Liquefaction Loss Estimation in US

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ABSTRACT

Liquefaction is a secondary hazard that occurs during earthquakes and can cause severe damage to overlaying infrastructure. As a result, liquefaction can be a significant contributor to loss due to earthquakes as observed during the 2011 New Zealand earthquakes. A geospatial liquefaction model developed by Zhu et al. 2017 and implemented by the USGS on the earthquake overview page can be used to estimate liquefaction extent after an earthquake. The geospatial liquefaction model estimates liquefaction spatial extent (LSE) using globally available parameters: water table depth, precipitation, distance to body of water, topography-based shear wave velocity, peak ground velocity, and peak ground acceleration. The geospatial liquefaction model, however, does not predict infrastructure or economic loss, as needed by the USGS Pager System. We present a liquefaction loss database based on numerous past events with a focus on events in the United States. Using this database, we will relate economic loss due to liquefaction to the LSE from the geospatial liquefaction model using infrastructure proxies. Infrastructure proxies are derived from the Tufts University geographic information systems communal drive. Resulting correlations will estimate liquefaction loss in the aftermath of an earthquake.

BUILDING A LIQUEFACTION LOSS DATABASE

To quantify loss due to liquefaction, we built a database recording damages due to liquefaction in 10 North American earthquakes spanning from 1989 to 2018. The project will also analyze six other North American earthquakes which are suspected to have caused damage due to liquefaction. These damages were recorded based on information presented in government reports, scientific papers, and news articles. The Geotechnical Extreme Events Reconnaissance (GEER) Association presents reports following extreme events which document their impact on the world. GEER reports cover all of the reports of interest to our database, oftentimes mentioning specifically which damages were due to liquefaction. In cases where the cause of damage was not clear, best assumptions were made to estimate the proportion of. This helped us specify categories to use when calculating cost estimates for infrastructure damages.

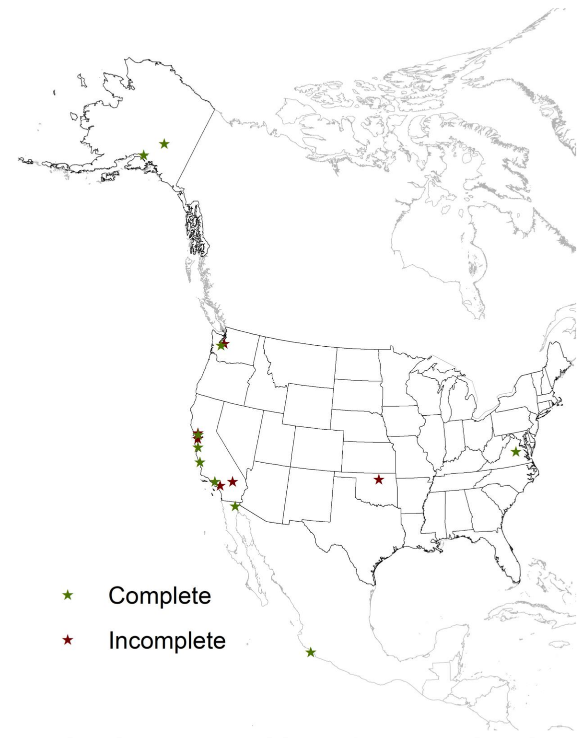

Figure 1: Locations of earthquakes across North America suspected to have caused liquefaction-related damages, categorized by complete estimations or incomplete estimations.

Table 1: Breakdown of costs due to liquefaction for all completed events, sorted by ascending total cost values. Priority was given to earthquakes which had high predicted total liquefaction spatial extent and high damages costs. After this US database is complete, we hope to move onto events in other countries. As seen in the table, liquefaction losses can vary from almost nothing to hundreds of millions of dollars. Thus, properly estimating liquefaction losses can drastically change an earthquake's overall economic impact. Costs were estimated by gathering information about each event from government, reports, scientific papers, and news articles, determining which damages were likely due to liquefaction, and placing a value on the replacement cost for that damage from various other sources.

