.77	29	14.33	38	14.12	14.12	2.39	38
251	WHG	1.2	1.4	1.30	12.75	29	15.31	-	-	-	-	-
252	WHG	1.2	1.4	1.30	12.75	29	15.31	30	11.67	11.67	2.39	38
254	Wa	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
255	Wa	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	22.50	0
256	Wc	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
257	Wc	1.2	1.4	1.30	12.75	45	16.73	3	46.13	19.97	28.73	0
258	WlA	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
259	WlA	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
260	WlA	1.2	1.4	1.30	12.75	45	16.73	108	46.35	46.35	28.73	0
261	WlA	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
262	WlA	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
263	WlA	1.3	1.5	1.40	13.73	50	18.15	108	48.86	48.86	28.73	0
264	WlC	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
265	WlC	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
266	WlC	1.2	1.4	1.30	12.75	45	16.73	108	46.35	46.35	28.73	0
267	WtE	1.35	1.5	1.43	13.98	29	16.54	-	-	-	-	-
268	WtE	1.3	1.4	1.35	13.24	31	15.98	19	7.77	7.77	2.39	35
270	WuA	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
271	WuA	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
272	WuA	1.3	1.5	1.40	13.73	50	18.15	108	48.86	48.86	28.73	0
273	WuC	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
274	WuC	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
Marion County													
275	WuC	WOODBURN	3	CL-ML ML	32	68	1.93	15	30	25	35	5	10
276	WuD	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
277	WuD	WOODBURN	2	CL	17	32	0.38	20	35	30	40	10	20
278	WuD	WOODBURN	3	CL-ML ML	32	68	1.93	15	30	25	35	5	10
Polk County													
1	1A	ABIQUA	1	ML	0	25	0.64	27	40	35	40	10	15
2	1A	ABIQUA	2	CL CH	25	60	2.11	35	50	40	55	15	30
3	1B	ABIQUA	1	ML	0	25	0.64	27	40	35	40	10	15
4	1B	ABIQUA	2	CL CH	25	60	2.11	35	50	40	55	15	30
5	2	ABIQUA	1	ML	0	25	0.64	27	35	35	40	10	15
6	2	ABIQUA	2	MH	25	60	2.11	45	50	50	60	20	30
7	3	AMITY	1	ML	0	25	0.64	15	25	30	40	5	10
8	3	AMITY	2	CL	25	63	2.11	27	35	40	45	15	20
9	4D	APT	1	ML MH	0	8	0.20	30	40	40	60	10	20
10	4D	APT	2	MH	8	66	1.47	45	60	50	60	10	20
11	4D	APT	3	MH ML	66	78	0.30	30	45	40	60	10	20
12	4E	APT	1	ML MH	0	8	0.20	30	40	40	60	10	20
13	4E	APT	2	MH	8	66	1.47	45	60	50	60	10	20
14	4E	APT	3	MH ML	66	78	0.30	30	45	40	60	10	20
15	5D	ASTORIA	1	ML	0	10	0.25	20	27	40	50	0	5
16	5D	ASTORIA	2	ML	10	19	0.23	25	35	40	50	5	10
17	5D	ASTORIA	3	MH	19	49	0.76	35	60	50	60	10	15
18	5D	ASTORIA	4	MH	49	61	1.50	27	35	50	60	10	15
19	5E	ASTORIA	1	ML	0	10	0.25	20	27	40	50	0	5
20	5E	ASTORIA	2	ML	10	19	0.23	25	35	40	50	5	10
21	5E	ASTORIA	3	MH	19	49	0.76	35	60	50	60	10	15
22	5E	ASTORIA	4	MH	49	61	1.50	27	35	50	60	10	15
23	6A	BASHAW	1	CL	0	11	0.28	35	40	40	50	20	30
24	6A	BASHAW	2	CH	11	51	1.02	55	70	70	90	40	60
25	6A	BASHAW	3	CH	51	60	1.45	50	70	60	90	35	60
26	6C	BASHAW	1	CH	0	11	0.28	60	80	50	60	25	35
27	6C	BASHAW	2	CH	11	60	2.46	60	80	70	90	40	60

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density--Low (kg/m³)	Moist Bulk Density--High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Marion County												
275	WuC	1.3	1.5	1.40	13.73	50	18.15	108	48.86	48.86	28.73	0
276	WuD	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
277	WuD	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
278	WuD	1.3	1.5	1.40	13.73	50	18.15	108	48.86	48.86	28.73	0
Polk County												
1	1A	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
2	1A	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	28.73	0
3	1B	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
4	1B	1.2	1.3	1.25	12.26	52	16.85	108	46.23	46.23	28.73	0
5	2	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
6	2	1.3	1.5	1.40	13.73	52	18.33	108	49.33	49.33	28.73	0
7	3	1.2	1.45	1.33	13.00	45	16.97	-	-	-	-	-
8	3	1.2	1.4	1.30	12.75	52	17.34	12	47.34	23.42	28.73	0
9	4D	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
10	4D	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
11	4D	1.1	1.3	1.20	11.77	52	16.36	0	32.42	12.98	28.73	0
12	4E	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
13	4E	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
14	4E	1.1	1.3	1.20	11.77	52	16.36	0	32.42	12.98	28.73	0
15	5D	0.85	0.95	0.90	8.83	45	12.80	-	-	-	-	-
16	5D	0.7	1	0.85	8.34	45	12.31	-	-	-	-	-
17	5D	0.9	1.2	1.05	10.30	52	14.89	-	-	-	-	-
18	5D	0.9	1.2	1.05	10.30	52	14.89	108	39.73	39.73	28.73	0
19	5E	0.85	0.95	0.90	8.83	45	12.80	-	-	-	-	-
20	5E	0.7	1	0.85	8.34	45	12.31	-	-	-	-	-
21	5E	0.9	1.2	1.05	10.30	52	14.89	-	-	-	-	-
22	5E	0.9	1.2	1.05	10.30	52	14.89	108	39.73	39.73	28.73	0
23	6A	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
24	6A	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
25	6A	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	22.50	0
26	6C	1.2	1.35	1.28	12.51	52	17.10	-	-	-	-	-
27	6C	1.2	1.4	1.30	12.75	52	17.34	3	47.51	21.35	22.50	0

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
28	7	BASHAW	1	CH	0	4	0.10	55	70	70	90	40	60
29	7	BASHAW	2	CH	4	46	1.07	55	70	70	90	40	60
30	7	BASHAW	3	CH	46	60	1.57	50	70	60	90	35	60
31	8C	BELLPINE	1	CL	0	9	0.23	27	35	35	45	15	20
32	8C	BELLPINE	2	MH	9	32	0.58	40	55	50	60	20	25
34	8D	BELLPINE	1	CL	0	9	0.23	27	35	35	45	15	20
35	8D	BELLPINE	2	MH	9	32	0.58	40	55	50	60	20	25
37	8E	BELLPINE	1	CL	0	9	0.23	27	35	35	45	15	20
38	8E	BELLPINE	2	MH	9	32	0.58	40	55	50	60	20	25
40	8F	BELLPINE	1	CL	0	9	0.23	27	35	35	45	15	20
41	8F	BELLPINE	2	MH	9	32	0.58	40	55	50	60	20	25
43	8G	BELLPINE	1	CL	0	9	0.23	27	35	35	45	15	20
44	8G	BELLPINE	2	MH	9	32	0.58	40	55	50	60	20	25
46	9D	BLACHLY	1	MH	0	15	0.38	27	40	50	65	5	15
47	9D	BLACHLY	2	MH	15	60	2.36	40	50	50	65	10	20
48	9E	BLACHLY	1	MH	0	15	0.38	27	40	50	65	5	15
49	9E	BLACHLY	2	MH	15	60	2.36	40	50	50	65	10	20
50	10D	BOHANNON	1	GM SM	0	16	0.41	15	25	30	45	0	10
51	10D	BOHANNON	2	SC-SM GC	16	34	0.46	18	30	25	35	5	15
53	10E	BOHANNON	1	GM SM	0	16	0.41	15	25	30	45	0	10
54	10E	BOHANNON	2	SC-SM GC	16	34	0.46	18	30	25	35	5	15
56	10F	BOHANNON	1	GM SM	0	16	0.41	15	25	30	45	0	10
57	10F	BOHANNON	2	SC-SM GC	16	34	0.46	18	30	25	35	5	15
59	11	BRENNER	1	ML	0	11	0.28	20	27	25	35	0	5
60	11	BRENNER	2	CL	11	16	0.13	18	30	30	40	10	20
61	11	BRENNER	3	MH ML	16	60	2.34	27	50	35	55	10	20
62	12A	BRIEDWELL	1	ML	0	10	0.25	15	25	25	35	0	10
63	12A	BRIEDWELL	2	CL GC	10	17	0.18	27	35	30	40	10	15
64	12A	BRIEDWELL	3	GC	17	60	2.31	27	30	30	35	10	15
65	12C	BRIEDWELL	1	ML	0	10	0.25	15	25	25	35	0	10
66	12C	BRIEDWELL	2	CL GC	10	17	0.18	27	35	30	40	10	15
67	12C	BRIEDWELL	3	GC	17	60	2.31	27	30	30	35	10	15
68	12D	BRIEDWELL	1	ML	0	10	0.25	15	25	25	35	0	10

