Washington State Airports Seismic Resilience Project

CYBERSECURITY & INFRASTRUCTURE SECURITY AGENCY

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Project Description

Earthquakes are a central concern of emergency management personnel and infrastructure owners and operators in the Pacific Northwest, where a Cascadia Subduction Zone (CSZ) earthquake could cause severe damage and disruption to communities and infrastructure systems throughout the region (CREW 2013). The ability of Washington State's transportation system to support post-disaster response, recovery, and mobility needs is critical to the overall seismic resilience of the region. State and federal agency response plans for a Magnitude 9.0 (M9.0) CSZ earthquake outline a logistical response in which disaster logistics supply chains are established to transport, receive, organize, and distribute disaster relief supplies and equipment from around the country for transshipment to local communities (FEMA 2013). During initial response and recovery, emergency planners anticipate that air transportation will constitute the primary mode for moving goods and resources into the region, as key surface transportation systems (e.g., maritime, road, rail) are likely to be damaged and require repair.

The Federal Emergency Management Agency (FEMA) and the Washington Emergency Management Division (Washington EMD) have pre-identified numerous airports across Washington State as potential locations to serve as staging areas for planned post-disaster logistical supply chains. Airports serve this critical function as supply-chain staging areas due in part to the importance of air transportation for disaster response and recovery, but also due to the unique configuration of airports. Most airports also have full perimeter fencing, which enables secure storage of disaster response resources, as well as extensive paved areas, which facilitate the storage, sorting, and distribution of bulk materials.

State and regional exercises and studies have underscored the need to better understand the seismic vulnerability of regional transportation systems to a CSZ earthquake, and to enhance the resilience of those systems (FEMA 2016, Resilient Washington State Subcommittee 2012). In response to this need, and in collaboration with state and local partners, the Cybersecurity and Infrastructure Security Agency (CISA) sponsored two 3-year projects through its Regional Resiliency Assessment Program (RRAP), one in Washington (concluding in 2019) and one in Oregon (concluding in 2021). These projects assessed the ability of statewide and regional transportation systems to support the movement of post-disaster emergency response and recovery supplies throughout each state and to communities following a CSZ earthquake. In Washington, the focus of the RRAP project was on state highway systems, maritime transportation, and rail transportation; in Oregon, the focus was on statewide roadways, maritime transportation, and airports (CISA 2019, 2021).

Recognizing the need to better understand the resilience posture of airports in Washington, officials in CISA Region 10 worked with counterparts at the Washington EMD and the Washington State Department of Transportation's Aviation Division (WSDOT Aviation) to facilitate this supplemental study of 20 airports across Washington. The purpose was to complement the assessment of 12 airports in Oregon under the Oregon RRAP project and therefore provide a regional perspective on airport resilience to a CSZ earthquake.

This Washington State Airport Seismic Resilience Project occurred over a 2-year period beginning in 2019, and focused on 20 airports (shown in figure 1) identified in coordination with Washington EMD, WSDOT Aviation, and FEMA Region 10. These 20 airports are either identified in existing CSZ response plans to serve as post-disaster logistics staging areas or are currently under consideration for this role in future CSZ plans. The research team visited eight of these airports in person and 12 airports virtually to collect information about each airport's capabilities through a facilitated discussion with airport personnel and, in many cases, regional emergency managers and infrastructure owners and operators.[1] The in-person visits also included a physical tour of the airport facilities. Airport personnel conducted virtual tours—using satellite imagery, Google Street View, and other tools—at the 12 other airports.

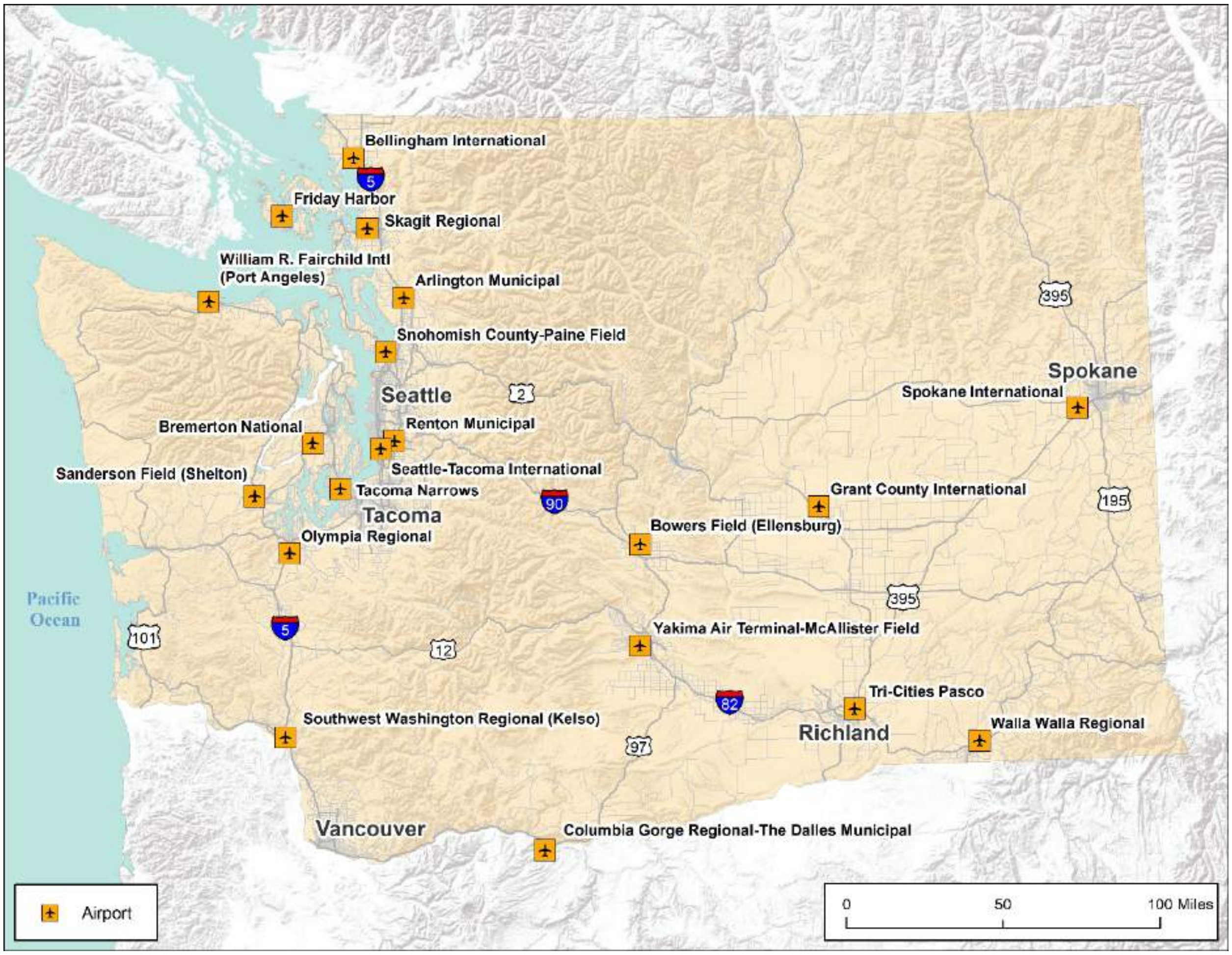

FIGURE 1.—Airports Visited and Assessed Under the Washington State Airports Seismic Resilience Project.

The primary analytical outcomes of this project are intended to provide state and federal planners with a better understanding of how well airports across Washington could support post-disaster response and recovery logistics functions, and also to highlight potential resilience enhancement actions that could better position airports to serve in such capacities. To accomplish this, the research team focused on three lines of effort as part of this project:

1. Collect relevant hazard data and analyze each airport's exposure to characterize relative vulnerability to potential CSZ-related impacts;
2. Screen airport runways for vulnerabilities to seismic-induced soil/ground failure, which could affect these facilities and potentially disrupt or disable air operations; and

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[1] The project's original intent was to visit all 20 airports to conduct in-person assessments, but due to the COVID-19 pandemic, the research team shifted to virtual site visits in the spring of 2020.

3. Synthesize the findings from facilitated discussions with personnel from each airport to summarize overall airport resilience capabilities, as well as airport dependencies on external lifeline infrastructure systems necessary to maintain air operations.

This report begins with background on the CSZ and relevant hazards considered in this project's analysis. It then outlines results from the hazard exposure analysis, runway liquefaction risk assessment, and the facilitated discussions with airports. It concludes with a series of key findings that result from the analysis for consideration by federal, state, and local officials. Each key finding is accompanied by a series of resilience enhancement options that partners could explore to improve resilience.

Stakeholders

WSDOT Aviation and Washington EMD worked with CISA Region 10 to jointly develop this project and coordinate with local airport officials on data collection visits. WSDOT Aviation and Washington EMD's continued involvement in this project ensured that project outcomes align with regional needs. Additional stakeholder organizations that provided input on the project's scope, approach, methodologies, analytical outcomes, and key findings include the following:

- U.S. Department of Defense
    - U.S. Transportation Command (USTRANSCOM)
    - U.S. Northern Command (USNORTHCOM)
- DHS
    - FEMA

In addition to these core stakeholders, the project research team met with numerous other state, regional and local stakeholders, and visited—either physically or virtually—20 airports across the state. Appendix A contains a full list of stakeholder organizations.

Analytical Activities and Outcomes

Background on the CSZ and Hazards Assessed

The CSZ is a megathrust fault zone located off the west coast of North America that stretches approximately 700 miles from northern Vancouver Island, Canada, to Cape Mendocino, Calif. (figure 2). Along this fault, three regional tectonic plates—the Explorer, Juan de Fuca, and Gorda plates—are pulling away from the larger Pacific plate and moving toward the North American plate. At the North American plate boundary, these three regional plates are descending—or subducting—underneath the North American plate (figure 3). As this subduction occurs, "a large portion of the boundary between the subducting and overriding plates resists the convergent motion, until this part of the boundary breaks in a great earthquake" (CREW 2013). Historic records suggest that the last such great earthquake along the CSZ boundary occurred in January 1700 with an estimated magnitude of 8.7–9.2 (Atwater et al. 2015). Furthermore, paleoseismology studies evaluating centuries' worth of seismic history in the region have identified numerous prior earthquakes that occurred as early as 1400 BC (Atwater et al. 2003). These studies place the likelihood of a major CSZ earthquake occurring in the next 50 years at approximately 10 percent (Goldfinger et al. 2012).[2]

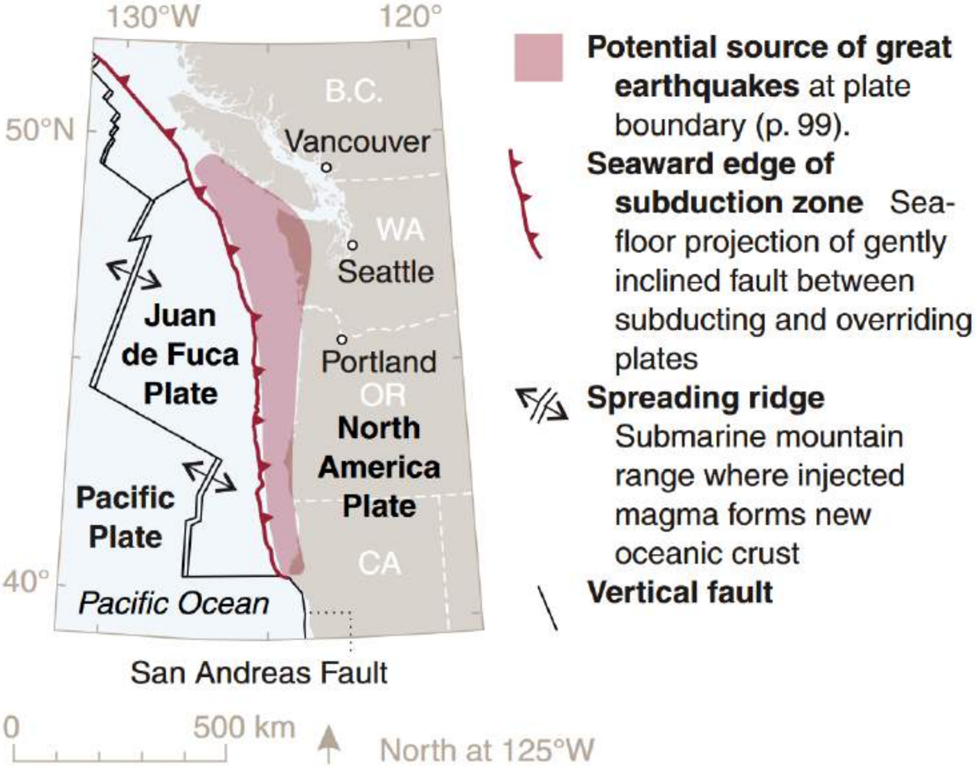

FIGURE 2.—CSZ Geographical Extent. (Source: Atwater et al. 2015)

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[2] Goldfinger et al. (2012) note that "time-independent probabilities for segmented ruptures range from 7–12 percent in 50 years for full or nearly full margin ruptures to ~21 percent in 50 years for a southern-margin rupture. Time-dependent probabilities are similar for northern margin events at ~7–12 percent and 37–42 percent in 50 years for the southern margin."

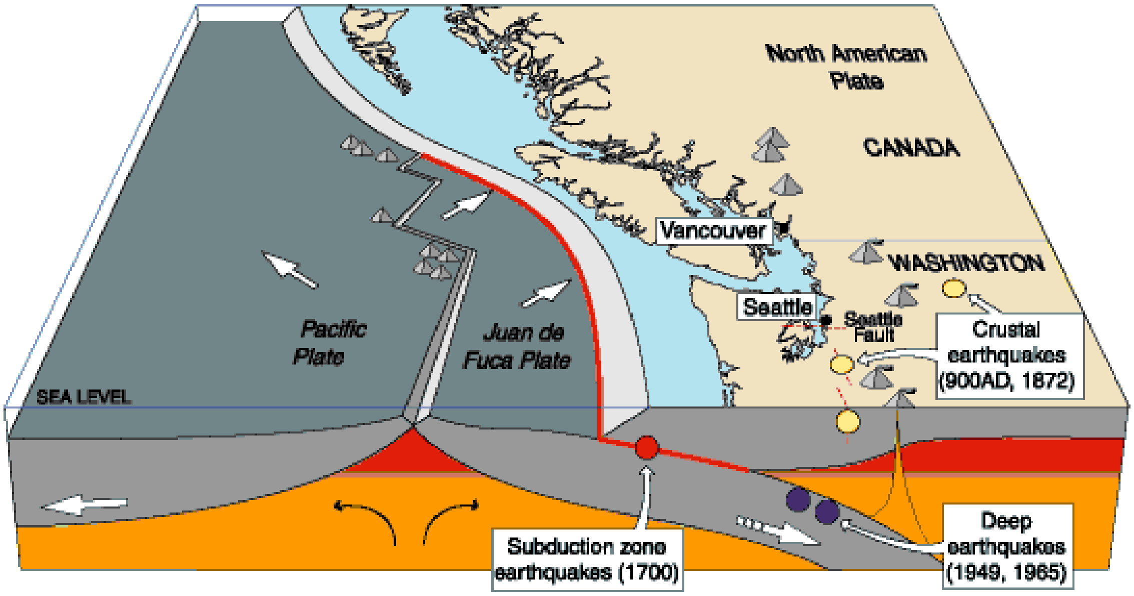

FIGURE 3.—Plate Tectonics in the CSZ. (Source: Wells et al. 2016)

Scientists project that a CSZ earthquake could occur with a magnitude of 9.0 and that the ground could shake for several minutes, releasing tremendous amounts of energy that could damage infrastructure and affect communities along the west coast of the United States and Canada. Since the mid-20th century, several other subduction zone earthquakes have occurred around the Pacific region that provide context for what the Pacific Northwest region could experience during a CSZ earthquake. These include an M9.2 earthquake in Prince William Sound, Alaska (1964); an M9.1 earthquake in Aceh-Andaman, Sumatra (2004); an M8.8 earthquake in Maule, Chile (2010); and an M9.0 earthquake in Tohoku, Japan (2011) (CREW 2013).

The primary hazard associated with a CSZ earthquake is strong and prolonged shaking, or ground motion, and the forces that such shaking can impart on infrastructure and the built environment. However, the primary earthquake can also trigger several secondary hazards associated with a CSZ earthquake. Of greatest consequence to airports, this study considered a limited number of secondary hazards, including ground failure (e.g., liquefaction, ground displacement or deformation) and tsunamis. While other secondary hazards can be triggered by the primary earthquake (e.g., landslides, rock falls, avalanches), the research team surveyed these other potential secondary hazards at the 20 airports and found that the airports' exposure to these potential hazards was either negligible or nonexistent. This section discusses the several hazards associated with a CSZ earthquake that this project considered, the supporting hazard data and information available that the research team used to inform this study's analysis.

Ground Motion

Ground motion is the most apparent and direct hazard associated with an earthquake. The size of an earthquake is expressed most commonly (by U.S. Geological Survey [USGS] and others) using the Moment Magnitude Scale (MMS), which quantifies the amount of energy that an earthquake releases (USGS undated[a]). In this project, the core stakeholder group agreed that the "USGS M9.0 Scenario Earthquake – Cascadia M9.0 Scenario (mean value)" should form the basis for all analysis (USGS undated[c]). This USGS CSZ scenario is a 2017 update to an earlier 2011 USGS scenario that the Cascadia Region Earthquake Workgroup (CREW) identified for use in regional catastrophic planning (CREW 2013), and it was also the basis for analysis in the Washington State Transportation

Systems RRAP and Oregon Transportation Systems RRAP projects (CISA 2019, 2021). Earlier versions of this USGS CSZ scenario were also used in the National Infrastructure Simulation and Analysis Center / Homeland Infrastructure Threat and Risk Analysis Center study, the Cascadia Rising 2016 exercise, and FEMA's *CSZ Catastrophic Earthquake and Tsunami Response Plan (Ver. 2.0)* (FEMA 2013, 2016; NISAC and HITRAC 2011).[3]

Peak ground acceleration (PGA) is a quantitative measure of shaking intensity that is commonly used in infrastructure-related seismic design specifications and building codes. Whereas MMS is a measure of an earthquake's overall size, PGA is a location-specific measure of ground shaking intensity that can be used to approximate the seismic forces that a specific location or structure will experience during an earthquake.[4] PGA is the primary metric for earthquake intensity used in this study to assess the vulnerability of Washington's airports to ground motion. Figure 4 shows the Geographic Information System (GIS) data collected from the USGS for PGA projected across Washington under the USGS M9.0 CSZ scenario. The strongest shaking is projected to occur in the coastal, Olympic Peninsula, and southwestern parts of the state, and it will generally diminish moving east across the state. The USGS scenario study area ends at approximately 118° west longitude (just west of Spokane) with projected PGA values of approximately 0.04*g*. Minor shaking of 0.04*g* or less could still be expected to occur east of the USGS scenario study area in eastern Washington.

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[3] The University of Washington and the USGS's current "M9 Project" (University of Washington 2021) offers improved characterization of a CSZ earthquake using dozens of scenarios; the research team, with the agreement of the core stakeholder group, decided to use the USGS M9.0 CSZ scenario to enable more consistent regional planning with the Washington State Transportation Systems RRAP project (CISA 2019).

[4] PGA is expressed as an acceleration in units of g; 1 g is the Earth's gravitational acceleration, or 9.81 m/s^2.

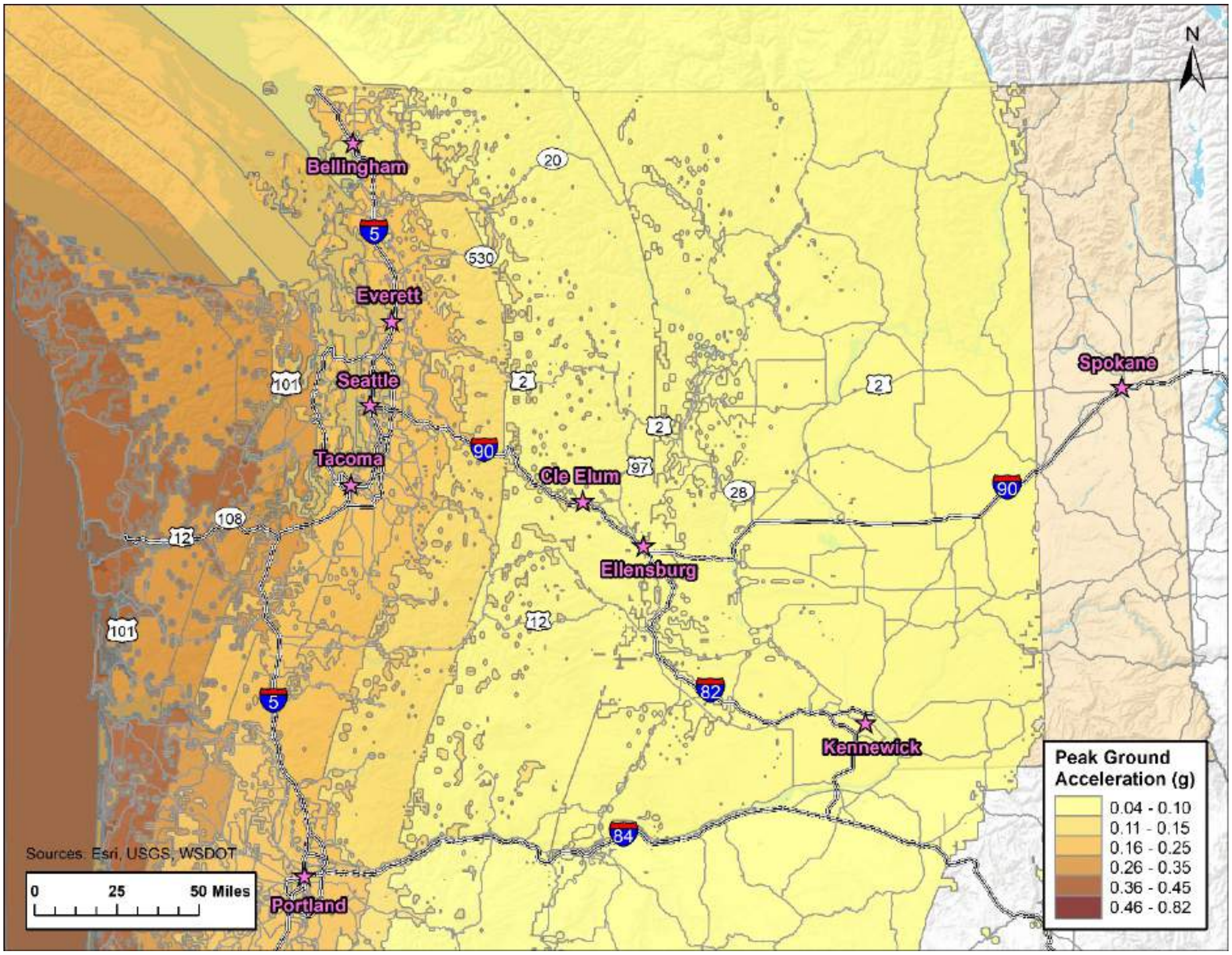


FIGURE 4.—Projected PGA for Washington under the USGS M9.0 CSZ Scenario.

Subduction earthquakes, in general, typically experience a longer duration of shaking as compared with other types of earthquakes, which increases the potential for structures to sustain damage or to fail. The duration of shaking for a CSZ earthquake is projected to range from 2–6 minutes (CREW 2013). The effects of longer-duration shaking on structures have not been widely studied, and current seismic design specifications and codes do not explicitly consider shaking duration in structural design and assessment practices (Chandramohan 2016). The earlier Washington State Transportation Systems RRAP project (CISA 2019) had incorporated some findings from this nascent field of research to account for the effects of longer-duration shaking on bridge structures, but this study made no special considerations to incorporate the effects of long-duration shaking on airport systems.

Strong aftershocks commonly occur in the hours, days, weeks, and months following subduction earthquakes. It is likely that strong aftershocks following a CSZ earthquake will cause additional damage to structures in the region; however, the occurrence of aftershocks and their impacts on already degraded infrastructure are impossible to predict. For these reasons, the core stakeholder group agreed that this study would focus on assessing impacts and vulnerabilities associated with the primary M9.0 earthquake and would not attempt to address the impacts of aftershocks on Washington airports.

Ground Failure

Ground failure refers to a range of secondary hazards that an earthquake can trigger, in which ground and soils become unstable, shift, flow, or lose their load-bearing capacity and ability to support structures. Such types of failures can include soil liquefaction, landslides, rock falls, lateral shifting, sinkholes, and others. Given the typically flat geography of airport properties, the research team found that ground failures related to steep slopes (e.g., landslides, rock falls) at airports would have, at best, negligible impacts to airfields or supporting facilities. Therefore, this study limited its consideration of ground failures to soil liquefaction.

Soil liquefaction (also referred to as liquefiable soils) refers to the phenomenon where certain types of soils that are saturated with water can behave like a liquid when they experience seismic shaking. Liquefaction can result in the loss of support for surface structures (e.g., buildings and bridges), in soil flows on even very gentle slopes, and in large differential settlements where areas of the ground surface sink in comparison to nearby or surrounding soils. Soil liquefaction occurs typically in alluvial soils—loose sand and silty soils that are characteristic of river valleys, river deltas, and other areas with flowing water (USGS 2016). Washington Department of Natural Resources (DNR) maintains a statewide geospatial database that characterizes soil liquefaction susceptibility in the top-most layer of soil for all of Washington (figure 5) (DNR 2010). This dataset served as the primary basis for analyzing seismic-related ground failure impacts to the statewide surface transportation system in Washington State.

As figure 5 shows, highly liquefiable soils in Washington State occur most frequently along river valleys, with some broader concentration of soils with very low to low liquefaction susceptibility in the low-lying areas surrounding these rivers and streams. Soils with some liquefaction susceptibility—ranging from very low to high—underlay much of the Puget Sound region.

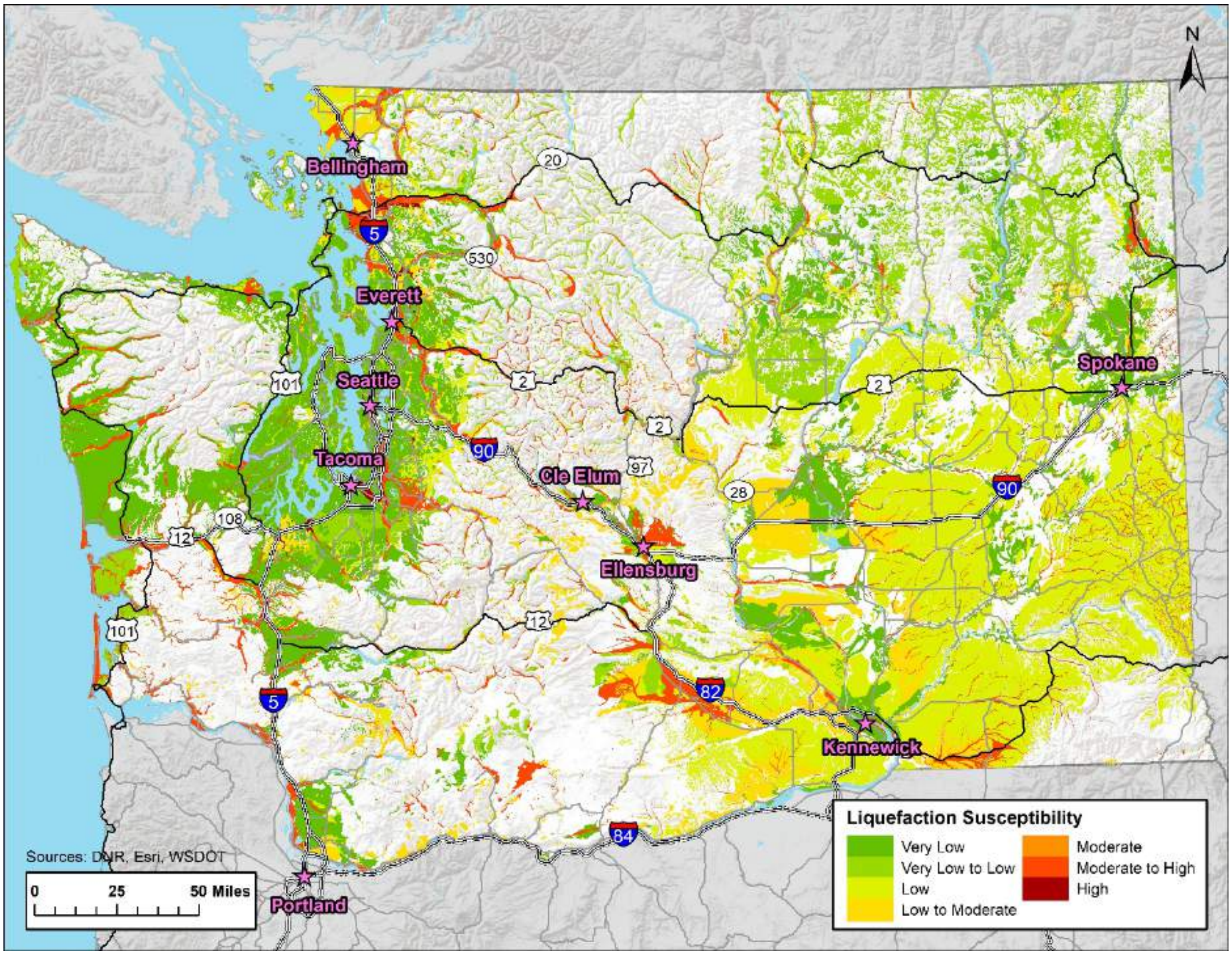


FIGURE 5.—Soil Liquefaction Susceptibility in Washington.

The impacts of seismic-induced soil liquefaction to infrastructure are commonly quantified as permanent ground deformation (PGD), which refers to the vertical and lateral deformation of soil resulting from soil liquefaction, as measured in inches or feet of displacement. PGD can create significant disruptions to regional transportation systems. In particular, runways, taxiways, and ramp areas at airports can sink or shift, similar to roadways, creating significant discontinuities or cracking. These disruptions could prevent aircraft from safely operating; critical structures such as air traffic control facilities, navigation systems, fuel storage facilities, and piping systems could experience foundation damage due to deformation or differential settlement.

FEMA's Hazus natural disaster risk model uses PGD as the primary measure of seismic-induced ground failure to evaluate infrastructure impacts. Accordingly, this study uses PGD as the primary metric for ground failure to assess airport vulnerability to seismically induced soil liquefaction, with a primary focus on airfield runways. PGD is projected in this study using a method adapted from by Bardet, Mace, and Tobita (1999), which the research team originally applied to evaluate CSZ-induced liquefaction impacts as part of the Washington State Transportation Systems RRAP project (Wilkey et al. 2019).

Tsunamis

A tsunami is a large ocean wave (or series of waves) that occurs when some incident or disruption displaces a large volume of water. In the context of a CSZ earthquake, the fault rupture causes the sudden movement of tectonic plates, displacing the ocean floor and propagating an ocean wave. The amplitude of the wave will increase as it travels out from the fault line and approaches shallower water near the coastline. The first CSZ tsunami wave is projected to reach the coastline within 20 to 30 minutes of the initial earthquake with wave heights up to 30 to 40 feet. Given experiences with similar coastal subduction zone earthquakes around the world, subsequent large waves could follow this initial tsunami wave in the hours following the earthquake (CREW 2013).

Tsunamis are only of concern at airports in Washington located on low-lying land on the Pacific coast or along Puget Sound. The large volume of water moving inland can inundate infrastructure for hours or days until floodwaters drain and subside. Tsunami waves can impose tremendous lateral forces on structures, resulting in extensive damage or failure. If flooding is prolonged, water infiltration into runway and apron subgrades could lead to the accelerated deterioration of pavement structures.

DNR publishes GIS datasets representing tsunami impacts along Washington State's shorelines, each of which aggregate a number of smaller studies conducted along portions of the state's coastline. The Washington State Transportation Systems RRAP project incorporated two of DNR's tsunami inundation datasets. The first dataset, the 1A Scenario, contains projected tsunami inundation data associated with a 500-year tsunami event; the second dataset, the L1 Scenario, contains projected tsunami inundation data associated with a 2,500-year event. In 2021, DNR released the Extended L1 Scenario, which characterizes the entirety of Puget Sound, and a greater extent of Washington's Pacific coastline (Dolcimascolo et. al, 2021). Figure 6 shows the modeled inundation area for the Extended L1 scenario, which was used as the basis for analysis in this project.

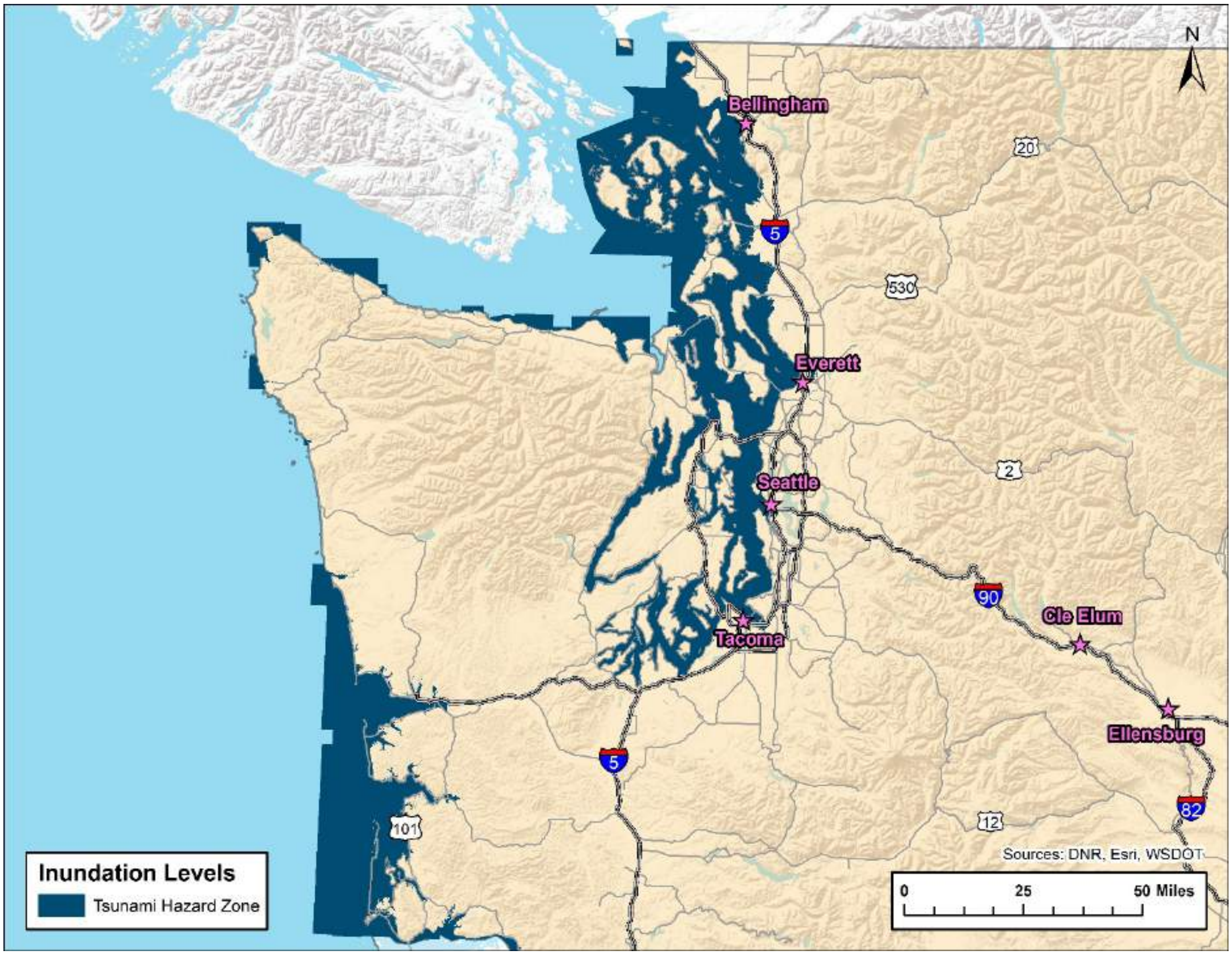


FIGURE 6.—Comparison of Tsunami Inundation Datasets from Washington DNR.

Airport Assessments

Airports will be vital to post-earthquake response and recovery activities, serving as logistics staging areas. To assess the ability of airports to perform this critical disaster response role, the research team conducted three analytical activities. First, the research team conducted an airport hazard exposure analysis to assess the relative vulnerability to potential CSZ-related impacts. Second, the research team conducted a runway liquefaction screening analysis to assess the relative risk of runway pavements to potential liquefaction-related disruptions. Third, the research team visited each airport to participate in a facilitated discussion with airport personnel, and then synthesized the findings from those discussions to provide a baseline understanding of each airport's overall resilience capabilities and also their dependencies on external lifeline infrastructure systems. The following sections describe these analyses and their outcomes in greater detail.

Airport Hazard Exposure Analysis

The most important feature of an airport is the airfield itself—the runways, taxiways, aprons, and ramp areas that facilitate the arrival, departure, and ground movement of aircraft. For these pavement-based assets, the greatest concern in a seismic disaster is ground failure, whether it occurs through liquefaction and vertical displacement of soils, lateral shifting, or slope failures within the vicinity of pavements. Any of these effects can cause discontinuities or failures in pavements sufficient to prevent the movement of aircraft. In fact, staff at many of the airports visited either explicitly stated that liquefiable soils were of immediate and ongoing concern for their facilities in the context of a CSZ earthquake, or they indicated that site conditions indicative of liquefiable soils (e.g., wetlands, rivers and streams, frequent flooding) exist at their facility. Therefore, the research team first assessed the exposure of the 20 airfields to liquefiable soils using DNR data. Appendix B contains the full set of maps showing airport facility exposure to potential soil liquefaction; a screening analysis of liquefaction-induced PGD is presented in the next section.

Four of the airports assessed—Bellingham International, Skagit Regional, Tacoma Narrows, and William R. Fairchild (Port Angeles)—are situated near the coastline. While tsunami inundation under the 2,500-year L1 scenarios is not projected to extend inland to within the boundaries of these four airports, tsunami wave forces could disrupt local lifeline infrastructure (e.g., electric power, transportation) upon which airports depend for their operations. Therefore, the research team mapped tsunami inundation extents at these four airports for broader situational awareness among state and federal planners.

Enclosed bodies of water, such as lakes, reservoirs, or ponds, can experience seismic seiches, which occur when a standing wave forms in the water body as a result of seismic ground motions (USGS undated[b])—a phenomenon similar to "water sloshing back and forth in swimming pool, bathtub, or cup of water" (NOAA undated). During the previous Washington State Transportation Systems RRAP project, state researchers and officials expressed concern that a seismic seiche could form in Lake Washington, in Seattle. For example, Renton Municipal is located on the southern shore of Lake Washington and could experience some flooding if a seismic seiche formed in the lake. The research team was unable to locate sufficient data to evaluate the vulnerability of Renton Municipal airport to CSZ seismic seiche-related flooding. As such, further study is required to confirm that airports actual flood vulnerability, which would depend on numerous factors including the location of the epicenter, earthquake intensity, lake level, and other factors.

Airport Runway Liquefaction Screening Analysis

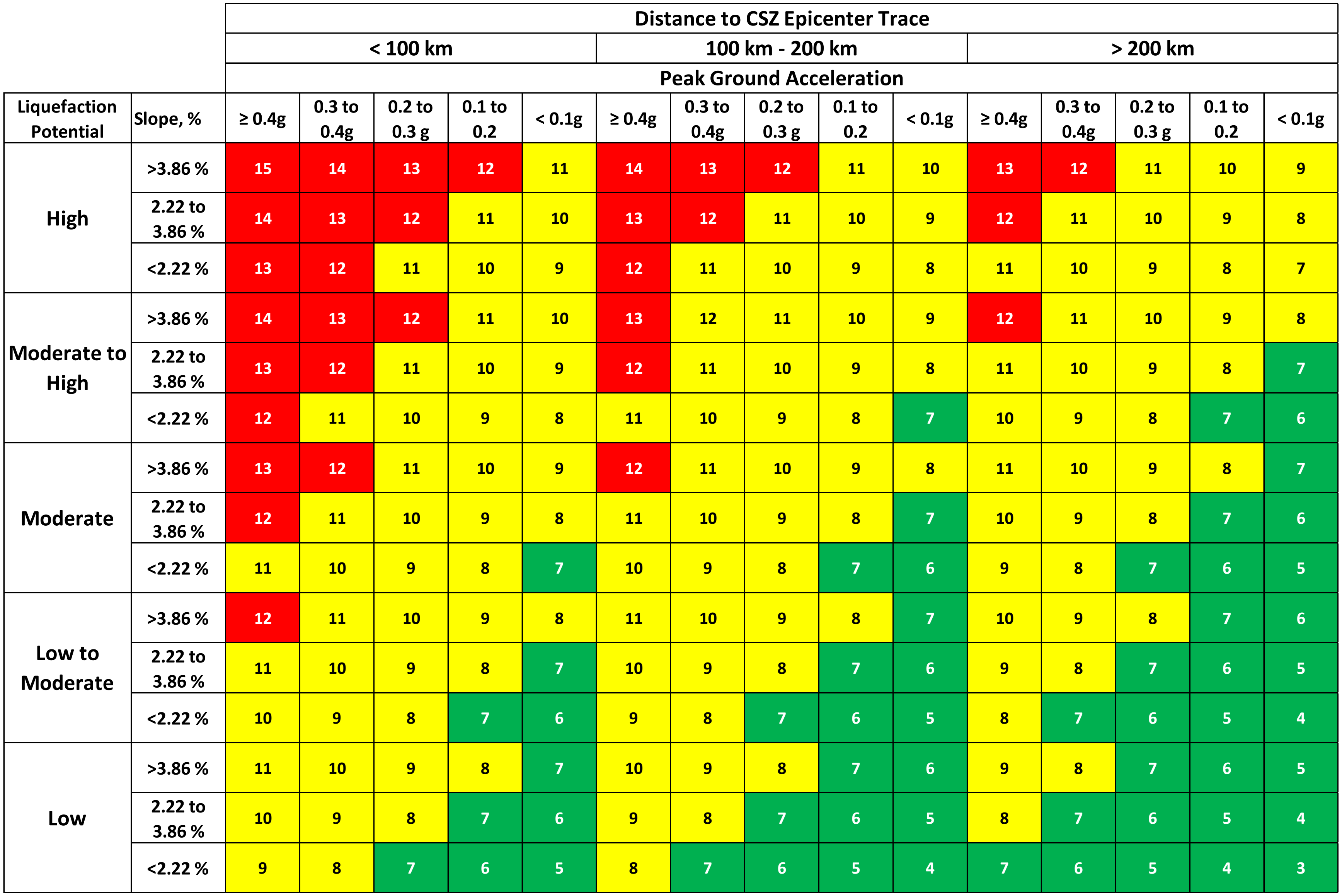
In addition to developing hazard exposure maps for liquefaction and tsunami for each airport, the research team conducted a screening-level analysis of liquefaction-induced PGD impacts to runways at the 20 airports evaluated in this study. This analysis provides federal and state emergency managers and planners with an indication of the relative liquefaction risk present at airports across the state. In addition, these outcomes can inform the prioritization of more detailed, in-depth geotechnical engineering analyses of airport soils, pavements, and facilities. For results, a relative risk matrix ranks airports according to the vulnerability of their runways to PGD impacts. The following section briefly outlines the methodology; Appendix D contains a more detailed discussion.

The research team evaluated the relative risk of liquefaction at the 20 Washington airports using a method adapted from a deterministic PGD estimation approach developed by Bardet, Mace, and Tobita (1999). The relative liquefaction risk at each airport is calculated as a function of four parameters related to site and seismic conditions at representative points along each airport's runways—one point at the end of each runway (i.e., the runway threshold), and one point at each runway's midpoint. The four parameters evaluated at each of these representative runway points include: liquefaction potential, maximum topographic slope in the vicinity of each point, distance to the CSZ epicenter, and PGA. Each parameter is divided into several ranges, and each range is assigned to a component risk rating ranging between 0 and 5, as table 1 shows.

TABLE 1.—Runway Liquefaction Risk Evaluation Parameters.

RISK RATING	LIQUEFACTION POTENTIAL	SLOPE	DISTANCE TO CSZ	PGA
5	High			≥ 0.4g
4	Moderate to High			0.3 to 0.4g
3	Moderate	>3.98%		0.2 to 0.3g
2	Low to Moderate	1.81 to 3.98%	< 100 km	0.1 to 0.2g
1	Low	<1.81%	100 - 200 km	< 0.1g
0			> 200km	

The research team then aggregated the pertinent risk ratings for each of the four parameters for each airport using a relative risk matrix (figure 7). The aggregation process involved adding the risk ratings for the four parameters at each representative runway point, ultimately producing overall values that ranged from 3 to 15. The research team then divided the relative risk matrix into three categories of relative risk: high risk was associated with aggregate values ranging from 12 to 15, medium risk associated with aggregate values ranging from 8 to 11, and low risk associated with aggregate values ranging from 3 to 7. Using these methods, the research team evaluated 114 representative runway points to determine the relative risk of earthquake-induced liquefaction resulting from a CSZ earthquake.



		Distance to CSZ Epicenter Trace														
		< 100 km					100 km - 200 km					> 200 km				
		Peak Ground Acceleration														
Liquefaction Potential	Slope, %	≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g	≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g	≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g
High	>3.86 %	15	14	13	12	11	14	13	12	11	10	13	12	11	10	9
	2.22 to 3.86 %	14	13	12	11	10	13	12	11	10	9	12	11	10	9	8
	<2.22 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
Moderate to High	>3.86 %	14	13	12	11	10	13	12	11	10	9	12	11	10	9	8
	2.22 to 3.86 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
	<2.22 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
Moderate	>3.86 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
	2.22 to 3.86 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
	<2.22 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
Low to Moderate	>3.86 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
	2.22 to 3.86 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
	<2.22 %	10	9	8	7	6	9	8	7	6	5	8	7	6	5	4
Low	>3.86 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
	2.22 to 3.86 %	10	9	8	7	6	9	8	7	6	5	8	7	6	5	4
	<2.22 %	9	8	7	6	5	8	7	6	5	4	7	6	5	4	3

FIGURE 7.—Runway Liquefaction Relative Risk Matrix.

Table 2 summarizes the individual runway point risk ratings; these ratings are also presented visually for each airport in Appendix B. In addition to the individual risk ratings for each runway point at each airport, table 2 also aggregates the individual runway point risk ratings into a “blended” risk rating that summarizes the relative liquefaction risk for all runways at each airport.

Of the 114 airport runway points evaluated, only one runway point—the north end of runway 16/34 at Renton Municipal Airport—was projected to be at a high risk of liquefaction-induced PGD. This conclusion makes sense as Renton Municipal is located alongside the Cedar River where it enters Lake Washington; the northern-most portion of the runway is immediately adjacent to the lakeshore, where one would expect to find highly liquefiable soils. The two other representative points evaluated at Renton Municipal were projected to be at medium risk for liquefaction, and therefore the blended risk rating is projected as “high-medium.”

TABLE 2.—Runway Blended Relative Risk Ratings.

AIRPORT CODE	AIRPORT NAME	RUNWAY POINTS	RUNWAY POINT RISK RATING			BLENDED RISK RATING
			LOW	MED	HIGH	
RNT	Renton Municipal Airport	3		2	1	HM
CLM	Fairchild International Airport	6		6		M
ELN	Bowers Field Airport	6		6		M
OLM	Olympia Regional Airport	6		6		M
YKM	Yakima Air Terminal-McAllister Field	6		6		M
KLS	Southwest Washington Regional Airport	3		3		M
SHN	Sanderson Field Airport	3		3		M
SEA	Seattle-Tacoma International	9	1	8		ML
ALW	Walla Walla Regional Airport	9	6	3		ML
BVS	Skagit Regional	6	4	2		ML
PWT	Bremerton National Airport	3	2	1		ML
FHR	Friday Harbor	3	2	1		ML
AWO	Arlington Municipal	6	5	1		ML
PAE	Paine Field	9	8	1		ML
PSC	Tri-Cities Airport	9	9			L
DLS	Columbia Gorge Regional	6	6			L
GEG	Spokane International	6	6			L
MWH	Grant County International	6	6			L
BLI	Bellingham International	3	3			L
TIW	Tacoma Narrows	3	3			L

Figure 9 shows the geographic distribution of the blended risk ratings for each airport across the state. Airports and runways at greater risk to liquefaction-related impacts are generally located in western Washington, where projected shaking intensity from a CSZ event will be greater and airports are in close proximity to rivers or other natural bodies of water, where liquefiable alluvial soils are typically more prevalent. Those airport in western Washington that are projected to suffer less severe liquefaction impacts as compared with nearby airports are typically built onto more stable local soils.

Bowers Field is notable among the medium risk airports, as it is located in central Washington, east of the Cascade Mountains, where ground shaking intensity is projected to be much lower. However, the DNR dataset indicates that the entire airport is constructed on soils with moderate to high liquefaction potential. (See Appendix B, figure B-3.) Airport personnel supported this observation and also noted that numerous streams cross that airport's property, which may indicate a greater incidence of alluvial soils that are more prone to liquefaction.