Event	Agriculture	Building	Residential	Transportation	Utilities	Total
2011 Mineral				$1,125		$1,125
2014 Napa			$5,625	$13,490	$3,783	$22,898
2003 Tecoman			$480,000	$70,014		$550,014
2003 San Simeon			$237,341	$316,189	$5,625	$559,156
2001 Nisqually		$944,716		$1,772,994	$45,594	$2,763,304
2018 Anchorage		$204,505	$1,837,486	$1,043,099	$26,089	$3,111,178
2002 Denali				$19,546,758	$7,065	$19,553,823
2010 Baja	$45,589,749	$4,807,511	$5,596,542	$731,543	$339,750	$57,065,096
1994 Northridge		$380,250	$97,855,251	$35,204,201	$11,666,831	$145,106,532
1989 Loma Prieta		$27,695,776	$46,523,703	$221,221,253	$40,859,527	$336,300,258
Total	**$45,589,749**	**$34,032,757**	**$152,535,948**	**$263,591,854**	**$52,953,479**	**$565,033,385**

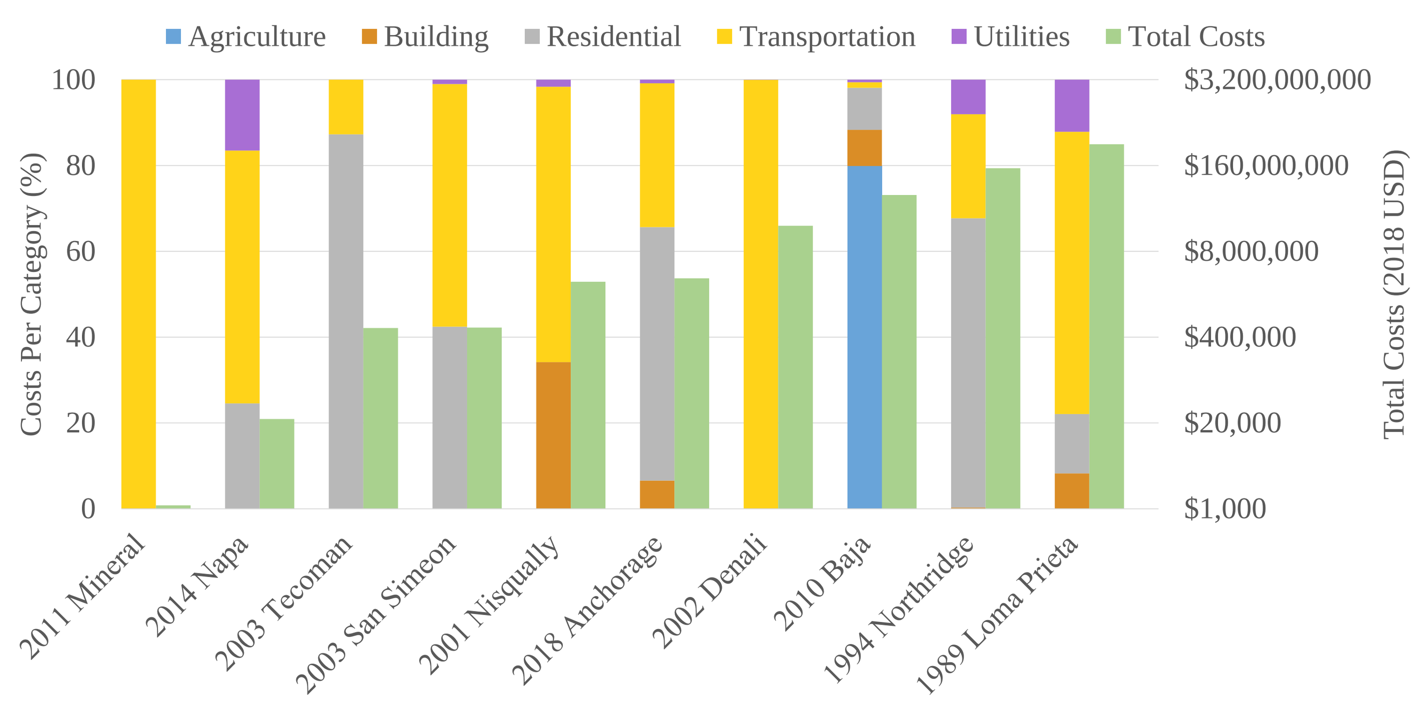

Figure 2: Percentages of the total costs by category and total cost for each event. From this plot, it is clear that damages categorized as transportation composed the majority of total costs for most events. We also see that events in rural areas such as Baja and Anchorage have higher costs in categories other than transportation.