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density--Low (kg/m³)	Moist Bulk Density--High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
28	7	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
29	7	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
30	7	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	22.50	0
31	8C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
32	8C	1.1	1.4	1.25	12.26	52	16.85	0	13.81	5.84	28.73	0
34	8D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
35	8D	1.1	1.4	1.25	12.26	52	16.85	0	13.81	5.84	28.73	0
37	8E	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
38	8E	1.1	1.4	1.25	12.26	52	16.85	0	13.81	5.84	28.73	0
40	8F	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
41	8F	1.1	1.4	1.25	12.26	52	16.85	0	13.81	5.84	28.73	0
43	8G	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
44	8G	1.1	1.4	1.25	12.26	52	16.85	0	13.81	5.84	28.73	0
46	9D	1.1	1.2	1.15	11.28	52	15.87	-	-	-	-	-
47	9D	1.1	1.3	1.20	11.77	52	16.36	108	44.70	44.70	28.73	0
48	9E	1.1	1.2	1.15	11.28	52	15.87	-	-	-	-	-
49	9E	1.1	1.3	1.20	11.77	52	16.36	108	44.70	44.70	28.73	0
50	10D	0.85	0.95	0.90	8.83	32	11.65	-	-	-	-	-
51	10D	1	1.3	1.15	11.28	35	14.37	0	11.31	2.84	2.39	33
53	10E	0.85	0.95	0.90	8.83	32	11.65	-	-	-	-	-
54	10E	1	1.3	1.15	11.28	35	14.37	0	11.31	2.84	2.39	33
56	10F	0.85	0.95	0.90	8.83	32	11.65	-	-	-	-	-
57	10F	1	1.3	1.15	11.28	35	14.37	0	11.31	2.84	2.39	33
59	11	0.9	1.2	1.05	10.30	45	14.27	-	-	-	-	-
60	11	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
61	11	1.1	1.3	1.20	11.77	52	16.36	6	44.30	18.89	28.73	0
62	12A	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
63	12A	1.2	1.3	1.25	12.26	43	16.06	-	-	-	-	-
64	12A	1.2	1.3	1.25	12.26	31	15.00	108	41.52	41.52	2.39	35
65	12C	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
66	12C	1.2	1.3	1.25	12.26	43	16.06	-	-	-	-	-
67	12C	1.2	1.3	1.25	12.26	31	15.00	108	41.52	41.52	2.39	35
68	12D	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
69	12D	BRIEDWELL	2	CL GC	10	17	0.18	27	35	30	40	10	15
70	12D	BRIEDWELL	3	GC	17	60	2.31	27	30	30	35	10	15
71	13	CAMAS	1	GM SM	0	12	0.30	5	10	-	-	0	0
72	13	CAMAS	2	GP GP-GM	12	60	2.44	0	5	-	-	0	0
73	14	CHEHALIS	1	CL	0	12	0.30	30	40	40	50	20	30
74	14	CHEHALIS	2	ML	12	47	0.89	25	35	35	45	5	15
75	14	CHEHALIS	3	CL	47	64	1.55	25	45	30	45	10	20
76	15C	CHEHULPUM	1	ML	0	6	0.15	18	27	25	35	0	10
77	15C	CHEHULPUM	2	ML	6	16	0.25	20	30	30	40	5	10
79	15E	CHEHULPUM	1	ML	0	6	0.15	18	27	25	35	0	10
80	15E	CHEHULPUM	2	ML	6	16	0.25	20	30	30	40	5	10
82	16E	CHEHULPUM	1	ML	0	6	0.15	18	27	25	35	0	10
83	16E	CHEHULPUM	2	ML	6	16	0.25	20	30	30	40	5	10
85	16E	CHEHULPUM	1	ML	0	15	0.38	20	27	30	40	5	10
86	16E	CHEHULPUM	2	ML	15	26	0.28	27	35	40	50	5	15
88	17	CLOQUATO	1	ML	0	34	0.86	5	15	20	30	0	5
89	17	CLOQUATO	2	ML	34	45	0.28	5	15	20	30	0	5
90	17	CLOQUATO	3	SM	45	60	1.60	2	10	0	14	0	0
91	18	COBURG	1	CL	0	15	0.38	27	35	30	40	10	15
92	18	COBURG	2	CL	15	60	2.36	35	45	40	50	15	25
93	19	COBURG	1	ML CL	0	15	0.38	28	33	35	40	10	15
94	19	COBURG	2	CL	15	60	2.36	35	40	40	50	15	25
95	20	CONCORD	1	ML	0	8	0.20	20	25	30	40	5	10
96	20	CONCORD	2	CL	8	31	0.58	35	50	40	50	15	25
97	20	CONCORD	3	ML	31	60	1.96	20	35	30	40	5	10
98	21	COVE	1	CL	0	8	0.20	30	40	30	40	10	20
99	21	COVE	2	CH	8	60	2.54	50	60	60	80	40	50
100	22	COVE	1	CL	0	19	0.48	30	40	30	40	10	20
101	22	COVE	2	CH	19	60	2.26	50	60	60	80	40	50
102	23D	CRUISER	1	SM	0	12	0.30	18	27	0	14	0	0
103	23D	CRUISER	2	GM MH	12	42	0.76	20	30	50	60	5	10
105	23E	CRUISER	1	SM	0	12	0.30	18	27	0	14	0	0
106	23E	CRUISER	2	GM MH	12	42	0.76	20	30	50	60	5	10

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density--Low (kg/m³)	Moist Bulk Density--High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
69	12D	1.2	1.3	1.25	12.26	43	16.06	-	-	-	-	-
70	12D	1.2	1.3	1.25	12.26	31	15.00	108	41.52	41.52	2.39	35
71	13	1.3	1.5	1.40	13.73	32	16.56	-	-	-	-	-
72	13	1.4	1.6	1.50	14.72	29	17.28	108	47.17	47.17	2.39	37
73	14	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
74	14	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
75	14	1.3	1.5	1.40	13.73	52	18.33	108	48.25	48.25	28.73	0
76	15C	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
77	15C	1.3	1.4	1.35	13.24	45	17.22	0	7.00	3.01	28.73	0
79	15E	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
80	15E	1.3	1.4	1.35	13.24	45	17.22	0	7.00	3.01	28.73	0
82	16E	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
83	16E	1.3	1.4	1.35	13.24	45	17.22	0	7.00	3.01	28.73	0
85	16E	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
86	16E	1.3	1.4	1.35	13.24	52	17.83	0	11.54	5.06	28.73	0
88	17	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
89	17	1.3	1.5	1.40	13.73	45	17.71	-	-	-	-	-
90	17	1.3	1.5	1.40	13.73	35	16.82	108	46.31	46.31	2.39	35
91	18	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
92	18	1.2	1.4	1.30	12.75	52	17.34	24	47.58	26.65	28.73	0
93	19	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
94	19	1.25	1.35	1.30	12.75	52	17.34	24	47.39	26.46	28.73	0
95	20	1.4	1.6	1.50	14.72	45	18.69	-	-	-	-	-
96	20	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
97	20	1.4	1.6	1.50	14.72	45	18.69	3	51.05	24.89	28.73	0
98	21	1.25	1.35	1.30	12.75	52	17.34	-	-	-	-	-
99	21	1.2	1.3	1.25	12.26	52	16.85	6	46.33	20.92	22.50	0
100	22	1.25	1.35	1.30	12.75	52	17.34	-	-	-	-	-
101	22	1.2	1.3	1.25	12.26	52	16.85	6	46.47	21.05	22.50	0
102	23D	0.85	0.95	0.90	8.83	35	11.92	-	-	-	-	-
103	23D	0.9	1	0.95	9.32	35	12.41	0	13.09	2.62	2.39	37
105	23E	0.85	0.95	0.90	8.83	35	11.92	-	-	-	-	-
106	23E	0.9	1	0.95	9.32	35	12.41	0	13.09	2.62	2.39	37

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
PolkCounty													
108	23F	CRUISER	1	SM	0	12	0.30	18	27	0	14	0	0
109	23F	CRUISER	2	GM MH	12	42	0.76	20	30	50	60	5	10
111	24D	CUMLEY	1	CL ML	0	7	0.18	27	35	35	40	10	15
112	24D	CUMLEY	2	MH	7	60	2.57	40	55	50	60	15	25
113	25	DAYTON	1	ML	0	5	0.13	15	20	30	35	5	10
114	25	DAYTON	2	ML	5	12	0.18	15	30	30	40	5	15
115	25	DAYTON	3	CH	12	60	2.44	40	50	55	70	35	45
116	26C	DIXONVILLE	1	CL	0	16	0.41	27	40	35	40	15	20
117	26C	DIXONVILLE	2	CH	16	39	0.58	40	60	50	80	30	50
119	26D	DIXONVILLE	1	CL	0	16	0.41	27	40	35	40	15	20
120	26D	DIXONVILLE	2	CH	16	39	0.58	40	60	50	80	30	50
122	27C	DUPEE	1	ML	0	9	0.23	15	27	30	40	5	10
123	27C	DUPEE	2	MH	9	62	2.51	35	50	50	60	20	25
124	27D	DUPEE	1	ML	0	9	0.23	15	27	30	40	5	10
125	27D	DUPEE	2	MH	9	62	2.51	35	50	50	60	20	25
126	28	GRANDE RONDE	1	ML	0	7	0.18	30	40	40	50	10	20
127	28	GRANDE RONDE	2	CH	7	26	0.48	50	70	55	70	35	50
128	28	GRANDE RONDE	3	CH	26	62	2.08	55	70	60	70	40	50
129	29C	HAZELAIR	1	CL	0	10	0.25	22	27	30	40	10	20
130	29C	HAZELAIR	2	CL	10	17	0.18	35	50	40	50	20	25
131	29C	HAZELAIR	3	CH	17	38	0.53	60	70	60	80	40	50
133	29D	HAZELAIR	1	CL	0	10	0.25	22	27	30	40	10	20
134	29D	HAZELAIR	2	CL	10	17	0.18	35	50	40	50	20	25
135	29D	HAZELAIR	3	CH	17	38	0.53	60	70	60	80	40	50
137	29E	HAZELAIR	1	CL	0	10	0.25	22	27	30	40	10	20
138	29E	HAZELAIR	2	CL	10	17	0.18	35	50	40	50	20	25
139	29E	HAZELAIR	3	CH	17	38	0.53	60	70	60	80	40	50
141	30C	HELMICK	1	ML	0	10	0.25	18	27	30	40	5	15
142	30C	HELMICK	2	CL	10	16	0.15	27	45	40	50	15	25
143	30C	HELMICK	3	CH	16	62	2.34	40	50	60	80	40	50
144	30D	HELMICK	1	ML	0	10	0.25	18	27	30	40	5	15
145	30D	HELMICK	2	CL	10	16	0.15	27	45	40	50	15	25
146	30D	HELMICK	3	CH	16	62	2.34	40	50	60	80	40	50

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
108	23F	0.85	0.95	0.90	8.83	35	11.92	-	-	-	-	-
109	23F	0.9	1	0.95	9.32	35	12.41	0	13.09	2.62	2.39	37
111	24D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
112	24D	1.3	1.4	1.35	13.24	52	17.83	30	48.84	29.40	28.73	0
113	25	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
114	25	1.25	1.4	1.33	13.00	45	16.97	-	-	-	-	-
115	25	1.25	1.4	1.33	13.00	52	17.59	12	48.09	24.17	22.50	0
116	26C	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
117	26C	1.3	1.6	1.45	14.22	52	18.82	0	18.44	8.72	22.50	0
119	26D	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
120	26D	1.3	1.6	1.45	14.22	52	18.82	0	18.44	8.72	22.50	0
122	27C	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
123	27C	1.25	1.35	1.30	12.75	52	17.34	18	47.21	24.79	28.73	0
124	27D	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
125	27D	1.25	1.35	1.30	12.75	52	17.34	18	47.21	24.79	28.73	0
126	28	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
127	28	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
128	28	1.3	1.4	1.35	13.24	52	17.83	21	48.75	27.07	22.50	0
129	29C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
130	29C	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-
131	29C	1	1.2	1.10	10.79	52	15.38	18	15.39	10.41	22.50	0
133	29D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
134	29D	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-
135	29D	1	1.2	1.10	10.79	52	15.38	18	15.39	10.41	22.50	0
137	29E	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
138	29E	1.05	1.2	1.13	11.04	52	15.63	-	-	-	-	-
139	29E	1	1.2	1.10	10.79	52	15.38	18	15.39	10.41	22.50	0
141	30C	1.1	1.2	1.15	11.28	45	15.25	-	-	-	-	-
142	30C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
143	30C	1.25	1.4	1.33	13.00	52	17.59	18	47.62	25.19	22.50	0
144	30D	1.1	1.2	1.15	11.28	45	15.25	-	-	-	-	-
145	30D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
146	30D	1.25	1.4	1.33	13.00	52	17.59	18	47.62	25.19	22.50	0