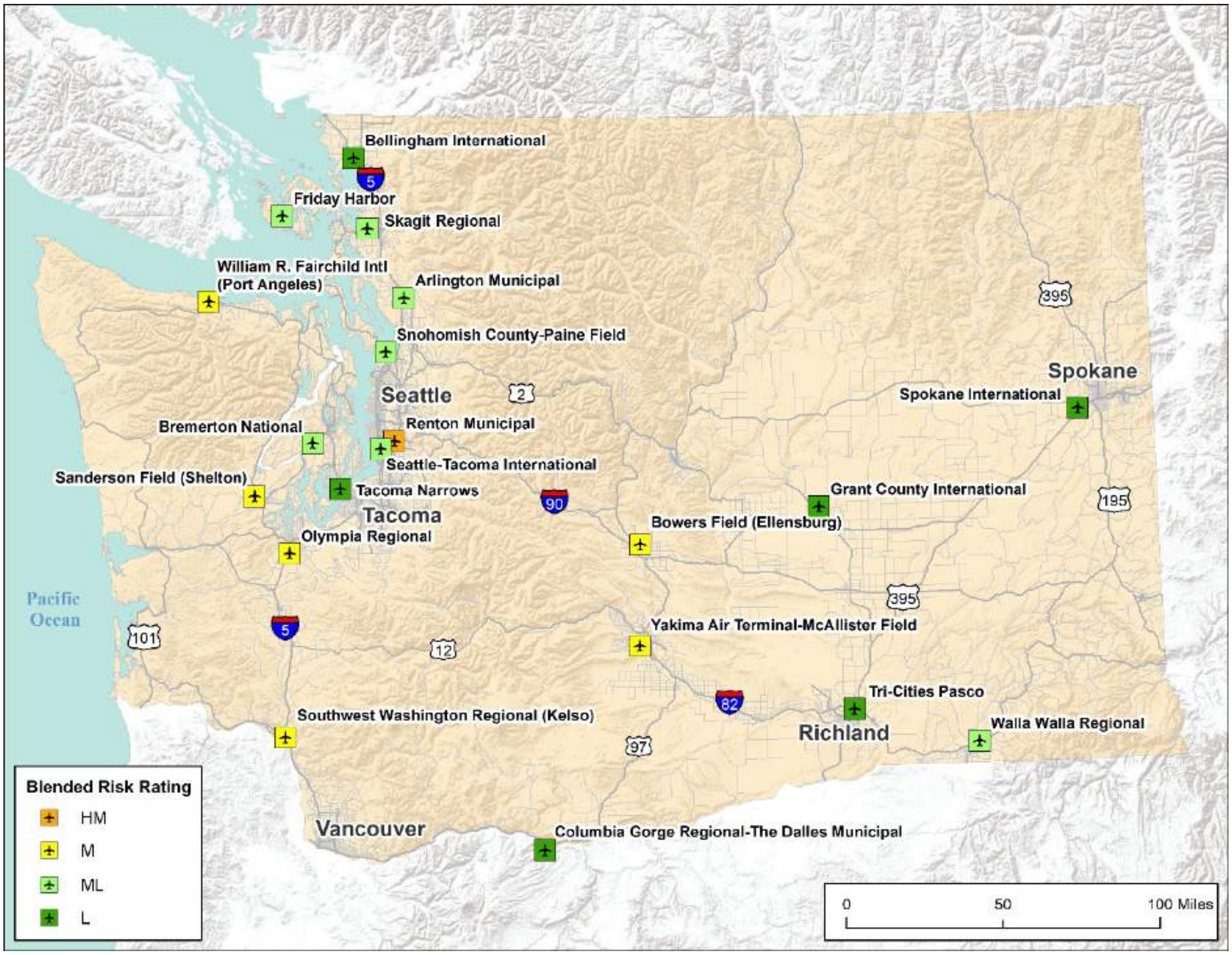


FIGURE 8.—Geographic Distribution of Blended Relative Risk Ratings for Airports.

Within the blended risk categories that table 2 shows, airports are ranked according to the number of representative runway points that fall in the higher individual risk categories, and some airports have a greater proportion of individual runway points in the medium risk category. For example, both Seattle-Tacoma International and Snohomish County-Paine field both have a blended risk rating of medium-low, yet eight of Seattle-Tacoma International's nine runway points are at medium risk, whereas only one of Paine's nine runway points is at medium risk. Therefore, considering the individual ratings of the representative runway points, as well as the overall blended risk ratings, is important when evaluating potential liquefaction susceptibility of runways at Washington airports using this methodology.

This relative risk evaluation is intended to provide insight into which airports may be at a greater relative risk to liquefaction-induced disruptions resulting from a CSZ earthquake, but it is not intended to replace more detailed, site-specific geotechnical studies. Nonetheless, it may provide a good indication of which airports should be prioritized for more immediate consideration of detailed geotechnical analysis, which will be able to more conclusively determine the potential for seismically induced ground failure, and any related disruptions to airport pavements and operations.

Synthesis of Facilitated Discussions with Airport Stakeholders

Members of the research team visited each airport in this study—either physically or virtually—to participate in a facilitated discussion with airport managers; operations and engineering personnel; and regional emergency managers and infrastructure owners and operators from city, county, and state agencies in order to do the following:

1. Discover any prior or planned efforts undertaken by airports to plan for or understand their vulnerabilities to a CSZ earthquake.
2. Gather information about the overall capabilities and resilience of airport and airfield infrastructure, and potential impacts to each airport from a projected CSZ earthquake.
3. Assess how dependent airports are on external lifeline infrastructure systems (i.e., fuel, natural gas, electricity, water/wastewater, telecommunications, and surface transportation).

Airport CSZ Earthquake Planning or Vulnerability Studies

None of the 20 airports in Washington that the research team visited had completed either a general airport resiliency assessment or an earthquake-specific seismic resiliency assessment. However, several airports noted that some capital improvement projects had previously included seismic studies of limited scope. For example, Bremerton National noted that some site geotechnical engineering studies had occurred for site construction projects; Seattle-Tacoma International undertook extensive project-oriented seismic studies for its recent north satellite terminal and third runway construction projects; Renton Municipal noted that it had conducted a seismic assessment of its control tower following the 2001 Nisqually Earthquake. These findings were consistent with information collected during facilitated discussions with 12 airports visited during the Oregon Transportation Systems RRAP project, except that three airports in Oregon—Portland International, Hillsboro, and Newport Municipal—reported conducting CSZ seismic resilience studies at their facilities (HNTB Corporation 2015; Pyrch, Marsters, and Nafie 2019; McFarland, Pyrch, and Marsters 2018). These three assessments provide a comprehensive inventory of onsite assets, facilities, and resources (e.g., onsite structures, fuel capacities, pavement geometry and capacities) and feature detailed, site-specific geotechnical assessments of potential seismic-induced ground failures that could occur during a CSZ earthquake. These assessments provide a useful model that airports in Washington could use to assess the seismic resilience of their infrastructure.

Airports typically pointed to a lack of available funding as the key reason for not having conducted general or seismic-specific resilience studies at their facilities. Airports noted that the Federal Aviation Administration (FAA), which supports capital improvements at airports, will not fund seismic resilience studies, nor improvements that are intended specifically to enhance airport resilience to a potential seismic hazard (William R. Fairchild Airport 2019). In Oregon, either the airports themselves or the Oregon Department of Aviation funded the three resilience studies. Relevant state agencies in Washington (e.g., WSDOT Aviation, Washington EMD) could consider funding similar studies among the airports evaluated here.

Airport Resilience Capabilities and Dependencies on External Lifeline Infrastructure

The research team discussed airport resilience capabilities with airport managers and staff, regional emergency managers, and infrastructure owners and operators, in the specific context of each airport's ability to support the air operations for post-disaster logistics supply chains following a CSZ earthquake. Capabilities to resume commercial or general aviation were beyond the scope of these facilitated discussions and site visits. Appendix C summarizes key airport metrics (e.g., runway geometry and weight capacities, onsite fuel storage, square footage of pavement), which provide a general overview of the relative capacities of Washington airports.

From the facilitated discussions at the 20 airports, officials nearly unanimously indicated that electricity and fuel were the two most critical resources for an airport to support post-disaster logistics. Electricity enables numerous critical functions at an airport: it is essential to powering navigational aids (NAVAIDS) and airfield lighting, pumping fuel, maintaining wireless communications between aircraft and ground staff and broader coordination, and providing site access via automated security gates. Several of the airports visited receive power from multiple or redundant systems. For example, Arlington Municipal, Grant County International, and Spokane International receive power from redundant systems—separate substations power the airports from separate distribution feeder lines, and the airports can be fully powered from either. In the case of Seattle-Tacoma International, two different distribution grid providers (Puget Sound Energy and Seattle City Light) power the airport. However, most of the airports evaluated rely on either a single electrical substation or distribution feeder lines to power the airport. In some cases, different parts of airports are powered separately by isolated or split systems (i.e., separate distribution feeders power different sides of an airport). Most commonly, and particularly at smaller airports, single feeders provide all electricity for a particular airport, although multiple individual connections to that single feeder may exist to power separate airport functions (e.g., lighting vaults, NAVAIDS) or site tenants.

In some instances, airport personnel were aware of the location of the local power utility substation serving their facility, but in most cases, airport personnel were unaware of power system configurations beyond their property boundaries. The research team was unable to coordinate more broadly with regional power utilities—beyond the few instances where personnel from local power providers attended the airport facilitated discussions—to assess the vulnerability of these power systems and the potential for a disruption to adversely impact airport operations.

Given the importance of electricity to airport operations, and the uncertainty of power availability following a CSZ earthquake, during onsite visits, airport stakeholders discussed options for backup power generation. (Appendix C summarizes backup power generation capabilities at the airports visited.) In general, most airports have permanent backup generators connected to airfield lighting, which is frequently co-located at the airfield's lighting vault. In addition, airports with onsite airport rescue and firefighting (ARFF) facilities have dedicated backup generation at those locations. These backup generators are almost always diesel-operated; one exception was Seattle-Tacoma International, which fuels its Alternate Utility Facility with Jet A aviation fuel. At nearly all airports, officials indicated that NAVAIDS were not connected to airport-owned backup generation, since the FAA owns, operates, and maintains NAVAIDS as separate and autonomous systems. But some exceptions did emerge. For example, Walla Walla Regional and Seattle-Tacoma International's NAVAIDS are connected to backup generation. At other airports, select NAVAIDs were connected to backup generation; for example, the terminal radar approach control (TRACON) radar at Grant County International, or the instrument landing system (ILS) at Spokane International. In all other instances, airport officials reported that NAVAIDS would most likely only have dedicated backup batteries to enable ongoing operations ranging from 4 hours up to a few days, depending on the application and use. However, one official at Bremerton National indicated that battery backups are intended to ensure that "the last plane on approach" can land safely, and not for sustained operations (Bremerton National 2019). In addition, the FAA typically owns and operates airport control towers (either directly, or via subcontract). As such, while some of these towers have backup generation capabilities, the FAA owns and operates these systems, so airport officials had limited knowledge of their capabilities.

At most airports, officials reported that a disruption to power would limit air operations, particularly during at night or during times of inclement weather and limited visibility. As airfield lighting was the most commonly found airfield system connected to backup generation, daytime and nighttime visual flight rules (VFR) operations would be able to continue during a power disruption so long as backup generation fuel supplies allow. Airport officials estimated that, depending on usage, time of year, and weather, backup generation for airfield lighting could last between 1–5 days before refueling is required.

NAVAIDS were most frequently found to be connected only to short-term backup batteries but not backup generation. Therefore, instrument flight rules (IFR) operations, which enable pilots to take off and land during inclement weather or limited visibility conditions, would likely be able to continue only for the hours or days immediately following a CSZ earthquake disaster power disruption. In instances where airports have Global Positioning System (GPS)-based approach systems, which do not rely on any local ground-based equipment to function, so-called non-precision IFR operations could occur indefinitely, but would require greater minimum ceilings and visibility than true precision IFR operations. If both utility power and backup generation power were disrupted, airport officials indicated that their airports would revert to daytime VFR or non-precision IFR operations (where GPS approaches exist). This would limit the flexibility and capacity volume of inbound airborne supply lines for emergency response purposes.

As mentioned, airports are strong candidates as secure staging areas for disaster logistics given that most have a fenced perimeter. Some airports indicated the need to improve perimeter fencing, either extending fencing to fully enclose the airport, or increasing the height of existing full-perimeter fencing. In many instances, and particularly at larger airports, officials indicated that electric gates with electronic access control systems facilitate site-access and security. These access control systems had backup power in only a few instances (e.g., Yakima Air Terminal-McAllister Field). In most other instances, access control systems would either be fully disabled due to lack of backup power, or would be severely limited. When access control is disrupted, security or emergency response personnel would have to operate gates manually until utility service power is restored.

In addition to electric power, airport officials indicated that aircraft and vehicle fuel were also critical resources for their facilities to serve as post-disaster logistics staging areas. Although USTRANSCOM indicated that it would conduct any military-based operations such that aircraft would not have to rely on refueling services at the disaster logistics staging areas (USTRANSCOM 2018), other civilian aviation operations supporting disaster response would require functional ground refueling capabilities at the disaster logistics staging areas. (Appendix C provides the airports' total onsite fuel storage capacities.) These include the capacities of both storage tanks and fuel trucks that are owned and/or operated by the airports, fixed base operators (FBOs), or other large onsite public facilities (e.g., aviation museums). In many instances, airport personnel noted that private or commercial tenants had their own limited fuel storages—ranging from several hundred gallons, in the case of small private or corporate operators, to hundreds of thousands of gallons, in the case of large commercial organizations such as Boeing. Only the tank capacities of public, or publicly-available fuel storage are summarized in this study.

The larger airports with commercial airline service (e.g., Bellingham International, Seattle-Tacoma International, Yakima Air Terminal-McAllister Field) indicated that they generally maintain no less than 50 percent capacity of fuel on hand (generally Jet A aviation fuel). At most other airports, and in particular smaller general aviation airports, officials indicated that storage varies widely based on seasonal demand, and that tanks minimums frequently fall to 20–50 percent capacity. These lower minimum volumes are due to the economics of fuel contracts and delivery charges—when ordering fuel to replenish supplies, it is generally not economically advantageous for airport fuel operators to order small quantities to simply “top-off” tanks, and they therefore seek to maximize fuel orders. Following this approach means that although airports have large onsite fuel storage capacities, the quantity of available fuel on-hand at any given time could be far less than capacity. Therefore, predicting the quantity of fuel that may be located at each airport at any given point in time is difficult. Nonetheless, knowledge of onsite storage capacities could enable emergency managers to understand and plan for fuel shipments during post-disaster response and recovery activities, or to assume potential minimum amounts of fuel on-hand at airports.

In addition, the delivery supply chain for aviation fuel in the state relies heavily on bulk fuel storage terminals located in western Washington, where the impacts of a CSZ earthquake are likely to be the greatest. This feature of the aviation fuel supply chain in Washington could result in substantial delivery disruptions and fuel shortages at airports. Of the 20 airports visited, all but one rely on trucked fuel deliveries from a handful of bulk fuel storage terminals in western Washington and western Oregon. Although Seattle-Tacoma International receives fuel directly via pipeline, not truck, fuel carried by that pipeline system similarly originates from facilities located in western Washington. Only Spokane International could confirm that it receives fuel shipments originating from a location outside of western Washington. This heavy reliance on facilities in western Washington for aviation fuel deliveries could affect greatly the ability of airports, even those east of the Cascade Mountains and outside of the primary CSZ impact area, to resume operations quickly and to support post-disaster logistics activities.

Given their configuration, airport fuel storage facilities generally require electricity to pump fuel from in-ground or above-ground storage tanks. With the exception of Columbia Gorge Regional, Spokane International and Seattle-Tacoma International, none of the airports has dedicated backup power generators connected to their onsite fuel storage facilities, limiting significantly their utility in a post-disaster logistics capacity. Some airports (for example, Bellingham International and Bowers Field) indicated that their onsite fuel storage tanks had permanent connection points for portable generators. Grant County International indicated that, due to the large volume of its above-ground tanks, crews could possibly load fuel into aircraft or vehicles via gravity feed but only if the facility’s above-ground tanks were relatively full.

Last, with respect to fuel, the research team observed that, particularly at smaller airports, none of the airport fuel storage facilities incorporated any seismic anchoring or restraints beyond simple bolted attachments to concrete foundation pads, which would likely shear during a CSZ earthquake event. This condition greatly increases the likelihood that CSZ-earthquake ground motions could damage fuel storage facilities and either limit their utility to post-disaster response and recovery activities or otherwise render them entirely unusable. Furthermore, some airports (e.g., Bowers Field) expressed concern that an earthquake could damage the underground fuel pipes used to move fuel from storage tanks to either self-serve fuel facilities or terminal fuel hydrants. Damage of this nature will depend largely on the condition of the underground piping system and subsurface soil conditions.

Among the other lifeline infrastructure systems discussed with airport stakeholders, officials indicated that these resources are critical to normal airport operations but may have limited or little impact to their airports’ immediate ability to serve as disaster logistics staging areas. In many instances airports have comparatively greater resilience in some of these systems. For example, water and wastewater services are essential for safe building occupancy (e.g., sanitation, fire suppression), as is natural gas (e.g., for heating). A functional supply of water was only critical to airfield operations at airports with onsite ARFF facilities, and even then, only where commercial passenger operations exist. Even in the instance of ARFF, airports indicated that emergency airfield use could still continue without these functions, and that they could seek waivers from the FAA to enable this operation.

Despite these observations, many airports have onsite wells or onsite backup storage of potable water. For example, Columbia Gorge Regional, Friday Harbor, Grant County International, Sanderson Field, Skagit Regional, Tacoma Narrows, Walla Walla Regional, and Yakima Air Terminal all have wells on site to provide water, and many of these airports (e.g., Sanderson Field, Tacoma Narrows, Walla Walla Regional) have onsite storage capacity of at least 100,000 gallons. In addition, Bellingham International, Renton Municipal, and William R. Fairchild all indicated that large water supply lines bisect their runways, raising concern that seismic ground motions could damage these water lines, and therefore damage runway pavements and supporting soil structures.

Most airport officials indicated that telecommunications were essential for sharing airport operations information with the FAA and pilots (e.g., automated weather observation information, notices to airmen), but that the majority of telephone systems rely on internet-based Voice over Internet Protocol (VoIP) systems, which in turn rely on functioning internet connections. If electric power is disrupted at airports, these VoIP telephone systems would be disabled in the absence of backup power generation. Some airports indicated that they still maintained traditional legacy phone lines, but generally only in airport office spaces. Nonetheless, most airports indicated that in the event of land-based telecommunication disruptions, rechargeable hand-held radios could enable ground-to-air communications, which would be sufficient for post-disaster emergency operations.

Surface transportation linkages are, of course, critical to the broader function of airports as disaster logistics staging areas, as emergency officials must be able to move goods and resources from airports to surrounding communities. In general, the research team discussed transportation topics with local officials, and considered or assessed any relevant findings—most of which dealt with the connectivity of local roadways serving the airport to regional highway and interstate systems. A frequent focus of these discussions was the vulnerability of bridges located within the surrounding roadway network, which if disrupted, could restrict or completely cut off access to airport facilities. The Washington State Transportation Systems RRAP project (CISA 2019) assessed highway bridge and highway pavement vulnerability using separate bridge vulnerability and highway vulnerability screening tools developed in that study. Subsequent to the completion of that project, CISA Region 10 analysts then extended the analysis to include non-highway county and local bridges and roadways. Appendix B contains maps locating seismically vulnerable roadways and bridges in the vicinity of each airport assessed. These maps may be useful to emergency planners and infrastructure owners/operators in understanding connectivity issues that could arise following a CSZ earthquake and that could impede the movement of post-disaster resources out from airports to surrounding communities. The Washington State Transportation Systems RRAP project report provides additional context and information regarding post-CSZ earthquake mobility across the state.

Key Findings

The remainder of this report focuses on documenting key findings for the Washington State Airports Seismic Resilience Project. Key findings are a result of the information-gathering and analytic activities conducted during this project. Each finding is supported by an explanation of its significance, relevant options for consideration to improve resilience, and suggested partners to engage in implementing these options.

Key Finding 1: A CSZ earthquake has the potential to significantly disrupt Washington airports—particularly those located in western Washington—as a result of seismic ground motion and ground failure; more focused, site-specific studies of seismic resilience at airports statewide are necessary to better understand extent to which these disruptions may disable airports from serving as disaster logistics staging areas.

Airports and airfields in Washington are critical to early disaster response and recovery efforts, serving as staging and distribution points for an anticipated national influx of critical supplies and resources into the region. During a CSZ earthquake, Washington airports will experience direct seismic impacts associated with ground motion and seismic forces, as well as secondary seismic impacts in some areas (e.g., potential ground failure through soil liquefaction that affects airfield pavements or facility foundations). Although ground motions are expected to be much stronger, with a greater potential to damage infrastructure, west of the Cascade Mountains, airports located in central Washington could still experience ground motions with sufficient strength to damage infrastructure. In particular, these ground motions could induce ground failures at airports built on soils with higher liquefaction potential, despite being located farther from the primary fault line. For example, this study's runway liquefaction risk screening analysis found that Bowers Field in Ellensburg, Wash., which is built on soils with moderate to high liquefaction potential, may be at an elevated risk of liquefaction-induced damage, despite being located east of the Cascade Mountains. Nonetheless, the actual seismic vulnerability of airports, and in particular to liquefaction-induced or other types of ground failure, is difficult to predict as none of the 20 airports visited have conducted any site-specific seismic resilience assessments of their infrastructure, systems and facilities.

Tsunami inundation is of little immediate concern to the 20 airports assessed as all are located outside of the projected 2,500-year tsunami impact zones. However, tsunamis could affect surrounding and supporting infrastructure (e.g., electric power, water/wastewater, telecommunications, and transportation) at numerous airports in western Washington, which could have cascading impacts that disrupt airport services and operations. This study identified that electric power and fuel supply chains are among the supporting infrastructure systems of greatest importance, and should be studied further, but other infrastructure systems could also be affected by tsunami inundation.

Finally, through extensive outreach and engagement with local airport officials, the research team was able to summarize airport resilience capabilities of the 20 airports assessed, including runway weight capacities, square footage of pavements/hardstand, onsite fuel storage capacity, backup generation capabilities, and other factors. In some instances, the research team was able to leverage state-level resources in this endeavor, including WSDOT Aviation's airport pavement management database. Nonetheless, a broader state-level database of airport resilience capabilities, which is updated regularly as facilities and systems are updated, could assist federal, state, or local planners in better understanding the current capacities of airports across the state, enabling them to best utilize airports for emergency and disaster response needs across a range of disaster types, not only a CSZ earthquake.

Resilience Enhancement Options

WSDOT Aviation, in coordination with Washington EMD, should work with airport managers to conduct focused seismic resiliency assessments at the airports identified in the study, and support similar airport-led assessments at other public use airports that are either designated currently, or being considered for future inclusion as disaster logistics staging areas in the state and federal CSZ response plans. This funding and support should prioritize those shown in this study's airport runway liquefaction screening analysis to be at greater risk to liquefaction-induced ground failure, but also those smaller, less well-resourced airports that are less able to self-fund such studies.

WSDOT Aviation should work with the FAA and the Washington state government to identify funding that can more directly support seismic resilience studies and investments at airports, as airport officials in Washington (and Oregon) identified that current FAA funding mechanisms do not support such investments.

WSDOT Aviation should develop and maintain a more extensive database of relevant airport resilience capabilities and factors, including but not limited to: pavement condition, extent, usage, and weight bearing capacities; systems and facilities with permanent backup generation; mobile backup generation capabilities; onsite fuel storage capacities and approximate average minimum volumes; airport electric feeds and airport regions served by separate or redundant feeds. Airport owners and operators should also coordinate with WSDOT Aviation to provide regular updates to these airport resilience capabilities and factors so that emergency planners and managers have access to the most current or up to date information.

WSDOT Aviation should collaborate with FEMA and WAEMD Earthquake Program Managers to provide airport operators specific information on structural and non-structural seismic hardening/mitigation ideas. In addition, these agencies could facilitate a meeting with Washington airport operators and the Port of Portland International Airport officials to discuss earthquake mitigation projects. For instance, Portland International Airport just completed a project to harden one of its runways using a grout injection technique and made other significant investments in seismic retrofits to airport facilities

Key Finding 2: Airports rely heavily on electric power to maintain full air operations, but the abilities of airports across Washington to manage electric disruptions vary widely.

Electricity is an important, if not the most important, external infrastructure dependency for airports to maintain air operations, as expressed by officials at all 20 airports assessed in this study. As noted earlier, electricity is essential during emergency situations to power NAVAIDS and airfield lighting, pump fuel, maintain wireless communications between aircraft and ground staff (and for broader post-disaster coordination), provide site access via automated security gates, and support ARFF activities at commercial airports. Electricity is important for numerous other functions under normal operations, including facility heating/cooling, telecommunications/information technology, water/wastewater services, and tenant use. Most of the airports assessed have some onsite backup power generation capabilities (although a small number did not have any), but the types of functions and services supported by backup generation varied widely.

Airfield lighting was the system most frequently connected to dedicated or permanent diesel backup generators, although this was not true at every airport visited, and in most cases these connections would not power NAVAIDS (which are frequently owned, operated, and maintained separately by the FAA). At commercial airports, ARFF facilities and terminal buildings were frequently also connected to permanent diesel backup generators. The ability of these generators to sustain air operations depends on the amount of diesel fuel on hand and also on usage, which is a function the number of aircraft landing, time of year, weather conditions, and other factors. Generator operation times varied somewhat across the airports with generation installed, but most airports indicated that backup generation, where available, could sustain air operations for 1-5 days. Also, this generally assumed VFR flight operations, or non-precision IFR flight rules (i.e., where GPS navigation runway approaches exist), as other NAVAIDS necessary for full IFR flight rules were most frequently not connected with backup generation (battery backups on these systems can generally support only several hours of emergency operations).

Most notably, only three airports—Columbia Gorge Regional-The Dalles Municipal, Seattle-Tacoma International, and Spokane International—have backup generators connected to power their fuel storage facilities. At all other airports, any fuel in onsite storage tanks will be inaccessible for disaster response and recovery activities without electric service power or, in a few instances, mobile generators being deployed to bulk storage tanks with dedicated generator hookups. Any fuel currently stored in mobile fuel trucks would be accessible, provided those trucks have sufficient diesel fuel supplies onboard to run and operate pumping equipment.

Lastly, several airports had a good understanding of the local distribution power grid (i.e., local substations, distribution feeders) supplying power to the airport—particularly the larger and commercial airports—but the majority of airport officials had much more limited knowledge, generally focused on onsite electric system and distributions only, or the feeder lines immediately adjacent to their airports.

Resilience Enhancement Options

Washington airports should take actions to ensure that airfield lighting, communications, and fuel systems vital to unrestricted air operations (i.e., IFR and VFR) will have a reliable source of backup power following a CSZ earthquake. These actions could include installing new permanent backup generation, expanding connections to existing backup generation to support broader array of airfield systems, or otherwise hardening existing backup systems to seismic impacts. These systems should support, at a minimum, airfield lighting, fuel storage and pumping, site access control, ground-to-air communications, and where possible, NAVAIDS.

WSDOT Aviation should work with the FAA and airports to ensure that FAA-owned NAVAIDS or other systems also have backup generation capabilities beyond short-term battery backup. These could be connections to airport backup generation, air traffic control tower backup generation (as control towers are frequently owned and operated by the FAA), or new dedicated backup generators installed at the NAVAIDs. Airports and the FAA should also considerer coordinating with the U.S. Army Corps of Engineers (USACE) to perform emergency prime-power analyses at each of these airfields to assist the USACE in providing emergency generators to airfield NAVAIDS or other airport systems post-disaster.

Washington airports should engage with their local electric utilities to better understand the resilience of the electric grid supporting the airport. Where possible, airports and utilities should work together on projects that build greater redundancy and resilience into airport electric power supplies. For example, at airports where multiple feeds power different parts of the airport separately, interconnection systems and switching equipment can be installed to allow greater or full redundancy; airports and power providers can work to ensure that where power is supplied by feeders from a single primary substation, backup or redundant feeder lines are connected to alternate substations; if practical, redundant power could be supplied by separate distribution substations, each connected to different transmission line systems (as is the case currently at Grant County International). These engagements should also include discussions of power restoration timelines and contingency planning in the event of a major disruption, such as a CSZ earthquake.

Key Finding 3: Liquid fuel is a vital resource for Washington airports to support sustained post-disaster logistics, but the supporting infrastructure and supply chains are vulnerable to the effects of a CSZ earthquake.

Airports noted that fuel is a critical resource for airports to both maintain air operations, and ground operations as well, in a post-disaster response and recovery capacity. Most airports had undertaken little to no joint planning, analysis, or engagement with external fuel providers to assess or understand the resilience of their fuel supply chains. In fact, for 18 of the 20 airports—including most in central and eastern Washington—fuel deliveries originate from facilities in western Washington or western Oregon, where the impacts of a CSZ earthquake are projected to be greatest. Among these 18 airports, only Walla Walla Regional indicated that it was currently in discussions with their fuel provider to explore renegotiating their contract to include the contingency for supply deliveries originating from Spokane, Idaho, or Montana.

As discussed earlier, only three of the twenty assessed airports have permanent backup generators connected to their fuel storage facilities—all others rely entirely on utility service power to pump fuel from storage tanks into airplanes or fuel trucks. In addition, only two airports indicated that their fuel storage facilities have permanent generator hookups that could be rapidly connected to deployed mobile generators. Many airports noted that they had mobile backup generators onsite, but such generators will likely be in high demand to power multiple competing airport systems following a disaster. Also, without permanent connections at fuel storage facilities, ad-hoc connections to mobile generators could pose a safety hazard to airport personnel, emergency responders, and others. Backup generators also require a sustained supply of fuel, but only a handful of airports reported having onsite diesel reserves, and in those cases capacities ranged generally from 50-500 gallons. Airport managers frequently noted that diesel generators could be powered by Jet A aviation fuel, but that doing so for prolonged times (i.e., weeks/months) could damage generators.

Lastly, many airports reported uncertainty about seismic design considerations for older fuel tanks—many of which were 20-30 years old. Particularly at smaller airports with above-ground tanks, fuel storage tanks did not appear to incorporate any seismic anchoring or restraints beyond simple bolted attachments to concrete foundations, which would likely shear during a CSZ earthquake event. This condition greatly increases the likelihood that CSZ-earthquake ground motions could damage fuel storage facilities and either limit their utility to post-disaster response and recovery activities or otherwise render them entirely unusable.

Resilience Enhancement Options

Airports should engage with their fuel providers to seek contingency plans, perhaps even formally included in their contracts, for fuel deliveries to originate from fuel terminals and bulk storage facilities located, at a minimum, east of the Cascade Mountains, in order to ensure a more resilient fuel supply chain following a CSZ earthquake.

WSDOT Aviation, in coordination with Washington State Department of Commerce (Emergency Support Function 12—Energy), Washington EMD and FEMA, should engage with fuel providers to help project potential fuel demands at airports following a CSZ earthquake, in order to provide a region-wide perspective on fuel requirements, so that fuel providers can plan accordingly. Additionally, the Washington State Department of Commerce should coordinate with FEMA to identify any pre-scripted fuel requirements for incorporation into CSZ response plans.

Airports in Washington should make investments to enhance the seismic resilience of their onsite fuel storage facilities. This should include, at a minimum, assessing the seismic integrity of storage tanks and supporting infrastructure (e.g., foundations, piping systems), making necessary seismic retrofits (e.g., seismic anchoring), and ensuring the ability to pump fuel during a loss of utility service power (e.g., backup generators and/or permanent hookups, manual pumps, gravity-based operations).

Conclusion

The Washington State Airports Seismic Resilience Project integrated the expertise and knowledge of participants across the state into an assessment of airports' abilities to support post CSZ earthquake response and recovery activities. The project revealed that Washington airports will play an important role as post-disaster logistic supply chain hubs to receive, organize and distribute disaster relief supplies and equipment from around the country to local communities, but that the full resilience of their facilities is not well-understood at a local level. More focused, site-specific studies of airports' seismic resilience are necessary to better understand the extent to which seismic impacts may affect or disrupt the ability of airports to serve as post-disaster logistics staging areas. In particular, better studies of site-specific geotechnical vulnerabilities to seismic impacts at airports are important to characterize how ground failures may disrupt airport pavements and facilities. This project conducted a screening-level analysis of airport runway liquefaction risks which may be useful in prioritizing these more detailed geotechnical studies of Washington airports.

In addition, this project assessed the resilience capabilities of airports, as well as their dependencies on external lifeline infrastructure systems to operate, by synthesizing findings from a series of facilitated discussions and site visits at 20 Washington airports. Airports consistently indicated their dependence on electric power and fuel to support ongoing operations, and the research team identified some clear actions to enhance the resilience of airports related to these interdependencies, including actions to increase the resilience of onsite fuel storage and fuel supply chains, and more widespread installation of backup generation to support critical airport systems and functions.

CISA, WSDOT Aviation, Washington EMD, and the public and private partners involved in this resilience project intend for its outcomes, and all associated documents and data, to provide guidance to state, county, and local officials. In particular, this project offers guidance to the core stakeholders and the airport personnel that participated in this project as to key challenges facing Washington airports, and their ability to support post-CSZ response and recovery activities, but also actions that can help to address these gaps and ultimately inform greater emergency management planning and infrastructure investments that will collectively enhance the resilience of Washington. For more information about this resilience project, please contact CISA Region 10 at CISARegion10@hq.dhs.gov and/or CISA Headquarters at Resilience@hq.dhs.gov.

Acronyms and Abbreviations

ARFF	Airport Rescue and Firefighting
CISA	Cybersecurity and Infrastructure Security Agency
CREW	Cascadia Region Earthquake Workgroup
CSZ	Cascadia Subduction Zone
DNR	Washington Department of Natural Resources
EMD	Washington Emergency Management Division
FAA	Federal Aviation Administration
FBO	Fixed Base Operator
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPS	Global Positioning System
IFR	Instrument Flight Rules
KM	Kilometers
M	Magnitude
MMS	Moment Magnitude Scale
NAVAID	Navigational Aid
PGA	Peak Ground Acceleration
PGD	Permanent Ground Deformation
RRAP	Regional Resiliency Assessment Program
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USNORTHCOM	U.S. Northern Command
USTRANSCOM	U.S. Transportation Command
VFR	Visual Flight Rules
VoIP	Voice Over Internet Protocol
WSDOT	Washington State Department of Transportation

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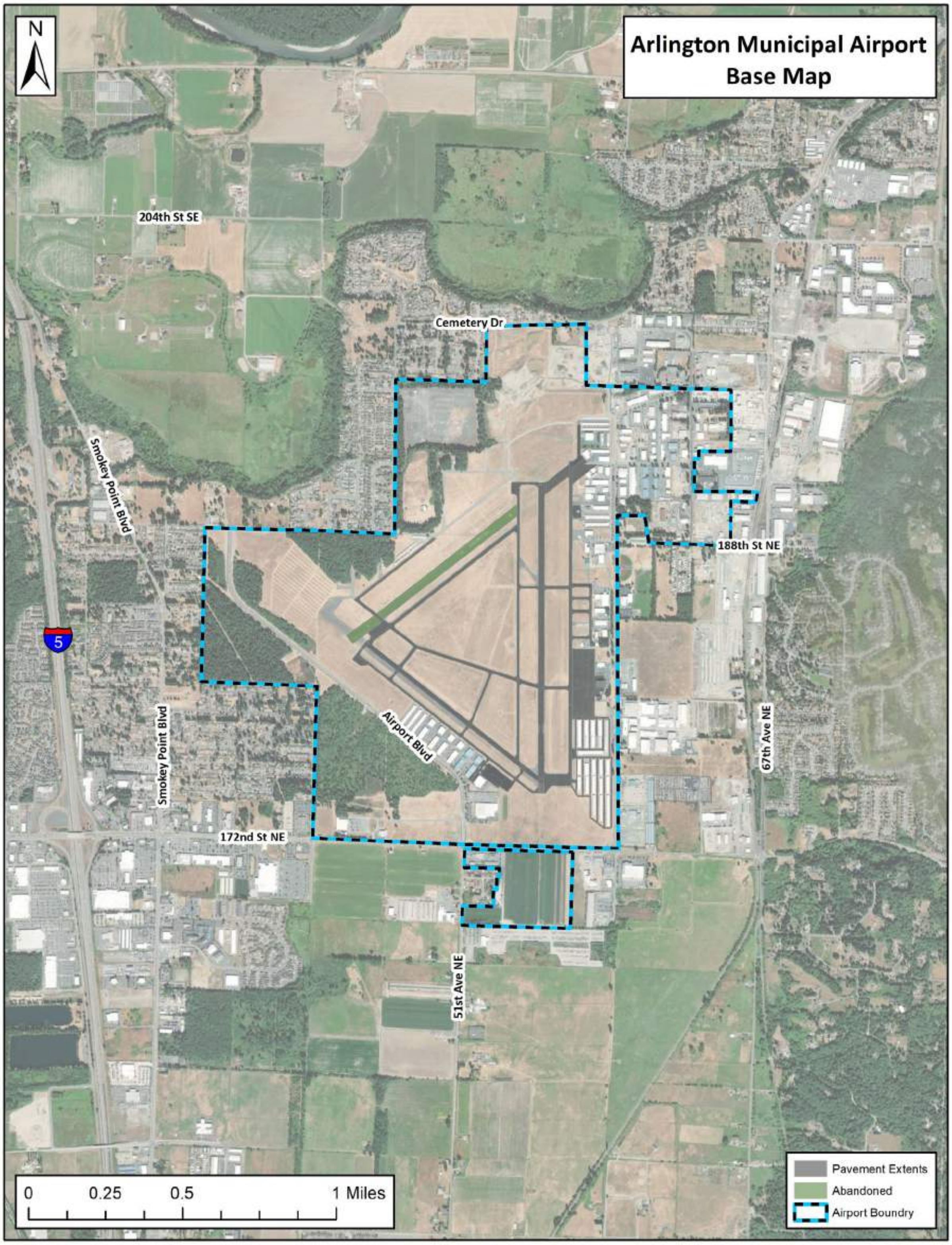
Appendix A

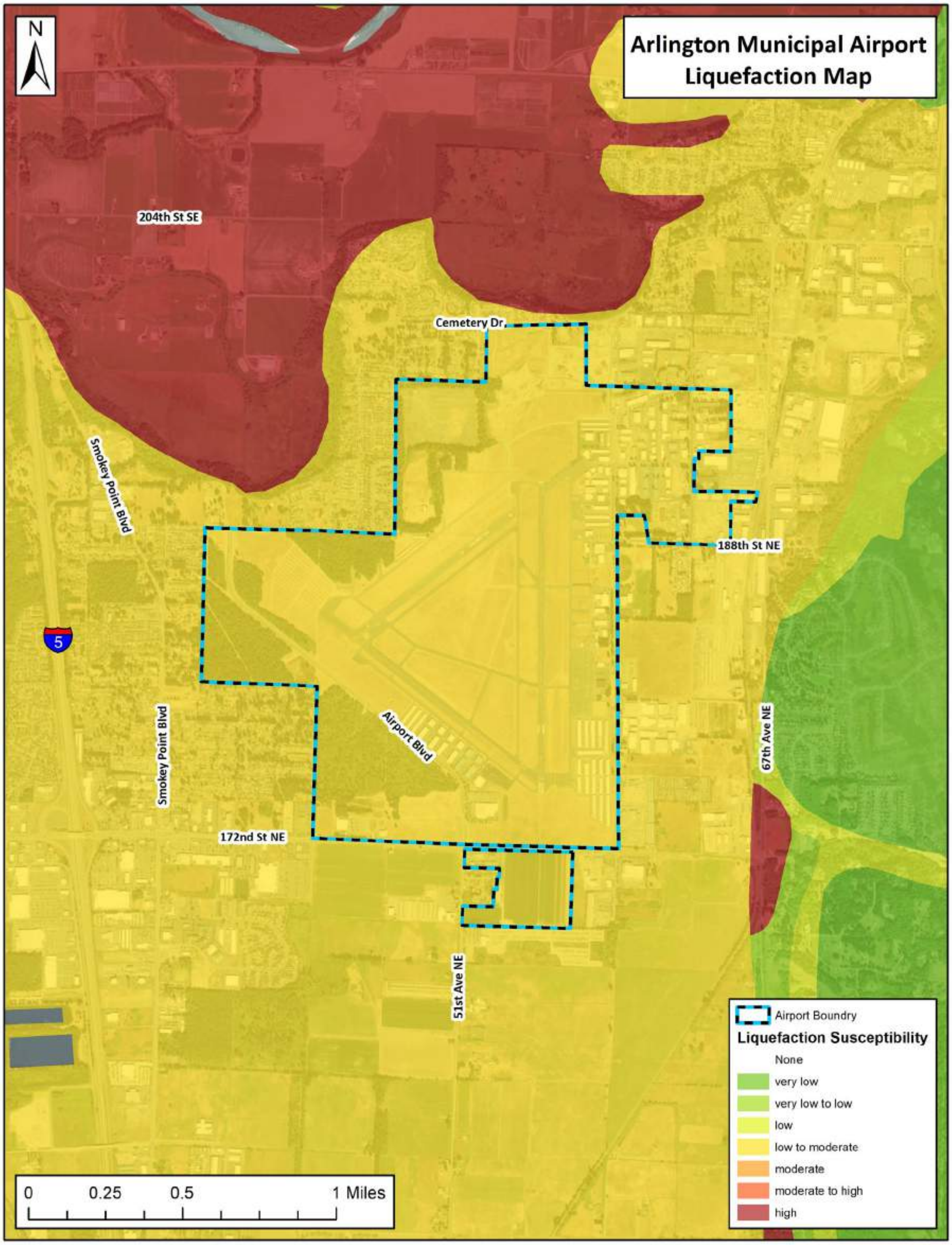
Table A1. Stakeholders Met with by Research Team During Resilience Project

Federal Government	State Government	Regional, County, and City Government	Airports	Private Sector
DHS • Cybersecurity and Infrastructure Security Agency • Federal Emergency Management Agency Region 10 U.S. Department of Defense • U.S. Transportation Command • U.S. Northern Command U.S. Department of Transportation	Washington Military Department • Washington Emergency Management Division Washington State Department of Transportation • Aviation Division • Maintenance Operations	Clallam County Emergency Management Clallam County Sheriff's Office Kitsap County Department of Emergency Management City of Bremerton Public Works Mason County Fire District #11 Mason Public Utility District 3 Mason County Division of Emergency Management Thurston County Emergency Management San Juan County Emergency Management Skagit County Department of Emergency Management Snohomish County Emergency Management King County Emergency Management City of Renton Emergency Management City of Renton Public Works Cowlitz County Emergency Management Walla Walla County Emergency Management Klickitat County Department of Emergency Management Wasco County Emergency Management Spokane County Emergency Management City of Spokane Department of Emergency Management	Arlington Municipal Bellingham International Bowers Field (Ellensburg) Bremerton National Columbia Gorge Regional-The Dalles Municipal Friday Harbor Grant County International Olympia Regional Renton Municipal Sanderson Field (Shelton) Seattle-Tacoma International Skagit Regional Snohomish County-Paine Field Southwest Washington Regional (Kelso) Spokane International Tacoma Narrows Tri-Cities Pasco Walla Walla Regional William R. Fairchild International (Port Angeles) Yakima Air Terminal-McAllister Field	Century West KPG Small and Sons Oil Skydive Kapowsin Cascade Natural Gas Hood Canal Communications Bellingham Aviation Services

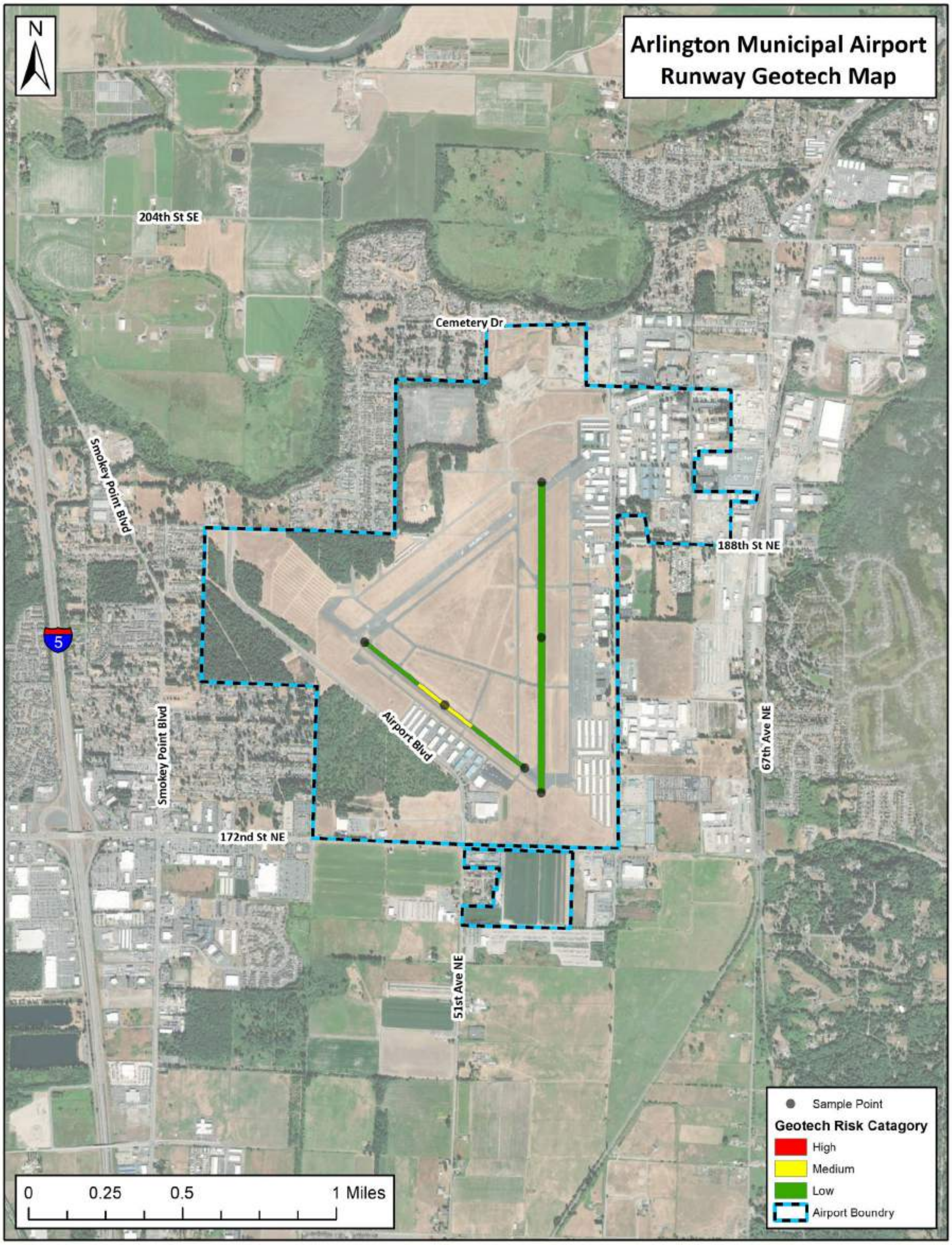
Appendix B

Appendix B-1. Arlington Municipal

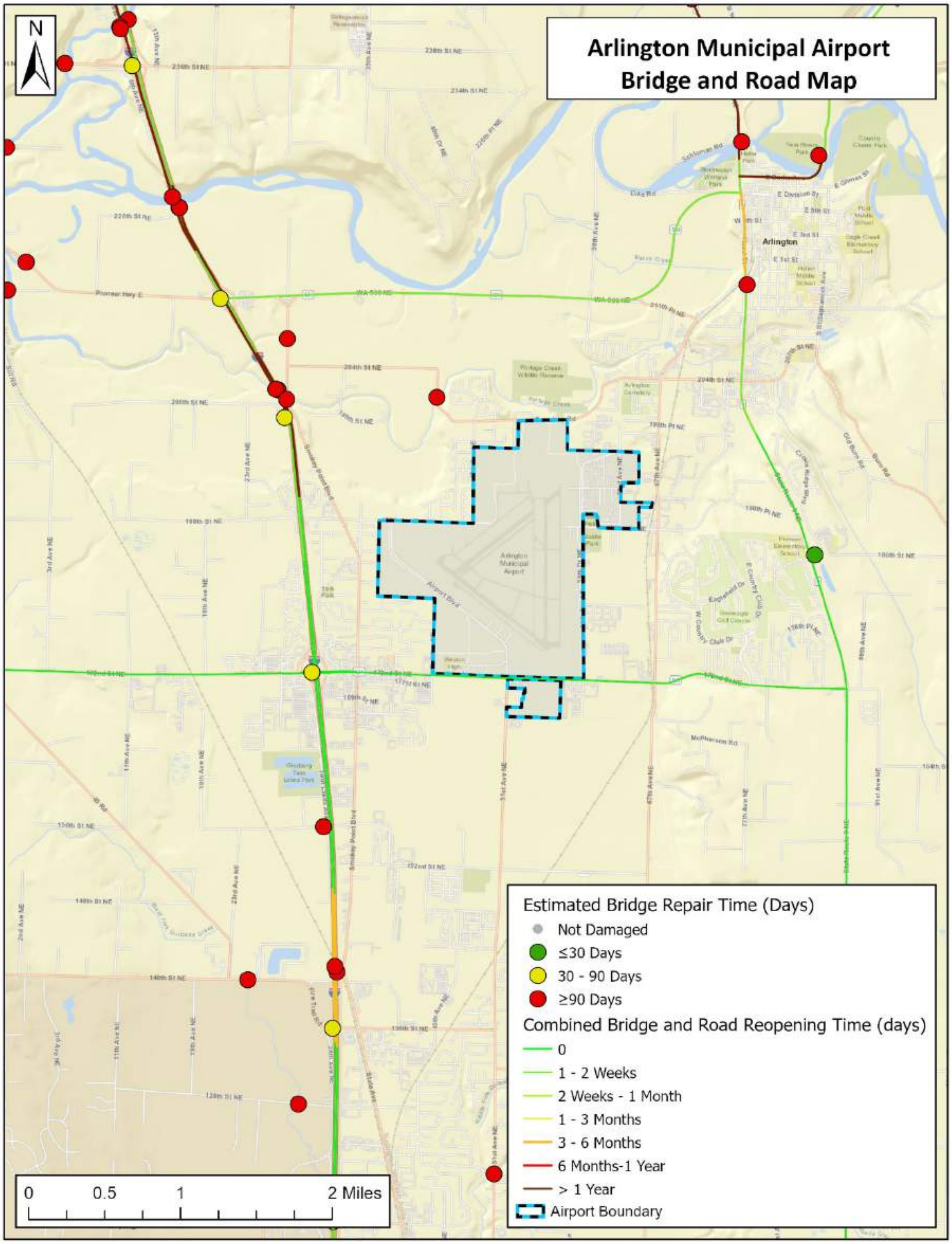



Arlington Municipal Airport
Liquefaction Map
N
204th St SE
Cemetery Dr.
Smokey Point Blvd
188th St NE
5
Airport Blvd
Smokey Point Blvd
67th Ave NE
172nd St NE
51st Ave NE
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

