Liquefaction Loss Clusters and Risk in the United States
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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. Prior to this project, I assembled a liquefaction loss database based on numerous past events with a focus on events in the United States. Using this database, this project assesses the locations of damages as well as a . 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.

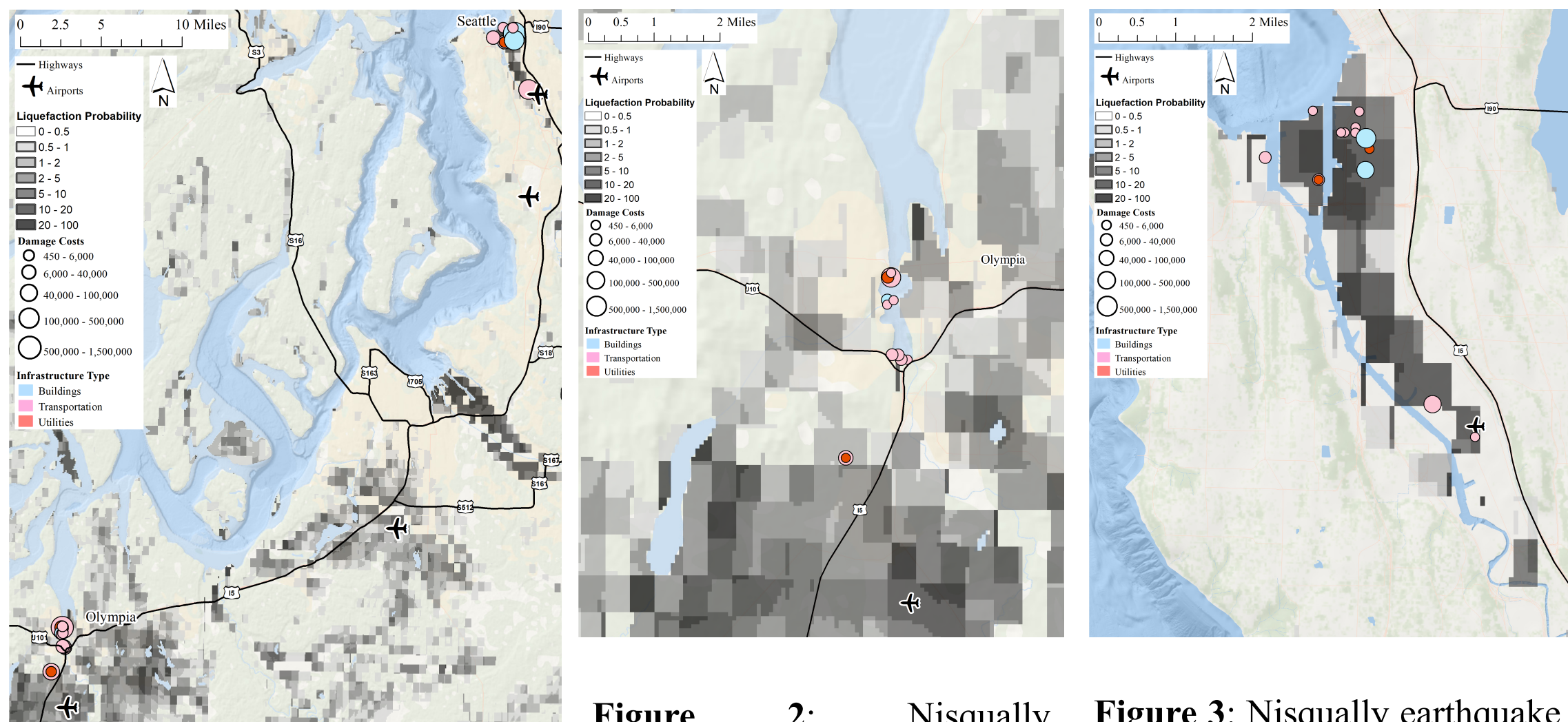## BACKGROUND: 2001 Nisqually Earthquake Liquefaction

Figure 1: Nisqually earthquake LSE and liquefaction-related damage locations, infrastructure types, and costs.

Figure 2: Nisqually earthquake LSE and liquefaction-related damage locations, costs, and categories, zoomed in to Olympia region.

Figure 3: Nisqually earthquake LSE and liquefaction-related damage locations, costs, and categories, zoomed in to Seattle region.

