2017 3rd NASL
3rd North American Symposium on Landslides
June 4-8 2017, Roanoke, Virginia, USA

ESTIMATING LOSSES FROM LANDSLIDES IN OREGON

Burns, W.J., bill.burns@oregon.gov, Calhoun, N.C., nancy.calhoun@oregon.gov, Franczyk, J.J., jon.j.franczyk@oregon.gov
Oregon Department of Geology and Mineral Industries, Portland, OR 97232

Koss, E.J., ericka.koss@portlandoregon.gov
City of Portland Bureau of Development Services, Portland, OR 97201

Bordal, M.G., mbordal@pdx.edu
Portland State University, Department of Geology, Portland, OR 97201

ABSTRACT: Landslides are one of the most widespread and damaging disasters in Oregon. Oregon experiences losses greater than $15.4M (million) annually, and can exceed $154M in exceptionally wet or stormy years, as previously estimated by the Oregon Department of Geology and Mineral Industries (Wang et al., 2002). Understanding losses caused by landslides is critical for decision makers, but losses are often only partially recorded or not recorded at all. Landslide losses in Portland, and eventually throughout Oregon, can be better understood by comparing the results of several previous landslide hazard and risk studies with a newly created City of Portland landslide dataset. Over 1,800 landslide records were compiled for events which occurred between 1928 and 2016 within Portland. Subsets of this data were analyzed in detail to better distinguish trends in losses. Two types of exposure analyses were examined to estimate losses. Permit valuations for landslide repairs on private property in 1996 and 2000-2013 were used for comparison. Exposure analysis estimated an average landslide loss of $144,000 while permit valuations average cost per landslide was $89,300. The initial finding of this 1.45 ratio could provide a method, with further validation, for evaluating losses on private land, preempting the need for individual permit data. This study estimates a range of $1.5M-$3M in losses in typical winter years within the City of Portland. In extreme weather years, this increases to approximately $64M-$81M.

INTRODUCTION

A U.S. National Research Council report estimated total cost of landslides in the United States to be $1B (billion) to $2B annually (Committee on Ground Failure Hazards, 1985). Adjusted for inflation, the estimated cost is $1.5B to $3.1B in 2016 dollars. This loss estimate is comparable to other natural hazard annual losses nationwide (NOAA NCEI, 2016). The State of Oregon is especially prone to landslides and experiences losses greater than $15.4M (million) annually. Losses can exceed $154M in exceptionally wet or stormy years (Wang et al., 2002). Estimating losses for landslides is complicated by their (1) lack of centralized origin, (2) association with specific and often complex geologic conditions, and (3) entanglement with other natural hazards, such as earthquakes, storms, or floods (Schuster and Highland, 2001). Further complications come from the occurrence of casualties and/or fatalities, as well as from direct and indirect losses that occur on private and public entities (Schuster and Highland, 2001). In this paper, only direct monetary losses are examined. All values in this paper have been converted to 2016 dollars using http://www.usinflationcalculator.com/.

Annual loss estimates for the United States and Oregon are helpful for understanding the scale of the landslide problem. For perspective, the annual loss payments by FEMA for the National Flood Insurance Plan (NFIP) is $142.6M/year nationwide and $2.6M/year for Oregon (FEMA, 2016). These losses are only for private landowners who have flood insurance with the NFIP. However, these large-scale loss averages do not lend themselves towards cost benefit analysis or local decision making and planning. Finding equivalent loss numbers on a community scale can be challenging. Oftentimes, losses from landslides are combined with other hazard loss data, such as flooding or overall storm event loss, losses are not fully recorded, or the recorded data is not accessible. Published landslide loss data generally focuses on direct socioeconomic losses, including casualties and injuries, for very large and destructive landslides. Examples include the most devastating landslide records available for Canada (Guthrie, 2013), Washington State (WA DNR GER, 2014), or compilations of landslide economic impact for regions (Schuster and Highland, 2001). Other landslide losses are recorded from specific storm or earthquake events, such as the Colorado September 2013 storm and associated flood events (Godt et al., 2014), the Nisqually 2001 earthquake-induced landslides (Highland, 2003), or the Oregon 1996 storms (Burns, 1998; Wang et al., 2002). While these landslide impacts are significant, devastating, and representative of the losses on a national or regional scale, this data does not reflect small, chronic, high frequency landslide losses. These high frequency events that have impacts at a community scale, cannot be extrapolated solely from extreme events, and are difficult to quantify (Klose et al., 2014). Furthermore, most studies focus on either public or private losses, but rarely both combined.