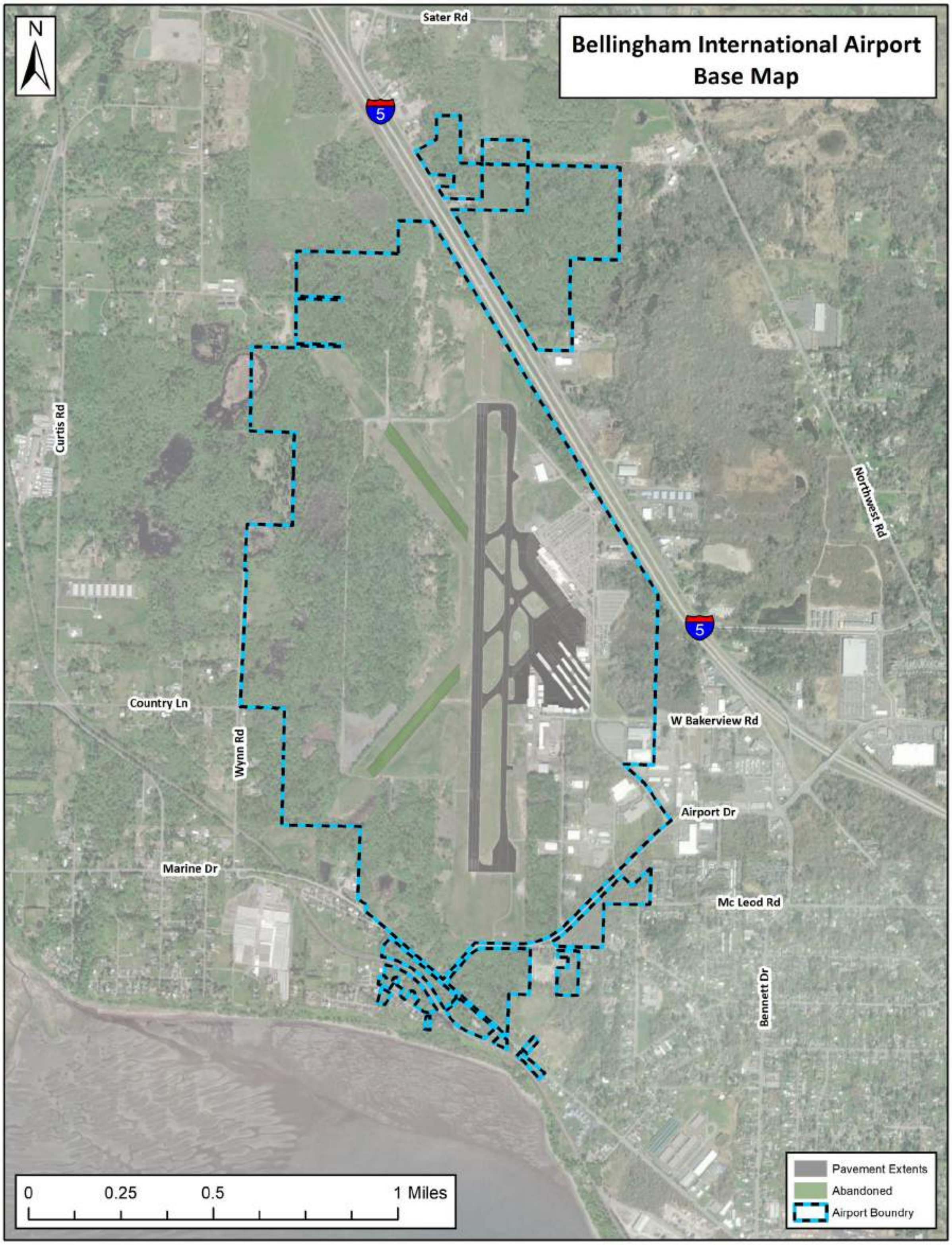
B-3

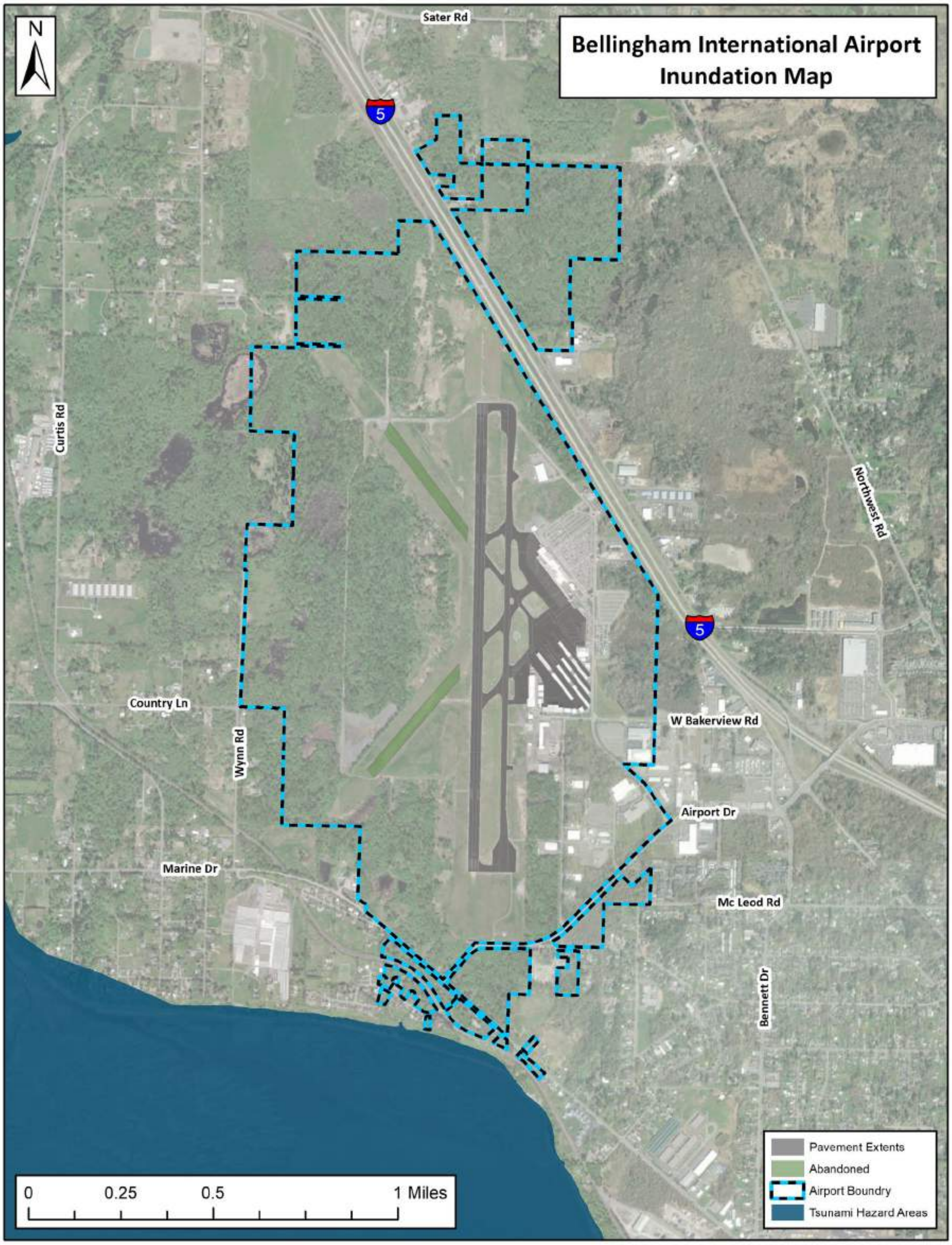

Arlington Municipal Airport
Runway Geotech Map
N
204th St SE
Cemetery Dr
Smokey Point Blvd
188th St NE
5
Airport Blvd
67th Ave NE
Smokey Point Blvd
172nd St NE
51st Ave NE
Sample Point
Geotech Risk Catagory
High
Medium
Low
Airport Boundry
0
0.25
0.5
1 Miles

B-4


Arlington Municipal Airport
Bridge and Road Map
N
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
Airport Boundary
0
0.5
1
2 Miles
Arlington
Arlington Municipal Airport
Pioneer Hwy E
172nd St NE
Airport Blvd
Smokey Point Blvd
51st Ave NE
180th St NE
204th St NE

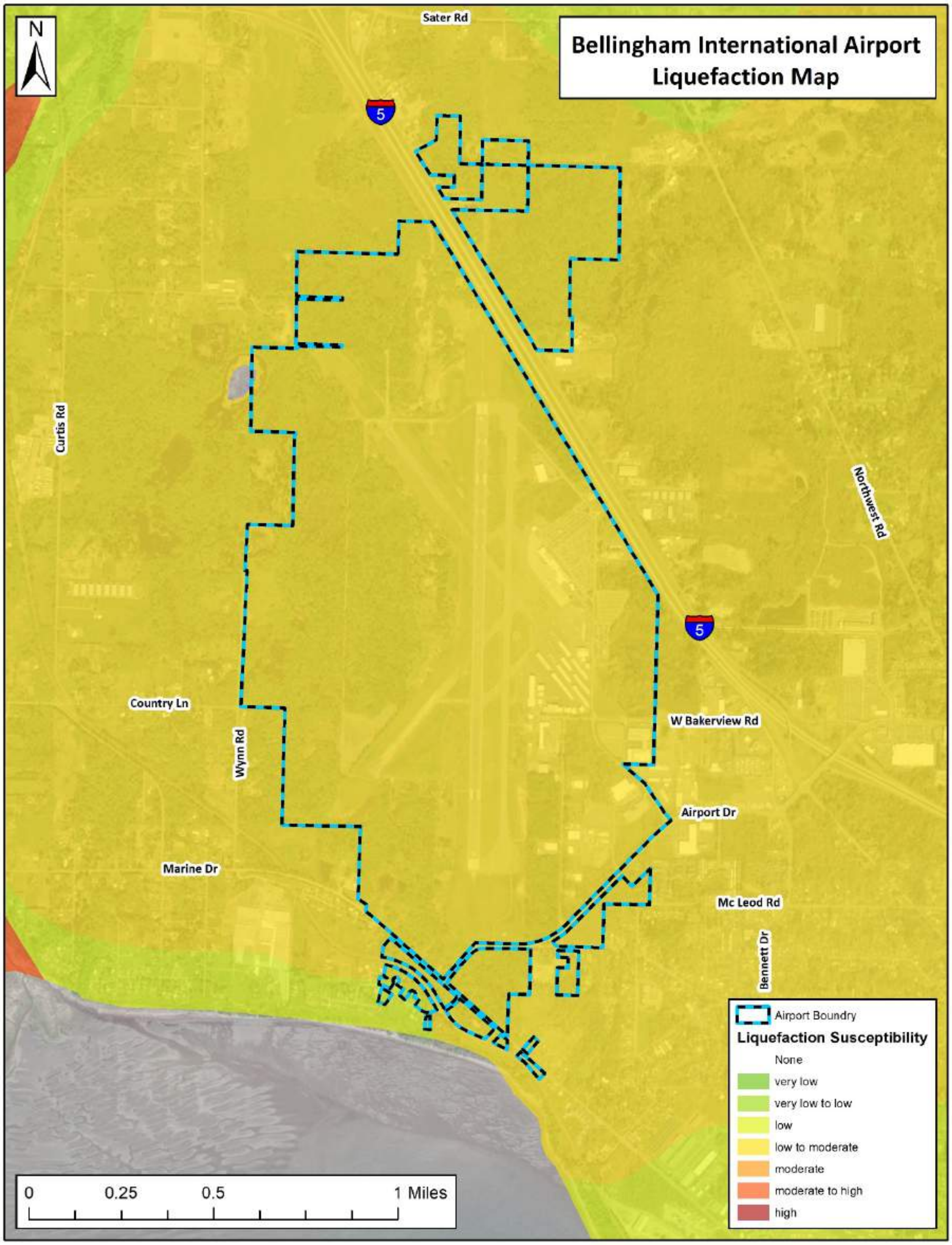
Appendix B-2. Bellingham International

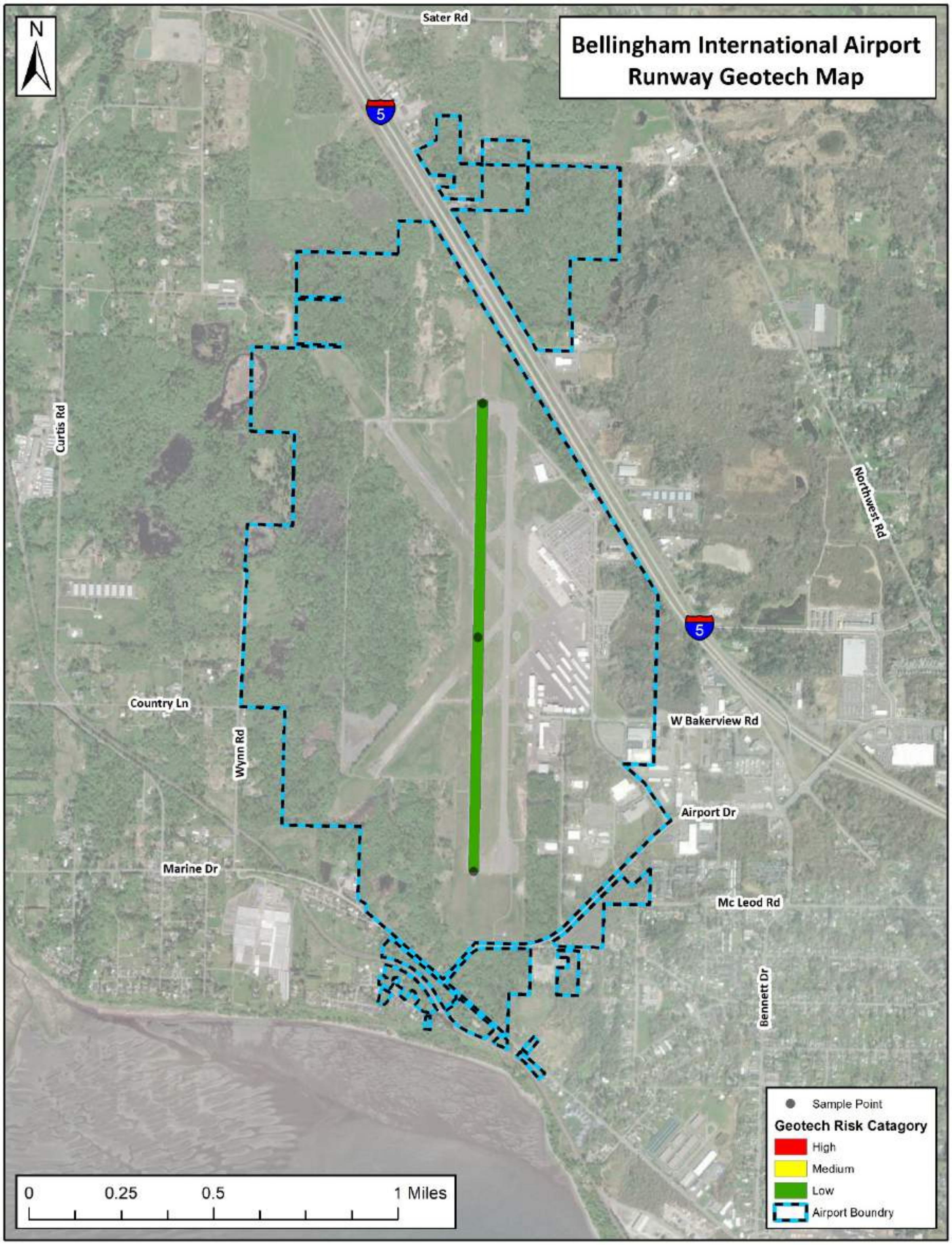


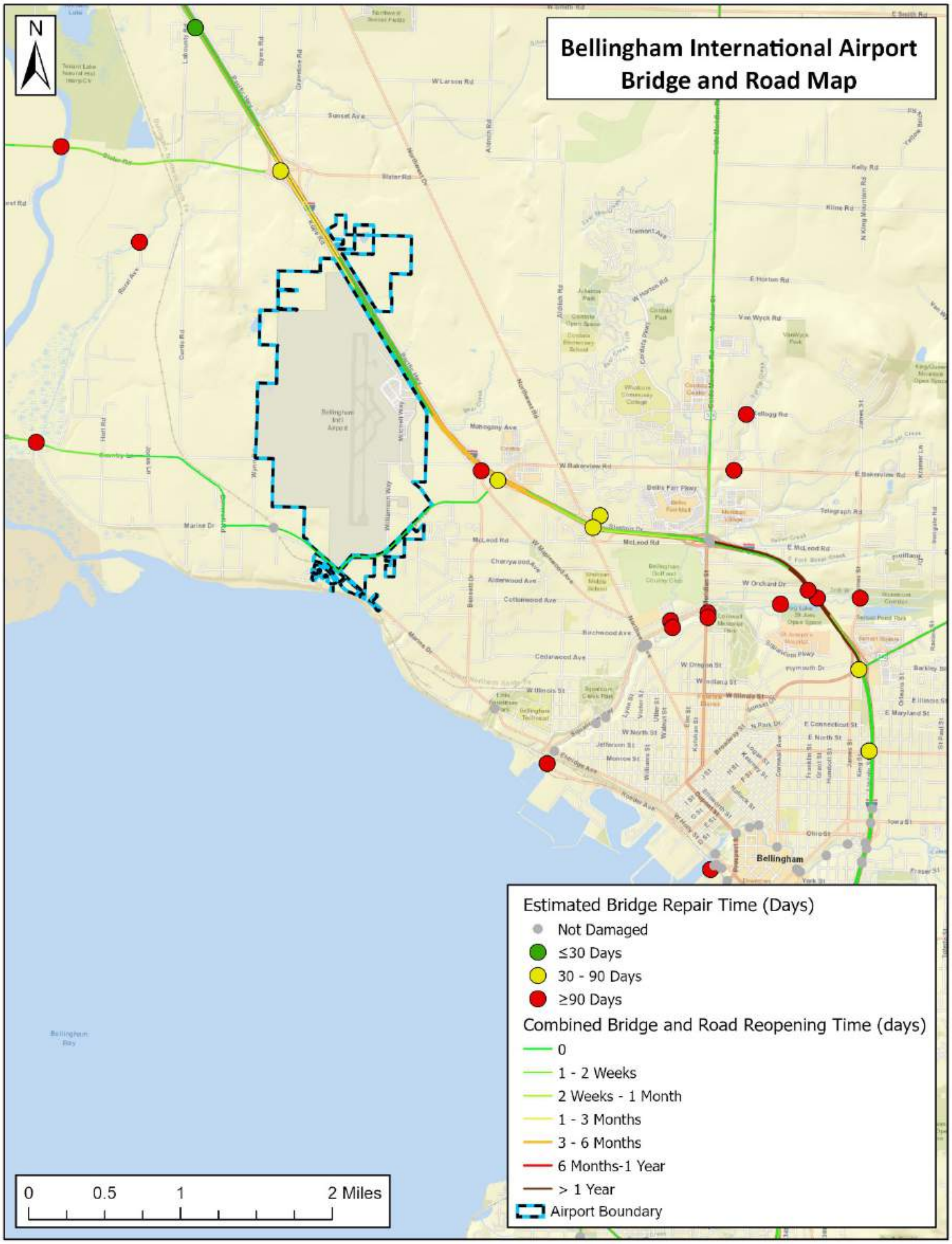


Bellingham International Airport Inundation Map

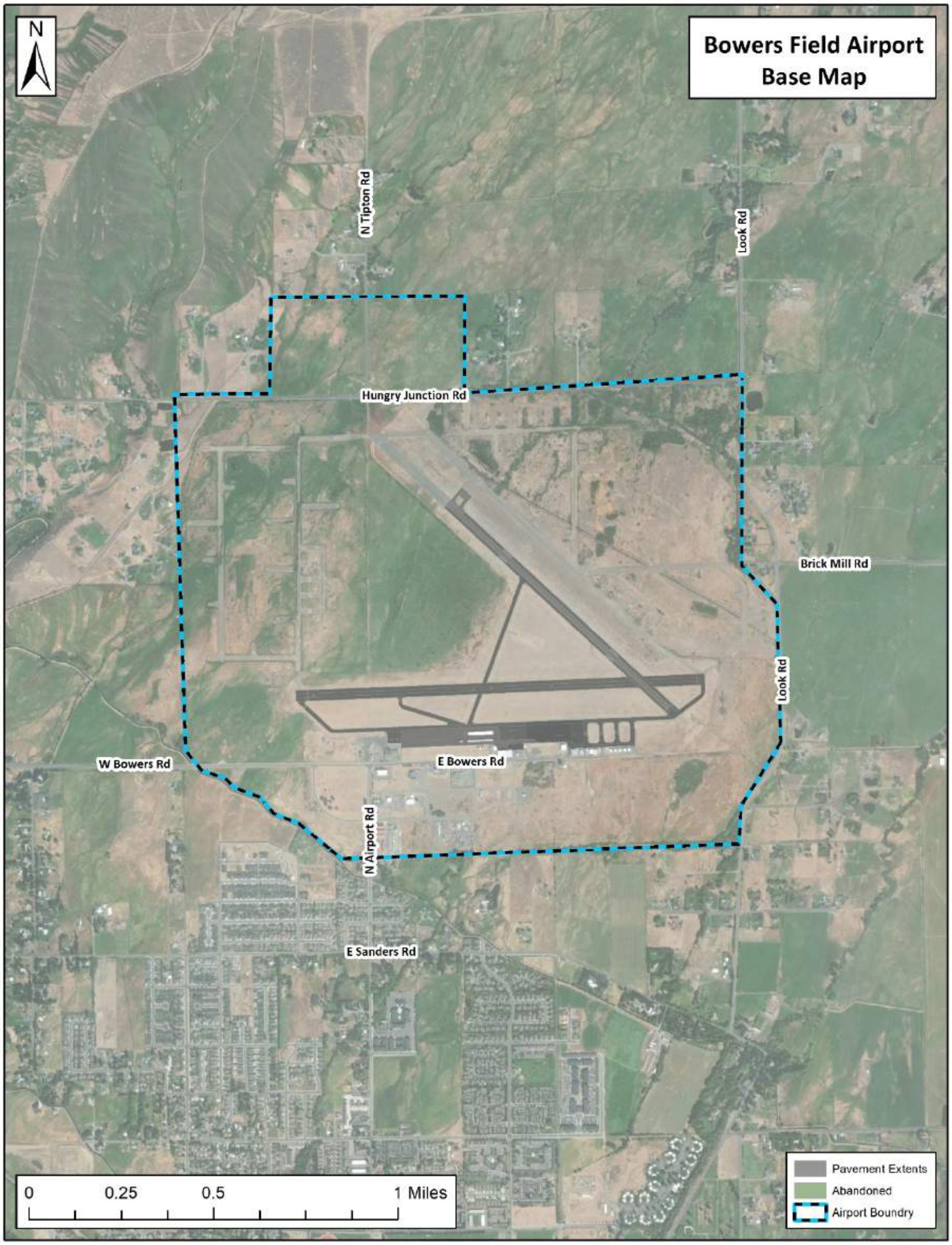
B-7

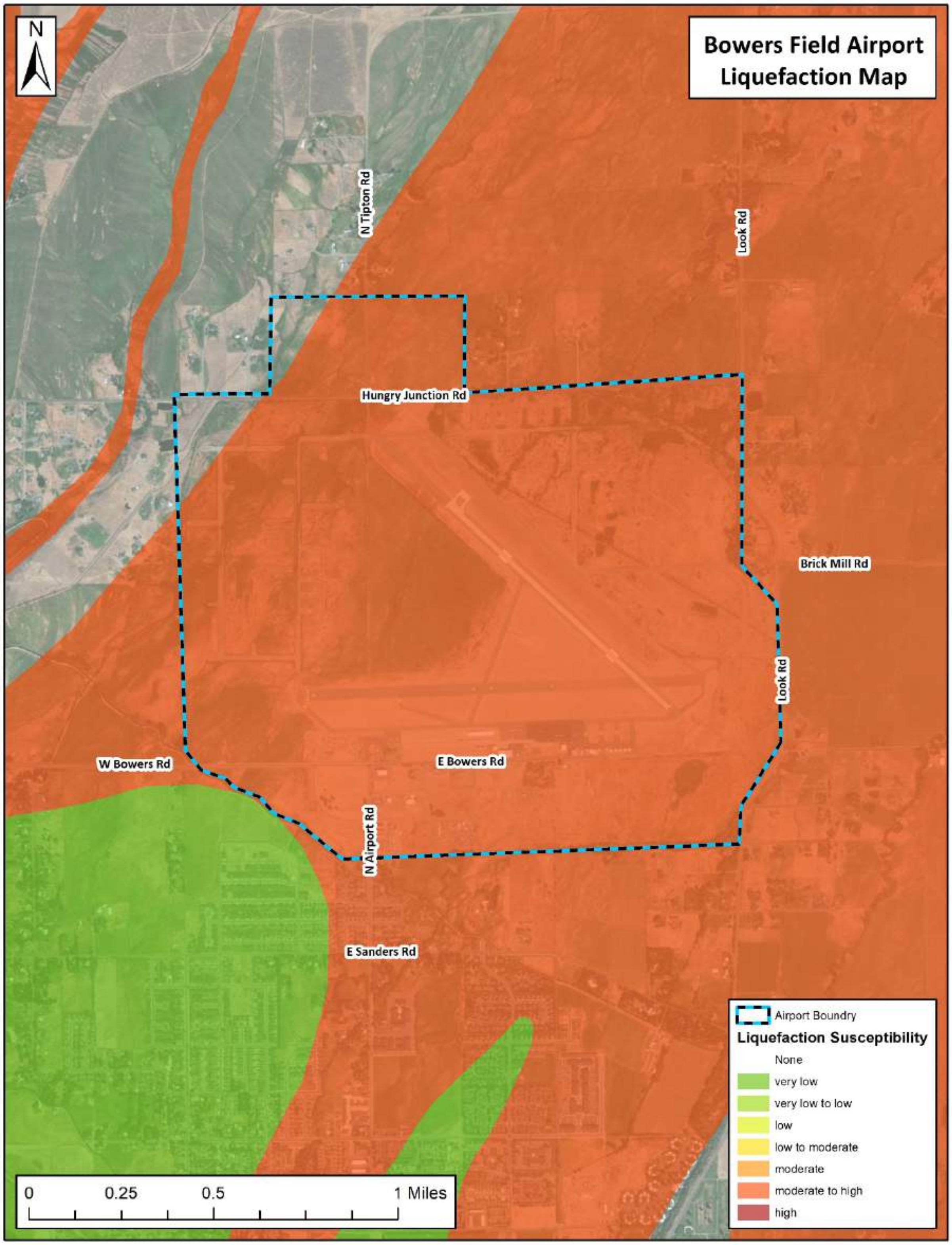

Bellingham International Airport
Liquefaction Map
N
Sater Rd
5
5
Curtis Rd
Northwest Rd
Country Ln
Wynn Rd
W Bakerview Rd
Airport Dr
Marine Dr
Mc Leod Rd
Bennett Dr
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles


Bellingham International Airport
Runway Geotech Map
N
Sater Rd
5
Curtis Rd
Northwest Rd
Country Ln
Wynn Rd
W Bakerview Rd
Airport Dr
Marine Dr
Mc Leod Rd
Bennett Dr
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles

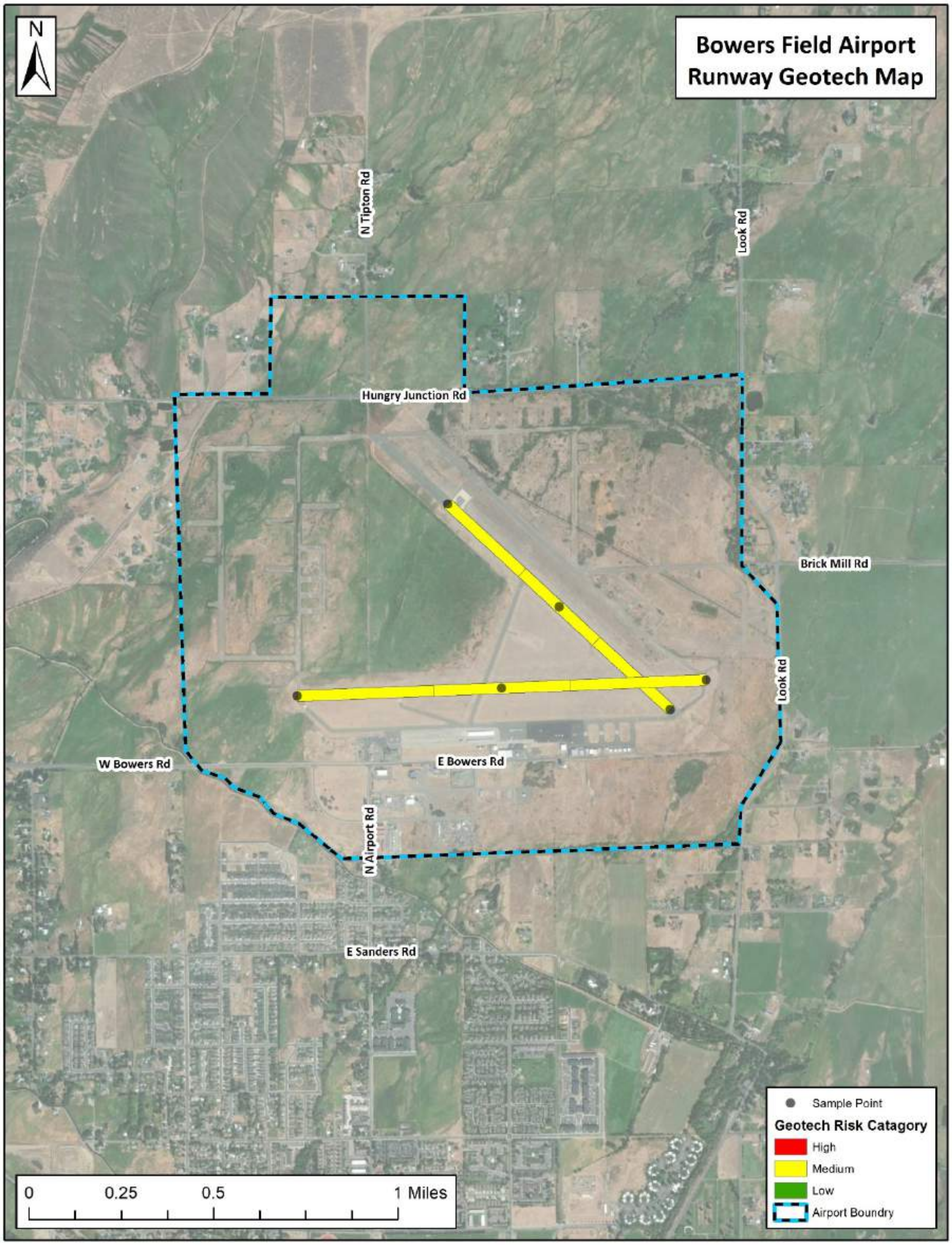

Bellingham International Airport
Bridge and Road Map
N
Bellingham
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles

Appendix B-3. Bowers Field (Ellensburg)

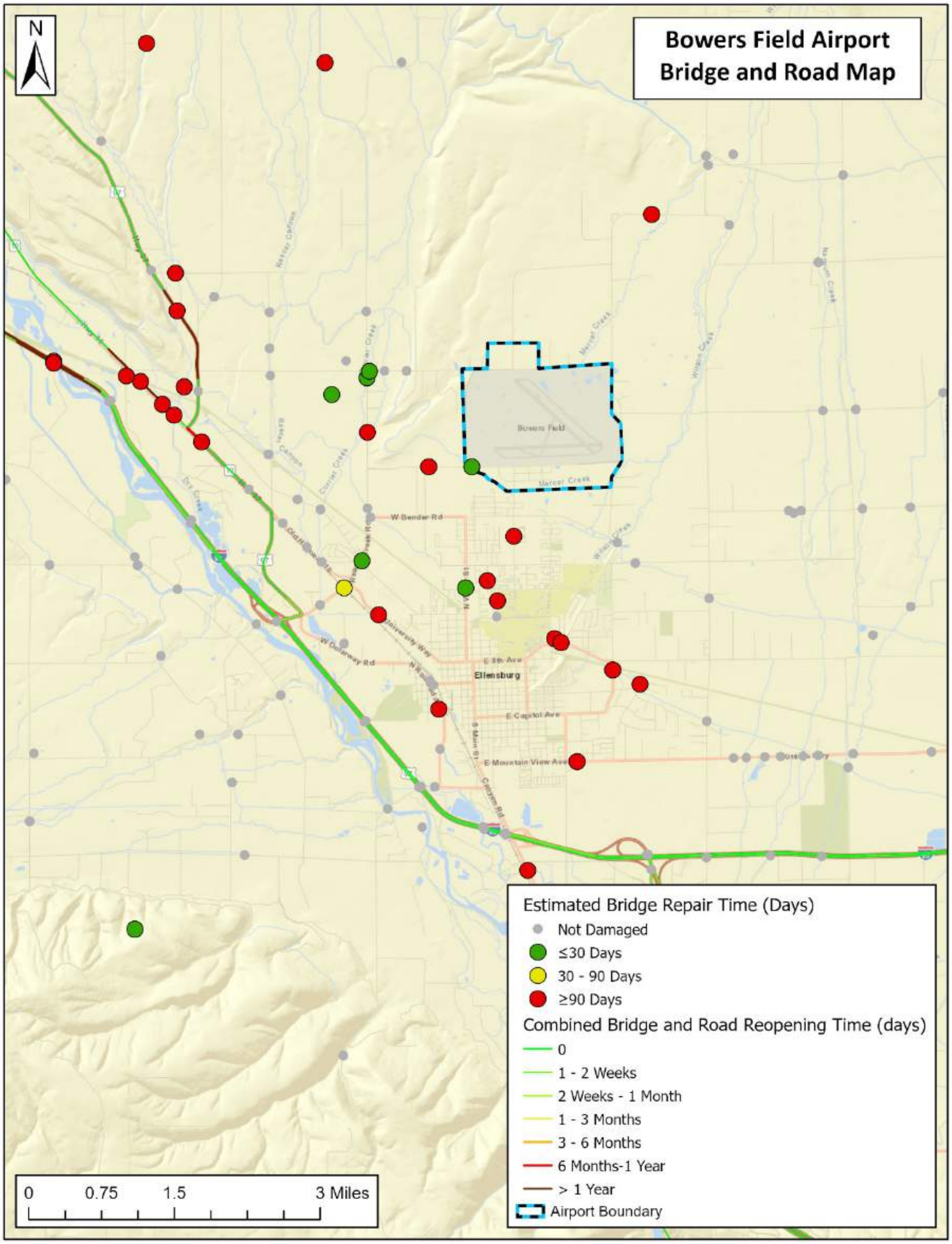



N
Bowers Field Airport
Liquefaction Map
N Tipton Rd
Look Rd
Hungry Junction Rd
Brick Mill Rd
Look Rd
W Bowers Rd
E Bowers Rd
N Airport Rd
E Sanders Rd
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

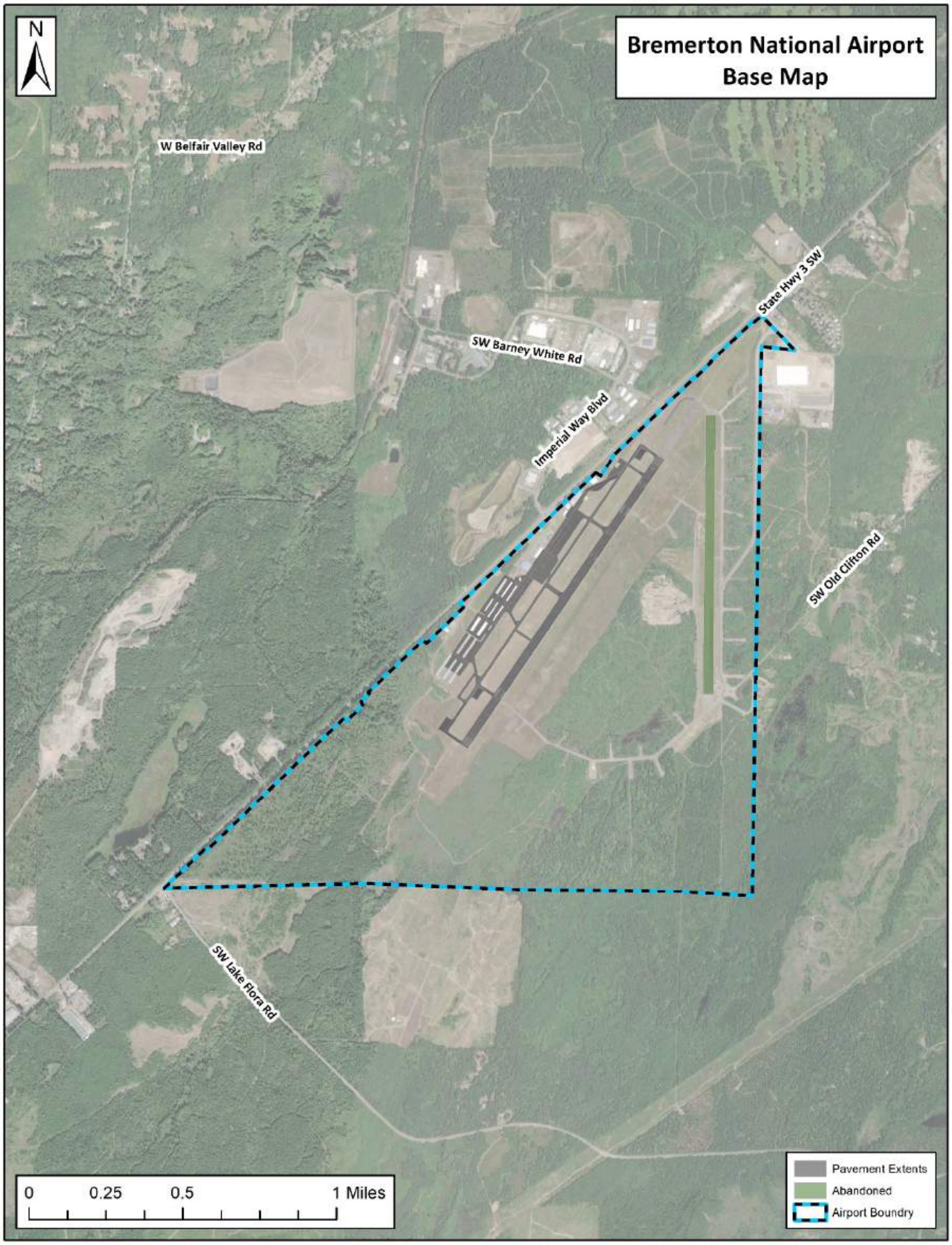
B-12

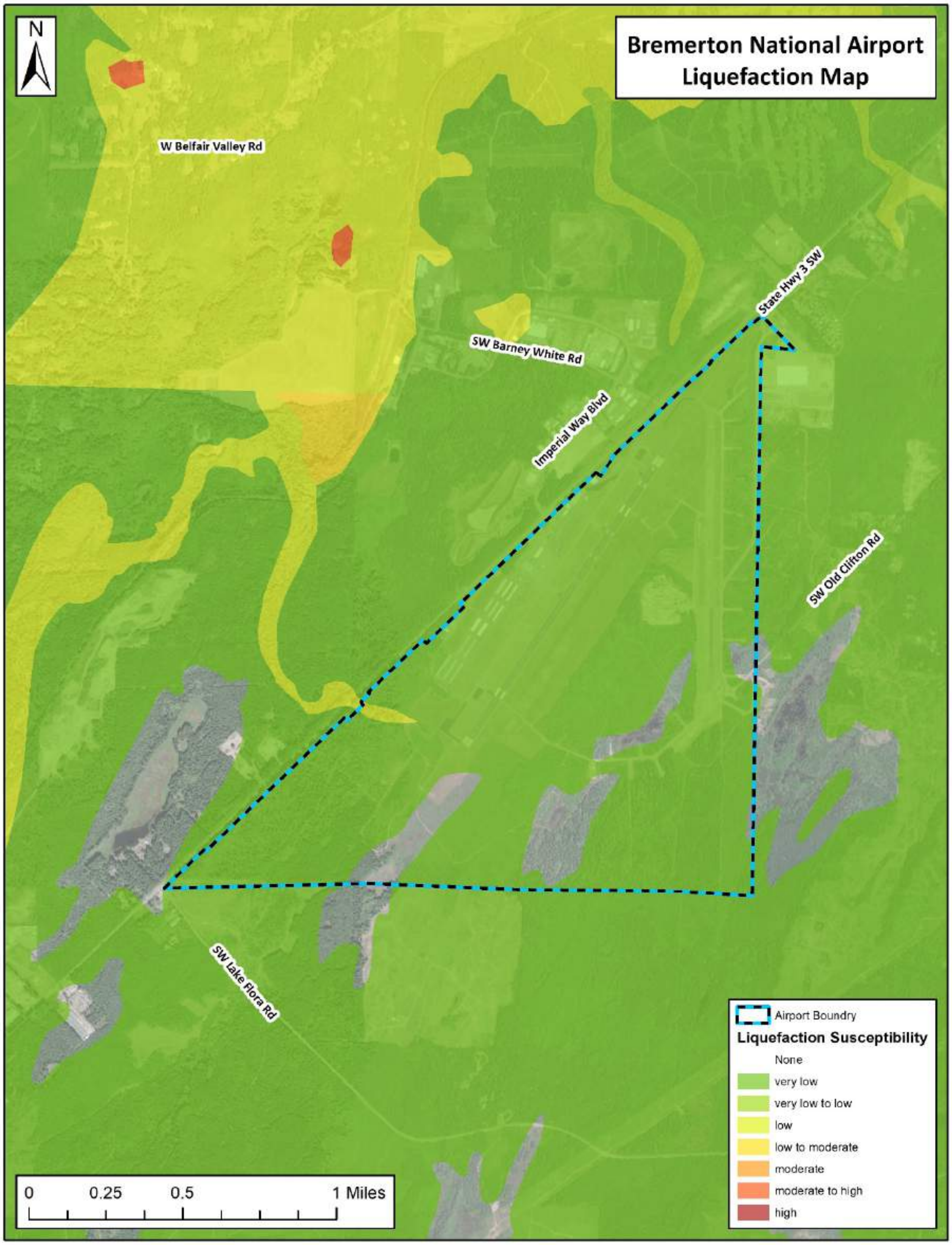

N
Bowers Field Airport
Runway Geotech Map
N Tipton Rd
Look Rd
Hungry Junction Rd
Brick Mill Rd
Look Rd
W Bowers Rd
E Bowers Rd
N Airport Rd
E Sanders Rd
0
0.25
0.5
1 Miles
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry

B-13

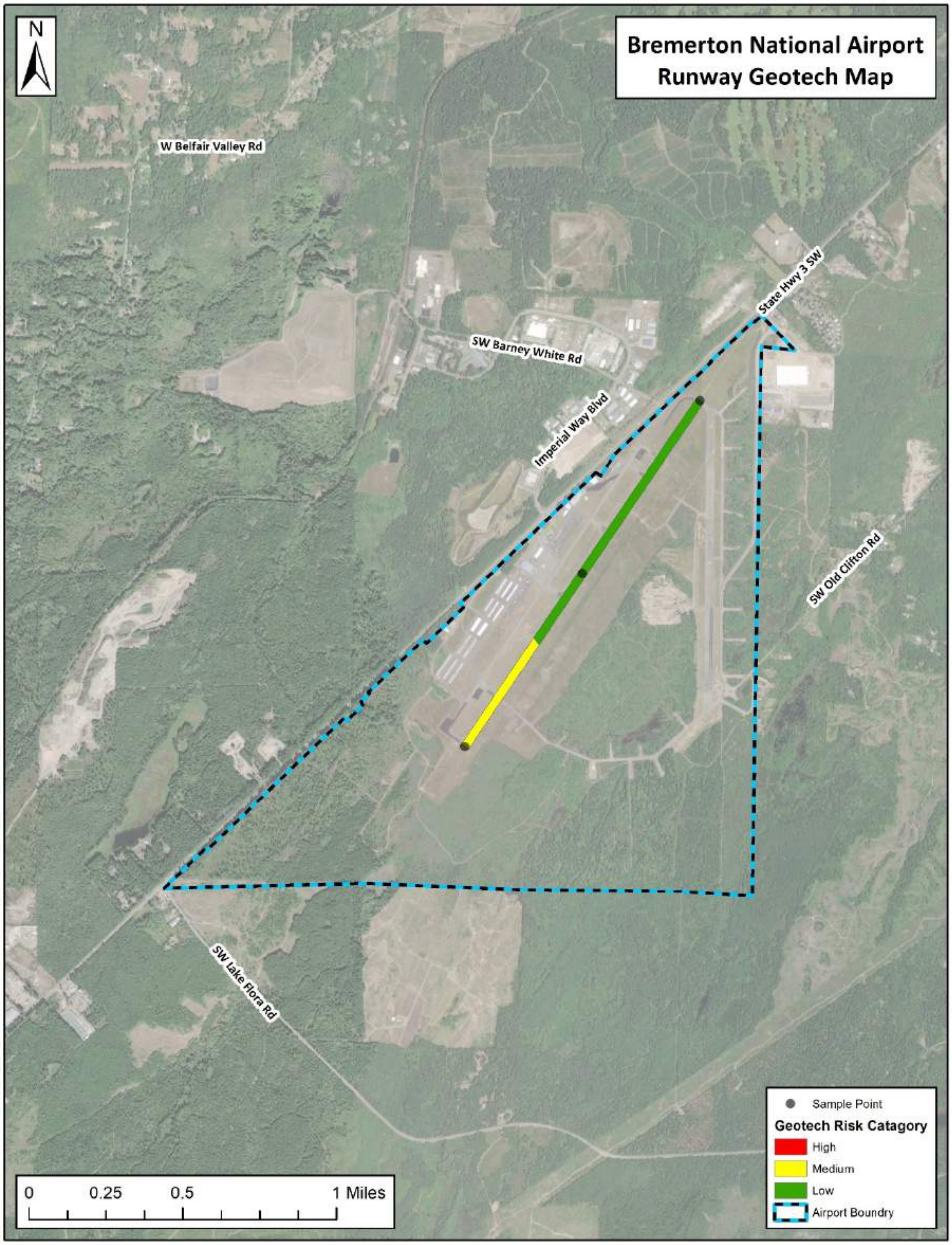

Bowers Field Airport
Bridge and Road Map
N
Bowers Field
Mercer Creek
W Bender Rd
University Way
W Dolarway Rd
E 8th Ave
Ellensburg
E Capitol Ave
E Mountain View Ave
S Main St
Canyon Rd
Estimated Bridge Repair Time (Days)
● Not Damaged
🟢 ≤30 Days
🟡 30 - 90 Days
🔴 ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
Airport Boundary
0
0.75
1.5
3 Miles

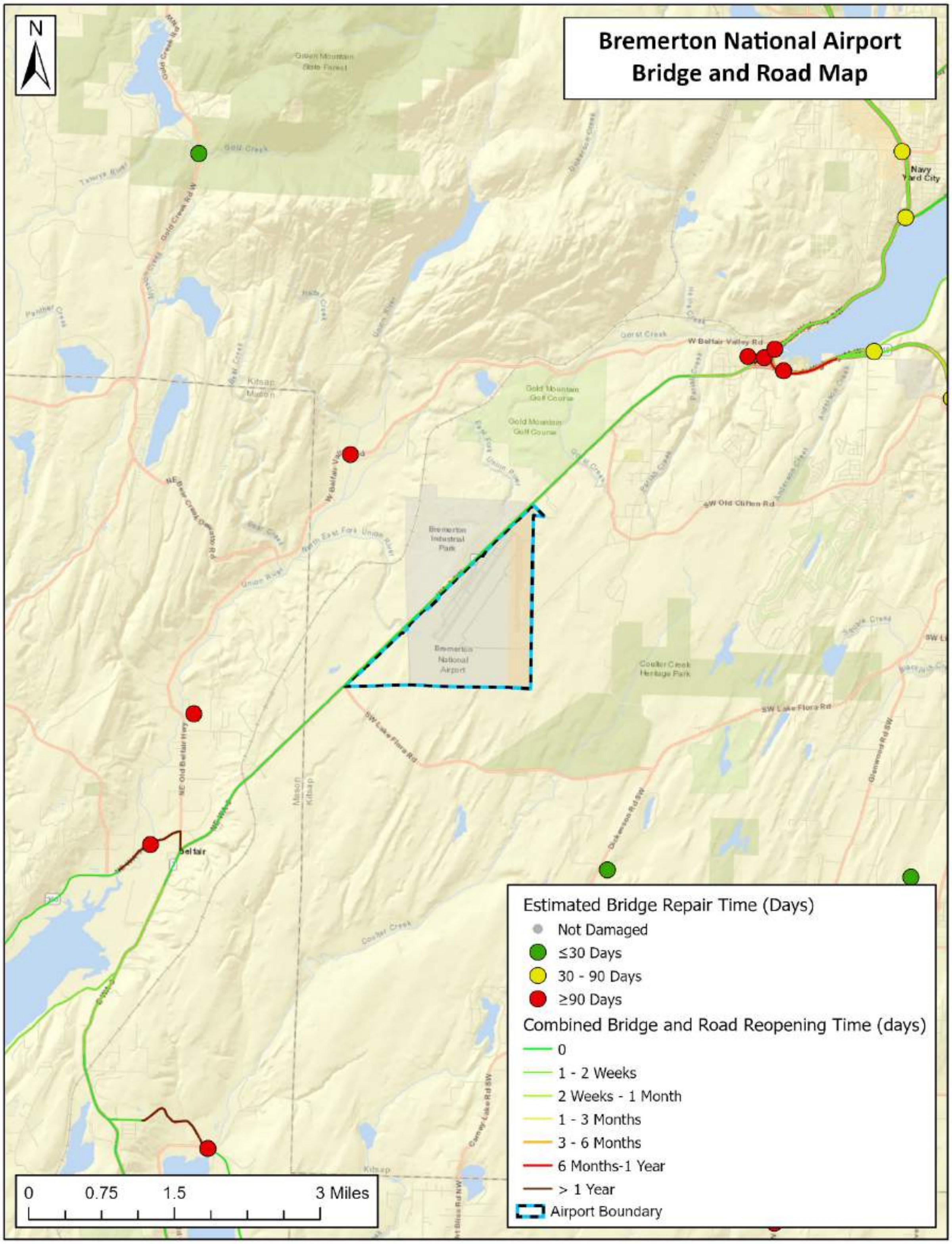
Appendix B-4. Bremerton National



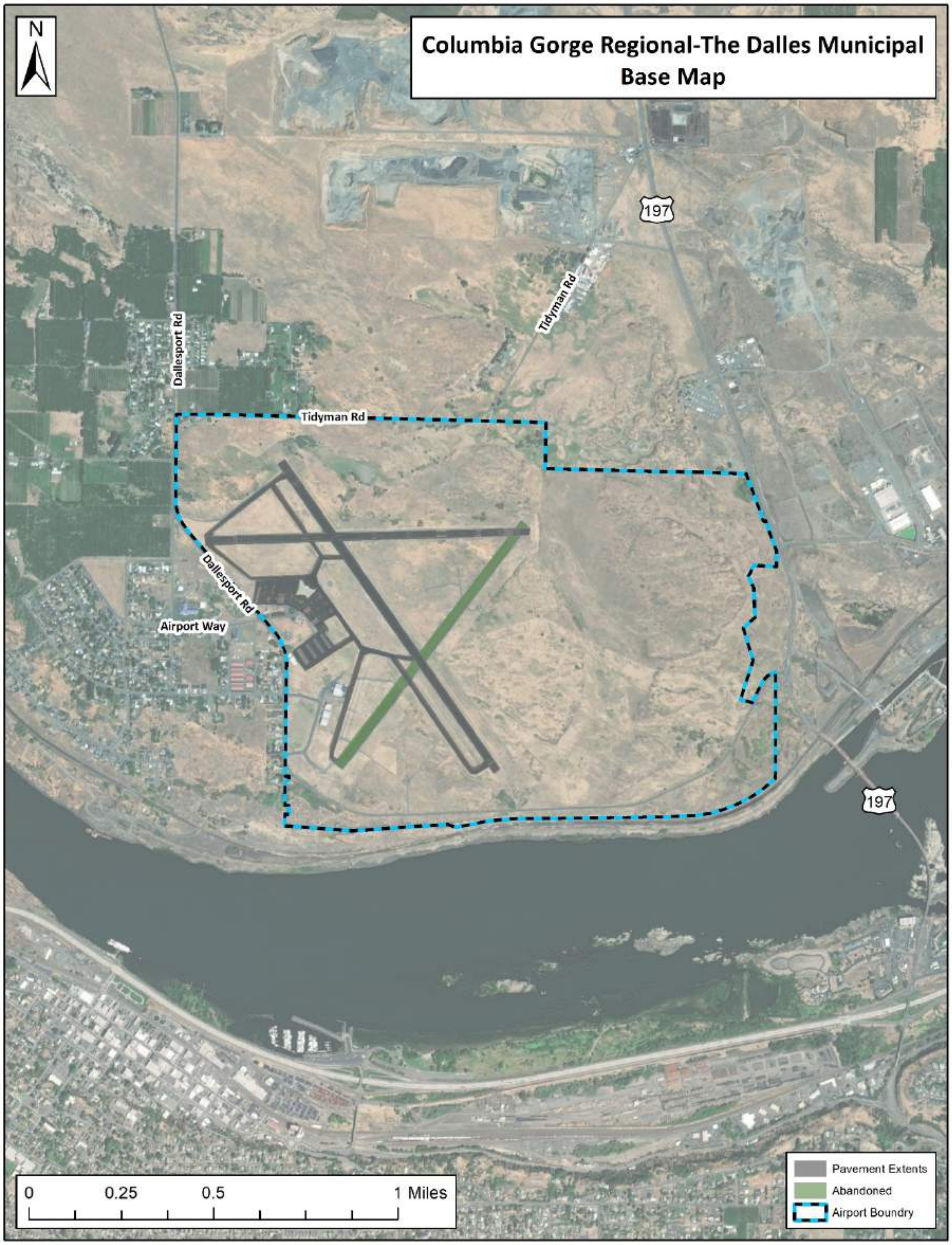

Bremerton National Airport
Liquefaction Map
N
W Belfair Valley Rd
State Hwy 3 SW
SW Barney White Rd
Imperial Way Blvd
SW Old Clifton Rd
SW Lake Flora Rd
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