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
147	30E	HELMICK	1	ML	0	10	0.25	18	27	30	40	5	15
148	30E	HELMICK	2	CL	10	16	0.15	27	45	40	50	15	25
149	30E	HELMICK	3	CH	16	62	2.34	40	50	60	80	40	50
150	31C	HELVETIA	1	ML	0	15	0.38	15	25	25	35	0	5
151	31C	HELVETIA	2	ML MH CL CH	15	62	2.36	35	50	40	55	15	25
152	31D	HELVETIA	1	ML	0	15	0.38	15	25	25	35	0	5
153	31D	HELVETIA	2	ML MH CL CH	15	62	2.36	35	50	40	55	15	25
154	32D	HEMBRE	1	ML GM SM	0	10	0.25	18	27	30	40	5	10
155	32D	HEMBRE	2	ML MH	10	54	1.12	27	32	40	55	5	15
157	32E	HEMBRE	1	ML GM SM	0	10	0.25	18	27	30	40	5	10
158	32E	HEMBRE	2	ML MH	10	54	1.12	27	32	40	55	5	15
160	32F	HEMBRE	1	ML GM SM	0	10	0.25	18	27	30	40	5	10
161	32F	HEMBRE	2	ML MH	10	54	1.12	27	32	40	55	5	15
163	33	HOLCOMB	1	ML	0	18	0.46	20	25	30	35	5	10
164	33	HOLCOMB	2	ML CL	18	24	0.15	25	30	30	40	5	15
165	33	HOLCOMB	3	CH	24	60	2.13	40	50	60	80	40	50
166	34D	HONEYGROVE	1	ML	0	15	0.38	30	40	30	40	5	10
167	34D	HONEYGROVE	2	MH	15	62	2.36	50	60	55	70	10	20
168	34E	HONEYGROVE	1	ML	0	15	0.38	30	40	30	40	5	10
169	34E	HONEYGROVE	2	MH	15	62	2.36	50	60	55	70	10	20
170	34F	HONEYGROVE	1	ML	0	15	0.38	30	40	30	40	5	10
171	34F	HONEYGROVE	2	MH	15	62	2.36	50	60	55	70	10	20
172	35C	JORY	1	ML	0	20	0.51	18	27	35	40	5	10
173	35C	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
174	35D	JORY	1	ML	0	20	0.51	18	27	35	40	5	10
175	35D	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
176	35E	JORY	1	ML	0	20	0.51	18	27	35	40	5	10
177	35E	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
178	36C	JORY	1	ML	0	20	0.51	27	40	40	50	10	15
179	36C	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
180	36D	JORY	1	ML	0	20	0.51	27	40	40	50	10	15
181	36D	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
182	36E	JORY	1	ML	0	20	0.51	27	40	40	50	10	15

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
147	30E	1.1	1.2	1.15	11.28	45	15.25	-	-	-	-	-
148	30E	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
149	30E	1.25	1.4	1.33	13.00	52	17.59	18	47.62	25.19	22.50	0
150	31C	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
151	31C	1.2	1.4	1.30	12.75	52	17.34	54	46.97	33.51	28.73	0
152	31D	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
153	31D	1.2	1.4	1.30	12.75	52	17.34	54	46.97	33.51	28.73	0
154	32D	0.9	1	0.95	9.32	40	12.85	-	-	-	-	-
155	32D	1	1.15	1.08	10.55	52	15.14	0	20.18	6.73	28.73	0
157	32E	0.9	1	0.95	9.32	40	12.85	-	-	-	-	-
158	32E	1	1.15	1.08	10.55	52	15.14	0	20.18	6.73	28.73	0
160	32F	0.9	1	0.95	9.32	40	12.85	-	-	-	-	-
161	32F	1	1.15	1.08	10.55	52	15.14	0	20.18	6.73	28.73	0
163	33	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
164	33	1.3	1.4	1.35	13.24	50	17.66	-	-	-	-	-
165	33	1.3	1.4	1.35	13.24	52	17.83	15	48.61	25.44	22.50	0
166	34D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
167	34D	1.2	1.4	1.30	12.75	52	17.34	108	47.58	47.58	28.73	0
168	34E	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
169	34E	1.2	1.4	1.30	12.75	52	17.34	108	47.58	47.58	28.73	0
170	34F	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
171	34F	1.2	1.4	1.30	12.75	52	17.34	108	47.58	47.58	28.73	0
172	35C	1.2	1.3	1.25	12.26	45	16.24	-	-	-	-	-
173	35C	1.3	1.5	1.40	13.73	52	18.33	108	49.21	49.21	28.73	0
174	35D	1.2	1.3	1.25	12.26	45	16.24	-	-	-	-	-
175	35D	1.3	1.5	1.40	13.73	52	18.33	108	49.21	49.21	28.73	0
176	35E	1.2	1.3	1.25	12.26	45	16.24	-	-	-	-	-
177	35E	1.3	1.5	1.40	13.73	52	18.33	108	49.21	49.21	28.73	0
178	36C	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
179	36C	1.3	1.5	1.40	13.73	52	18.33	108	49.52	49.52	28.73	0
180	36D	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
181	36D	1.3	1.5	1.40	13.73	52	18.33	108	49.52	49.52	28.73	0
182	36E	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
183	36E	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
184	37D	JORY	1	ML	0	20	0.51	27	40	40	50	10	15
185	37D	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
186	37E	JORY	1	ML	0	20	0.51	27	40	40	50	10	15
187	37E	JORY	2	CL	20	70	2.24	45	60	40	50	15	25
188	38E	KILCHIS	1	SM ML	0	4	0.10	18	27	20	30	0	5
189	38E	KILCHIS	2	GM	4	15	0.28	18	27	20	30	0	5
191	38F	KILCHIS	1	SM ML	0	4	0.10	18	27	20	30	0	5
192	38F	KILCHIS	2	GM	4	15	0.28	18	27	20	30	0	5
194	39F	KILCHIS	1	SM ML	0	4	0.10	18	27	20	30	0	5
195	39F	KILCHIS	2	GM	4	15	0.28	18	27	20	30	0	5
197	39F	KILCHIS	1	GC CL SC	0	7	0.18	27	32	30	40	10	15
198	39F	KILCHIS	2	GC	7	42	0.89	27	33	30	40	10	15
200	40D	KILOWAN	1	ML CL	0	13	0.33	27	35	30	40	5	15
201	40D	KILOWAN	2	MH	13	24	0.28	35	50	50	60	15	20
203	40E	KILOWAN	1	ML CL	0	13	0.33	27	35	30	40	5	15
204	40E	KILOWAN	2	MH	13	24	0.28	35	50	50	60	15	20
206	40F	KILOWAN	1	ML CL	0	13	0.33	27	35	30	40	5	15
207	40F	KILOWAN	2	MH	13	24	0.28	35	50	50	60	15	20
209	41D	KLICKITAT	1	GC CL SC	0	7	0.18	27	32	30	40	10	15
210	41D	KLICKITAT	2	GC	7	42	0.89	27	33	30	40	10	15
212	41E	KLICKITAT	1	GC CL SC	0	7	0.18	27	32	30	40	10	15
213	41E	KLICKITAT	2	GC	7	42	0.89	27	33	30	40	10	15
215	41F	KLICKITAT	1	GC CL SC	0	7	0.18	27	32	30	40	10	15
216	41F	KLICKITAT	2	GC	7	42	0.89	27	33	30	40	10	15
218	42B	KNAPPA	1	ML	0	12	0.30	15	25	30	35	5	10
219	42B	KNAPPA	2	ML CL	12	60	2.44	22	35	35	40	10	15
220	43D	LUCKIAMUTE	1	GM-GC GC	0	3	0.08	20	30	25	30	5	10
221	43D	LUCKIAMUTE	2	GM GC	3	16	0.33	27	35	35	40	10	15
223	43F	LUCKIAMUTE	1	GM-GC GC	0	3	0.08	20	30	25	30	5	10
224	43F	LUCKIAMUTE	2	GM GC	3	16	0.33	27	35	35	40	10	15
226	44D	LURNICK	1	GM SM	0	9	0.23	18	22	25	30	0	5
227	44D	LURNICK	2	GM SM	9	30	0.53	38	50	50	60	15	20

