OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
INTERPRETIVE MAP SERIES 24

GEOLOGIC HAZARDS, EARTHQUAKE AND LANDSLIDE HAZARD MAPS, AND FUTURE EARTHQUAKE DAMAGE ESTIMATES FOR SIX COUNTIES IN THE MID/SOUTHERN WILLAMETTE VALLEY INCLUDING YAMHILL, MARION, POLK, BENTON, LINN, AND LANE COUNTIES AND THE CITY OF ALBANY, OREGON

APPENDIX H: PROCEDURE USED TO DEVELOP RELATIVE GROUND-SHAKING AMPLIFICATION SUSCEPTIBILITY MAP, RELATIVE LIQUEFACTION HAZARD SUSCEPTIBILITY MAP, RELATIVE EARTHQUAKE-INDUCED LANDSLIDE SUSCEPTIBILITY MAP, IDENTIFIED LANDSLIDE AREAS MAP, AND REFERENCE MAP

SURFACE GEOLOGIC COMPILATION

The following steps were used to develop the relative ground-shaking amplification, liquefaction, and earthquake-induced landslide susceptibility hazard layers for Yamhill, Marion, Polk, Linn, and Lane Counties, and the City of Albany.

We combined available digital GIS data from previous surface geology studies. The base geologic layer consisted of the USGS Willamette Valley Compilation (O'Connor and others, 2001) and the USGS digital, 1:500,000 scale geologic map or the State of Oregon (Walker and others, 2002).

To improve the base geologic map, we digitized numerous geologic maps and/or incorporated existing GIS data into the base map through "heads-up" digitization. A geographic reference to these previous studies is included in this appendix (Figures H1–H4), and the maps used are listed as full references (Table H1).

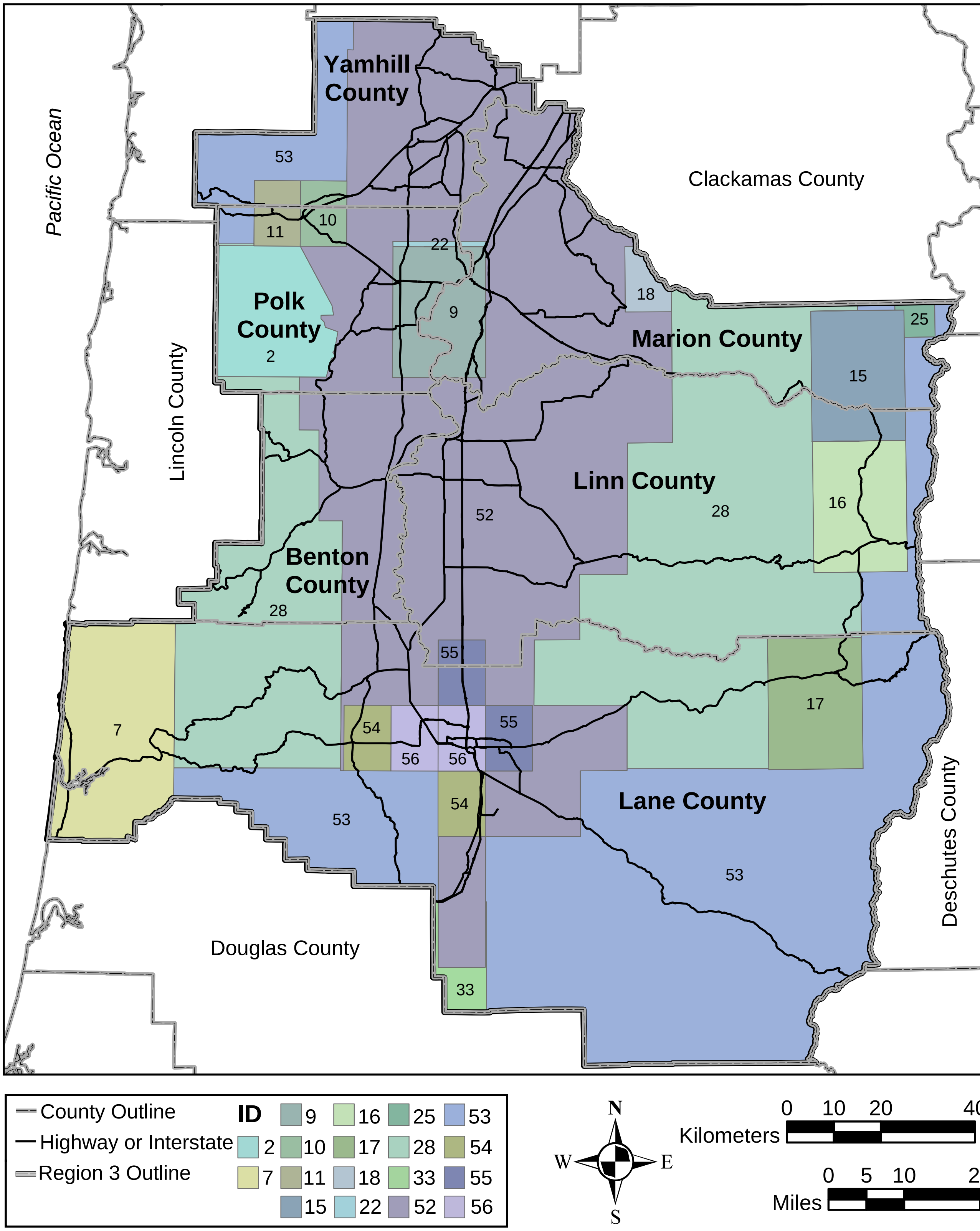

Figure H1. Map of references and extent of references used to compile the base geologic map. Number (reference ID) corresponds to the map reference in Table H1.