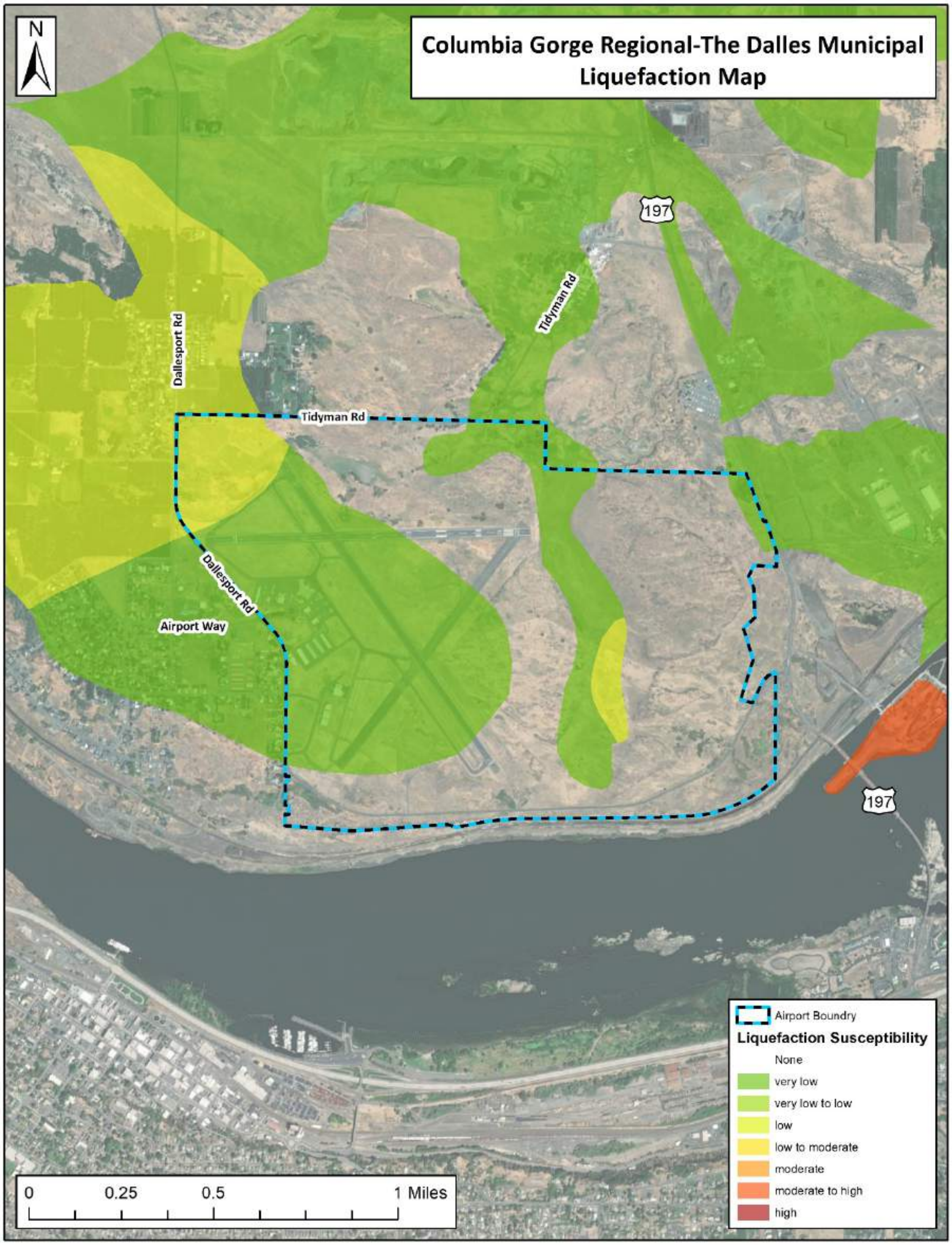
B-16


N
Bremerton National Airport
Runway Geotech Map
W Belfair Valley Rd
State Hwy 3 SW
SW Barney White Rd
Imperial Way Blvd
SW Old Clifton Rd
SW Lake Flora Rd
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles


N
Bremerton National Airport
Bridge and Road Map
Green Mountain State Forest
Gold Creek
Navy Yard City
W Belfair Valley Rd
Gold Mountain Golf Course
Kitsap
Mason
Bremerton Industrial Park
Bremerton National Airport
SW Old Clifton Rd
Union River
Coulter Creek Heritage Park
SW Lake Flora Rd
NE Old Belfair Hwy
Belfair
Coulter Creek
Estimated Bridge Repair Time (Days)
Not Damaged
≤30 Days
30 - 90 Days
≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.75
1.5
3 Miles

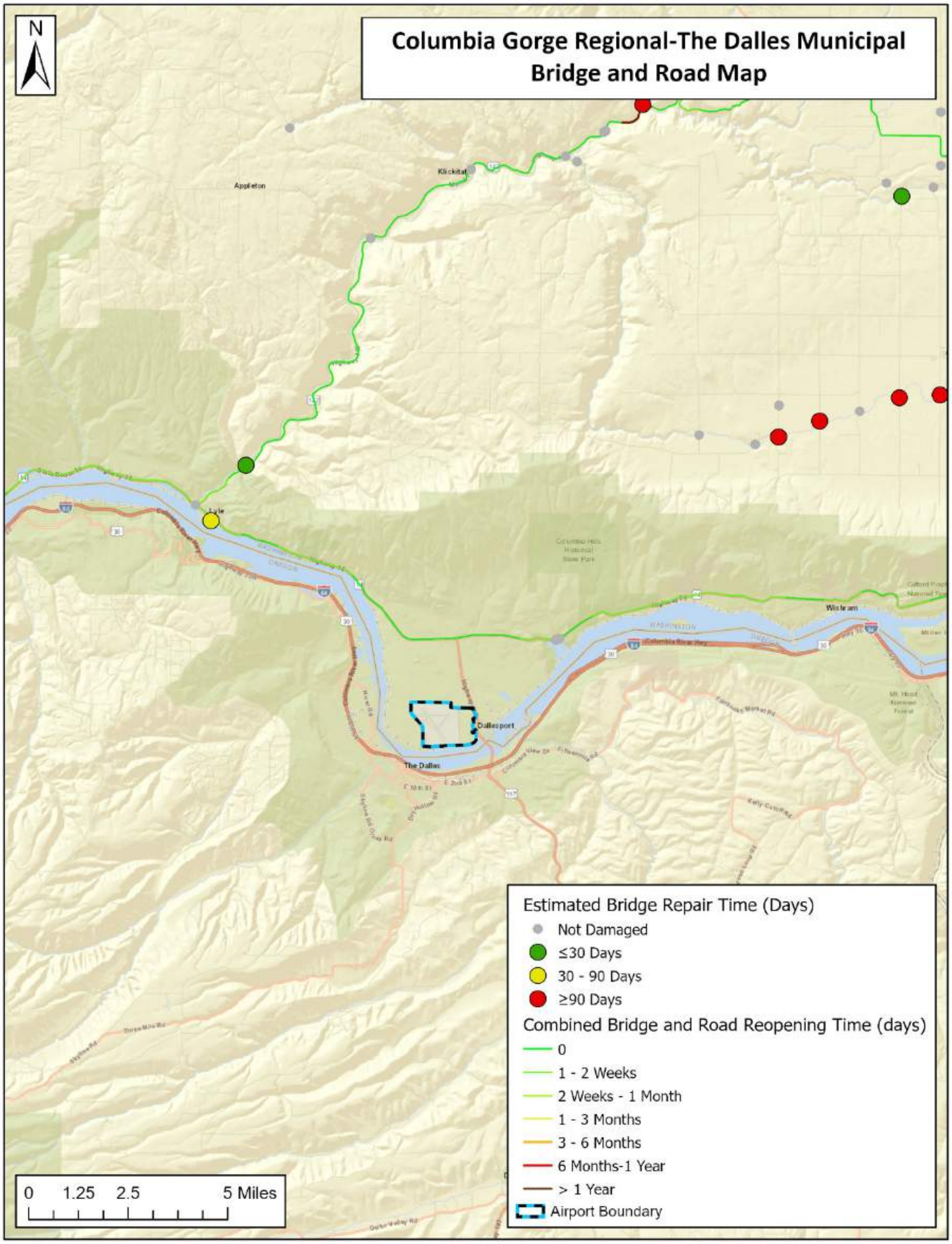
Appendix B-5. Columbia Gorge Regional – The Dalles Municipal



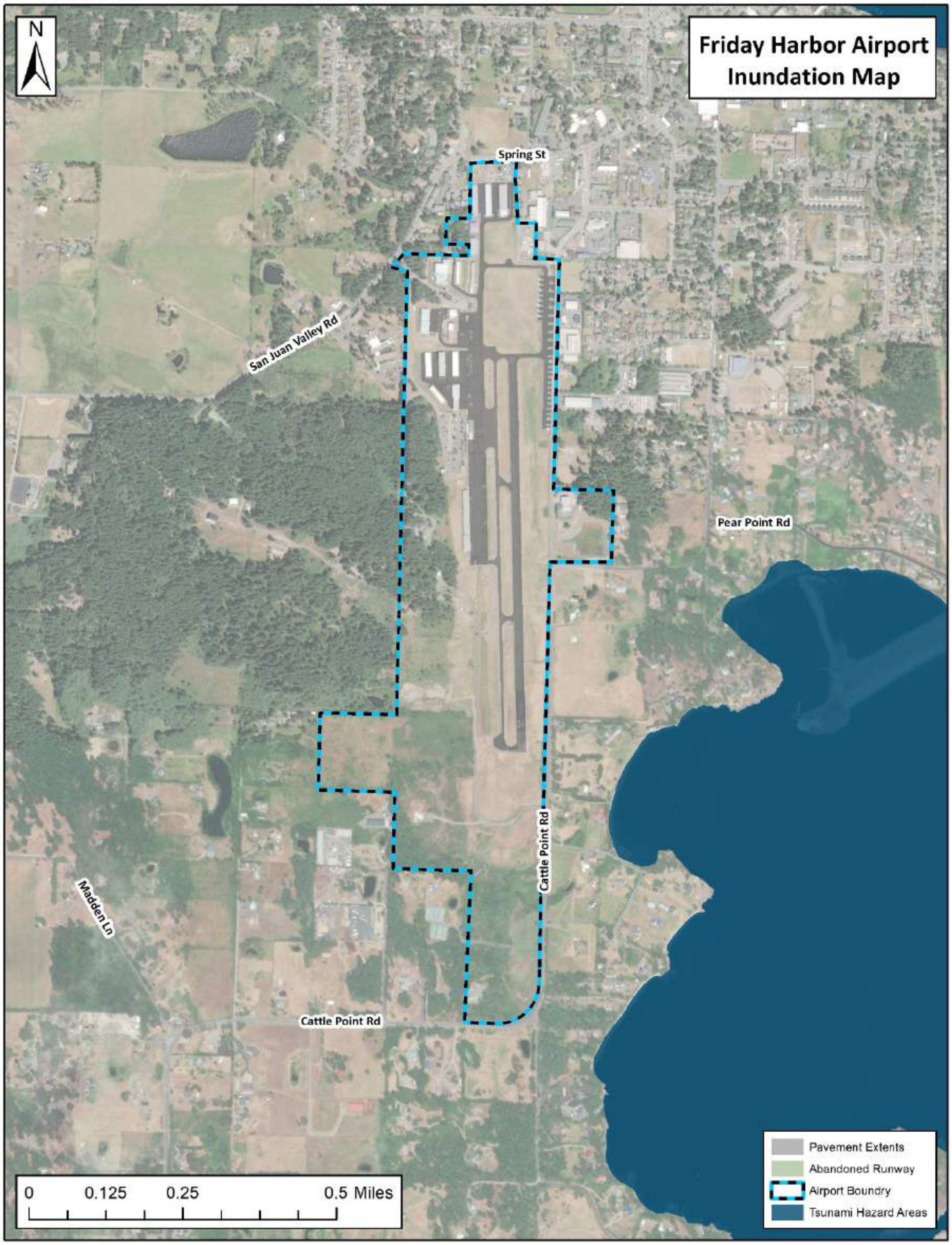

Columbia Gorge Regional-The Dalles Municipal
Liquefaction Map
N
197
Tidyman Rd
Dallesport Rd
Tidyman Rd
Dallesport Rd
Airport Way
197
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

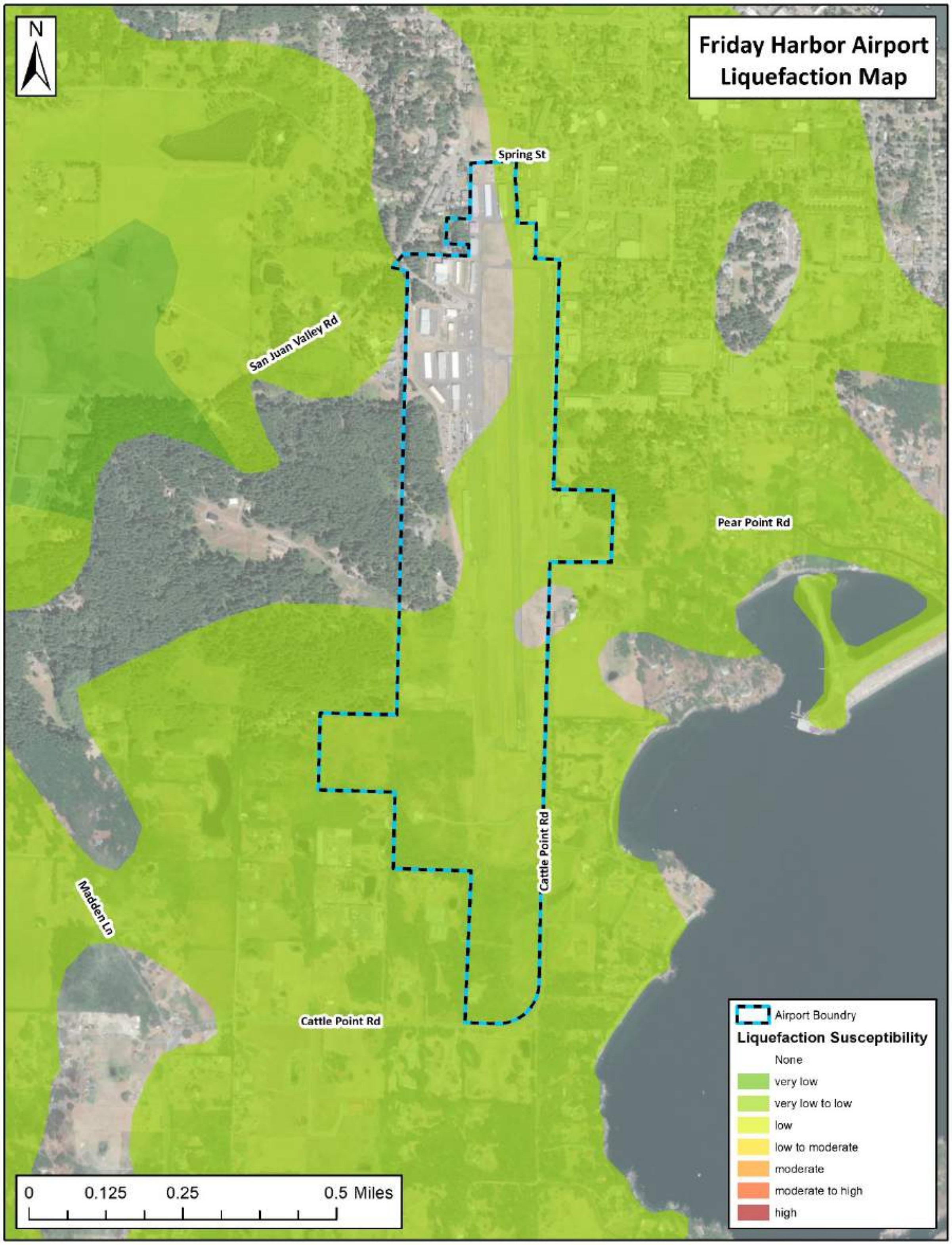

N
Columbia Gorge Regional-The Dalles Municipal
Runway Geotech Map
197
Tidyman Rd
Dallesport Rd
Tidyman Rd
Dallesport Rd
Airport Way
197
● Sample Point
Runway_Geotech
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Fence Line
0
0.25
0.5
1 Miles

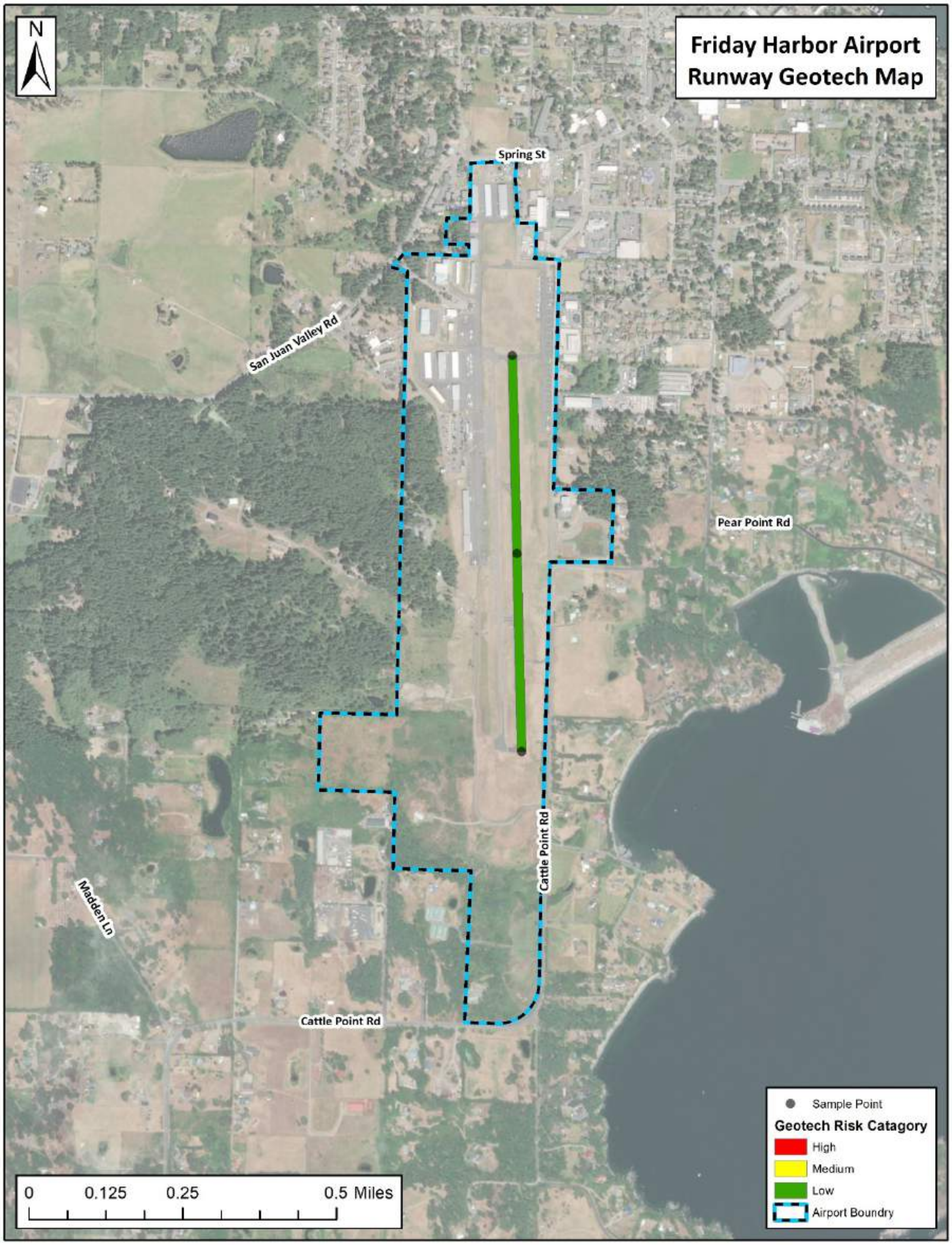
B-21

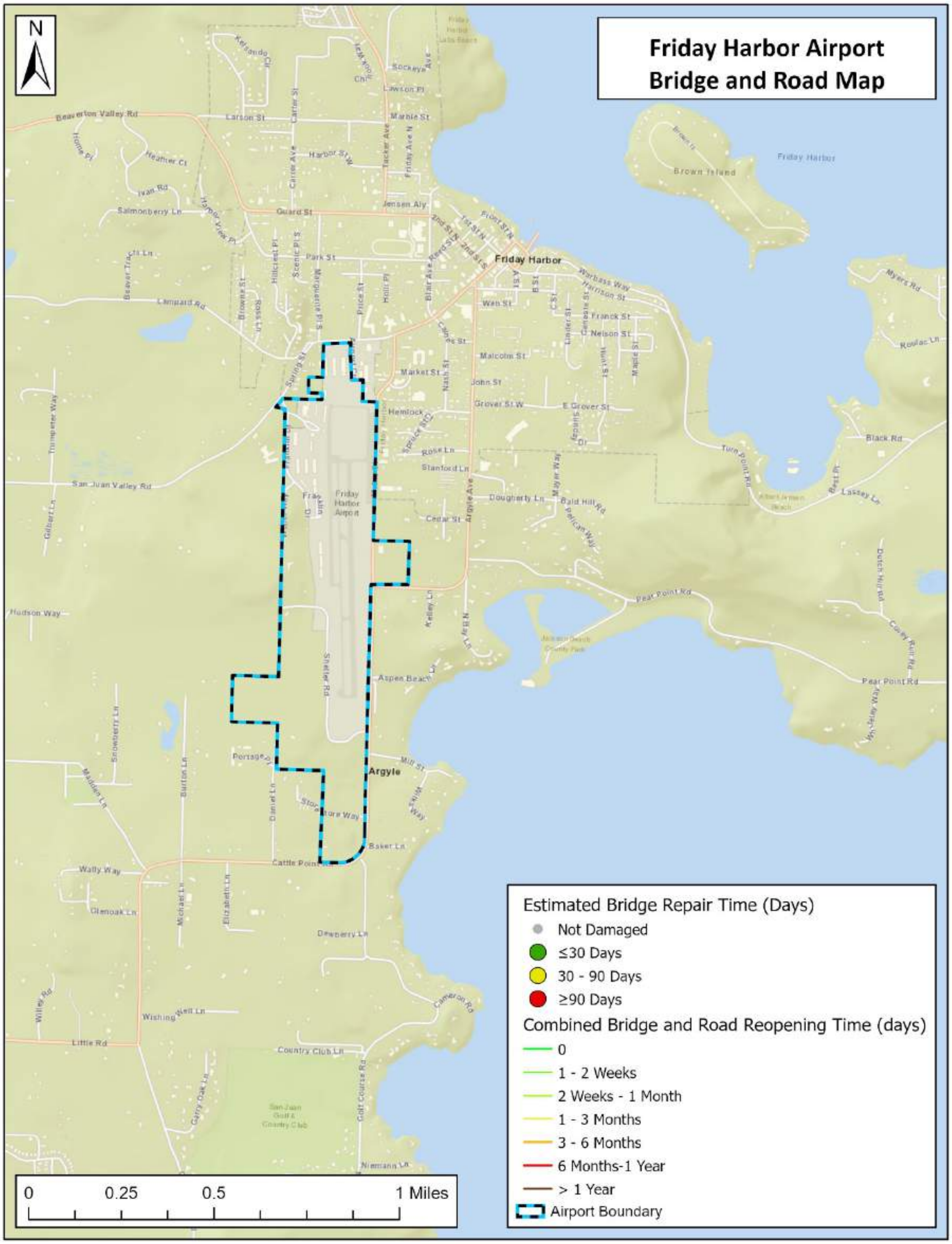

N
Columbia Gorge Regional-The Dalles Municipal Bridge and Road Map
Klickitat
Appleton
Lyle
Columbia Hills Historical State Park
Wishram
Washington
Dallesport
The Dalles
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
1.25
2.5
5 Miles

Appendix B-6. Friday Harbor

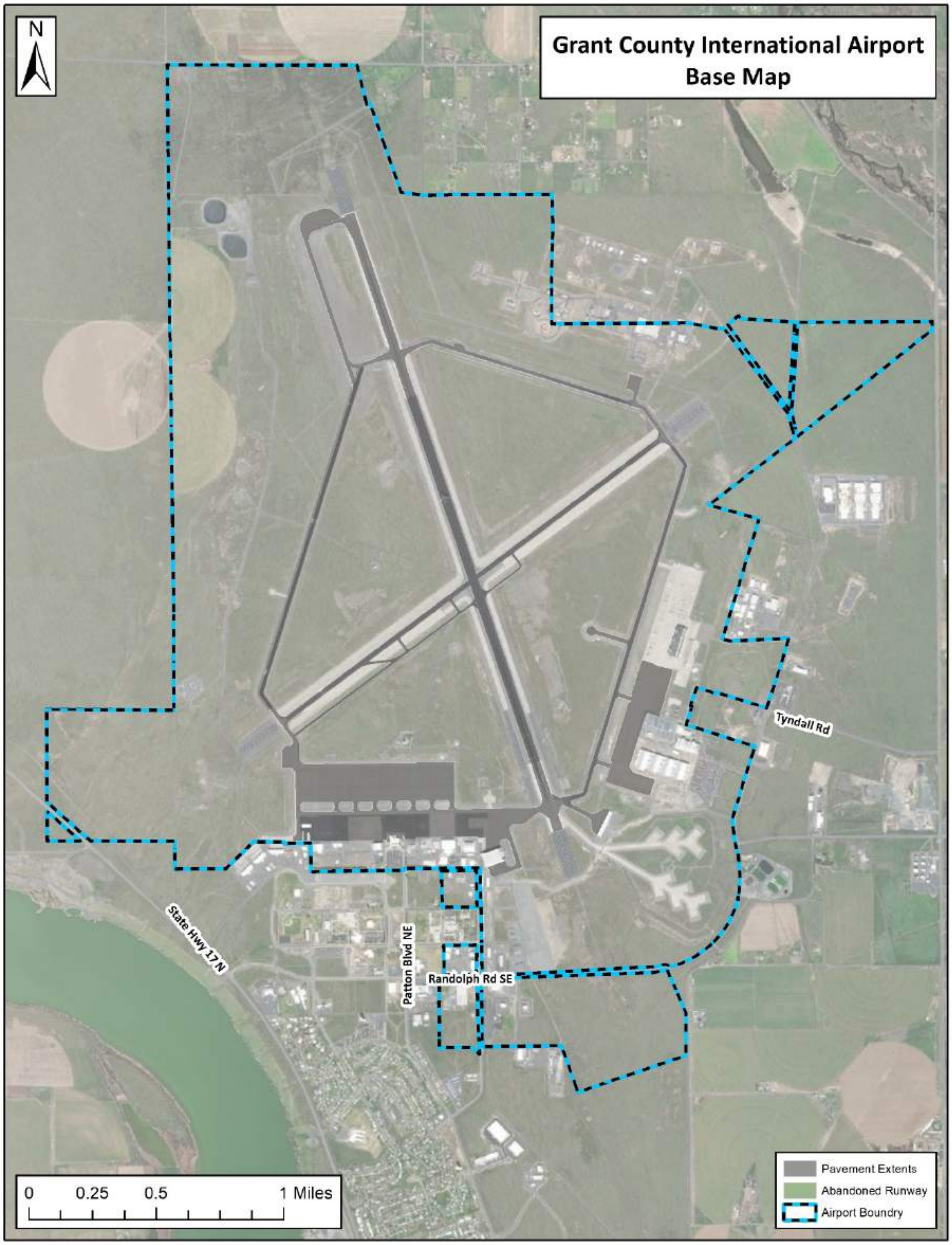

Friday Harbor Airport
Inundation Map
N
Spring St
San Juan Valley Rd
Pear Point Rd
Cattle Point Rd
Madden Ln
Cattle Point Rd
Pavement Extents
Abandoned Runway
Airport Boundry
Tsunami Hazard Areas
0
0.125
0.25
0.5 Miles

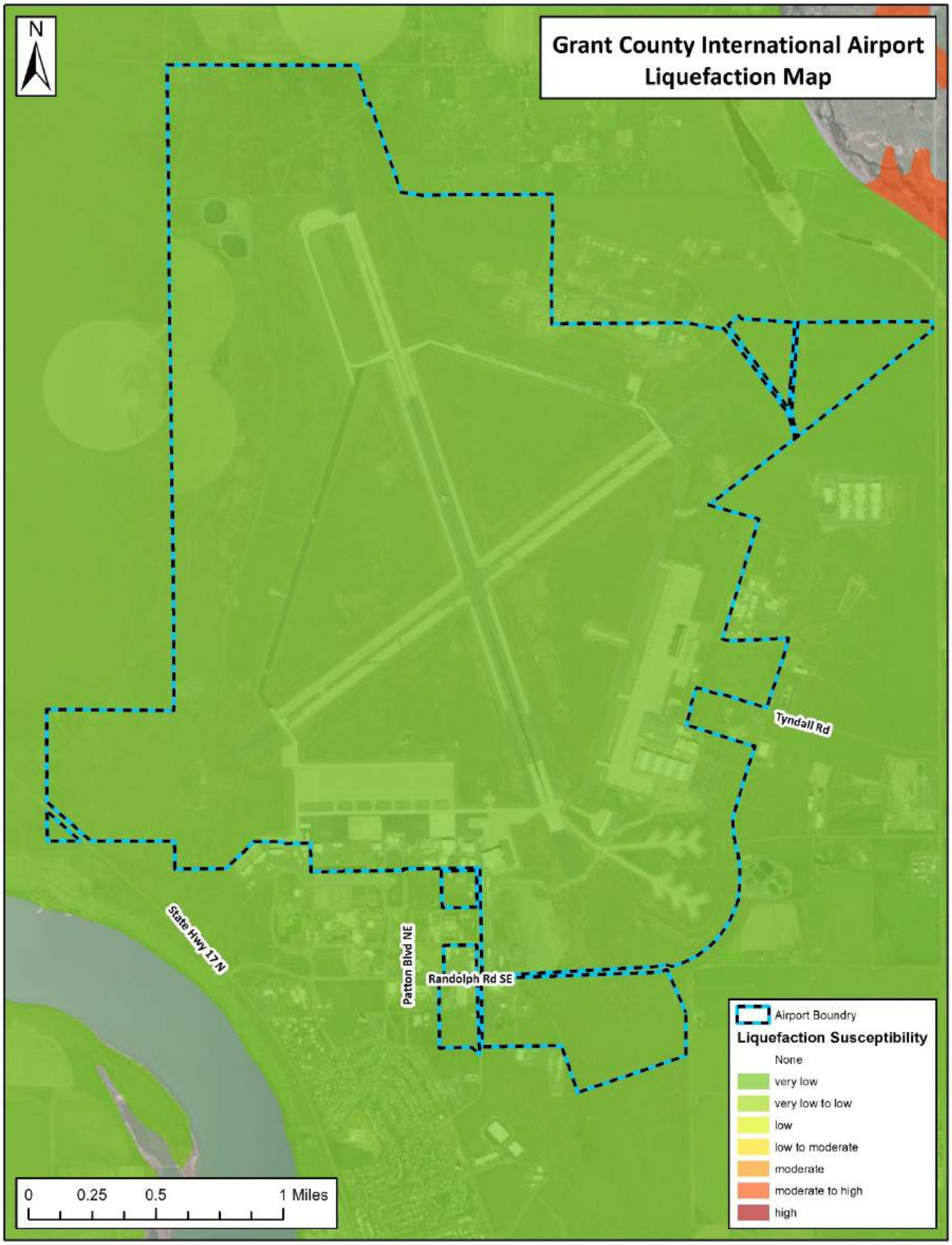

N
Friday Harbor Airport
Liquefaction Map
Spring St
San Juan Valley Rd
Pear Point Rd
Cattle Point Rd
Madden Ln
Cattle Point Rd
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.125
0.25
0.5 Miles

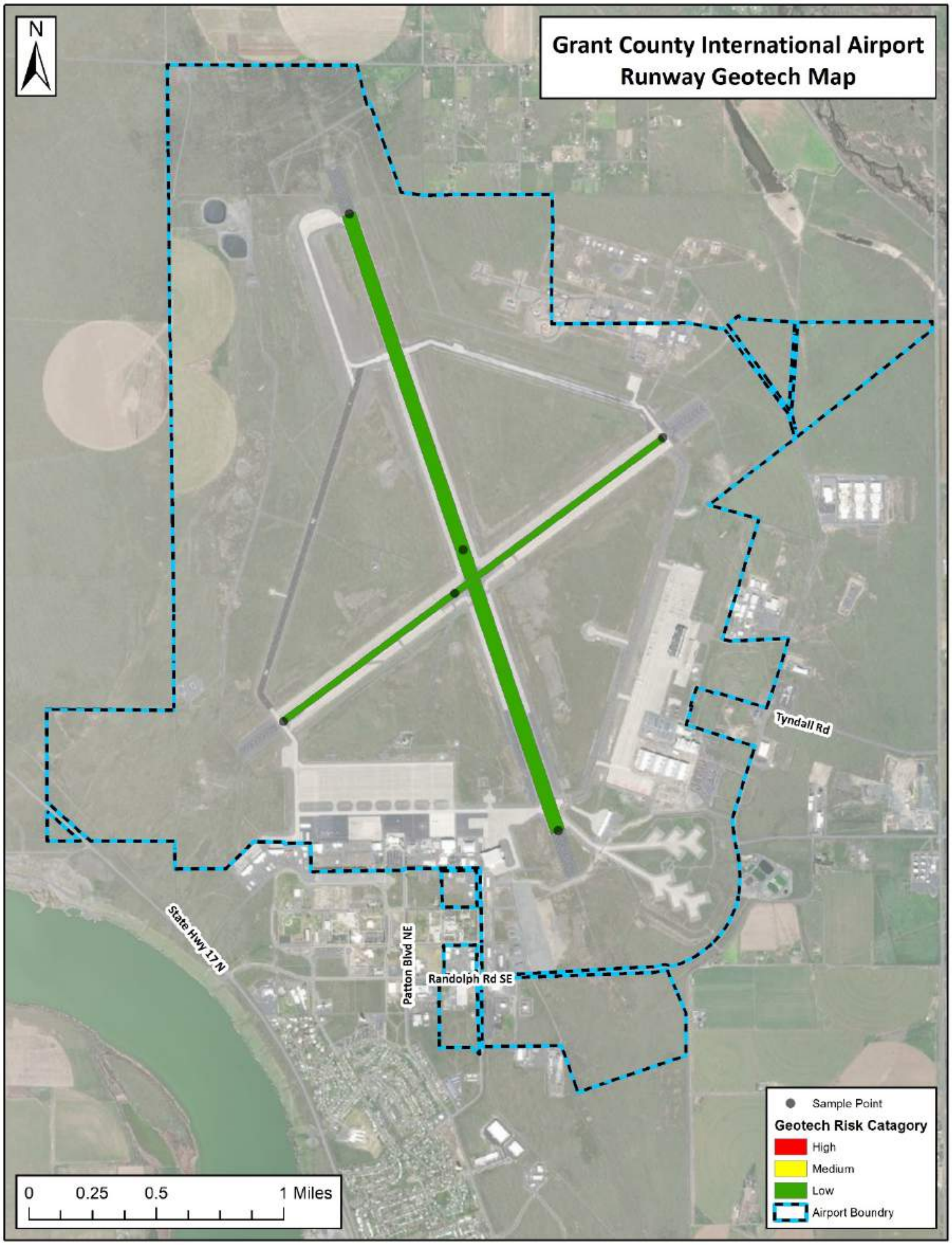

N
Friday Harbor Airport
Runway Geotech Map
Spring St
San Juan Valley Rd
Pear Point Rd
Cattle Point Rd
Madden Ln
Cattle Point Rd
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.125
0.25
0.5 Miles

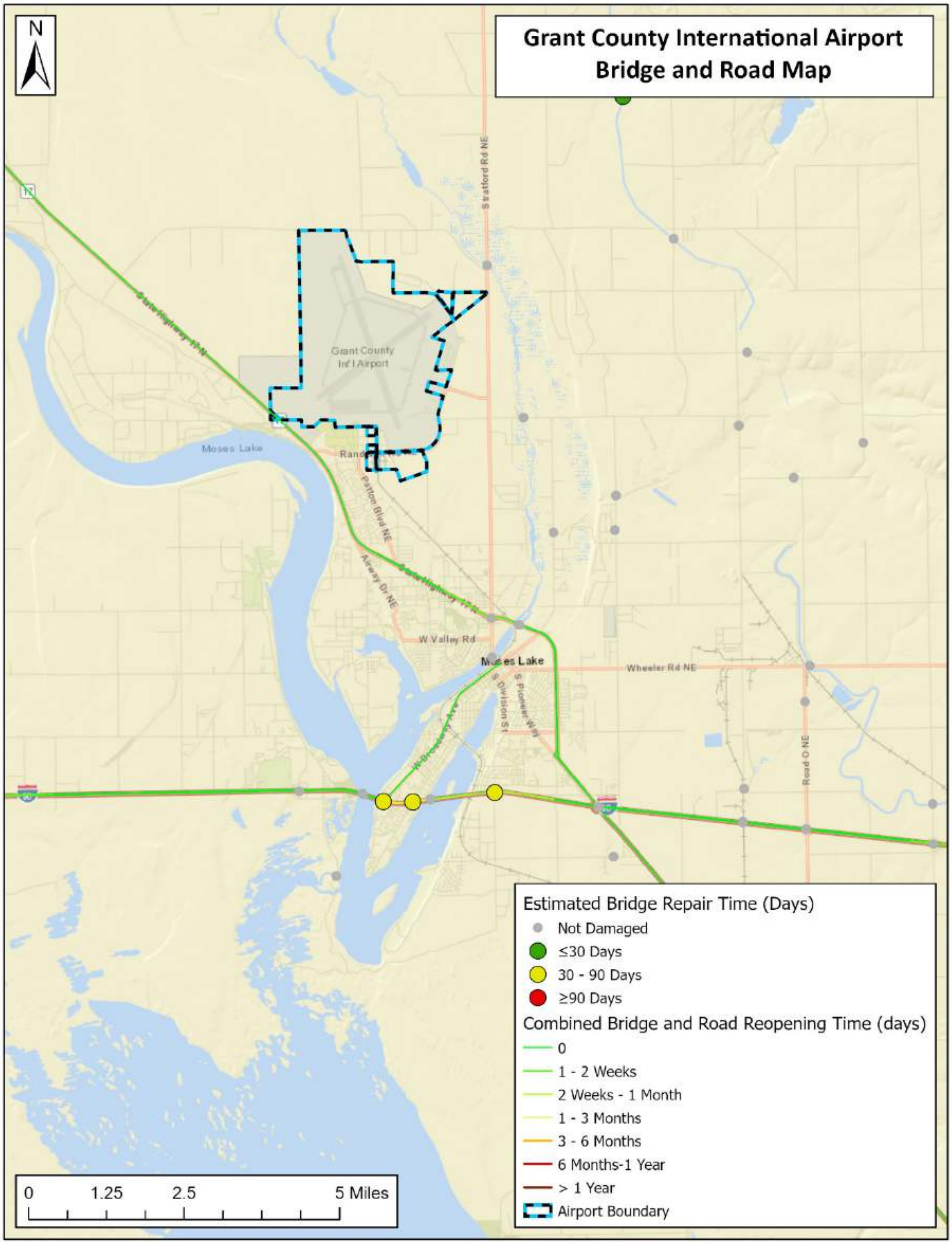

N
Friday Harbor Airport
Bridge and Road Map
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
▭ Airport Boundary
0
0.25
0.5
1 Miles
Friday Harbor
Friday Harbor Airport
Argyle
Brown Island
Beaverton Valley Rd
San Juan Valley Rd
Cattle Point
Spring St
Argyle Ave
Pear Point Rd
Turn Point Rd
Shelter Rd
Aspen Beach
Mill St
Baker Ln
Dewberry Ln
Wishing Well Ln
Little Rd
Country Club Ln
Golf Course Rd
Cameron Rd
Hudson Way
Trumpeter Way
Gilbert Ln
Wally Way
Glenoak Ln
Burton Ln
Michael Ln
Elizabeth Ln
Daniel Ln
Portage Dr
Store Way
Kelley Ln
Cedar St
Dougherty Ln
Bald Hill Rd
Pelican Way
Mayer Way
Grover St W
E Grover St
John St
Malcolm St
Market St
Nash St
Hemlock
Rose Ln
Stanford Ln
Guard St
Park St
Larson St
Lawson Pl
Marble St
Harbor St
Jensen Aly
Front St N
Web St
Franck St
Nelson St
Harrison St
Warbass Way
Black Rd
Lassey Ln
Roslac Ln
Myers Rd
Dutch Hill Rd
Carter Ave
Tucker Ave
Price St
Blair Ave
Salmonberry Ln
Ivan Rd
Heather Ct
Home Pl
Beaver Trail
Larnard Rd
Snowberry Ln
Madden Ln
Willey Rd
Garry Oak Ln
Niemann Ln
San Juan Golf & Country Club
Jackson Beach County Park

Appendix B-7. Grant County International

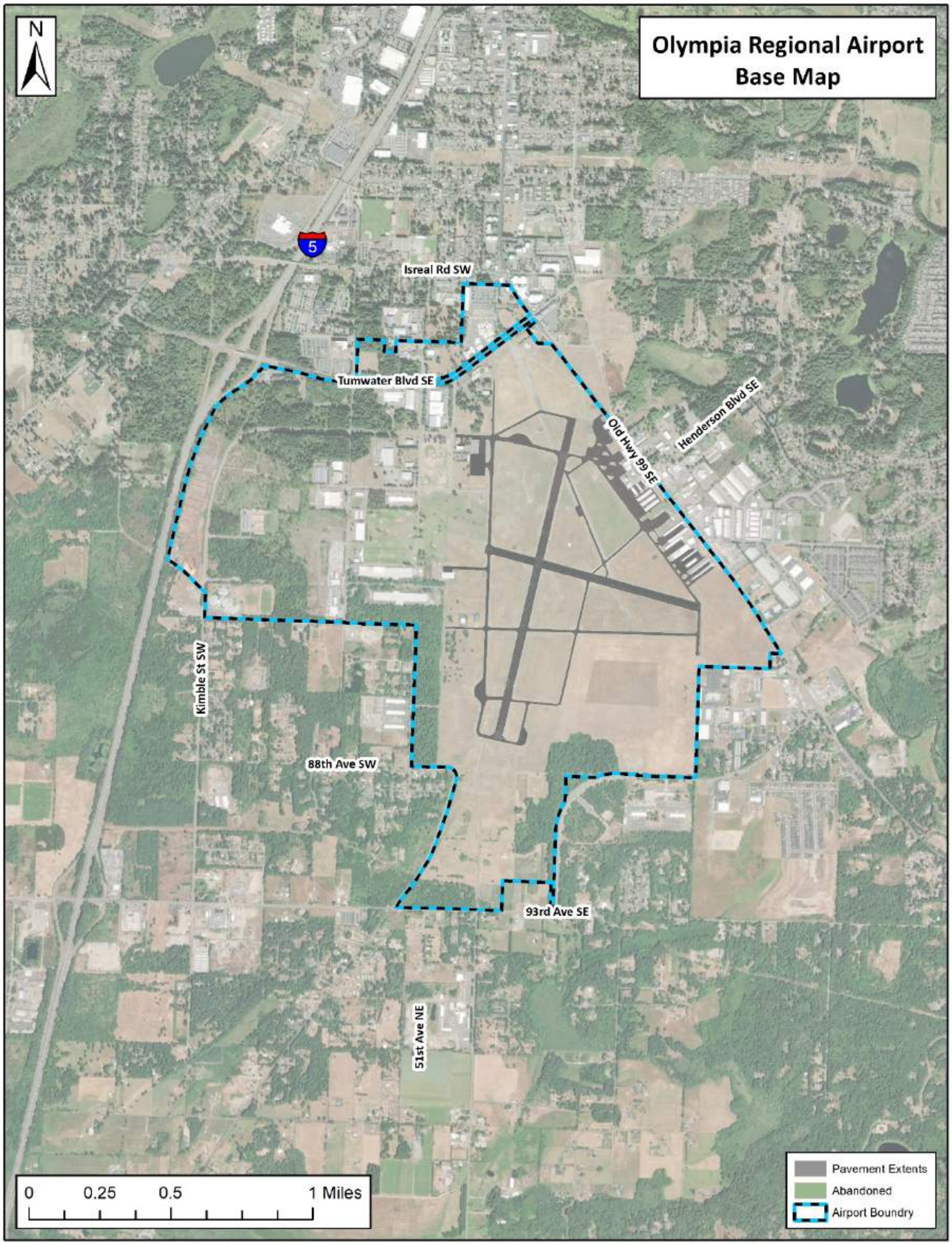


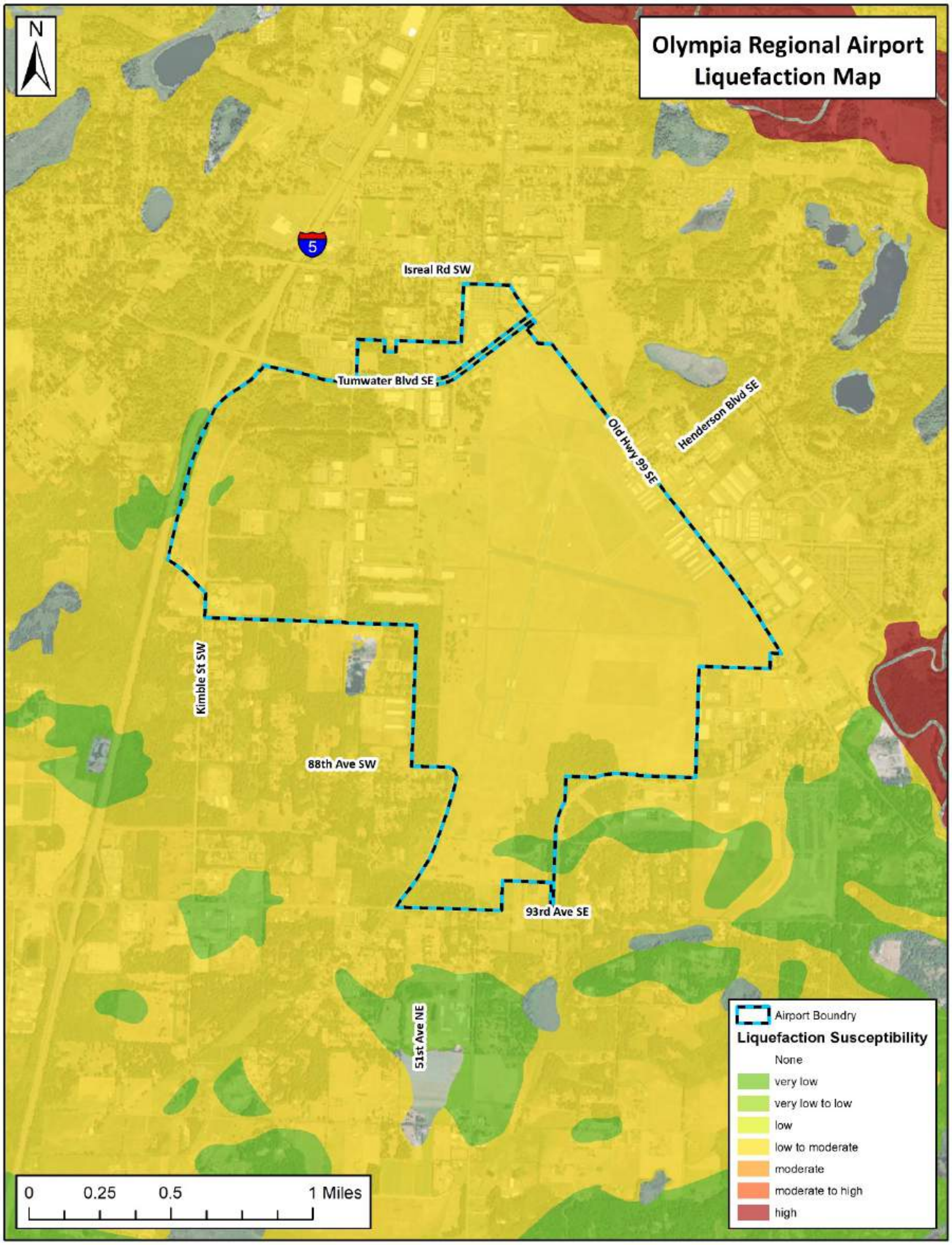

Grant County International Airport
Liquefaction Map
N
Tyndall Rd
State Hwy 17 N
Patton Blvd NE
Randolph Rd SE
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