Combining persistent and episodic loss data for a region or community allows for the most accurate expected future losses. Landslide loss estimates are one of two foundational datasets for the establishment of landslide insurance, along with accurate landslide hazard maps; without landslide loss data, the public will continue to lack insurance coverage of this sometimes devastating natural hazard.

The purpose of this study is to present abbreviated findings from several landslide hazard and risk studies in northwestern Oregon, and to compare them to new data in the City of Portland so that landslide losses in the City of Portland and eventually throughout Oregon can be better understood. Landslides in the City of Portland occur in most years, with a strong dependency on winter storms and rainfall and are likely to happen during future earthquakes (Burns et al., 1998). Landslides in the City of Portland can be broadly separated into two categories: shallow, sometimes rapid, and relatively small slides and moderate to large, slow moving, deep landslides (Burns et al., 2012). Significant structural damage and losses are often a result of downslope inundation and debris impact from shallow landslides. In addition, high population density and degree of development can lead to significant losses even when the landslide is relatively small (Fig.1).

Figure 1. The Burlingame Landslide, in SW Portland, caused estimated losses exceeding $1.5 million in 2008. One house and lot slid down the hill into two other houses. Two houses were complete losses and three houses had moderate to significant damage. The landslide was relatively small at approximately 20 meters wide.

In this study, we summarize the results of exposure analysis and annualized loss estimation from several past studies in Oregon. In the City of

Portland, we performed exposure analyses with two landslide datasets, we compiled cost data from permits for landslide repair on private property, and we compiled total loss data for landslides that occurred during the winter of 2015 to 2016. We examined this data using simple statistics including mean and range. Finally, the results were compared, contrasted, and discussed.

BACKGROUND

Losses from landslides have been examined in Oregon using several techniques over the past several decades. In 1996, Oregon experienced a widespread 100-year recurrence interval precipitation event, which resulted in thousands of landslides (Hofmeister, 2000). Directly after the 1996 event, Wang et al. (2002) followed a "top-down" approach acquiring data on losses mostly from public agencies. Wang et al. (2002) reported \$37.1M in landslide losses in the City of Portland from the 1996 event. The majority (93%) of this total was public losses (\$34.3M), leaving \$2.8M in private losses. Burns et al. (1998) reported that landslides in the 1996 event caused significant damage to over 100 homes in the City of Portland. This indicates that the \$2.8M in private losses was significantly underestimated.

Burns et al. (2011) estimated \$3.4M per year in losses from landslides over the long term in the Mt. Hood region, Oregon. In Clackamas County, Oregon, Burns et al. (2013) estimated historic landslide losses to range from hundreds of thousands in typical weather years to tens of millions of dollars in severe storm years such as 1996. In comparison, the city of Cincinnati, Ohio, which is analogous in size to Portland and has available landslide loss data, spent \$7.5M in landslide repairs between 1988 to 1992, equivalent to \$1.9M per year in landslide costs (Rockaway et al., 2002). The whole of Hamilton County, Ohio, which encompasses Cincinnati and surrounding area, and includes 806,000 people and 413 mi^2, experienced \$5.17M per year in landslide losses between 1973 and 1978 (Fleming and Taylor, 1980). In 2016 dollars, the annual loss estimate for Hamilton County is \$15.1M.

Two techniques have been used in specific communities in Oregon to estimate landslide risk and losses: exposure analysis and annualized loss estimation. Exposure analysis is the spatial intersection of assets and mapped landslides, and includes building and land values from local tax lot data (Fig. 2). Exposure is not equivalent to direct loss, but it does define the value of assets that are at risk. Annualized loss estimation is an estimate of loss per year.

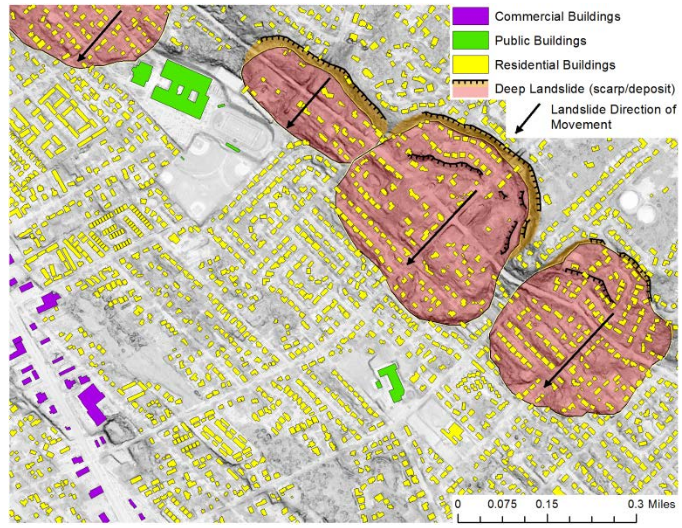

Figure 2. Example map of exposed buildings to a Special Paper 42 (SP-42) landslide inventory in Clackamas County, Oregon.