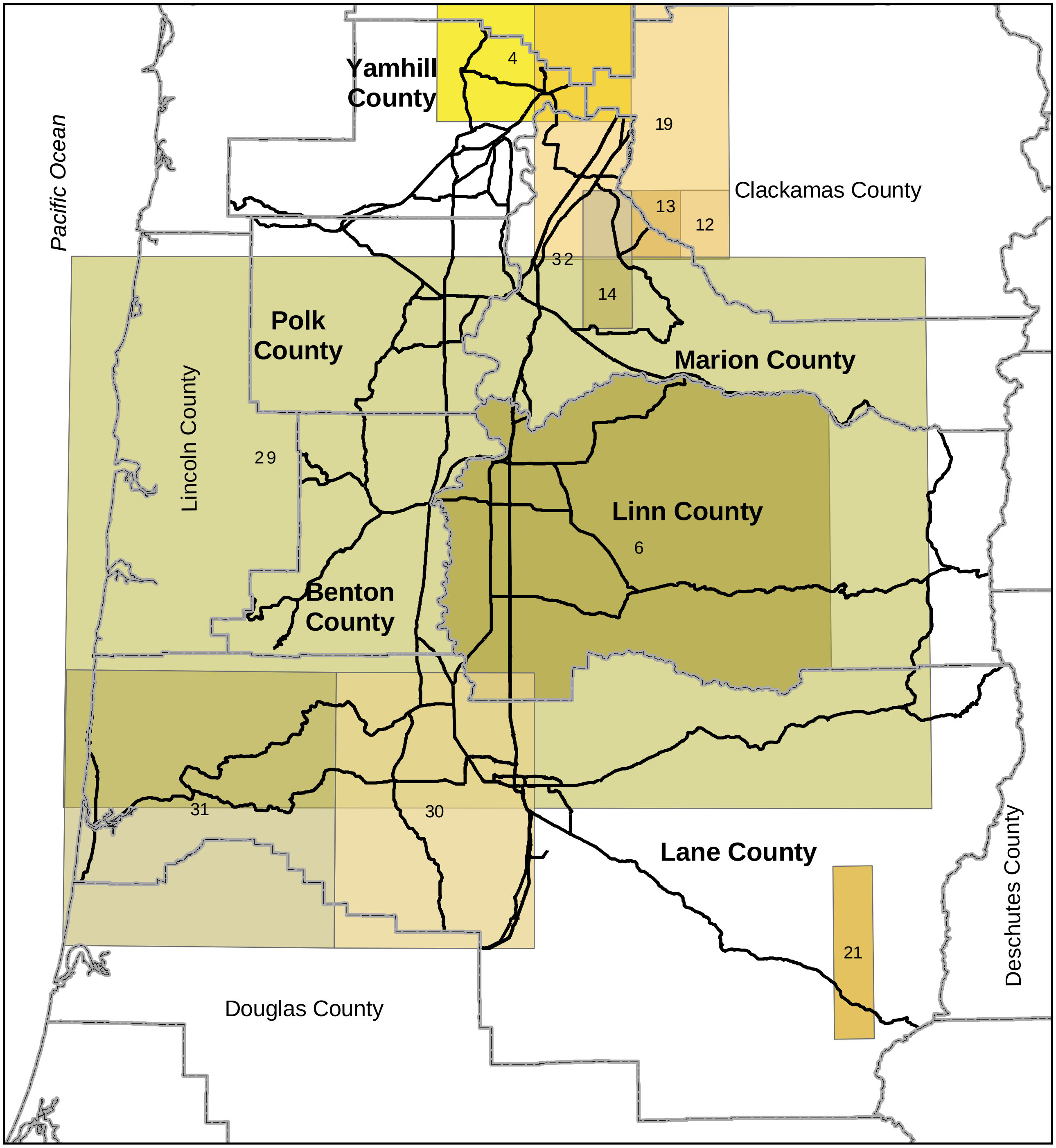

Figure H2. Map of references partially used to compile the base geologic map. Most of these maps were used only to improve the base Quaternary alluvium and landslide deposits. Number (reference ID) corresponds to the map reference in Table H1.