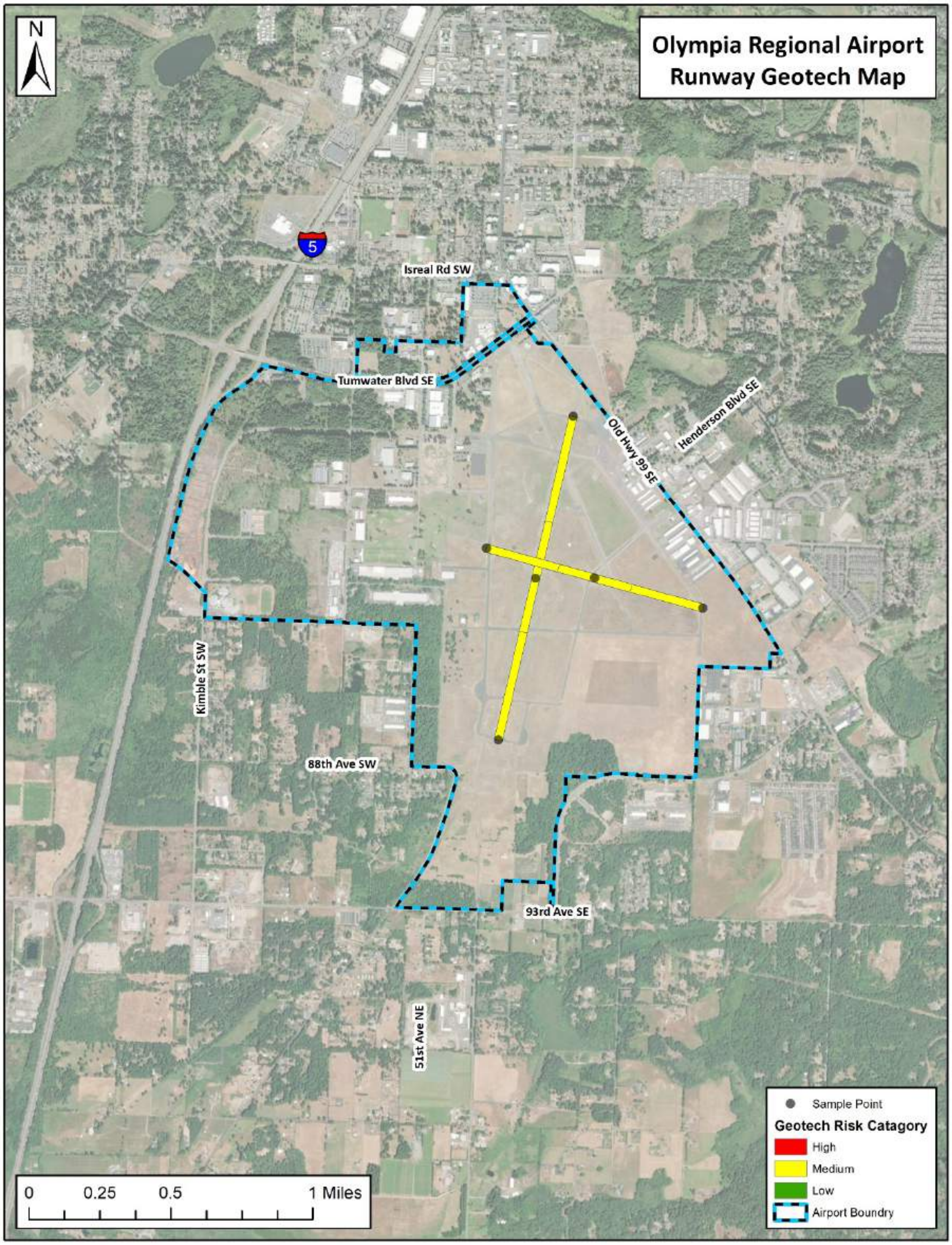

Grant County International Airport
Runway Geotech Map
N
Tyndall Rd
State Hwy 17 N
Patton Blvd NE
Randolph Rd SE
0
0.25
0.5
1 Miles
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry

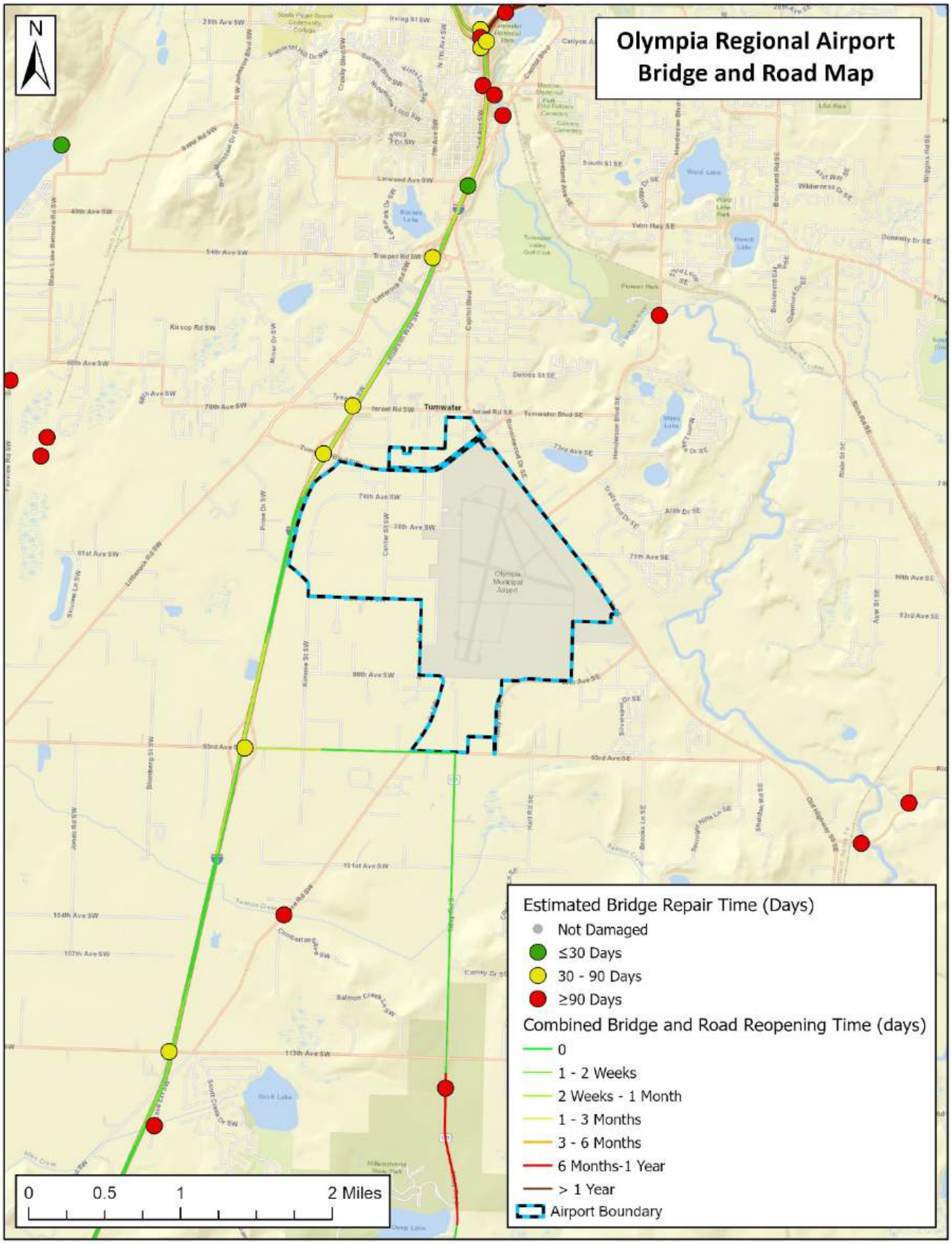

N
Grant County International Airport
Bridge and Road Map
Stratford Rd NE
State Highway 17 N
Grant County Int'l Airport
Moses Lake
Patton Blvd NE
Airway Dr NE
W Valley Rd
Moses Lake
Wheeler Rd NE
S Division St
S Pioneer Way
W Broadway Ave
Road O NE
17
90
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
1.25
2.5
5 Miles

Appendix B-8. Olympia Regional

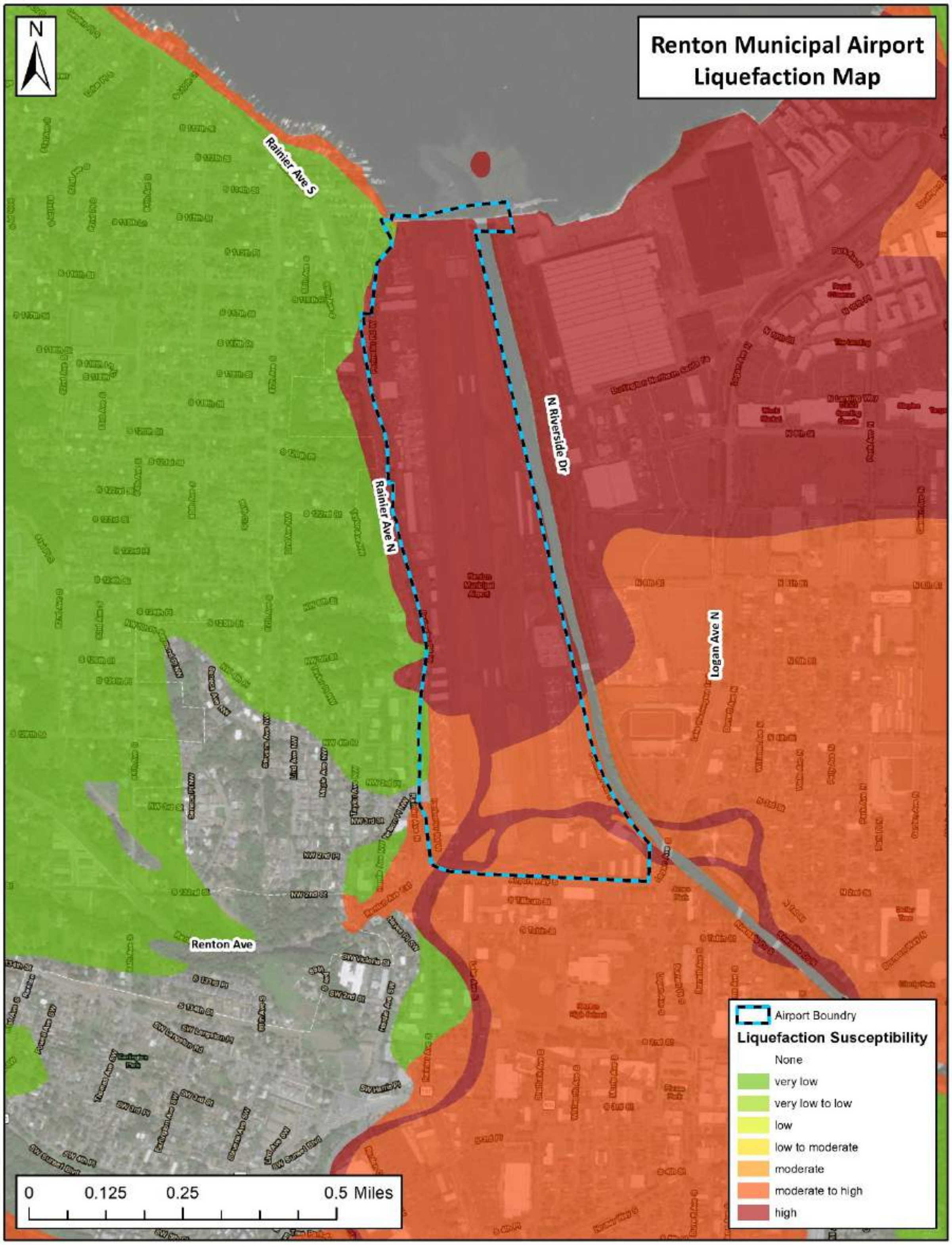


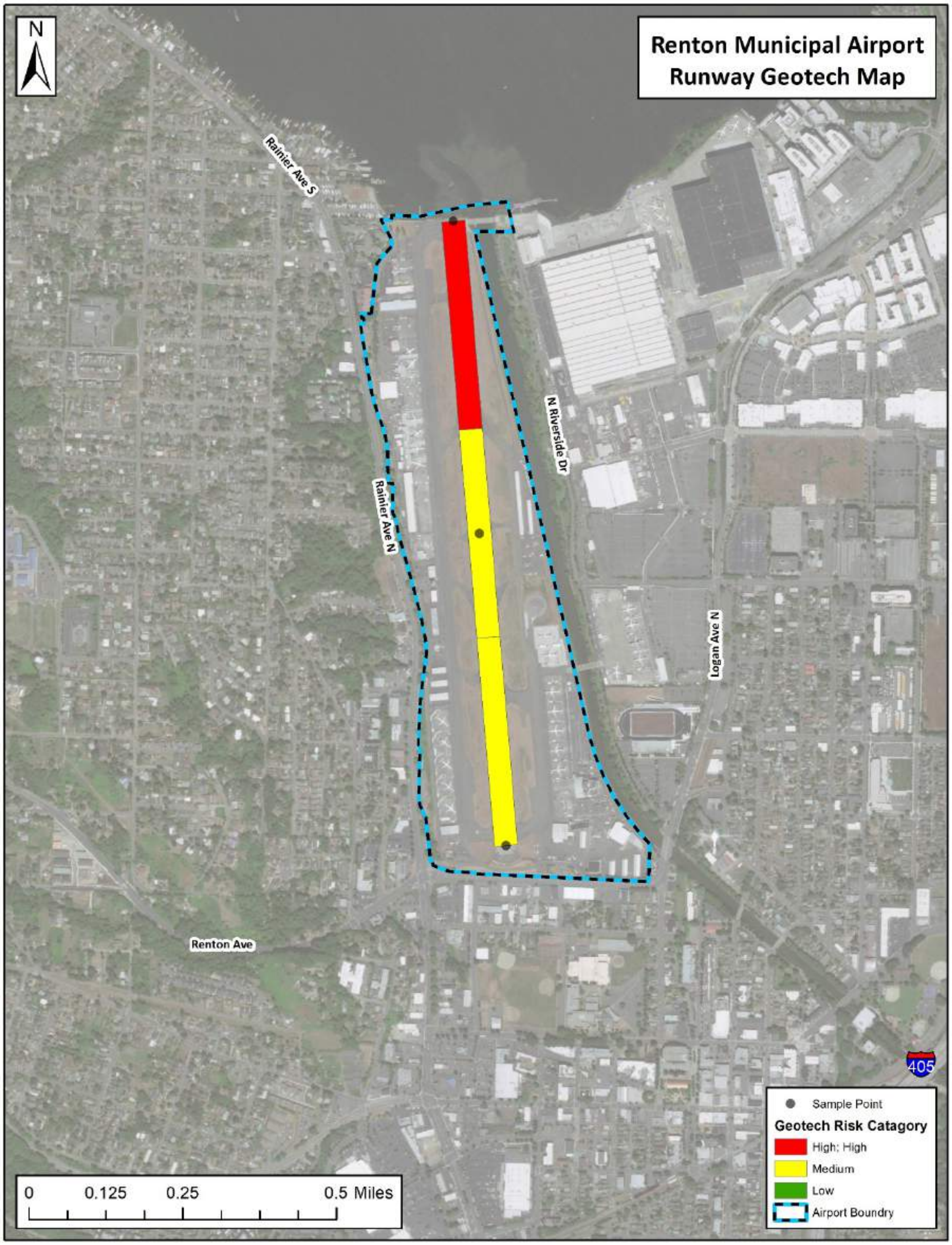

Olympia Regional Airport
Liquefaction Map
N
5
Isreal Rd SW
Tumwater Blvd SE
Henderson Blvd SE
Old Hwy 99 SE
Kimble St SW
88th Ave SW
93rd Ave SE
51st Ave NE
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles


Olympia Regional Airport
Runway Geotech Map
N
5
Isreal Rd SW
Tumwater Blvd SE
Old Hwy 99 SE
Henderson Blvd SE
Kimble St SW
88th Ave SW
93rd Ave SE
51st Ave NE
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles


Olympia Regional Airport
Bridge and Road Map
N
Tumwater
Olympia Municipal Airport
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
Airport Boundary
0
0.5
1
2 Miles

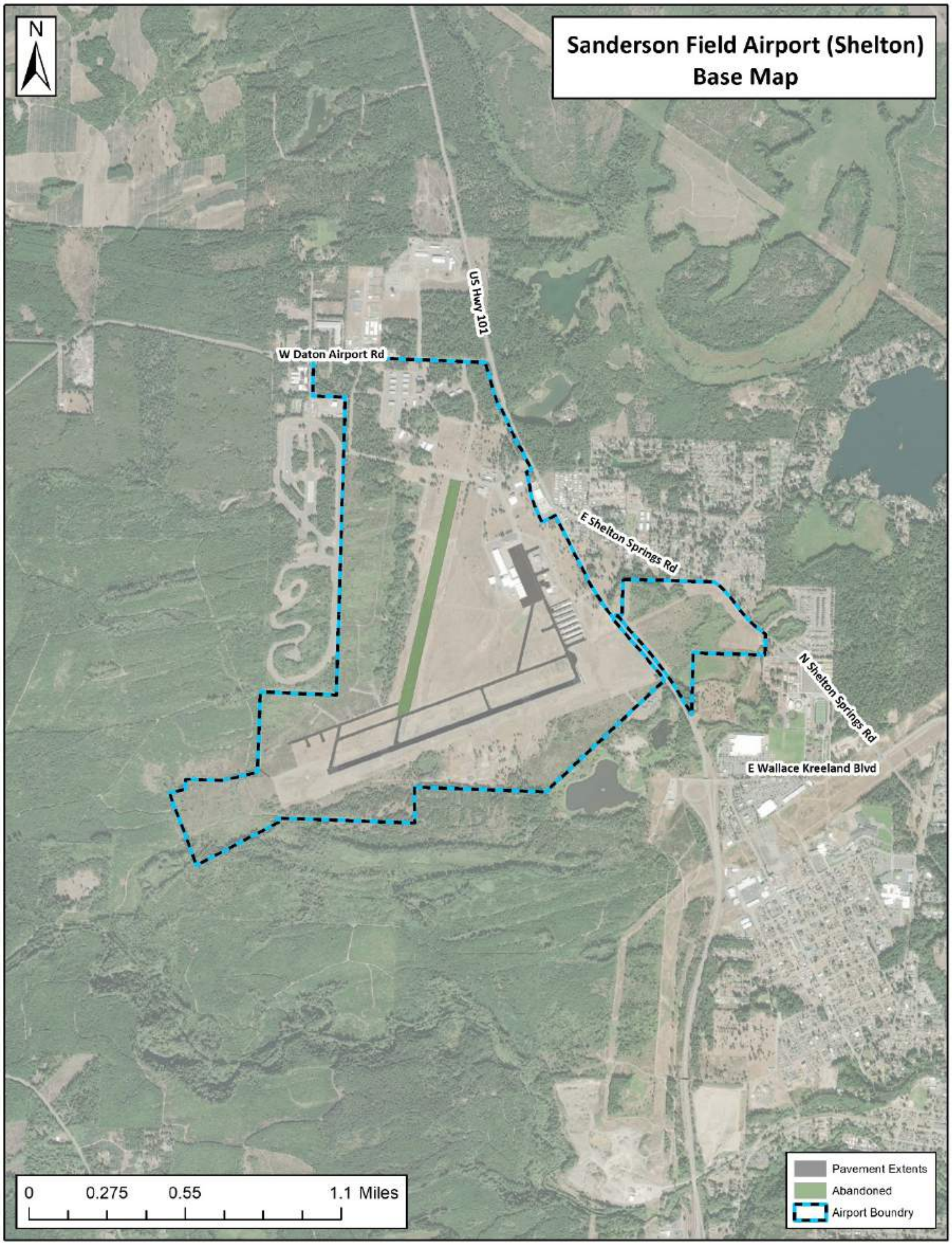
Appendix B-9. Renton Municipal

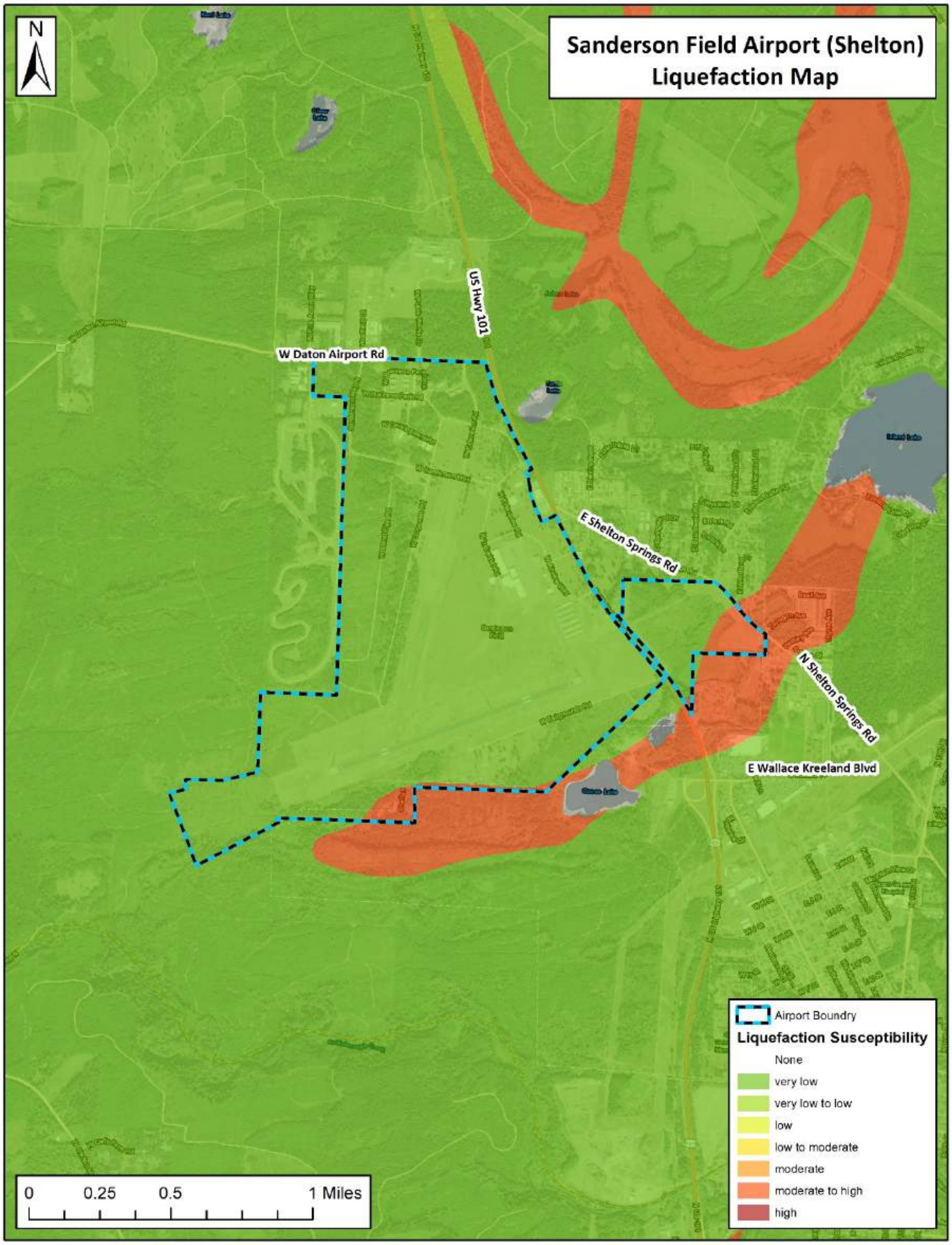

Renton Municipal Airport
Liquefaction Map
N
Rainier Ave S
N Riverside Dr
Rainier Ave N
Logan Ave N
Renton Ave
0
0.125
0.25
0.5 Miles
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high

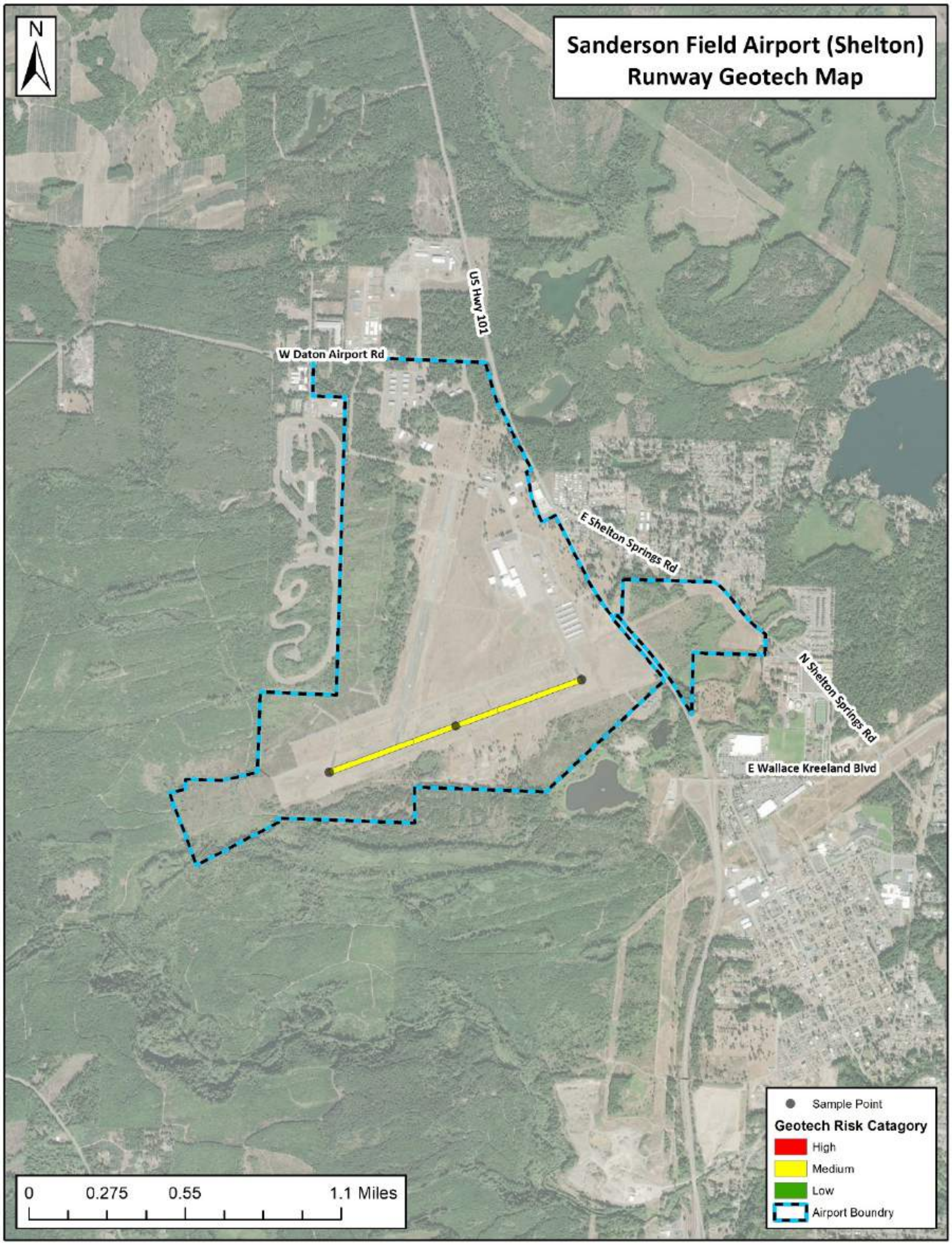

Renton Municipal Airport
Runway Geotech Map
N
Rainier Ave S
N Riverside Dr
Rainier Ave N
Logan Ave N
Renton Ave
405
● Sample Point
Geotech Risk Catagory
🟥 High; High
🟨 Medium
🟩 Low
Airport Boundry
0
0.125
0.25
0.5 Miles

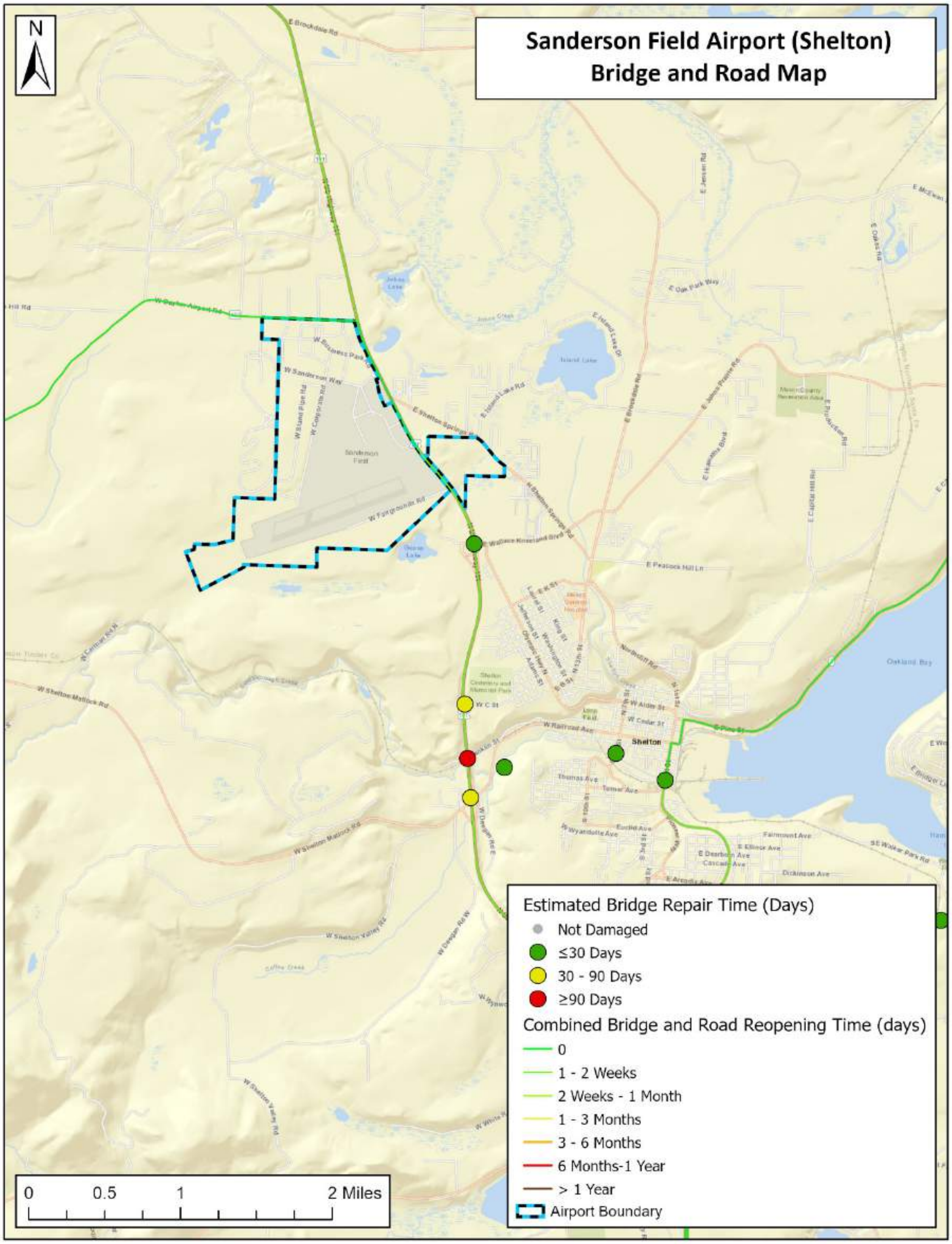

Renton Municipal Airport
Bridge and Road Map
N
Lake Washington
Renton Municipal Airport
Renton
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
Airport Boundary
0
0.25
0.5
1 Miles
N 30th St
NE 24th St
NE 10th St
N 8th St
N 6th St
N 3rd St
S 2nd St
S 3rd St
SW 7th St
S 7th St
S Grady Way
SW 16th St
SW 27th St
Logan Ave N
N Riverside Dr
Airport Way
SW Sunset Blvd
Lake Washington Blvd N
Sunset Blvd NE
Maple Valley Hwy
Oakesdale Ave SW
E Valley Rd
Talbot Rd S
Rainier Ave S
Monster Rd SW
Black River Forest
Boeing Longacres Industrial Park
Cedar River Park - Renton
Cedar River Natural Zone

Appendix B-10. Sanderson Field (Shelton)

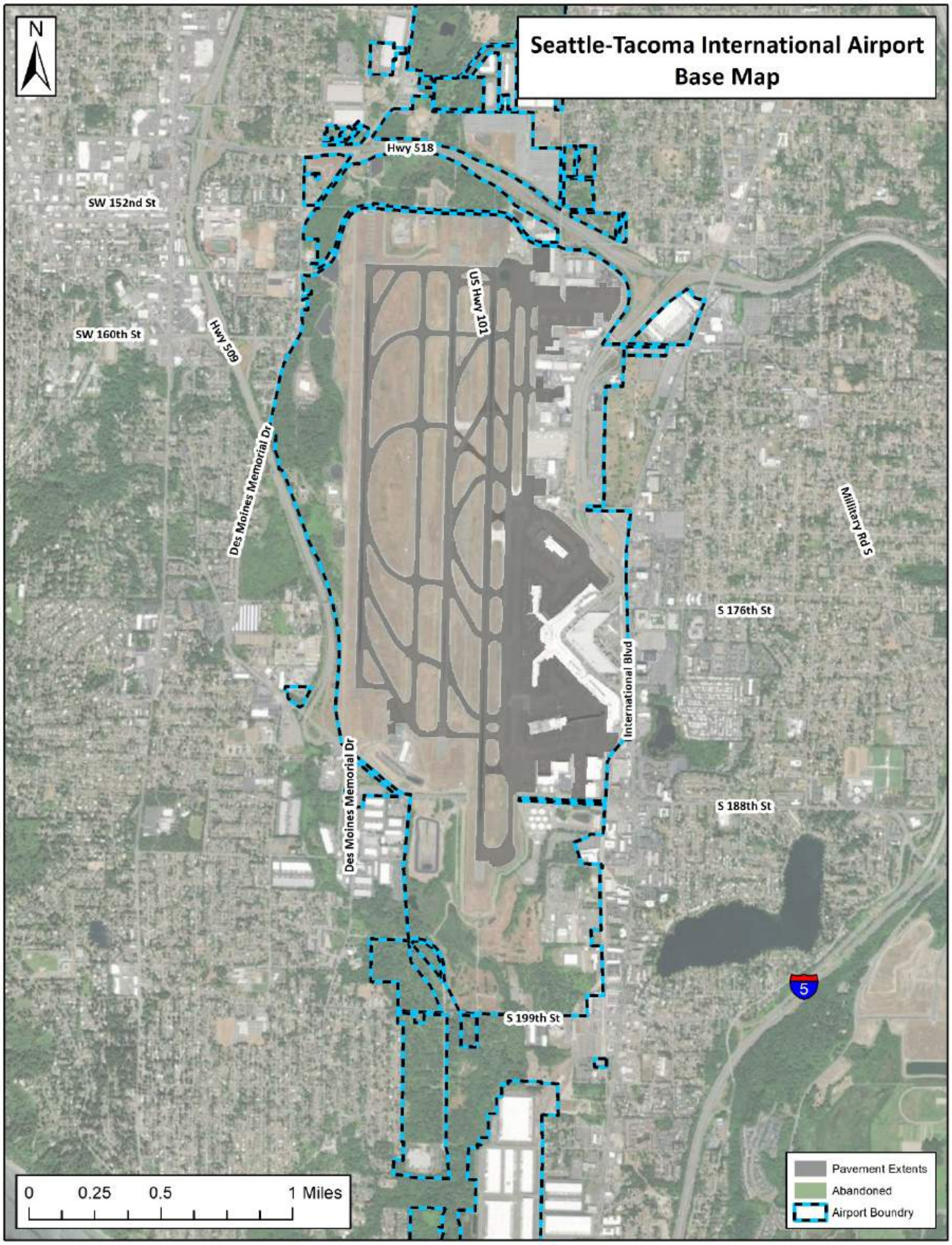


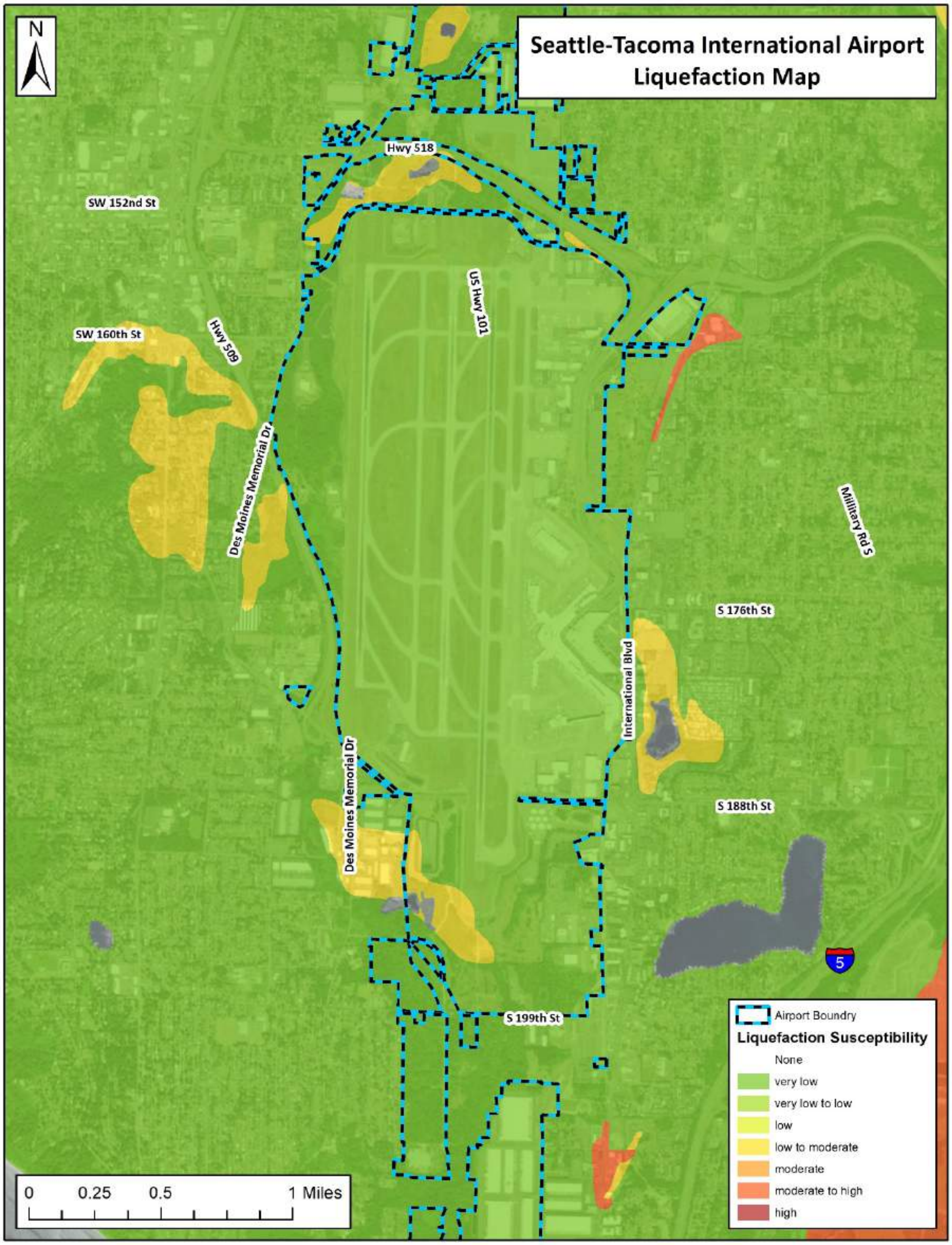

Sanderson Field Airport (Shelton)
Liquefaction Map
N
US Hwy 101
W Daton Airport Rd
E Shelton Springs Rd
N Shelton Springs Rd
E Wallace Kreeland Blvd
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles

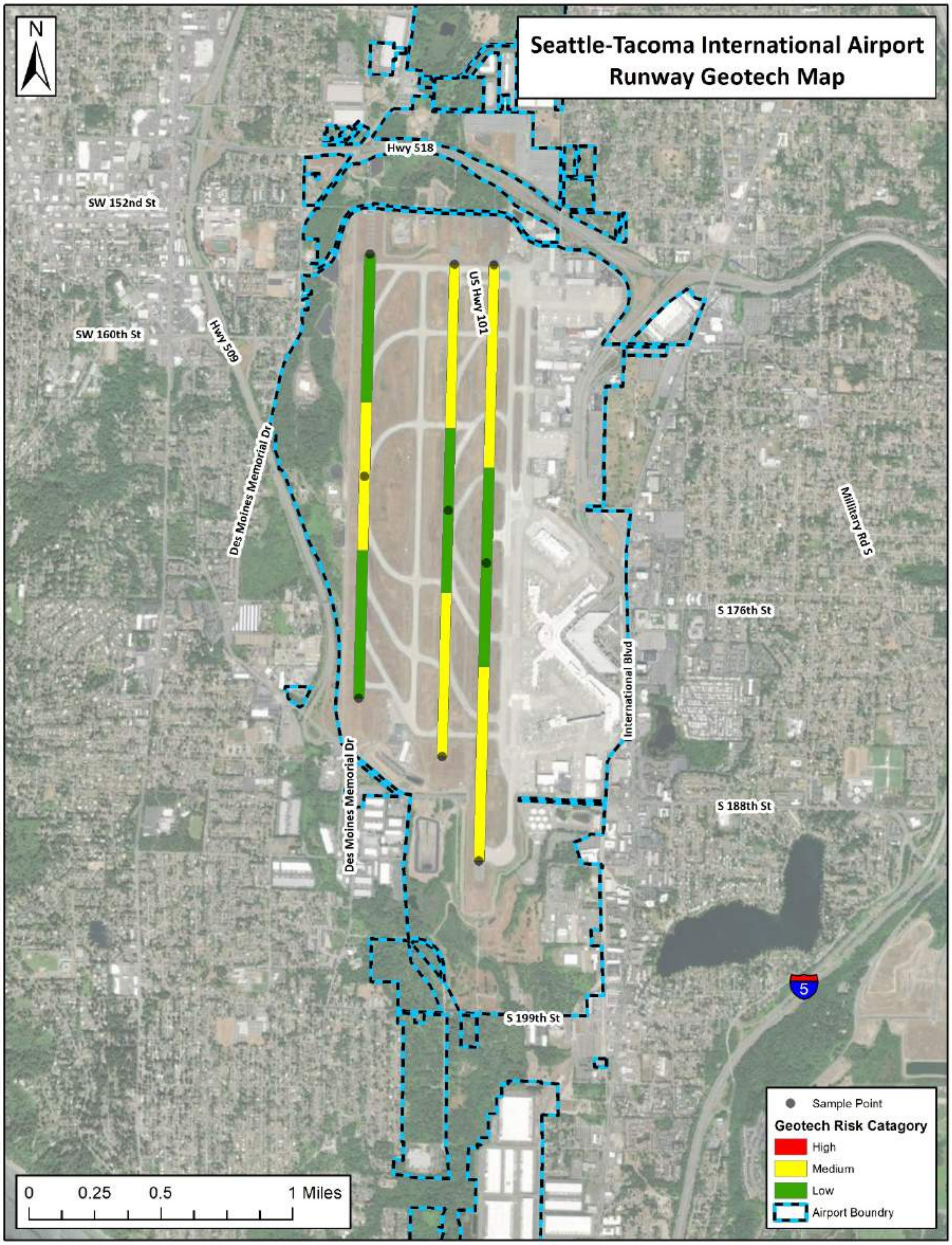

Sanderson Field Airport (Shelton)
Runway Geotech Map

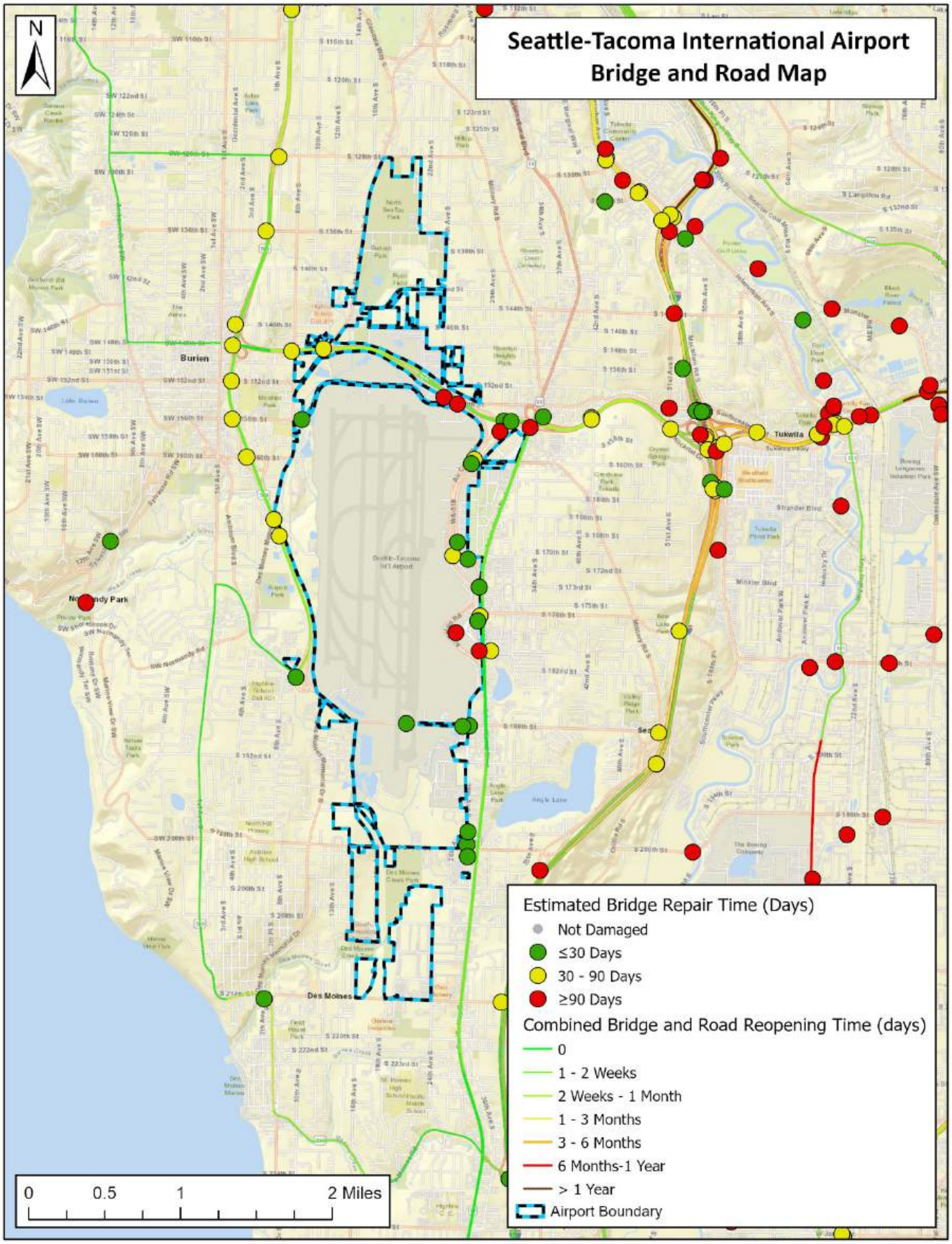

Sanderson Field Airport (Shelton)
Bridge and Road Map
N
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles
Sanderson Field
Shelton
Island Lake
Oakland Bay
W Dayton Airport Rd
W Sanderson Way
W Fairgrounds Rd
E Shelton Springs Rd
W Wallace Kneeland Blvd
W Railroad Ave
W Shelton Matlock Rd
W Shelton Valley Rd
E Pine St
E Peacock Hill Ln
W C St