2001 NISQUALLY EARTHQUAKE LIQUEFACTION

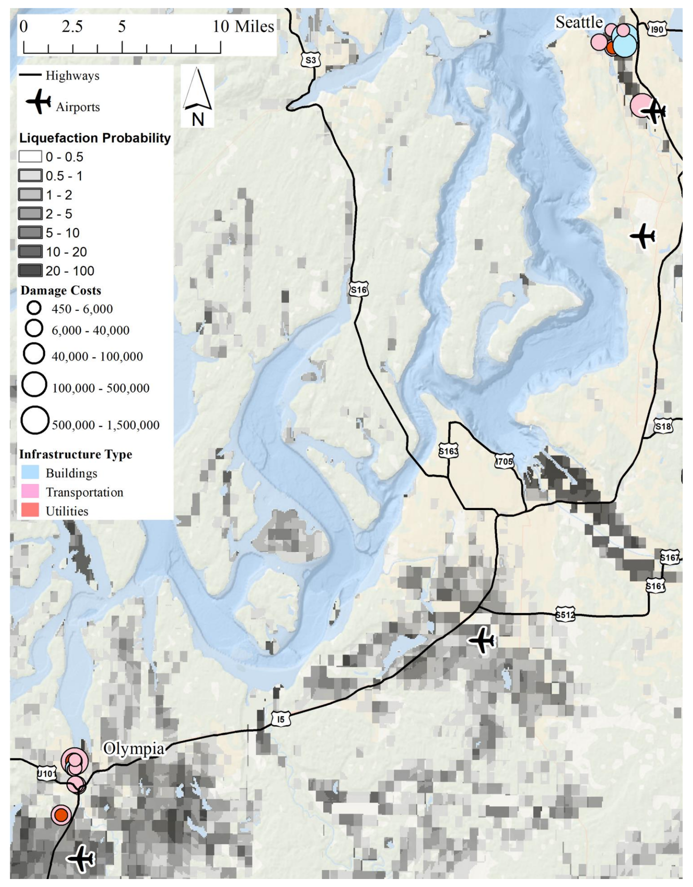

Figure 3: Nisqually earthquake LSE and liquefaction-related damage locations, infrastructure types, and costs.

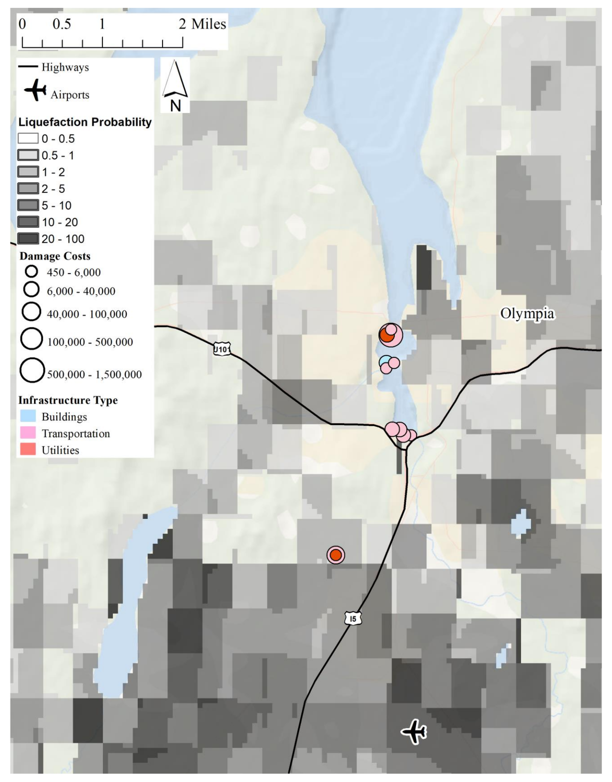

Figure 4: Nisqually earthquake LSE and liquefaction-related damage locations, costs, and categories, zoomed in to Olympia region.