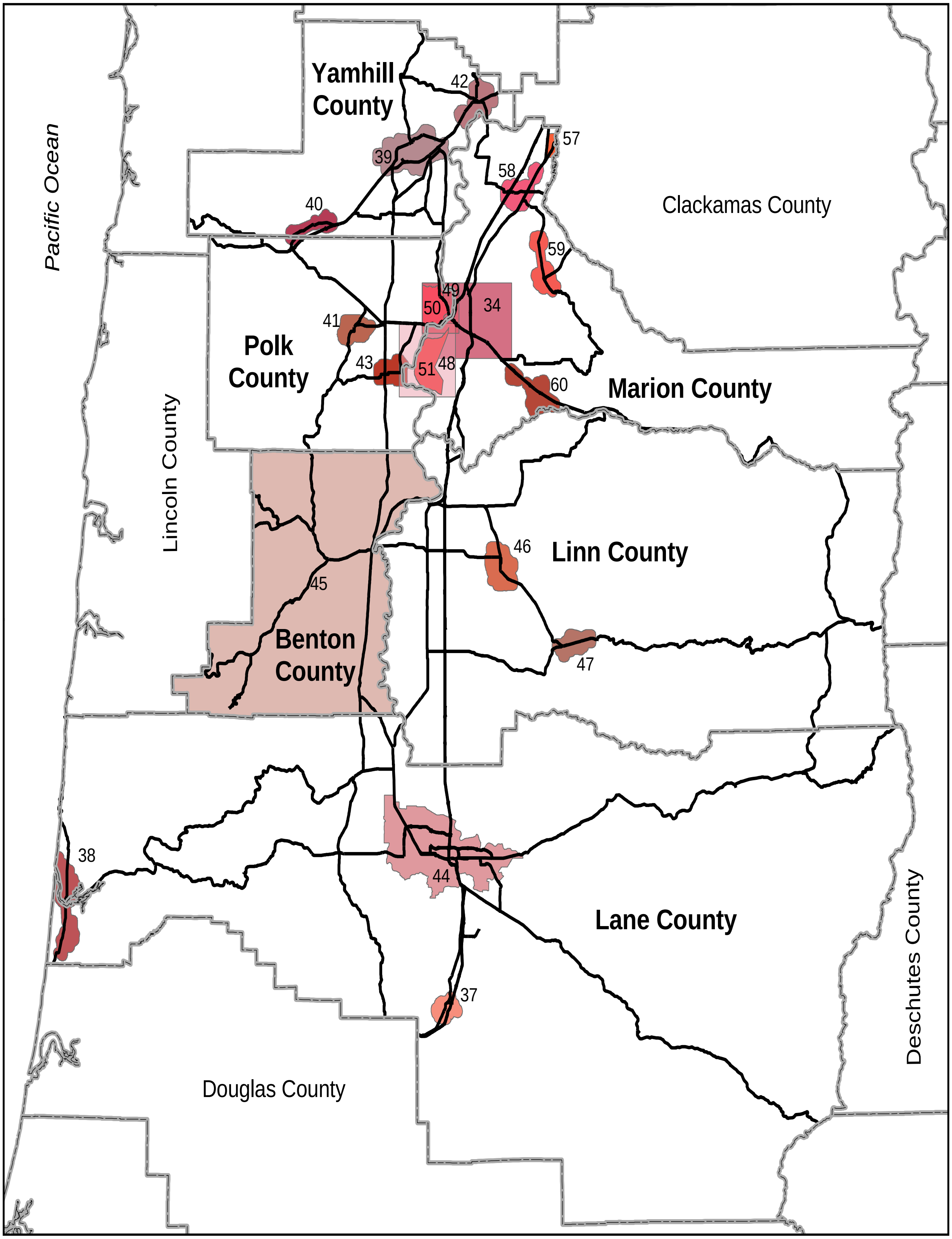

Figure H3. Map of existing hazards studies used it to supersede the countywide data at all locations. Number (reference ID) corresponds to the map reference in Table H1.

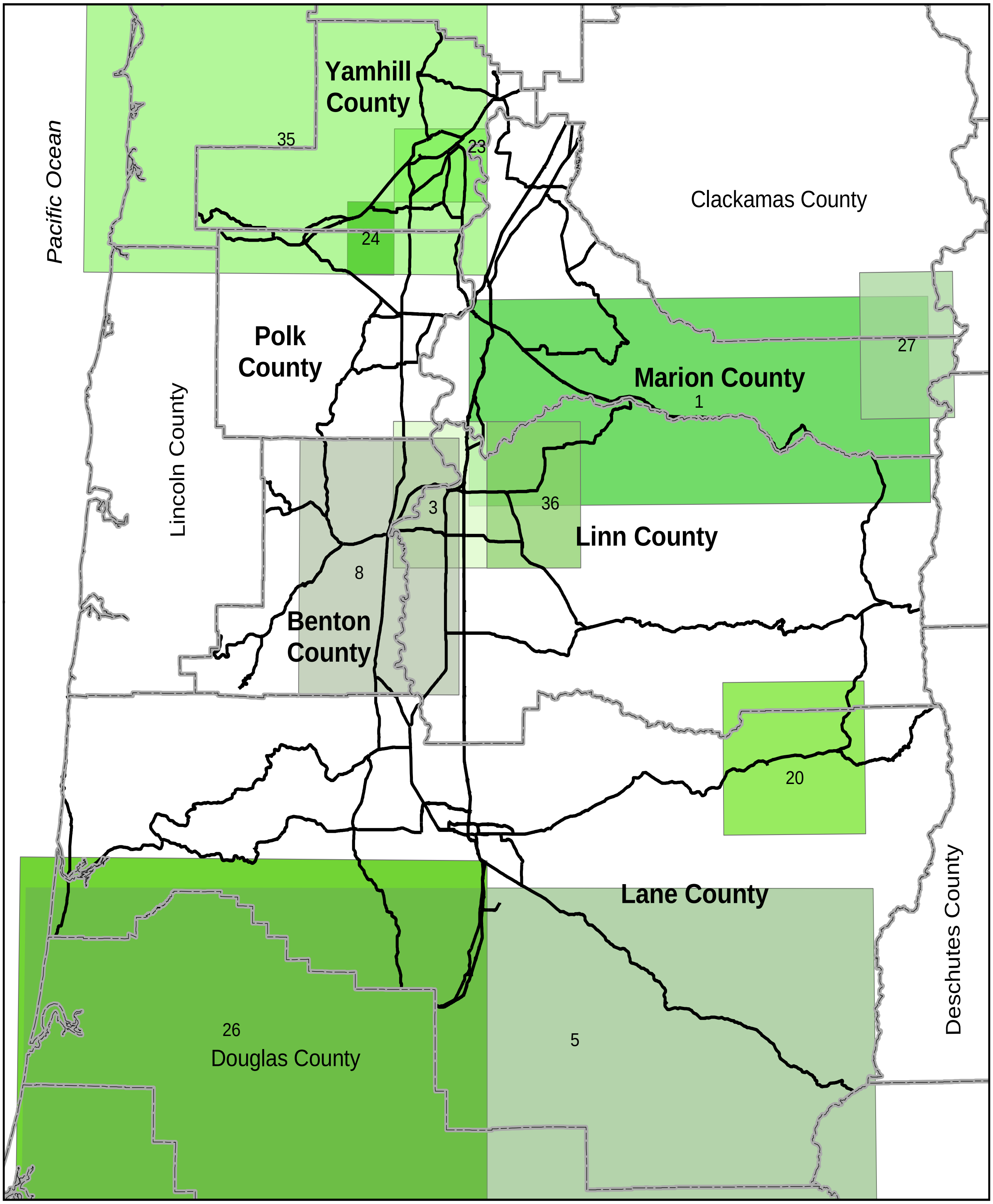

Figure H4. Map of references used only as references to compile the base geologic map. Number (reference ID) corresponds to the map reference in Table H1.

Table H1. Publications referred to in Figures H1–H4; reference ID number in first column corresponds to number labels on figures.