Three recent studies of exposure focused on the cities of Clatskanie (Mickelson and Burns, 2012), Astoria (Burns and Mickelson, 2013),West Linn, Milwaukie, Happy Valley, Lake Oswego, Oregon City, and Gladstone (Burns et al., 2013), which serve as a foundation for the work presented here (Table 1). The exposure analyses in these studies were performed by using a lidar-based landslide inventory following the method by Burns and Madin (2009), referred to as SP-42 landslide inventory in this paper. This method includes all types and ages of landslides that can be mapped using topographic data. Although following the SP-42 method results in a significantly improved landslide polygon inventory, the results commonly miss the small, shallow, and frequent landslides. To capture this data, a historic landslide point dataset was collected for each study in conjunction with SP-42 landslide mapping.

The eight Oregon cities previously studied vary in size, population density, and value of assets as well as landslide hazards. For example, the City of Astoria is a relatively small city on the Oregon coast with a total value of land and buildings of $1,542M, but has a high percentage (51%) of these assets located on landslide hazards (Table 1). In contrast, the City of Lake Oswego adjacent to the City of Portland has $7,590M value of land and buildings, but a relatively low percentage (1%) of those assets are exposed to landslide hazard.

Table 1. Summary of SP-42 landslide inventory exposure results for eight Oregon cities from three recent projects. All dollars are in millions.

Building and Land $ Values	Astoria	Clatskanie	West Linn	Oregon City	Gladstone	Milwaukie	Happy Valley	Lake Oswego
Total ($M)	1,542	221	3,328	2,865	834	1,824	2,017	7,590
On Landslides ($M)	790	59	71	15	12	0.1	2	60
Percent Total	51%	27%	2.1%	0.5%	1.5%	~0%	0.1%	0.8%

Losses are typically analyzed and reported by calendar year. This can be done as a long-term average (decades), a short term average (several years), or for typical weather years and extreme weather years.

METHODS

SP-42 Exposure Analysis

Exposure analysis was performed for the City of Portland using the SP-42 landslide inventory in order to compare City of Portland results to other communities. The basic exposure analysis method consists of spatial calculation of the overlap of datasets in geographic information system (GIS) software. For buildings, if a landslide overlapped or even intersected a building, the entire building value was included. For land, if a landslide completely overlapped the parcel, the total land value was included or if the landslide covered a portion of a tax lot, that portion was used to calculate the percent of the total land value that is exposed. This is the same method as used in previous studies, enabling direct comparisons. The City of Portland results are organized by neighborhood boundaries used by city planners, emergency managers, and other city bureaus. The results were divided by neighborhoods because of the significant variation in slope and geology across the relatively large area of the City of Portland compared to other, usually much smaller cities in Oregon. Since the tax lot data commonly does not have dollar values for public property, the results include almost exclusively residential and commercial property exposure.

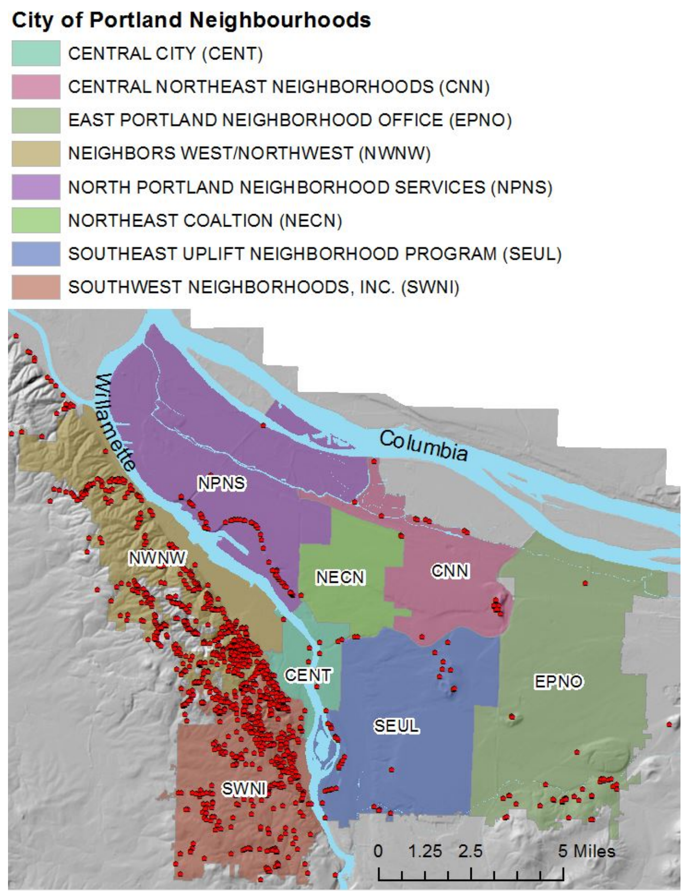

Figure 3. Map of 1,806 historic landslide points (red dots) from 1928-2016 for the City of Portland and eight of the City of Portland Neighborhoods.