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
183	36E	1.3	1.5	1.40	13.73	52	18.33	108	49.52	49.52	28.73	0
184	37D	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
185	37D	1.3	1.5	1.40	13.73	52	18.33	108	49.52	49.52	28.73	0
186	37E	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
187	37E	1.3	1.5	1.40	13.73	52	18.33	108	49.52	49.52	28.73	0
188	38E	1.1	1.3	1.20	11.77	40	15.30	-	-	-	-	-
189	38E	1.2	1.4	1.30	12.75	29	15.31	0	5.83	2.10	2.39	37
191	38F	1.1	1.3	1.20	11.77	40	15.30	-	-	-	-	-
192	38F	1.2	1.4	1.30	12.75	29	15.31	0	5.83	2.10	2.39	37
194	39F	1.1	1.3	1.20	11.77	40	15.30	-	-	-	-	-
195	39F	1.2	1.4	1.30	12.75	29	15.31	0	5.83	2.10	2.39	37
197	39F	1.2	1.4	1.30	12.75	37	16.02	-	-	-	-	-
198	39F	1.2	1.4	1.30	12.75	31	15.49	0	16.62	6.15	2.39	37
200	40D	1.15	1.3	1.23	12.02	52	16.61	-	-	-	-	-
201	40D	1.25	1.5	1.38	13.49	52	18.08	0	10.54	4.56	28.73	0
203	40E	1.15	1.3	1.23	12.02	52	16.61	-	-	-	-	-
204	40E	1.25	1.5	1.38	13.49	52	18.08	0	10.54	4.56	28.73	0
206	40F	1.15	1.3	1.23	12.02	52	16.61	-	-	-	-	-
207	40F	1.25	1.5	1.38	13.49	52	18.08	0	10.54	4.56	28.73	0
209	41D	1.2	1.4	1.30	12.75	37	16.02	-	-	-	-	-
210	41D	1.2	1.4	1.30	12.75	31	15.49	0	16.62	6.15	2.39	36
212	41E	1.2	1.4	1.30	12.75	37	16.02	-	-	-	-	-
213	41E	1.2	1.4	1.30	12.75	31	15.49	0	16.62	6.15	2.39	36
215	41F	1.2	1.4	1.30	12.75	37	16.02	-	-	-	-	-
216	41F	1.2	1.4	1.30	12.75	31	15.49	0	16.62	6.15	2.39	36
218	42B	1.1	1.3	1.20	11.77	45	15.75	-	-	-	-	-
219	42B	1.2	1.35	1.28	12.51	50	16.92	108	46.06	46.06	28.73	0
220	43D	1	1.2	1.10	10.79	31	13.53	-	-	-	-	-
221	43D	1.1	1.3	1.20	11.77	31	14.51	0	5.82	1.83	2.39	37
223	43F	1	1.2	1.10	10.79	31	13.53	-	-	-	-	-
224	43F	1.1	1.3	1.20	11.77	31	14.51	0	5.82	1.83	2.39	37
226	44D	1	1.2	1.10	10.79	32	13.62	-	-	-	-	-
227	44D	1.1	1.3	1.20	11.77	32	14.60	0	10.90	3.42	4.79	35

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
229	44E	LURNICK	1	GM SM	0	9	0.23	18	22	25	30	0	5
230	44E	LURNICK	2	GM SM	9	30	0.53	38	50	50	60	15	20
232	44F	LURNICK	1	GM SM	0	9	0.23	18	22	25	30	0	5
233	44F	LURNICK	2	GM SM	9	30	0.53	38	50	50	60	15	20
235	45	MALABON	1	ML	0	15	0.38	27	35	35	40	10	15
236	45	MALABON	2	CL	15	60	2.36	35	45	45	50	20	25
237	46	MALABON	1	ML CL	0	15	0.38	27	35	35	40	10	15
238	46	MALABON	2	CL	15	60	2.36	35	45	40	50	15	25
239	47D	MARTY	1	ML	0	13	0.33	18	27	40	50	0	10
240	47D	MARTY	2	ML	13	60	2.41	18	30	40	50	10	15
241	47E	MARTY	1	ML	0	13	0.33	18	27	40	50	0	10
242	47E	MARTY	2	ML	13	60	2.41	18	30	40	50	10	15
243	48A	MCALPIN	1	ML CL	0	25	0.64	30	40	35	40	10	15
244	48A	MCALPIN	2	CL	25	62	2.11	40	50	40	50	15	25
245	48B	MCALPIN	1	ML CL	0	25	0.64	30	40	35	40	10	15
246	48B	MCALPIN	2	CL	25	62	2.11	40	50	40	50	15	25
247	49	MCBEE	1	ML	0	12	0.30	27	35	35	40	10	15
248	49	MCBEE	2	ML CL	12	64	2.44	25	45	34	40	10	15
249	50D	MCDUFF	1	ML CL	0	11	0.28	27	35	35	40	10	15
250	50D	MCDUFF	2	MH	11	38	0.69	40	60	50	60	20	25
252	50E	MCDUFF	1	ML CL	0	11	0.28	27	35	35	40	10	15
253	50E	MCDUFF	2	MH	11	38	0.69	40	60	50	60	20	25
255	50F	MCDUFF	1	ML CL	0	11	0.28	27	35	35	40	10	15
256	50F	MCDUFF	2	MH	11	38	0.69	40	60	50	60	20	25
258	51D	MULKEY	1	MH	0	23	0.58	10	20	50	60	5	10
259	51D	MULKEY	2	MH SM	23	35	0.30	10	20	50	60	5	10
261	52C	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
262	52C	NEKIA	2	CL GC	9	25	0.69	40	50	40	50	15	25
264	52D	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
265	52D	NEKIA	2	CL GC	9	25	0.69	40	50	40	50	15	25
267	52E	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15
268	52E	NEKIA	2	CL GC	9	25	0.69	40	50	40	50	15	25
270	52F	NEKIA	1	ML	0	9	0.23	30	40	35	40	10	15

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
229	44E	1	1.2	1.10	10.79	32	13.62	-	-	-	-	-
230	44E	1.1	1.3	1.20	11.77	32	14.60	0	10.90	3.42	4.79	35
232	44F	1	1.2	1.10	10.79	32	13.62	-	-	-	-	-
233	44F	1.1	1.3	1.20	11.77	32	14.60	0	10.90	3.42	4.79	35
235	45	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
236	45	1.2	1.4	1.30	12.75	52	17.34	108	47.58	47.58	28.73	0
237	46	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
238	46	1.2	1.4	1.30	12.75	52	17.34	108	47.58	47.58	28.73	0
239	47D	0.85	1	0.93	9.07	45	13.05	-	-	-	-	-
240	47D	1.1	1.3	1.20	11.77	45	15.75	108	42.30	42.30	28.73	0
241	47E	0.85	1	0.93	9.07	45	13.05	-	-	-	-	-
242	47E	1.1	1.3	1.20	11.77	45	15.75	108	42.30	42.30	28.73	0
243	48A	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
244	48A	1.2	1.4	1.30	12.75	52	17.34	30	47.58	28.14	28.73	0
245	48B	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
246	48B	1.2	1.4	1.30	12.75	52	17.34	30	47.58	28.14	28.73	0
247	49	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
248	49	1.2	1.4	1.30	12.75	52	17.34	30	47.58	28.14	28.73	0
249	50D	0.95	1.1	1.03	10.06	52	14.65	-	-	-	-	-
250	50D	0.95	1.1	1.03	10.06	52	14.65	0	14.14	4.67	28.73	0
252	50E	0.95	1.1	1.03	10.06	52	14.65	-	-	-	-	-
253	50E	0.95	1.1	1.03	10.06	52	14.65	0	14.14	4.67	28.73	0
255	50F	0.95	1.1	1.03	10.06	52	14.65	-	-	-	-	-
256	50F	0.95	1.1	1.03	10.06	52	14.65	0	14.14	4.67	28.73	0
258	51D	0.5	0.85	0.68	6.62	45	10.59	-	-	-	-	-
259	51D	0.5	0.85	0.68	6.62	42	10.33	0	9.34	0.62	28.73	0
261	52C	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
262	52C	1.1	1.3	1.20	11.77	43	15.57	0	14.42	5.45	28.73	0
264	52D	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
265	52D	1.1	1.3	1.20	11.77	43	15.57	0	14.42	5.45	28.73	0
267	52E	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
268	52E	1.1	1.3	1.20	11.77	43	15.57	0	14.42	5.45	28.73	0
270	52F	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
271	52F	NEKIA	2	CL GC	9	25	0.69	40	50	40	50	15	25
273	53	NEWBERG	1	SM	0	15	0.38	7	15	20	25	0	5
274	53	NEWBERG	2	SM	15	26	0.28	5	15	20	25	0	5
275	53	NEWBERG	3	SM	26	60	2.08	2	10	-	-	0	0
276	54	NEWBERG	1	ML	0	15	0.38	7	15	30	35	0	5
277	54	NEWBERG	2	SM	15	37	0.56	5	15	20	25	0	5
278	54	NEWBERG	3	SM	37	60	1.80	2	10	-	-	0	0
279	55D	PEAVINE	1	ML MH	0	18	0.46	30	40	45	55	10	20
280	55D	PEAVINE	2	MH	18	30	0.30	45	60	60	85	25	45
282	55E	PEAVINE	1	ML MH	0	18	0.46	30	40	45	55	10	20
283	55E	PEAVINE	2	MH	18	30	0.30	45	60	60	85	25	45
285	55F	PEAVINE	1	ML MH	0	18	0.46	30	40	45	55	10	20
286	55F	PEAVINE	2	MH	18	30	0.30	45	60	60	85	25	45
288	56C	PHILOMATH	1	CH	0	4	0.10	40	55	50	60	35	45
289	56C	PHILOMATH	2	CH	4	14	0.25	40	60	60	80	40	50
291	57E	PHILOMATH	1	CH	0	4	0.10	40	55	50	60	35	45
292	57E	PHILOMATH	2	CH	4	14	0.25	40	60	60	80	40	50
294	58	PILCHUCK	1	ML	0	7	0.18	0	5	0	14	0	0
295	58	PILCHUCK	2	SM SP-SM	7	62	2.57	0	5	0	14	0	0
296	59	PITS	1	GP GW	0	6	0.15	0	1	0	14	0	0
297	59	PITS	2	GP GW SP SW	6	60	1.37	0	1	0	14	0	0
299	60C	RICKREALL	1	ML	0	5	0.13	27	35	40	45	10	15
300	60C	RICKREALL	2	MH	5	17	0.30	40	50	50	60	20	25
302	60D	RICKREALL	1	ML	0	5	0.13	27	35	40	45	10	15
303	60D	RICKREALL	2	MH	5	17	0.30	40	50	50	60	20	25
305	60E	RICKREALL	1	ML	0	5	0.13	27	35	40	45	10	15
306	60E	RICKREALL	2	MH	5	17	0.30	40	50	50	60	20	25
308	60F	RICKREALL	1	ML	0	5	0.13	27	35	40	45	10	15
309	60F	RICKREALL	2	MH	5	17	0.30	40	50	50	60	20	25
311	61C	RITNER	1	GC GM	0	14	0.36	30	40	35	40	10	15
312	61C	RITNER	2	CL GC	14	26	0.30	35	50	35	50	15	25
313	61C	RITNER	3	CL GC	26	38	0.30	35	50	40	50	15	25
315	61D	RITNER	1	GC GM	0	14	0.36	30	40	35	40	10	15