Ref ID	Reference
1	Thayer, T. P., 1939, Geology of the Salem Hills and North Santiam River Basin: Oregon Department of Geology and Mineral Industries Bulletin B-15, 40 p., 1 plate.
2	Baldwin, E. M., 1964, Geology of the Dallas and Valsetz [15′] quadrangles, Oregon (revised ed.): Oregon Department of Geology and Mineral Industries Bulletin B-35, 56 p., 3 plates.
3	Allison, I. S., 1953, Geology of the Albany [15′] quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-37, 18 p., 1 plate.
4	Schlicker, H., and Deacon, R. J., 1967, Engineering geology of the Tualatin Valley region, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-60, 103 p., 4 plates.
5	Ramp, L., 1972, Geology and mineral resources of Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-75, 106 p., 1 plate.
6	Beaulieu, J. D., Hughes, P. W., and Mathoit, R. K., 1974, Environmental geology of western Linn County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 84, 117 p., 22 plates.
7	Schlicker, H., Deacon, R. J., Newcomb, R. C., and Jackson, R. L., 1974, Environmental geology of coastal Lane County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-85, 116 p., 3 plates.
8	Bela, J. L., 1979, Geologic hazards of eastern Benton County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-98, 122 p., 5 plates.
9	Bela, J. L., 1981, Geologic map of the Rickreall and Salem West [7.5′] quadrangles, Oregon; Geologic map of the Monmouth and Sidney [7.5′] quadrangles, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-18, 2 plates.
10	Brownfield, M. E., 1982a, Geologic map of the Sheridan quadrangle, Polk and Yamhill Counties, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-23, 1 plate.
11	Brownfield, M. E., 1982b, Geologic map of the Grande Ronde quadrangle, Polk and Yamhill Counties, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-24, 1 plate.
12	Miller, P. R., and Orr, W. N., 1984a, Geologic map of the Wilhoit quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-32, 1 plate.
13	Miller, P. R., and Orr, W. N., 1984b, Geologic map of the Scotts Mills quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-33, 1 plate.
14	Orr, W. N., and Miller, P. R., 1984, Geologic map of the Stayton NE quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-34, 1 plate.
15	Priest, G. R., Woller, N. M., and Ferns, M. L., 1987, Geology of the Breitenbush River area, Linn and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-46, 4 p., 1 plate.
16	Black, G. L., Woller, N. M., and Ferns, M. L., 1987, Geologic map of the Crescent Mountain area, Linn County, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-47, 1 plate.
17	Priest, G. R., Black, G. L., Woller, N. M., and Taylor, E. M., 1988, Geologic map of the McKenzie Bridge [15′] quadrangle, Lane County: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-48, 2 plates.
18	Orr, W. N., and Miller, P. R., 1986, Geologic map of the Elk Prairie quadrangle, Marion and Clackamas Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-51, 1 plate.
19	Burns, S., Growney, L., Broderson, B., Yeats, R. S., and Popowski, T. A., 1997, Map showing faults, bedrock geology, and sediment thickness of the western half of the Oregon City 1:100,000 quadrangle, Washington, Multnomah, Clackamas, and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-4, 1 plate.
20	Brownfield, M. E., 1982c, Preliminary geologic map of the Ballston quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-82-2, 1 plate.
21	Brown, D. E., McLean, G. D., Woller, N. M., and Black, G. L., 1980, Preliminary geology and geothermal resource potential of the Willamette Pass area, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-80-3, 65 p., 1 plate.
22	Brownfield, M. E., and Schlicker, H. G., 1981a, Preliminary geologic map of the Amity and Mission Bottom quadrangles, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-81-5, 1 plate.
23	Brownfield, M. E., and Schlicker, H. G., 1981b, Preliminary geologic map of the McMinnville and Dayton quadrangles, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-81-6, 1 plate.
24	Brown, D. E., 1980, Preliminary geology and geothermal resource potential of the Belknap-Foley area, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-80-2, 58 p., 1 plate.

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Table H1, continued.

Ref ID	Reference
25	Sherrod, D. R., 1988, Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties: Oregon Department of Geology and Mineral Industries Open-File Report O-88-5.
26	Niem, A. R., Niem, W. A., and Baldwin, E. M., 1989, Geology and oil, gas, and coal resources of the southern Tyee Basin, southern Coast Range, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-89-3, 44 p., 3 plates.
27	White, C. M., 1980, Geology of the Breitenbush Hot Springs quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Special Paper SP-9, 26 p, 1 plate.
28	Snavely, P. D., MacLeod, N. S., Wagner, H. C., and Rau, W. W., 1976, Geologic map of the Waldport and Tidewater quadrangles, Lincoln, Lane, and Benton Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I-866, 1 plate.
29	Walker, G. W., and Duncan, R. A., 1989, Geologic map of the Salem 1° × 2° quadrangle, western Oregon: U S. Geological Survey Miscellaneous Investigations Series Map I-1893, 1 plate.
30	Vokes, E. E., Snavely, P. D., and Myers, D. A., 1951, Geology of the southern and southwestern border area of the Willamette Valley, Oregon: U.S. Geological Survey Oil and Gas Investigations Map OM-110, 1 plate.
31	Baldwin, E. M., 1956, Geologic map of the lower Siuslaw River area, Oregon: U.S. Geological Survey Oil and Gas Investigations Map OM-186, 1 plate.
32	Tolan, T., Beeson, M., and Wheeler, K. L., 1999, Geologic map of the Scotts Mills, Silverton, and Stayton Northeast 7 5 minute quadrangles, northwest Oregon; a digital database: U.S. Geological Survey Open-File Report 99-141.
33	Baldwin, E. M., 1974, Eocene stratigraphy of southwestern Oregon: Oregon Department of Geology and Mineral Industries Bulletin B-83, 40 p., 1 plate.
34	Wang, Y., and Leonard, W. J., 1996, Relative earthquake hazard maps of Salem East and Salem West quadrangles, Marion and Polk Counties: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-105, 10 p., 4 plates.
35	Wells, R. E., Niem, A. R., MacLeod, N. S., Snavely, Jr., P. D., and Niem, W. A.,1983, Preliminary geologic map of west half of Vancouver (Wa.-Ore.) 1° × 2° quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-83-06, 1 plate.
36	Allison, I. S., and Felts, W. M., 1956, Reconnaissance geologic map of the Lebanon [15′] quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Quadrangle Map QM-5, 1 plate.
37	Madin, I. P., and Wang, Z., 2000b, Relative earthquake hazard maps for selected urban areas in western Oregon: Cottage Grove area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-9, 21 p., 20 plates.
38	Madin, I. P., and Wang, Z., 1999, Relative earthquake hazard maps for selected coastal communities in Oregon: Florence-Dunes City area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-10, 25 p., 36 plates.
39	Madin, I. P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: McMinnville-Dayton-Lafayette area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 24 p., 4 plates.
40	Madin, I. P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: Sheridan-Willamina area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 24 p., 4 plates.
41	Madin, I. P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: Dallas area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 24 p., 4 plates.
42	Madin, I. P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: Newburg-Dundee area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 24 p., 4 plates.
43	Madin, I. P., and Wang, Z., 2000c, Relative earthquake hazard maps for selected urban areas in western Oregon: Monmouth-Independence area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-7, 24 p., 4 plates.
44	Black, G. L., Wang, Z., Wiley, T., Keefer, D., and Wang, Y., 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, 16 p., 1 plate.
45	Wang, Z., Graham, G. B., and Madin, I. P., 2001, Preliminary earthquake hazard and risk assessment and water-induced landslide hazard in Benton County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-01-05, 89 p., GIS data files.
46	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Lebanon area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.
47	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Sweet Home area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.