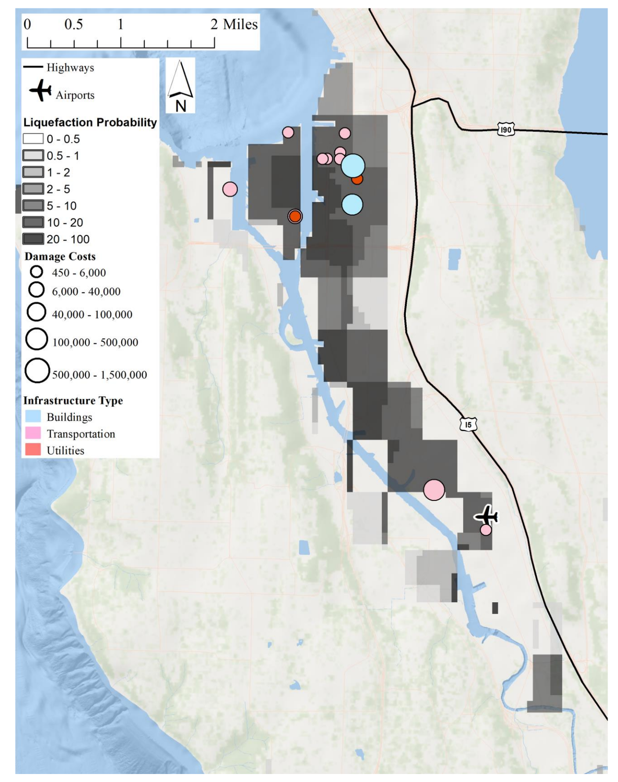

Figure 5: Nisqually earthquake LSE and liquefaction-related damage locations, costs, and categories, zoomed in to Seattle region.

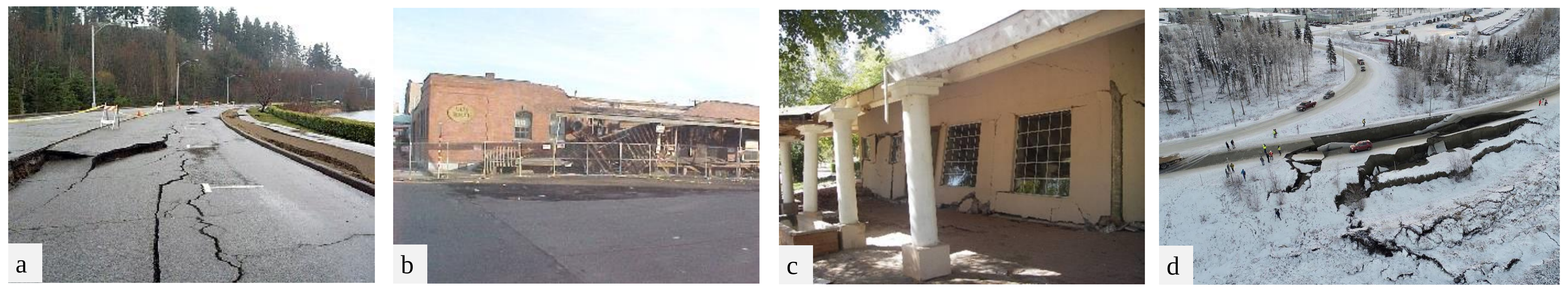

Figure 6: Liquefaction-related damages. **6a:** Damage to the Deschutes Parkway, Olympia, due to the Nisqually earthquake. **6b:** Damage to two adjoined brick buildings in Seattle, due to the Nisqually earthquake. **6c:** Residential damage due to lateral spreading in the 2010 Baja, California, earthquake, which resulted in demolition. **6d:** Road and embankment failure in Alaska due to liquefaction in the 2018 Anchorage earthquake. *All images sourced from geerassociation.org.*

Table 2: Detailed breakdown of Nisqually liquefaction-related damages, rounded to the nearest dollar in 2018 USD. Building cost estimates were found from RSMeans online building construction cost estimator. Each calculated cost was multiplied by 1.125 to account for shortages in material and labor in construction periods immediately following natural disasters. The cost for adjoined stucco buildings collapse is only 10% of the estimated cost for the two adjoined buildings, because we were only approximately 10% confident that the damage was due to liquefaction.