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
271	52F	1.1	1.3	1.20	11.77	43	15.57	0	14.42	5.45	28.73	0
273	53	1.2	1.4	1.30	12.75	35	15.84	-	-	-	-	-
274	53	1.2	1.4	1.30	12.75	35	15.84	-	-	-	-	-
275	53	1.2	1.4	1.30	12.75	35	15.84	108	43.46	43.46	2.39	34
276	54	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
277	54	1.2	1.4	1.30	12.75	35	15.84	-	-	-	-	-
278	54	1.2	1.4	1.30	12.75	35	15.84	108	43.80	43.80	2.39	34
279	55D	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
280	55D	1.1	1.3	1.20	11.77	52	16.36	0	12.47	4.99	28.73	0
282	55E	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
283	55E	1.1	1.3	1.20	11.77	52	16.36	0	12.47	4.99	28.73	0
285	55F	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
286	55F	1.1	1.3	1.20	11.77	52	16.36	0	12.47	4.99	28.73	0
288	56C	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
289	56C	1.3	1.4	1.35	13.24	52	17.83	0	6.34	2.85	22.50	0
291	57E	1.3	1.4	1.35	13.24	52	17.83	-	-	-	-	-
292	57E	1.3	1.4	1.35	13.24	52	17.83	0	6.34	2.85	22.50	0
294	58	1.5	1.6	1.55	15.21	45	19.18	-	-	-	-	-
295	58	1.5	1.6	1.55	15.21	35	18.30	36	50.35	32.41	2.39	36
296	59	-	-	1.40	13.73	29	16.29	-	-	-	-	-
297	59	-	-	1.45	14.22	29	16.78	0	25.51	10.56	2.39	38
299	60C	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
300	60C	1.2	1.3	1.25	12.26	52	16.85	0	7.28	3.04	28.73	0
302	60D	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
303	60D	1.2	1.3	1.25	12.26	52	16.85	0	7.28	3.04	28.73	0
305	60E	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
306	60E	1.2	1.3	1.25	12.26	52	16.85	0	7.28	3.04	28.73	0
308	60F	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
309	60F	1.2	1.3	1.25	12.26	52	16.85	0	7.28	3.04	28.73	0
311	61C	1.2	1.4	1.30	12.75	31	15.49	-	-	-	-	-
312	61C	1.3	1.5	1.40	13.73	43	17.53	-	-	-	-	-
313	61C	1.3	1.5	1.40	13.73	43	17.53	0	16.19	6.73	28.73	0
315	61D	1.2	1.4	1.30	12.75	31	15.49	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
316	61D	RITNER	2	CL GC	14	26	0.30	35	50	35	50	15	25
317	61D	RITNER	3	CL GC	26	38	0.30	35	50	40	50	15	25
319	61E	RITNER	1	GC GM	0	14	0.36	30	40	35	40	10	15
320	61E	RITNER	2	CL GC	14	26	0.30	35	50	35	50	15	25
321	61E	RITNER	3	CL GC	26	38	0.30	35	50	40	50	15	25
323	62	RIVERWASH	1	GP GW	0	6	0.15	0	1	0	14	0	0
324	62	RIVERWASH	2	GP SP GW SW	6	60	1.37	0	1	0	14	0	0
325	63	ROCK OUTCROP	1	-	0	60	1.52	0	0	0	14	-	-
326	64B	SALKUM	1	CL	0	12	0.30	27	35	40	45	15	20
327	64B	SALKUM	2	MH	12	37	0.64	40	55	50	65	15	25
328	64B	SALKUM	3	ML MH	37	60	0.58	35	50	45	60	15	25
329	64C	SALKUM	1	CL	0	12	0.30	27	35	40	45	15	20
330	64C	SALKUM	2	MH	12	37	0.64	40	55	50	65	15	25
331	64C	SALKUM	3	ML MH	37	60	0.58	35	50	45	60	15	25
332	65B	SANTIAM	1	ML	0	17	0.43	18	27	30	40	5	10
333	65B	SANTIAM	2	CL	17	34	0.43	35	45	30	50	10	30
334	65B	SANTIAM	3	CH	34	60	1.88	40	50	50	60	30	40
335	65C	SANTIAM	1	ML	0	17	0.43	18	27	30	40	5	10
336	65C	SANTIAM	2	CL	17	34	0.43	35	45	30	50	10	30
337	65C	SANTIAM	3	CH	34	60	1.88	40	50	50	60	30	40
338	65D	SANTIAM	1	ML	0	17	0.43	18	27	30	40	5	10
339	65D	SANTIAM	2	CL	17	34	0.43	35	45	30	50	10	30
340	65D	SANTIAM	3	CH	34	60	1.88	40	50	50	60	30	40
341	66D	SLICKROCK	1	ML SM OL GM	0	15	0.38	18	27	30	45	0	10
342	66D	SLICKROCK	2	ML SM	15	27	0.30	20	35	30	45	0	10
343	66D	SLICKROCK	3	SM ML	27	65	2.06	20	35	30	45	0	10
344	66E	SLICKROCK	1	ML SM OL GM	0	15	0.38	18	27	30	45	0	10
345	66E	SLICKROCK	2	ML SM	15	27	0.30	20	35	30	45	0	10
346	66E	SLICKROCK	3	SM ML	27	65	2.06	20	35	30	45	0	10
347	67C	STEIWER	1	ML	0	15	0.38	20	27	30	40	5	10
348	67C	STEIWER	2	ML	15	26	0.28	27	35	40	50	5	15
350	67D	STEIWER	1	ML	0	15	0.38	20	27	30	40	5	10
351	67D	STEIWER	2	ML	15	26	0.28	27	35	40	50	5	15

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
316	61D	1.3	1.5	1.40	13.73	43	17.53	-	-	-	-	-
317	61D	1.3	1.5	1.40	13.73	43	17.53	0	16.19	6.73	28.73	0
319	61E	1.2	1.4	1.30	12.75	31	15.49	-	-	-	-	-
320	61E	1.3	1.5	1.40	13.73	43	17.53	-	-	-	-	-
321	61E	1.3	1.5	1.40	13.73	43	17.53	0	16.19	6.73	28.73	0
323	62	-	-	1.40	13.73	29	16.29	-	-	-	-	-
324	62	-	-	1.45	14.22	29	16.78	0	25.51	10.56	2.39	38
325	63	-	-	-	-	-	-	-	-	-	-	-
326	64B	1	1.35	1.18	11.53	52	16.12	-	-	-	-	-
327	64B	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
328	64B	1	1.5	1.25	12.26	52	16.85	0	26.40	11.44	28.73	0
329	64C	1	1.35	1.18	11.53	52	16.12	-	-	-	-	-
330	64C	1.3	1.5	1.40	13.73	52	18.33	-	-	-	-	-
331	64C	1	1.5	1.25	12.26	52	16.85	0	26.40	11.44	28.73	0
332	65B	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
333	65B	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
334	65B	1.4	1.5	1.45	14.22	52	18.82	30	50.08	30.64	22.50	0
335	65C	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
336	65C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
337	65C	1.4	1.5	1.45	14.22	52	18.82	30	50.08	30.64	22.50	0
338	65D	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
339	65D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
340	65D	1.4	1.5	1.45	14.22	52	18.82	30	50.08	30.64	22.50	0
341	66D	0.75	0.85	0.80	7.85	43	11.64	-	-	-	-	-
342	66D	0.75	0.85	0.80	7.85	43	11.64	-	-	-	-	-
343	66D	1	1.3	1.15	11.28	40	14.81	108	38.46	38.46	2.39	33
344	66E	0.75	0.85	0.80	7.85	43	11.64	-	-	-	-	-
345	66E	0.75	0.85	0.80	7.85	43	11.64	-	-	-	-	-
346	66E	1	1.3	1.15	11.28	40	14.81	108	38.46	38.46	2.39	33
347	67C	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
348	67C	1.3	1.4	1.35	13.24	52	17.83	0	11.54	5.06	28.73	0
350	67D	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
351	67D	1.3	1.4	1.35	13.24	52	17.83	0	11.54	5.06	28.73	0

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High-(%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
353	67E	STEIWER	1	ML	0	15	0.38	20	27	30	40	5	10
354	67E	STEIWER	2	ML	15	26	0.28	27	35	40	50	5	15
356	68C	SUVER	1	CL	0	11	0.28	27	35	35	40	15	20
357	68C	SUVER	2	CH	11	42	0.79	40	50	55	75	30	45
359	68D	SUVER	1	CL	0	11	0.28	27	35	35	40	15	20
360	68D	SUVER	2	CH	11	42	0.79	40	50	55	75	30	45
362	68E	SUVER	1	CL	0	11	0.28	27	35	35	40	15	20
363	68E	SUVER	2	CH	11	42	0.79	40	50	55	75	30	45
365	69D	TRASK	1	SM GM	0	7	0.18	18	27	25	30	0	5
366	69D	TRASK	2	GM	7	31	0.61	20	30	25	30	0	5
368	69F	TRASK	1	SM GM	0	7	0.18	18	27	25	30	0	5
369	69F	TRASK	2	GM	7	31	0.61	20	30	25	30	0	5
371	70D	VALSETZ	1	SM MH	0	4	0.10	20	25	50	60	0	5
372	70D	VALSETZ	2	GM	4	24	0.51	20	30	40	60	0	10
374	70E	VALSETZ	1	SM MH	0	4	0.10	20	25	50	60	0	5
375	70E	VALSETZ	2	GM	4	24	0.51	20	30	40	60	0	10
377	70F	VALSETZ	1	SM MH	0	4	0.10	20	25	50	60	0	5
378	70F	VALSETZ	2	GM	4	24	0.51	20	30	40	60	0	10
380	71F	VALSETZ	1	SM MH	0	4	0.10	20	25	50	60	0	5
381	71F	VALSETZ	2	GM	4	24	0.51	20	30	40	60	0	10
383	71F	VALSETZ	1	GM SM MH	0	4	0.10	10	20	50	60	0	5
384	71F	VALSETZ	2	GM SM	4	18	0.36	5	15	40	60	0	10
386	72	WALDO	1	ML CL	0	13	0.33	27	40	35	40	10	15
387	72	WALDO	2	MH CH	13	60	2.41	40	55	50	60	20	30
388	73	WAPATO	1	ML	0	15	0.38	27	35	35	40	10	15
389	73	WAPATO	2	ML	15	60	2.36	20	35	30	40	5	15
390	74C	WILLAKENZIE	1	ML	0	13	0.33	27	30	35	45	5	10
391	74C	WILLAKENZIE	2	ML	13	33	0.51	30	35	35	45	10	15
393	74D	WILLAKENZIE	1	ML	0	13	0.33	27	30	35	45	5	10
394	74D	WILLAKENZIE	2	ML	13	33	0.51	30	35	35	45	10	15
396	74E	WILLAKENZIE	1	ML	0	13	0.33	27	30	35	45	5	10
397	74E	WILLAKENZIE	2	ML	13	33	0.51	30	35	35	45	10	15
399	74F	WILLAKENZIE	1	ML	0	13	0.33	27	30	35	45	5	10