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Table H1, continued.

Ref ID	Reference
48	Hofmeister, R. J., Wang, Y., 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 plate.
49	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 plate.
50	Harvey, A., and Peterson, G., 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, 18 p., 1 plate.
51	Harvey, A., and Peterson, G., 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, 13 p., 1 plate.
52	O'Connor, J., Sarna-Wojcicki, A., Wozniak, K. C., Polette, D. J., and Fleck, R. J., 2001, Origin, extent, and thickness of Quaternary geologic units in the Willamette Valley, Oregon: U S. Geological Survey Professional Paper PP-1620, 52 p., 1 plate.
53	Walker, G. W., MacLeod, N. S., Miller, R. J., Raines, G. L., and Connors, K. A., 2002, Spatial digital database for the geologic map of Oregon: U.S. Geological Survey Open-File Report 03-67, 21 p., digital database.
54	Murray, R. B., 2005, Preliminary geologic map of the Creswell quadrangle, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-06-12, 15 p., 1 plate; and Madin, I. P., and Murray, R. B., 2005, Preliminary geologic map of the Veneta quadrangle, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-06-13, 12 p., 1 plate.
55	Hladky, F. R., and McCaslin, G. R., 2005, Preliminary geologic map of the Springfield quadrangle, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-06-07, 31 p., 1 plate; and Madin, I. P., Murray, R. B., and Hladky, F. R., 2006, Preliminary geologic map of the Coburg quadrangle, Lane and Linn Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-06-06, 24 p., 2 plates.
56	Madin, I. P., and Murray, R. B., 2003, Preliminary geologic map of the Eugene East and Eugene West quadrangles, Lane County, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-06-17, 20 p., 1 plate.
57	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Canby-Barlow-Aurora area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.
58	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Woodburn-Hubbard area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.
59	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Silverton-Mt. Angel area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.
60	Madin, I. P., and Wang, Z., 2000a, Relative earthquake hazard maps for selected urban areas in western Oregon: Stayton-Sublimity-Aumsville area: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS-8, 22 p., 4 plates.

GEOLOGIC HAZARD LAYER DEVELOPMENT

We assigned susceptibility classes based on dominant lithologies for each unit in the study area. Three earthquake-induced geologic hazards layers (ground-shaking amplification, liquefaction, and landslides) and the identified landslides map were developed using the following methods. It is important to note that the quality and scale of the available geologic maps precluded identification of all hazard areas, particularly in the Coast Range and Cascade Range portions of the study area.

Relative Ground-Shaking Amplification

We used the common means of categorizing regional ground-shaking amplification hazards developed by the National Earthquake Hazard Reduction Program (NEHRP). The NEHRP 1997 method classifies geologic locations into one of six geology/soil categories generally labeled hard rock (type A), rock (type B), very dense soil and soft rock (type C), stiff soils (type D), soft soils (type E), and soils requiring site specific evaluations (type F). Table H2 summarizes some of the defining characteristics of these categories. Because we did not have enough information to classify any soils as type F, this class was combined with type E soils in this study. A site-specific evaluation must be performed to differentiate these two classes.

Table H2. National Earthquake Hazards Reduction Program ground-shaking amplification site classes (FEMA, 2003b) and corresponding DOGAMI ground-shaking amplification hazard classes used in this study.

Site Class	Site Class Description	Shear Wave Velocity, $\bar{v}_s$ (m/s) Min.	Max.	DOGAMI Hazard Class
A	**HARD ROCK**	1500	—	very low
B	**ROCK**	760	1500	low
C	**VERY DENSE SOIL AND SOFT ROCK.** $s_u \geq$ 2,000 psf (100 kPa) or $N > 50$	360	760	moderate
D	**STIFF SOILS** (stiff soil with undrained shear strength). 1,000 psf $\leq s_u \leq$ 2,000 psf (50 kPa $\leq s_u \leq$ 100 kPa) or $15 \leq N \leq 50$	180	360	high
E	**SOFT SOILS.** Profile with more than 3 m of soft clay defined as soil with $PI > 20$, moisture content $w > 40\%$, and undrained shear strength $s_u <$ 2,000 psf (50 kPa) ($N < 15$ blows/ft)	—	180	very high*
F	**SOILS REQUIRING SITE-SPECIFIC EVALUATIONS** 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peat and/or highly organic clays ($H > 3$ m of peat and/or highly organic clay) 3. Very high plasticity clays ($H > 8$ m with PI > 75) 4. Very thick, soft/medium stiff clays ($H > 36$ m) with $s_u <$ 1,000 psf (50 kPa)	—	—	

Min. is minimum, Max. is maximum, s_u is undrained shear strength; *N* is ; *PI* is plasticity index; *H* is soil thickness.
*Note that because site-specific information is needed to classify soils as type F, this class was lumped with the type E soils in this study; furthermore, type F soils may also be located within other hazard classes.

After we established the soil classes (amp_class), we converted them to relative susceptibility zones (amp_suscep), and then to the input parameters (hazus_type) necessary for HAZUS-MH as shown in Table H3. In general, areas characterized by loose Quaternary sedimentary deposits are mapped as Moderate and High hazard for ground-shaking amplification (mostly D, E, and F type soil profiles). Most areas adjacent to major rivers in the more populated central portion of the study area are mapped as High and Very High hazard. Upland areas in the eastern part of the study area are mapped as Low ground motion amplification hazard, reflecting bedrock exposures and thin mantles of soil overlying rock. The western portion of the study area is varied, with competent bedrock areas mapped as Low hazard, dense soil areas mapped as Moderate hazard, and younger landslide and alluvial deposit areas mapped as High hazard for ground-shaking amplification.

Using professional judgement, we assigned a site class to each polygon in the base geologic map. Table H4 displays the ground-shaking amplification (GSA) site class assignment for each map unit.