Historic Landslide Exposure Analysis

The second method used to calculate exposure was performed on a subset of historic landslide points. Data from the Statewide Landslide Information Database of Oregon (SLIDO; Burns, 2014) and the City of Portland were combined to create an updated historic landslide GIS dataset with 1,806 landslide records from 1928 through the first half of 2016. Figure 3 shows the City of Portland neighborhoods and the historic landslide points.

The concentration of historic landslides in certain neighborhoods and not others is due to several geologic and geomorphic conditions (Fig. 3). Northwest and southwest of the Willamette River (neighborhoods NWNW and SWNI) the surficial geologic conditions often consist of loess deposits overlying bedrock, bounded by northwest-trending faults and steep topography created by the Portland Hill anticline (Evarts and others, 2009). The landslide pattern in the NPNS neighborhood follows the river's bluff, a high relief feature caused by the catastrophic Missoula floods.

Of the 1,806 landslides, 831 of these occurred during 1996. Further examination of the data found incomplete records or lack of data collection from 1928 to 1973. Excluding the year 1996, there is an average of 20 landslides per year, from 1974 to 2016.

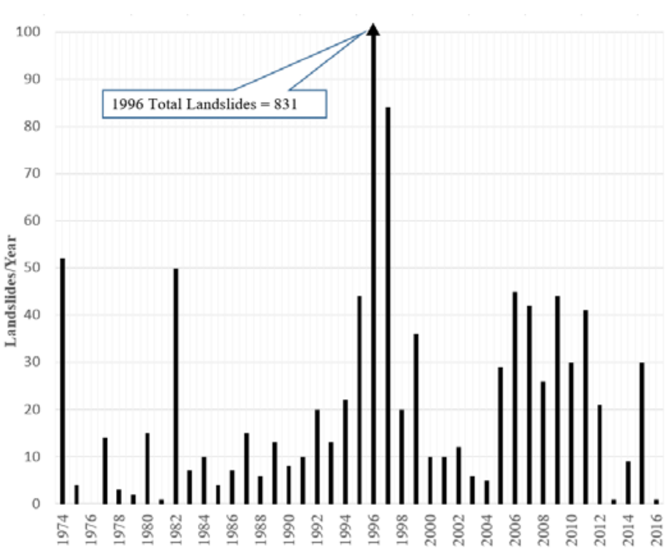

Figure 4. Historic landslide records in the City of Portland displayed as number of landslides per year from 1974-2016.

These historic records include point location data, rather than a polygon that represents areal extent of a landslide. Records often contained limited or generic site information, such as an address, which was not enough detail to create a polygon. The limitation of landslide records as points does not allow us to establish if they are predominately located on private or public land. However, records for 457 of the 831 landslides that occurred during the 1996 event included length and width data, which we used to create simple polygons for application in exposure analysis. Using the 457 landslides, we calculated land and building exposure values using the area of the generated landslide polygon. Instead of including the entire house value if touched by a landslide, as previously done in the SP-42 Exposure Analysis, the building and land values were combined and distributed equally across the lot in the exposure calculation. This method was implemented to reduce inflated exposure when including the entire building value. Distribution of the structure value over the property provides a proxy method to account for other exposed improvements such as driveways, retaining walls, and outbuildings. Since the tax lot data commonly does not contain dollar values for most of the public land, we only performed this exposure analysis on the landslides located predominantly on private tax lots. Of these 457 polygons, 177 (39%) were located with more than 50 percent of their area overlapping private land and were used to calculate private property exposure.

Historic Permit Data Compilation

Permits for landslide repair are required in the City of Portland when grading of more than 10 cubic yards of soil is proposed, where repair to a structure is required, or when new improvements for slope stabilization, such as subsurface drainage or retaining walls, are proposed. The small, frequent landslides that only necessitate debris removal do not require permits. The City of Portland Bureau of Development Services reviews permit applications for work proposed on private property. Permit applicants submit an approximate construction cost with permit applications. Records of permit construction costs submitted in support of landslide repair projects were compiled between 2000 and 2013 as well as for select sites where landslides occurred in 1996.