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
353	67E	1.3	1.4	1.35	13.24	45	17.22	-	-	-	-	-
354	67E	1.3	1.4	1.35	13.24	52	17.83	0	11.54	5.06	28.73	0
356	68C	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
357	68C	1.25	1.4	1.33	13.00	52	17.59	18	18.56	12.58	22.50	0
359	68D	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
360	68D	1.25	1.4	1.33	13.00	52	17.59	18	18.56	12.58	22.50	0
362	68E	1.2	1.3	1.25	12.26	52	16.85	-	-	-	-	-
363	68E	1.25	1.4	1.33	13.00	52	17.59	18	18.56	12.58	22.50	0
365	69D	1.1	1.3	1.20	11.77	32	14.60	-	-	-	-	-
366	69D	1.1	1.3	1.20	11.77	29	14.33	0	11.33	3.61	2.39	38
368	69F	1.1	1.3	1.20	11.77	32	14.60	-	-	-	-	-
369	69F	1.1	1.3	1.20	11.77	29	14.33	0	11.33	3.61	2.39	38
371	70D	0.75	0.85	0.80	7.85	40	11.38	-	-	-	-	-
372	70D	0.75	0.85	0.80	7.85	29	10.41	0	6.44	0.46	2.39	37
374	70E	0.75	0.85	0.80	7.85	40	11.38	-	-	-	-	-
375	70E	0.75	0.85	0.80	7.85	29	10.41	0	6.44	0.46	2.39	37
377	70F	0.75	0.85	0.80	7.85	40	11.38	-	-	-	-	-
378	70F	0.75	0.85	0.80	7.85	29	10.41	0	6.44	0.46	2.39	37
380	71F	0.75	0.85	0.80	7.85	40	11.38	-	-	-	-	-
381	71F	0.75	0.85	0.80	7.85	29	10.41	0	6.44	0.46	2.39	37
383	71F	0.75	0.85	0.80	7.85	32	10.67	-	-	-	-	-
384	71F	0.75	0.85	0.80	7.85	32	10.67	0	4.88	0.39	2.39	37
386	72	1.1	1.3	1.20	11.77	52	16.36	-	-	-	-	-
387	72	1.1	1.3	1.20	11.77	52	16.36	3	44.89	18.72	28.73	0
388	73	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
389	73	1.2	1.4	1.30	12.75	45	16.73	6	46.12	20.70	28.73	0
390	74C	1.15	1.25	1.20	11.77	45	15.75	-	-	-	-	-
391	74C	1.15	1.3	1.23	12.02	52	16.61	0	13.64	5.41	28.73	0
393	74D	1.15	1.25	1.20	11.77	45	15.75	-	-	-	-	-
394	74D	1.15	1.3	1.23	12.02	52	16.61	0	13.64	5.41	28.73	0
396	74E	1.15	1.25	1.20	11.77	45	15.75	-	-	-	-	-
397	74E	1.15	1.3	1.23	12.02	52	16.61	0	13.64	5.41	28.73	0
399	74F	1.15	1.25	1.20	11.77	45	15.75	-	-	-	-	-

APPENDIX B. MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Unit Name	Layer Number	USCS	Layer Depth-Low (in)	Layer Depth-High (in)	Max Thickness (m)	Clay Content-Low (%)	Clay Content-High (%)	Liquid Limit-Low (%)	Liquid Limit High- (%)	Plasticity Index-Low	Plasticity Index-High
Polk County													
400	74F	WILLAKENZIE	2	ML	13	33	0.51	30	35	35	45	10	15
402	75A	WILLAMETTE	1	ML	0	26	0.66	20	27	35	40	5	10
403	75A	WILLAMETTE	2	CL	26	52	0.66	25	35	40	50	15	25
404	75A	WILLAMETTE	3	ML	52	69	1.42	20	30	35	40	10	15
405	75C	WILLAMETTE	1	ML	0	26	0.66	20	27	35	40	5	10
406	75C	WILLAMETTE	2	CL	26	52	0.66	25	35	40	50	15	25
407	75C	WILLAMETTE	3	ML	52	69	1.42	20	30	35	40	10	15
408	75D	WILLAMETTE	1	ML	0	26	0.66	20	27	35	40	5	10
409	75D	WILLAMETTE	2	CL	26	52	0.66	25	35	40	50	15	25
410	75D	WILLAMETTE	3	ML	52	69	1.42	20	30	35	40	10	15
411	76C	WITZEL	1	GM	0	4	0.10	18	25	25	30	0	5
412	76C	WITZEL	2	GC	4	17	0.38	25	35	35	40	15	20
414	76E	WITZEL	1	GM	0	4	0.10	18	25	25	30	0	5
415	76E	WITZEL	2	GC	4	17	0.38	25	35	35	40	15	20
417	77A	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
418	77A	WOODBURN	2	CL	17	65	1.22	20	35	30	40	10	20
419	77A	WOODBURN	3	ML CL-ML	65	69	1.09	15	30	25	35	5	10
420	77C	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
421	77C	WOODBURN	2	CL	17	42	0.64	20	35	30	40	10	20
422	77C	WOODBURN	3	ML CL-ML	42	65	1.68	15	30	25	35	5	10
423	77D	WOODBURN	1	ML	0	17	0.43	10	20	25	30	0	5
424	77D	WOODBURN	2	CL	17	42	0.64	20	35	30	40	10	20
425	77D	WOODBURN	3	ML CL-ML	42	65	1.68	15	30	25	35	5	10
426	78	XEROCHREPTS	1	CL-ML ML	0	12	0.30	18	27	25	35	5	10
427	78	XEROCHREPTS	2	CL-ML SC-SM	12	61	1.24	20	30	25	35	5	10
428	78	XEROCHREPTS	1	ML CL	0	15	0.38	15	35	25	40	0	15
429	78	XEROCHREPTS	2	ML SM SC CL	15	60	1.14	15	35	30	40	5	15
430	79	XEROFLUVENTS	1	-	0	5	0.13	-	-	0	14	-	-
431	79	XEROFLUVENTS	2	-	5	60	1.40	-	-	0	14	-	-
432	80D	YELLOWSTONE	1	GM SM MH	0	4	0.10	10	20	50	60	0	5
433	80D	YELLOWSTONE	2	GM SM	4	18	0.36	5	15	40	60	0	10
435	80F	YELLOWSTONE	1	GM SM MH	0	4	0.10	10	20	50	60	0	5
436	80F	YELLOWSTONE	2	GM SM	4	18	0.36	5	15	40	60	0	10

APPENDIX B: MARION AND POLK COUNTY SOIL UNIT PROPERTIES

County ID	Unit ID	Moist Bulk Density-- Low (kg/m³)	Moist Bulk Density-- High (kg/m³)	Dry Bulk Density (kg/m³)	Dry Unit Weight (S = 90%) (kN/m³)	Porosity (%)	Total Unit Weight (kN/m³)	Depth to Water Table (in)	Total Normal Stress (kPa)	Effective Normal Stress (kPa)	Cohesion (kPa)	Angle of Internal Friction (degrees)
Polk County												
400	74F	1.15	1.3	1.23	12.02	52	16.61	0	13.64	5.41	28.73	0
402	75A	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
403	75A	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
404	75A	1.2	1.4	1.30	12.75	45	16.73	108	46.29	46.29	28.73	0
405	75C	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
406	75C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
407	75C	1.2	1.4	1.30	12.75	45	16.73	108	46.29	46.29	28.73	0
408	75D	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
409	75D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
410	75D	1.2	1.4	1.30	12.75	45	16.73	108	46.29	46.29	28.73	0
411	76C	1.35	1.5	1.43	13.98	29	16.54	-	-	-	-	-
412	76C	1.3	1.4	1.35	13.24	31	15.98	0	7.77	3.03	2.39	35
414	76E	1.35	1.5	1.43	13.98	29	16.54	-	-	-	-	-
415	76E	1.3	1.4	1.35	13.24	31	15.98	0	7.77	3.03	2.39	35
417	77A	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
418	77A	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
419	77A	1.3	1.5	1.40	13.73	50	18.15	30	48.19	28.75	28.73	0
420	77C	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
421	77C	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
422	77C	1.3	1.5	1.40	13.73	50	18.15	30	48.66	29.22	28.73	0
423	77D	1.2	1.4	1.30	12.75	45	16.73	-	-	-	-	-
424	77D	1.2	1.4	1.30	12.75	52	17.34	-	-	-	-	-
425	77D	1.3	1.5	1.40	13.73	50	18.15	30	48.66	29.22	28.73	0
426	78	1.1	1.4	1.25	12.26	50	16.68	-	-	-	-	-
427	78	1.1	1.4	1.25	12.26	48	16.50	0	25.62	10.42	28.73	0
428	78	1.1	1.6	1.35	13.24	50	17.66	-	-	-	-	-
429	78	1.1	1.6	1.35	13.24	43	17.04	0	26.20	11.25	28.73	0
430	79	-	-	1.30	12.75	45	12.75	-	-	-	-	-
431	79	-	-	1.30	12.75	45	12.75	0	19.44	4.49	28.73	0
432	80D	0.75	0.85	0.80	7.85	32	10.67	-	-	-	-	-
433	80D	0.75	0.85	0.80	7.85	32	10.67	0	4.88	0.39	2.39	37
435	80F	0.75	0.85	0.80	7.85	32	10.67	-	-	-	-	-
436	80F	0.75	0.85	0.80	7.85	32	10.67	0	4.88	0.39	2.39	37

Appendix C. Simplified Newmark Results Using a Uniform Slope Angle of 22.5° (sorted by Factor of Safety)[1]