Table H3. Field attributes for the ground-shaking amplification layer.

Ground-Shaking Amplification id	amp_ class	amp_suscep	hazus_ type
1	a	very_low	a
2	b	low	b
3	c	moderate	c
4	d	high	d
5	e	very_high	e
6	f	site_spec	f

The ground-shaking amplification id column serves as a unique identifier. Amp_class relates the zone to the NEHRP 1997 site classes. Amp_suscep is a relative descriptive relation to the amp_class, and hazus_type is the corresponding value in the HAZUS-MH program.

Table H4. Relationship between geologic units and relative susceptibility of ground-shaking amplification (GSA), liquefaction (LIQ), and earthquake-induced landslide (LS_UNIT) site classes.

Map Unit	Description	General Rock Type	Site Class GSA	LIQ	LS_ UNIT
OW	open water	water	3	3	2
Qa	fine-grained alluvium	Quaternary alluvium	4	3	2
Qaf	alluvial fans	Quaternary alluvium	4	3	2
Qal	alluvial deposits	Quaternary alluvium	4	3	2
Qas	alluvial silt and sand	Quaternary alluvium	4	3	2
Qat	major river alluvium	Quaternary alluvium	4	2	2
Qau	undifferentiated alluvium and colluvium	Quaternary alluvium	4	3	2
Qay	minor river alluvium	Quaternary alluvium	4	3	2
Qbf	minor river fine-grained alluvium	Quaternary alluvium	4	3	2
Qc	colluvium	Quaternary colluvium	4	4	2
Qd	dune sand	Quaternary dune	5	3	2
Qda	debris avalanche deposit	Quaternary landslide	5	3	3
Qes	eolian silt and sand	Quaternary eolian	4	4	2
Qf	braided fan	Quaternary alluvium	4	3	2
Qfd	sand gravel fan	Quaternary alluvium	4	3	2
Qff	Missoula Flood fine-grained alluvium	Quaternary alluvium	4	3	2
Qgf	glacial and fluvial alluvium	Quaternary gravels	3	2	2
Qj	block and ash flow	Tertiary volcanic alluvium	4	2	2
Qlg	gravel alluvium	Quaternary gravels	3	2	2
Qls	landslide	Quaternary landslide	5	3	3
Qmg	Missoula Flood sand and gravel	Quaternary terrace deposits	4	2	2
Qoa	older alluvium	Quaternary alluvium	4	3	2
Qoam	old alluvium of Mohawk	Quaternary alluvium	4	3	2
Qs	lacustrine and fluvial alluvium	Quaternary alluvium	5	5	2
QTat	Quaternary and Tertiary strongly weathered sand/ gravel terraces	Quaternary terrace deposits	4	2	2
QTb	young basalt - Boring Lavas and Pigeon Prairie Basalt	Quaternary volcanics	2	1	1
Qtg	terrace gravel	Quaternary gravel	3	2	2
Qth	high terrace deposits	Quaternary terrace deposits	4	2	2
Qtlb	low and bottomland terrace deposits	Quaternary low terrace deposits	5	3	2
Qtm	middle terrace deposits	Quaternary terrace deposits	4	2	2
QTs	siltstone, sandstone, and conglomerates- Parkette Creek Formation	Quaternary-Tertiary fluvial alluvium	3	1	2
QTt	siltstone, sandstone, and conglomerates - Troutdale Formation	Quaternary -Tertiary fluvial alluvium	3	1	2
Qt	terrace deposits	Quaternary alluvium	4	3	2
QTtg	terrace Gravels	Quaternary gravels	3	2	2
Qws	Willamette silts	Quaternary terrace deposits	4	2	2
Rf	recent fill	Quaternary fill	5	4	2
Tal	sand-gravel mixture / weak conglomerate	Tertiary fluvial alluvium	3	1	2
Tb	basalt flows and volcaniclastic	Tertiary volcanic Cascade*	2	1	2
Tbac	Basalt of Camp Creek	Tertiary volcanic Cascade*	2	1	2
Tbah	basalt and andesite of Coberg Hills	Tertiary volcanic Cascade*	2	1	2
Tbd	basalt dikes	Tertiary intrusive	2	1	2
Tbm	Basalt of Mohawk	Tertiary volcanic Cascade*	2	1	2
Tbmp	Basalt of Mount Pigsah	Tertiary volcanic Cascade*	2	1	2
Tbr	basalt flows	Tertiary volcanic Cascade*	2	1	2
Tco	Cowlitz Formation	Tertiary marine sedimentary rock	3	1	2
Tcr	Columbia River Basalt	Tertiary volcanic Cascade*	2	1	2

(table continued on next page)

Table H4, continued.