Table 1: 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	

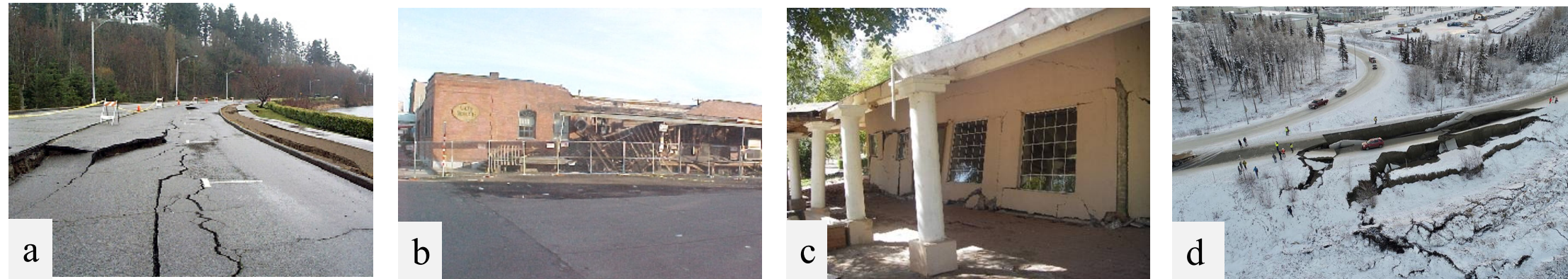## Liquefaction Damage Examples

Figure 4: Liquefaction-related damages which highlight the need for liquefaction estimations. **4a:** Damage to the Deschutes Parkway, Olympia, due to the Nisqually earthquake. **4b:** Damage to two adjoined brick buildings in Seattle, due to the Nisqually earthquake. **4c:** Residence damage due to lateral spreading in the 2010 Baja, California, earthquake, which resulted in demolition. **4d:** Road and embankment failure in Alaska due to liquefaction in the 2018 Anchorage earthquake.
All images sourced from the GEER Association geotechnical reports, 2001 – 2018.

METHODOLOGY: Infrastructure Proxies

A common method of assessing risk is to integrate hazards, exposure, and vulnerability. Vulnerability generally differs between countries, but remains relatively constant within each nation. When assessing risk at the national scale, vulnerability does not change much spatially. This suitability analysis calculates zones of risk based on a hazard (liquefaction spatial extent) and exposure (infrastructure proxies).