Category	Location	Description	Cost	Percent of Total
		Buildings		
Commercial	South Downtown, Seattle	Brick masonry building collapse	$797,151	28.85
	South Downtown, Seattle	Two adjoined stucco buildings collapse	$136,315	4.93
Public	Marathon Park, Olympia	Outhouse structure collapse	$11,250	0.41
		Transportation		
Parking	Boeing Field	2,000 sq ft road replacement, traffic class 3 of $8.85/ sq ft	$199,125	7.21
	Sunset Lake, Turnwater	1,000 sq ft road replacement, traffic class 2 of $8.17/ sq ft	$91,913	3.33
Port	Terminal 18, Harbor Island, Seattle	328 sq ft of thick cement, $18/sq ft	$6,642	0.24
	Terminal 18, Harbor Island, Seattle	Circular crack with vertical offset	$2,657	0.10
	Terminal 5, Harbor Island, Seattle	2300 sq ft cement replacement, $9/sq ft	$23,288	0.84
	Terminal 30, Harbor Island, Seattle	300 sq ft cement replacement, $9/sq ft	$3,038	0.11
	Port of Olympia	2 small road cracks, estimated $1,000 each	$2,250	0.08
Rail	South Downtown, Seattle	2 ground losses beneath rail ties, estimated $1,000 each	$2,250	0.08
	South Downtown, Seattle	Removal of sand boils from rails estimated $1,000	$1,125	0.04
	Marathon Park, Olympia	50 ft by 50 ft of cement replacement under rails, $9 /sq ft	$2,531	0.09
Road	Deschutes Parkway	96,880 sq ft road replacement, traffic class 4, $12.22/sq ft	$1,368,848	49.54
	Deschutes Parkway	67 cubic yards soil replacement, $33.5/cy	$2,525	0.09
	Deschutes Parkway	80 cubic yards soil replacement, $33.5/cy	$3,015	0.11
	Deschutes Parkway	12.9 cubic yards soil replacement, $33.5/cy	$486	0.02
	Deschutes Parkway	320 square feet cement replacement, $9/sq ft	$3,240	0.12
	Deschutes Parkway	20 cubic yards soil replacement, $33.5/cy	$15,829	0.57
	Deschutes Parkway	Cement and soil settled, replaced	$12,303	0.45
	Deschutes Parkway	Cement and soil settled, replaced	$18,798	0.68
Runway	King County International Airport	279 sq ft, $18/ sq ft	$5,650	0.20
	King County International Airport	115 sq ft, $18/ sq ft	$2,329	0.08
Sidewalk	Central West Deschutes Parkway	200 square feet of cement and soil replacement, est. $12/sq ft	$2,750	0.10
	South Downtown, Seattle	120 sq ft of cement, $9/ sq ft	$1,215	0.04
	South Downtown, Seattle	100 sq ft of cement, $9 sq ft, 1.18 cubic yards of soil at $33.5/ cy	$1,190	0.04
		Utilities		
Embankment	South Downtown, Seattle	1,000 cubic yards of soil replacement, $33.5 / cy	$37,688	1.36
Gas	Sunset Lake, Turnwater	1 gas pipeline rupture, est. $5,000	$5,625	0.20
Water	Terminal 18, Harbor Island, Seattle	2 water pipe rupture, est. $1,000 each	$2,282	0.08
Total			**$2,763,304**	