2015-2016 Winter Landslide Loss Data Compilation

Losses to both public infrastructure and private property were compiled for landslides that occurred during the 2015 to 2016 winter season. This data was collected as part of this project and therefore the data is not yet in SLIDO. Of the 15 landslides recorded, accurate loss data was available for 11.

Several of the landslides were in the process of being mitigated, with final cost data not yet available. In these cases, final costs were approximated using reasonable approximations based on experience of work conducted under similar conditions.

Upon field review, the landslides documented for the 2015-2016 winter represented a typical range of damage to public and private infrastructure, from relatively small landslides that required only limited debris removal to landslides requiring substantial engineered solutions for stabilization. Notably absent were outlier landslides with very high losses such as those that have destroyed one or more structures (Fig.1).

RESULTS

SP-42 Exposure Analysis

The results of the City of Portland SP-42 landslide inventory polygons exposure analysis are summarized in Table 2 by city neighborhoods. As anticipated, the highest exposure percentages correspond directly with the neighborhoods containing the greatest number of mapped landslides.

Table 2. Summary of exposure of building and land values to SP-42 landslide inventory results by neighborhood in the City of Portland.

Building and Land $ Value	CENT	CNN	EPNO	NWNW	NPNS	NECN	SEUL	SWNI
Total ($B)	18	6.9	13	8.2	11	11	22	14
On Landslides ($M)	160	0.5	5.6	670	2.4	0.1	0.4	280
Percent of Total	0.8 %	0.0 %	0.0 %	8.1 %	0.0 %	0.0 %	0.0 %	2.0 %

Historic Landslide Exposure Analysis

The analysis of these 177 historic landslides converted from points to polygons and with more than 50% area on private land produced a total exposure value of $25.5M, with a mean of $144,000 per landslide and a range from $0 to $2.5M. Table 3 provides the total value of private property and exposure amount by neighborhood.

Of the 457 landslides with known spatial extents, 39% are majority private property slides. In order to approximate total private property exposure, 39% is extrapolated to the total 831 landslides, equaling approximately 324 landslides. To estimate the total exposure, the mean exposure value is multiplied by the 324 private property landslides, resulting in $47M in total exposure to private property.

The remaining estimated 507 landslides on public land caused approximately $34.3M in losses (Wang et al., 2002). Therefore, mean public losses would equal approximately $67,600 per landslide.

These 507 landslides touched 174 pieces (34%) of recreational land, as classified in the tax lot data and are considered parks or greenspaces which may have minimal infrastructure, or damageable property. The remaining 66% of landslides on public land were not located on recreational land and therefore likely had the majority of the $34.3M in public losses which would equal an average of approximately $102,500 per landslide.

Table 3. Summary of exposure of buildings and land values to 177 polygons derived from the 1996 historic landslide records to private property.

Building and Land $ Value	CENT	CNN	EPNO	NWNW	NPNS	NECN	SEUL	SWNI
Total ($B)	18	6.9	13	8.2	11	11	22	14
On Landslide Polygons ($M)	1.3	0.0	0.0	16	2.0	0.0	0.1	5.9

Historic Permit Data Analysis

Records of permits submitted for landslide repair projects were compiled between 2000 and 2013 and select sites in 1996. In rare cases, there were multiple permits for one landslide event. The mean and range of the permit valuations per permit are summarized in Table 4. Additionally, 17 of the 1996 permit records corresponded to landslide events from the 1996 historic landslide records previously used to generate polygons for exposure analysis.

Table 4. Summary of permit based loss and landslide repair valuation data for 1996 and 2000-2013.

	Number of Landslides	Mean	Range
1996	39*	$89,300	$1,300-$1.08M
1996 With corresponding exposure data	17	$99,100	$1,300-$256,700
2000-2013	60*	$93,100	$113-$1.46M

*Number of landslides with permit data.

The total and mean permit based loss values for these 17 landslides are $1.68M and $99,100, respectively; the total and mean exposure values of the same 17 landslides, as calculated from polygon length and width data, are $4.24M and $249,600, respectively. Therefore, the average exposure values are generally 2.5 times greater than the average permit values for these 17 matched pairs.

Assessment of the landslide loss for private property based on permit valuation does not include the following direct costs to the homeowners: engineering, legal counsel, permit fees, loss of personal property, and other incidental costs such as landscaping. In addition, permit fees are based upon permit valuation and, therefore, submitted permit valuations may be underestimated by the applicant. Many landslides affect both private and public property, and these records do not include losses to public property or private utility infrastructure.