Map Unit	Description	General Rock Type	Site Class		
			GSA	LIQ	LS_ UNIT
Tcs	Miocene continental sedimentary rocks	Tertiary sedimentary rock	3	1	2
Tdc	Tuff of Daniels Creek	Tertiary volcanic Cascade*	2	1	2
Tdxt	Tuff of Dexter	Tertiary volcanic Cascade*	2	1	2
Te	Eugene Formation	Tertiary fluvial alluvium	3	1	2
Tf	siltstone and sandstone - Fisher Formation	Tertiary sedimentary rock	3	1	2
Tfc	Miocene andesite/basalt rocks, flows, and clastic rocks	Tertiary volcanic Cascade*	2	1	2
Tfe	Fisher and Eugene Formations and correlative rocks	Tertiary Fluvial alluvium	3	1	2
Thi	hypabyssal intrusive rocks	Tertiary Intrusive	2	1	2
Ti	intrusive	Tertiary Intrusive	2	1	2
Tib	basalt and andesite intrusions	Tertiary Intrusive	2	1	2
Tiba	basaltic andesite Intrusive	Tertiary Intrusive	2	1	2
Tid	dacite dike	Tertiary Intrusive	2	1	2
Tim	mafic and intermediate intrusive rocks	Tertiary Intrusive	2	1	2
Tl	Loane Shale	Tertiary Sedimentary	3	1	2
Tlb	basalt - Little Butte Formation	Tertiary volcanic Cascade*	2	1	2
Tm	marine sedimentary rocks - Tyee, Yamhill Formations, etc.	Tertiary Marine Sedimentary Rock	3	1	2
Tmba	basalt andesite	Tertiary volcanic Cascade*	2	1	2
Tomb	basaltic andesite	Tertiary volcanic Cascade*	2	1	2
Tos	volcaniclastic sedimentary	Tertiary Volcanic alluvium	4	2	2
Tpb	porphyritic basalt	Tertiary Volcanic Coast	3	2	2
Tpb	pyroxene basalt	Tertiary volcanic Cascade*	2	1	2
Tr	ryolite intrusive rocks	Tertiary intrusive	2	1	2
Ts	Spencer Formation	Tertiary sedimentary	3	1	2
Tsmc	volcanic conglomerate and mudstone - Scotts Mills Formation	Tertiary volcanic alluvium	3	2	2
Tsr	Siletz River volcanics and related rocks	Tertiary volcanic Coast†	3	2	2
Tss	tuffaceous siltstone and sandstone	Tertiary marine sedimentary rock	3	1	2
Tsv	silicic vent complexes	Tertiary volcanic Cascade*	2	1	2
Tt	Tyee Formation	Tertiary marine sedimentary rock	3	1	2
Ttb	Tuff of Bond Creek	Tertiary volcanic Cascade*	2	1	2
Ttd	Tuff of Daniels Creek	Tertiary volcanic Cascade*	2	1	2
Ttf	Tuff of Fox Hollow	Tertiary volcanic Cascade*	2	1	2
Ttg	Tuff of Gimp Hill Road	Tertiary volcanic Cascade*	2	1	2
Ttq	Tuff of Quaker Road	Tertiary volcanic Cascade*	2	1	2
Tts	tuff	Tertiary volcanic Cascade*	2	1	2
Ttv	Tillamook Volcanics	Tertiary volcanic Coast†	2	1	2
Ttw	Tuff of Willamette Street	Tertiary volcanic Cascade*	2	1	2
Tty	Tyee Formation	Tertiary sedimentary	3	1	2
Tu	Miocene-Oligocene tuffaceous, sedimentary clastic, basalt flows/breccias	Tertiary volcanic Cascade*	2	1	2
Tub	undifferentiated basaltic lava flows	Tertiary volcanic Cascade*	2	1	2
Tus	undifferentiated sedimentary and volcaniclastic rocks	Tertiary volcanic alluvium	4	2	2
Tut	undifferentiated tuff - welded	Tertiary volcanic alluvium	4	2	2
Tv	vent deposits	Tertiary volcanic Cascade*	2	1	2
Tvc	volcaniclastic rocks	Tertiary volcanic Cascade*	2	1	2
Tvs	Volcaniclastic sedimentary	Tertiary volcanic Cascade*	2	1	2
Twc	volcaniclastic rocks of Wallace Creek	Tertiary volcanic alluvium	4	2	2
Ty	Yamhill Formation and related rock	Tertiary marine sedimentary rock	3	1	2

* Tertiary Cascade Range volcanic bedrock.
† Tertiary Coast Range volcanic bedrock.

Liquefaction Susceptibility

Liquefaction hazard groupings were primarily based on lithologies or type of deposit (Table H5). To develop the regional liquefaction hazard maps for this study, we started by collecting the best available geologic information, as we did for the assessment of ground-shaking amplification hazards. We based hazard groupings primarily on lithologies. With the available information compiled, we assigned liquefaction susceptibility classes based on the dominant lithologies for each geologic unit in the study area, checked source data boundaries, and simplified the GIS outputs into six relative hazard classes: Rare, Very Low, Low, Moderate, High, and Very High.

Table H5. Liquefaction susceptibility rating system (Youd and Perkins, 1978).

Type of Deposit	General Distribution of Cohesionless Sediments in Deposits	Likelihood that Cohesionless Sediments when Saturated would be susceptible to Liquefaction (by Age of Deposit)			
		Modern < 500 yr	Holocene < 11 ka	Pleistocene 11 ka - 2 Ma	Pre-Pleistocene > 2 Ma
(a) Continental Deposits					
River channel	locally variable	very high	high	low	very low
Flood plain	locally variable	high	moderate	low	very low
Alluvial fan and plain	widespread	moderate	low	low	very low
Marine terraces and plains	widespread	—	low	very low	very low
Delta and fan-delta	widespread	high	moderate	low	very low
Lacustrine and playa	variable	high	moderate	low	very low
Colluvium	variable	high	moderate	low	very low
Talus	widespread	low	low	very low	very low
Dunes	widespread	high	moderate	low	very low
Loess	variable	high	high	high	unknown
Glacial till	variable	low	low	very low	very low
Tuff	rare	low	low	very low	very low
Tephra	widespread	high	high	?	?
Residual soils	rare	low	low	very low	very low
Sebka	locally variable	high	moderate	low	very low
(b) Coastal Zone					
Delta	widespread	very high	high	low	very low
Esturine	locally variable	high	moderate	low	very low
Beach					
—high wave energy	widespread	moderate	low	very low	very low
—low wave energy	widespread	high	moderate	low	very low
Lagoonal	locally variable	high	moderate	low	very low
Fore shore	locally variable	high	moderate	low	very low
(c) Artificial					
Uncompacted fill	variable	very high	—	—	—
Compacted fill	variable	low	—	—	—

After we established the relative liquefaction classes (liq_class), we converted them to relative susceptibility zones (liq_suscep), and then to the input parameters (hazus_type) necessary for HAZUS-MH as shown in Table H6.

Earthquake-Induced Landslide Susceptibility

In this study, we used a combination of approaches to develop the primary earthquake-induced landslide hazard identification classes. First, we developed a regional landslide hazard map that distinguishes different areas based on simple geologic group as shown in Table H7 (Low, Moderate, High).

Crystalline and well-consolidated rocks have the lowest susceptibility, weakly cemented sedimentary rocks and unconsolidated sediments have moderate susceptibility, and existing landslides and colluvium deposits have high susceptibility. Table H2 displays the relationship between the geologic unit and the landslide susceptibility groups.

We then combined these geologic groups with the slope gradient derived from a 10-m digital elevation model (DEM). Landslide hazard class assignments based on the combination of material type categories (Low, Moderate, High, and Very High) and slope gradient values in degrees were made as shown in Table H7. We derived the hazard classes of low, moderate, high, and very high from the combination of the slope map and the material type categories according to Table H7.