Many proxies were considered when visualizing infrastructure loss due to liquefaction. For the purpose of a simple suitability analysis, three proxies were chosen. Major highways and railroads were included as they make up many liquefaction damages in the Nisqually event. Additionally, many roads will be built near railroads and highways to assist in transportation, so these layers can also be thought of as proxies themselves. A buffer of 1,000 meters was placed around the highways and railroads before suitability. Population density is used as a proxy for the remaining infrastructure categories.
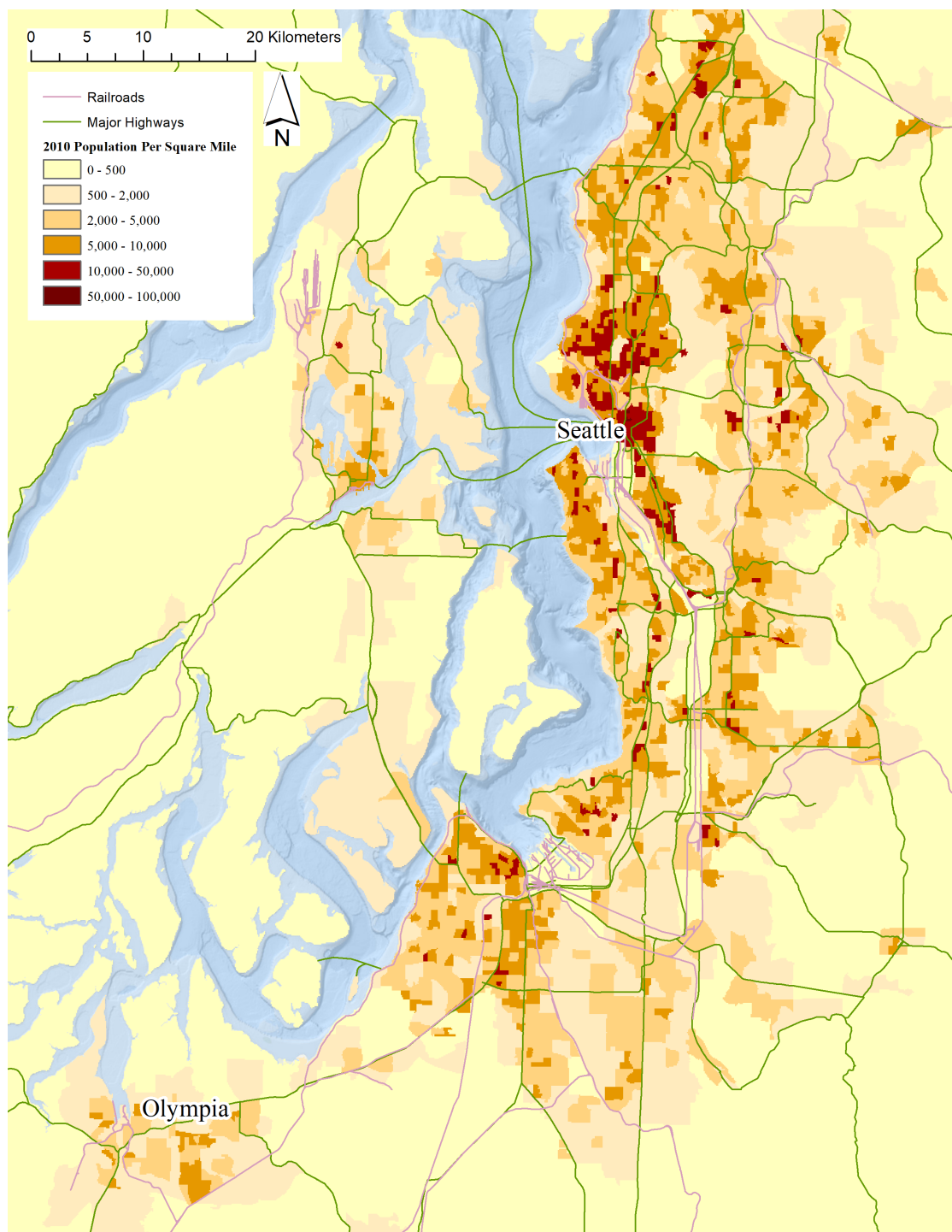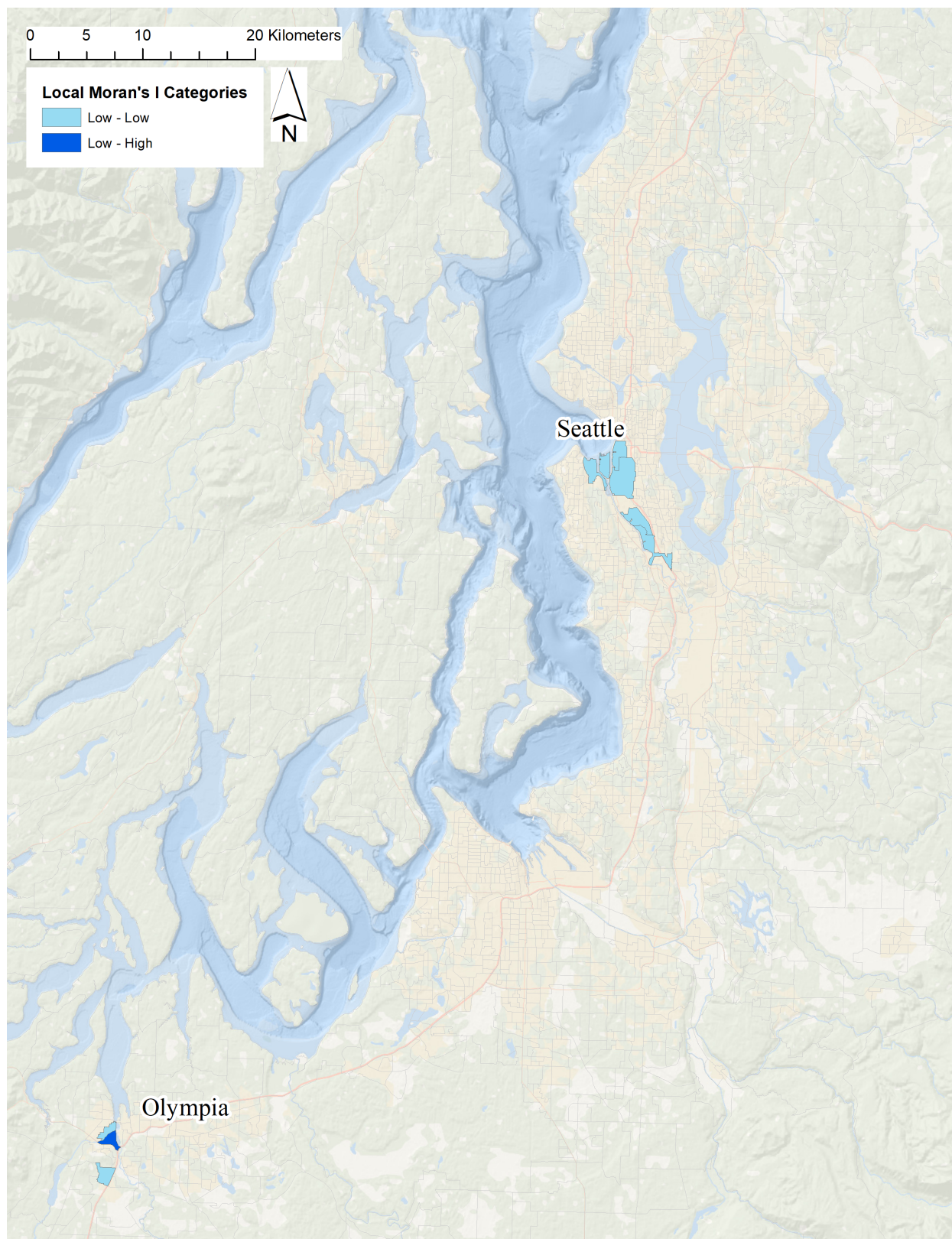
Figure 5: Proxies for infrastructure damaged by liquefaction used in the suitability analysis are population density, railroads, and major highways.