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
23D	CRUISER	2.394	37	13.09	2.62	0.84	-0.06	338.86
23E	CRUISER	2.394	37	13.09	2.62	0.84	-0.06	338.86
23F	CRUISER	2.394	37	13.09	2.62	0.84	-0.06	338.86
Cu	COURTNEY	2.394	38	44.70	18.54	0.92	-0.03	212.68
Ck	CLACKAMAS	2.394	35	45.17	21.00	0.92	-0.03	210.04
10D	BOHANNON	2.394	33	11.31	2.84	0.95	-0.02	184.63
10E	BOHANNON	2.394	33	11.31	2.84	0.95	-0.02	184.63
10F	BOHANNON	2.394	33	11.31	2.84	0.95	-0.02	184.63
59	PITS	2.394	38	25.51	10.56	1.03	0.01	115.96
62	RIVERWASH	2.394	38	25.51	10.56	1.03	0.01	115.96
41D	KLICKITAT	2.394	36	16.62	6.15	1.03	0.01	115.92
41E	KLICKITAT	2.394	36	16.62	6.15	1.03	0.01	115.92
41F	KLICKITAT	2.394	36	16.62	6.15	1.03	0.01	115.92
39F	KILCHIS	2.394	37	16.62	6.15	1.05	0.02	100.64
70D	VALSETZ	2.394	37	6.44	0.46	1.10	0.04	74.39
70E	VALSETZ	2.394	37	6.44	0.46	1.10	0.04	74.39
70F	VALSETZ	2.394	37	6.44	0.46	1.10	0.04	74.39
71F	VALSETZ	2.394	37	6.44	0.46	1.10	0.04	74.39
HRD	HOREB	2.394	36	41.38	23.19	1.13	0.05	61.51
69D	TRASK	2.394	38	11.33	3.61	1.15	0.06	55.24
69F	TRASK	2.394	38	11.33	3.61	1.15	0.06	55.24
SnA	SANTIAM	22.5036	0	50.29	27.12	1.17	0.06	50.07
SnB	SANTIAM	22.5036	0	50.29	27.12	1.17	0.06	50.07
SnC	SANTIAM	22.5036	0	50.29	27.12	1.17	0.06	50.07
65B	SANTIAM	22.5036	0	50.08	30.64	1.17	0.07	48.64
65C	SANTIAM	22.5036	0	50.08	30.64	1.17	0.07	48.64
65D	SANTIAM	22.5036	0	50.08	30.64	1.17	0.07	48.64
28	GRANDE RONDE	22.5036	0	48.75	27.07	1.21	0.08	40.34
33	HOLCOMB	22.5036	0	48.61	25.44	1.21	0.08	39.55
25	DAYTON	22.5036	0	48.09	24.17	1.22	0.09	36.64
30C	HELMICK	22.5036	0	47.62	25.19	1.23	0.09	34.12
30D	HELMICK	22.5036	0	47.62	25.19	1.23	0.09	34.12
30E	HELMICK	22.5036	0	47.62	25.19	1.23	0.09	34.12
6C	BASHAW	22.5036	0	47.51	21.35	1.24	0.09	33.55
58	PILCHUCK	2.394	36	50.35	32.41	1.25	0.10	30.64
22	COVE	22.5036	0	46.47	21.05	1.27	0.10	28.53
21	COVE	22.5036	0	46.33	20.92	1.27	0.10	27.91
MUE	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
MUF	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
MUG	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
McB	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
McC	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
McD	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
McE	MCCULLY	22.5036	0	46.23	46.23	1.27	0.10	27.47
Wa	WALDO	22.5036	0	44.89	18.72	1.31	0.12	21.97

[1] Unit names and symbols correspond to Williams (1972) and Knezevich (1982). Please refer to the Soil Slide Analysis section for equations and conditions assumed. This is a comprehensive list of units; not all are located within the study area.

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
Ba	BASHAW	22.5036	0	44.89	18.72	1.31	0.12	21.97
6A	BASHAW	22.5036	0	44.89	18.72	1.31	0.12	21.97
7	BASHAW	22.5036	0	44.89	18.72	1.31	0.12	21.97
71F	VALSETZ	2.394	37	4.88	0.39	1.43	0.16	10.95
80D	YELLOWSTONE	2.394	37	4.88	0.39	1.43	0.16	10.95
80F	YELLOWSTONE	2.394	37	4.88	0.39	1.43	0.16	10.95
76C	WITZEL	2.394	35	7.77	3.03	1.47	0.18	8.84
76E	WITZEL	2.394	35	7.77	3.03	1.47	0.18	8.84
Co	CONCORD	28.728	0	51.14	24.97	1.47	0.18	8.72
20	CONCORD	28.728	0	51.05	24.89	1.47	0.18	8.60
JoB	JORY	28.728	0	49.71	49.71	1.51	0.20	6.81
JoC	JORY	28.728	0	49.71	49.71	1.51	0.20	6.81
JoD	JORY	28.728	0	49.71	49.71	1.51	0.20	6.81
JoE	JORY	28.728	0	49.71	49.71	1.51	0.20	6.81
36C	JORY	28.728	0	49.52	49.52	1.52	0.20	6.59
36D	JORY	28.728	0	49.52	49.52	1.52	0.20	6.59
36E	JORY	28.728	0	49.52	49.52	1.52	0.20	6.59
37D	JORY	28.728	0	49.52	49.52	1.52	0.20	6.59
37E	JORY	28.728	0	49.52	49.52	1.52	0.20	6.59
2	ABIQUA	28.728	0	49.33	49.33	1.52	0.20	6.37
35C	JORY	28.728	0	49.21	49.21	1.53	0.20	6.22
35D	JORY	28.728	0	49.21	49.21	1.53	0.20	6.22
35E	JORY	28.728	0	49.21	49.21	1.53	0.20	6.22
WlA	WILLAMETTE	28.728	0	48.86	48.86	1.54	0.21	5.85
WuA	WOODBURN	28.728	0	48.86	48.86	1.54	0.21	5.85
WuC	WOODBURN	28.728	0	48.86	48.86	1.54	0.21	5.85
WuD	WOODBURN	28.728	0	48.86	48.86	1.54	0.21	5.85
24D	CUMLEY	28.728	0	48.84	29.40	1.54	0.21	5.82
CLD	CUMLEY	28.728	0	48.81	30.12	1.54	0.21	5.79
77C	WOODBURN	28.728	0	48.66	29.22	1.54	0.21	5.63
77D	WOODBURN	28.728	0	48.66	29.22	1.54	0.21	5.63
Ho	HOLCOMB	28.728	0	48.63	24.46	1.54	0.21	5.60
Ch	CHEHALIS	28.728	0	48.53	48.53	1.55	0.21	5.50
14	CHEHALIS	28.728	0	48.25	48.25	1.56	0.21	5.21
77A	WOODBURN	28.728	0	48.19	28.75	1.56	0.21	5.15
48A	MCALPIN	28.728	0	47.58	28.14	1.58	0.22	4.58
48B	MCALPIN	28.728	0	47.58	28.14	1.58	0.22	4.58
49	MCBEE	28.728	0	47.58	28.14	1.58	0.22	4.58
MaA	MCALPIN	28.728	0	47.58	26.40	1.58	0.22	4.58
MaB	MCALPIN	28.728	0	47.58	26.40	1.58	0.22	4.58
18	COBURG	28.728	0	47.58	26.65	1.58	0.22	4.58
Mb	MCBEE	28.728	0	47.58	27.40	1.58	0.22	4.58
34D	HONEYGROVE	28.728	0	47.58	47.58	1.58	0.22	4.58
34E	HONEYGROVE	28.728	0	47.58	47.58	1.58	0.22	4.58
34F	HONEYGROVE	28.728	0	47.58	47.58	1.58	0.22	4.58
45	MALABON	28.728	0	47.58	47.58	1.58	0.22	4.58
46	MALABON	28.728	0	47.58	47.58	1.58	0.22	4.58

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
Da	DAYTON	28.728	0	47.54	21.38	1.58	0.22	4.55
19	COBURG	28.728	0	47.39	26.46	1.58	0.22	4.42
3	AMITY	28.728	0	47.34	23.42	1.59	0.22	4.38
CeC	CHEHALEM	28.728	0	47.33	23.16	1.59	0.22	4.37
27C	DUPEE	28.728	0	47.21	24.79	1.59	0.23	4.27
27D	DUPEE	28.728	0	47.21	24.79	1.59	0.23	4.27
MlD	MCCULLY	28.728	0	47.20	47.20	1.59	0.23	4.26
MmE	MCCULLY	28.728	0	47.06	47.06	1.60	0.23	4.14
31C	HELVETIA	28.728	0	46.97	33.51	1.60	0.23	4.07
31D	HELVETIA	28.728	0	46.97	33.51	1.60	0.23	4.07
AbA	ABIQUA	28.728	0	46.91	46.91	1.60	0.23	4.02
AbB	ABIQUA	28.728	0	46.91	46.91	1.60	0.23	4.02
La	LABISH	28.728	0	46.73	21.81	1.61	0.23	3.88
Am	AMITY	28.728	0	46.68	21.76	1.61	0.23	3.84
SkB	SALKUM	28.728	0	46.61	46.61	1.61	0.23	3.78
SkD	SALKUM	28.728	0	46.61	46.61	1.61	0.23	3.78
SlB	SALKUM	28.728	0	46.61	46.61	1.61	0.23	3.78
WlA	WILLAMETTE	28.728	0	46.35	46.35	1.62	0.24	3.59
WlC	WILLAMETTE	28.728	0	46.35	46.35	1.62	0.24	3.59
75A	WILLAMETTE	28.728	0	46.29	46.29	1.62	0.24	3.55
75C	WILLAMETTE	28.728	0	46.29	46.29	1.62	0.24	3.55
75D	WILLAMETTE	28.728	0	46.29	46.29	1.62	0.24	3.55
1A	ABIQUA	28.728	0	46.23	46.23	1.62	0.24	3.50
1B	ABIQUA	28.728	0	46.23	46.23	1.62	0.24	3.50
Wc	WAPATO	28.728	0	46.13	19.97	1.63	0.24	3.43
73	WAPATO	28.728	0	46.12	20.70	1.63	0.24	3.42
42B	KNAPPA	28.728	0	46.06	46.06	1.63	0.24	3.38
43F	LUCKIAMUTE	2.394	37	5.82	1.83	1.65	0.25	3.04
43D	LUCKIAMUTE	2.394	37	5.82	1.83	1.65	0.25	3.04
72	WALDO	28.728	0	44.89	18.72	1.67	0.26	2.64
MYB	MINNIECE	28.728	0	44.89	18.72	1.67	0.26	2.64
44D	LURNICK	4.788	35	10.90	3.42	1.68	0.26	2.54
44E	LURNICK	4.788	35	10.90	3.42	1.68	0.26	2.54
44F	LURNICK	4.788	35	10.90	3.42	1.68	0.26	2.54
9D	BLACHLY	28.728	0	44.70	44.70	1.68	0.26	2.53
9E	BLACHLY	28.728	0	44.70	44.70	1.68	0.26	2.53
11	BRENNER	28.728	0	44.30	18.89	1.69	0.27	2.32
38E	KILCHIS	2.394	37	5.83	2.10	1.73	0.28	1.93
38F	KILCHIS	2.394	37	5.83	2.10	1.73	0.28	1.93
39F	KILCHIS	2.394	37	5.83	2.10	1.73	0.28	1.93
66D	SLICKROCK	2.394	33	38.46	38.46	1.73	0.28	1.88
66E	SLICKROCK	2.394	33	38.46	38.46	1.73	0.28	1.88
JoB	JORY	28.728	0	42.89	42.89	1.75	0.29	1.67
54	NEWBERG	2.394	34	43.80	43.80	1.77	0.30	1.48
Nw	NEWBERG	2.394	34	43.69	43.69	1.77	0.30	1.47
Nu	NEWBERG	2.394	34	43.46	43.46	1.77	0.30	1.47
53	NEWBERG	2.394	34	43.46	43.46	1.77	0.30	1.47