LIQUEFACTION LOSS ACROSS INFRASTRUCTRURE

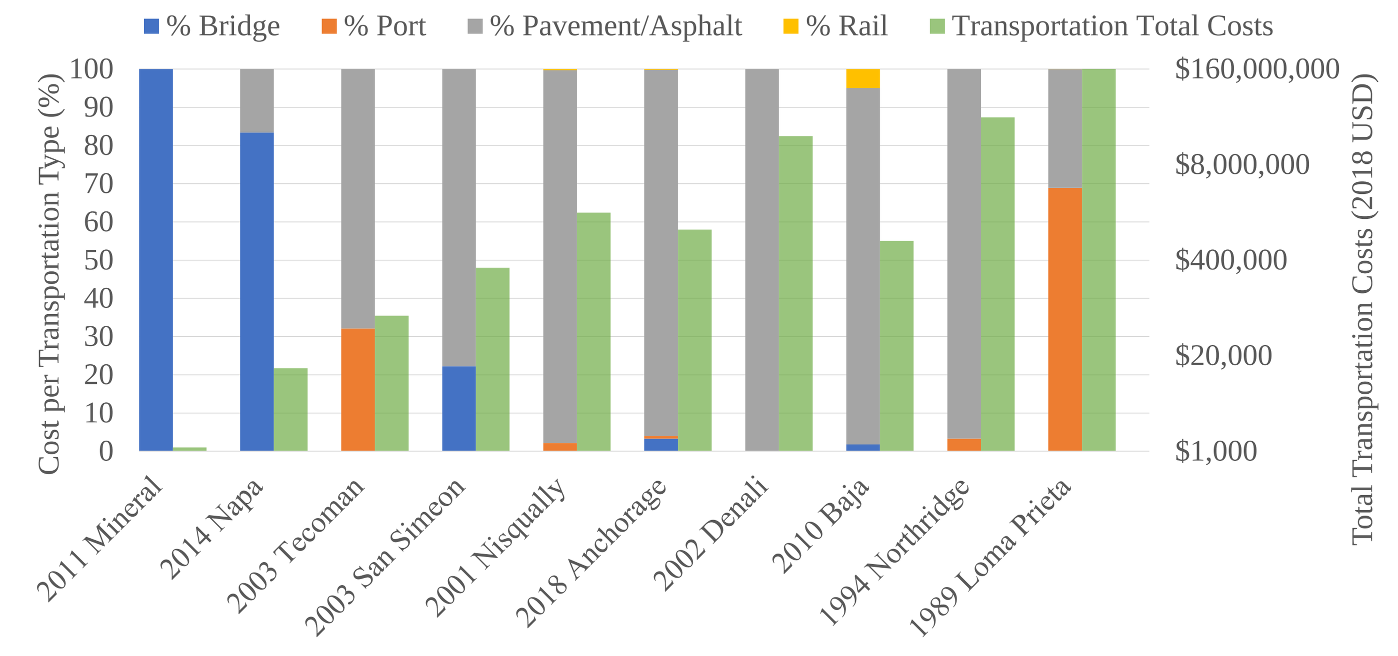

Figure 7: Percentages of the total costs by infrastructure type for transportation damages, sorted by total cost for each event. From this plot, we see that in the infrastructure category of transportation, most losses are composed of pavement or asphalt damages.