RESULTS & CONCLUSIONS: Assessing Damage Clusters

By spatially joining all of the damage values to the block groups within which they are located, a cluster analysis was completed using Local Moran's I. Resulting values explain whether block groups containing damages are part of a statistically significant cluster, are outliers, or are neither. Surprisingly, the analysis resulted in only seven block groups of low-low clustering and one block group of low-high outlier. This is because many damage points fall within only a few block groups. Thus, it appears that only a few block groups have high damage values, while groups immediately surrounding it have very low or zero values. By using blocks, the smallest form of census data, instead of block groups, we could determine more representative cluster and outlier values in these regions. Currently, the Tufts M Drive does not have blocks at a national level.

Figure 6: Calculating Local Moran's I for damages of each block group.

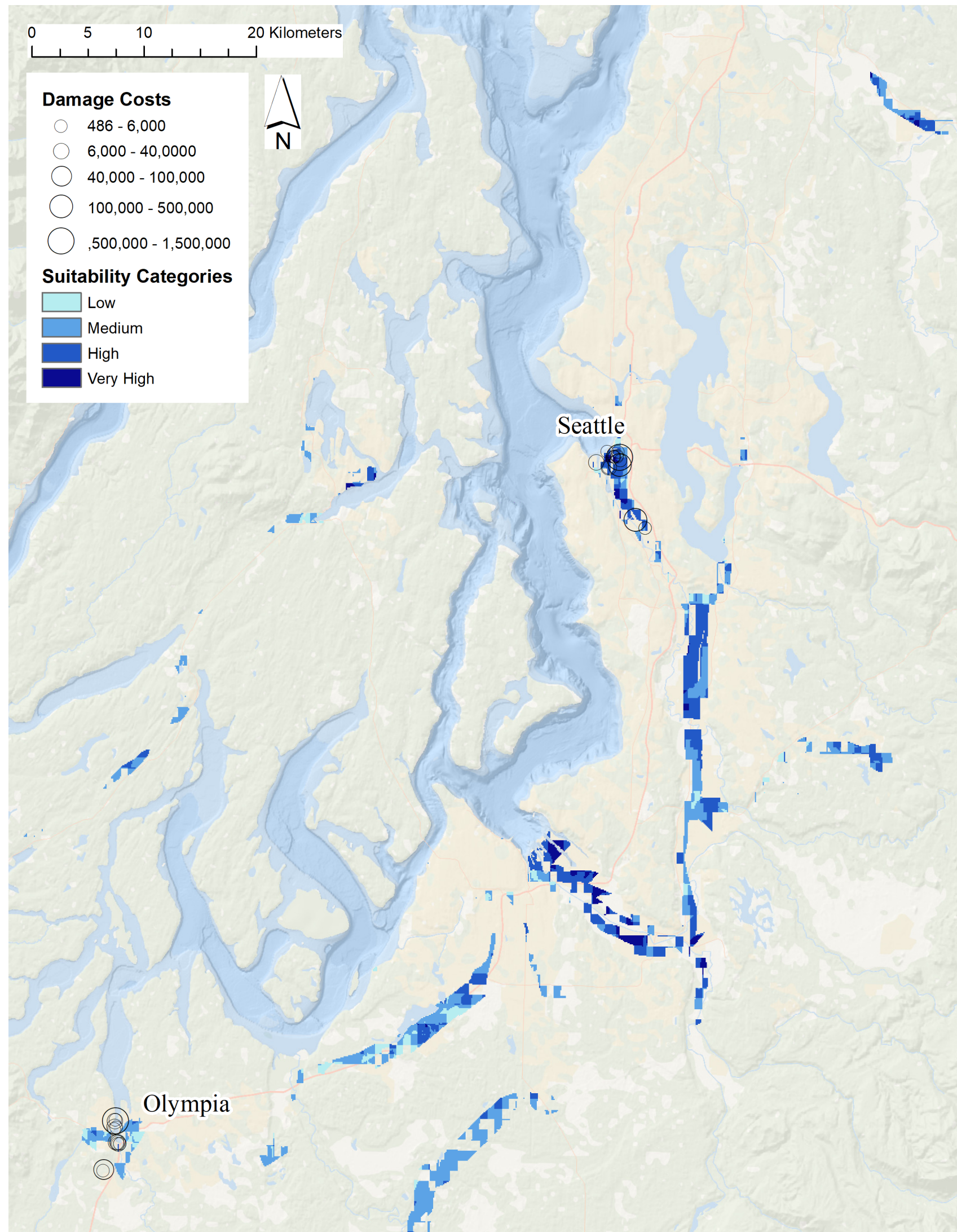## RESULTS & CONCLUSIONS: Suitability Analysis

Figure 7: Risk categories resulting from suitability analysis using liquefaction spatial extent (40%), population density (30%), major highways (20%), and railroads (10%).

A simple suitability analysis resulted in high risk categories of liquefaction damage in areas where damage was found, but also some in areas without any documented liquefaction damage. For this project, this is to be expected in some rural areas where railroads and highways both exist, but lack much other infrastructure. In other words, our proxies overestimate the amount of infrastructure. If more infrastructure proxy layers were integrated to the analysis and weighted properly, these areas of high risk in rural areas are expected to reduce significantly.

Additionally, our data collection may have some human error. When geotechnical engineers observe damage after earthquakes due to liquefaction, they may not focus as much on rural areas, so some liquefaction damages in these regions may go unreported.

Future Steps

As mentioned earlier, to obtain more representative Local Moran's I values, block census data will be utilized instead of block groups. This should help viewers more easily visualize the clusters of damage values in comparison with many kilometers of no liquefaction between clusters.

To improve the suitability analysis. In the future, a multivariate linear regression analysis will be conducted to estimate weights of each infrastructure proxy. This will allow us to assign more exact weights for the suitability rather than simple estimations.

More infrastructure layers or infrastructure proxies will also be included in future analyses. Ideally, all layers will be freely and easily available for others to reproduce my work in the future.

References

Bird, J., Bommer, J., Crowley, H., and Pinho, R. (2006). Modelling Liquefaction-induced Building Damage in Earthquake Loss Estimation. *Soil Dynamics and Earthquake Engineering, 26.1,*15-30.

Zhu, J., Daley, D., Baise, L., Thompson, E., Wald, D., and Knudsen, K. (2015). A Geospatial Liquefaction Model for Rapid Response and Loss Estimation. *Earthquake Spectra,* 31.3, 1813-837.

Zhu, J., Baise, L., and Thompson, E. (2017). An Updated Geospatial Liquefaction Model for Global Application. *Bulletin of the Seismological Society of America. Berkeley CA,* 107.3, 1365-385.

Whitman, R., Thalia A., Charles A., Lagorio, H., Lawson, S., and Schneider, P. (1997). Development of a National Earthquake Loss Estimation Methodology. *Earthquake Spectra,* 13.4, 643-61.

Rashidian, V., Baise, L. (2019) Regional Efficacy of a Global Geospatial Liquefaction Model. *In review.*