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
47D	MARTY	28.728	0	42.30	42.30	1.77	0.30	1.45
47E	MARTY	28.728	0	42.30	42.30	1.77	0.30	1.45
Cm	CLOQUATO	2.394	35	46.85	46.85	1.82	0.32	1.09
Ad	ALLUVIAL LAND	2.394	35	46.43	46.43	1.83	0.32	1.08
17	CLOQUATO	2.394	35	46.31	46.31	1.83	0.32	1.08
12A	BRIEDWELL	2.394	35	41.52	41.52	1.84	0.32	0.98
12C	BRIEDWELL	2.394	35	41.52	41.52	1.84	0.32	0.98
12D	BRIEDWELL	2.394	35	41.52	41.52	1.84	0.32	0.98
5D	ASTORIA	28.728	0	39.73	39.73	1.89	0.34	0.74
5E	ASTORIA	28.728	0	39.73	39.73	1.89	0.34	0.74
Te	TERRACE ESCARPMENTS	2.394	36	43.76	43.76	1.90	0.34	0.71
13	CAMAS	2.394	37	47.17	47.17	1.95	0.36	0.51
Ca	CAMAS	2.394	37	47.23	47.23	1.95	0.36	0.51
Sa	SALEM	2.394	37	46.21	46.21	1.95	0.37	0.51
Sy	STONY ROCK LAND	2.394	38	61.52	61.52	1.99	0.38	0.42
HSC	HOREB	2.394	38	42.36	42.36	2.03	0.40	0.32
HSE	HOREB	2.394	38	42.36	42.36	2.03	0.40	0.32
St	SIFTON	2.394	38	37.63	37.63	2.05	0.40	0.29
4D	APT	28.728	0	32.42	12.98	2.32	0.50	0.06
4E	APT	28.728	0	32.42	12.98	2.32	0.50	0.06
WHE	WHETSTONE	2.394	38	14.12	14.12	2.33	0.51	0.06
WHF	WHETSTONE	2.394	38	14.12	14.12	2.33	0.51	0.06
WHG	WHETSTONE	2.394	38	14.12	14.12	2.33	0.51	0.06
HEE	HENLINE	2.394	38	11.67	11.67	2.42	0.54	0.03
HEF	HENLINE	2.394	38	11.67	11.67	2.42	0.54	0.03
HEG	HENLINE	2.394	38	11.67	11.67	2.42	0.54	0.03
WHG	WHETSTONE	2.394	38	11.67	11.67	2.42	0.54	0.03
NsE	NEKIA	2.394	35	7.80	7.80	2.49	0.57	0.02
WtE	WITZEL	2.394	35	7.77	7.77	2.50	0.57	0.02
So	SEMIAHMOO	28.728	0	28.74	3.57	2.61	0.62	0.01
64B	SALKUM	28.728	0	26.40	11.44	2.84	0.71	0.00
64C	SALKUM	28.728	0	26.40	11.44	2.84	0.71	0.00
78	XEROCHREPTS	28.728	0	26.20	11.25	2.86	0.71	0.00
78	XEROCHREPTS	28.728	0	25.62	10.42	2.93	0.74	0.00
68C	SUVER	22.5036	0	18.56	12.58	3.17	0.83	0.00
68D	SUVER	22.5036	0	18.56	12.58	3.17	0.83	0.00
68E	SUVER	22.5036	0	18.56	12.58	3.17	0.83	0.00
26C	DIXONVILLE	22.5036	0	18.44	8.72	3.19	0.84	0.00
26D	DIXONVILLE	22.5036	0	18.44	8.72	3.19	0.84	0.00
HTD	HULLT	28.728	0	22.86	22.86	3.28	0.87	0.00
HTE	HULLT	28.728	0	22.86	22.86	3.28	0.87	0.00
HTF	HULLT	28.728	0	22.86	22.86	3.28	0.87	0.00
HuB	HULLT	28.728	0	22.86	22.86	3.28	0.87	0.00
HuD	HULLT	28.728	0	22.86	22.86	3.28	0.87	0.00
SuC	SILVERTON	22.5036	0	16.68	16.68	3.53	0.97	0.00
SuD	SILVERTON	22.5036	0	16.68	16.68	3.53	0.97	0.00
32D	HEMBRE	28.728	0	20.18	6.73	3.72	1.04	0.00

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
32E	HEMBRE	28.728	0	20.18	6.73	3.72	1.04	0.00
32F	HEMBRE	28.728	0	20.18	6.73	3.72	1.04	0.00
HaB	HAZELAIR	22.5036	0	15.54	10.56	3.78	1.07	0.00
HaD	HAZELAIR	22.5036	0	15.54	10.56	3.78	1.07	0.00
HcD2	HAZELAIR	22.5036	0	15.54	10.56	3.78	1.07	0.00
29C	HAZELAIR	22.5036	0	15.39	10.41	3.82	1.08	0.00
29D	HAZELAIR	22.5036	0	15.39	10.41	3.82	1.08	0.00
29E	HAZELAIR	22.5036	0	15.39	10.41	3.82	1.08	0.00
79	XEROFLUVENTS	28.728	0	19.44	4.49	3.86	1.10	0.00
KCD	KINNEY	28.728	0	18.84	18.84	3.98	1.14	0.00
KCF	KINNEY	28.728	0	18.84	18.84	3.98	1.14	0.00
KCG	KINNEY	28.728	0	18.84	18.84	3.98	1.14	0.00
61C	RITNER	28.728	0	16.19	6.73	4.64	1.39	0.00
61D	RITNER	28.728	0	16.19	6.73	4.64	1.39	0.00
61E	RITNER	28.728	0	16.19	6.73	4.64	1.39	0.00
NkC	NEKIA	28.728	0	15.88	15.88	4.73	1.43	0.00
NsE	NEKIA	28.728	0	15.88	15.88	4.73	1.43	0.00
NsF	NEKIA	28.728	0	15.88	15.88	4.73	1.43	0.00
52C	NEKIA	28.728	0	14.42	5.45	5.21	1.61	0.00
52D	NEKIA	28.728	0	14.42	5.45	5.21	1.61	0.00
52E	NEKIA	28.728	0	14.42	5.45	5.21	1.61	0.00
52F	NEKIA	28.728	0	14.42	5.45	5.21	1.61	0.00
NeB	NEKIA	28.728	0	14.42	14.42	5.21	1.61	0.00
NeC	NEKIA	28.728	0	14.42	14.42	5.21	1.61	0.00
NeD	NEKIA	28.728	0	14.42	14.42	5.21	1.61	0.00
NeE	NEKIA	28.728	0	14.42	14.42	5.21	1.61	0.00
NeF	NEKIA	28.728	0	14.42	14.42	5.21	1.61	0.00
SCE	STEIWER	28.728	0	14.17	14.17	5.30	1.65	0.00
SwB	STEIWER	28.728	0	14.17	14.17	5.30	1.65	0.00
SwD	STEIWER	28.728	0	14.17	14.17	5.30	1.65	0.00
50D	MCDUFF	28.728	0	14.14	4.67	5.31	1.65	0.00
50E	MCDUFF	28.728	0	14.14	4.67	5.31	1.65	0.00
50F	MCDUFF	28.728	0	14.14	4.67	5.31	1.65	0.00
8C	BELLPINE	28.728	0	13.81	5.84	5.44	1.70	0.00
8D	BELLPINE	28.728	0	13.81	5.84	5.44	1.70	0.00
8E	BELLPINE	28.728	0	13.81	5.84	5.44	1.70	0.00
8F	BELLPINE	28.728	0	13.81	5.84	5.44	1.70	0.00
8G	BELLPINE	28.728	0	13.81	5.84	5.44	1.70	0.00
74C	WILLAKENZIE	28.728	0	13.64	5.41	5.51	1.72	0.00
74D	WILLAKENZIE	28.728	0	13.64	5.41	5.51	1.72	0.00
74E	WILLAKENZIE	28.728	0	13.64	5.41	5.51	1.72	0.00
74F	WILLAKENZIE	28.728	0	13.64	5.41	5.51	1.72	0.00
55D	PEAVINE	28.728	0	12.47	4.99	6.02	1.92	0.00
55E	PEAVINE	28.728	0	12.47	4.99	6.02	1.92	0.00
55F	PEAVINE	28.728	0	12.47	4.99	6.02	1.92	0.00
16E	CHEHULPUM	28.728	0	11.54	5.06	6.50	2.11	0.00
67C	STEIWER	28.728	0	11.54	5.06	6.50	2.11	0.00

Unit ID	Unit name	Cohesion	Angle of internal Friction	Total normal stress	Effective normal stress	Factor of Safety	Critical Acceleration (a_c)	Newmark Displacement (D_N) for 22.5° Slopes
67D	STEIWER	28.728	0	11.54	5.06	6.50	2.11	0.00
67E	STEIWER	28.728	0	11.54	5.06	6.50	2.11	0.00
40D	KILOWAN	28.728	0	10.54	4.56	7.13	2.34	0.00
40E	KILOWAN	28.728	0	10.54	4.56	7.13	2.34	0.00
40F	KILOWAN	28.728	0	10.54	4.56	7.13	2.34	0.00
51D	MULKEY	28.728	0	9.34	0.62	8.04	2.69	0.00
56C	PHILOMATH	22.5036	0	6.34	2.85	9.27	3.17	0.00
57E	PHILOMATH	22.5036	0	6.34	2.85	9.27	3.17	0.00
60C	RICKREALL	28.728	0	7.28	3.04	10.32	3.56	0.00
60D	RICKREALL	28.728	0	7.28	3.04	10.32	3.56	0.00
60E	RICKREALL	28.728	0	7.28	3.04	10.32	3.56	0.00
60F	RICKREALL	28.728	0	7.28	3.04	10.32	3.56	0.00
15C	CHEHULPUM	28.728	0	7.00	3.01	10.73	3.72	0.00
15E	CHEHULPUM	28.728	0	7.00	3.01	10.73	3.72	0.00
16E	CHEHULPUM	28.728	0	7.00	3.01	10.73	3.72	0.00
SvB	STAYTON	28.728	0	5.59	5.59	13.44	4.76	0.00
SCE	STEIWER	28.728	0	5.25	5.25	14.31	5.09	0.00