2015 to 2016 Winter Landslide Loss Data Compilation

Results of the landslide losses compiled for the 2015 to 2016 winter season indicate a mean of $67,500 per landslide and a range of $1,300 to $183,000. Four of the landslides consisted of minor road cut failures such as the landslide shown in Figure 5. For these events, losses consisted of only the cost of debris removal and totalled less than $6,000 per landslide.

Of the remaining landslides, four included slides that required engineered solutions such as retaining walls or slope reinforcement. These slides exceeded losses of $90,000 per event.

Figure 5. Road cut failure on Southeast Flavel Street after debris cleanup, December 2015.

DISCUSSION AND CONCLUSIONS

The City of Portland exposure to the SP-42 mapped landslide inventory totals almost $1B and ranges by neighborhood from approximately $0.1M to $670M. This analysis was performed on private and public property, but as we found during this project, the public parcels rarely have building and land values and therefore these totals should be considered mostly private. This amount of exposure to existing landslides indicates a significant level of landslide risk in the City of Portland. These numbers are in the same range as many other cities in Oregon, which demonstrates a widespread level of risk and potential for significant future losses across the state, especially during future storms and earthquakes.

The results of the City of Portland private property exposure using the polygons derived from the 1996 landslide inventory are estimated to be $47M. These values are significantly lower than the values for the SP-42 landslide inventory because the SP-42 inventory includes prehistoric, large, deep-seated landslides. The mapped deep-seated landslides included in SP-42 have a very wide range in age. The landslides included in the 1996 inventory are only a small temporal fraction of the landslides in the SP-42 landslide inventory. The exposure analysis result of $47M is significantly more than the estimated private losses of $2.8M by Wang et al. (2002). The mean exposure on private land from the 1996 event is $144,000/landslide. The permit total for 17 landslides in 1996 is $1.68M, which is less than the estimated private losses of \$2.8M by Wang et al. (2002). Both of these values are likely underestimates primarily because the permit-derived total is from 17 of the total 324 landslides on private land, and the Wang et al. (2002) total is from 93 of the total 324 landslides on private land. When the average permit value (\$99,100) is extrapolated to the total 324 landslides on private land, the total loss estimate is \$32.1M.

The results of the 2000 to 2013 permit valuations, considering private losses exclusively, have a mean of approximately \$93,100. The 1996 polygon landslide inventory exposure mean of \$144,000 is 1.5 times larger than the 2000-2013 permit mean. This seems to be an appropriate difference, because, as previously explained, permit values are likely less than the actual direct loss, and the exposure is likely overestimating loss.

The results of the compilation of the actual losses suffered by private property owners and public bureaus during the winter of 2015-16 indicate a mean of approximately \$67,500 per landslide. This mean is less than the mean derived by exposure analyses and the mean derived from permit valuation per landslide on private land. The lesser mean is a result of the inclusion of small, high frequency, low loss events such as the landslide shown in Figure 5. These high frequency events commonly occur within public right of way and do not trigger building permit requirements. Therefore, this type of event was not included in either the exposure analyses or building permit valuation methods.

Based on historic data, there is an average of 20 landslides per year (Fig. 1). Stormy, wet, or otherwise extreme landslide years, such as the 1996 winter, can cause hundreds of landslides. The number of landslides multiplied by the average loss estimates provides a preliminary estimate of losses per year (Table 5.)

Based on Table 5, one can conclude that annual loss estimates for private or public range from approximately \$1.5M to \$3M per year. The assumption for this annual estimate is that the average 20 landslides are neither extremely destructive, nor low to no damage landslides. In extreme years, this annual estimate increases to approximately \$34M for public and \$29M-\$47M for private. Together the estimated total is approximately \$64M-\$81M. If the typical losses per year values are extrapolated over the 42 years, the total cumulative losses are likely in the range of \$63M to \$126M for the City of Portland. This indicates that one to two extreme years can add up to about 40 years of typical losses.