LIQUEFACTION LOSS VS. TLSE

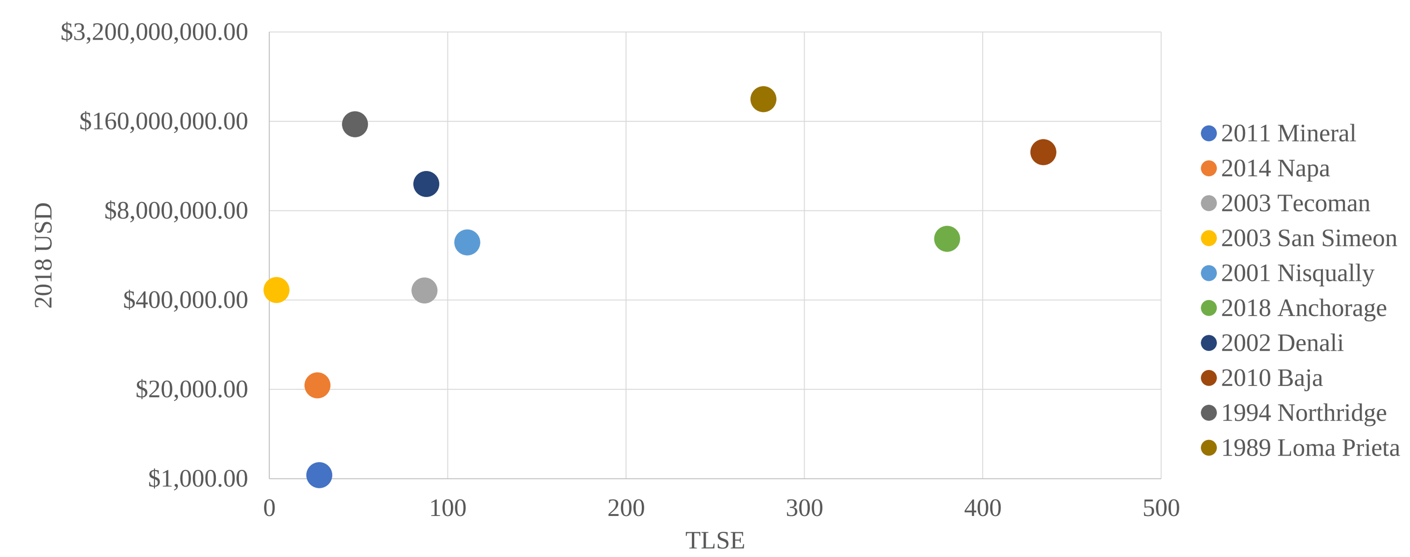

Figure 8: Liquefaction Damage Costs versus Total LSE for all events. As expected, estimated liquefaction-related damage costs follows an upward trend with increased modeled liquefaction spatial extent. TLSE is found by equation (4) in *Rashidian*, 2019.

FUTURE STEPS

The project's final goal is to use correlations of TLSE, damage costs, and GIS layers of liquefaction loss to estimate liquefaction loss. One step towards this predictive model will be normalizing liquefaction damage costs by population values. This will be accomplished by dividing the total damage costs for each subsection of a region by a value assigned to the subsection based on its population density. For example, in the Nisqually earthquake, we could assign a value of 5 to the subsection of Seattle, as it is heavily urbanized. Its liquefaction damage costs would then be divided by five, and replotted on the map seen in **figure 8.** We could then assign a value of 4 to the subsection including Olympia, as it is slightly less densely populated than Seattle, and divide the liquefaction damage costs in this area by 4 before replotting on **figure 8**. Next, our group aims to produce to increase the number of events in our database to increase accuracy of any models produced. In **figure 8**, this will decrease the variation of liquefaction damage costs explained by the variation in TLSE.

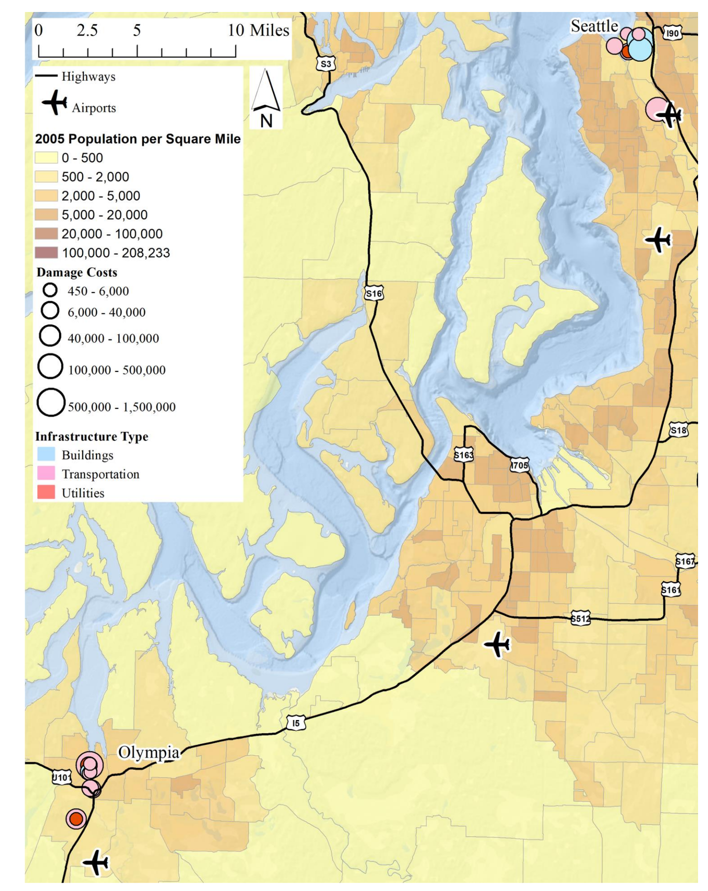

Figure 9: Nisqually population densities per square mile within census tracts and liquefaction-related damage locations, costs, and categories. Damage locations appear to be concentrated in areas of both high LSE and high population density.

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