Appendix B-11. Seattle-Tacoma International

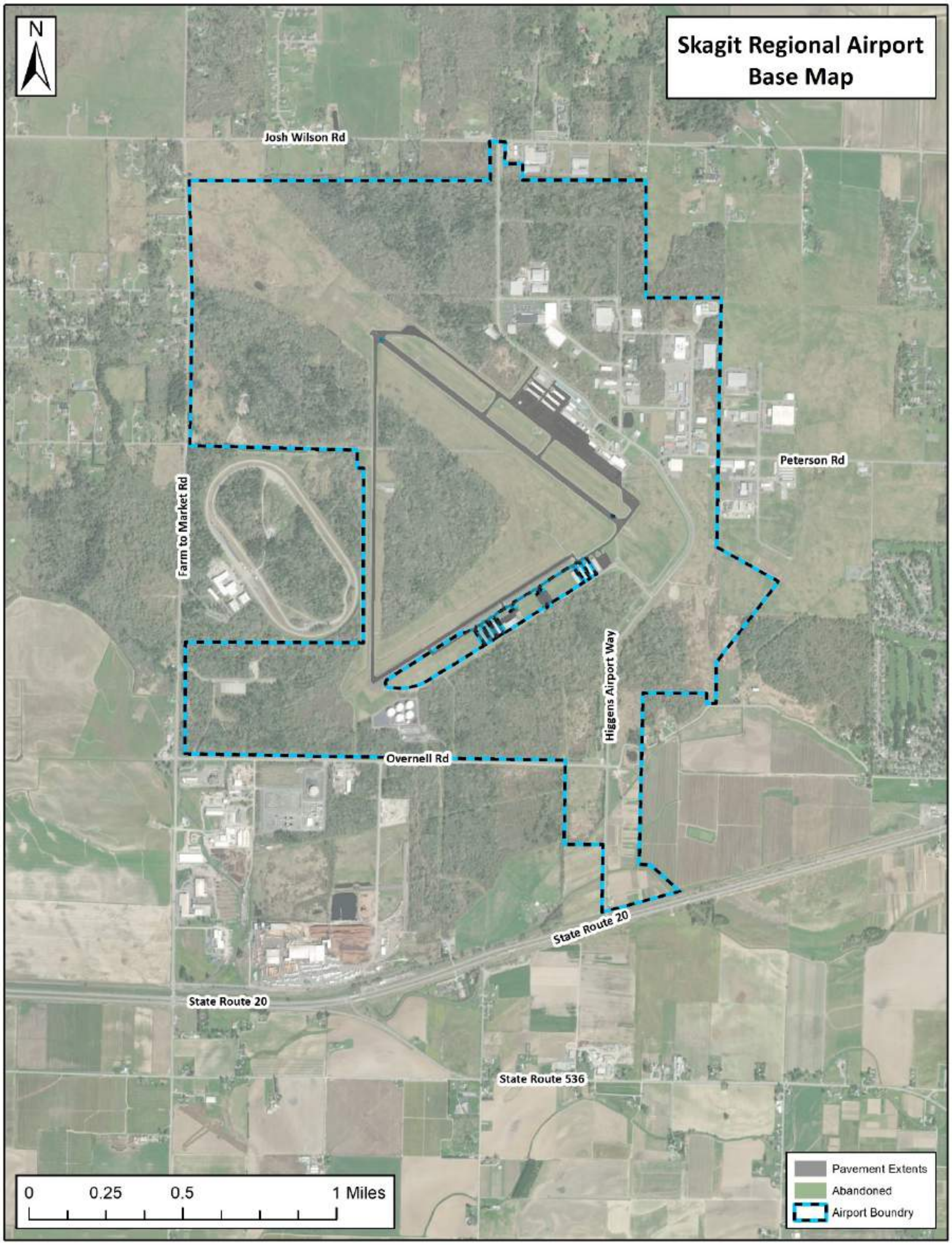


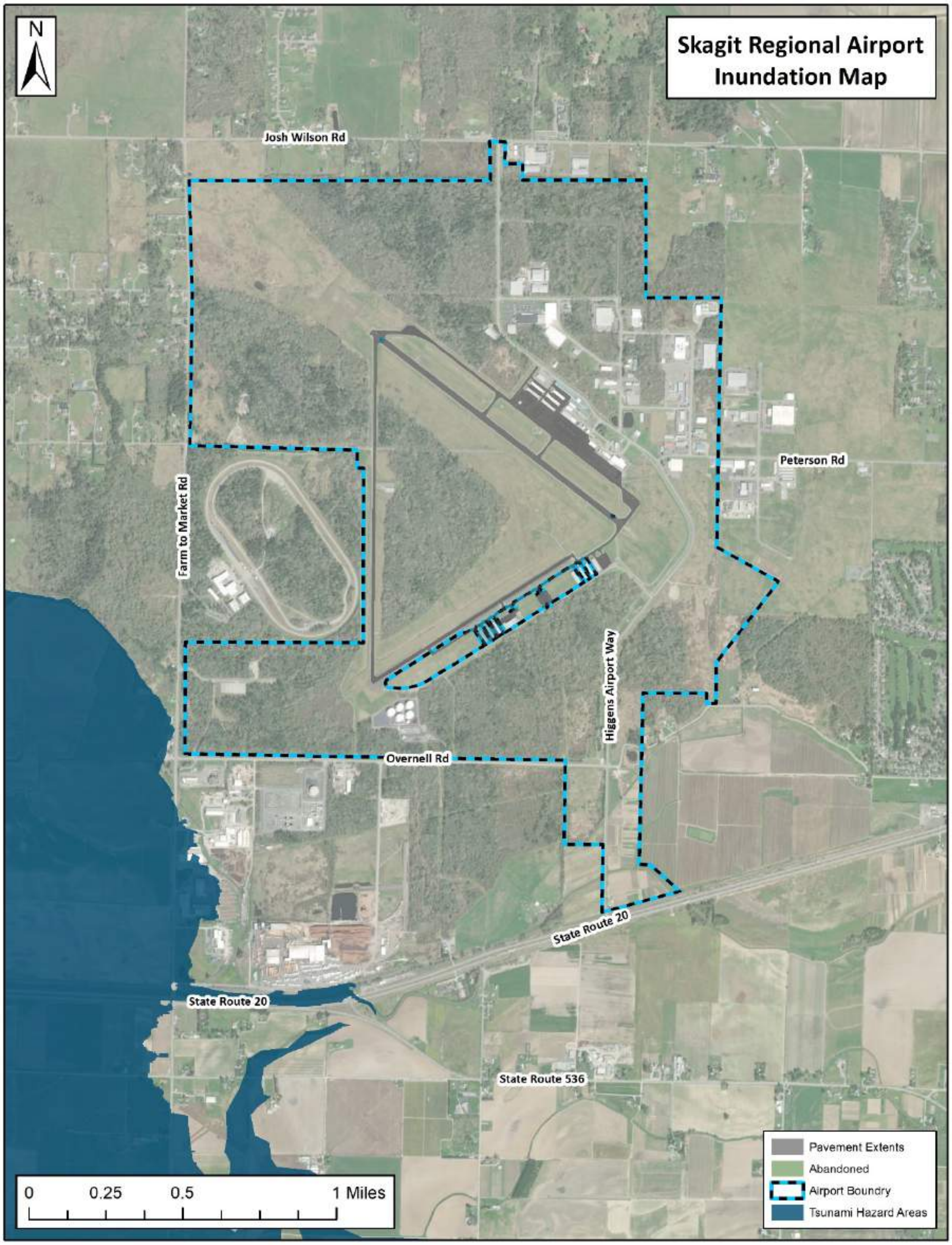

Seattle-Tacoma International Airport
Liquefaction Map
N
Hwy 518
SW 152nd St
US Hwy 101
SW 160th St
Hwy 509
Des Moines Memorial Dr
Military Rd S
S 176th St
International Blvd
Des Moines Memorial Dr
S 188th St
5
S 199th St
0 0.25 0.5 1 Miles
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high

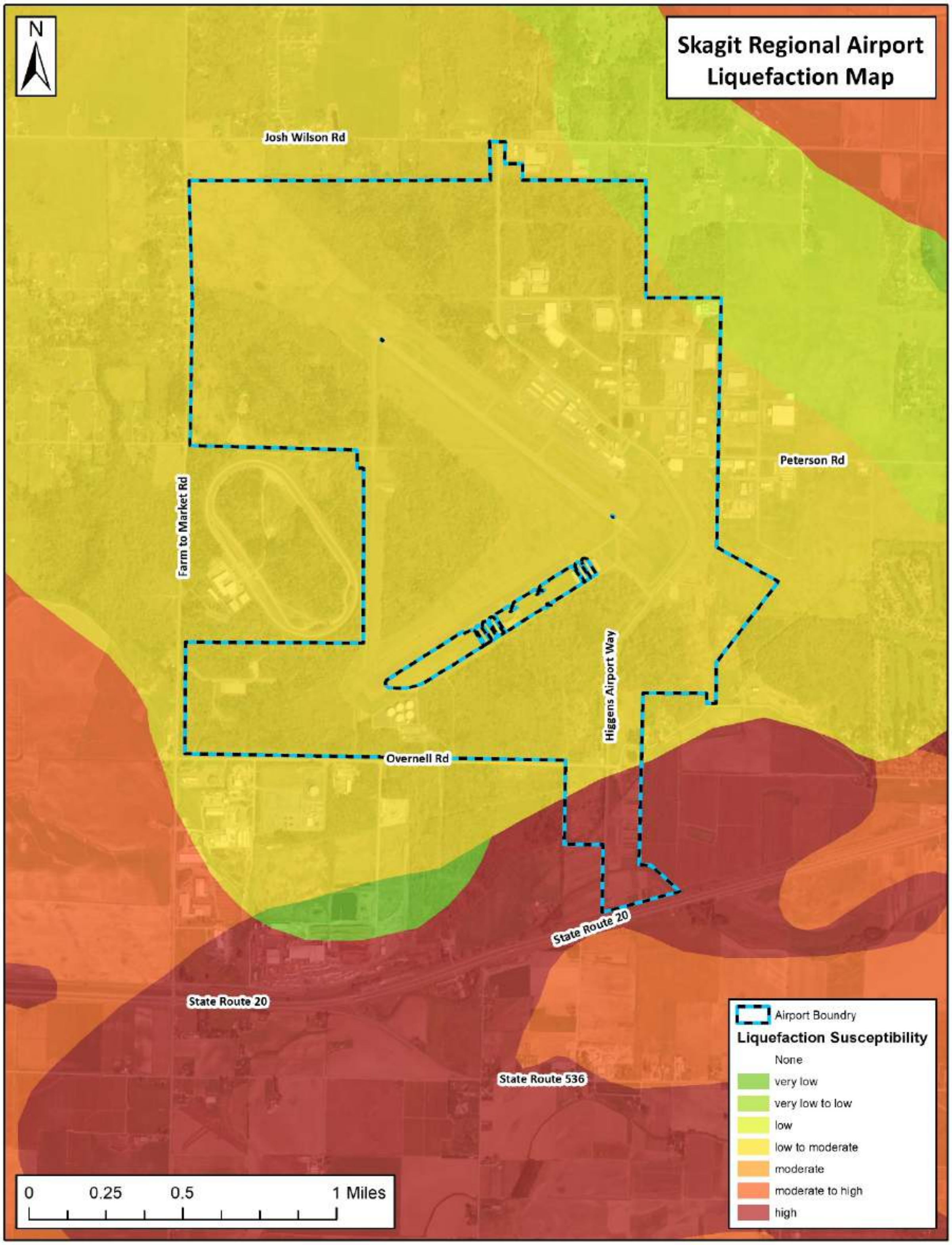

N
Seattle-Tacoma International Airport
Runway Geotech Map
Hwy 518
SW 152nd St
SW 160th St
Hwy 509
US Hwy 101
Des Moines Memorial Dr
Military Rd S
S 176th St
International Blvd
S 188th St
Des Moines Memorial Dr
5
S 199th St
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles

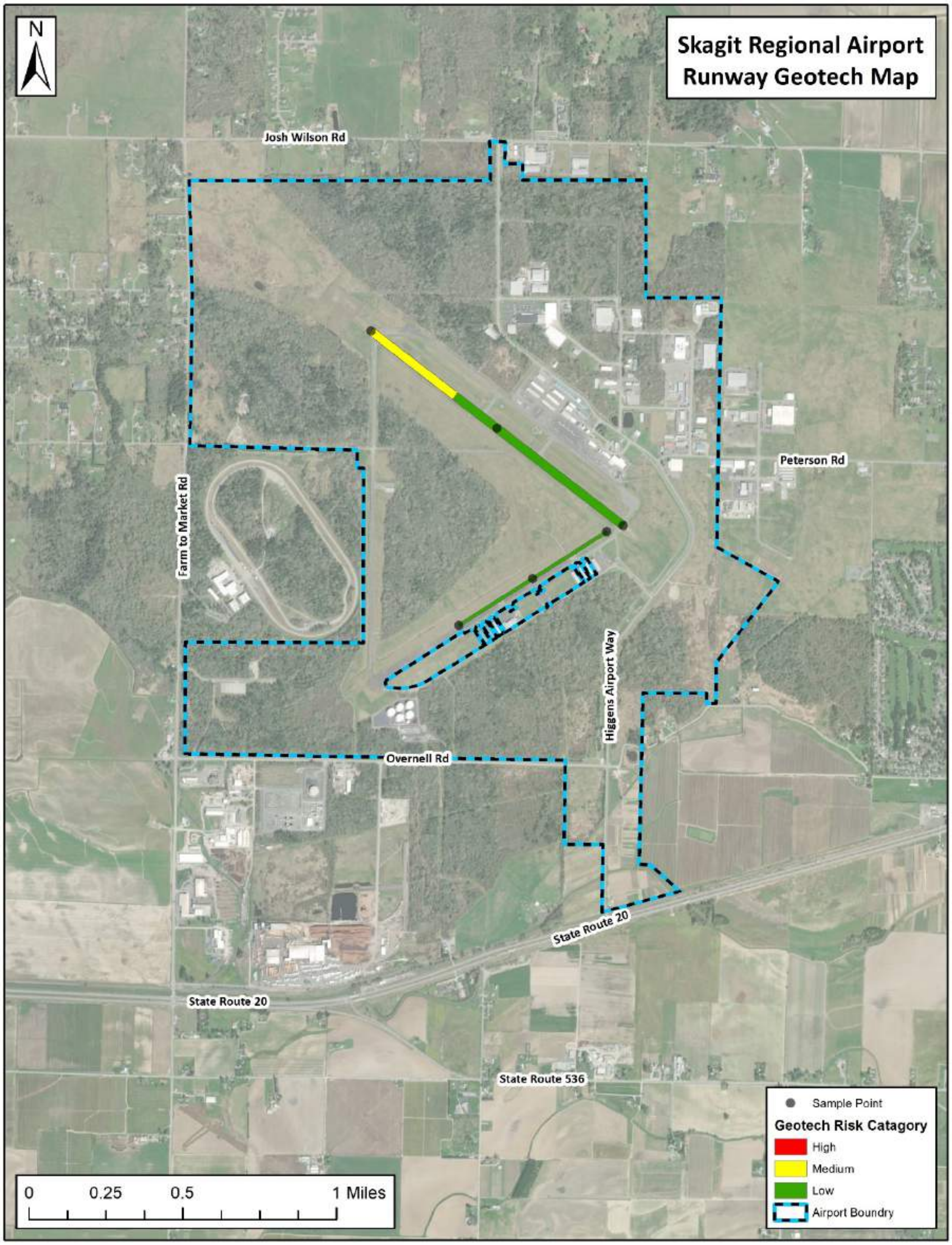

Seattle-Tacoma International Airport
Bridge and Road Map
N
Estimated Bridge Repair Time (Days)
● Not Damaged
🟢 ≤30 Days
🟡 30 - 90 Days
🔴 ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles
Burien
Normandy Park
Tukwila
Des Moines

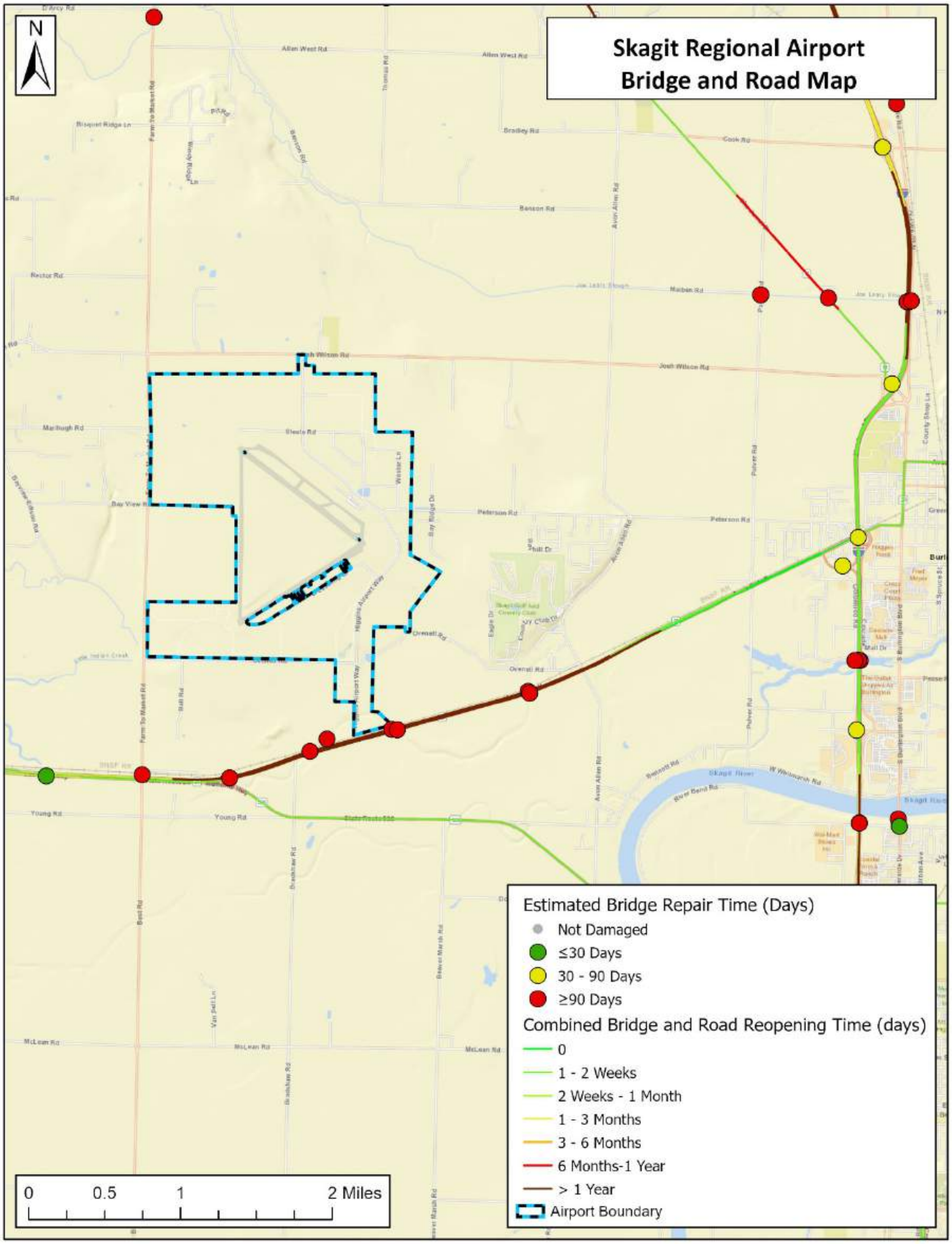
Appendix B-12. Skagit Regional




Skagit Regional Airport Inundation Map
N
Josh Wilson Rd
Peterson Rd
Farm to Market Rd
Higgens Airport Way
Overnell Rd
State Route 20
State Route 20
State Route 536
Pavement Extents
Abandoned
Airport Boundry
Tsunami Hazard Areas
0
0.25
0.5
1 Miles

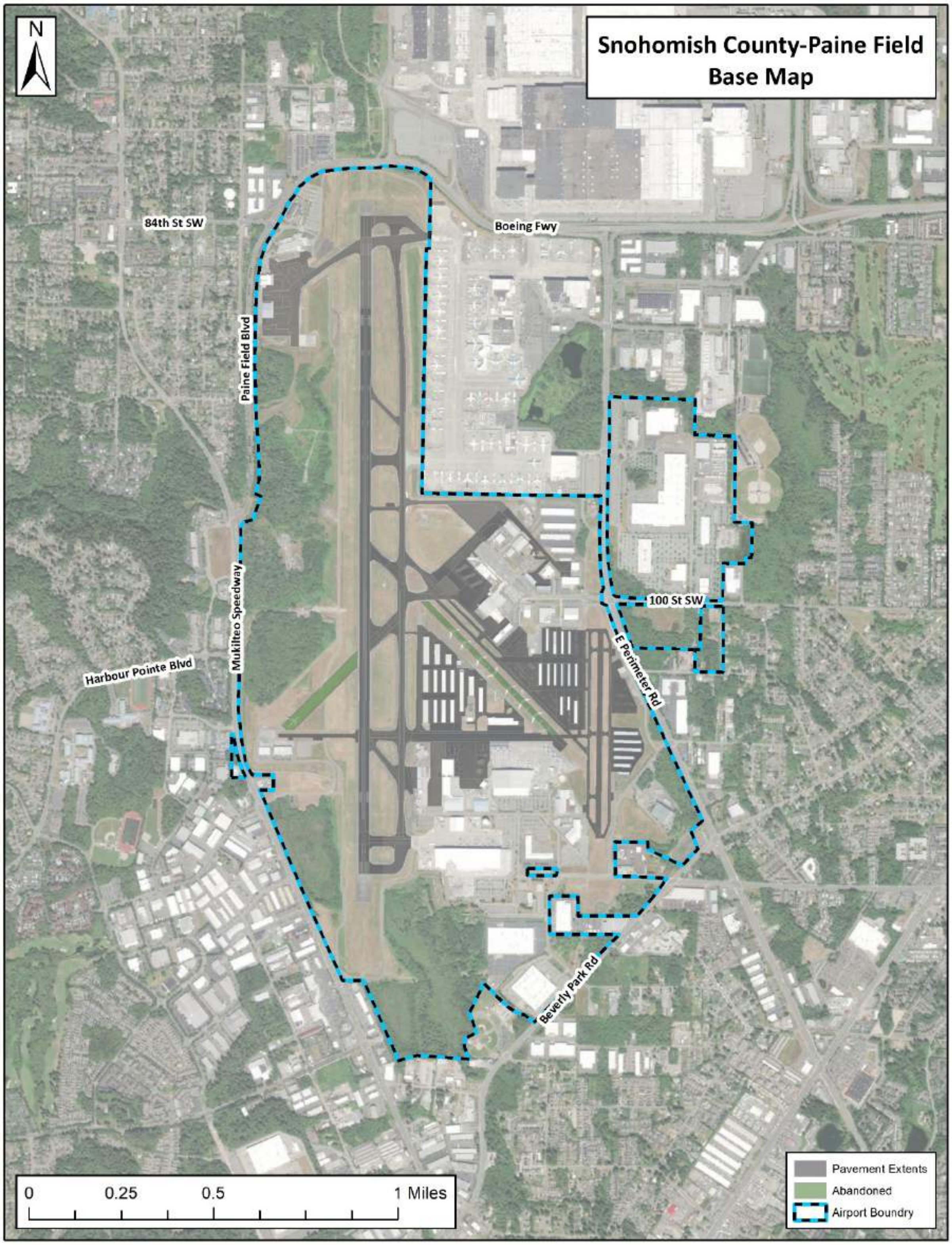

N
Skagit Regional Airport
Liquefaction Map
Josh Wilson Rd
Peterson Rd
Farm to Market Rd
Higgens Airport Way
Overnell Rd
State Route 20
State Route 20
State Route 536
0
0.25
0.5
1 Miles
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high

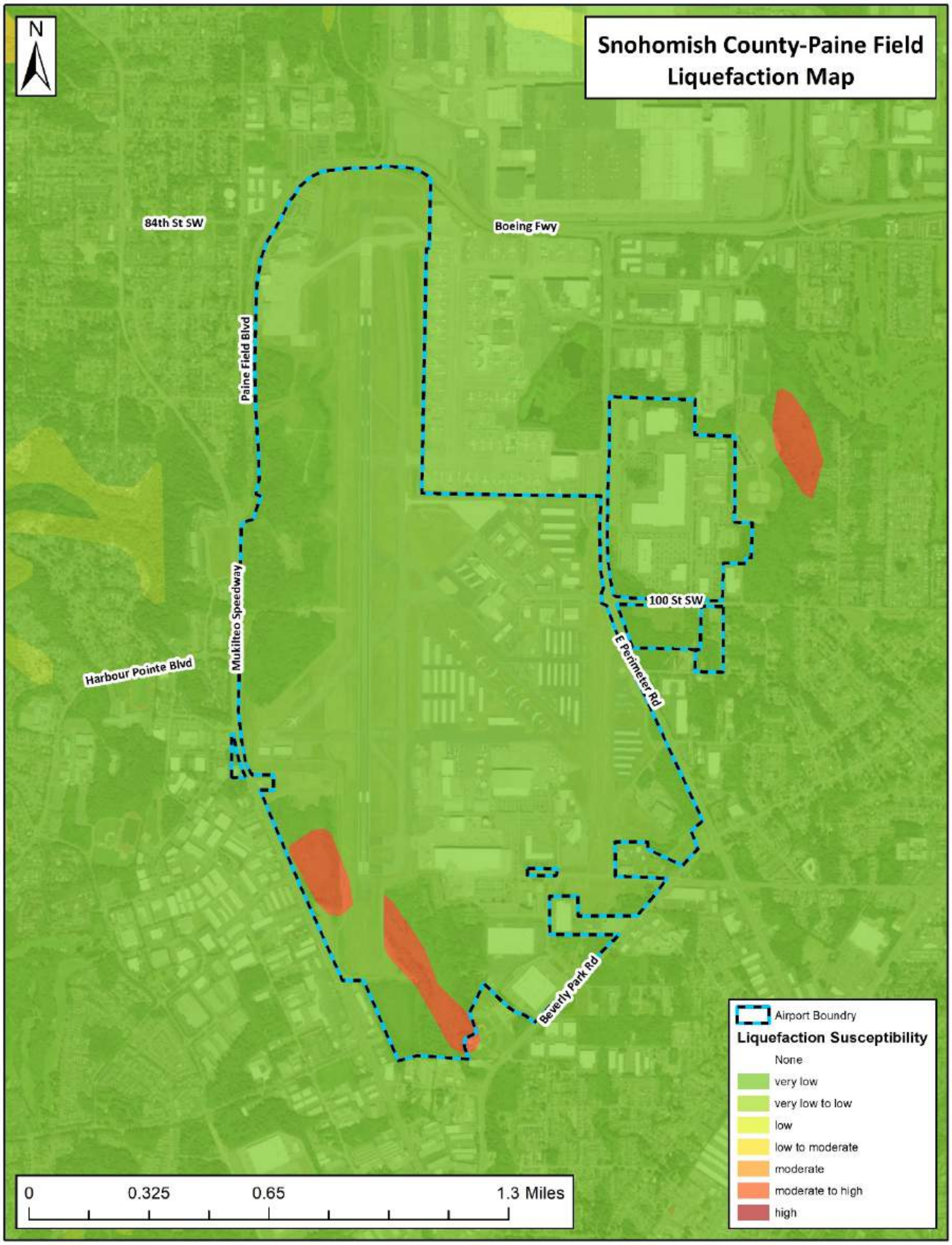

N
Skagit Regional Airport
Runway Geotech Map
Josh Wilson Rd
Peterson Rd
Farm to Market Rd
Higgens Airport Way
Overnell Rd
State Route 20
State Route 20
State Route 536
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles

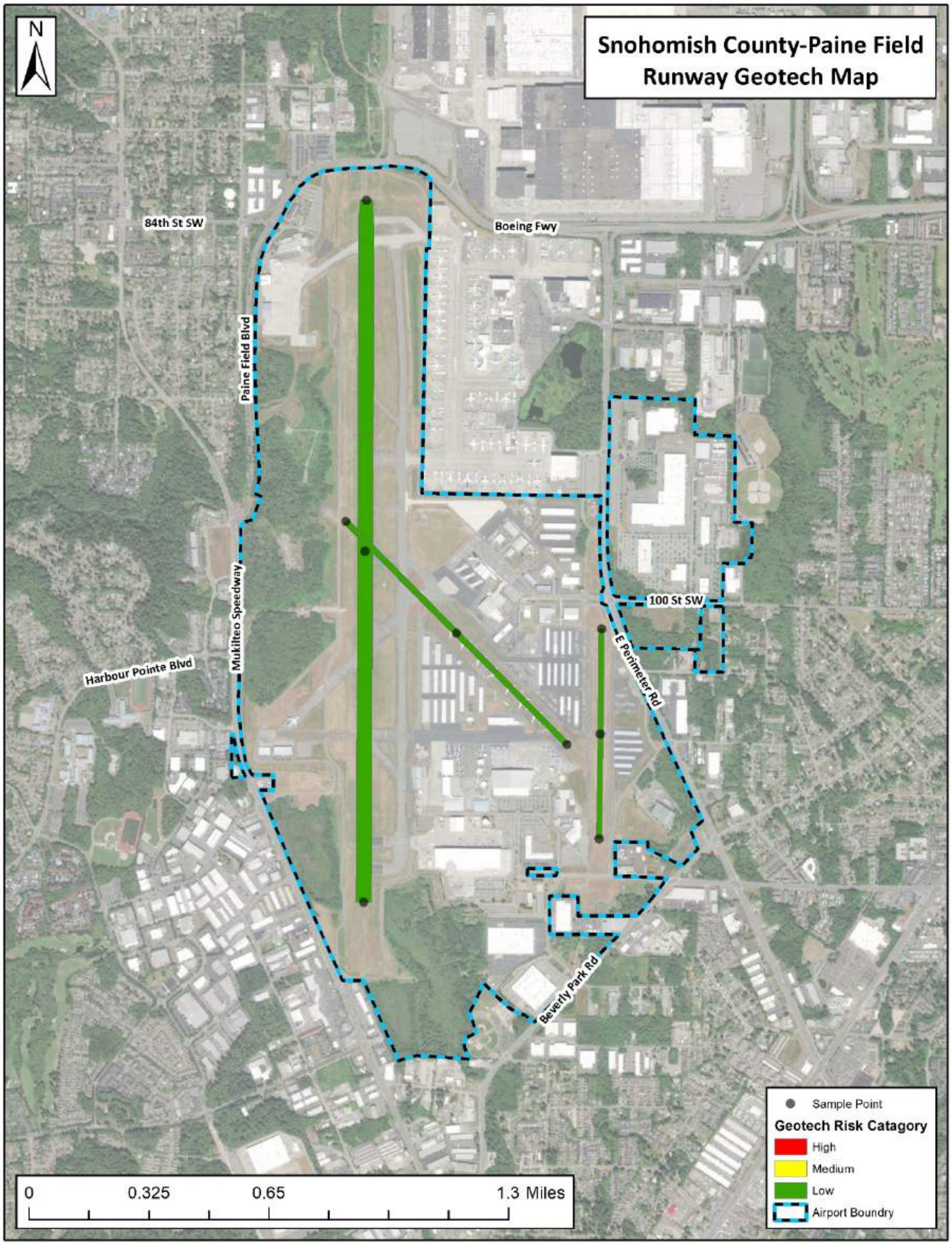


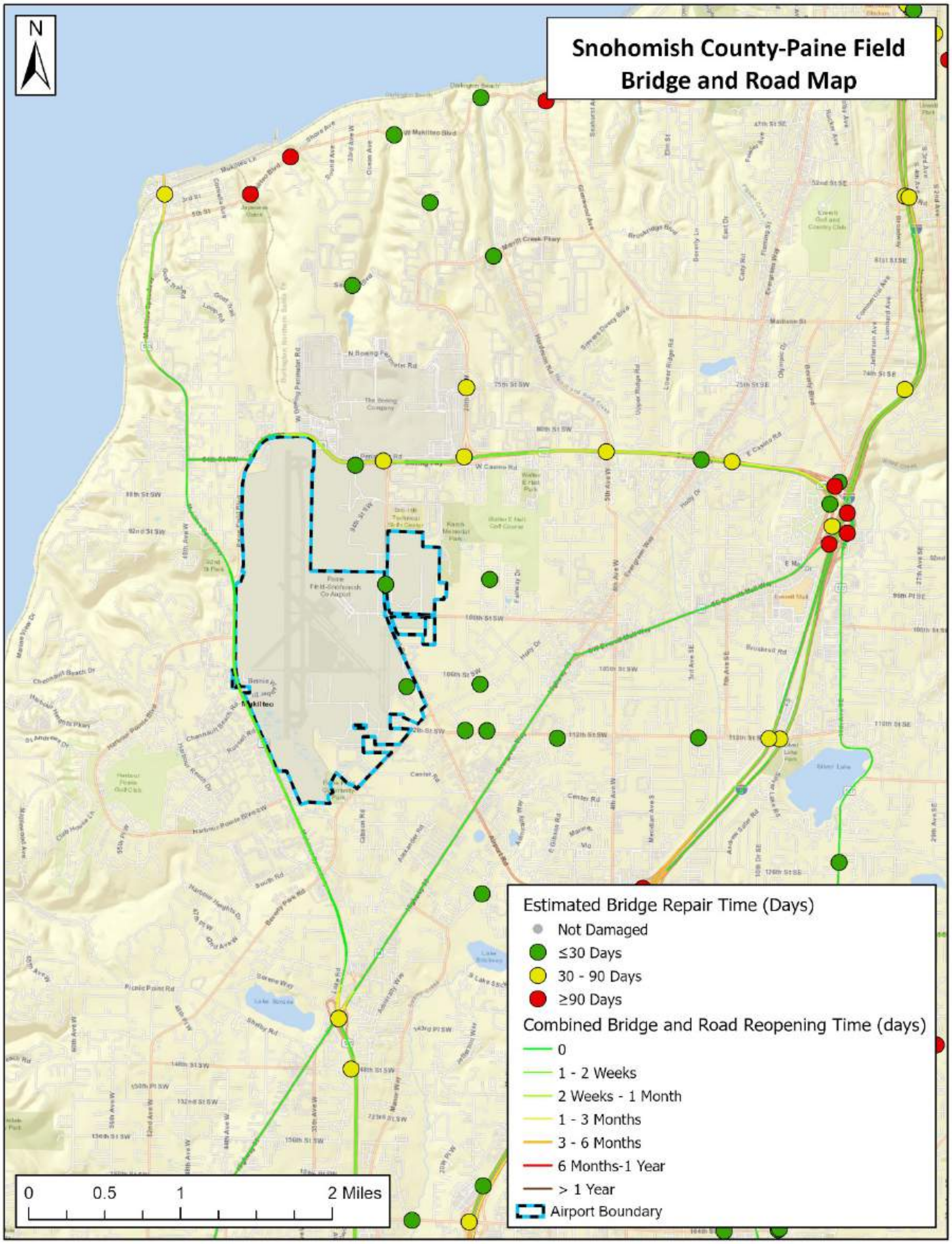
Skagit Regional Airport Bridge and Road Map

Appendix B-13. Snohomish County-Paine Field

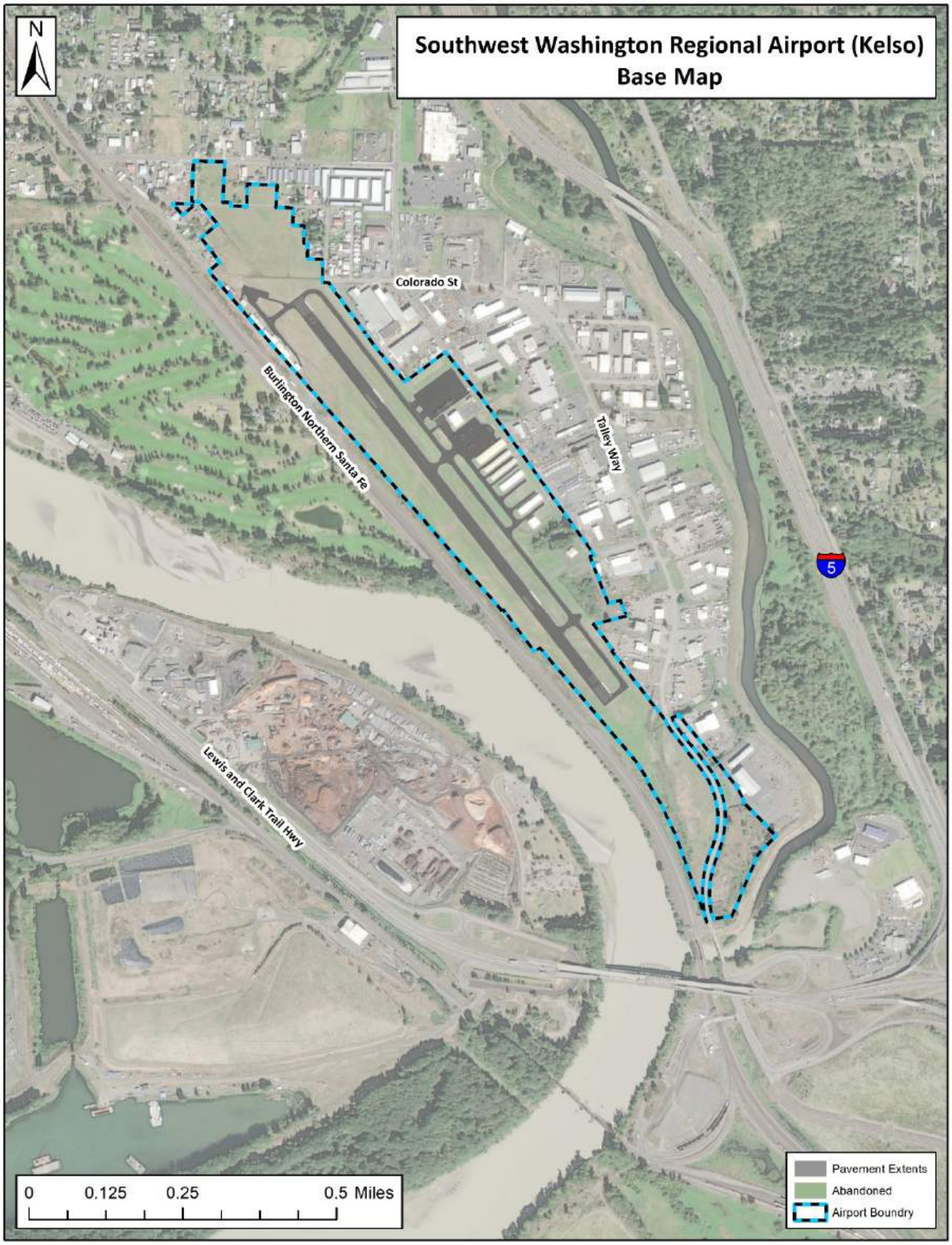


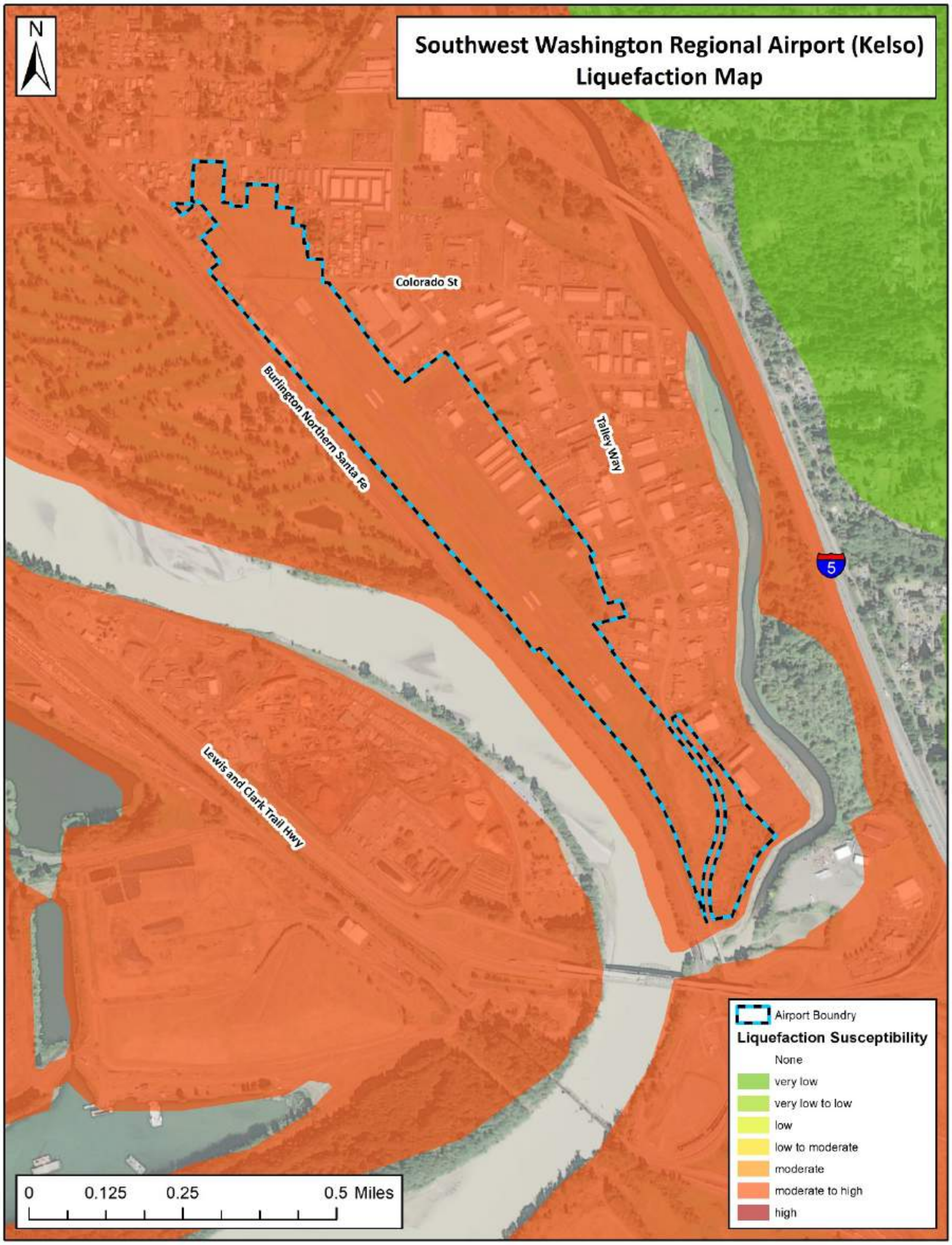

N
Snohomish County-Paine Field
Liquefaction Map
84th St SW
Boeing Fwy
Paine Field Blvd
Mukilteo Speedway
Harbour Pointe Blvd
100 St SW
E Perimeter Rd
Beverly Park Rd
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.325
0.65
1.3 Miles

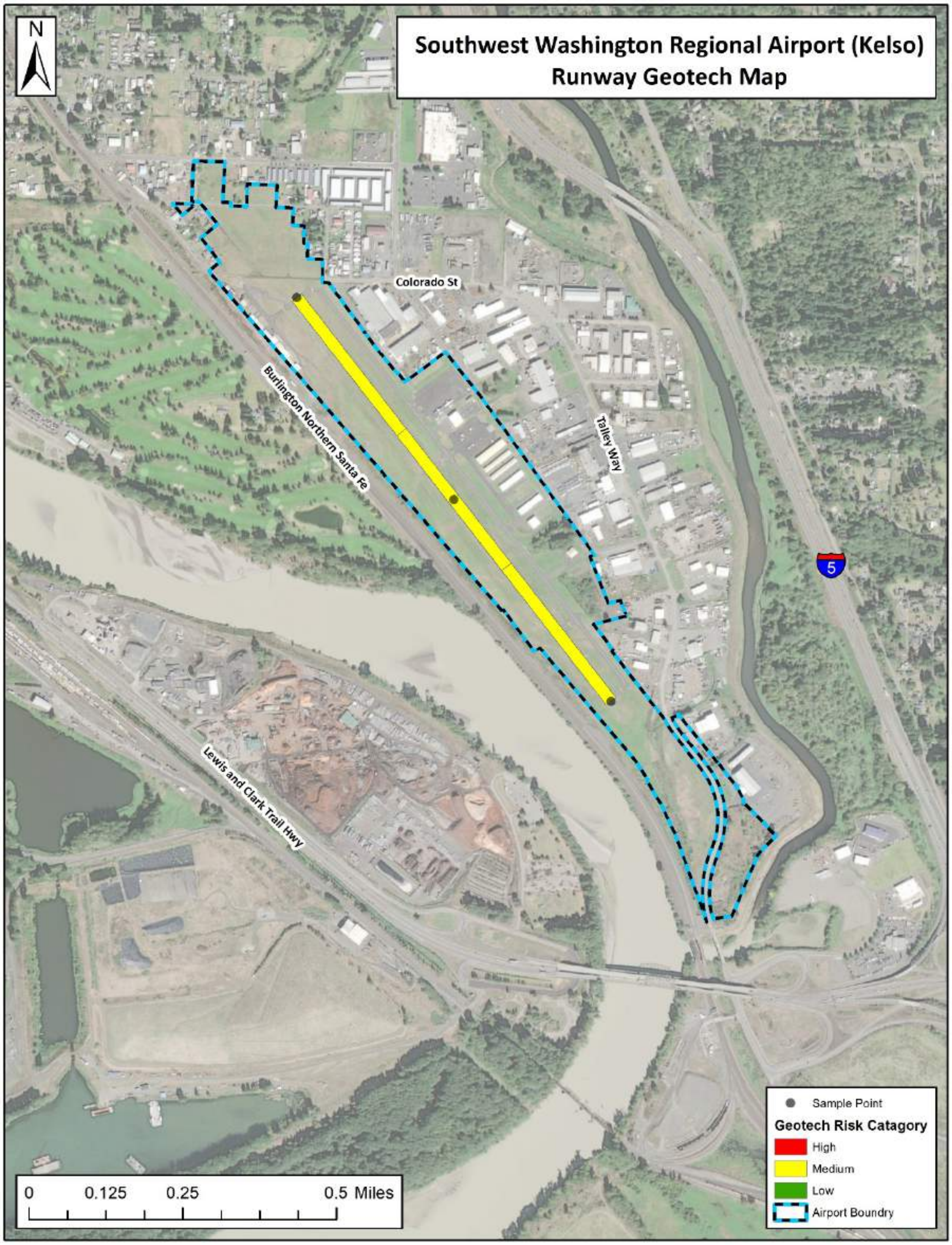

N
Snohomish County-Paine Field
Runway Geotech Map
84th St SW
Boeing Fwy
Paine Field Blvd
Mukilteo Speedway
Harbour Pointe Blvd
100 St SW
E Perimeter Rd
Beverly Park Rd
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.325
0.65
1.3 Miles

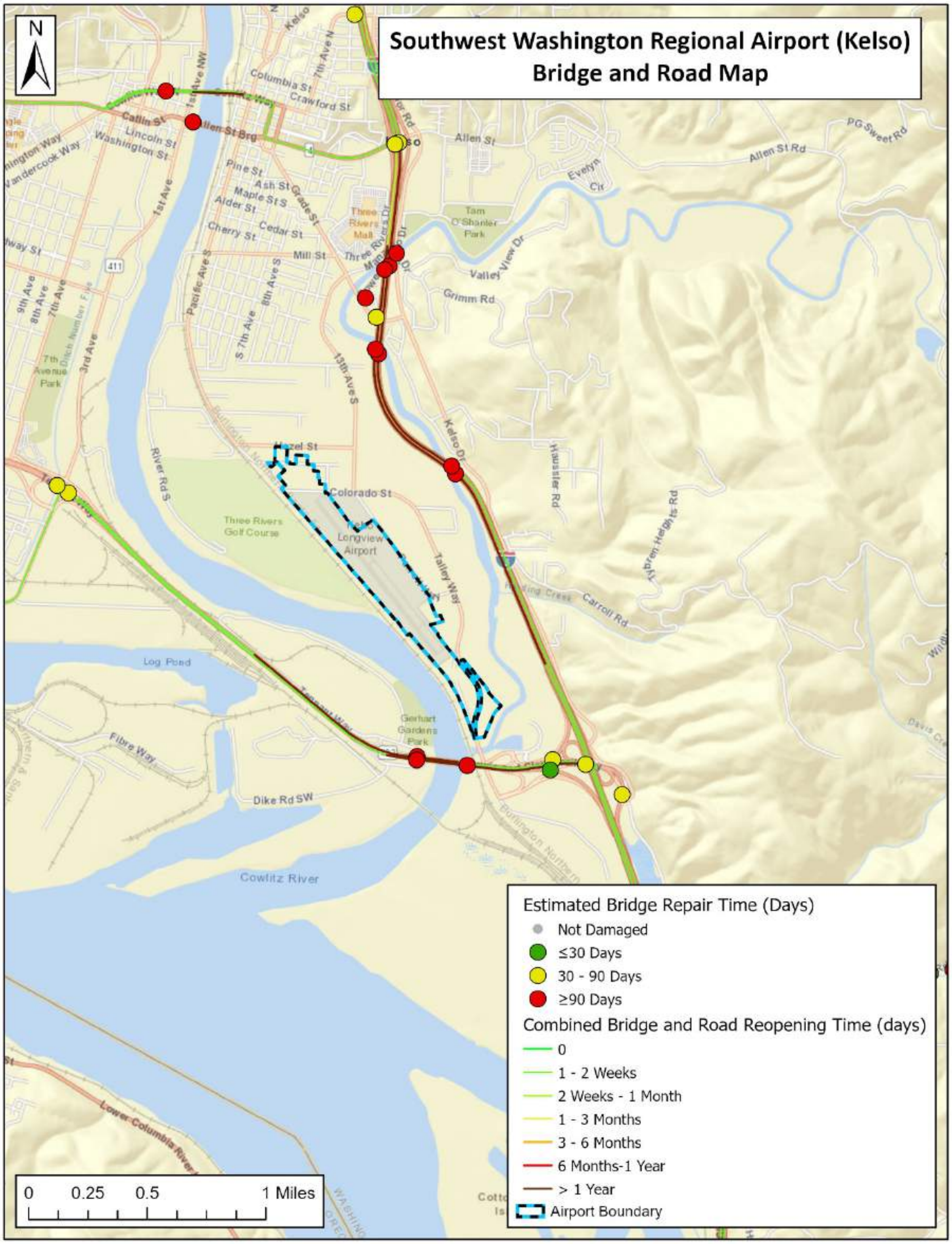

N
Snohomish County-Paine Field
Bridge and Road Map
Estimated Bridge Repair Time (Days)
Not Damaged
≤30 Days
30 - 90 Days
≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles
Paine Field-Snohomish Co Airport
Mukilteo

Appendix B-14. Southwest Washington Regional (Kelso)



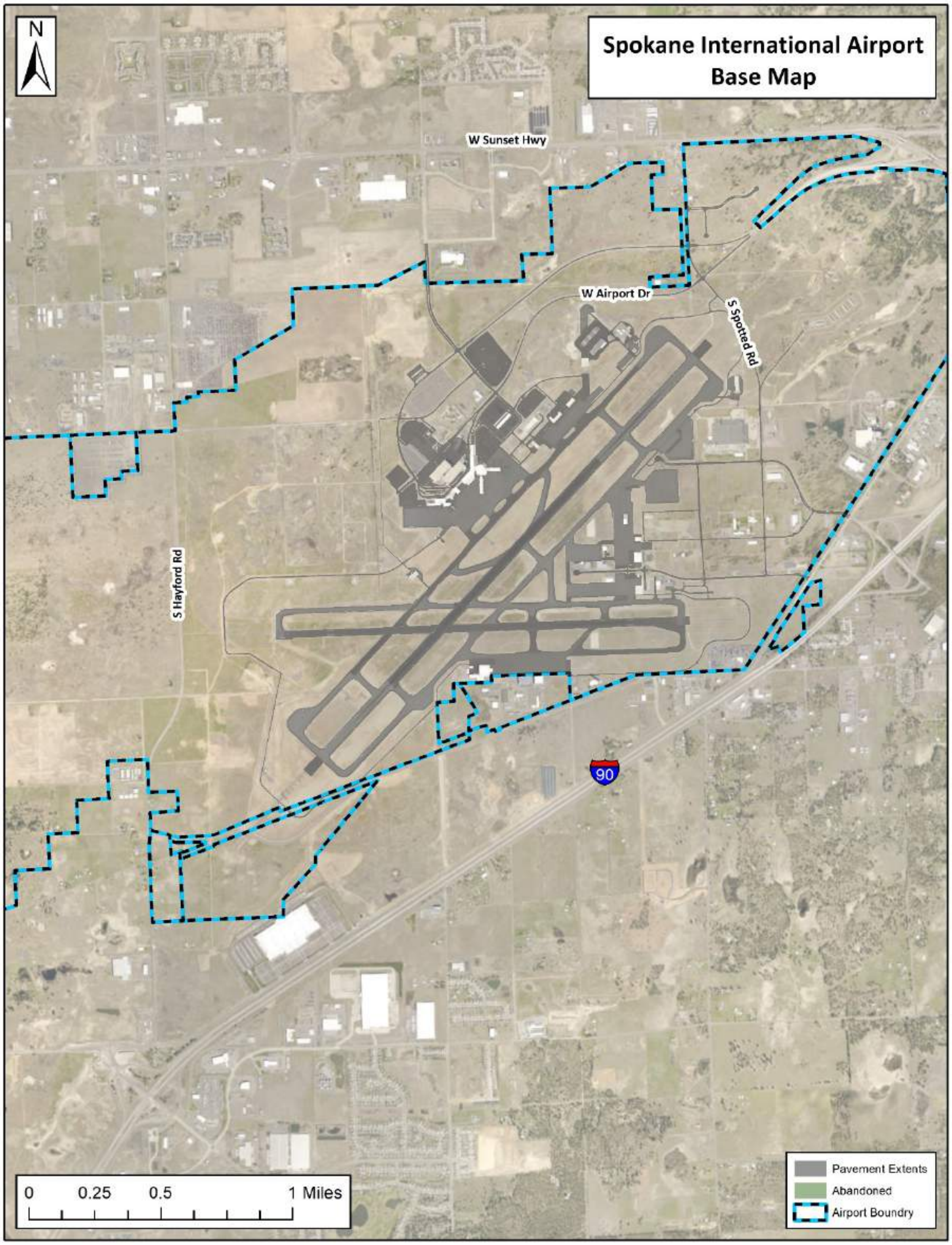

N
Southwest Washington Regional Airport (Kelso)
Liquefaction Map
Colorado St
Burlington Northern Santa Fe
Talley Way
5
Lewis and Clark Trail Hwy
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.125
0.25
0.5 Miles