Table 5. Summary of annualized loss estimates

Dataset	Estimated Mean Dollars per Landslide	Estimated Loss in Typical Year (20 Landslides)	Estimated Loss in Extreme Year
Public land (extrapolated from 1996 data)	\$67,600#	\$1.4M	\$34M
Public land (extrapolated from 1996 data)	\$102,500##	\$2.1M	\$34M
Private land exposure (1996 landslide polygons)	\$144,000	\$2.9M	\$47M*
Private land (1996 permits)	\$89,300	\$1.8M	\$29M*
Private land (permits 2000-2013)	\$93,100	\$1.9M	\$30M*
Private & Public (2015-16 season)	\$67,500	\$1.4M	\$56M**

#507 landslides; includes recreational land such as parks or greenspaces, which may have minimal infrastructure, or damageable property
##333 landslides; does not include recreation land
*324 landslides on private land multiplied by mean per landslide
**831 landslides on private and public land multiplied by mean per landslide

The new examination of losses during the 1996 event found the private property losses were likely significantly underestimated in the City of Portland (\$2.8M) by Wang et al. (2002) and could be in the range of the public loss estimate of \$34M. The two methods used to evaluate private losses (permits and exposure) both appear to capture private losses and generally correlate with each other. However, both methods have limitations and likely overestimate average losses.

This study found that available tax lot data in the City of Portland generally lacks dollar values for public land. For example, the public transportation parcels have no dollar value. However, some recreational parcels have dollar values. Therefore, tax lot data should only be used for private land exposure unless appropriate land values can be obtained for public property. As previously stated, exposure values are not directly equal to losses. If exposure is going to be used as a proxy for landslide losses, further investigation should be performed. In this study, the 2015 tax lot values were used to evaluate exposure of the 1996 landslide polygons. Using tax lot values from many years after the event resulted in data inaccuracy. For example, one lot had a landslide which destroyed a house worth \$80,000 in 1996. The house was rebuilt and had a value of \$1.2M in 2015. The inverse was also noticed on a lot worth over \$0.7M in 2008 prior to a landslide (Fig. 1), and the 2015 tax lot value was \$1,700, because the structure was destroyed and land degraded. Therefore, we recommend using tax lot data records from just before the landslide date to limit errors from inflation, changes in tax rates, changes to individual properties, and fluctuations in the real estate market.

The permit data has the benefit of 1) established and mandatory record system, 2) monetary values of loss estimates for a particular landslide, and 3) representing private property losses. However, as previously noted, the permits likely do not include many portions of direct costs and may be underestimated by the applicant. Furthermore, it is very likely that most sites that experience relatively small landslides, or landslides without any damage, did not submit a permit.

This study found mean exposure was greater than the mean permit values. One of our initial project goals was to compare landslide exposure directly to a permit record on the same lot. However, we were only able to do this for 17 sites. In the future, a better understanding of this correlation might result in a method for evaluating losses on private land without needing individual permit data. More accurate loss estimates could be obtained with more accurate location data. It is anticipated that accurate location data will be more readily obtained and recorded in the future. Subsequent studies should include a correlation between accurate landslide geometry and asset valuation.

Both of these methods (exposure and permits) should be considered effective on average sized landslides with average damage in an urban region on private land. It is likely that one large destructive landslide can cause as much or more damage as many average landslides. Losses on large destructive landslides should be collected individually.

Finally, the accuracy of the mapped location and dimensions of each landslide makes a difference. The difference in land use, density, and land value has a large effect on the estimated losses.

REFERENCES

Burns, S.F.; Burns, W.J.; James, D.H.; and Hinkle, J.C., 1998, Landslides in Portland, Oregon: Metropolitan Area Resulting from the Storm of February 1996: Inventory Map, Database, and Evaluation. METRO Natural Hazards Publication 905828, pp.1-65.

Burns, W. J., 2007, Comparison of remote sensing datasets for the establishment of a landslide mapping protocol in Oregon: Conference Presentations, 1st North American Landslide Conference, Vail, Colorado, Association of Environmental & Engineering Geologists Special Publication, Vol. 23, pp. 335-345.

Burns, W.J., 2014, Statewide Landslide Information Database for Oregon, release 3.2: Oregon Department of Geology and Mineral Industries, Web: http://www.oregongeology.org/sub/slido/

Burns, W.J., and Madin, I.P., 2009, Protocol for Inventory Mapping of Landslide Deposits from Light Detection and Ranging (lidar) Imagery: Oregon Department of Geology and Mineral Industries, Special Paper 42, 30 p. http://www.oregongeology.org/pubs/sp/p-SP.htm

Burns, W.J.; Hughes, K.B.; Olson, K.V.; McClaughry, J.D.; Mickelson, K.A.; Coe, D.E.; English, J.T.; Roberts, J.T.; Lyles Smith, R.R.; and Madin, I.P., 2011, Multi-Hazard and Risk Study for the Mount Hood Region, Multnomah, Clackamas, and Hood River Counties, Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-11-16, 173 p. http://www.oregongeology.org/pubs/ofr/p-O-11-16.htm