Table H6. Field attributes for the liquefaction layer.

liquefaction id	liq_class	liq_suscep	hazus_type
1	a	rare	0
2	b	very_low	1
3	c	low	2
4	d	moderate	3
5	e	high	4
6	f	very_high	5

Liquefaction id serves as a unique identifier of classes. Liq_class relates the zone to the type of deposit (Table H2). Liq_suscep is a relative descriptive relation to liq_class. Hazus_type is the corresponding value in the HAZUS-MH program.

Table H7. Landslide hazard class assignments based on the combination of material type categories (low, moderate, high) and slope gradient values in degrees.

Geologic Group (relative slope instability susceptibility)	Slope					
	0°–10°	10°–15°	15°–20°	20°–30°	30°–40°	40°+
Low (consolidated rock)	low	low	low	moderate	high	very high
Moderate (highly weathered rock and unconsolidated sediments)	moderate	moderate	moderate	high	very high	very high
High (existing landslides, landslide topography, and colluvium)	high	high	high	very high	very high	very high

After we established the relative landslide classes (ls_class), we converted them to relative susceptibility zones (ls_suscep), and then to the input parameters (hazus_type) necessary for HAZUS-MH as shown in Table H8.

Table H8. Field attributes for the earthquake-induced landslide layer.

Landslide id	ls_class	ls_suscep	hazus_type
1	—	—	0
2	low	low	1
3	—	—	2
4	—	—	3
5	moderate	moderate	4
6	—	—	5
7	—	—	6
8	high	high	7
9	—	—	8
10	—	—	9
11	very_high	very_high	10

The landslide column serves as a unique identifier. The ls_class relates the zone to the type of deposit (Table H2). The ls_suscep is a relative descriptive relation to the ls_class and the hazus_type are the related values which HAZUS-MH can read. Since we could not determine if any of the geologic groups within the study area are not susceptible to landsliding at any slope, the hazus_type=0 was not used. Hazus_types 2, 3, 5, 6, 8, and 9 were not subdelineated due to the lack of detail of the original geology base map.

Existing Geologic Hazard Data

In addition to the hazard maps developed for this study, we used other hazard maps to develop the geologic layers (Figure H3, Table H1). Figure H3 is a geographic reference to these previous studies. The existing hazard maps have several different classification schemes. We converted the classifications to match those used in this study and assigned required parameters for HAZUS-MH according to the scheme listed in Table H8. Then we simply overlaid the layers on top of the countywide hazard maps developed for this study. Because the existing studies use more stringent procedures, such as collecting shear wave velocities in the field to develop the hazard zones, we used these layers rather than countywide data wherever data existed.

We used the following procedures to convert individual hazard maps.

- GMS-105 (Wang and Leonard, 1996): Existing study has six liquefaction categories, so, we set liquefaction categories 0 and 1 to 1, and left 2, 3, 4, and 5 as is. The landslide layer has six categories, so we set 5 to Very High, 4 and 3 to High, 1 and 2 to Moderate, and 0 to Low. The earthquake-induced landslide data from IMS-17 and IMS-18 were both stamped onto GMS-105 where they overlapped. We used the common means of categorizing regional ground-shaking amplification hazards developed by NEHRP for ground-shaking amplification.
- IMS-7 (Madin and Wang, 2000c): Existing study has four liquefaction categories, so we set None to 2, Low to 3, Moderate to 4, and High to 5. Ground-shaking amplification and landslide layers were left as is. The earthquake-induced landslide data from IMS-17 and IMS-18 were both stamped onto IMS-7 where they overlapped.
- IMS-8 (Madin and Wang 2000a): Existing study has four liquefaction categories, so we set None to 2, Low to 3, Moderate to 4, and High to 5. Ground-shaking amplification and landslide layers were left as is.

- IMS-9 (Madin and Wang, 2000b): Existing study has four liquefaction categories, so we set None to 2, Low to 3, Moderate to 4, and High to 5. Ground-shaking amplification and landslide layers were left as is.
- IMS-10 (Madin and Wang, 1999): Existing study has four liquefaction categories, so we set None to 2, Low to 3, Moderate to 4, and High to 5. Ground-shaking amplification and landslide layers were left as is.
- IMS-14 (Black and others, 2000): Existing study had five landslide categories, so we set 1 and 2 to Low, 3 to Moderate, 4 to High, and 5 to Very High. Ground-shaking amplification was left as is. There is no liquefaction layer included in this study.
- IMS-17 (Hofmeister and others, 2000): Existing study has four landslide categories, so we set Very Low to Low, Low to Moderate, Moderate to High, and High to Very High. There are no liquefaction or ground-shaking amplification layers included in this study.
- IMS-18 (Hofmeister and Wang, 2000): Existing study has four landslide categories, so we set very Very Low to Low, Low to Moderate, Moderate to High, and High to Very High. The earthquake-induced landslide data from IMS-17 were stamped onto IMS-18 where they overlapped. There are no liquefaction or ground-shaking amplification layers included in this study.
- Open-File Report O-01-05 (Wang and others, 2001): The earthquake-induced landslide layer was left as is. The ground-shaking amplification layers were left as is. The liquefaction layer was left as is. The landslide hazard map has four categories, so we extracted the "existing hazard" or existing landslides category and combined it with the identified landslides from the geologic map discussed in the next subsection of this appendix. These GIS files had many topology problems, so we converted all polygons to grids and then recombined the separate grids by stamping the Very High category onto the High onto the Moderate onto the Low. This is a conservative approach of correcting the topology and attribute errors in the original files.

Existing Landslides

We extracted existing landslide polygons from the final geologic map (Figure 3, main text) to create the identified landslide hazard layer included in this study. This GIS compilation of previously identified landslide areas was derived from published geologic reports and existing geologic hazard studies.

GIS Topology Cleanup Process

Each GIS file was subjected to the following topology cleanup process:

1. Convert the final polygon file to a 10-m grid using MapInfo® Vertical Mapper™,
2. Reclassify the grid in Vertical Mapper back into the original relative hazard classes,
3. Recontour the grid to polygons,
4. Process the file in MapInfo Geometry Manager and manually check the topology and attributes, and
5. Define the final attributes.