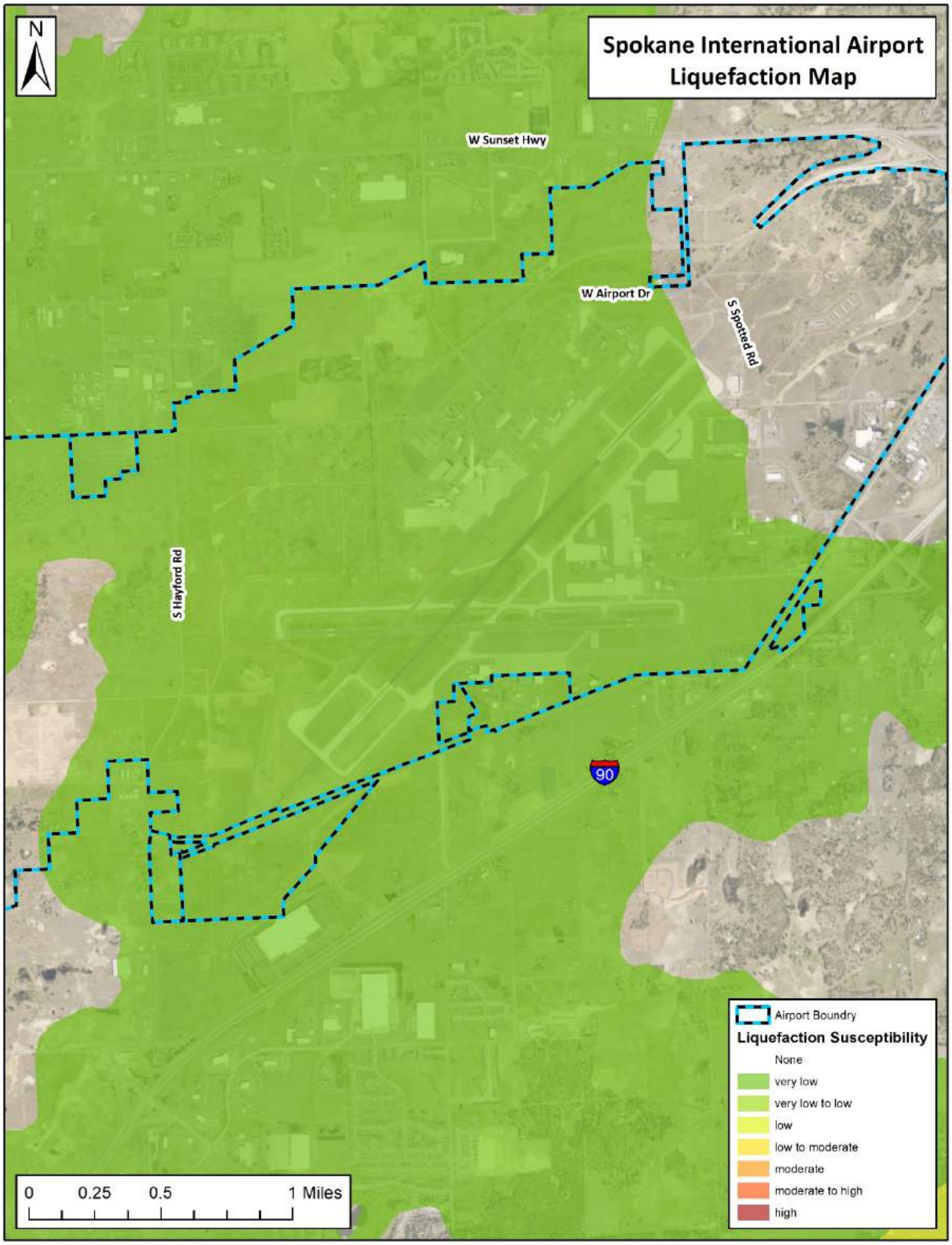

N
Southwest Washington Regional Airport (Kelso)
Runway Geotech Map
Colorado St
Burlington Northern Santa Fe
Talley Way
5
Lewis and Clark Trail Hwy
0
0.125
0.25
0.5 Miles
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry

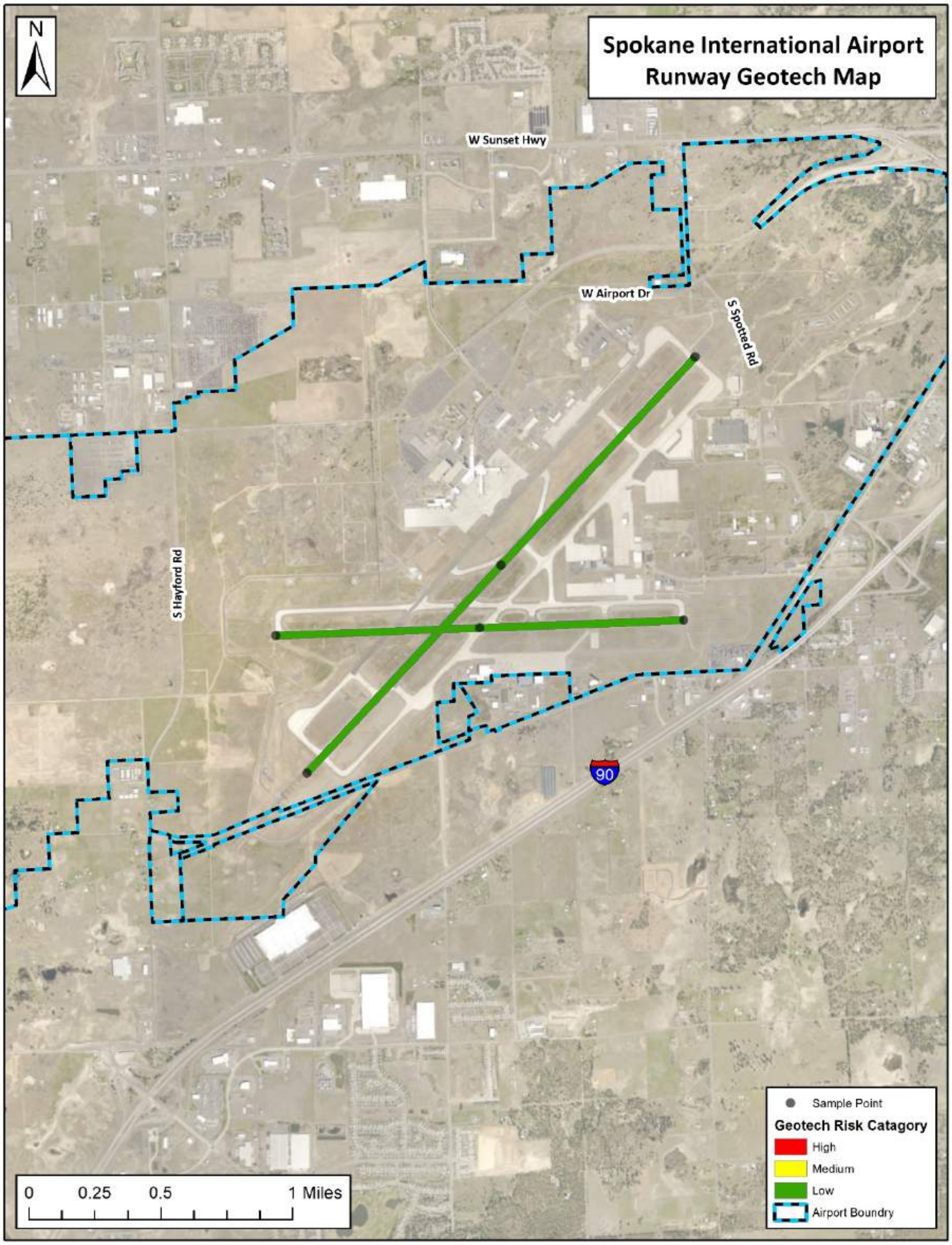


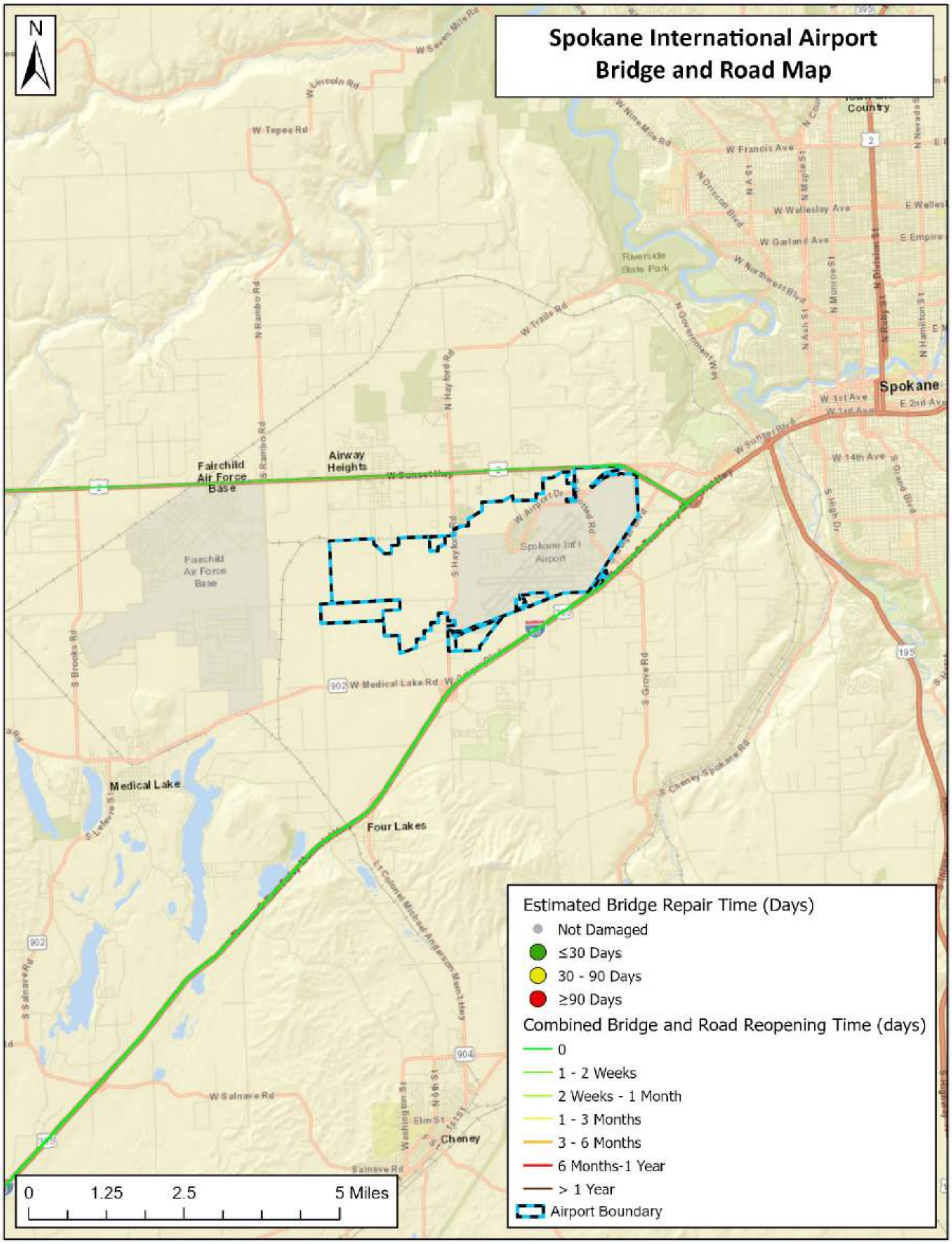
Southwest Washington Regional Airport (Kelso)
Bridge and Road Map

Appendix B-15. Spokane International

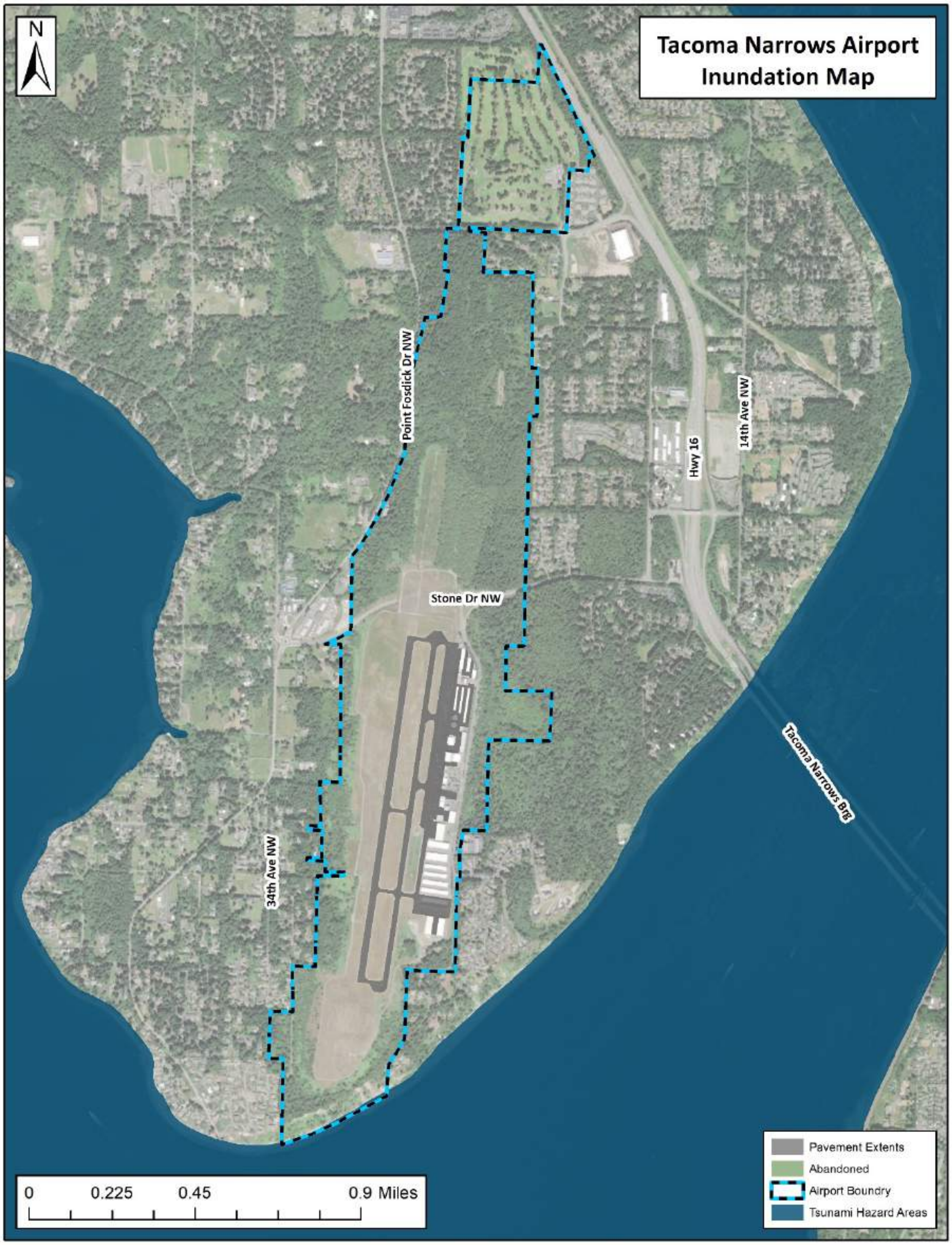


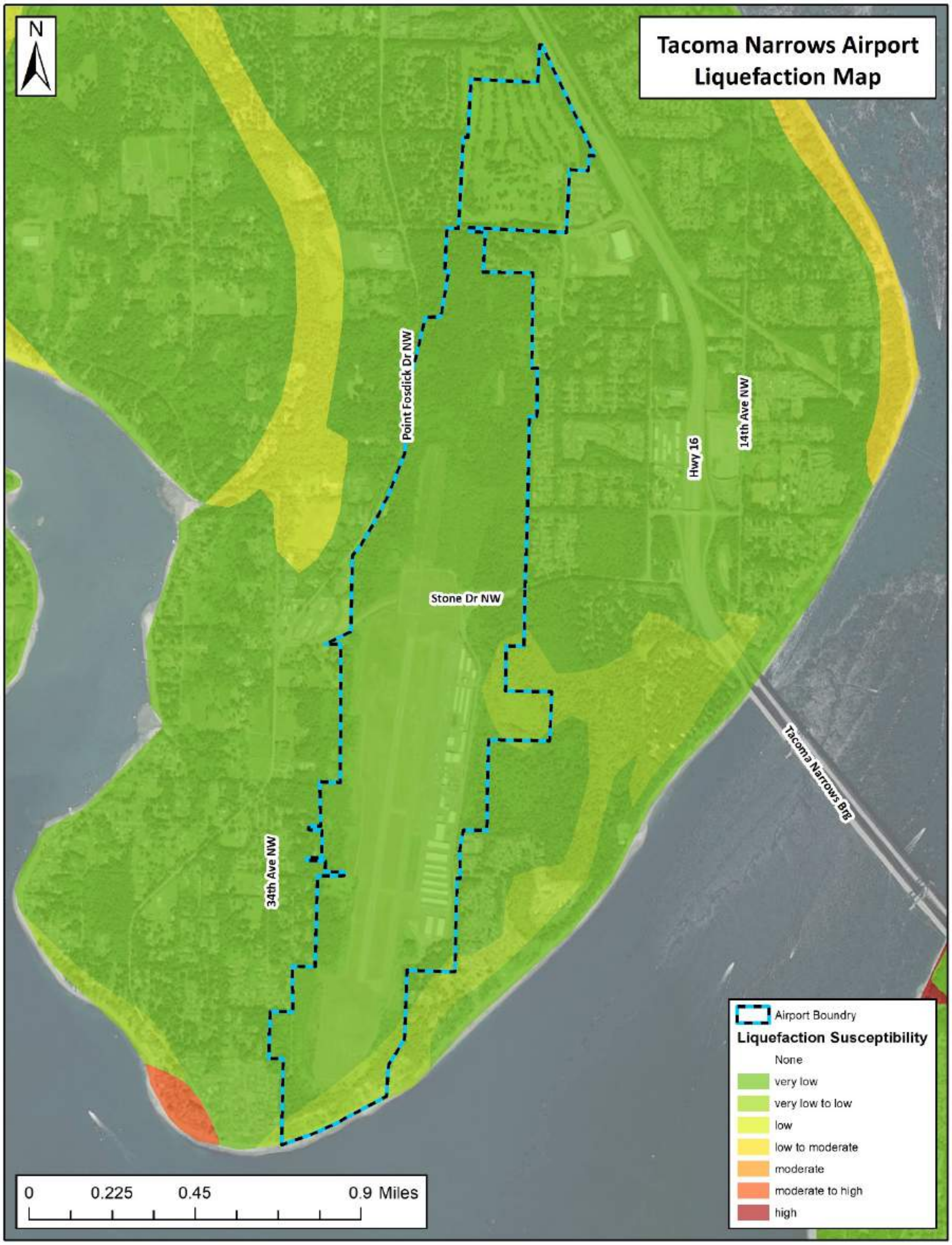

Spokane International Airport
Liquefaction Map
N
W Sunset Hwy
W Airport Dr
S Spotted Rd
S Hayford Rd
90
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.25
0.5
1 Miles


Spokane International Airport
Runway Geotech Map
N
W Sunset Hwy
W Airport Dr
S Spotted Rd
S Hayford Rd
90
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0 0.25 0.5 1 Miles


Spokane International Airport
Bridge and Road Map
N
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
Airport Boundary
0
1.25
2.5
5 Miles
Spokane
Spokane Int'l Airport
Fairchild Air Force Base
Airway Heights
Medical Lake
Four Lakes
Cheney
Riverside State Park
Country
W Sunset Hwy
W Airport Dr
S Hayford Rd
N Hayford Rd
W Medical Lake Rd
S Grove Rd
S Brooks Rd
S Rambo Rd
N Rambo Rd
W Tepee Rd
W Lincoln Rd
W Seven Mile Rd
W Nine Mile Rd
W Trails Rd
N Government Way
W Francis Ave
W Wellesley Ave
W Garland Ave
W Northwest Blvd
N Division St
N Monroe St
N Ash St
W 1st Ave
W 2nd Ave
E 2nd Ave
W 14th Ave
S High Dr
S Cheney Spokane Rd
Lt Colonel Michael Anderson Mem'l Hwy
W Salnave Rd
Salnave Rd
S Salnave Rd
S Lefevre St
Washington St
N 6th St
Elm St
1st St
F St
2
90
195
395
902
904

Appendix B-16. Tacoma Narrows

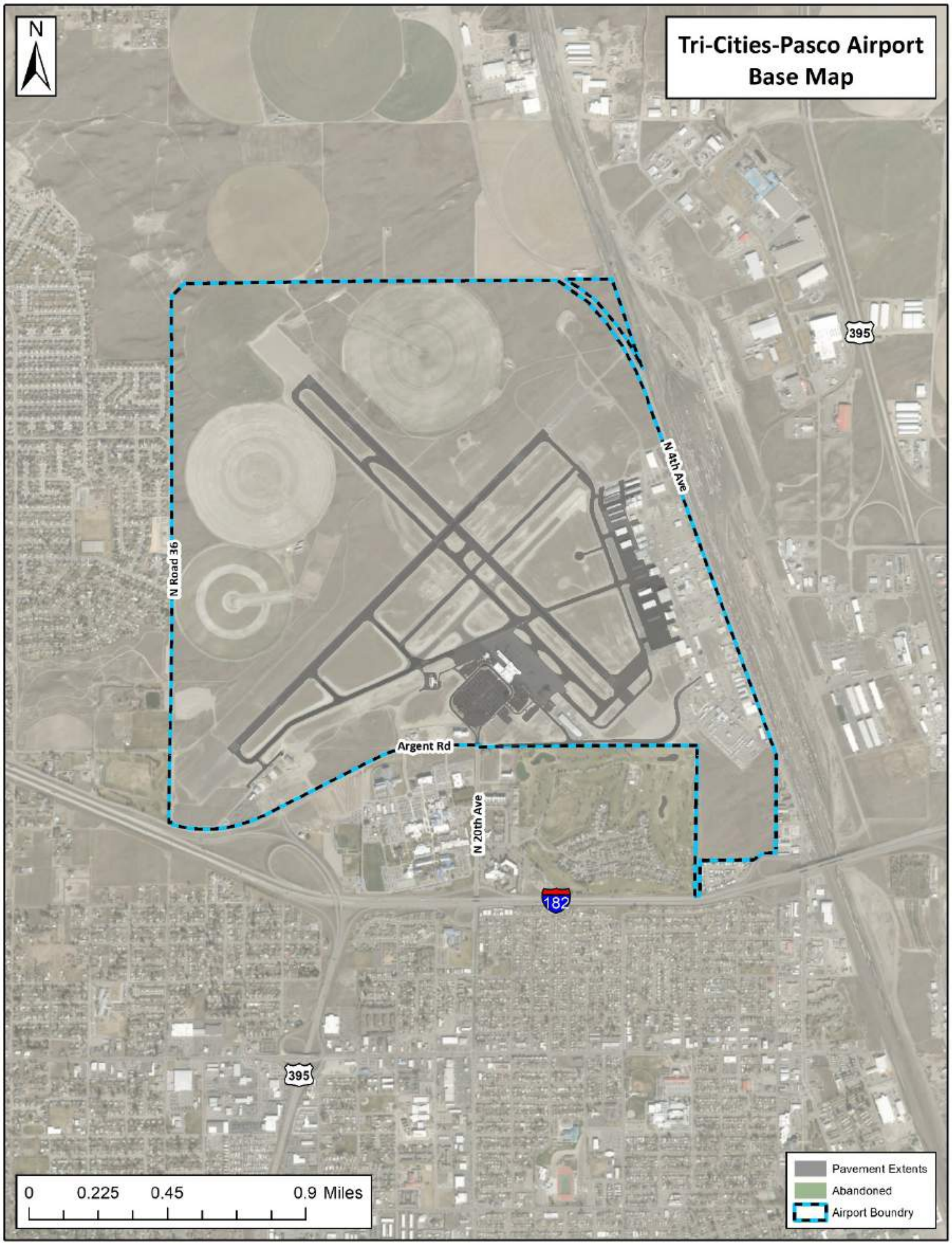

Tacoma Narrows Airport
Inundation Map
N
Point Fosdick Dr NW
Stone Dr NW
14th Ave NW
Hwy 16
Tacoma Narrows Brg
34th Ave NW
0
0.225
0.45
0.9 Miles
Pavement Extents
Abandoned
Airport Boundry
Tsunami Hazard Areas

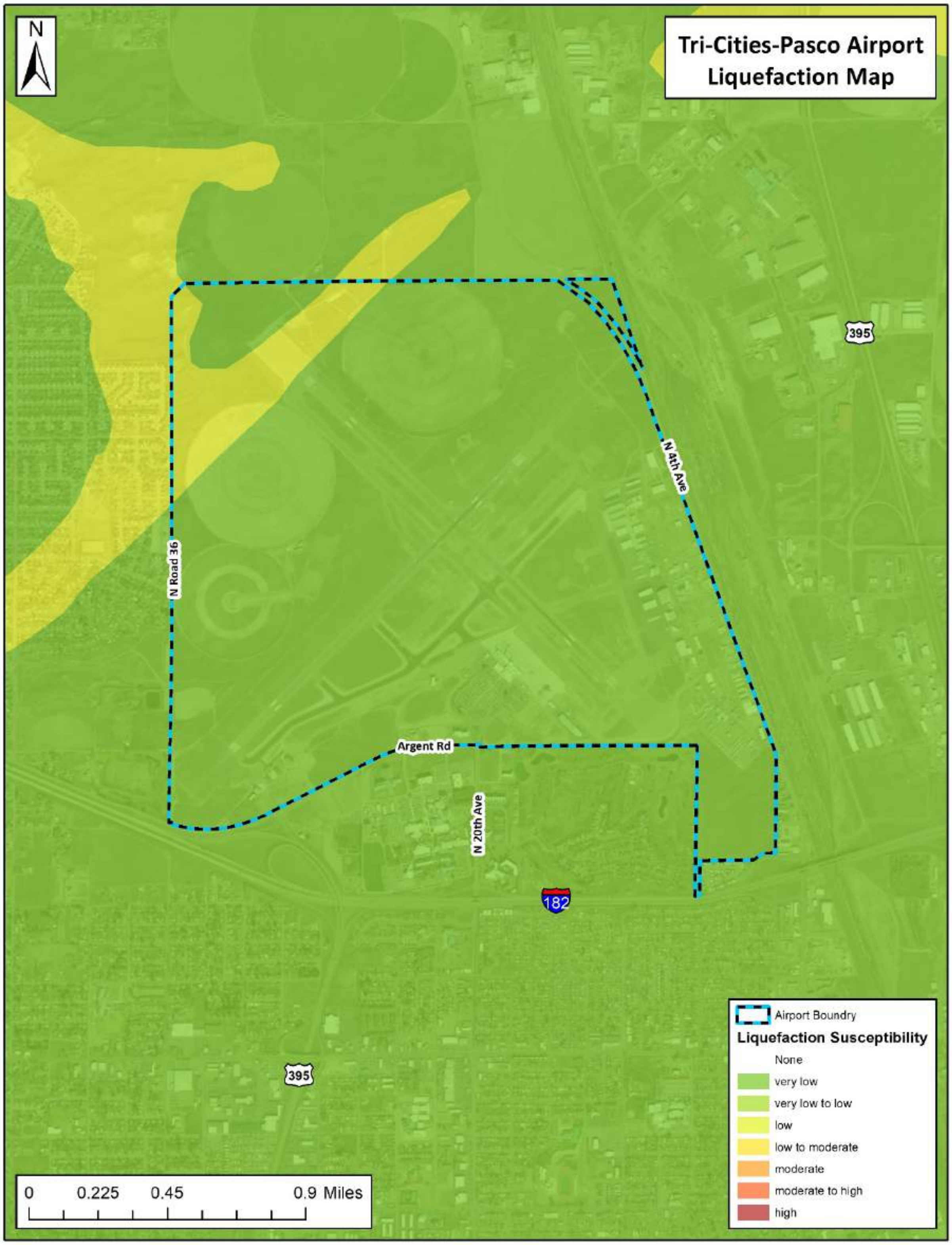

N
Tacoma Narrows Airport
Liquefaction Map
Point Fosdick Dr NW
14th Ave NW
Hwy 16
Stone Dr NW
Tacoma Narrows Brg
34th Ave NW
0
0.225
0.45
0.9 Miles
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high


N
Tacoma Narrows Airport
Runway Geotech Map
Point Fosdick Dr NW
Hwy 16
14th Ave NW
Stone Dr NW
Tacoma Narrows Brg
34th Ave NW
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.225
0.45
0.9 Miles

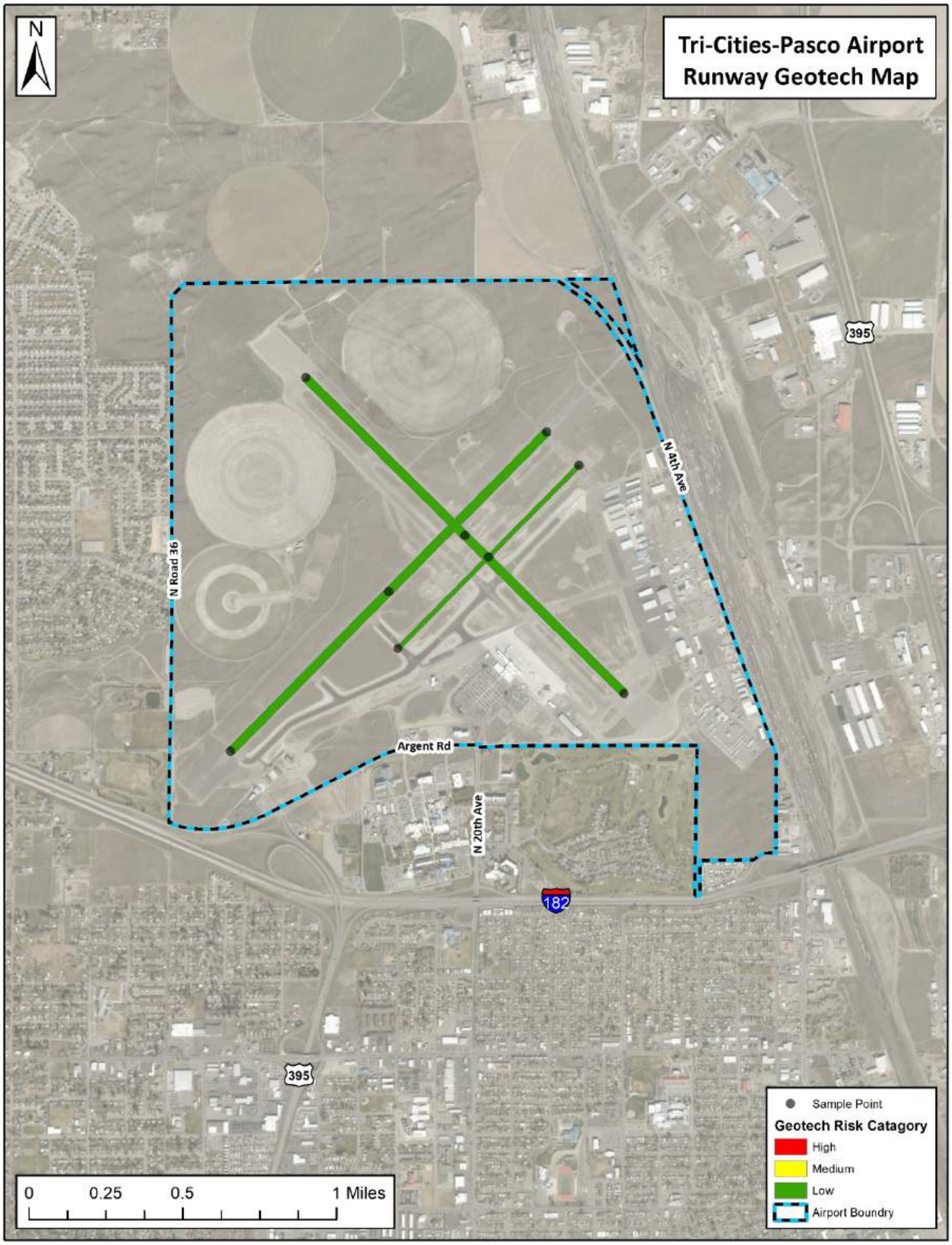

Tacoma Narrows Airport
Bridge and Road Map
N
Gig Harbor
Ruston
Fox Island
Hale Passage
Wollochet Bay
Tacoma Narrows Airport
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles

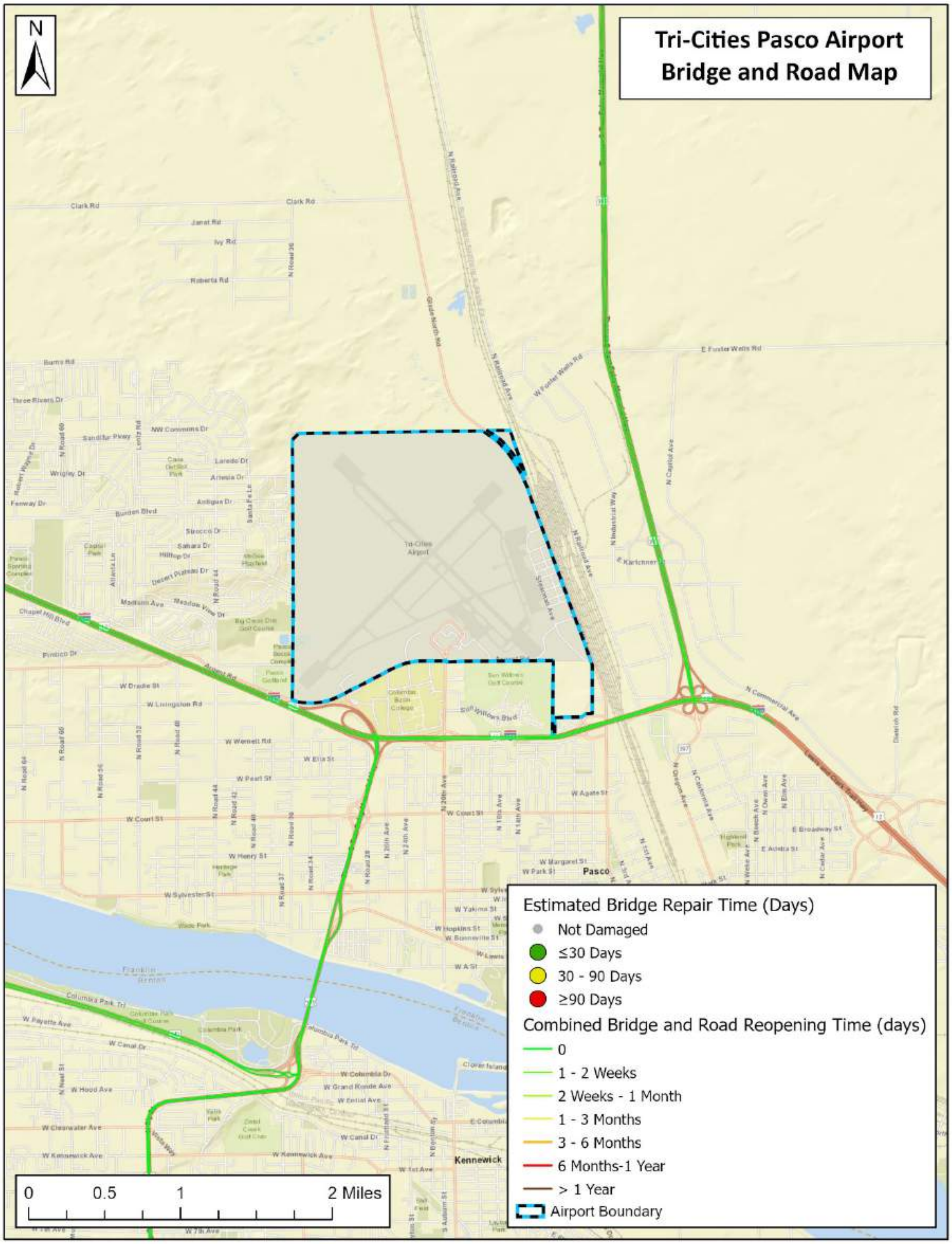
Appendix B-17. Tri-Cities (Pasco)



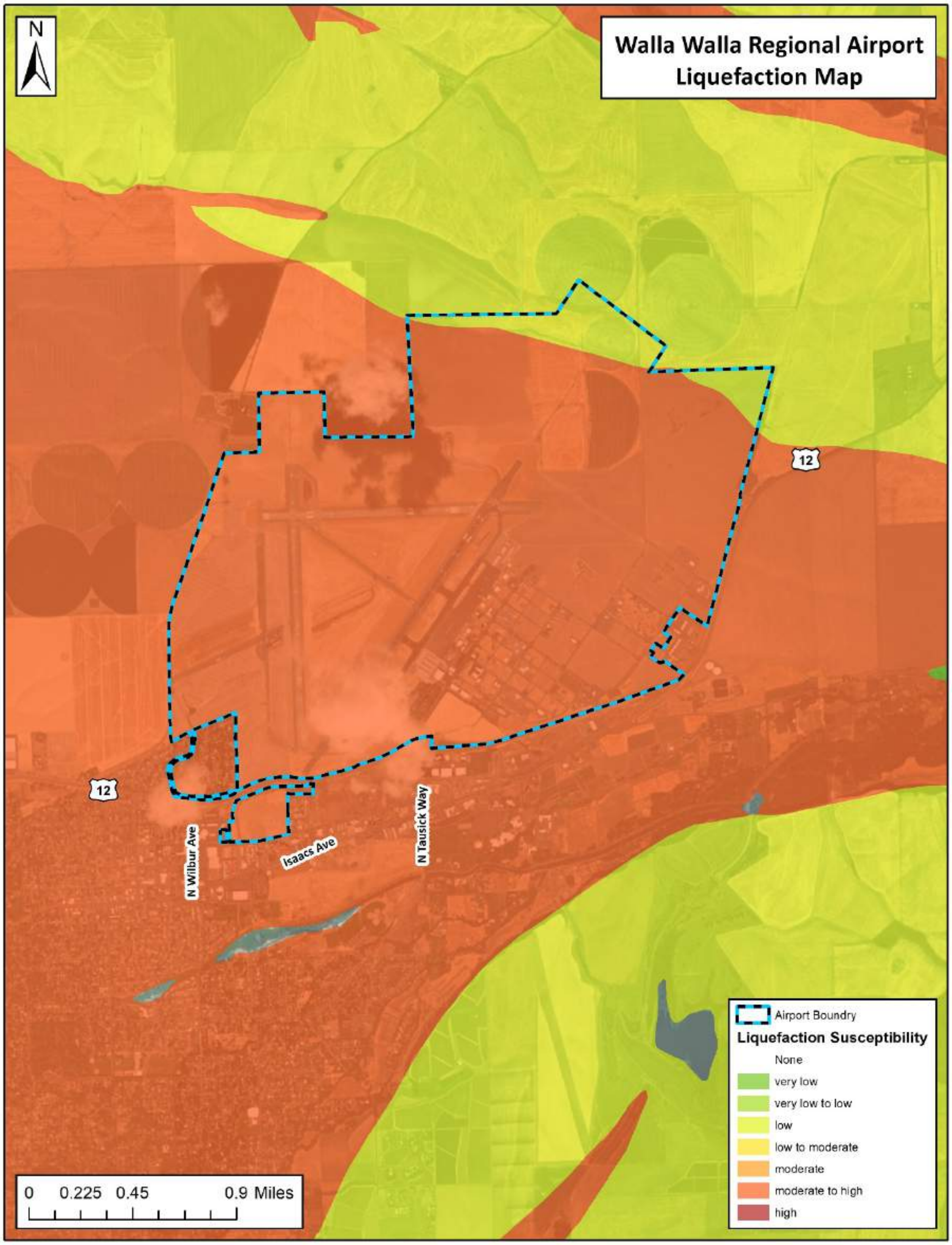


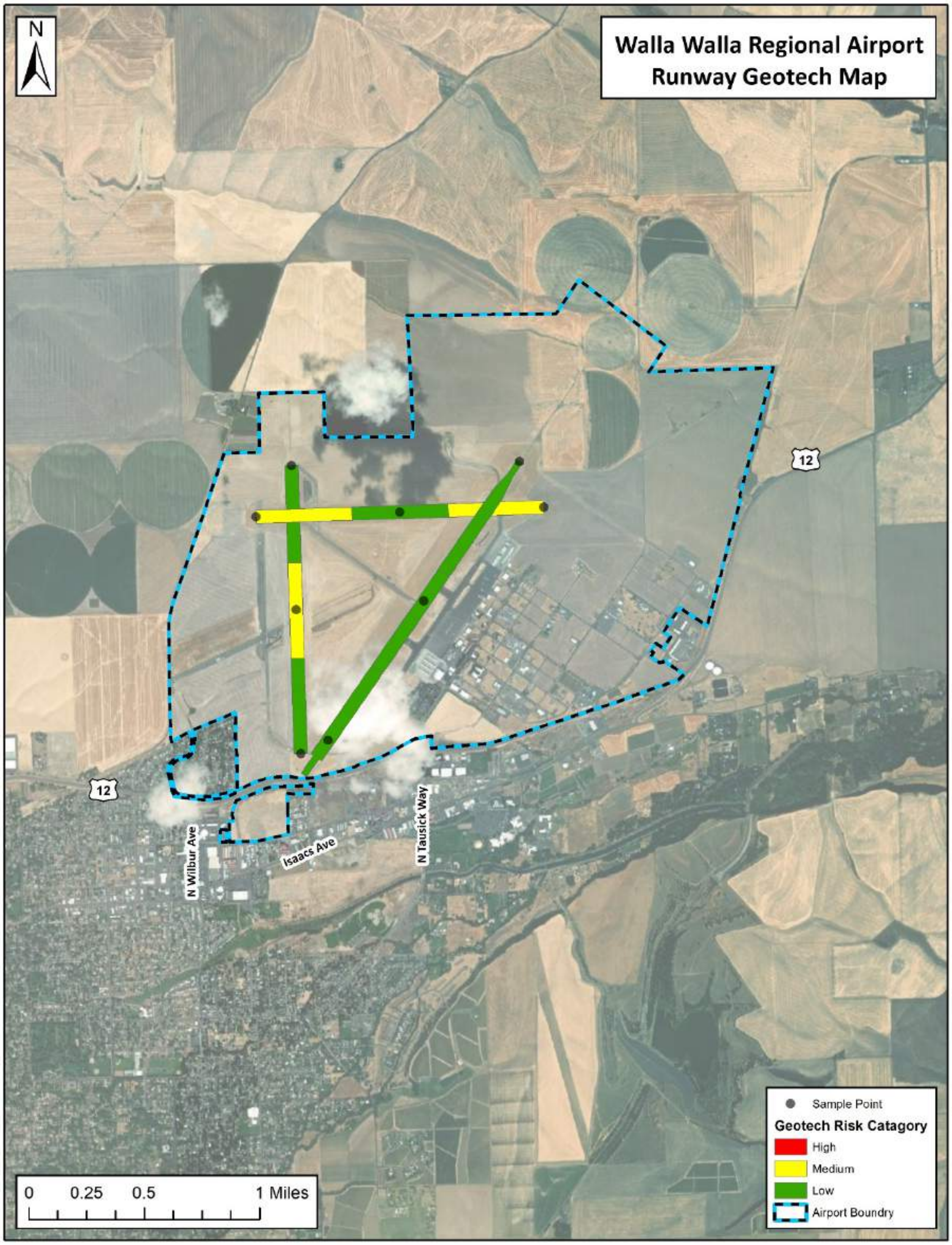
Tri-Cities-Pasco Airport Liquefaction Map


N
Tri-Cities-Pasco Airport
Runway Geotech Map
395
N 4th Ave
N Road 36
Argent Rd
N 20th Ave
182
395
Sample Point
Geotech Risk Catagory
High
Medium
Low
Airport Boundry
0
0.25
0.5
1 Miles


N
Tri-Cities Pasco Airport
Bridge and Road Map
Tri-Cities Airport
Pasco
Kennewick
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
— 0
— 1 - 2 Weeks
— 2 Weeks - 1 Month
— 1 - 3 Months
— 3 - 6 Months
— 6 Months-1 Year
— > 1 Year
▭ Airport Boundary
0
0.5
1
2 Miles

Appendix B-18. Walla Walla Regional


Walla Walla Regional Airport
Liquefaction Map
N
12
12
N Wilbur Ave
Isaacs Ave
N Tausick Way
Airport Boundry
Liquefaction Susceptibility
None
very low
very low to low
low
low to moderate
moderate
moderate to high
high
0
0.225
0.45
0.9 Miles

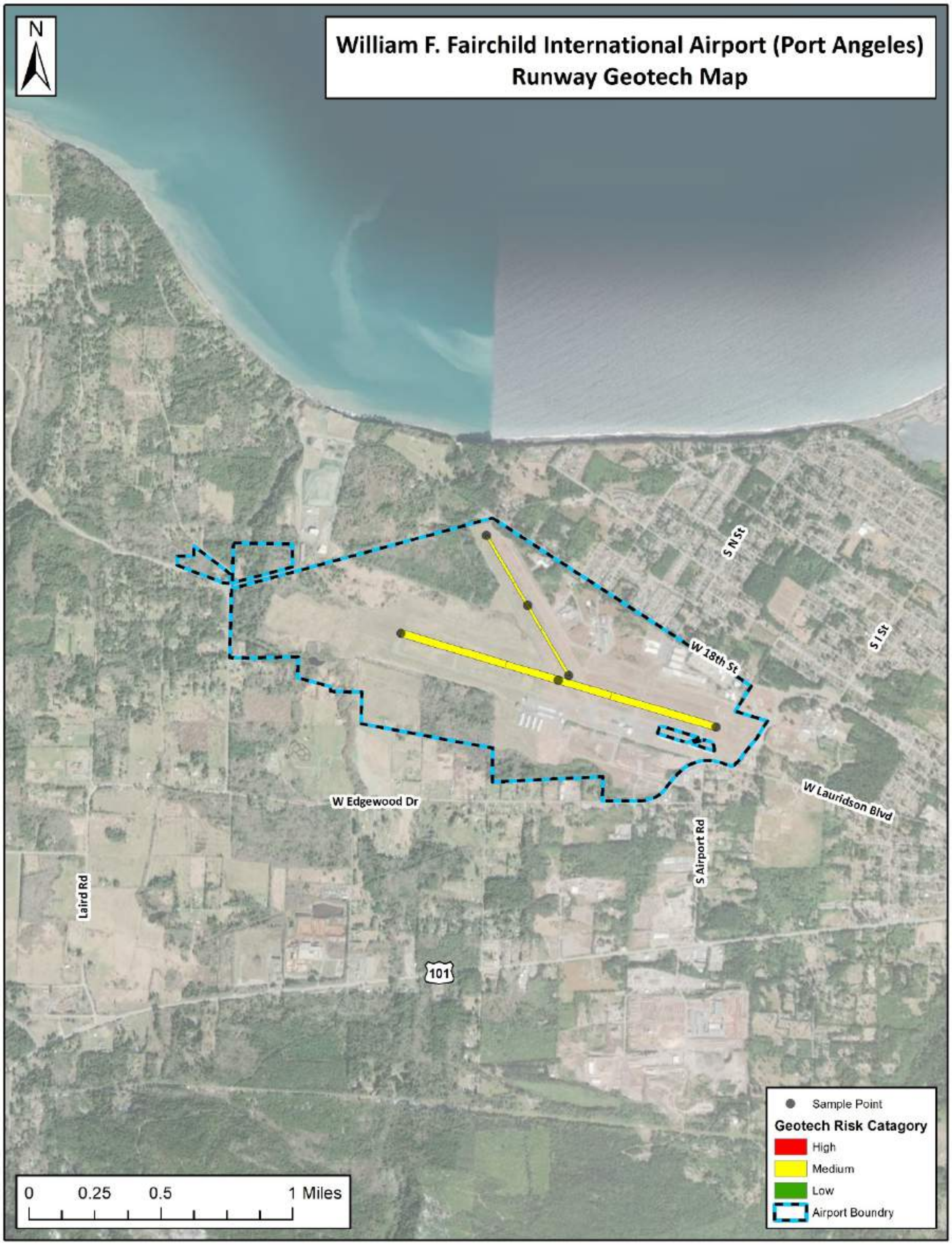

Walla Walla Regional Airport
Runway Geotech Map
N
12
12
N Wilbur Ave
Isaacs Ave
N Tausick Way
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles

Walla Walla Regional Airport
Bridge and Road Map

Appendix B-19. William R. Fairchild International (Port Angeles)