Burns, W.J.; Madin, I.P.; Mickelson, K.A.; and Duplantis, S., 2012, Inventory of Landslide Deposits from Light Detection and Ranging (Lidar) Imagery of the Portland Metropolitan Region, Oregon and Washington, Oregon: Oregon Department of Geology and Mineral Industries, Interpretive Map 53, scale 1:63,360. http://www.oregongeology.org/pubs/ims/p-ims-053.htm

Burns, W.J.; Mickelson, K.A.; Jones, C.B.; Pickner, S.G.; Hughes, K.L.; and Sleeter, R., 2013, Landslide hazard and risk study of northwestern Clackamas County, Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-13-08, 74 map plates, 38 p. http://www.oregongeology.org/pubs/ofr/p-O-13-08.htm

Burns, W.J. and Mickelson, K.A., 2013, Landslide Inventory, Susceptibility Maps, and Risk Analysis for the City of Astoria, Clatsop County, Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-13-05, 29 p. http://www.oregongeology.org/pubs/ofr/p-O-13-05.htm

Committee on Ground Failure Hazards, 1985, Reducing losses from landslides in the United States: Commission on Engineering and Tech Systems, U.S. National Research Council, Washington, D.C., 41 p.

Evarts, R.C.; O'Connor, J.E.; Wells, R.E.; and Madin, I.P., 2009, The Portland Basin: A (big) river runs through it, September 2009: GSA Today, Vol. 19, No. 9, pp. 4-10.

Federal Emergency Management Agency (FEMA), 2016, Policy and Claim Statistics for Flood Insurance, Claim Information by State (1978 – Current Month). Retrieved from: https://bsa.nfipstat.fema.gov/reports/1040.htm

Fleming, R.W. and Taylor, F.A., 1980, Estimating the Costs of Landslide Damage in the United States: U.S. Geological Survey, Circular 832, 21 p.

Godt, J.; Coe, J.; Kean, J.; Baum, R.; Jones, E.; Harp, E.; Staley, D.; and Barnhart, W., 2014, Landslides in the Northern Colorado Front Range Caused by Rainfall, September 11-13, 2013: U.S.Geological Survey Fact Sheet 2013-3114, 3 p.

Guthrie, R., 2013, Socio-economic Significance: Canadian Technical Guidelines and Best Practices related to Landslides: a national initiative for loss reduction: Geological Survey of Canada, Open File 7311, 19 p.

Highland, L., 2003, An Account of Preliminary Landslide Damage and Losses Resulting from the February 28, 2001, Nisqually, Washington, Earthquake: U.S. Geological Survey Open-file Report 03-211, 48 p.

Hofmeister, R.J., 2000, Slope failures in Oregon: GIS inventory for three 1996/97 storm events: Portland, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 34, 20 p.

Klose, M.; Highland, L.M.; Damm, B.; and Terhorst, B., 2014, Estimation of Direct Landslide Costs in Industrialized Countries: Challenges, Concepts, and Case Study. In Sassa, K.; Canuti, P.; and Yin, Y. (Eds.) Landslide Science for a Safer Geoenvironment, pp. 661-667.

Mickelson, K.A.; and Burns, W.J., 2012, Landslide Hazard and Risk Study of the U.S. Highway 30 Corridor, Clatsop and Columbia Counties, Oregon: Oregon Department of Geology and Mineral Industries, Open-File Report O-12-06, 105 p. http://www.oregongeology.org/pubs/ofr/p-O-12-06.htm

NOAA National Centers for Environmental Information (NCEI), 2016, U.S. Billion-Dollar Weather and Climate Disasters. https://www.ncdc.noaa.gov/billions/

Rockaway, J.; Cobb, J.C.; and Kiefer, J.D., 2002, Final Report: Northern Kentucky Landslide Documentation Investigation Statewide Considerations, 7 p. http://pubs.usgs.gov/of/2006/1032/pdf/Kentucky.pdf

Schuster, R.L. and Highland, L.M., 2001, Socioeconomic and Environmental Impacts of Landslides in the Western Hemisphere: U.S. Geological Survey Open-File Report 01-276, 48 p.

Washington State Department of Natural Resources, 2014, Significant Deep-Seated Landslides in Washington State – 1984 to 2014, Electronic document 2/10//2015jlc, 5 p.

Wang, Y.; Summers, R.D.; and Hofmeister, R.J., 2002, Landslide Loss Estimation Pilot Project in Oregon, State of Oregon: Department of Geology and Mineral Industries Open-File Report O-02-05, 23 p.

ACKNOWLEDGEMENTS

This project was partially funded through a grant from FEMA, with special thanks to Cynthia McCoy. We also want to thank Lynn Highland, USGS-retired, for helpful discussions.