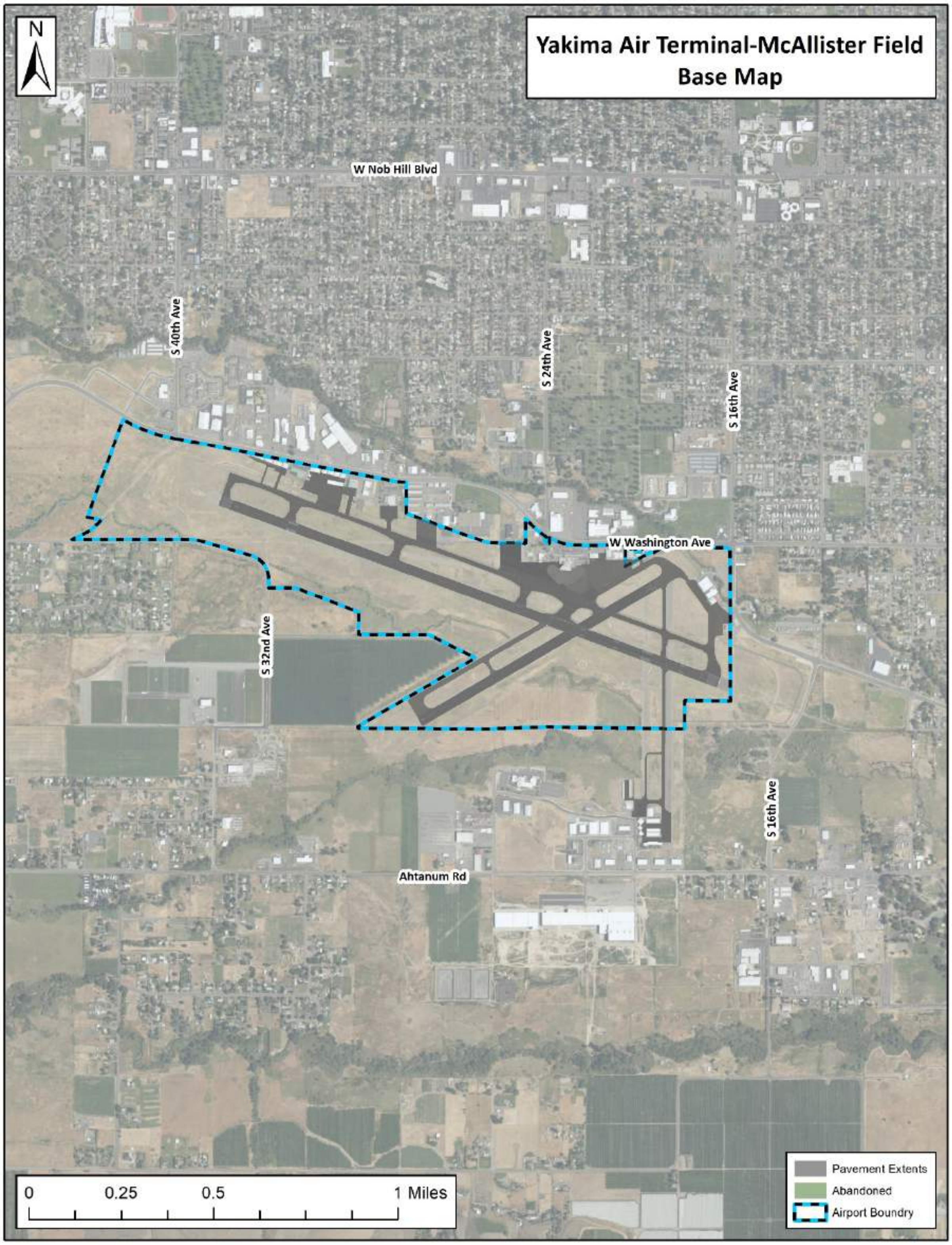
William F. Fairchild International Airport (Port Angeles)
Inundation Map

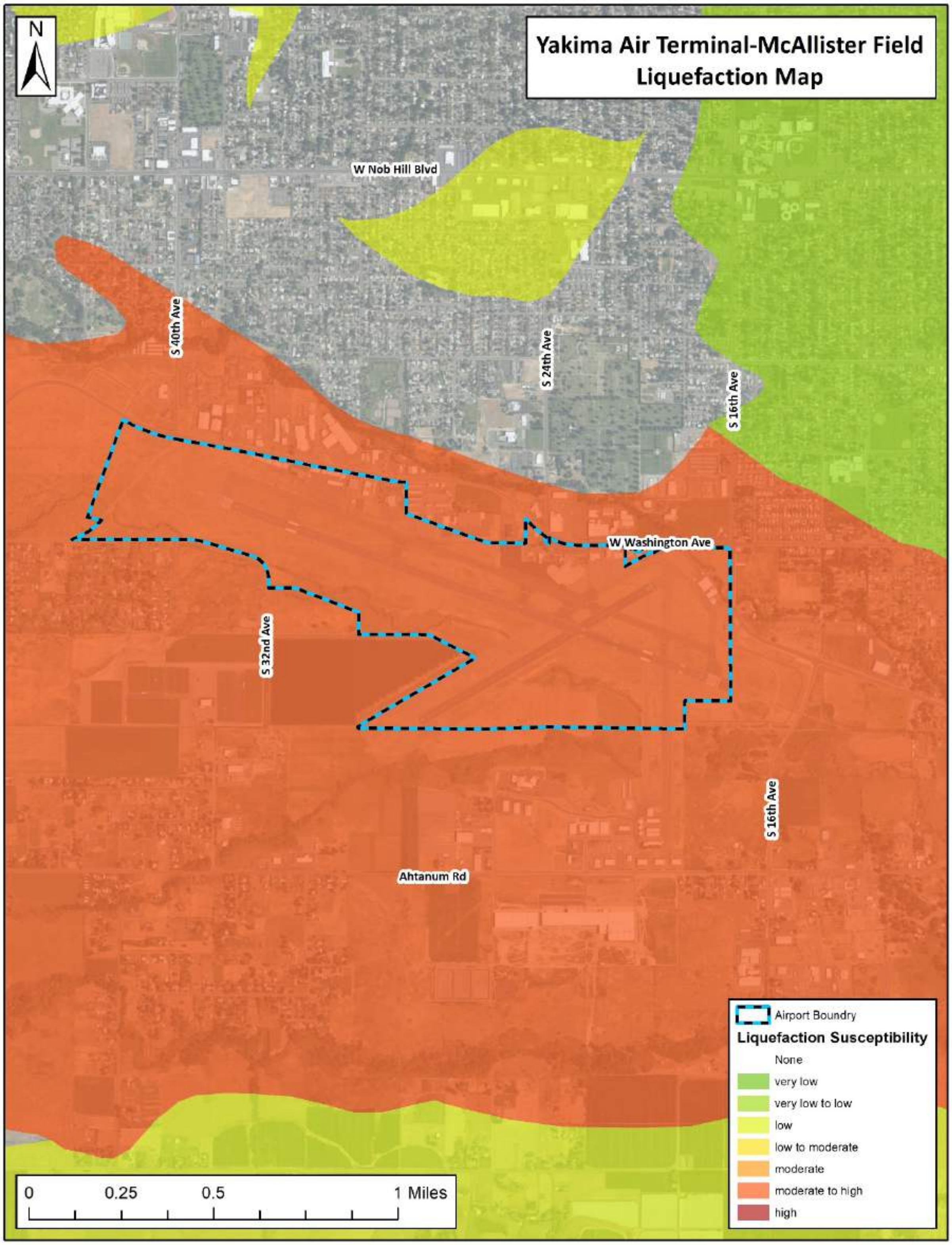

William F. Fairchild International Airport (Port Angeles)
Liquefaction Map


N
William F. Fairchild International Airport (Port Angeles)
Runway Geotech Map
S N St
S I St
W 18th St
W Lauridson Blvd
W Edgewood Dr
S Airport Rd
Laird Rd
101
0
0.25
0.5
1 Miles
● Sample Point
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry

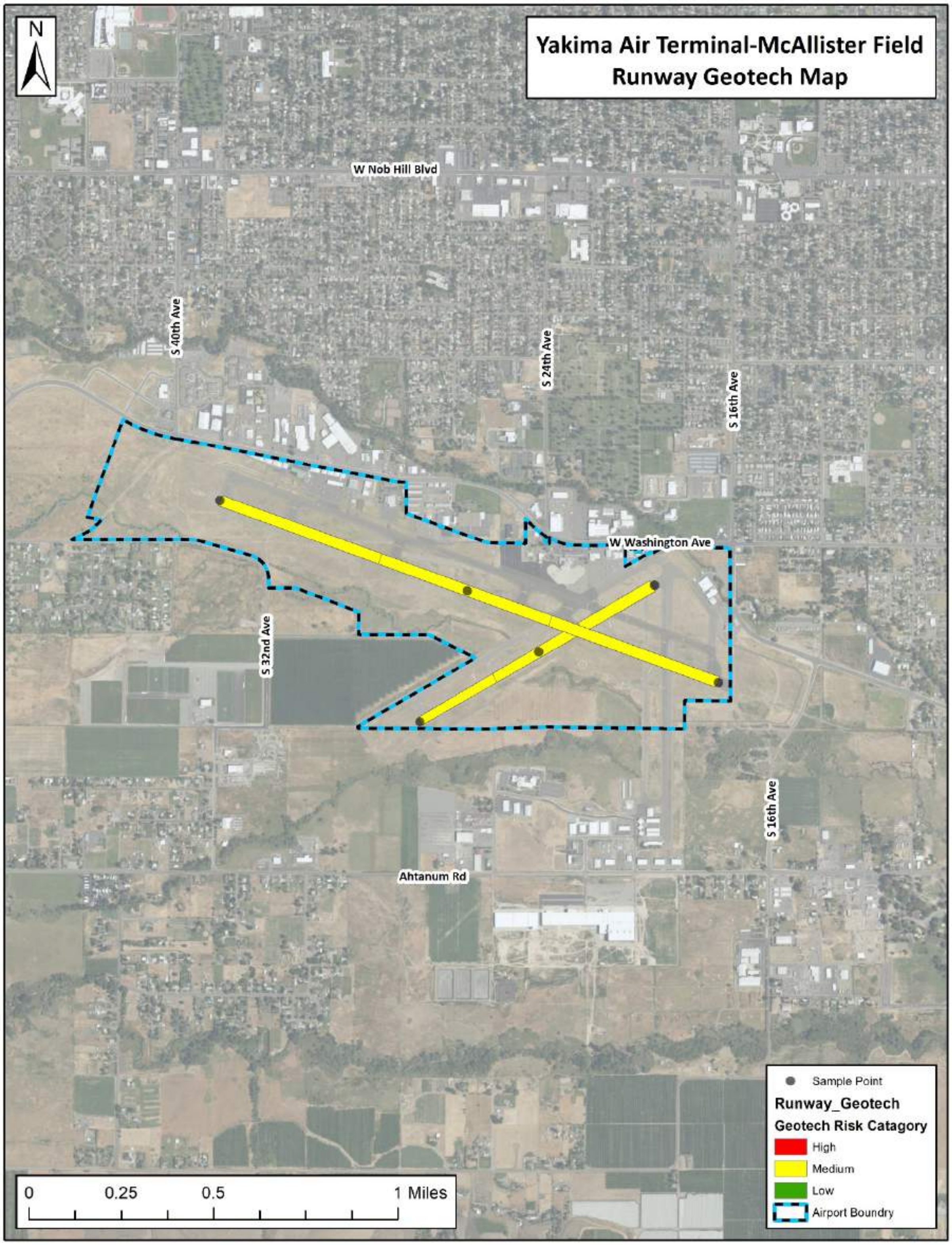

N
William R. Fairchild International Airport (Port Angeles)
Bridge and Road Map
Estimated Bridge Repair Time (Days)
Not Damaged
≤30 Days
30 - 90 Days
≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles
W Edgewood Dr
Power Plant Rd
Elwha River Rd
Lower Elwha Rd
W Lauridsen Blvd
S Airport Rd
S Dry Creek Rd
W Ediz Hook Rd
Whidby Ave
E Park Ave
E Viewcrest Ave
E Ahlvers Rd

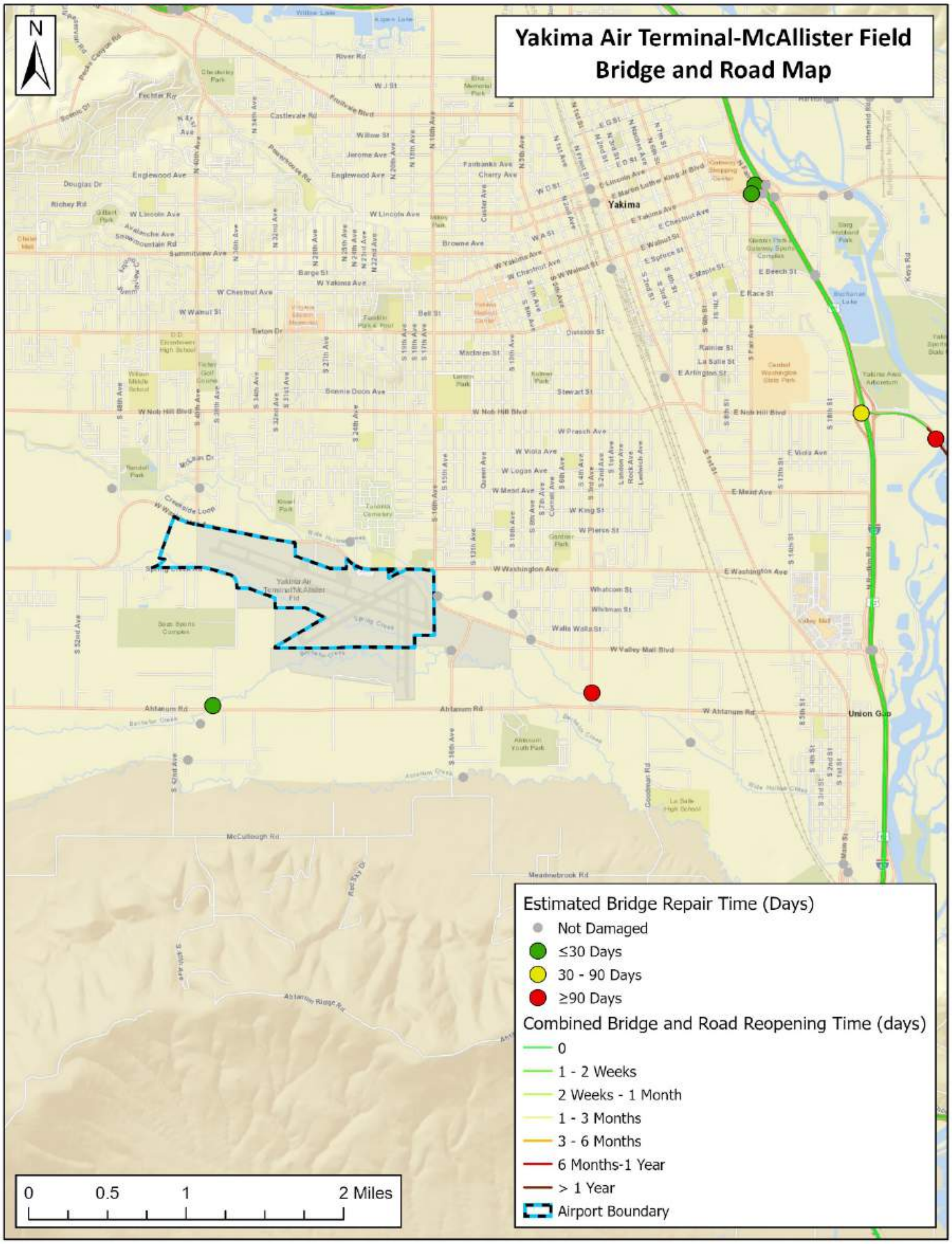
Appendix B-20. Yakima Air Terminal-McAllister Field





Yakima Air Terminal-McAllister Field Liquefaction Map


N
Yakima Air Terminal-McAllister Field
Runway Geotech Map
W Nob Hill Blvd
S 40th Ave
S 24th Ave
S 16th Ave
W Washington Ave
S 32nd Ave
S 16th Ave
Ahtanum Rd
● Sample Point
Runway_Geotech
Geotech Risk Catagory
🟥 High
🟨 Medium
🟩 Low
Airport Boundry
0
0.25
0.5
1 Miles


Yakima Air Terminal-McAllister Field
Bridge and Road Map
N
Estimated Bridge Repair Time (Days)
● Not Damaged
● ≤30 Days
● 30 - 90 Days
● ≥90 Days
Combined Bridge and Road Reopening Time (days)
0
1 - 2 Weeks
2 Weeks - 1 Month
1 - 3 Months
3 - 6 Months
6 Months-1 Year
> 1 Year
Airport Boundary
0
0.5
1
2 Miles
Yakima
Union Gap
W Nob Hill Blvd
W Washington Ave
Ahtanum Rd
W Valley Mall Blvd
Yakima Air Terminal/McAllister Fld

Appendix C

Airport Name	Code	City	Runways								Pavement Areas				Fuel			Other Facilities with Backup Generation[5]
			Runway	Length	Width	Pavement Type	Runway Pavement Capacity (1,000 lbs.)				Abandoned Runways (sq. ft.)	Aprons (sq. ft.)	Active Runways (sq. ft.)	Taxiways (sq. ft.)	Fuel Capacity Onsite (gal)		Backup Gen	
							Single Wheel	Dual Wheels	Two Dual Wheels Tandem	Two Dual Wheels Double Tandem					AvGas/ 100LL	Jet A		
Arlington Municipal	AWO	Arlington	16/34	5,332	100	ASPH-G	114	150	270	-	540,951	916,882	821,506	1,467,096	40,000 (tank)	5,000 (truck) + ~8,000 in tenant tanks	None	Airfield lighting vault Admin building
			11/29	3,498	75	ASPH-G	32	34	59	-								
Bellingham International	BLI	Bellingham	16/34	6,700	150	ASPH-G	75	160	250	-	595,259	1,123,952	1,005,099	1,045,948	24,000 (tanks) 2,000 (trucks)	100,000 (tanks) 13,000 (trucks)	None, but generator hookups	Airfield lighting, Port building, gates, parking lot lighting, tollbooth and access control Commercial terminal, security gates, server room
Bowers Field	ELN	Ellensburg	11/29	4,300	150	CONC-G	35	57	100	-	-	693,246	1,302,212	659,230	11,000 (tanks)	11,000 (tanks) 1,800 (trucks)	None, but generator hookups	None
Bremerton National	PWT	Bremerton	02/20	6,000	150	ASPH-G	33	150	336	-	700,528	898,904	900,251	672,110	15,000 (tanks) 1,000 (trucks)	10,000 (tanks) 3,000 (trucks)	None	Airfield lighting Terminal building
Columbia Gorge Regional – The Dalles Municipal	DLS	Dallesport	13/31	5,097	100	ASPH-G	30	30	-	-	400,000	286,550	974,400	466,350	12,000 (tank)	22,000 (tank) 8,000 (truck)	Yes (tied to terminal building backup generator)	Airfield lighting vault Terminal building
			07/25	4,647	100	ASPH-G	30	30	-	-								
Friday Harbor	FHR	Friday Harbor	16/34	3,402	75	ASPH-G	12.5	-	-	-	-	461,958	255,000	180,138	20,000	None	None	Airfield lighting vault Terminal building and airport offices

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[5] This column refers to facilities with permanent, dedicated backup generators; numerous airports noted that they had small, portable generators onsite that are not captured in this table

			Runways								Pavement Areas				Fuel			
							Runway Pavement Capacity (1,000 lbs.)								Fuel Capacity Onsite (gal)			
Airport Name	Code	City	Runway	Length	Width	Pavement Type	Single Wheel	Dual Wheels	Two Dual Wheels Tandem	Two Dual Wheels Double Tandem	Abandoned Runways (sq. ft.)	Aprons (sq. ft.)	Active Runways (sq. ft.)	Taxiways (sq. ft.)	AvGas/ 100LL	Jet A	Backup Gen	Other Facilities with Backup Generation^5
Grant County International	MWH	Moses Lake	18/36	3,327	75	ASPH-G	75	170	300	400	-	7,154,632	4,146,553	2,634,839	12,000 (tanks)	3,030,000 (tanks)	None, limited gravity ops possible	Control tower Airfield lighting vault ARFF Facility TRACON Radar
			14R/32L	2,936	75	CONC-G	100	200	400	400								
			14L/32R	13,503	200	ASPH-CONC-G	85	155	320	600								
			09/27	3,500	90	CONC-G	100	150	270	475								
			04/22	10,000	100	ASPH-G	75	100	175	475								
Olympia Regional	OLM	Olympia	17/35	5,500	150	ASPH-G	75	94	142	-		850,677	1,462,660	1,671,300	30,000	36,000	None	Airfield lighting FBO building (Glacier) WSDOT Aviation Division offices
			08/26	4,157	150	ASPH-G	30	-	-	-								
Renton Municipal	RNT	Renton	16/34	5,382	200	ASPH-CONC-G	100	130	340	-	-	153,606	1,075,797	881,147	75,000 (tank) 14,000 (truck)	24,500 (tank) 15,000 (truck)	None	Control tower Airfield lighting Access control
Sanderson Field	SHN	Shelton	05/23	5,005	100	ASPH-G	55	72	130	-	915,035	336,756	500,537	769,994	12,000 (tank)	16,000 (tanks) 4,900 (trucks)	None	None
Seattle-Tacoma International	SEA	Sea-Tac	16C/34C	9,426	150	CONC-E	120	250	550	1,120	-	9,535,343	4,458,815	6,737,190	None	22,000,000 (tanks)	Yes (via Alternate Utility Facility)	All airport facilities connected to Alternate Utility Facility, except airfield lighting Airfield lighting (own generator)
			16R/34L	8,500	150	CONC-E	100	216	448	1,157								
			16L/34R	11,901	150	CONC-E	100	230	600	1,400								
Skagit Regional	BVS	Burlington / Mount Vernon	11/29	5,478	100	ASPH-G	19	-	-	-	-	825,347	723,009	1,153,407	24,000 (tanks) 1,000 (truck)	12,000 (tank) 8,000 (trucks)	None	None
			04/22	3,000	60	ASPH-E	12.5	-	-	-								

C-3

Airport Name	Code	City	Runways								Pavement Areas				Fuel			Other Facilities with Backup Generation[5]
			Runway	Length	Width	Pavement Type	Runway Pavement Capacity (1,000 lbs.)				Abandoned Runways (sq. ft.)	Aprons (sq. ft.)	Active Runways (sq. ft.)	Taxiways (sq. ft.)	Fuel Capacity Onsite (gal)		Backup Gen	
							Single Wheel	Dual Wheels	Two Dual Wheels Tandem	Two Dual Wheels Double Tandem					AvGas/ 100LL	Jet A		
Snohomish County-Paine Field	PAE	Everett	16L/34R	3,004	75	ASPH-G	12.5	-	-	-	428,634	4,210,575	1,574,556	2,722,383	4,000 (tanks) 3,000 (trucks)	120,000 (tanks) 21,000 (trucks)	None	Control tower Airfield lighting vault Terminal building ARFF facility
			11/29	4,504	75	ASPH-F	30	-	-	-								
			16R/34L	9,010	150	ASPH-CONC-G	100	200	350	830								
Southwest Washington Regional	KLS	Kelso	12/30	4,391	100	ASPH-F	38	46	74	-	-	234,304	439,500	329,292	12,000 (tank)	12,000 (tank) 1,500 (Truck)	None	None
Spokane International	GEG	Spokane	08/26	8,199	150	ASPH-G	150	180	280	-	-	5,112,187	2,771,100	4,486,115	20,000 (tanks) 2,000 (truck)	750,000 (tanks) 100,000 (truck)	Yes	Control Tower Airfield lighting Airport terminals ARFF ILS Airport operations building
			03/21	11,002	150	ASPH-CONC-E	200	200	400	-								
Tacoma Narrows	TIW	Tacoma	17/35	5,002	100	ASPH-G	50	80	80	150	-	1,210,502	509,304	447,853	18,000 (tanks) 5,000 (truck)	22,000 (tank) 15,000 (trucks)	None	Control Tower Airfield lighting Water system
Tri-Cities	PSC	Pasco	12/30	7,704	150	ASPH-G	150	200	400	-	-	2,078,993	2,700,809	2,354,928	15,000 (tanks) 750 (truck)	80,000 (tanks) 19,000 (trucks)	None	Control tower Airfield lighting ARFF Terminal building
			03R/21L	4,423	75	ASPH-F	52	85	108	150								
			03L/21R	7,707	150	ASPH-G	150	200	400	-								
Walla Walla Regional	ALW	Walla Walla	02/20	6,527	150	CONC-G	60	80	130	-	1,661,813	1,936,742	1,711,050	783,966	24,000 (tank)	12,000 (tank) 5,000 (truck)	None	Control tower Airfield lighting ARFF Airport maintenance facility NAVAIDS Terminal building Water well

C-4

Airport Name	Code	City	Runways								Pavement Areas				Fuel			Other Facilities with Backup Generation[5]
			Runway	Length	Width	Pavement Type	Runway Pavement Capacity (1,000 lbs.)				Abandoned Runways (sq. ft.)	Aprons (sq. ft.)	Active Runways (sq. ft.)	Taxiways (sq. ft.)	Fuel Capacity Onsite (gal)		Backup Gen	
							Single Wheel	Dual Wheels	Two Dual Wheels Tandem	Two Dual Wheels Double Tandem					AvGas/ 100LL	Jet A		
William R. Fairchild International	CLM	Port Angeles	08/26	6,347	150	ASPH-G	55	66	115	-	-	815,005	1,123,154	650,128	12,000 (tank) 500 (truck)	12,000 (tank) 1,000 (truck)	None	Airfield lighting Terminal building
			13/31	3,255	50	ASPH-F	30	-	-	-								
Yakima Air Terminal-McAllister Field	YKM	Yakima	09/27	7,604	150	ASPH-E	95	160	220	550	-	1,264,343	1,715,020	1,614,705	24,000 (tank) 10,000 (truck)	24,000 (tank) 7,000 (truck)	None	Airfield lighting ARFF
			04/22	3,835	150	ASPH-	70	80	120	-								

Appendix D

Airport Runway Liquefaction Potential Screening

The airport runways in Washington will be subject to deformation due to the propagation of waves of energy during a Cascadia Subduction Zone (CSZ) earthquake. Linear infrastructure, such as runways, may be subject to ground deformations resulting in partial to complete disruption of their function. A major source of these deformations associated with a CSZ event is the liquefaction of the soils underlying the runways. Airports located in valleys with alluvial soils and man-made fills, which are subject to liquefaction under earthquake loadings, may be especially vulnerable.

Alluvial valley soils are often made up of saturated loose sands and silts that behave much like a liquid when subjected to shaking by an earthquake. The waves of energy cause pore pressures in the sediments to increase resulting in a decrease in the normal pressure between soil grains, and therefore a reduction in the friction that give the sediments their shear strength. When this grain-to-grain contact is reduced or lost, the sediments lose their strength and behave like a liquid. Such liquefaction can result in the loss of support to surface structure such as buildings and bridges, soil flows on even very gentle slopes, large differential settlements, and if the liquefaction occurs at depth, sand boils erupting at the surface. These settlements and down slope soil flows can result in major damage to buildings, roads, rail lines, and pipelines.[6]

The three factors needed for liquefaction to occur are as follows:

- loose, granular soils,
- ground water saturation of the sediment, and
- strong shaking.[7]

In Washington, all these factors could be present at locations across the state during a CSZ earthquake. Datasets provided by Washington Department of Natural Resources indicate that liquefiable soils are prevalent in the alluvial valleys in the Cascadia range and Olympic peninsula and in low lying areas around Puget Sound Liquefiable soils classified in that dataset as moderate to high liquefaction potential and above, located in the valleys descending from the Cascadia Range topographic divide are classified in large as Quaternary alluvium. The liquefiable soils in the valleys and shoreline areas of Puget Sound consist of Quaternary alluvium, Pleistocene glacial deposits, and Holocene soils including man-made fills. The depth of ground water in the alluvial valleys and shoreline areas is commonly near the surface, leading to a near complete saturation of the soil column. In this study, the reference earthquake for the Cascadia Subduction Zone is an M9.0 earthquake, which will result in strong shaking as far east as Cle Elum, Wash., which could affect these liquefiable soils.

In order to better understand and prioritize the 20 airports identified by Washington Emergency Management Division and Washington State Department of Transportation Aviation for assessment in this project, this study conducted a relative risk evaluation of airports using seismic parameters and site parameters. The method is adapted from an approach that Bardet, Mace, and Tobita developed (1999).

Baseline for Evaluation

The scenario earthquake is an M9.0 event arising from the Cascadia Subduction Zone that parallels the Pacific coast of Washington. The U.S. Geological Survey (USGS) M 9.0 Scenario Earthquake -

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[6] About Liquefaction, https://geomaps.wr.usgs.gov/sfgeo/liquefaction/aboutliq.html

[7] Factors of Liquefaction, https://geomaps.wr.usgs.gov/sfgeo/liquefaction/factors.html

Cascadia M9.0 Scenario (mean value) was used as the reference case in this study (USGS undated[c]). An epicenter is assumed to be on a line 45 kilometers (km) east-northeast and parallel to the CSZ trace in the Seismogenic Fault as depicted in the Washington geology portal (Washington Geologic Information Portal 2010a). The distance of 45 km is based on the USGS Scenario CSZ epicenter located at latitude 45.733, and longitude -125.125 (USGS undated [c]). The earthquake is assumed to occur anywhere along the constructed line with distances to the airports being determined by the minimum distance to the fault line.

Relative Risk Matrix

Parameters

The relative risk of liquefaction at the Washington airport sites was evaluated using a set of four parameters related to the site and seismic conditions at points along the runways. The parameters were selected based on their use in deterministic approaches to calculating the permanent ground displacement associated with liquefaction. The parameters used in the evaluation are:

- Liquefaction potential
- Maximum topographic slope
- Distance to the CSZ epicenter
- Peak ground acceleration (PGA)

Liquefaction potential

The liquefaction potential was derived from information in the Washington Geologic Information Portal. Table D-1 shows the risk ratings associated with five categories of liquefaction potential that range from 1 to 5. The original data from the portal had categories below low which were aggregated into the low category for this evaluation.

TABLE D-1.—Liquefaction Potential Risk Ratings. (Source: Washington Geologic Information Portal 2010b)

Liquefaction Potential	
High	5
Moderate to High	4
Moderate	3
Low to Moderate	2
Low	1

Slope

USGS topographic data were used to determine the maximum slope within 200 meters of three representative points along each runway—each endpoint, located near the runway threshold, and the runway midpoint. A total of 114 slope values were generated across the Washington airports runways evaluated. The average slope among the runway points is 1.81 percent with a standard deviation of 2.17 percent. The breakpoints for the slope risk ratings were set so values below the mean were assigned the low value of 1 and values above the mean plus one standard deviation were set at 3. Values between the mean and the mean plus one standard deviation were set at 2.

TABLE D-2.—Slope Risk Ratings.

Slope	
>3.98%	3
1.81 to 3.98%	2
<1.81%	1

Distance to the CSZ

Using the assumed USGS earthquake scenario and the mapping of the CSZ fault line as described above, distances were determined to each runway points from the assumed trace of the potential epicenters for a CSZ event. The trace was used to conservatively generate the minimum distance to the runway points evaluated. The shortest distance incorporates coastal areas of Washington, the middle-distance sites extend to the I-5 corridor, and farther sites are east of the I-5 corridor.

TABLE D-3.—Distance to CSZ Epicenter Trace Risk Ratings.

Distance to CSZ	
< 100 k	2
100 k - 200 k	1
> 200 k	0

Peak Ground Acceleration

Peak ground acceleration reflects the attenuation of the energy generated by an earthquake as it passes through the subsurface and dissipates as it moves away from the epicenter. PGA depends on the magnitude of the earthquake, its depth, the characteristics of the geology through which the energy passes, and the distance from the epicenter. PGA is expressed as a fraction of the acceleration due to gravity (g). PGA values for the reference CSZ earthquake range from over 0.4g to 0g in eastern Washington. Table D-4 shows contours at intervals of 0.1g are commonly used to plot PGA and were used to set the range of value.

TABLE D-4.—PGA Risk Ratings. (USGS Undated[c])

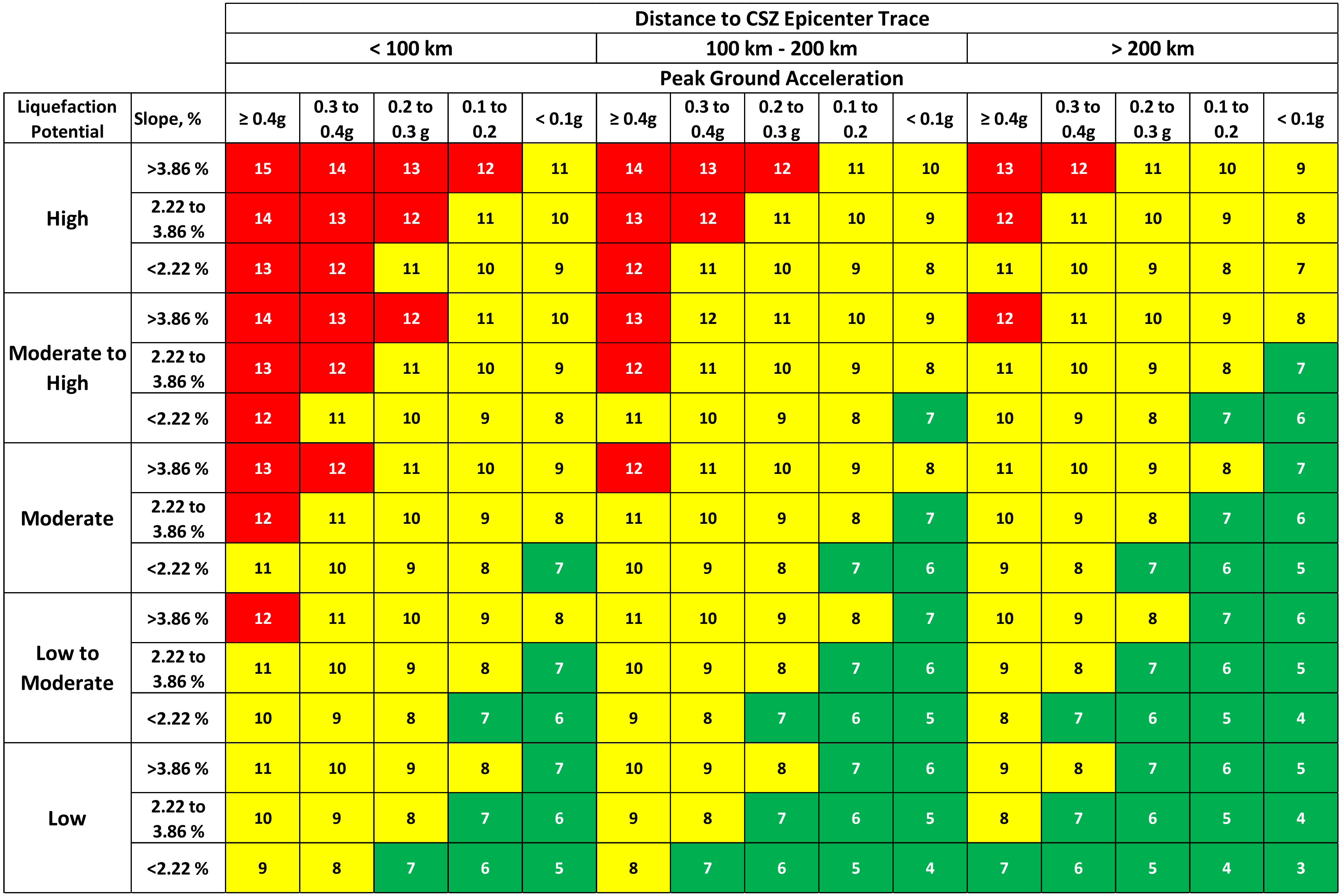
PGA	
≥ 0.4g	5
0.3 to 0.4g	4
0.2 to 0.3g	3
0.1 to 0.2g	2
< 0.1g	1

Aggregating Relative Risk

The four risk parameters were aggregated into a relative risk matrix by adding the individual parameter risk ratings. The relative risk scores within the risk matrix range from 3 to 15. The Relative Risk Matrix was divided into three relative risk categories with high-risk associate with values from 12 to 15, medium risk associated with values from 8 to 11, and low risk associated with values from 3 to 7. Table D-5 shows the breakdown of the relative risk ratings within the matrix and the resulting risk categorization.

The relative risk does not reflect the absolute risk at any airport site but rather the risk at the runway points in relationship to one another. The risk matrix is meant to facilitate decision regarding resilience efforts where the potential for permanent ground displacement associated with a CSZ earthquake is used in combination with other resilience needs and continuity considerations. It should not be viewed as a replacement for more focused, site-specific studies of geotechnical conditions.

TABLE D-5.—Relative Risk Matrix.



Liquefaction Potential	Slope, %	Distance to CSZ Epicenter Trace														
		< 100 km					100 km - 200 km					> 200 km				
		Peak Ground Acceleration														
		≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g	≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g	≥ 0.4g	0.3 to 0.4g	0.2 to 0.3 g	0.1 to 0.2	< 0.1g
High	>3.86 %	15	14	13	12	11	14	13	12	11	10	13	12	11	10	9
	2.22 to 3.86 %	14	13	12	11	10	13	12	11	10	9	12	11	10	9	8
	<2.22 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
Moderate to High	>3.86 %	14	13	12	11	10	13	12	11	10	9	12	11	10	9	8
	2.22 to 3.86 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
	<2.22 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
Moderate	>3.86 %	13	12	11	10	9	12	11	10	9	8	11	10	9	8	7
	2.22 to 3.86 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
	<2.22 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
Low to Moderate	>3.86 %	12	11	10	9	8	11	10	9	8	7	10	9	8	7	6
	2.22 to 3.86 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
	<2.22 %	10	9	8	7	6	9	8	7	6	5	8	7	6	5	4
Low	>3.86 %	11	10	9	8	7	10	9	8	7	6	9	8	7	6	5
	2.22 to 3.86 %	10	9	8	7	6	9	8	7	6	5	8	7	6	5	4
	<2.22 %	9	8	7	6	5	8	7	6	5	4	7	6	5	4	3

Evaluation

For the representative runway points evaluated at the 20 Washington airports, the relative liquefaction risk ratings were generated by determining the values for each of the four risk parameters for the individual runway points identified. Geographic information systems tools were used to determine the distance to the epicenter trace. The values for PGA and liquefaction potential were determined from the geographic distributions derived from USGS data. The slopes around the individual runway points were derived from analysis of USGS topographic data.

For all 114 runway points identified, the derived risk parameter values were totaled to generate a relative risk rating and categorization for each point. Table D-6 shows the distribution of relative risk ratings for the individual runway points.

TABLE D-6.—Distribution of Relative Risk Ratings.

Risk Rating	# of Runway Points	%	Cumulative %
12	1	0.9%	100.0%
10	8	7.0%	99.1%
9	11	10.5%	92.1%
8	24	25.4%	81.6%
7	21	18.4%	56.1%
6	14	12.3%	37.7%
5	6	10.5%	25.4%
4	16	14.0%	14.9%
3	1	0.9%	0.9%

Only one runway point, located at the northern end of Renton Municipal Airport's runway 16/34, had a relative risk rating in the high category. Slightly less than 43 percent of the runway points distributed across 14 airports have a relative risk rating that fell into the medium relative risk category. The remaining 56 percent of the runway points across 14 airports were categorized as low relative risk.

Summary of Results

The relative risk ratings are not intended to replace a site-specific study to generate estimates of permanent ground displacement associated with a CSZ event. The relative risk ratings provide a means to characterize the potential for PGD at an airport and to inform risk and resilience decisions. For each airport, an average risk rating was calculated for the values generated for the points along the runway at that airport. Table D-7 shows the average risk rating for the airports. The average risk rating at the 20 airports ranged from 4.17 to 10.33. No airports had an average risk rating above 12, the lower limit for high risk. Seven airports had average risk ratings in the medium range with remaining 14 airports having a low average relative risk rating.

Table D-7 - Rank Order of Average Relative Risk Rating

AIRPORT CODE	AIRPORT NAME	RUNWAY POINTS	AVERAGE RISK RATING
RNT	Renton Municipal	3	10.33
KLS	Southwest Washington Regional	3	10.00
ELN	Bowers	6	9.17
CLM	Fairchild International	6	8.83
SHN	Sanderson Field	3	8.67
OLM	Olympia Regional	6	8.17
YKM	Yakima Air Terminal-McAllister Field	6	8.17
SEA	Seattle-Tacoma International	9	7.78
PTW	Bremerton National Airport	3	7.67
ALW	Walla Walla Regional	9	7.44
AWO	Arlington Municipal	6	7.33
TIW	Tacoma Narrows	3	7.00
BVS	Skagit Regional	6	6.83
PAE	Paine Field	9	6.67
FHR	Friday Harbor	3	6.33
BLI	Bellingham International	3	6.00
MWH	Grant County International	6	5.00
DLS	Columbia Gorge Regional	6	4.67
PSC	Tri-Cities Airport	9	4.22
GEG	Spokane International	6	4.17

Figure D-1 shows the statewide distribution of the average relative risk ratings.

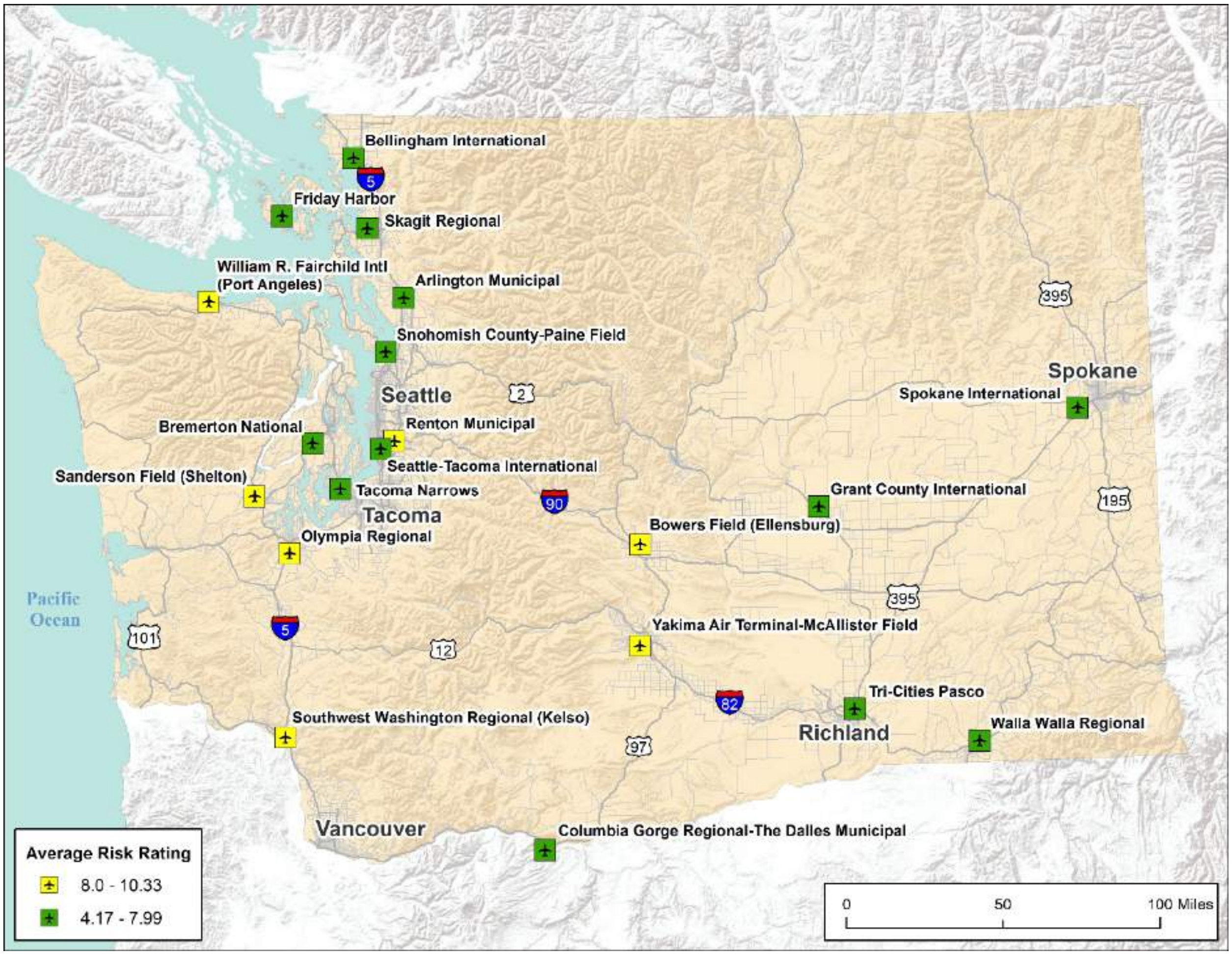


FIGURE D-1.—Distribution of Average Airport Relative Risk Ratings.

The average risk ratings may under-represent the relative risk of airport runways to liquefaction impacts, as even one large disruption in runway can render it unusable; that is, a disruption at one of the representative runway points could close a runway, even if no disruptions at the other representative points were to occur. Therefore, a second approach was used to look at the variation of the relative risk categories of the runway points at each airport. The blended relative risk rating was assigned based on the mix of rating categories at the individual airport. Table D-8 shows the results of this evaluation. Only Renton Municipal Airport has a blended risk rating of High/Medium. Six airports had runway points that were only categorized as medium relative risk. Seven airports have runway points that were a mix of medium and low relative risk and seven had only runway points with only low relative risk ratings. Within blended categories, the rank order was set based on the proportion of runway in the higher category. Where only one risk category is represented, the rankings were based on the number of runway points.

TABLE D-8.—Rank Order of Blended Relative Risk Rating.

AIRPORT CODE	AIRPORT NAME	RUNWAY POINTS	RUNWAY POINT RISK RATING			BLENDED RISK RATING
			LOW	MED	HIGH	
RNT	Renton Municipal Airport	3		2	1	HM
CLM	Fairchild International Airport	6		6		M
ELN	Bowers Field Airport	6		6		M
OLM	Olympia Regional Airport	6		6		M
YKM	Yakima Air Terminal-McAllister Field	6		6		M
KLS	Southwest Washington Regional Airport	3		3		M
SHN	Sanderson Field Airport	3		3		M
SEA	Seattle-Tacoma International	9	1	8		ML
ALW	Walla Walla Regional Airport	9	6	3		ML
BVS	Skagit Regional	6	4	2		ML
PWT	Bremerton National Airport	3	2	1		ML
FHR	Friday Harbor	3	2	1		ML
AWO	Arlington Municipal	6	5	1		ML
PAE	Paine Field	9	8	1		ML
PSC	Tri-Cities Airport	9	9			L
DLS	Columbia Gorge Regional	6	6			L
GEG	Spokane International	6	6			L
MWH	Grant County International	6	6			L
BLI	Bellingham International	3	3			L
TIW	Tacoma Narrows	3	3			L

Figure D-2 shows the statewide distribution of the blended relative risk ratings.

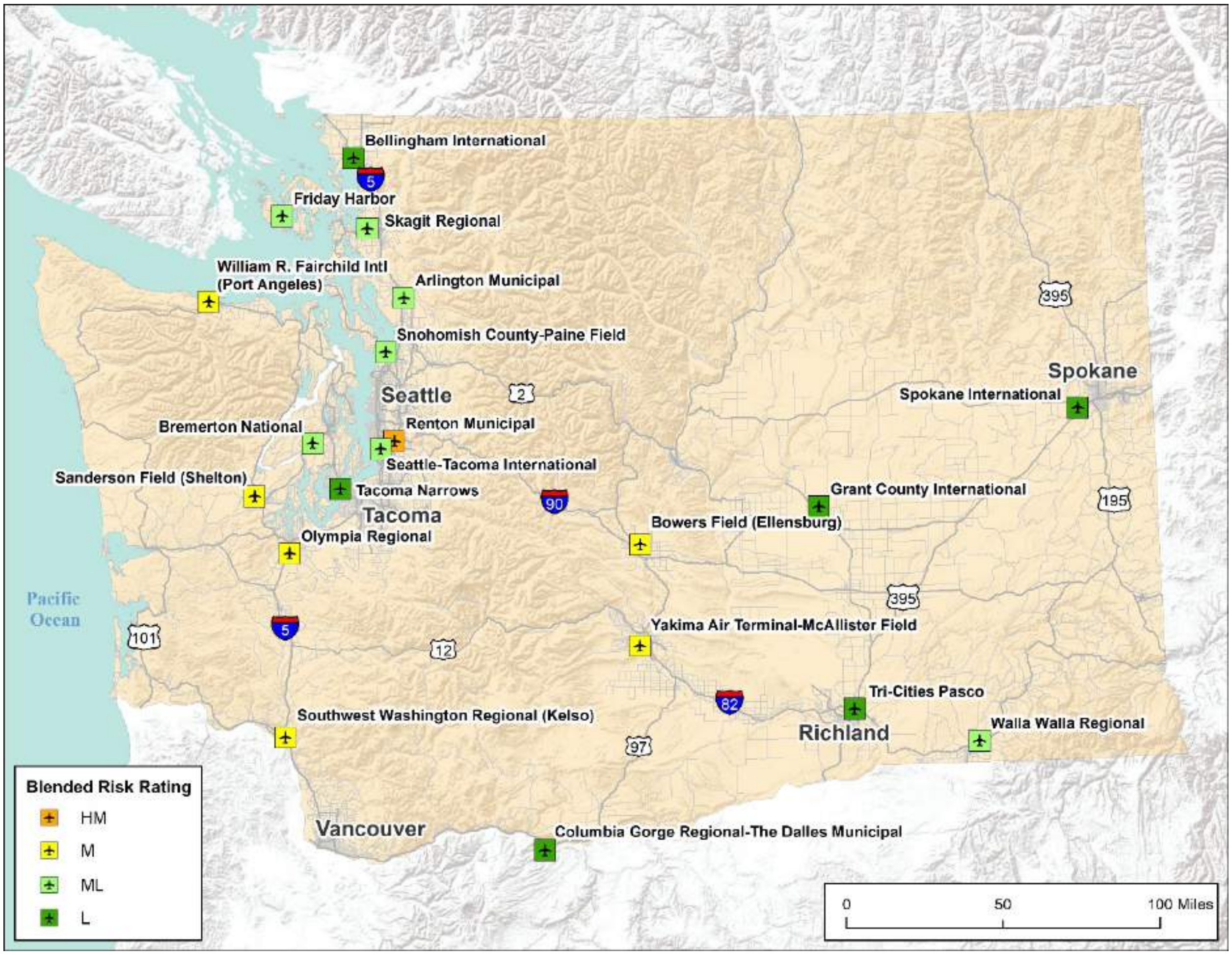


FIGURE D-2.—Distribution of Blended Airport Relative Risk Ratings.